

Coating Inspector Program
Level 2
Student Manual

July 2011



Your CIP Level 2 Instructors are:

_____

_____

_____

IMPORTANT NOTICE:

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Policy on Use of Laptop Computers and Camera Phones

In order to be pro-active and provide students with the best opportunity for them to be as fully prepared for the course as possible; NACE has recently implemented a new policy of sending a CD-ROM of the student manual to each student when they register for a CIP course. We are hoping that this process will provide students the opportunity to review and (hopefully) study the manual prior to arriving at the class.

As a result, we have started experiencing students arriving at class with their CD-ROM and a laptop computer. In order to bring ourselves into the 21st Century, the CIP Committee has made the decision to allow students to use their laptops to follow along electronically versus working from their student manual and to also use their laptop to take notes of the class lecture.

In order to make this work, the following guidelines have been put into place:

1. Students are not allowed to be on the internet or connect with the outside world through their computer.
2. Students are not allowed to record any portion of the classroom/lab activities (including lectures)
3. All laptops must be kept in “silent” mode so as not to disturb others in the class.
4. Laptops cannot be used while quizzes or exams are taking place.
5. Laptops cannot be used during the Peer Review

In addition, with the use of more and more camera cell phones, students are forbidden to use their cell phone to take pictures while in the class.

Thank you,

NACE CIP Committee

Acknowledgements

The time and expertise of a many members of NACE International have gone into the development of this course. Their dedication and efforts are greatly appreciated by the authors and by those who have assisted in making this work possible.

The scope, desired learning outcomes and performance criteria of this course were developed by the NACE Coating Inspector Program (CIP) Subcommittee under the auspices of the NACE Education Administrative Committee in cooperation with the NACE Certification Administrative Committee.

On behalf of NACE, we would like to thank the CIP subcommittee for its work. Their efforts were extraordinary and their goal was in the best interest of public service — to develop and provide a much needed training program that would help improve corrosion control efforts industry-wide. We also wish to thank their employers for being generously supportive of the substantial work and personal time that the members dedicated to this program.

NACE COATINGS NETWORK (NCN)

NACE has established the NACE Coatings Network, an electronic list serve that is free to the public. It facilitates communications among professionals who work in all facets of corrosion prevention and control.

If you subscribe to the NACE Coatings Network, you will be part of an E-Mail driven open discussion forum on topics A-Z in the coatings industry. Got a question? *Just ask!* Got the answer? *Share it!* The discussions sometimes will be one-time questions, and sometimes there will be debates.

What do you need to join? An E-Mail address. *That's all!* Then:

1. To subscribe, send a blank email to:

Join-coatings@nacecorrosionnetwork.com

2. To unsubscribe, send a blank email to:

Leave-coatings@nacecorrosionnetwork.com

3. You're done! You'll get an email back telling you how to participate, but it's so easy that you'll figure it out without any help!

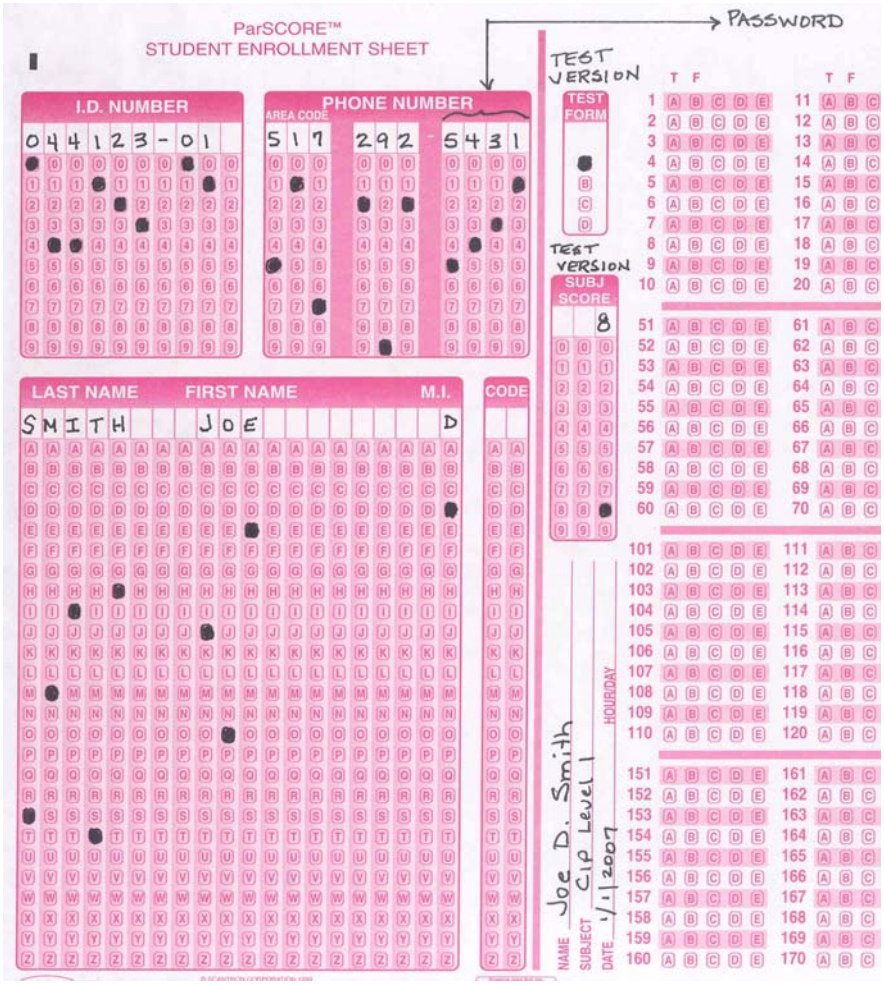
Instructions for Completing the ParSCORE™ Student Enrollment/Score Sheet

1. Use a Number 2 (or dark lead) pencil.

2. Fill in **all** of the following information **and** the corresponding bubbles for each category:

√	ID Number:	Student ID, NACE ID or Temporary ID provided
√	PHONE:	Your phone number. **The last four digits of this number will be your password for accessing your grades on-line.** *(for Privacy issues, you may choose a different four-digit number in this space)*
√	LAST NAME:	Your last name (surname)
√	FIRST NAME:	Your first name (given name)
√	M.I.:	Middle initial (if applicable)
√	TEST FORM:	This is the version of the exam you are taking
√	SUBJ SCORE:	This is the version of the exam you are taking
√	NAME:	_____ (fill in your entire name)
√	SUBJECT:	_____ (fill in the type of exam you are taking,e.g., CIP Level 1)
√	DATE:	_____ (date you are taking exam)

3. The next section of the form (1 to 200) is for the answers to your exam questions.
   - **All answers MUST be bubbled in on the ParSCORE™ Score Sheet .** Answers recorded on the actual exam will NOT be counted.
   - If changing an answer on the ParSCORE™ sheet, be sure to **erase completely**.
   - Bubble only **one** answer per question and do not fill in more answers than the exam contains.



EXAMINATION RESULTS POLICY AND PROCEDURES

It is NACE policy to not disclose student grades via the telephone, e-mail, or fax. Students will receive a grade letter, by regular mail or through a company representative, in approximately 6 to 8 weeks after the completion of the course. However, in most cases, within 7 to 10 business days following receipt of exams at NACE Headquarters, students may access their grades via the NACE Web site.

WEB Instructions for accessing student grades on-line:

Go to: **www.nace.org**

Choose:**Education**
Grades
Access Scores Online

Find your **Course ID Number** (Example 07C44222 or 42407002) in the drop down menu.
Type in your **Student ID or Temporary Student ID** (Example 123456 or 4240700217)*****.
Type in your **4-digit Password** (the last four digits of the telephone number entered on your Scantron exam form)
Click on **Search**

Use the spaces provided below to document your access information:

STUDENT ID_____COURSE CODE_____
PASSWORD (Only Four Digits) _____

*Note that the Student ID number for NACE members will be the same as their NACE membership number unless a Temporary Student ID number is issued at the course. For those who register through NACE Headquarters, the Student ID will appear on their course confirmation form, student roster provided to the instructor, and/or students' name badges.

For In-House, Licensee, and Section-Registered courses, a Temporary ID number will be assigned at the course for the purposes of accessing scores online only.

For In-House courses, this information may not be posted until payment has been received from the hosting company.

Information regarding the current shipment status of grade letters is available upon the web upon completion of the course. Processing begins at the receipt of the paperwork at NACE headquarters. When the letters for the course are being processed, the "Status" column will indicate "Processing". Once the letters are mailed, the status will be updated to say "Mailed" and the date mailed will be entered in the last column. Courses are listed in date order. ***Grade letter shipment status can be found at the following link:***

http://web.nace.org/Departments/Education/Grades/GradeStatus.aspx

If you have not received your grade letter within 2-3 weeks after the posted "Mailed date" (6 weeks for International locations), or if you have trouble accessing your scores on-line, you may contact us at GradeQuestions@nace.org

DAILY SCHEDULE	
DAY ONE	
Registration	
Chapter 1	Introduction
Chapter 2	Advanced Corrosion
Lunch	
Chapter 3	Environmental Controls
Chapter 4	Advanced Environmental Testing Instrumentation
Chapter 5	Advanced Environmental Testing Instrumentation - Practice Lab
DAY TWO	
Chapter 6	Centrifugal Blast Cleaning
Chapter 7	Waterjetting
Chapter 8	Interpersonal Relationship Dynamic in the Workplace
Lunch	
Chapter 9	Safety Awareness
Chapter 10	Advanced Nondestructive Test Instruments
Chapter 11	Advanced Nondestructive Test Instruments - Practice Lab
DAY THREE	
Chapter 12	Linings and Special Coatings
Chapter 13	Thick Barrier Linings
Chapter 14	Advanced Standards and Resources
Lunch	
Chapter 15	Coating Concrete and Inspection
Chapter 16	Test Instruments for Coating Concrete
Chapter 17	Concrete Inspection Equipment - Practice Lab

DAILY SCHEDULE	
DAY FOUR	
Chapter 18	Pipeline Mainline and Field Joint Coatings
Chapter 19	Destructive Instruments and Tests
Lunch	
Chapter 20	Destructive Instruments and Tests - Practice Lab
Chapter 21	Surface Preparation, Coating and Inspection of Special Substrates
Chapter 22	Maintenance Coating Operations
DAY FIVE	
Chapter 23	Non Liquid Coatings
Chapter 24	Coating Surveys
Chapter 25	Specialized Tests and Test Equipment
Lunch	
Chapter 26	Coating Types, Failure Modes, and Inspection Criteria
Chapter 27	Peer Review
DAY SIX	
Course Review	
Course Exam	

Paul Knobloch Scholarship

Background

The Coating Inspector Program (CIP) Task Group (formerly ETC-40 Subcommittee and later the NICITCP Task Group) of PDC voted to establish an annual honoree scholarship entitled "The Paul Knobloch Scholarship".

The subcommittee chairman appointed a Scholarship Committee (now to be known as Scholarship Task Group) to develop recommendations related to such a scholarship. They are as follows:

Purpose

The Paul Knobloch Scholarship is a discretionary scholarship awarded on merit by the CIP Task Group in honor of one of their founding members, Mr. Paul Knobloch. Paul was generous with his time throughout the development of the CIP, and was a member of the committee that implemented the program. He was particularly interested in training development for individuals with a practical hands-on background.

Resolution

Be it hereby resolved that the Coating Inspector Program Task Group may offer an annual scholarship entitled "The Paul Knobloch Scholarship". A maximum of two (2) scholarships may be granted each calendar year solely at the discretion of the CIP Task Group. It is understood that the scholarship is not an official award of NACE International, but is offered in order to honor the efforts of Paul Knobloch on behalf of the Coating Inspector Program. Granting of such a scholarship shall be subject to the following rules.

Eligibility

- People who have successfully completed Level 1 of the Coating Inspector Program shall be eligible for the scholarship.

- Successful completion of each subsequent course (i.e., CIP Level 2) shall be the criterion for the continuation of the scholarship. Failure to achieve a passing grade in any examination shall terminate the scholarship award.

Scholarship Committee

Each year at the NACE Annual Conference, the Chairman of the CIP Task Group shall appoint a Scholarship Task Group. The Scholarship Task Group shall consist of three members with one being designated as Chairman. All three members must be CIP Task Group members.

Nominations

At the time the Scholarship Task Group is formed (NACE Annual Conference), nominations shall be considered for the scholarship. Nominations must be made in writing on the proper Nomination Form (example attached) and shall be submitted to the CIP Scholarship Task Group Chairman (c/o NACE Education Division).

The Scholarship Chairman shall maintain a list of nominations received.

The Scholarship Task Group shall review nominations for complete and accurate data. The Scholarship Task Group will not consider incomplete or inaccurate nominations.

The Scholarship Task Group will only consider information provided in writing on the proper forms. Information provided to the Task Group will not be disclosed to any third party, and shall remain confidential.

The Scholarship Task Group will consider all valid nominations, and will make their decision based on the criteria stated below. All decisions of the Task Group are final, and reasons for the selection will not be disclosed.

The Scholarship Task Group will submit the name of the recipient(s) to NACE and the CIP Committee within 30 days of the closing of nominations, unless otherwise determined by the chairman of the CIP Committee.

Criteria for Nomination

In making its decision, the Scholarship Task Group shall consider the following criteria:

- Financial need
- Leadership potential
- Technical knowledge
- Examination results in CIP Level 1. Successful completion of Level 1 is a mandatory requirement. The examination results achieved will be a contributory factor to any successful application.

Who May Nominate

Nominations must be jointly submitted by two persons, each of whom must be associated with the Coating Inspector Program, i.e., individuals currently holding NACE Coating Inspector-Level 3 Certification.

The Scholarship

The scholarship program shall consist of the following:

1. **Letter of Notification:** The recipient shall be officially notified of the receipt of the scholarship by letter from the CIP Committee Chairman.

2. **Certificate:** A certificate for the scholarship will be awarded to the recipient.

3. **Tuition:** The recipient shall be granted a scholarship to attend one (1) or two (2) eligible training courses as defined in item 4 below. The value of the scholarship shall consist of course registration fees only, at actual cost.

4. **Eligible Training Courses:** The scholarship may be applied to registration fees for any or all of the following, provided the candidate has not already successfully completed them:

    - Level 2
    - Peer Review

5. **Payment of Tuition Costs:** Registration fees shall be paid to NACE International, and not paid directly to recipient.

6. **Scholarship Tuition Fee Payment/Registration:** The scholarship recipient shall notify the NACE Education Division at least thirty (30) days in advance of the course offering which the recipient wishes to attend. The recipient shall be added to the class roster provided that the class is not fully booked.

    It shall be the responsibility of the recipient to make all other arrangements related to attendance at the course. These arrangements include, but are not limited to, transportation, lodging and meals.

Time Limit

The recipient shall make use of the provisions of the scholarship within two (2) calendar years of award of scholarship. Should recipient fail to make use of the scholarship within two years, the CIP Task Group may, at its own discretion, vote to extend the benefit period, or the recipient will be declared ineligible for further use of the scholarship.

If a scholarship recipient is unable to use the scholarship due to circumstances such as their work schedule, illness or lack of company support that might not permit its full use, they may make application to the CIP Task Group to postpone the award of scholarship. In such circumstances, the CIP Task Group may, at its own discretion, agree to extend the benefit period.

NOMINATION FORM FOR PAUL KNOBLOCH SCHOLARSHIP

Nomination guidelines and required information:

1. In order for a person to be eligible, a written nomination form and required documents must be submitted to the CIP Scholarship Task Group, c/o NACE Education Division.

2. Nominee must have successfully completed NACE International Coating Inspector Program Level 1.

3. A resume of work experience and education must accompany the nomination package. The Scholarship Task Group Chairman will verify Work experience.

This nomination requires that two (2) people complete the attached forms. They must both be associated with the Coating Inspector Program (subcommittee member, peer, instructor, or person holding NACE Coating Inspector Certification).

Please use the Submission CheckList to make certain that your nomination package is complete.

We hereby nominate the following person for consideration for the Paul Knobloch Scholarship as a result of outstanding performance in Level 1 of the NACE International Coating Inspector Program:

Nominee Name: _____

Address: _____

City, State, Country, and ZIP: _____

Telephone Number: _____

Fax Number: _____

E-mail Address: _____

Nomination Form for the Paul Knobloch Scholarship:

Submitted by:

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Mail to:

CIP Knobloch Scholarship
Task Group
c/o NACE Education Division
1440 South Creek Drive
Houston, TX 77084-4906

For HQ Use Only

Level 1 Date: _____ Work Experience Verified:_____
Written Exam Grade:_____
Practical Exam Grade:_____
Logbook Grade: _____ _____
Level 2 Date: _____ Scholarship Task Group Chairman
Written Exam Grade:_____
Practical Exam Grade:_____

KNOBLOCH SCHOLARSHIP NOMINATION SUBMISSION CHECK LIST

Please use this form to be certain that you are forwarding a complete information package. Incomplete submissions will be returned to the nominators with a request that all items be submitted in one package.

_____ Nomination Form

_____ Information Form #1

_____ Information Form #2

_____ Scholarship Nominee Form

_____ Resume

INFORMATION FORM #1

Please answer the following based upon your knowledge of, or personal experience with the nominee, _____ (nominee's name):

1. The nominee's completion of Coating Inspection Certification will further the integrity or enhance the Coating Inspection Program because of the following reasons:

   A.

   B.

   C.

2. How would the Knobloch Scholarship aid this individual in receiving his/her certification:

Nominator #1:

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Telephone No.: _____ Fax Number: _____

E-mail Address:_____

Address: _____

City, State, Country, ZIP Code _____

INFORMATION FORM #2

Please answer the following based upon your knowledge of, or personal experience with the nominee, _____ (nominee's name):

1. The nominee's completion of Coating Inspection Certification will further the integrity or enhance the Coating Inspection Program because of the following reasons:

   A.

   B.

   C.

2. How would the Knobloch Scholarship aid this individual in receiving his certification:

Nominator #2:

Signature: _____

Date: _____

NACE Certified Coating Inspector-Level 3 Certification Number: _____

Telephone No.: _____ Fax Number: _____

E-mail Address:_____

Address: _____

City, State, Country, ZIP Code _____

FOR THE KNOBLOCH SCHOLARSHIP NOMINEE

Please give this page to the nominee. It must be completed and returned with the complete scholarship nomination package.

To the Knobloch Scholarship nominee:

If you were awarded the Knobloch Scholarship, how would this benefit you as an individual?

How will you use this scholarship to enhance the coatings industry as a whole?

Nominee Signature: _____

Print Name: _____

Address: _____

City, State, Country, Zip: _____

Phone/Fax: _____

E-mail address: _____

CIP Peer Review

Work Experience Assessment Procedure and Documentation

1. Two years of coatings-related work experience is required in order to take peer review. Completed work experience forms **must** be received at NACE Headquarters at least two months in advance of the date of peer review for verification and approval purposes. If you plan to take the peer review in the next year, it is to your benefit to complete and send the forms to NACE Headquarters as soon as possible.
2. At this time, there is no waiting period between CIP Level 1 and Level 2 courses. This means that:
   a. No matter how much or how little experience you have in the coatings industry, you can take CIP Level 1 and CIP Level 2 with no waiting period in between.
   b. You do not have to complete any work experience forms in order to attend the CIP Level 1 or Level 2 training courses.
3. Thirty-six (36) field-related work experience points are strongly recommended before you attempt to take the Peer Review to achieve Certification under the CIP. Peer Review is significantly more difficult without the field experience of 36 points.

How the Work Experience Assessment Procedure Operates

Your work experience documentation must provide documentation of field-related work experience points. Experience points are calculated on Form 2.

Only **coatings-related field work experience** (defined as coatings-related field work in a place where protective coatings are applied or inspected). Experience points are assigned as follows when the work experience has been uninterrupted:

Type of Coatings-Related Work Experience	Points Awarded Per Month of Uninterrupted Work Experience
Coating Inspection	2.0
Other Field Experience	1.5
Non-Field Experience	1.0

Points are not given for non-field coatings-related experience. The following lists, while neither definitive nor exhaustive, indicate what kinds of experience would and would not be considered **coatings-related field work experience**.

Accepted	Not Accepted
•Coating Inspector	•Laboratory technician without field-related responsibilities
•Paint Crew Foreman	•Specification writing without field-related responsibilities
•Industrial Maintenance Painter	•Protective coatings sales without field-related responsibilities
•Blast cleaning operator	
•Protective coating sales with field-related responsibilities	
•Site manager of coatings operation	

INTERRUPTED EXPERIENCE CALCULATION

When coatings-related work experience has been interrupted for two years or longer, the points awarded for the work experience prior to interruption are reduced, as follows:

Length of Interruption in Continuity of Coatings-Related Work	Factor for Reduced Points Awarded for Coatings-Related Work Prior to Interruption
Up to 2 years	No reduction factor
2 years to 3 years	80%
3 years to 4 years	70%
4 years to 5 years	60%
5 years and more	50%

For example: An applicant worked 24 months as a painter applying industrial maintenance coatings, then worked in a job not at all related to protective coatings for 2 years, then most recently worked 12 months as a coating inspector. The coatings-related total work points awarded are calculated as follows:

24 months x 1.5 points per month x 80%	=	28.8 points for work as a painter
12 months x 2.0 points per month x 100%	=	24.0 points for inspection work
Total Work Points	=	52.8

How to fill out the forms

Disregard of these instructions may seriously delay your application process. NACE cannot be responsible, and accepts no responsibility for delays caused by incomplete, inaccurate, or illegible information.

1. Carefully read these instructions, and look over the sample forms, before proceeding.
2. Read and sign the **attestation and affirmation pages**. These must be included with the work experience forms for them to be considered.
3. **Form 1: Summary of Protective Coatings-Related Work Experience**. This form is a summary, just as it is entitled. Complete, sign and date.
4. **Form 2: Individual Job Documentation**: You should complete one Form 2 for each job listed on the summary page (Form 1). Make as many copies as you need of Form 2 to document the 36 work experience points you need to attend the Peer Review. Write clearly and legibly or type the information. Be sure to include a brief description of the coating related responsibilities for each job at the bottom of each form. Write only on one side of each page. Sign and date each page.

   Notes:

   You must provide complete information. If you are self employed, provide names and addresses of specific individuals at major clients who can verify your work history.

   For the purpose of these forms, job is defined as a position in which you are regularly employed for a period of time. For those who work for a company who provides services to clients, you only need to list the company you are employed by, not the individual clients.
5. Make and keep a copy of the completed forms for your records.
6. Send the completed, signed, and dated forms to:

   NACE International – Education Div.
   Attention: Carol Steele
   1440 South Creek Drive
   Houston, TX 77084-4906 USA

   Phone: 281/228-6244
   FAX: 281/228-6344
   E-Mail: Carol.Steele@nace.org

   Note: Faxed, scanned and e-mailed documents are acceptable with signature. You do not need to return the instructions or sample pages, only your completed forms.
7. If you require assistance, contact NACE at the above address or phone.

Forms must be received at NACE Headquarters not less than 60 days from the first day of the Peer Review you plan to attend to allow time for the verification and approval process to be completed.

S A M P L E

Form 1: Summary of Protective Coatings-Related Work Experience

Applicant Information:

Your Name: A. Sample Phone: 409/111-4321

Current Employer: ZZZ Coating Inspection Inc. Fax: 409/111-1234

Address: 987 Gage Avenue E-mail:

City: Millspec State/Province: TX

Zip/Postal Code: 77987 Country: USA

Please summarize below the information on each copy of Form 2, Individual Job Documentation. List your experience beginning with the most recent, followed by less recent experience.

From Month/Year	To Month/Year	Number of months in this job	Points for this job	Job Title	Company Name
1/92	1/95	36	72	Coating Inspector	ZZZ Inspection Inc.
12/89	12/91	24	36	Painter	AAA Painters
12/87	12/89	24	36	Helper	AAA Painters
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
		TOTAL POINTS:	144		

SAMPLE

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my recognition under this program, it will be grounds for disciplinary procedures.

Signed: XXX Date: XXX

S A M P L E

Form 2: Individual Job Documentation

Use one of these forms for each job; that is, each period of work experience you wish to document. Note that for this form, ***job*** is defined as ***a position in which you are regularly employed for a period of time***. Make and use as many copies of this form as you need. Please provide all information requested in the form.

JOB INFORMATION:

Job Title: Painter

AAA Painters

From: Month 1 Year 92

To: Month 1 Year 95 (present)

Who can NACE contact to verify this experience?

Name: Bob Roberts

Company: AAA Painters

Address: 123 Coating St.

City: Paintersville

State/Province: TX Zip/Postal Code 77123

Country: USA

Phone: 409/123-4567

Fax: 409/123-7654

SAMPLE

WORK EXPERIENCE POINT CALCULATION:

a. Number of months in this job: 24

b. Experience Points (check one):

☐ Field, coating inspection (2 points)

☒ Field, other than inspection (1.5 points)

☐ Non-field experience (1.0 points)

Write the point value here: 1.5

c. Points for this job

Multiply a. (number of months)

by b. (experience points).

Write results in this box: 36

Describe in detail what are/were your specific coatings-related duties in this job. NOTE: Do not write on the back of this form, attach additional sheets if necessary, writing only on one side of each page.

LIST COATING RELATED JOB DUTIES IN THIS AREA

Experience with conventional airspray and airless spray equipment. Responsible for making sure that equipment was set up right, and cleaned up at end of day.
Responsible for correctly applying the coating as directed by supervisor. Took wet-film readings as directed.
Worked mainly on offshore structure during this time, but also had a couple of projects in refineries.
Applicant Affidavit: I understand that if I knowingly provide false information in connection with my certification under this program, it will be grounds for disciplinary procedures.

Signed: XXX_____ Date: XXX_____

Form 1: Summary of Protective Coatings-Related Work Experience

Instructions: Make and use as many copies of this form as needed. Please provide all information requested. Forms must be printed legibly in black ink or typed. Illegible information can delay the application process. For assistance with this form, contact the Education Division at NACE International Headquarters.

Applicant Information:

Your Name: _____ Phone: _____

Current Employer: _____ Fax: _____

Address: _____ Email: _____

_____

City: _____ State/Province: _____

Zip/Postal Code: _____ Country: _____

Please summarize below the information on each copy of Form 2, Individual Job Documentation. List your experience beginning with the most recent, followed by less recent experience.

From Month/Year	To Month/Year	Number of months in this job	Points for this job	Job Title	Company Name
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
		TOTAL POINTS:			

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my certification under this program, it will be grounds for disciplinary procedures.

Signed: _____ Date: _____

Form 2: Individual Job Documentation

Use one of these forms for each job; that is, each period of work experience you wish to document. Note that for this form, ***job*** is defined as ***a position in which you are regularly employed for a period of time***. Make and use as many copies of this form as you need. Please provide all information requested in the form.

JOB INFORMATION:

Job Title: _____

_____

From: Month _____ Year _____

To: Month _____ Year _____

Who can NACE contact to verify this experience?

Name: _____

Company: _____

Address: _____

_____

_____

City: _____

State/Province: _____

Zip/Postal Code _____

Country: _____

Phone: _____

Fax: _____

Email: _____

WORK EXPERIENCE POINT CALCULATION:

a. Number of months in this job: ☐

b. Experience Points (check one):

☐ Field, coating inspection (2 points)

☐ Field, other than inspection (1.5 points)

☐ Non-field experience (1.0 points)

Write the point value here: ☐

c. Points for this job

Multiply **a.** (number of months) by **b.** (experience points).

Write results in this box: ☐

<u>BRIEFLY DESCRIBE</u> what are/were your specific <u>coating-related</u> duties in this job. Your application will NOT be accepted if this section is not completed. NOTE: Do not write on the back of this form. Attach additional sheets if necessary, writing only on one side of page.

Applicant Affidavit: I understand that if I knowingly provide false information in connection with my certification under this program, it will be grounds for disciplinary procedures.

Signed: _____ Date: _____

PRINTED NAME:_____

I affirm that:

1. I understand that I am **solely** responsible for making sure that all necessary work experience documentation is completely submitted in good order to, and on hand at NACE Headquarters not less than 60 days prior to the first day of the Peer Review I wish to attend, and that failure to do so may result in my not being able to take the Peer Review.
2. I understand that if I knowingly provide, or cause to be provided, any false information in connection with my recognition under the NACE International Coating Inspector Program, that it will be grounds for action against my standing in the program.
3. It is the responsibility of the individual to complete the renewal or update process, and to notify NACE International of address changes. Each level successfully completed expires on the date noted on the wallet card issued (or three years from the completion date). Failure to receive notices from NACE does not alleviate the individual's responsibility to contact NACE to complete the renewal or update process.
4. With respect to the Peer Review examination;
   a. I understand that passing the Peer Review examination is significantly more difficult than passing any of the training courses and that successful completion of the training courses does not guarantee successful completion of the Peer Review examination. I also understand that in the event that I do not pass the Peer Review examination I must wait not less than one week before making a second attempt.
   b. I understand that in the event that I fail the Peer Review examination twice, I must wait not less than six months before a third or additional retake, and that any person who fails the second or subsequent attempts must wait a minimum of six months between additional attempts.
5. I understand that the names of the categories within the NACE International Coating Inspector Program are as follows:

Highest Level Successfully Completed	**Category Title**
CIP Level 1	NACE Coating Inspector Level 1—Certified[1]
CIP Level 2 (must also have CIP Level 1)	NACE Coating Inspector Level 2—Certified[2]
CIP Level 2 – Maritime Emphasis (must also have CIP Level 1 or approved documentation on file)	NACE Coating Inspector Level 2 – Marine Certified[3]
CIP Levels 1, 2 (standard or maritime) and Peer Review Examination	NACE Certified Coating Inspector—Level 3

[1]The NACE Coating Inspector Level 1 – Certified person is qualified to undertake basic coating inspection of structural steel using nondestructive techniques and instrumentation under the supervision of a NACE Certified Coating Inspector – Level 3. The person certified at this level has basic knowledge of coating materials and techniques for surface preparation and application on steel substrates.

[2]The NACE Coating Inspector Level 2 – Certified person is qualified to perform advanced coating inspections using both nondestructive and destructive techniques and instrumentation. The person certified at this level has sufficient knowledge of specialized coating materials and techniques for the surface preparation and application used on a wide variety of substrates. He/she also has ample knowledge in advanced report writing, condition surveys, failure analysis, and refurbishment.

[3]The NACE Coating Inspector Level 2 – Marine Certified person is qualified as stated above as well as the skills and knowledge required to correctly address the inspection requirements of the International Maritime Organization's (IMO) Performance Standard for Protective Coatings (PSPC).

6. NACE has a firm policy regarding the use of its logos and certification numbers and titles. The certification number and category title may be used only by individuals who are NACE Coating Inspector Level 1—Certified, NACE Coating Inspector Level 2—Certified, or NACE Certified Coating Inspector—Level 3 and may not be used by any other persons. All active CIP card holders are permitted to use the term ***NACE Coating Inspector Level 1—Certified***, ***NACE Coating Inspector Level 2—Certified***, or ***NACE Certified Coating Inspector—Level 3*** (whichever level of certification is attained), and their certification number on business cards. This example illustrates how this information can be used someone who has achieved the status of **NACE Coating Inspector Level 1—Certified**:

John Smith
NACE Coating Inspector Level 1—Certified, Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

Those who have achieved any level of certification and who are members in good standing of NACE International may display the NACE Logo for the purpose of identifying the individual as having achieved NACE certification.

I understand that violation of these rules will result in action against my standing in the program on the basis of violation of the NACE International Coating Inspector Program Attestation.

7. I (re) affirm the NACE International Coating Inspector Program attestation and agree to abide by its provisions as long as I hold any level of certification under the program.

Signature:_____ Date:_____

ATTESTATION: Requirements for certification under the NACE International Coating Inspector Program include the signing of the following Attestation. In order to maintain your certification as a NACE International Coating Inspector, you must, on an ongoing basis, fully comply with the NACE International Coating Inspector Program Code of Professional Conduct and the standards contained in this Attestation. Failure to fully comply with the Code of Professional Conduct and/or the Attestation constitutes unprofessional conduct and is a sufficient reason for a reprimand, suspension, revocation, or for the denial of the initial certification or recertification, which will be determined at the sole discretion of NACE.

I, the undersigned, recognize and acknowledge that:

1. Proper coating inspection can be critical to the safety and welfare of the general public and industrial facilities.
2. Coating inspection is obligatory to maximize conservation of our material resources and to reduce economic losses.
3. The entire field of coatings encompasses many diverse skills and disciplines and level of technical competence which must often be taken into consideration.
4. Through continual association and cooperation with others in the coatings field, the safest and most economical solutions may be found to many types of coating problems.
5. The quality of work and personal conduct of each coating inspector reflect on the entire profession of coating inspection.

Therefore, I hereby agree to:

1. Give first consideration in my coating inspection work to safety and public welfare.
2. Apply myself with diligence and responsibility to my coating inspection work.
3. Pursue my work with fairness, honesty, integrity, and courtesy, ever mindful of the best interests of the public, my employer and my fellow workers.
4. Not represent myself to be proficient or make recommendations concerning coatings-related work for which I am not qualified by knowledge and experience.
5. Avoid and discourage untrue, sensational, exaggerated, or unwarranted statements regarding my work.
6. Treat as confidential my knowledge of the business affairs or technical processes of clients, employers, or customers.
7. Inform clients or employers of any affiliations, interests, or connections which might influence my judgment.
8. Accept no money gratuities of any kind or other gratuities whose value could cause a question as to whether they may have influenced my inspection activities, decisions, or reports.
9. Be fair, reasonable, and objective in my work, not allowing myself to be influenced by personalities or other individual considerations.
10. Completely, accurately, and honestly fulfill the reporting requirements of the specifications for any coating operation I may be responsible for inspecting.
11. Take it upon myself to determine from my superiors the scope of my authority and work within it.
12. Ensure, to the best of my ability, that the terms, language, and requirements of the coating specification are clearly understood and agreed to by all parties involved.
13. Strive to obtain the best possible results under given conditions within a given coating specification.

I hereby agree to uphold and abide by the NACE International Coating Inspector Program Code of Professional Conduct and the standards contained in this Attestation as an applicant under this Program, and so long as I am a participant in the NACE International Coating Inspector Program. I understand that failure to fully comply with the Code of Professional Conduct and/or the Attestation will be deemed to constitute unprofessional conduct and is a sufficient reason for a reprimand, suspension, revocation, or for the denial of the initial certification or recertification, which will be determined at the sole discretion of NACE.

Signature:_____ Date:_____

Printed Name:_____

Coating Inspector Program Level 2

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Chapter 1: Introduction

Objectives

When this module is complete, you will have knowledge and understanding of:

- NACE policy regarding logos, titles, and certification numbers
- CIP certification update and renewal programs
- The code of conduct and attestation
- Classroom policies
- What to expect from the exam
- Where to find additional resources
- Class introductions and team formation exercises

1.1 NACE International Coating Inspector Program

The Coating Inspector Program (CIP) is designed to accommodate the inexperienced candidate. No prior knowledge or experience is required to begin either of the two levels. A minimum of two years work experience in coatings, whether gained prior to, during, or after attendance of the courses, is required before any candidate can register for the Peer Review examinations. This information is summarized as follows:

- Successful completion of each level is required to move on to the next level
- Two years work experience is required before Peer Review

Upon successful completion of CIP Level 1, CIP Level 2, which must be taken in sequence and the Peer Review, the participant will be a NACE Certified Coating Inspector — Level 3.

1.2 Introduction

The intended service life of a corrosion protection system represents the engineered economic value of a particular system that provides protection from corrosion to an asset (ship, bridge, power plant, oil rig, etc.). The selection of a particular corrosion protection system is typically a function of economic, operational, environmental, and safety issues.

Inspection during corrosion protection system installation is a tool to ensure that the system is within the design parameters. The emphasis of industry efforts in the form of practices, standards and training has been primarily directed to this mission.

1.3 Economy and Value of Inspection

The life of any coating system on a steel substrate depends significantly on the quality of the surface preparation. Smooth welds, radius edges and clean surfaces contribute to a longer service life for installed coatings.

The level of effort required to properly prepare the steel substrate increases the cost of fabrication, but the initial cost to prepare the surface properly is completely outweighed by the extended service life of properly installed coating systems. Extensive down time for repairs and recoating are minimized, resulting in maximized utilization of the asset over its intended service life and greater revenue generation.

1.4 Course Overview

The overall CIP program provides extensive training. CIP Level 2 covers advanced coating inspection and builds on the basic coatings inspection skills learned in CIP Level 1. The CIP program recognizes that participants with prior experience may well exceed some of the stated capability and intent of this course. However, both the inexperienced candidate and competent basic inspector will benefit from the structured training presented in this course. Upon successful completion of CIP Level 2, participants will have demonstrated the ability to undertake advanced coating inspection work (Figure 1.1).

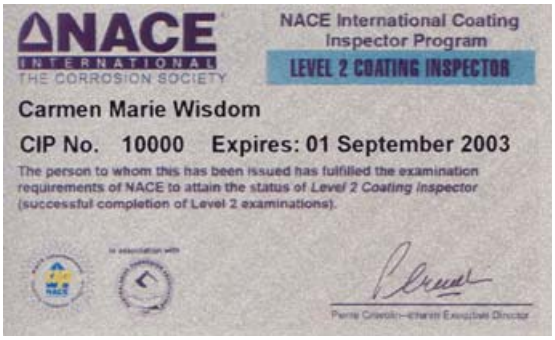


Figure 1.1 CIP Level 2 Recognition

For inspectors who want to become a NACE Certified Coating Inspector — Level 3, this training course is the second of two that must be successfully completed.

Throughout this week, the course offers lecture sessions covering many topics, including:

- Advanced corrosion
- Dehumidification and its role in coatings projects
- Advanced environmental testing instrumentation
- Environmental testing
- Centrifugal blast cleaning
- Waterjetting
- Interpersonal relationship dynamics in the workplace
- Safety awareness
- Advanced nondestructive test instruments
- Linings and special coatings
- Thick barrier linings
- Advanced standards and resources
- Concrete coatings inspection
- Concrete coatings inspection test instruments
- Pipeline coatings
- Destructive test instruments
- Surface preparation, coatings, and inspection of special substrates
- Maintenance coatings operations
- Non liquid coatings — galvanizing and spray metallizing
- Coatings condition assessment surveys
- Specialized tests and equipment
- Coating types and inspection criteria
- Peer review procedure — what to expect

The course includes classroom learning (Figure 1.2 and Figure 1.3) and practical labs where students have a chance to practice with the equipment and reinforce its proper use. As part of the exercise, students will work with the advanced tools and techniques of coating inspection, including:

- Advanced environmental testing and data collection
- Adhesion testing
- Optical evaluation of dry film thickness
- Hardness testing
- Soluble salts testing
- Advanced data collection

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- Recognition of coatings defects



Figure 1.2 Class Layout



Figure 1.3 Class Layout

1.5 NACE Policy: Use of Logos, Titles, and Certification Numbers

All active CIP card holders are permitted to use the term appropriate for their level of certification along with the certification number on their business cards:

- NACE Coating Inspector Level 1 — Certified
- NACE Coating Inspector Level 2 — Certified
- NACE Certified Coating Inspector — Level 3

Only those individuals who have achieved NACE Coating Inspector Level 1 — Certified, NACE Coating Inspector Level 2 — Certified, or NACE Certified Coating Inspector — Level 3, and who are members in good standing of NACE International may display the NACE logo, their certification title and number to identify themselves.

Neither the logo, certification title and number may be used by any other persons.

This example illustrates how this information can be used by an individual who is NACE Coating Inspector **Level 1** — Certified.

John Smith
NACE Coating Inspector
Level 1 — Certified
Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

This example illustrates how this information can be used by a NACE Certified Coating Inspector — **Level 3**.

John Smith
NACE-Certified Coating
Inspector — Level 3
Cert. No. 9650
ACE Inspections, Inc., Knoxville, TN

1.6 CIP Update and Renewal Programs

Update or renewal of NACE CIP certification must be completed every three years.

The **Update Program** is for those who have not passed Peer Review. The update process can be completed by one of two methods:

- Attendance at the next CIP course or peer review

or

- Completing a home study program

If students take another CIP course within a three-year period, the date of the next required update will be three years from the date the most recent course was completed.

The **Renewal Program** applies to Level 3 Inspectors. The renewal process can be completed by one of several methods, depending on the number of work experience points accumulated in the three years since passing Peer Review, or last renewal:

- 73+ points requires only work experience
- 37 to 72 points requires work documentation and completion of home study program
- 36 or fewer points requires work experience documentation and class attendance with successful completion of CIP Level 2 at a regularly scheduled offering

Work experience documentation forms and instructions for completing the forms are provided at the back of this manual.

Notification of the update or renewal process will be mailed 90 days prior to the expiration date of recognition to the address on file at NACE. The notification packets supply all the information and forms needed to begin the update or renewal process. It is important to keep addresses, email, and phone numbers current with NACE at all times.

1.7 Code of Conduct and NACE CIP Attestation

Requirements for CIP certification include signing NACE's Code of Conduct. Failure to comply with the Code of Conduct at any time may result in loss of CIP Certification.

1.8 Classroom Policies

To provide the best environment for training, the following policies must be in effect. Please observe and follow these requirements:

- No smoking or other tobacco products in the classroom
- Class starts at designated times
- Participants are responsible for their own learning and for timekeeping
- Please turn off mobile phone ring tones, and do not make or answer calls, text messages, or tweets while in the classroom
- Comply with timing for lunch breaks, coffee breaks and smoke breaks
- Be aware of toilet location(s) and smoking location(s)

1.9 Examinations

At the end of the course, there are two final examinations:

- one written
- one hands-on practical examination using selected test instruments

Students must pass both exams with a minimum grade of 70%.

1.9.1 Written Exam

The written exam is closed book and consists of 150 multiple-choice questions. The time allotted is 2.5 hours.

1.9.2 Practical Exam

The practical exam covers the tools and techniques for inspection. Students are required to demonstrate how well they perform the coating inspection tests covered in the course. Each student is assigned tasks and must record the results. Grades are based on the accuracy of those recorded results.

There are eight (8) inspection tools and eight (8) minutes allowed at each workstation.

To help prepare for the practical exam, there are lectures, practical labs, and practice sessions using the advanced inspection tools and techniques listed in CIP Level 2. During the week, students will also take short written quizzes, all closed book, to help prepare for the final written exam.

Students will receive written notification of exam results as quickly as possible. Instructors will not be able to tell students their results the day of the exam. The following is the procedure for grading and notifying students of their grade:

- Exams marked by computer at NACE HQ
- Written notification of exam results are mailed from NACE within 2 to 3 weeks
- Exam results are first available on the internet at www.nace.org. Access requires password and course ID number
- Results **are never** available by telephone

Please *do not call* NACE HQ for results because staff are *not* allowed to give out this information by telephone.

1.10 Additional Resources

1.10.1 NACE Corrosion Network

The NACE Corrosion Network is an active online message board used by members from around the world who work in the corrosion prevention industry. You must sign up as a member of the list server at www.nace.org.

1.10.2 Technical Committees

More than 1,000 NACE members participate in technical committee activities. The **Technical Coordination Committee (TCC**) is the administrative and policy-making body for all the committees.

The technical committees are organized into **Specific Technology Groups (STGs)**. STGs are assigned specific technical areas within three administrative classes:

- Industry-Specific Technology (N)
- Cross-Industry Technology (C)
- Science (S)

Technology Management Groups (TMGs) are formed by the TCC to provide a structure and a conduit for communication between the TCC and the various STGs within their respective areas. They provide assistance, when necessary, to help STGs achieve their objectives.

1.10.3 Standards and Reports

NACE standards are prepared by NACE technical committees to serve as voluntary guidelines in the field of corrosion prevention and control. These standards are prepared using consensus procedures. NACE offers its standards to the industrial and scientific communities as voluntary standards to be used by any person, company, or organization. NACE standards are free to NACE members.

A **Technical Committee Report** is a limited-life document developed by a technical committee. Typical categories for committee reports are:

1. **State-of-the-art reports** that deal with the current science and technology of a method, technique, material, device, system, or other aspect of corrosion control work
2. **Informational reports** that can be statements on a specific problem (summariz-

ing its ramifications, controversial points, and possible solutions), surveys of common practices, bibliographies on special subjects, etc.

1.11 Introductions

Before instruction begins, students should know something about each other. Students should stand, one at a time, and introduce themselves to the class. Provide:

- Name
- Company's name and location
- Job function
- Experience in coating inspection
- Hobbies

1.12 Team Formation Exercise

NACE believes the coating inspector's job is part of a team effort in the coating project. Students will form teams to reflect a cross-section of the industries represented in the class, and students will work in teams throughout the course. Right now, students will make a permanent shift in the seating arrangement (Figure 1.4).



Figure 1.4 Working in Teams

At the end of the course, the lead instructors should review expectations and reservations to see how well the course fulfilled expectations and minimized reservations.

Students will be working within teams on a wide variety of tasks, exercises, and assignments. Please get together with your group and do the following (Figure 1.5):

- **Team name:** Decide on a team name that represents who you are, tells how you intend to perform during the workshops, and gives your group a personality.
- **Reason:** Select your team name for a specific reason. That is, do not just give your team an arbitrary name. Think it through carefully. Be prepared to share your reason with the class upon completion of this exercise.
- **Team logo:** Create a logo or trademark for your team that graphically represents your team's name and the rationale behind the name.
- **Expectations and reservations:** As a team, develop a list of expectations and reservations about the course.
- **Summarize all your team's work on this exercise** on the flipchart.
- **Prepare to deliver** a five minute presentation to the entire group.
- **Select a spokesperson to make the presentation.** You have 20 minutes to complete your work.



Figure 1.5 Team Presentation

1.13 Disclaimer

As an attendee of this course, you are hereby advised that NACE International's view on in-process inspection is to ***"inspect and document"*** the functions described. The inspector must always work solely within and abide by the job description and documents governing responsibilities and authority granted by management.

You are advised that by fulfilling the requirements of this course, with its qualifying terminology, you understand and accept the fact that NACE International does not state, affirm, imply, endorse, or otherwise by any action, express or implied, indicate that the use of the words ensure and/or enforce is intended to convey any meaning of guarantee nor any assumption of responsibility for the adequacy of any work inspected and documented by the inspector.

Chapter 2: Advanced Corrosion

Objectives

When this module is complete, you will have knowledge and understanding of:

- The full definition of what corrosion is
- Corrosion as an electrochemical process
- How the corrosion cell concept works
- Factors that affect corrosion rate
- Various types of corrosion
- Basic knowledge of cathodic protection

Key Terms

- Corrosion
- Anode
- Cathode
- Return path
- Electrolyte
- General corrosion
- Localized corrosion
- Pitting corrosion
- Crevice corrosion
- Galvanic corrosion
- Cathodic protection

2.1 Introduction

A basic understanding of the nature of the corrosion process helps inspectors understand how corrosion protection systems are used and what attributes to look for when evaluating each system's effectiveness.

Everyone has observed corrosion in one form or another. However, most do not have a clear understanding of the processes involved with corrosion. This chapter reviews some of the information presented in CIP Level 1 and then expands on the subjects.

2.2 Corrosion Review

Corrosion is usually described by its results. The terms rust (Figure 2.1), scaling, discoloration, oxidation, pitting, etc. are familiar terms. These descriptive terms focus on the readily observable characteristics of corrosion products, which are results of the corrosion process. The actual *process* of corrosion is less noticeable and was not accurately characterized until the early 20th century.

Research to increase understanding and better arm inspectors in the battle to control corrosion is ongoing. Knowledge of the corrosion process is necessary to properly identify and deal with its outward effects.



Figure 2.1 Rusted Surface

The corrosion process acts upon engineered materials, usually metals. Engineered materials are produced by man to serve as components of society's infrastructure. For the purpose of this discussion, steel represents the most common material used in marine construction. Steel is composed principally

of approximately 95% iron (Fe). Most of the economically significant corrosion in industry results from the deterioration of iron. While steel contains constituents other than iron, some of which dramatically impact corrosion resistance, they will be ignored in this discussion of the basics.

2.3 Definition

The corrosion process is the deterioration of a substance, usually a metal, or its properties, because of a reaction with its environment.

This definition is very broad and recognizes that materials other than steel (e.g., wood, concrete, and plastics) are also subject to corrosion. Because the underlying processes of non-metallic corrosion are fundamentally different from metallic corrosion, they will not be addressed in this course.

In essence, corrosion processes change the iron in steel to another substance that no longer has the desired properties (e.g., strength, toughness). The most common corrosion product in the environment is an oxide of iron (iron oxide or "rust") formed by the addition of oxygen.

Iron oxide has few desirable properties for use as an engineered material. The iron oxide produced in the corrosion process consumes the metal. The volume of metal and its thickness are eventually reduced to the point where structural components are not able to perform the function for which they were designed.

Corrosion is the reverse process of steel manufacturing. Steel is made by taking an ore (iron oxide is commonly used), and introducing a large amount of energy to extract the iron from the ore in the steel mill. The resulting product is naturally unstable so when the right conditions occur, the iron converts back to the more stable iron oxide (Figure 2.2, Figure 2.3).

Identifying and controlling the corrosion process (corrosion control) is made much easier by understanding how metals corrode, how fast they corrode, and the factors that tend to increase or decrease the rate of corrosion.

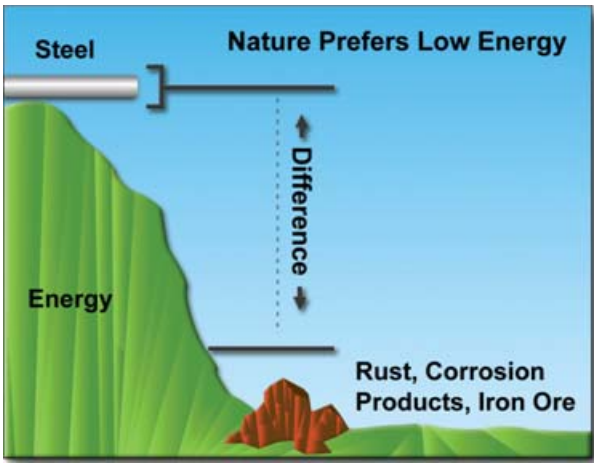


Figure 2.2 Energy Mountain for Iron

Steel is not the only engineered metal used in construction. Copper, brass, zinc (e.g., as the coating on galvanized steel), aluminum, nickel, and chromium (a major constituent in "stainless" steel) are also commonly used. The corrosion of these metals follows the same principles described below, but may proceed at slower rates. The slower corrosion rates of these metals are often due to the production of a tightly adherent layer formed from the corrosion product (oxide, carbonate, chloride, sulfate, or other compounds).

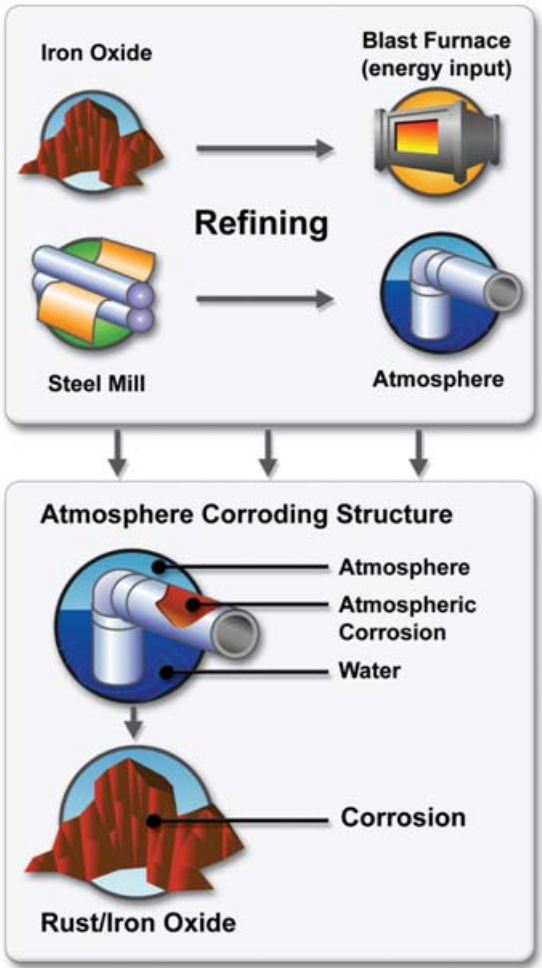


Figure 2.3 Life Cycle of Iron in Steel

The formation of this surface layer, whether an oxide, carbonate, chloride, sulfate, or other compounds, while relatively thin, can form an effective barrier against further attack and slow the rate of the corrosion process. This phenomenon is known as *passivation*. Unfortunately, under the conditions found in many environments, iron alone does not form such a barrier.

2.4 Corrosion as an Electrochemical Process

All corrosion of iron at normal ambient conditions is an electrochemical process. This means that the process involves the transfer of ions and electrons across a surface. Transfer of electrons implies the generation of a current (corrosion current). Both electrons (through a metallic conductor) and ions (through an electrolyte) carry the corrosion current.

Corrosion is established as a direct current (DC) circuit. DC circuits are defined by the relationship called **Ohms Law, E=IR,** where:

- **E** is the driving voltage of the circuit
- **I** is the current magnitude
- **R** is the resistance of the circuit

The greater the current flow in the corrosion circuit, the greater the metal loss.

2.5 The Corrosion Cell

In order for corrosion to occur, certain conditions and elements are essential. These are collectively referred to as the corrosion cell as depicted in Figure 2.4.

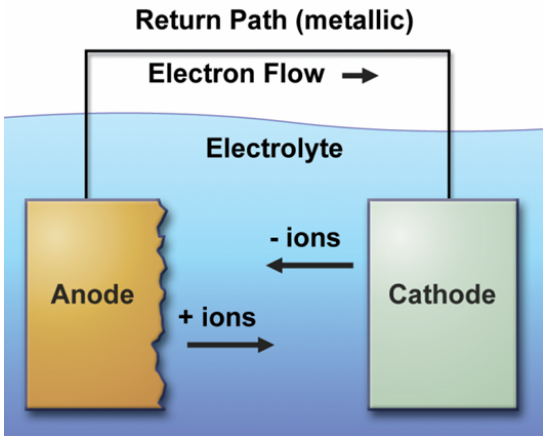


Figure 2.4 Corrosion Cell

2.5.1 Anode

The **anode** is the less noble part of the metal that corrodes, i.e., dissolves in the electrolyte. It is the negatively charged portion of the cell where metallic iron is first converted to another substance and dissolves in the

form of positively charged ions; the electrons generated are conducted to the cathode. Another way to say it is: the anode is the location on the metallic surface where oxidation occurs.

2.5.2 Cathode

The **cathode** is the more noble region on the electrode (metal surface or a battery's carbon rod) where electrons are consumed. The electrical reaction continues at the cathode, which is positive, the opposite of the anode. The reaction generally ionizes the electrolyte to form species such as hydrogen (released as gas) and hydroxyl ions. These often combine with the dissolved metal to form compounds such as ferrous hydroxide (with iron or steel), subsequently reacting further to become iron oxide or rust. **While oxidation occurs at the anode, reduction occurs at the cathode.** Excess electrons generated at the anode are consumed at the cathode. **Oxidation and reduction always occur together; there is never just oxidation or just reduction**. The anode and cathode have different potentials, creating a "voltage" difference between them. Potentials are a function of the chemical and physical states. **The difference of potential is the driving force for the corrosion process.**

2.5.3 Return Path (Metallic Pathway)

The **return path** connects the anode and cathode and allows electrons generated at the anode to pass (move) to the cathode. When corrosion takes place on a metal surface there is **always** a metal pathway joining the anode/anodic areas to the cathode/ cathodic areas. Without a metallic pathway, the corrosion reaction could not take place.

2.5.4 Electrolyte

The **electrolyte** conducts ionic rather than electronic current. The majority of electrolytes are water based and contain ions (particles of matter that carry a positive or negative charge).

- **Anions** = negatively (-) charged ions
- **Cations** = positively (+) charged ions

In order for oxidation/reduction to proceed, there must be a pathway to transport the ions between the anode and cathode. The electrolyte "closes the loop" in the corrosion cell; it carries the corrosion current. Anions are attracted to the anode and cations to the cathode, where they may combine with oxidation and reduction products. In the marine environment, water containing dissolved chemical salts is the primary electrolyte.

2.5.5 Summary

All **four** components **must be present** for corrosion to occur. Removing one or more of them prevents corrosion from occurring. It is not always possible or practical to remove them, but the attempt to nullify or prevent their presence **is** corrosion control.

On most structures, the anode and cathode are at different locations on the steel. The structure itself is the return path, and the environment serves as the electrolyte.

2.6 Corrosion Rate Factors

Corrosion rates are determined by a variety of factors, some of them quite complicated. However, five factors play an overwhelmingly important role in determining corrosion rates. These factors are:

Oxygen

Like water, oxygen increases the rate of corrosion. Corrosion can take place in an oxygen-deficient environment, but the rate of the corrosion reaction and destruction of the metal is generally much slower.

In immersed conditions, the metal surface is frequently in contact with areas of electrolytes which have different oxygen concentration levels. The metal areas in contact with the higher-oxygen-concentration electrolyte are cathodic relative to the remaining surface. An oxygen concentration cell forms, resulting in rapid corrosion.

Temperature

Corrosion reactions are electrochemical in nature and usually *accelerate with increased temperature*. Therefore, corrosion proceeds faster in warmer environments than in cooler ones.

Chemical Salts

Chemical salts increase the rate of corrosion by increasing the efficiency (conductivity) of the electrolyte. The most common chemical salt is sodium chloride, a major constituent of seawater. Sodium chloride deposited on atmospherically exposed surfaces also acts as a hygroscopic material (extracts moisture from the air), which increases corrosivity in non-immersed areas.

Humidity (or Wetness)

Humidity and time-of-wetness have a strong impact on initiating and accelerating corrosion rates. Time-of-wetness refers to the length of time a substrate is exposed to an atmosphere with sufficient moisture to support the corrosion process. The wetter the environment, the more corrosion is likely to occur.

The aviation industry takes advantage of low humidity when they store aircraft in the desert without enclosing them in air-conditioned buildings. Even at elevated temperatures, there is very little electrolyte available to develop corrosion cells. Corrosion can occur without visible water, but about 60% humidity significantly decreases iron's corrosion rate.

Pollutants and Acid Gases

Acid rain, chemical by-products from manufacturing and processing plants, and chlorides in coastal areas all promote corrosion. Acid gases, such as carbon dioxide, can also dissolve in a moisture film on a metal. In addition to the effect of a direct chemical attack, these materials reduce the electrical resistance of the electrolyte. Reduced resistance in a corrosion cell generates higher corrosion currents and thus, increased corrosion rates.

Again, corrosion is the degradation of engineered materials in contact with a corrosive environment. **The corrosive environment is usually defined by the characteristics of the electrolyte.** Environments may be immersion in a liquid (water) or atmospheric, as the next section explains.

2.7 Types of Corrosion

There are two broad classifications of corrosion, **general** and **localized** corrosion (Figure 2.5 and Figure 2.6).

2.7.1 General Corrosion

General corrosion results in a relatively uniform loss of material over the entire sur-

face. Usually, this causes a general thinning of the affected surface. General corrosion is relatively easy to inspect and does not cause catastrophic failures.



Figure 2.5 General Corrosion



Figure 2.6 General Corrosion

2.7.2 Localized Corrosion

Localized corrosion occurs at discrete sites on the metal surface (Figure 2.7 and Figure 2.8). The areas immediately adjacent to the localized corrosion normally corrode to a much lesser extent, if at all. Localized corrosion often occurs in areas that are difficult to inspect.



Figure 2.7 Localized Corrosion



Figure 2.8 Localized Corrosion

Localized corrosion is less common in atmospheric exposure than in immersion or splash/spray exposures; there is always a causative factor, such as long exposure to liquid water, pollutants, or galvanic cells. Galvanic cells generate when different types of metals are in electrical contact in a common electrolyte. Corrosion activity at localized corrosion sites can vary with changes such as:

- Defects in coatings
- Changes in contaminants or pollutants
- Changes in the electrolyte

The predominant forms of localized corrosion found on marine structures are **pitting** and **crevice** corrosion.

2.7.2.1 Pitting Corrosion

Corrosion does not develop uniformly in **pitting corrosion**, but primarily at distinct spots where deep pits result (Figure 2.9 and Figure 2.10). The bottoms of pits are anodes in a small, localized corrosion cell, often aggravated by a large cathode-to-anode area ratio. Pitting can initiate on an open, freely exposed surface or at imperfections in the coating.



Figure 2.9 Pitting Corrosion

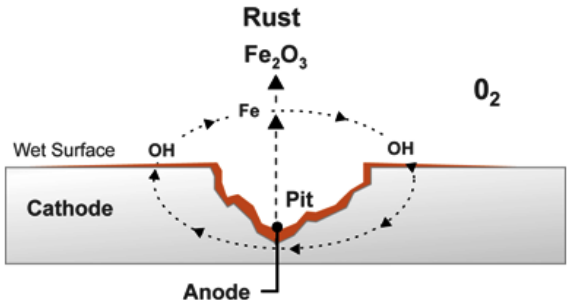


Figure 2.10 Pitting Corrosion

Deep, even fully penetrating pits, can develop with only a relatively small amount of metal loss. Pitting can be isolated or a group of pits may coalesce to form a large area of damage. Pitting is particularly prevalent in metals that form a protective oxide layer and in environments high in chloride contamination (where chlorides promote the breakdown of the oxide layer). Pitting is also found under the following conditions:

- When a metal is subjected to high velocity liquids, known as **impingement attack** or **corrosion-erosion**
- When two metals are in contact and there is slight relative movement, known as **fretting corrosion**
- When a metal is exposed to **cavitation** (formation and collapse of vapor bubbles in a liquid), known as **cavitation-erosion**

2.7.2.2 Crevice Corrosion

Crevice corrosion occurs on a metal surface that is shielded from full exposure to the environment because of the close proximity of another material. The closeness creates a narrow gap between the two materials. Differences in concentration of corrosion species or oxygen between the environment inside and outside of the crevice generate the driving force for the corrosion cell, especially in areas that are water traps (see Figure 2.11, Figure 2.12, and Figure 2.13).

Crevices are common where there is metal-to-metal contact, such as in support straps or at pipe flanges. In addition, **deposits of debris** and corrosion products also generate crevices with **poultice corrosion**.

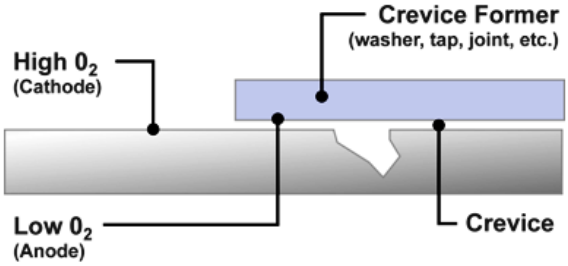


Figure 2.11 Oxygen Concentration Cell

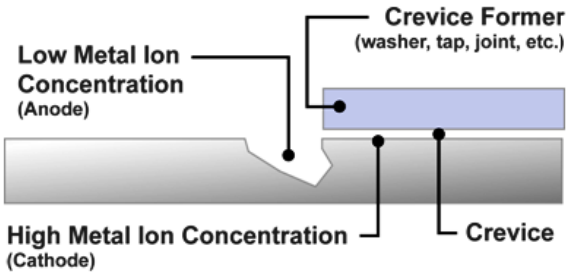


Figure 2.12 Ion Concentration Cell



Figure 2.13 Crevice Corrosion

2.7.3 Significance of Localized Corrosion

Of the two classifications of corrosion, localized corrosion more frequently causes the need for *unplanned* maintenance. Localized corrosion is often hidden in crevices or under multiple coats of maintenance coatings, which can disguise the true extent of damage. The risk of rapid, unseen substrate penetration can lead to serious consequences unless operators deal with it promptly upon detection. Localized corrosion also produces characteristically sharp features that serve as "stress risers." These stress risers result in conditions that increase the level of stress at the leading edge of the pit or crevice, creating initiation points for failure.

2.7.4 Galvanic Corrosion

Galvanic corrosion is the electrochemical action of two dissimilar metals in contact in the presence of an electrolyte, and an electron conductive path. The more reactive metal corrodes to protect the more noble metal (Figure 2.14). The extent of corrosion resulting from the coupled metals depends on the following factors:

- The potential difference between the two metals
- The nature of the environment
- The polarization behavior of the metals or alloys
- The geometric relationship of the components

Galvanic corrosion is seen as a buildup of corrosion at a joint between dissimilar metals. For example, when aluminum alloys or magnesium alloys are in contact with carbon or stainless steel, galvanic corrosion occurs and accelerates the corrosion of the aluminum or magnesium.

This phenomena is used as a benefit in galvanic cathodic protection systems.

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Figure 2.14 Galvanic Corrosion Resulting from Carbon Steel Welded to Stainless Steel

2.8 Coating Inspection and Cathodic Protection Introduction

Cathodic protection is a widely used form of corrosion control. NACE International offers three courses on the subject, so there is a lot more to learn beyond what is presented here. The following section is a very basic overview based on what a coating inspector may need to know in this area. Four things must be present for corrosion to occur:

- Anode
- Cathode
- Metallic pathway
- Electrolyte

Recall that:

1. Electrons flow from the anode to the cathode via the metallic pathway
2. Ions flow from the anode to the cathode through the electrolyte
3. Wastage of the metal (corrosion) occurs at the anode

One amp for one year removes 23.5 lbs (10.6) kg of iron.

Cathodic protection protects structures using an electric current that flows thorough whatever substance the structure is buried or submerged in, which is either primarily water-based (aqueous) or contains some water (like an oil storage tank with some water at the bottom). The environment from which the structure is being protected is the electrolyte.

One reason to apply coatings to a structure, among the many other reasons discussed, is to provide electrical insulation (resistance inhibition) between the structure and the electrolyte.

The more effectively the coating insulates the structure, the less electric current is required to provide cathodic protection. It makes the system more efficient since it reduces both corrosion and coating installation and maintenance costs. Because instruction time to cover the very extensive topic of corrosion control is limited, this course covers only the major points. NACE offers a number of week-long courses that teach corrosion and corrosion control in greater depth.

The following section briefly explains what cathodic protection is, how it works, and what it means to the coating inspector.

2.8.1 Cathodic Protection Definition

Cathodic protection reduces or eliminates corrosion by turning the protected structure into a cathode by either an impressed current or attachment to a galvanic anode (usually magnesium, aluminum, or zinc).

The cathode is the electrode where, for the purpose of instruction, assume no significant corrosion occurs. **Before** applying cathodic

protection, corroding structures have both cathodic and anodic (where corrosion is occurring) areas. If all anodic areas are converted to cathodic areas, the entire structure becomes a cathode and corrosion of the structure is satisfactorily controlled.

2.8.2 How Cathodic Protection Works

Applying direct current electricity to a corroding metal structure causes the structure to become entirely cathodic. Direct current electricity is associated with the corrosion process on a buried or submerged metallic structure. This is illustrated by Figure 2.15, which shows the flow of direct current between anodic and cathodic areas on a section of buried pipe. As shown in this example of a buried structure, direct current is flowing from the anodic areas into the soil, through the soil, onto the cathodic areas, then back through the pipe itself to complete the circuit.

Key to the illustration:

- A - Anodic areas of the pipeline before cathodic protection
- B - Dotted lines represent lines of current flow which existed within the pipeline prior to applying cathodic protection
- C - The protection structure itself
- D - Current flowing from ground bed to surface of protected structure. Now the ground bed is the anode and the pipeline is the cathode and protected.

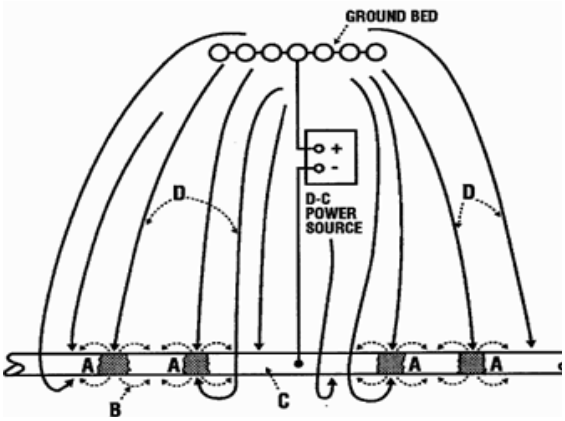


Figure 2.15 How Cathodic Protection Works

For a given driving voltage (the galvanic potential between anode and cathode), the resistivity of the environment (ohm-centimeters), and the degree of polarization at anodic and cathodic areas limit the amount of current.

Corrosion occurs at anodic areas where the current discharges from metal into the electrolyte (soil). Where current flows from the environment onto the pipe (cathodic areas), no corrosion develops. In applying cathodic protection to a structure, the objective is to force the entire surface exposed to the environment to be cathodic to the environment. When this condition is attained, the structure's entire exposed surface becomes a cathode and controls the corrosion of the structure.

The cathodic protection current must flow into the environment from a special ground connection (usually called a ground bed) in buried-structures constructed for this function. By definition, the materials used in the ground beds are anodes, and material consumption (corrosion) must occur. Original anodic areas discharging current and corroding are areas such as:

- Dotted lines that represent lines of current flow, which existed prior to applying protection
- Protected structure
- Current flowing from ground bed to surface of protected structure

Cathodic protection systems can be monitored by measuring the electrical potential (voltage) of the protected structure with a reference cell and a special voltmeter. Reference cells are made of copper, copper sulfate, silver, silver chloride, mercury (calomel), or a metal based upon specially refined high-purity zinc.

2.8.3 Cathodic Protection Systems

This section discusses two types of cathodic protection systems:

- Galvanic
- Impressed current

2.8.3.1 Galvanic Systems

In this industry, the term galvanic often describes dissimilar metal contact that causes electrolytic potential. An anode is the corroding metal in a dissimilar metal combination; a galvanic (sacrificial) anode is a metal that has a voltage difference with the corroding structure and discharges current that flows through the environment to the structure. The galvanic anodes corrode preferentially to the protected structure, thereby protecting the structure. Figure 2.16 diagrams the principle of galvanic cathodic protection systems.

Materials suitable for use as galvanic anodes include aluminum, magnesium, and zinc (Figure 2.17).

Anode materials are cast in numerous weights and shapes to meet cathodic protection design requirements. Data for available anodes is available from suppliers of cathodic protection materials.

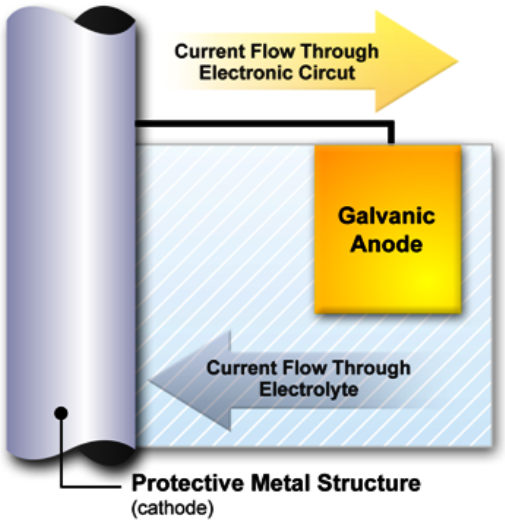


Figure 2.16 Galvanic Anode Cathodic Protection System

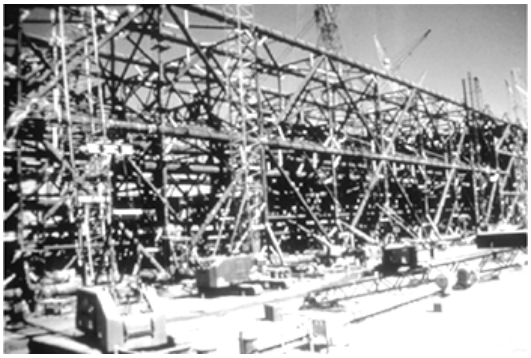


Figure 2.17 Aluminum Anodes

2.8.4 Impressed Current Systems

In an impressed current system, the ground bed anodes are not the source of electrical energy. Instead, an external source of direct current power is connected (or impressed) between the structure to be protected and the ground bed (Figure 2.18).

The positive terminal of the power source *must* be connected to the *ground bed*, which then forces it to discharge as much cathodic

protection current as is desirable. **A correct connection is crucial**. If the positive terminal is mistakenly connected to the structure to be protected, the structure becomes an anode instead of a cathode and corrodes actively, which is the **opposite** of the desired results.

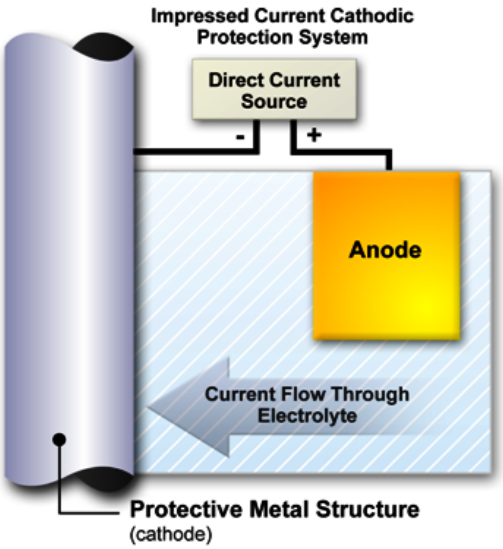


Figure 2.18 Impressed Current Cathodic Protection System

2.8.4.1 Impressed Current System Anodes

Ground bed anodes forced to discharge current will corrode. It is important to use anode materials that are consumed at relatively low rates so ground beds can be built to discharge large amounts of current and still have long service lives. The following materials are used for impressed current anodes:

- Scrap steel
- Graphite
- Iron oxide
- High-silicon chromium-bearing cast iron
- Platinized niobium and titanium

2.8.4.2 Impressed Current Power Sources

An impressed current system requires a current supply. Common current sources include:

- Rectified commercial power
- Solar cells
- Generators
- Fuel cells
- Wind-powered cells
- Thermoelectric cells

A rectifier is a device that uses power from electric utility lines to convert the alternating current to a lower voltage direct current by means of a step-down transformer (Figure 2.19).



Figure 2.19 Impressed Current Rectifier

2.8.4.3 Factors of Cathodic Protection Systems

Development of an effective cathodic protection system is a complex task requiring experience, knowledge, and judgment. This course only mentions some of the factors that must be taken into consideration when designing a cathodic protection system such as:

- Regulatory requirements
- Economics
- Metal to be protected
- Service requirements
- Total current requirements
- Variation in environment
- Protective coatings
- Electrical shielding
- Maintenance
- Stray current effect
- Temperature
- Wire and cable
- Anode backfill

Problem areas are:

- Resistance/throw
- Cathodic disbondment
- Inspection criteria

2.8.4.3.1 Resistance and Throw

A potential of –0.85 V is a minimum requirement for cathodic protection. In order to maintain the protected structure at this potential (voltage), some areas will have an increased (more negative) potential. Due to the size, design, placement of the anodes, and the type and resistance of the electrolyte, without exacting care, this increased (more negative) potential can result in the phenomenon of cathodic disbondment.

2.8.4.3.2 Cathodic Disbondment

Systems operating at a stable potential (voltage) of –0.85 V usually have no detrimental effect on the coating. However, as the potential increases (becomes more negative), reactions take place that can be detrimental to the coating (Figure 2.20). These reactions result in separation of the coating from the surface (cathodic disbondment). As this potential increases slightly, disbondment generally occurs through hydroxyl (OH–) formation. As the potential increases even more disbondment occurs through hydrogen formation.

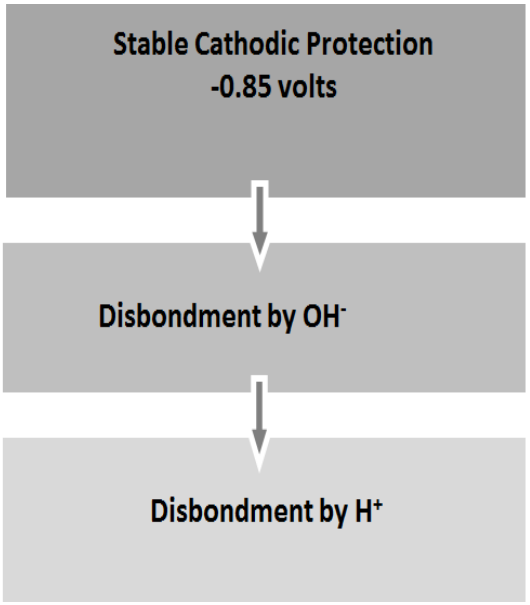


Figure 2.20 Cathodic Disbondment Sequence

2.9 Other Resources for Information

NACE International offers a specialized training and certification program in cathodic protection from tester to designer as well as a “Coatings in Conjunction with Cathodic Protection” course. For more information contact NACE International.

A copy of NACE Standard SP0 169, Control of External Corrosion on Underground or Submerged Metallic Piping Systems, is provided at the end of this chapter as supplemental information on cathodic protection.

For anyone interested in further cathodic protection training, NACE has a four-level

cathodic protection training and certification program.

Key Terms Definitions

Anode: The negatively charged electrode of an electrochemical cell where oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode.

Cathode: The positively charged electrode of an electrochemical cell where reduction is the principal reaction. Electrons flow towards the cathode in the external circuit.

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Crevice Corrosion: Localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from full exposure to the environment because of close proximity of the metal to the surface of another material.

Electrolyte: A chemical substance containing ions that migrate in an electric field.

Galvanic Corrosion: The electrochemical action of two dissimilar metals in contact in the presence of an electrolyte, and an electron conductive path.

Generalized Corrosion: Corrosion that is distributed more or less uniformly over the surface of a material.

Localized Corrosion: Corrosion that occurs at discrete sites on the metal surface.

Return Path (Metallic Pathway): Path that connects the anode and cathode, allowing passage of electrons, generated at the anode, to the cathode.

Study Guide

1. Describe passivation

_____
_____
_____

2. Describe the following factors and how they affect corrosion:
   - Oxygen: _____
   - Temperature: _____
   - Chemical salts: _____
   - Humidity (or wetness): _____
   - Pollutants and acid gases: _____

3. Two broad categories of corrosion can be described as:

_____
_____

4. Describe galvanic corrosion:

_____
_____
_____

5. Describe cathodic protection:

_____
_____
_____

6. The two primary types of cathodic protection are:

_____
_____

7. Impressed current power sources include:

_____
_____
_____
_____

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8. Describe cathodic disbondment:

_____
_____
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NACE SP0169-2007
(formerly RP0169-2002)
Item No. 21001

Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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Foreword

This standard practice presents procedures and practices for achieving effective control of external corrosion on buried or submerged metallic piping systems. These recommendations are also applicable to many other buried or submerged metallic structures. It is intended for use by corrosion control personnel concerned with the corrosion of buried or submerged piping systems, including oil, gas, water, and similar structures. This standard describes the use of electrically insulating coatings, electrical isolation, and cathodic protection (CP) as external corrosion control methods. It contains specific provisions for the application of CP to existing bare, existing coated, and new piping systems. Also included are procedures for control of interference currents on pipelines.

This standard should be used in conjunction with the practices described in the following NACE standards and publications, when appropriate (use latest revisions):

SP0572[1] RP0177[2] RP0285[3] SP0186[4] SP0286[5] SP0387[6] SP0188[7]
TPC 11[8] TM0497[9]

For accurate and correct application of this standard, the standard must be used in its entirety. Using or citing only specific paragraphs or sections can lead to misinterpretation and misapplication of the recommendations and practices contained in this standard.

This standard does not designate practices for every specific situation because of the complexity of conditions to which buried or submerged piping systems are exposed.

This standard was originally published in 1969, and was revised by NACE Task Group (TG) T-10-1 in 1972, 1976, 1983, and 1992. It was reaffirmed in 1996 by NACE Unit Committee T-10A on Cathodic Protection, and in 2002 and 2007 by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings. This standard is issued by NACE International under the auspices of STG 35, which is composed of corrosion control personnel from oil and gas transmission companies, gas distribution companies, power companies, corrosion consultants, and others concerned with external corrosion control of buried or submerged metallic piping systems.

In NACE standards, the terms *shall*, *must*, *should*, and may are used in accordance with the definitions of these terms in the NACE Publications Style Manual, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term should is used to state something considered good and is recommended but is not mandatory. The term may is used to state something considered optional.

NACE International
Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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Section 1: General

1.1 This standard presents acknowledged practices for the control of external corrosion on buried or submerged steel, cast iron, ductile iron, copper, and aluminum piping systems.

1.2 This standard is intended to serve as a guide for establishing minimum requirements for control of external corrosion on the following systems:

1.2.1 New piping systems: Corrosion control by a coating supplemented with CP, or by some other proven method, should be provided in the initial design and maintained during the service life of the piping system, unless investigations indicate that corrosion control is not required. Consideration should be given to the construction of pipelines in a manner that facilitates the use of in-line inspection tools.

1.2.2 Existing coated piping systems: CP should be provided and maintained, unless investigations indicate that CP is not required.

1.2.3 Existing bare piping systems: Studies should be made to determine the extent and rate of corrosion on existing bare piping systems. When these studies indicate that corrosion will affect the safe or economic operation of the system, adequate corrosion control measures shall be taken.

1.3 The provisions of this standard should be applied under the direction of competent persons who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics, acquired by education and related practical experience, are qualified to engage in the practice of corrosion control on buried or submerged metallic piping systems. Such persons may be registered professional engineers or persons recognized as corrosion specialists or CP specialists by NACE if their professional activities include suitable experience in external corrosion control of buried or submerged metallic piping systems.

1.4 Special conditions in which CP is ineffective or only partially effective sometimes exist. Such conditions may include elevated temperatures, disbonded coatings, thermal insulating coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte. Deviation from this standard may be warranted in specific situations provided that corrosion control personnel in responsible charge are able to demonstrate that the objectives expressed in this standard have been achieved.

1.5 This standard does not include corrosion control methods based on chemical control of the environment, on the use of electrically conductive coatings, or on control of internal corrosion.

Section 2: Definitions [(1)]

Amphoteric Metal: A metal that is susceptible to corrosion in both acid and alkaline environments.

Anode: The electrode of an electrochemical cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter solution at the anode.

Anodic Polarization: The change of the electrode potential in the noble (positive) direction caused by current across the electrode/electrolyte interface. (See *Polarization*.)

Backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Beta Curve: A plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate) versus the corresponding structure-to-electrolyte potentials at a selected location on the affected structure (abscissa) (see Appendix A [nonmandatory]).

Cable: One conductor or multiple conductors insulated from one another.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

(1) Definitions in this section reflect common usage among practicing corrosion control personnel and apply specifically to how the terms are used in this standard. In many cases, in the interests of brevity and practical usefulness, the scientific definitions are abbreviated or paraphrased.

Cathodic Polarization: The change of electrode potential in the active (negative) direction caused by current across the electrode/electrolyte interface. See *Polarization*.

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Coating: A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film.

Coating Disbondment: The loss of adhesion between a coating and the pipe surface.

Conductor: A material suitable for carrying an electric current. It may be bare or insulated.

Continuity Bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Corrosion Potential (E_{corr}): The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions (also known as *rest potential*, *open-circuit potential*, or *freely corroding potential*).

Corrosion Rate: The rate at which corrosion proceeds.

Criterion: Standard for assessment of the effectiveness of a cathodic protection system.

Current Density: The current to or from a unit area of an electrode surface.

Diode: A bipolar semiconducting device having a low resistance in one direction and a high resistance in the other.

Distributed-Anode Impressed Current System: An impressed current anode configuration in which the anodes are "distributed" along the structure at relatively close intervals such that the structure is within each anode's voltage gradient. This anode configuration causes the electrolyte around the structure to become positive with respect to remote earth.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrical Survey: Any technique that involves coordinated electrical measurements taken to provide a basis for deduction concerning a particular electrochemical condition relating to corrosion or corrosion control.

Electrode: A conductor used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte.

Electroosmotic Effect: Passage of a charged particle through a membrane under the influence of a voltage. Soil or coatings may act as the membrane.

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purpose of this standard, electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic piping system, including the moisture and other chemicals contained therein.

Foreign Structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.

Galvanic Series: A list of metals and alloys arranged according to their corrosion potentials in a given environment.

Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying cathodic protection.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection.)

In-Line Inspection: The inspection of a steel pipeline using an electronic instrument or tool that travels along the interior of the pipeline.

Insulating Coating System: All components of the protective coating, the sum of which provides effective electrical isolation of the coated structure.

Interference: Any electrical disturbance on a metallic structure as a result of stray current.

Interference Bond: An intentional metallic connection, between metallic systems in contact with a common electrolyte, designed to control electrical current interchange between the systems.

IR Drop: The voltage across a resistance in accordance with Ohm's Law.

Isolation: See *Electrical Isolation*.

Line Current: The direct current flowing on a pipeline.

Long-Line Current: Current through the earth between an anodic and a cathodic area that returns along an underground metallic structure.

Mixed Potential: A potential resulting from two or more electrochemical reactions occurring simultaneously on one metal surface.

Pipe-to-Electrolyte Potential: See Structure-to-Electrolyte Potential.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Reverse-Current Switch: A device that prevents the reversal of direct current through a metallic conductor.

Shielding: (1) Protecting; protective cover against mechanical damage. (2) Preventing or diverting the cathodic protection current from its intended path.

Shorted Pipeline Casing: A casing that is in direct metallic contact with the carrier pipe.

Sound Engineering Practices: Reasoning exhibited or based on thorough knowledge and experience, logically valid and having technically correct premises that demonstrate good judgment or sense in the application of science.

Stray Current: Current through paths other than the intended circuit.

Stray-Current Corrosion: Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth.

Structure-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged metallic structure and electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Telluric Current: Current in the earth as a result of geomagnetic fluctuations.

Voltage: An electromotive force or a difference in electrode potentials expressed in volts.

Wire: A slender rod or filament of drawn metal. In practice, the term is also used for smaller-gauge conductors (6 mm^2 [No. 10 AWG[(2)]] or smaller).

Section 3: Determination of Need for External Corrosion Control

3.1 Introduction

3.1.1 This section recommends practices for determining when an underground or submerged metallic piping system requires external corrosion control.

3.1.2 Metallic structures, buried or submerged, are subject to corrosion. Adequate corrosion control procedures should be adopted to ensure metal integrity for safe and economical operation.

3.2 The need for external corrosion control should be based on data obtained from one or more of the following: corrosion surveys, operating records, visual observations, test results from similar systems in similar environments, in-line inspections, engineering and design specifications, and operating, safety, and economic requirements. The absence of leaks alone is insufficient evidence that corrosion control is not required.

3.2.1 Environmental and physical factors include the following:

3.2.1.1 Corrosion rate of the particular metallic piping system in a specific environment (see Appendix B [nonmandatory]);

3.2.1.2 Nature of the product being transported, the working temperature, temperature differentials within the pipeline causing thermal expansion and contraction, tendency of backfill to produce soil stress, and working pressure of the piping system as related to design specification;

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(2) American Wire Gauge.

3.2.1.3 Location of the piping system as related to population density and frequency of visits by personnel;

3.2.1.4 Location of the piping system as related to other facilities; and

3.2.1.5 Stray current sources foreign to the system.

3.2.2 Economic factors include the following:

3.2.2.1 Costs of maintaining the piping system in service for its expected life (see Appendix B [nonmandatory])

3.2.2.2 Contingent costs of corrosion (see Appendix C [nonmandatory]); and

3.2.2.3 Costs of corrosion control (see Appendix D [nonmandatory]).

Section 4: Piping System Design

4.1 Introduction

4.1.1 This section provides accepted corrosion control practices in the design of an underground or submerged piping system. A person qualified to engage in the practice of corrosion control should be consulted during all phases of pipeline design and construction (see Paragraph 1.3). These recommendations should not be construed as taking precedence over recognized electrical safety practices.

4.2 External Corrosion Control

4.2.1 External corrosion control must be a primary consideration during the design of a piping system. Materials selection and coatings are the first line of defense against external corrosion. Because perfect coatings are not feasible, CP must be used in conjunction with coatings. For additional information, see Sections 5 and 6.

4.2.2 New piping systems should be externally coated unless thorough investigation indicates that coatings are not required (see Section 5).

4.2.3 Materials and construction practices that create electrical shielding should not be used on the pipeline. Pipelines should be installed at locations where proximity to other structures and subsurface formations do not cause shielding.

4.3 Electrical Isolation

4.3.1 Isolation devices such as flange assemblies, prefabricated joint unions, or couplings should be installed within piping systems in which electrical isolation of portions of the system is required to facilitate the application of external corrosion control. These devices should be properly selected for temperature, pressure, chemical resistance, dielectric resistance, and mechanical strength. Installation of isolation devices should be avoided or safeguarded in areas in which combustible atmospheres are likely to be present. Locations at which electrical isolating devices should be considered include, but are not limited to, the following:

4.3.1.1 Points at which facilities change ownership, such as meter stations and well heads;

4.3.1.2 Connections to mainline piping systems, such as gathering or distribution system laterals;

4.3.1.3 Inlet and outlet piping of in-line measuring and pressure regulating stations;

4.3.1.4 Compressor or pumping stations, either in the suction and discharge piping or in the main line immediately upstream and downstream from the station;

4.3.1.5 Stray current areas;

4.3.1.6 The junction of dissimilar metals;

4.3.1.7 The termination of service line connections and entrance piping;

4.3.1.8 The junction of a coated pipe and a bare pipe; and

4.3.1.9 Locations at which electrical grounding is used, such as motorized valves and instrumentation.

4.3.2 The need for lightning and fault current protection at isolating devices should be considered. Cable connections from isolating devices to arresters should be short, direct, and of a size suitable for short-term high-current loading.

4.3.3 When metallic casings are required as part of the underground piping system, the pipeline should be electrically isolated from such casings. Casing insulators must be properly sized and spaced and be tightened securely on the pipeline to withstand insertion stresses without sliding on the pipe. Inspection should be made to verify that the leading insulator has remained in position. Concrete coatings on the carrier pipe could preclude the use of casing insulators. Consideration should be given to the use of support under the pipeline at each end of the casing to minimize settlement. The type of support selected

should not cause damage to the pipe coating or act as a shield to CP current.

4.3.4 Casing seals should be installed to resist the entry of foreign matter into the casing.

4.3.5 When electrical contact would adversely affect CP, piping systems should be electrically isolated from supporting pipe stanchions, bridge structures, tunnel enclosures, pilings, offshore structures, or reinforcing steel in concrete. However, piping can be attached directly to a bridge without isolation if isolating devices are installed in the pipe system on each side of the bridge to isolate the bridge piping electrically from adjacent underground piping.

4.3.6 When an isolating joint is required, a device manufactured to perform this function should be used, or, if permissible, a section of nonconductive pipe, such as plastic pipe, may be installed. In either case, these should be properly rated and installed in accordance with the manufacturer's instructions.

4.3.7 River weights, pipeline anchors, and metallic reinforcement in weight coatings should be electrically isolated from the carrier pipe and designed and installed so that coating damage does not occur and the carrier pipe is not electrically shielded.

4.3.8 Metallic curb boxes and valve enclosures should be designed, fabricated, and installed in such a manner that electrical isolation from the piping system is maintained.

4.3.9 Insulating spacing materials should be used when it is intended to maintain electrical isolation between a metallic wall sleeve and the pipe.

4.3.10 Underground piping systems should be installed so that they are physically separated from all foreign underground metallic structures at crossings and parallel installations and in such a way that electrical isolation could be maintained if desired.

4.3.11 Based on voltage rating of alternating current (AC) transmission lines, adequate separation should be maintained between pipelines and electric transmission tower footings, ground cables, and counterpoise. Regardless of separation, consideration should always be given to lightning and fault current protection of pipeline(s) and personnel safety (see NACE Standard RP0177[2]).

4.4 Electrical Continuity

4.4.1 Nonwelded pipe joints may not be electrically continuous. Electrical continuity can be ensured by the use of fittings manufactured for this purpose or by bonding across and to the mechanical joints in an effective manner.

4.5 Corrosion Control Test Stations

4.5.1 Test stations for potential, current, or resistance measurements should be provided at sufficient locations to facilitate CP testing. Such locations may include, but are not limited to, the following:

4.5.1.1 Pipe casing installations,

4.5.1.2 Metallic structure crossings,

4.5.1.3 Isolating joints,

4.5.1.4 Waterway crossings,

4.5.1.5 Bridge crossings,

4.5.1.6 Valve stations,

4.5.1.7 Galvanic anode installations,

4.5.1.8 Road crossings,

4.5.1.9 Stray-current areas, and

4.5.1.10 Rectifier installations.

4.5.2 The span of pipe used for line current test stations should exclude:

4.5.2.1 Foreign metallic structure crossings;

4.5.2.2 Lateral connections;

4.5.2.3 Mechanical couplings or connections such as screwed joints, transition pieces, valves, flanges, anode or rectifier attachments, or metallic bonds; and

4.5.2.4 Changes in pipe wall thickness and diameter.

4.5.3 Attachment of Copper Test Lead Wires to Steel and Other Ferrous Pipes

4.5.3.1 Test lead wires may be used both for periodic testing and for current-carrying purposes. As such, the wire/pipe attachment should be mechanically strong and electrically conductive.

4.5.3.2 Methods of attaching wires to the pipe include (a) thermit welding process, (b) soldering, and (c) mechanical means.

4.5.3.3 Particular attention must be given to the attachment method to avoid (a) damaging or penetrating the pipe, (b) sensitizing or altering of pipe properties, (c) weakening the test lead wire, (d) damaging internal or external pipe coatings, and (e) creating hazardous conditions in explosive environments.

4.5.3.4 Attachment by mechanical means is the least desirable method. Such a connection may

loosen, become highly resistant, or lose electrical continuity.

4.5.3.5 The connection should be tested for mechanical strength and electrical continuity. All exposed portions of the connection should be thoroughly cleaned of all welding slag, dirt, oils, etc.; primed, if needed; and coated with materials compatible with the cable insulation, pipe coating, and environment.

4.5.4 Attachment of Aluminum Test Lead Wire to Aluminum Pipes

4.5.4.1 Aluminum test lead wire, or aluminum tabs attached to aluminum wire, may be welded to aluminum pipe using the tungsten inert-gas shielded arc (TIG) or metal inert-gas shielded arc (MIG) process. Welded attachments should be made to flanges or at butt weld joints. Attachment at other sites may adversely affect the mechanical properties of the pipe because of the heat of welding.

4.5.4.2 Test lead wire may be attached to aluminum pipe by soldering. If low-melting-point soft solders are used, a flux is required. Flux residues may cause corrosion unless removed.

NOTE: The use of copper test lead wire may cause preferential galvanic attack on the aluminum pipe. When copper wire or flux is used, care must be taken to seal the attachment areas against moisture. In the presence of moisture, the connection may disbond and be damaged by corrosion.

4.5.4.3 Aluminum tabs to which test lead wires have been TIG welded can be attached by an explosive bonding technique called high-energy joining.

4.5.4.4 Mechanical connections that remain secure and electrically conductive may be used.

4.5.5 Attachment of Copper Test Lead Wire to Copper Pipe.

4.5.5.1 Copper test lead wire, or copper tabs attached to copper wire, may be attached to copper pipe by one of the following methods. The relative thickness of the wire and the pipe wall dictates, in part, which of the methods can be used.

4.5.5.1.1 Arc welding (TIG, MIG, or shielded metal);

4.5.5.1.2 Electrical resistance (spot) welding;

4.5.5.1.3 Brazing;

4.5.5.1.4 Soldering; or

4.5.5.1.5 Mechanical connection.

4.5.5.2 Attention should be given to proper joining procedures to avoid possible embrittlement or loss of mechanical properties of the metals from the heat of welding or brazing.

4.5.5.3 A flux may be required, or self-produced, when brazing with some filler metals or soldering with some low-melting-point soft solders. Because flux residues may cause corrosion, they should be removed.

Section 5: External Coatings

5.1 Introduction

5.1.1 This section recommends practices for selecting, testing and evaluating, handling, storing, inspecting, and installing external coating systems for external corrosion control on piping systems.

The function of external coatings is to control corrosion by isolating the external surface of the underground or submerged piping from the environment, to reduce CP current requirements, and to improve current distribution.

5.1.2 External coatings must be properly selected and applied and the coated piping carefully handled and installed to fulfill these functions. Various types of external coatings can accomplish the desired functions.

5.1.2.1 Desirable characteristics of external coatings include the following:

5.1.2.1.1 Effective electrical insulator;

5.1.2.1.2 Effective moisture barrier;

5.1.2.1.3 Application to pipe by a method that does not adversely affect the properties of the pipe;

5.1.2.1.4 Application to pipe with a minimum of defects;

5.1.2.1.5 Good adhesion to pipe surface;

5.1.2.1.6 Ability to resist development of holidays with time;

5.1.2.1.7 Ability to resist damage during handling, storage, and installation;

5.1.2.1.8 Ability to maintain substantially constant electrical resistivity with time;

5.1.2.1.9 Resistance to disbonding;

5.1.2.1.10 Resistance to chemical degradation;

5.1.2.1.11 Ease of repair;

5.1.2.1.12 Retention of physical characteristics;

5.1.2.1.13 Nontoxic to the environment; and

5.1.2.1.14 Resistance to changes and deterioration during aboveground storage and long-distance transportation.

5.1.2.2 Typical factors to consider when selecting an external pipe coating include:

5.1.2.2.1 Type of environment;

5.1.2.2.2 Accessibility of piping system;

5.1.2.2.3 Operating temperature of piping system;

5.1.2.2.4 Ambient temperatures during application, shipping, storage, construction, installation, and pressure testing;

5.1.2.2.5 Geographical and physical location;

5.1.2.2.6 Type of external coating on existing pipe in the system;

5.1.2.2.7 Handling and storage;

5.1.2.2.8 Pipeline installation methods;

5.1.2.2.9 Costs; and

5.1.2.2.10 Pipe surface preparation requirements.

5.1.2.3 Pipeline external coating systems shall be properly selected and applied to ensure that adequate bonding is obtained. Unbonded coatings can create electrical shielding of the pipeline that could jeopardize the effectiveness of the CP system.

5.1.3 Information in this section is primarily by reference to other documents. It is important that the latest revision of the pertinent reference be used.

5.1.3.1 Table 1 is a listing of types of external coating systems, showing the appropriate references for material specifications and recommended practices for application.

5.1.3.2 Table 2 is a grouping of references for general use during installation and inspection, regardless of coating type.

5.1.3.3 Table 3 is a list of external coating system characteristics related to environmental conditions containing suggested laboratory test references for various properties.

5.1.3.4 Table 4 is a list of external coating system characteristics related to design and construction, with recommended laboratory tests for evaluating these properties.

5.1.3.5 Table 5 lists the references that are useful in field evaluation of external coating systems after the pipeline has been installed.

5.2 Storage, Handling, Inspection, and Installation

5.2.1 Storage and Handling

5.2.1.1 Coated pipe to be stored should be protected internally and externally from atmospheric corrosion and coating deterioration.

5.2.1.2 Damage to coating can be minimized by careful handling and by using proper pads and slings.

TABLE 1

Generic External Coating Systems with Material Requirements and Recommended Practices for Application[A]

Generic External Coating System	Reference
Coal Tar	ANSI[B]/AWWA[C] C 203[10]
Wax	NACE Standard RP0375[11]
Prefabricated Films	ANSI/AWWA C 214[12] ANSI/AWWA C 209[13]
Fusion-Bonded Epoxy Coatings	*Peabody's Control of Pipeline Corrosion*[14] ANSI/AWWA C 213[15] API[D] RP 5L7[16] CSA[E]Z245.20M[17] NACE Standard RP0394[18]
Polyolefin Coatings	NACE Standard RP0185[19] DIN[F] 30 670[20] ANSI/AWWA C 215[21]

[A] NOTE: Many other references are available, and this table is not comprehensive. Listing does not constitute endorsement of any external coating system in preference to another. Omission of a system may be due to unavailability of reference standards or lack of data.
[B] American National Standards Institute (ANSI), 1819 L St. NW, Washington, DC 20036.
[C] American Water Works Association (AWWA), 6666 West Quincy Ave., Denver, CO 80235.
[D] American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005-4070.
[E] CSA International, 178 Rexdale Blvd., Toronto, Ontario, Canada M9W 1R3.
[F] Deutsches Institut fur Normung (DIN), Burggrafenstrasse 6, D-10787 Berlin, Germany.

TABLE 2
References for General Use in the Installation and Inspection of External Coating Systems for Underground Piping

Subject	Reference
Application of Organic Pipeline Coatings	ANSI/AWWA C 203[10] NACE Standard RP0375[11] *Peabody's Control of Pipeline Corrosion*[14] ANSI/AWWA C 213[15] API RP 5L7[16] CSA Z245.20M[17]
Film Thickness of Pipeline Coatings	ASTM[A] G 128[22]
Inspection of Pipeline Coatings	NACE Standard RP0274[23]

[A] ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

TABLE 3
External Coating System Characteristics Relative to Environmental Conditions[A]

Environmental Factor	Recommended Test Methods[B]
General underground exposure with or without CP	*Peabody's Control of Pipeline Corrosion*[14] ANSI/AWWA C 213[15] API RP 5L7[16] CSA Z245.20M[17] ASTM G 8[24] ASTM G 19[25] ASTM G 42[26] ASTM G 95[27]
Resistance to water penetration and its effect on choice of coating thickness	ASTM G 9[28]
Resistance to penetration by stones in backfill	ASTM G 17[29] ASTM D 2240[30] ASTM G 13[31] ASTM G 14[32]
Soil stress	*Underground Corrosion*[33] ASTM D 427[34]
Resistance to specific liquid not normally encountered in virgin soil	ASTM D 543[35] Federal Test Standard[C] No. 406A, Method 7011[36] ASTM G 20[37]
Resistance to thermal effects	ASTM D 2304[38] ASTM D 2454[39] ASTM D 2485[40]
Suitability of supplementary materials for joint coating and field repairs	ASTM G 8[24] ASTM G 19[25] ASTM G 42[26] ASTM G 95[27] ASTM G 9[28] ASTM G 18[41] ASTM G 55[42]
Resistance to microorganisms	ASTM G 21[43] Federal Test Standard No. 406A, Method 6091[44]

[A] NOTE: Apply only those factors pertinent to the installation.
[B] No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.
[C] Available from General Services Administration, Business Service Center, Washington, DC 20025.

TABLE 4
External Coating System Characteristics Related to Design and Construction

Design and Construction Factor	Recommended Test Methods[A]
Yard Storage, Weathering	ASTM G 11[45]
Yard Storage, Penetration Under Load	ASTM G 17[29] ASTM D 2240[30]
Handling Resistance, Abrasion	ASTM G 6[46]
Handling Resistance, Impact	ASTM G 13[31] ASTM G 14[32]
Field Bending Ability	ASTM G 10[47]
Driving Ability (Resistance to Sliding Abrasion)	ASTM G 6[46] ASTM D 2197[48]
Special Requirements for Mill-Applied Coating	ANSI/AWWA C 203[10] NACE Standard RP0375[11] ANSI/AWWA C 214[12] ANSI/AWWA C 209[13] *Peabody's Control of Pipeline Corrosion*[14] ANSI/AWWA C 213[15] API RP 5L7[16] CSA Z245.20M[17] NACE Standard RP0185[19] DIN 30 670[20] ANSI/AWWA C 215[21]
Special Requirements for Application of Coating Over the Ditch	ANSI/AWWA C 203[10] NACE Standard RP0375[11] ANSI/AWWA C 214[12] ANSI/AWWA C 209[13] *Peabody's Control of Pipeline Corrosion*[14] ANSI/AWWA C 213[15] API RP 5L7[16] CSA Z245.20M[17]
Backfill Resistance	ASTM G 13[31] ASTM G 14[32]
Resistance to Thermal Effects	ASTM G 8[24] ASTM G 19[25] ASTM G 42[26] ASTM G 95[27] ASTM D 2304[38] ASTM D 2454[39] ASTM D 2485[40]
Suitability of Joint Coatings and Field Repairs	*Peabody's Control of Pipeline Corrosion*[14] ANSI/AWWA C 213[15] API RP 5L7[16] CSA Z245.20M[17] ASTM G 8[24] ASTM G 19[25] ASTM G 42[26] ASTM G 95[27] ASTM G 9[28] ASTM G 18[41] ASTM G 55[42]

[A] No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.

TABLE 5
Methods for Evaluating In-Service Field Performance of External Coatings

Title or Subject of Method	Reference	Basis for Rating
(1) Rate of Change in Current Required for CP	*Underground Corrosion*[33]	Comparison of initial current requirement with subsequent periodic determination of current requirement
(2) Inspection of Pipeline Coating	NACE Standard RP0274[23]	(a) With CP: no active corrosion found (b) Without CP: no new holidays showing active corrosion
(3) Cathodic Disbondment	ASTM G 8[24] ASTM G 19[25] ASTM G 42[26] ASTM G 95[27]	Purpose is to obtain data relative to specific conditions for comparison with laboratory data

5.2.2 Inspection

5.2.2.1 Qualified personnel should keep every phase of the coating operation and piping installation under surveillance.

5.2.2.2 Surface preparation, primer application, coating thickness, temperature, bonding, and other specific requirements should be checked periodically, using suitable test procedures, for conformance to specifications.

5.2.2.3 The use of holiday detectors is recommended to detect coating flaws that would not be observed visually. The holiday detector should be operated in accordance with the manufacturer's instructions and at a voltage level appropriate to the electrical characteristics of the coating system.

5.2.3 Installation

5.2.3.1 Joints, fittings, and tie-ins must be coated with a material compatible with the existing coating.

5.2.3.2 Coating defects should be repaired.

5.2.3.3 Materials used to repair coatings must be compatible with the existing pipe coating.

5.2.3.4 The ditch bottom should be graded and free of rock or other foreign matter that could damage the external coating or cause electrical shielding. Under difficult conditions, consideration should be given to padding the pipe or the ditch bottom.

5.2.3.5 Pipe should be lowered carefully into the ditch to avoid external coating damage.

5.2.3.6 Care should be taken during backfilling so that rocks and debris do not strike and damage the pipe coating.

5.2.3.7 Care shall be exercised when using materials such as loose wrappers, nonconducting urethane foam, and rock shield around pipelines as protection against physical damage or for other purposes, because these materials may create an electrical shielding effect that would be detrimental to the effectiveness of CP.

5.2.3.8 When a pipeline comes above ground, it must be cleaned and externally coated, or jacketed with a suitable material, for the prevention of atmospheric corrosion.

5.3 Methods for Evaluating External Coating Systems

5.3.1 Established Systems Proven by Successful Use

5.3.1.1 Visual and electrical inspection of in-service pipeline coatings should be used to evaluate the performance of an external coating system. These inspections can be conducted wherever the pipeline is excavated or at bell holes made for inspection purposes.

5.3.2 Established or Modified Systems for New Environments

5.3.2.1 This method is intended for use when external coating systems will continue to be used and are qualified under Paragraph 5.3.1, but when application will be extended to new environments or when it is desired to revise a system to make use of new developments, one of the following should be used:

5.3.2.1.1 The use of applicable material requirements, material specifications, standards, and recommended practices for application, as given in Table 1, is recommended.

5.3.2.1.2 The use of applicable references in Table 2 is recommended unless previously covered in applicable references in Table 1.

5.3.3 New External Coating System Qualification

5.3.3.1 The purpose of this method is to qualify a new external coating material by subjecting it to laboratory tests appropriate for the intended service. After laboratory tests have been conducted and indicate that the external coating system appears to be suitable, application and installation are conducted in accordance with recommended practices. In-service field performance tests are made to confirm the success of the previous steps. The steps of the method are (1) laboratory tests, (2) application under recommended practices, (3) installation under recommended practices, and (4) in-service field performance tests. If good results are obtained after five years, only Steps 2 and 3 are required thereafter.

5.3.3.1.1 Applicable sections of Tables 3 and 4 are recommended for the initial laboratory test methods.

5.3.3.1.2 Applicable sections of Tables 1 and 2 are recommended for conditional use during Steps 2 and 3.

5.3.3.1.3 During a period of five years or more, the use of the evaluation methods given in Table 5, Item 1 or 2 are recommended. The test method in Item 3 may be used as a supplementary means for obtaining data for correlation with laboratory tests.

5.3.4 Method for Evaluating an External Coating System by In-Service Field Performance Only

5.3.4.1 The purpose of this method is to qualify an external coating system when none of the first three methods given in Paragraph 5.3 has been or will be used. It is intended that this method should be limited to minor pilot installations.

5.3.4.1.1 The use of at least one of the first two methods given in Table 5 is recommended on the basis of at least one investigation per year for five consecutive years.

Section 6: Criteria and Other Considerations for CP

6.1 Introduction

6.1.1 This section lists criteria and other considerations for CP that indicate, when used either separately or in combination, whether adequate CP of a metallic piping system has been achieved (see also Section 1, Paragraphs 1.2 and 1.4).

6.1.2 The effectiveness of CP or other external corrosion control measures can be confirmed by visual observation, by measurements of pipe wall thickness, or by use of internal inspection devices. Because such methods sometimes are not practical, meeting any criterion or combination of criteria in this section is evidence that adequate CP has been achieved. When excavations are made for any purpose, the pipe should be inspected for evidence of corrosion and coating condition.

6.1.3 The criteria in this section have been developed through laboratory experiments or verified by evaluating data obtained from successfully operated CP systems. Situations in which a single criterion for evaluating the effectiveness of CP may not be satisfactory for all conditions may exist. Often a combination of criteria is needed for a single structure.

6.1.4 Sound engineering practices shall be used to determine the methods and frequency of testing required to satisfy these criteria.

6.1.5 Corrosion leak history is valuable in assessing the effectiveness of CP. Corrosion leak history by itself, however, shall not be used to determine whether adequate levels of CP have been achieved unless it is impractical to make electrical surveys.

6.2 Criteria

6.2.1 It is not intended that persons responsible for external corrosion control be limited to the criteria listed below. Criteria that have been successfully applied on existing piping systems can continue to be used on those piping systems. Any other criteria used must achieve corrosion control comparable to that attained with the criteria herein.

6.2.2 Steel and Cast Iron Piping

6.2.2.1 External corrosion control can be achieved at various levels of cathodic polarization depending on the environmental conditions. However, in the absence of specific data that demonstrate that adequate CP has been achieved, one or more of the following shall apply:

6.2.2.1.1 A negative (cathodic) potential of at least 850 mV with the CP applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage

drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement.

NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

6.2.2.1.1.1 Measuring or calculating the voltage drop(s);

6.2.2.1.1.2 Reviewing the historical performance of the CP system;

6.2.2.1.1.3 Evaluating the physical and electrical characteristics of the pipe and its environment; and

6.2.2.1.1.4 Determining whether or not there is physical evidence of corrosion.

6.2.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.

6.2.2.1.3 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.

6.2.2.2 Special Conditions

6.2.2.2.1 On bare or ineffectively coated pipelines when long-line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient.

6.2.2.2.2 In some situations, such as the presence of sulfides, bacteria, elevated temperatures, acid environments, and dissimilar metals, the criteria in Paragraph 6.2.2.1 may not be sufficient.

6.2.2.2.3 When a pipeline is encased in concrete or buried in dry or aerated high-resistivity soil, values less negative than the criteria listed in Paragraph 6.2.2.1 may be sufficient.

6.2.2.3 PRECAUTIONARY NOTES

6.2.2.3.1 The earth current technique is often meaningless in multiple pipe rights-of-way, in high-resistivity surface soil, for deeply buried pipe, in stray-current areas, or where local corrosion cell action predominates.

6.2.2.3.2 Caution is advised against using polarized potentials less negative than -850 mV for CP of pipelines when operating pressures and conditions are conducive to stress corrosion cracking (see references on stress corrosion cracking at the end of this section).

6.2.2.3.3 The use of excessive polarized potentials on externally coated pipelines should be avoided to minimize cathodic disbondment of the coating.

6.2.2.3.4 Polarized potentials that result in excessive generation of hydrogen should be avoided on all metals, particularly higher-strength steel, certain grades of stainless steel, titanium, aluminum alloys, and prestressed concrete pipe.

6.2.3 Aluminum Piping

6.2.3.1 The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

6.2.3.2 PRECAUTIONARY NOTES

6.2.3.2.1 Excessive Voltages: Notwithstanding the minimum criterion in Paragraph 6.2.3.1, if aluminum is cathodically protected at voltages more negative than -1,200 mV measured between the pipe surface and a saturated copper/copper sulfate reference electrode contacting the electrolyte and compensation is made for the voltage drops other than those across the pipe-electrolyte boundary, it may suffer corrosion as the result of the buildup of alkali on the metal surface. A polarized potential more negative than -1,200 mV should not be used unless previous test results indicate that no appreciable corrosion will occur in the particular environment.

6.2.3.2.2 Alkaline Conditions: Aluminum may suffer from corrosion under high-pH conditions, and application of CP tends to increase the pH at the metal surface. Therefore, careful investigation or testing should be done before applying CP to stop pitting attack on aluminum in environments with a natural pH in excess of 8.0.

6.2.4 Copper Piping

6.2.4.1 The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

6.2.5 Dissimilar Metal Piping

6.2.5.1 A negative voltage between all pipe surfaces and a stable reference electrode contacting the electrolyte equal to that required for the protection of the most anodic metal should be maintained.

6.2.5.2 PRECAUTIONARY NOTE

6.2.5.2.1 Amphoteric materials that could be damaged by high alkalinity created by CP should be electrically isolated and separately protected.

6.3 Other Considerations

6.3.1 Methods for determining voltage drop(s) shall be selected and applied using sound engineering practices. Once determined, the voltage drop(s) may be used for correcting future measurements at the same location, provided conditions such as pipe and CP system operating conditions, soil characteristics, and external coating quality remain similar. (Note: Placing the reference electrode next to the pipe surface may not be at the pipe-electrolyte interface. A reference electrode placed at an externally coated pipe surface may not significantly reduce soil voltage drop in the measurement if the nearest coating holiday is remote from the reference electrode location.)

6.3.2 When it is impractical or considered unnecessary to disconnect all current sources to correct for voltage drop(s) in the structure-to-electrolyte potential measurements, sound engineering practices should be used to ensure that adequate CP has been achieved.

6.3.3 When feasible and practicable, in-line inspection of pipelines may be helpful in determining the presence or absence of pitting corrosion damage. Absence of external corrosion damage or the halting of its growth may indicate adequate external corrosion control. The in-line inspection technique, however, may not be capable of detecting all types of external corrosion damage, has limitations in its accuracy, and may report as anomalies items that are not external corrosion. For example, longitudinal seam corrosion and general corrosion may not be readily detected by in-line inspection. Also, possible thickness variations, dents, gouges, and external ferrous objects may be detected as corrosion. The appropriate use of in-line inspection must be carefully considered.

6.3.4 Situations involving stray currents and stray electrical gradients that require special analysis may exist. For additional information, see Section 9, "Control of Interference Currents."

6.4 Alternative Reference Electrodes

6.4.1 Other standard reference electrodes may be substituted for the saturated copper/copper sulfate reference electrode. Two commonly used reference electrodes are listed below along with their voltage equivalent (at 25°C [77°F]) to -850 mV referred to a saturated copper/copper sulfate reference electrode:

6.4.1.1 Saturated KCl calomel reference electrode: -780 mV; and

6.4.1.2 Saturated silver/silver chloride reference electrode used in 25 ohm-cm seawater: -800 mV.

6.4.2 In addition to these standard reference electrodes, an alternative metallic material or structure may be used in place of the saturated copper/copper sulfate reference electrode if the stability of its electrode potential is ensured and if its voltage equivalent referred to a saturated copper/copper sulfate reference electrode is established.

Bibliography for Section 6

Criteria for Copper

Schwerdtfeger, W.J. "Criteria for Cathodic Protection—Highly Resistant Copper Deteriorates in Severely Corrosive Soil." *Materials Protection* 57, 9 (1968): p. 43.

Criteria for Aluminum

BS CP 1021 (latest revision). "Code of Practice for Cathodic Protection." London, England: BSI.[3]

DIN30 676 (latest revision). "Design and Application of Cathodic Protection of External Surfaces." Berlin, Germany: DIN

[3] British Standards Institution (BSI), British Standards House, 389 Chiswick High Road, London W4 4AL, United Kingdom.

NACE Publication 2M363 (withdrawn). "Recommended Practice for Cathodic Protection of Aluminum Pipe Buried in Soil or Immersed in Water." Houston, TX: NACE.

Schwerdtfeger, W.J. "Effects of Cathodic Current on the Corrosion of An Aluminum Alloy." National Bureau of Standards[4] *Journal of Research* 68c (Oct.-Dec. 1964): p. 283.

Criteria for Steel and Cast Iron

Doremus, E.P., and T.L. Canfield. "The Surface Potential Survey Can Detect Pipeline Corrosion Damage." *Materials Protection* 6, 9 (1967): p. 33.

Ewing, S.P. "Potential Measurements for Determination of Cathodic Protection Requirements." *Corrosion* 7, 12 (1951): p. 410.

Haycock, E.W. "Current Requirements for Cathodic Protection of Oil Well Casing." *Corrosion* 13, 11 (1957): p. 767.

Kuhn, R.C. "Cathodic Protection of Underground Pipelines Against Soil Corrosion." *American Petroleum Institute Proceedings* IV, 14 (1953): p. 153.

McCollum, B., and K.H. Logan. National Bureau of Standards Technical Paper No. 351, 1927.

Romanoff, M. *Underground Corrosion*. Houston, TX: NACE, 1989.

Pearson, J.M. "Electrical Instruments and Measurement in Cathodic Protection." *Corrosion* 3, 11 (1947): p. 549.

Pearson, J.M. "Null Methods Applied to Corrosion Measurements." *Transactions of the Electrochemical Society* 81 (1942): p. 485.

Schwerdtfeger, W.J., and O.N. McDorman. "Potential and Current Requirements for the Cathodic Protection of Steel in Soils." *Corrosion* 8, 11 (1952): p. 391.

Sudrabin, L.P., and F.W. Ringer. "Some Observations on Cathodic Protection Criteria." *Corrosion* 13, 5 (1957) p. 351t. Discussion on this paper *Corrosion* 13, 12 (1957): p. 835t.

Additional References

Barlo, T.J., and W.E. Berry. "A Reassessment of the -0.85 V and 100 mV Polarization Criteria for Cathodic Protection of Steel Buried in Soils. *Ninth International Congress on Metallic Corrosion* 4, (1984): June 7. National Research Council Canada.[5]

Barlo, T.J., and W.E. Berry. "An Assessment of the Current Criteria for Cathodic Protection of Buried Steel Pipes." *MP* 23, 9 (1984).

Barlo, T.J., and R.R. Fessler. "Interpretation of True Pipe-to-Soil Potentials on Coated Pipelines with Holidays."

CORROSION/83, paper no. 292. Houston, TX: NACE, 1983.

Barlo, T.J., and R.R. Fessler. "Investigation of Techniques to Determine the True Pipe-to-Soil Potential of a Buried Pipeline." AGA[6] Project PR-3-93, 1979 Annual Report, May, 1980.

Cathodic Protection Criteria—A Literature Survey. Houston, TX: NACE, 1989.

Comeaux, R.V. "The Role of Oxygen in Corrosion and Cathodic Protection." *Corrosion* 8, 9 (1952): pp. 305-309.

Compton, K.G. "Criteria and Their Application for Cathodic Protection of Underground Structures." *Materials Protection* 4, 8 (1965): pp. 93-96.

Dabkowski, J. "Assessing the Cathodic Protection Levels of Well Casings." AGA Project 151-106, Final Report, January 1983: pp. 3-92.

Dexter, S.C., L.N. Moettus, and K.E. Lucas. "On the Mechanism of Cathodic Protection." *Corrosion* 41, 10 (1985).

"Field Testing the Criteria for Cathodic Protection." AGA Interim Report PR-151-163, December, 1987.

Fischer, K.P. "Cathodic Protection in Saline Mud Containing Sulfate Reducing Bacteria." *MP* 20, 10 (1981): pp. 41-46.

Holler, H.D. "Studies on Galvanic Couples II-Some Potential-Current Relations in Galvanic Corrosion." *Journal of the Electrochemical Society* September (1950): pp. 277-282.

Gummow, R.A. "Cathodic Protection Criteria—A Critical Review of NACE Standard RP0169." *MP* 25, 9 (1986): pp. 9-16.

[4] National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards), 100 Bureau Dr., Gaithersburg, MD 20899.
[5] National Research Council Canada (NRC), 1200 Montreal Road, Ottawa, Ontario K1A 0R6, CANADA.
[6] American Gas Association (AGA), 400 North Capitol St. NW, Suite 400, Washington, DC 20001.

Hoey, G.R., and M. Cohen. "Cathodic Protection of Iron in the Temperature Range 25-92°C." *Corrosion* 14, 4 (1958): pp. 200t-202t.

Howell, R.P. "Potential Measurements in Cathodic Protection Designs." *Corrosion* 8, 9 (1952).

Jones, D. "Electrochemical Fundamentals of Cathodic Protection." CORROSION/87, paper no. 317. Houston, TX: NACE, 1987.

Kasahara, K., T. Sato, and H. Adachi. "Results of Polarization Potential and Current DensitySurveys on Existing Buried Pipelines." *MP* 19, 9 (1980): pp. 45-51.

Kehn, G.R., and E.J. Wilhelm. "Current Requirements for the Cathodic Protection of Steel in Dilute Aqueous Solutions." *Corrosion* 7, 5 (1951): pp. 156-160.

Koybayaski, T. "Effect of Environmental Factors on the Protective Potential of Steel." *Proceedings of the Fifth International Congress on Metallic Corrosion.* Houston, TX: NACE, 1980.

Krivian, L. "Application of the Theory of Cathodic Protection to Practical Corrosion Systems." *British Corrosion Journal* 19, 1 (1984).

Kuhn, R.J. "Cathodic Protection on Texas Gas Systems." AGA Annual Conference. Held Detroit, MI, April 1950.

Lattin, B.C. "The Errors of Your Ways (Fourteen Pitfalls for Corrosion Engineers and Technicians to Avoid)." *MP* 20, 3 (1981): p. 30.

Logan, K.H. "Comparison of Cathodic Protection Test Methods." *Corrosion* 10, 7 (1954).

Logan, K.H. "Underground Corrosion." National Bureau of Standards Circular C450, November 1945, pp. 249-278.

Logan, K.H. "The Determination of the Current Required for Cathodic Protection." National Bureau of Standards Soil Corrosion Conference, March 1943.

Martin, B.A. "Cathodic Protection: The Ohmic Component of Potential Measurements—Laboratory Determination with a Polarization Probe in Aqueous Environments." *MP* 20, 1 (1981): p. 52.

Martin, B.A., and J.A. Huckson. "New Developments in Interference Testing." *Industrial Corrosion* 4, 6 (1986): pp. 26-31.

Mears and Brown. "A Theory of Cathodic Protection." *Transactions of the Electrochemical Society* 74 (1938): p. 527.

Morgan, J. *Cathodic Protection.* 2nd Ed. Houston, TX: NACE, 1987.

NACE Technical Committee T-2C Report (withdrawn). "Criteria for Adequate Cathodic Protection of Coated, Buried, or Submerged Steel Pipe Lines and Similar Steel Structures." Houston, TX: NACE.

Pearson, J.M. "Concepts and Methods of Cathodic Protection." *The Petroleum Engineer* 15, 6 (1944): p. 218; and 15, 7 (1944): p. 199.

Pourbaix, M. *Atlas of Electrochemical Equilibria in Aqueous Solutions.* Houston, TX: NACE, 1974, p. 319.

Prinz, W. "Close Interval Potential Survey of Buried Pipelines, Methods and Experience." UK Corrosion '86, p. 67.

Riordan, M.A. "The Electrical Survey—What It Won't Do." *MP* 17, 11 (1978): pp. 38-41.

Riordan, M.A., and R.P. Sterk. "Well Casing as an Electrochemical Network in Cathodic Protection Design." *Materials Protection* 2, 7 (1963): pp. 58-68.

Schaschl, E., and G.A. Marsh. "Placement of Reference Electrode and Impressed Current Anode Effect on Cathodic Protection of Steel in a Long Cell." *MP* 13, 6 (1974): pp. 9-11.

Stern, M. "Fundamentals of Electrode Processes in Corrosion." *Corrosion* 13, 11 (1957): p. 97.

CEA 54277 (withdrawn). "State-of-the-Art Report, Specialized Surveys for Buried Pipelines." Houston, TX: NACE.

Thompson, N.G., and T.J. Barlo. "Fundamental Process of Cathodically Protecting Steel Pipelines." International Gas Research Conference, 1983.

Toncre, A.C. "A Review of Cathodic Protection Criteria." *Proceeding of Sixth European Congress on Metallic Corrosion.* Held London, England, September 1977, pp. 365-372.

Van Nouhuys, H.C. "Cathodic Protection and High Resistivity Soil." *Corrosion* 9, 12 (1953): pp. 448-458.

Van Nouhuys, H.C. "Cathodic Protection and High Resistivity Soil—A Sequel." *Corrosion* 14, 12 (1958): p. 55.

Von Baekmann, W., A. Ballest, and W. Prinz. "New Development in Measuring the Effectiveness of Cathodic Protection." *Corrosion Australasia,* February, 1983.

Von Baekmann, W., and W. Schwenk. *Handbook of Cathodic Protection.* Portellis Press, 1975, Chapter 2.

Webster, R.D. "Compensating for the IR Drop Component in Pipe-to-Soil Potential Measurements." *MP* 26, 10 (1987): pp. 38-41.

Wyatt, B.S., and K.C. Lax. "Close Interval Overline Polarized Potential Surveys of Buried Pipelines." UK Corrosion Conference, 1985.

Stress Corrosion Cracking

Barlo, T.J., et al. "An Assessment of the Criteria for Cathodic Protection of Buried Pipelines." AGA Final Report, Project PR-3-129, 1983.

Barlo, T.J., et al. "Controlling Stress-Corrosion Cracking by Cathodic Protection." AGA Annual Report, Project-3-164, 1984.

Parkins, R.N., A.J. Markworth, J.H. Holbrook, and R.R. Fessler. "Hydrogen Gas Evolution From Cathodically Protected Surfaces." *Corrosion* 41,7 (1985): pp. 389-

Parkins, R.N., and R.R. Fessler. "Stress Corrosion Cracking of High-Pressure Gas Transmission Pipelines." *Materials in Engineering Applications* 1, 2 (1978) pp. 80-96.

Parkins, R.N., and R.R. Fessler. "Line Pipe Stress Corrosion Cracking—Mechanisms and Remedies." CORROSION/86 paper no. 320. Houston, TX: NACE, 1986.

Parkins, R.N., A.J. Markworth, and J.H. Holbrook. "Hydrogen Gas Evolution From Cathodically Protected Pipeline Steel Surfaces Exposed to Chloride-Sulfate Solutions." *Corrosion* 44, 8 (1988): pp. 572-580.

McCaffrey, W.R. "Effect of Overprotection on Pipeline Coatings." *Materials Protection and Performance* 12, 2 (1973): p. 10.

PR-15-427. "An Assessment of Stress Corrosion Cracking (SCC) Research for Line Pipe Steels." AGA, 1985.

Section 7: Design of Cathodic Protection Systems

7.1 Introduction

7.1.1 This section recommends procedures for designing CP systems that will provide effective external corrosion control by satisfying one or more of the criteria listed in Section 6 and exhibiting maximum reliability over the intended operating life of the systems.

7.1.2 In the design of a CP system, the following should be considered:

7.1.2.1 Recognition of hazardous conditions prevailing at the proposed installation site(s) and the selection and specification of materials and installation practices that ensure safe installation and operation.

7.1.2.2 Specification of materials and installation practices to conform to the latest editions of applicable codes, National Electrical Manufacturers Association (NEMA)[7] standards, National Electrical Code (NEC),[8] appropriate international standards, and NACE standards.

7.1.2.3 Selection and specification of materials and installation practices that ensure dependable and economical operation throughout the intended operating life.

7.1.2.4 Selection of locations for proposed installations to minimize currents or earth potential gradients, which can cause detrimental effects on foreign buried or submerged metallic structures.

7.1.2.5 Cooperative investigations to determine mutually satisfactory solution(s) of interference problems (see Section 9).

7.1.2.6 Special consideration should be given to the presence of sulfides, bacteria, disbonded coatings, thermal insulating coatings, elevated temperatures, shielding, acid environments, and dissimilar metals.

7.1.2.7 Excessive levels of CP that can cause external coating disbondment and possible damage to high-strength steels as a result of hydrogen evolution should be avoided.

7.1.2.8 When amphoteric metals are involved, care should be taken so that high-pH conditions that could cause cathodic corrosion of the metal are not established.

7.2 Major objectives of CP system design include the following:

7.2.1 To provide sufficient current to the structure to be protected and distribute this current so that the selected criteria for CP are effectively attained;

[7] National Electrical Manufacturers Association (NEMA), 1300 North 17th St., Suite 1752, Rosslyn, Virginia 22209.
[8] National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

7.2.2 To minimize the interference currents on neighboring underground structures (see Section 9);

7.2.3 To provide a design life of the anode system commensurate with the required life of the protected structure, or to provide for periodic rehabilitation of the anode system;

7.2.4 To provide adequate allowance for anticipated changes in current requirements with time;

7.2.5 To install anodes when the possibility of disturbance or damage is minimal; and

7.2.6 To provide adequate monitoring facilities to test and evaluate the system performance.

7.3 Information Useful for Design

7.3.1 Useful piping system specifications and information include the following:

7.3.1.1 Route maps and atlas sheets;

7.3.1.2 Construction dates;

7.3.1.3 Pipe, fittings, and other appurtenances;

7.3.1.4 External coatings;

7.3.1.5 Casings;

7.3.1.6 Corrosion control test stations;

7.3.1.7 Electrically isolating devices;

7.3.1.8 Electrical bonds; and

7.3.1.9 Aerial, bridge, and underwater crossings.

7.3.2 Useful information on piping system site conditions includes the following:

7.3.2.1 Existing and proposed CP systems;

7.3.2.2 Possible interference sources (see Section 9);

7.3.2.3 Special environmental conditions;

7.3.2.4 Neighboring buried metallic structures (including location, ownership, and corrosion control practices);

7.3.2.5 Structure accessibility;

7.3.2.6 Power availability; and

7.3.2.7 Feasibility of electrical isolation from foreign structures.

7.3.3 Useful information from field surveys, corrosion test data, and operating experience includes the following:

7.3.3.1 Protective current requirements to meet applicable criteria;

7.3.3.2 Electrical resistivity of the electrolyte;

7.3.3.3 Electrical continuity;

7.3.3.4 Electrical isolation;

7.3.3.5 External coating integrity;

7.3.3.6 Cumulative leak history;

7.3.3.7 Interference currents;

7.3.3.8 Deviation from construction specifications; and

7.3.3.9 Other maintenance and operating data.

7.3.4 Field survey work prior to actual application of CP is not always required if prior experience or test data are available to estimate current requirements, electrical resistivity of the electrolyte, and other design factors.

7.4 Types of CP Systems

7.4.1 Galvanic Anode Systems

7.4.1.1 Galvanic anodes can be made of materials such as alloys of magnesium, zinc, or aluminum. The anodes are connected to the pipe, either individually or in groups. Galvanic anodes are limited in current output by the anode-to-pipe driving voltage and the electrolyte resistivity.

7.4.2 Impressed Current Anode Systems

7.4.2.1 Impressed current anodes can be of materials such as graphite, high-silicon cast iron, lead-silver alloy, precious metals, or steel. They are connected with an insulated cable, either individually or in groups, to the positive terminal of a direct-current (DC) source, such as a rectifier or generator. The pipeline is connected to the negative terminal of the DC source.

7.5 Considerations influencing selection of the type of CP system include the following:

7.5.1 Magnitude of protective current required;

7.5.2 Stray currents causing significant potential fluctuations between the pipeline and earth that may preclude the use of galvanic anodes;

7.5.3 Effects of CP interference currents on adjacent structures that may limit the use of impressed current CP systems;

7.5.4 Availability of electrical power;

7.5.5 Physical space available, proximity of foreign structures, easement procurement, surface conditions, presence of streets and buildings, river crossings, and other construction and maintenance concerns.

7.5.6 Future development of the right-of-way area and future extensions to the pipeline system;

7.5.7 Costs of installation, operation, and maintenance; and

7.5.8 Electrical resistivity of the environment.

7.6 Factors Influencing Design of CP Systems

7.6.1 Various anode materials have different rates of deterioration when discharging a given current density from the anode surface in a specific environment. Therefore, for a given current output, the anode life depends on the environment and anode material, as well as the anode weight and the number of anodes in the CP system. Established anode performance data may be used to calculate the probable deterioration rate.

7.6.2 Data on the dimensions, depth, and configuration of the anodes and the electrolyte resistivity may be used to calculate the resultant resistance to electrolyte of the anode system. Formulas and graphs relating to these factors are available in the bibliography literature and from most anode manufacturers.

7.6.3 Design of galvanic anode systems should consider anode-to-pipe potential, electrolyte resisivity, current output, and in special cases, anode lead-wire resistance. A separate design for each anode or anode system may not be necessary.

7.6.4 Galvanic anode performance in most soils can be improved by using special backfill material. Mixtures of gypsum, bentonite, and anhydrous sodium sulfate are most commonly used.

7.6.5 The number of impressed current anodes required can be reduced and their useful life lengthened by the use of special backfill around the anodes. The most common materials are coal coke, calcined petroleum coke, and natural or manufactured graphite.

7.6.6 In the design of an extensive distributed-anode impressed current system, the voltage and current attenuation along the anode-connecting (header) cable should be considered. In such cases, the design objective is to optimize anode system length, anode spacing and size, and cable size in order to achieve efficient external corrosion control at the extremities of the protected structure.

7.6.7 When it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current groundbed to deliver the required current, suitable provisions should be made for venting the anodes. For the same current output of the system, an increase in the surface area of the special backfill material or an increase in the number of anodes may reduce gas blockage.

7.6.8 When it is anticipated that electroosmotic effects could impair the ability of the impressed current groundbed to deliver the required current output, suitable provisions should be made to ensure adequate soil moisture around the anodes. Increasing the number of impressed current anodes or increasing the surface area of the special backfill materials may further reduce the electroosmotic effect.

7.7 Design Drawings and Specifications

7.7.1 Suitable drawings should be prepared to designate the overall layout of the piping to be protected and the location of significant items of structure hardware, corrosion control test stations, electrical bonds, electrical isolation devices, and neighboring buried or submerged metallic structures.

7.7.2 Layout drawings should be prepared for each impressed current CP installation, showing the details and location of the components of the CP system with respect to the protected structure(s) and to major physical landmarks. These drawings should include right-of-way information.

7.7.3 The locations of galvanic anode installations should be recorded on drawings or in tabular form, with appropriate notes on anode type, weight, spacing, depth, and backfill.

7.7.4 Specifications should be prepared for all materials and installation practices that are to be incorporated in construction of the CP system.

Bibliography for Section 7

Benedict. R.L., ed. *Anode Resistance Fundamentals and Applications—Classic Papers and Reviews*. Houston, TX: NACE, 1986.

Baboian, R., P.F. Drew, and K. Kawate. "Design of Platinum Clad Wire Anodes for Impressed Current Protection." *Materials Performance* 23, 9 (1984): pp. 31-35.

Collected Papers on Cathodic Protection Current Distribution. Houston, TX: NACE, 1989.

Doremus, G., and J.G. Davis. "Marine Anodes: The Old and New—Cathodic Protection for Offshore Structures." *Materials Performance* 6, 1 (1967): p. 30.

Dwight, H.B. "Calculations for Resistance to Ground." *Electrical Engineering* 55 (1936): p. 1319.

George P.F., J.J. Newport, and J.L. Nichols. "A High Potential Magnesium Anode." *Corrosion* 12, 12 (1956): p. 51.

Jacobs, J.A. "A Comparison of Anodes for Impressed Current Systems." NACE Canadian Region Western Conference, Edmonton, Alberta, Canada, February 1980.

Kurr, G.W. "Zinc Anodes—Underground Uses for Cathodic Protection and Grounding." *MP* 18, 4 (1979): pp. 34-41.

NACE Publication 2B160 (withdrawn). "Use of High Silicon Cast Iron for Anodes." Houston, TX: NACE.

NACE Publication 2B156 (withdrawn). "Final Report on Four Annual Anode Inspections." Houston, TX: NACE.

Parker, M.E. Pipe Line Corrosion and Cathodic Protection—A Field Manual. Houston, TX: Gulf Publishing Company, 1962.

Robinson, H.A., and P.F. George. "Effect of Alloying and Impurity Elements in Magnesium Cast Alloy Anodes." *Corrosion* 10, 6 (1954): p. 182.

Rudenberg, R. "Grounding Principles and Practices." *Electrical Engineering* 64 (1945): p. 1.

Schreiber, C.F., and G.L. Mussinelli. "Characteristics and Performance of the LIDA Impressed-Current System in Natural Waters and Saline Muds." CORROSION/86, paper no. 287. Houston, TX: NACE, 1986.

Sunde, E.D.. Earth Conduction Effects in Transmission Systems. New York, NY: Dover Publications, 1968.

Section 8: Installation of CP Systems

8.1 Introduction

8.1.1 This section recommends procedures that will result in the installation of CP systems that achieve protection of the structure. The design considerations recommended in Sections 4 and 7 should be followed.

8.2 Construction Specifications

8.2.1 All construction work on CP systems should be performed in accordance with construction drawings and specifications. The construction specifications should be in accordance with recommended practices in Sections 4 and 7.

8.3 Construction Supervision

8.3.1 All construction work on CP systems should be performed under the surveillance of trained and qualified personnel to verify that the installation is in strict accordance with the drawings and specifications. Exceptions may be made only with the approval of qualified personnel responsible for external corrosion control.

8.3.2 All deviations from construction specifications should be noted on as-built drawings.

8.4 Galvanic Anodes

8.4.1 Inspection, Handling, and Storage

8.4.1.1 Packaged anodes should be inspected and steps taken to ensure that backfill material completely surrounds the anode. The individual container for the backfill material and anode should be intact. If individually packaged anodes are supplied in waterproof containers, the containers must be removed before installation. Packaged anodes should be kept dry during storage.

8.4.1.2 Lead wire must be securely connected to the anode. Lead wire should be inspected for assurance that it is not damaged.

8.4.1.3 Other galvanic anodes, such as the unpackaged "bracelet" or ribbon type, should be inspected to ensure that dimensions conform to

design specifications and that any damage during handling does not affect application. If a coating is used on bands and the inner side of bracelet anode segments, it should be inspected and, if damaged, repaired before the anodes are installed.

8.4.2 Installing Anodes

8.4.2.1 Anodes should be installed according to construction specifications.

8.4.2.2 Packaged galvanic anodes should be backfilled with appropriately compacted material. When anodes and special chemical backfill are provided separately, anodes should be centered in special backfill, which should be compacted prior to backfilling. Care should be exercised during all operations so that lead wires and connections are not damaged. Sufficient slack should exist in lead wires to avoid strain.

8.4.2.3 When anodes in bracelet form are used, external pipe coating beneath the anode should be free of holidays. Care should be taken to prevent damage to the external coating when bracelet anodes are installed. After application of concrete (if used) to pipe, all coating and concrete should be removed from the anode surface. If reinforced concrete is used, there must be no metallic contact between the anode and the reinforcing mesh or between the reinforcing mesh and the pipe.

8.4.2.4 When a ribbon-type anode is used, it can be trenched or plowed in, with or without special chemical backfill as required, generally parallel to the section of pipeline to be protected.

8.5 Impressed Current Systems

8.5.1 Inspection and Handling

8.5.1.1 The rectifier or other power source should be inspected to ensure that internal connections are mechanically secure and that the unit is free of damage. Rating of the DC power source should comply with the construction specification. Care should be exercised in handling and installing the power source.

8.5.1.2 Impressed current anodes should be inspected for conformance to specifications concerning anode material, size, length of lead cable, anode lead connection, and integrity of seal. Care should be exercised to avoid cracking or damaging anodes during handling and installation.

8.5.1.3 All cables should be carefully inspected to detect defects in insulation. Care should be taken to avoid damage to cable insulation. Defects in the cable insulation must be repaired.

8.5.1.4 Anode backfill material should conform to specifications.

8.5.2 Installation Provisions

8.5.2.1 A rectifier or other power source should be installed so that the possibility of damage or vandalism is minimized.

8.5.2.2 Wiring to rectifiers shall comply with local and national electrical codes and requirements of the utility supplying power. An external disconnect switch should be provided in the AC circuit. A rectifier case shall be properly grounded.

8.5.2.3 On thermoelectric generators, a reverse current device should be installed to prevent galvanic action between the anode bed and the pipe if the flame is extinguished.

8.5.2.4 Impressed current anodes can be buried vertically, horizontally, or in deep holes (see NACE Standard RP0572[1]) as indicated in construction specifications. Backfill material should be installed to ensure that there are no voids around anodes. Care should be exercised during backfilling to avoid damage to the anode and cable.

8.5.2.5 The cable from the rectifier negative terminal to the pipe should be connected to the pipe as described in Paragraph 8.6. Cable connections to the rectifier must be mechanically secure and electrically conductive. Before the power source is energized, it must be verified that the negative cable is connected to the structure to be protected and that the positive cable is connected to the anodes. After the DC power source has been energized, suitable measurements should be made to verify that these connections are correct.

8.5.2.6 Underground splices on the header (positive) cable to the groundbed should be kept to a minimum. Connections between the header and anode cables should be mechanically secure and electrically conductive. If buried or submerged, these connections must be sealed to prevent moisture penetration so that electrical isolation from the environment is ensured.

8.5.2.7 Care must be taken during installation of direct-burial cable to the anodes (positive cable) to avoid damage to insulation. Sufficient slack should be left to avoid strain on all cables. Backfill material around the cable should be free of rocks and foreign matter that might cause damage to the insulation when the cable is installed in a trench. Cable can be installed by plowing if proper precautions are taken.

8.5.2.8 If insulation integrity on the buried or submerged header cable, including splices, is not

maintained, this cable may fail because of corrosion.

8.6 Corrosion Control Test Stations, Connections, and Bonds (see Paragraph 4.5)

8.6.1 Pipe and test lead wires should be clean, dry, and free of foreign materials at points of connection when the connections are made. Connections of test lead wires to the pipe must be installed so they will remain mechanically secure and electrically conductive.

8.6.2 All buried or submerged lead-wire attachments should be coated with an electrically insulating material, compatible with the external pipe coating and wire insulation.

8.6.3 Test lead wires should be color coded or otherwise permanently identified. Wires should be installed with slack. Damage to insulation should be avoided and repairs made if damage occurs. Test leads should not be exposed to excessive heat and sunlight. Aboveground test stations are preferred. If test stations are flush with the ground, adequate slack should be provided within the test station to facilitate test connections.

8.6.4 Cable connections at bonds to other structures or across isolating joints should be mechanically secure, electrically conductive, and suitably coated. Bond connections should be accessible for testing.

8.7 Electrical Isolation

8.7.1 Inspection and electrical measurements should ensure that electrical isolation is adequate (see NACE SP0286[5]).

Section 9: Control of Interference Currents

9.1 Introduction

9.1.1 This section recommends practices for the detection and control of interference currents. The mechanism and its detrimental effects are described.

9.2 Mechanism of Interference-Current Corrosion (Stray-Current Corrosion)

9.2.1 Interference-current corrosion on buried or submerged metallic structures differs from other causes of corrosion damage in that the direct current, which causes the corrosion, has a source foreign to the affected structure. Usually the interfering current is collected from the electrolyte by the affected structure from a DC source not metallically bonded to the affected structure.

9.2.1.1 Detrimental effects of interference currents usually occur at locations where the currents transfer between the affected structures and the electrolyte.

9.2.1.2 Structures made of amphoteric metals such as aluminum and lead may be subject to corrosion damage from a buildup of alkalinity at or near the metal surface collecting interference currents.

9.2.1.3 Coatings may become disbonded at areas where voltage gradients in the electrolyte force current onto the affected structure. However, as the external coating becomes disbonded, a larger area of metal may be exposed, which would increase the demand for a CP current. This disbondment may create shielding problems.

9.2.2 The severity of external corrosion resulting from interference currents depends on several factors:

9.2.2.1 Separation and routing of the interfering and affected structures and location of the interfering current source;

9.2.2.2 Magnitude and density of the current;

9.2.2.3 Quality of the external coating or absence of an external coating on the structures involved; and

9.2.2.4 Presence and location of mechanical joints having high electrical resistance.

9.2.3 Typical sources of interference currents include the following:

9.2.3.1 Direct current: CP rectifiers, thermoelectric generators, DC electrified railway and transit systems, coal mine haulage systems and pumps, welding machines, and other DC power systems;

9.2.3.2 Alternating current: AC power systems and AC electrified railway systems; and

9.2.3.3 Telluric current.

9.3 Detection of Interference Currents

9.3.1 During external corrosion control surveys, personnel should be alert for electrical or physical observations that could indicate interference from a foreign source such as the following:

9.3.1.1 Pipe-electrolyte potential changes on the affected structure caused by the foreign DC source;

9.3.1.2 Changes in the line current magnitude or direction caused by the foreign DC source;

9.3.1.3 Localized pitting in areas near or immediately adjacent to a foreign structure; and

9.3.1.4 Damage to external coatings in a localized area near an anode bed or near any other source of stray direct current.

9.3.2 In areas in which interference currents are suspected, appropriate tests should be conducted. All affected parties shall be notified before tests are conducted. Notification should be channeled through corrosion control coordinating committees, when they exist (see NACE Publication TPC 11[8]). Any one or a combination of the following test methods can be used.

9.3.2.1 Measurement of structure-electrolyte potentials with recording or indicating instruments;

9.3.2.2 Measurement of current flowing on the structure with recording or indicating instruments;

9.3.2.3 Development of beta curves to locate the area of maximum current discharge from the affected structure (see Appendix A); and

9.3.2.4 Measurement of the variations in current output of the suspected source of interference current and correlations with measurements obtained in Paragraphs 9.3.2.1 and 9.3.2.2.

9.4 Methods for Mitigating Interference Corrosion Problems

9.4.1 Interference problems are individual in nature and the solution should be mutually satisfactory to the parties involved. These methods may be used individually or in combination.

9.4.2 Design and installation of electrical bonds of proper resistance between the affected structures is a technique for interference control. The bond electrically conducts interference current from an affected structure to the interfering structure or current source.

9.4.2.1 Unidirectional control devices, such as diodes or reverse current switches, may be required in conjunction with electrical bonds if fluctuating currents are present. These devices prevent reversal of current flow.

9.4.2.2 A resistor may be necessary in the bond circuit to control the flow of electrical current from the affected structure to the interfering structure.

9.4.2.3 The attachment of electrical bonds can reduce the level of CP on the interfering structure. Supplementary CP may then be required on the interfering structure to compensate for this effect.

9.4.2.4 A bond may not effectively mitigate the interference problem in the case of a cathodically protected bare or poorly externally coated pipeline that is causing interference on an externally coated pipeline.

9.4.3 CP current can be applied to the affected structure at those locations at which the interfering current is being discharged. The source of CP current may be galvanic or impressed current anodes.

9.4.4 Adjustment of the current output from interfering CP rectifiers may resolve interference problems.

9.4.5 Relocation of the groundbeds of cathodic protection rectifiers can reduce or eliminate the pickup of interference currents on nearby structures.

9.4.6 Rerouting of proposed pipelines may avoid sources of interference current.

9.4.7 Properly located isolating fittings in the affected structure may reduce or resolve interference problems.

9.4.8 Application of external coating to current pick-up area(s) may reduce or resolve interference problems.

9.5 Indications of Resolved Interference Problems

9.5.1 Restoration of the structure-electrolyte potentials on the affected structure to those values that existed prior to the interference.

9.5.2 Measured line currents on the affected structure that show that the interference current is not being discharged to the electrolyte.

9.5.3 Adjustment of the slope of the beta curve to show that current discharge has been eliminated at the location of maximum exposure (see Appendix A).

Section 10: Operation and Maintenance of CP Systems

10.1 Introduction

10.1.1 This section recommends procedures and practices for energizing and maintaining continuous, effective, and efficient operation of CP systems.

10.1.1.1 Electrical measurements and inspection are necessary to determine that protection has been established according to applicable criteria and that each part of the CP system is operating properly. Conditions that affect protection are subject to change. Correspondingly, changes may be required in the CP system to maintain protection. Periodic measurements and inspections are necessary to detect changes in the CP system. Conditions in which operating experience indicates that testing and inspections need to be made more frequently than recommended herein may exist.

10.1.1.2 Care should be exercised in selecting the location, number, and type of electrical measurements used to determine the adequacy of CP.

10.1.1.3 When practicable and determined necessary by sound engineering practice, a detailed (close-interval) potential survey should be conducted to:

(a) assess the effectiveness of the CP system;

(b) provide base line operating data;

(c) locate areas of inadequate protection levels;

(d) identify locations likely to be adversely affected by construction, stray currents, or other unusual environmental conditions; or

(e) select areas to be monitored periodically.

10.1.1.4 Adjustments to a CP system should be accompanied by sufficient testing to assure the criteria remain satisfied and to reassess interference to other structures or isolation points.

10.2 A survey should be conducted after each CP system is energized or adjusted to determine whether the applicable criterion or criteria from Section 6 have been satisfied.

10.3 The effectiveness of the CP system should be monitored annually. Longer or shorter intervals for monitoring may be appropriate, depending on the variability of CP factors, safety considerations, and economics of monitoring.

10.4 Inspection and tests of CP facilities should be made to ensure their proper operation and maintenance as follows:

10.4.1 All sources of impressed current should be checked at intervals of two months. Longer or shorter intervals for monitoring may be appropriate. Evidence of proper functioning may be current output, normal power consumption, a signal indicating normal operation, or satisfactory CP levels on the pipe.

10.4.2 All impressed current protective facilities should be inspected annually as part of a preventive maintenance program to minimize in-service failure. Longer or shorter intervals for monitoring may be appropriate. Inspections may include a check for electrical malfunctions, safety ground connections, meter accuracy, efficiency, and circuit resistance.

10.4.3 Reverse current switches, diodes, interference bonds, and other protective devices, whose failures would jeopardize structure protection, should be inspected for proper functioning at intervals of two months. Longer or shorter intervals for monitoring may be appropriate.

10.4.4 The effectiveness of isolating fittings, continuity bonds, and casing isolation should be evaluated during the periodic surveys. This may be accomplished by electrical measurements.

10.5 When pipe has been uncovered, it should be examined for evidence of external corrosion and, if externally coated, for condition of the external coating.

10.6 The test equipment used for obtaining each electrical value should be of an appropriate type. Instruments and related equipment should be maintained in good operating condition and checked for accuracy.

10.7 Remedial measures should be taken when periodic tests and inspections indicate that CP is no longer adequate. These measures may include the following:

10.7.1 Repair, replace, or adjust components of CP systems;

10.7.2 Provide supplementary facilities in which additional CP is necessary;

10.7.3 Thoroughly clean and properly coat bare structures if required to attain CP;

10.7.4 Repair, replace, or adjust continuity and interference bonds;

10.7.5 Remove accidental metallic contacts; and

10.7.6 Repair defective isolating devices.

10.8 An electrical short circuit between a casing and carrier pipe can result in inadequate CP of the pipeline outside the casing due to reduction of protective current to the pipeline.

10.8.1 When a short results in inadequate CP of the pipeline outside the casing, steps must be taken to restore CP to a level required to meet the CP criterion. These steps may include eliminating the short between the casing and carrier pipe, supplementing CP, or improving the quality of the external coating on the pipeline outside the casing. None of these steps will ensure that external corrosion will not occur on the carrier pipe inside the casing; however, a shorted casing does not necessarily result in external corrosion of the carrier pipe inside the casing.

10.9 When the effects of electrical shielding of CP current are detected, the situation should be evaluated and appropriate action taken.

Section 11: External Corrosion Control Records

11.1 Introduction

11.1.1 This section describes external corrosion control records that will document in a clear, concise, workable manner data that are pertinent to the design, installation, operation, maintenance, and effectiveness of external corrosion control measures.

11.2 Relative to the determination of the need for external corrosion control, the following should be recorded:

11.2.1 Corrosion leaks, breaks, and pipe replacements; and

11.2.2 Pipe and external coating condition observed when a buried structure is exposed.

11.3 Relative to structure design, the following should be recorded:

11.3.1 External coating material and application specifications; and

11.3.2 Design and location of isolating devices, test leads and other test facilities, and details of other special external corrosion control measures taken.

11.4 Relative to the design of external corrosion control facilities, the following should be recorded:

11.4.1 Results of current requirement tests;

11.4.2 Results of soil resistivity surveys;

11.4.3 Location of foreign structures; and

11.4.4 Interference tests and design of interference bonds and reverse current switch installations.

11.4.4.1 Scheduling of interference tests, correspondence with corrosion control coordinating committees, and direct communication with the concerned companies.

11.4.4.2 Record of interference tests conducted, including location of tests, name of company involved, and results.

11.5 Relative to the installation of external corrosion control facilities, the following should be recorded:

11.5.1 Installation of CP facilities:

11.5.1.1 Impressed current systems:

11.5.1.1.1 Location and date placed in service;

11.5.1.1.2 Number, type, size, depth, backfill, and spacing of anodes;

11.5.1.1.3 Specifications of rectifier or other energy source; and

11.5.1.1.4 Cable size and type of insulation.

11.5.1.2 Galvanic anode systems:

11.5.1.2.1 Location and date placed in service;

11.5.1.2.2 Number, type, size, backfill, and spacing of anodes; and

11.5.1.2.3 Wire size and type of insulation.

11.5.2 Installation of interference mitigation facilities:

11.5.2.1 Details of interference bond installation:

11.5.2.1.1 Location and name of company involved;

11.5.2.1.2 Resistance value or other pertinent information; and

11.5.2.1.3 Magnitude and polarity of drainage current.

11.5.2.2 Details of reverse current switch:

11.5.2.2.1 Location and name of companies;

11.5.2.2.2 Type of switch or equivalent device; and

11.5.2.2.3 Data showing effective operating adjustment.

11.5.2.3 Details of other remedial measures.

11.6 Records of surveys, inspections, and tests should be maintained to demonstrate that applicable criteria for interference control and CP have been satisfied.

11.7 Relative to the maintenance of external corrosion control facilities, the following information should be recorded:

11.7.1 Maintenance of CP facilities:

11.7.1.1 Repair of rectifiers and other DC power sources; and

11.7.1.2 Repair or replacement of anodes, connections, wires, and cables.

11.7.2 Maintenance of interference bonds and reverse current switches:

11.7.2.1 Repair of interference bonds; and

11.7.2.2 Repair of reverse current switches or equivalent devices.

11.7.3 Maintenance, repair, and replacement of external coating, isolating devices, test leads, and other test facilities.

11.8 Records sufficient to demonstrate the evaluation of the need for and the effectiveness of external corrosion control measures should be maintained as long as the facility involved remains in service. Other related external corrosion control records should be retained for such a period that satisfies individual company needs.

References

1. NACE SP0572 (latest revision), “Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds” (Houston, TX: NACE).

2. NACE Standard RP0177 (latest revision), “Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems” (Houston, TX: NACE).

3. NACE Standard RP0285 (latest revision), “Corrosion Control of Underground Storage Tank Systems by Cathodic Protection” (Houston, TX: NACE).

4. NACE SP0186 (latest revision), “Application of Cathodic Protection for Well Casings” (Houston, TX: NACE).

5. NACE SP0286 (latest revision), “The Electrical Isolation of Cathodically Protected Pipelines” (Houston, TX: NACE).

6. NACE SP0387 (latest revision), “Metallurgical and Inspection Requirements for Cast Galvanic Anodes for Offshore Applications” (Houston, TX: NACE).

7. NACE SP0188 (latest revision), “Discontinuity (Holiday) Testing of Protective Coatings” (Houston, TX: NACE).

8. NACE Publication TPC 11 (latest revision), “A Guide to the Organization of Underground Corrosion Control Coordinating Committees” (Houston, TX: NACE).

9. NACE Standard TM0497 (latest revision), “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems” (Houston, TX: NACE).

10. ANSI/AWWA C 203 (latest revision), “Standard for Coal-Tar Protective Coatings and Linings for Steel Water Pipelines—Enamel and Tape—Hot Applied” (Washington, DC: ANSI and Denver, CO: AWWA).

11. NACE Standard RP0375 (latest revision), “Field-Applied Underground Coating Systems for Underground Pipelines: Application, Performance, and Quality Control” (Houston, TX: NACE).

12. ANSI/AWWA C 214 (latest revision), “Tape Coating Systems for the Exterior of Steel Water Pipelines” (Washington, DC: ANSI and Denver, CO: AWWA).

13. ANSI/AWWA C 209 (latest revision), “Cold-Applied Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines” (Washington, DC: ANSI and Denver: CO: AWWA).

14. Ronald Bianchetti, ed., Peabody’s Control of Pipeline Corrosion, 2nd ed. (Houston, TX: NACE, 2001).

15. ANSI/AWWA C 213 (latest revision), “Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines” (Washington, DC: ANSI and Denver: CO: AWWA).

16. API RP 5L7 (latest revision), “Recommended Practices for Unprimed Internal Fusion Bonded Epoxy Coating of Line Pipe” (Washington, DC: API).

17. CSA Z245.20M (latest revision), “External Fusion Bond Epoxy Coated Steel Pipe” (Toronto, ON: CSA).

18. NACE Standard RP0394 (latest revision), “Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating” (Houston, TX: NACE).

19. NACE Standard RP0185 (latest revision), “Extruded Polyolefin Resin Coating Systems with Soft Adhesives for Underground or Submerged Pipe” (Houston, TX: NACE).

20. DIN 30 670 (latest revision), “Polyethylene-Coatings for Steel Pipes and Fittings Requirements and Testing” (Berlin, Germany: DIN).

21. ANSI/AWWA C 215 (latest revision), “Extruded Polyolefin Coatings for the Exterior of Steel Water Pipe Lines” (Washington, DC: ANSI and Denver, CO: AWWA).

22. ASTM G 128 (latest revision), “Standard Guide for Control Of Hazards And Risks In Oxygen Enriched Systems” (West Conshohocken, PA: ASTM).

23. NACE Standard RP0274 (latest revision), “High-Voltage Electrical Inspection of Pipeline Coatings Prior to Installation” (Houston, TX: NACE).

24. ASTM G 8 (latest revision), “Standard Test Method for Cathodic Disbonding of Pipeline Coatings” (West Conshohocken, PA: ASTM).

25. ASTM G 19 (latest revision), “Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial” (West Conshohocken, PA: ASTM).

26. ASTM G 42 (latest revision), “Standard Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures” (West Conshohocken, PA: ASTM).

27. ASTM G 95 (latest revision), “Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)” (West Conshohocken, PA: ASTM).

28. ASTM G 9 (latest revision), “Standard Test Method for Water Penetration into Pipeline Coatings” (West Conshohocken, PA: ASTM).

29. ASTM G 17 (latest revision), “Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)” (West Conshohocken, PA: ASTM).

30. ASTM D 2240 (latest revision), “Standard Test Method for Rubber Property—Durometer Hardness” (West Conshohocken, PA: ASTM).

31. ASTM G 13 (latest revision), “Standard Test Method for Impact Resistance of Pipeline Coatings (Limestone Drop Test)” (West Conshohocken, PA: ASTM).

32. ASTM G 14 (latest revision), “Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)” (West Conshohocken, PA: ASTM).

33. M. Romanoff, Underground Corrosion (Houston, TX: NACE, 1989).

34. ASTM D 427 (latest revision), “Standard Test Method for Shrinkage Factors of Soils by the Mercury Method” (West Conshohocken, PA: ASTM).

35. ASTM D 543 (latest revision), “Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents” (West Conshohocken, PA: ASTM).

36. Federal Test Standard No. 406A, Method 7011 (latest revision), “Test Method for Resistance of Plastics to Chemical Reagents” (Washington, DC: GSA).

37. ASTM G 20 (latest revision), “Standard Test Method for Chemical Resistance of Pipeline Coatings” (West Conshohocken, PA: ASTM).

38. ASTM D 2304 (latest revision), “Standard Test Method for Thermal Endurance of Rigid Electrical Insulating Materials” (West Conshohocken, PA: ASTM).

39. ASTM D 2454 (latest revision), “Standard Practice for Determining the Effect of Overbaking on Organic Coatings” (West Conshohocken, PA: ASTM).

40. ASTM D 2485 (latest revision), “Standard Test Methods for Evaluating Coatings for High-Temperature Service” (West Conshohocken, PA: ASTM).

41. ASTM G 18 (latest revision), “Standard Test Method for Joints, Fittings, and Patches in Coated Pipelines” (West Conshohocken, PA: ASTM).

42. ASTM G 55 (latest revision), “Standard Test Method for Evaluating Pipeline Coating Patch Materials” (West Conshohocken, PA: ASTM).

43. ASTM G 21 (latest revision), “Standard Practice for Determining Resistance of Synthetic Polymetric Materials To Fungi” (West Conshohocken, PA: ASTM).

44. Federal Test Standard No. 406A, Method 6091 (latest revision), “Test Method for Mildew Resistance of Plastics by Mixed Culture Method (Agar Medium)” (Washington, DC: GSA).

45. ASTM G 11 (latest revision), “Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings” (West Conshohocken, PA: ASTM).

46. ASTM G 6 (latest revision), “Standard Test Method for Abrasion Resistance of Pipeline Coatings” (West Conshohocken, PA: ASTM).

47. ASTM G 10 (latest revision), “Standard Test Method for Specific Bendability of Pipeline Coatings” (West Conshohocken, PA: ASTM).

48. ASTM D 2197 (latest revision), “Test Method for Adhesion of Organic Coatings by Scrape Adhesion” (West Conshohocken, PA: ASTM).

Appendix A—Interference Testing

A beta curve is a plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate) versus values of corresponding structure-to-soil potentials at a selected location on the affected structure (abscissa). If the correlation is reasonably linear, the plot will indicate whether the affected structure is receiving or discharging current at the location where the structure-to-soil potential was measured. Dynamic interference investigation involves many beta curve plots to search for the point of maximum interference-current discharge. Interference is resolved when the correlation of maximum current discharge has been changed to a correlation that shows that current pickup is being achieved in the exposure area by the corrective measures taken. These corrective measures may be accomplished by metallic bonding or other interference control techniques.

Appendix B—Method for Determining Probable Corrosion Rate and Costs of Maintaining Service

Maintenance of a piping system may include repairing corrosion leaks and reconditioning or replacing all or portions of the system.

In order to make estimates of the costs involved, it is necessary to determine the probability of corrosion or the rate at which corrosion is proceeding. The usual methods of predicting the probability or rate of corrosion are as follows:

(a) Study of corrosion history on the piping system in question or on other systems of the same material in the same general area or in similar environments. Cumulative leak-frequency curves are valuable in this respect.

(b) Study of the environment surrounding a piping system: resistivity, pH, and composition. Redox potential tests may also be used to a limited extent. Once the nature of the environment has been determined, the probable corrosiveness is estimated by reference to actual corrosion experience on similar metallic structures, when environmental conditions are similar. Consideration of possible environmental changes such as might result from irrigation, spillage of corrosive substances, pollution, and seasonal changes in soil moisture content should be included in such a study.

(c) Investigation for corrosion on a piping system by visual inspection of the pipe or by instruments that mechanically or electrically inspect the condition of the pipe. Condition of the piping system should be carefully determined and recorded each time a portion of the line is excavated for any reason.

(d) Maintenance records detailing leak locations, soil studies, structure-to-electrolyte potential surveys, surface potential surveys, line current studies, and wall thickness surveys used as a guide for locating areas of maximum corrosion.

(e) Statistical treatment of available data.

(f) Results of pressure testing. Under certain conditions, this may help to determine the existence of corrosion.

Appendix C—Contingent Costs of Corrosion

In addition to the direct costs that result from corrosion, contingent costs include:

(a) Public liability claims;

(b) Property damage claims;

(c) Damage to natural facilities, such as municipal or irrigation water supplies, forests, parks, and scenic areas;

(d) Cleanup of product lost to surroundings;

(e) Plant shutdown and startup costs;

(f) Cost of lost product;

(g) Loss of revenue through interruption of service;

(h) Loss of contract or goodwill through interruption of service; and

(i) Loss of reclaim or salvage value of piping system.

Appendix D—Costs of Corrosion Control

The usual costs for protecting buried or submerged metallic structures are for complete or partial CP or for external coatings supplemented with cathodic protection. Other corrosion control costs include:

(a) Relocation of piping to avoid known corrosive conditions (this may include installing lines above ground);

(b) Reconditioning and externally coating the piping system;

(c) Use of corrosion-resistant materials;

(d) Use of selected or inhibited backfill;

(e) Electrical isolation to limit possible galvanic action; and

(f) Correction of conditions in or on the pipe that might accelerate corrosion.

Chapter 3: Environmental Controls

Objectives

When this module is complete, you will have knowledge and understanding of:

- Enclosures
- Moisture and humidity
- Effects of humidity on corrosion rate
- Equipment types
- Benefits of dehumidification to the coating contractor
- Inspection concerns
- Inspection checklist

Key Terms

- Absorbent desiccants
- Adsorbent desiccants
- Dehumidification
- Dessicants

3.1 Introduction

Dehumidification removes moisture vapor from the air to lower its dew point. This chapter focuses on using dehumidification to control work environments, and how dehumidification impedes steel corrosion and inhibits flash rusting (Figure 3.1).

Environmental (ambient) conditions, such as humidity and temperature, have a significant impact on surface preparation and coating operations and, ultimately, on the long-term performance of coatings.

In normal environmental conditions, it is essential to apply coatings to surfaces within a few hours of cleaning to avoid flash rusting. Coating work is often delayed because of high humidity and/or low temperatures. This necessary cycle of blasting and coating on the same day can adversely affect the quality of the coating work. Applicators often hurry to try to beat impending weather. This leads to mistakes, which add to the overall cost. Almost immediately, mistakes can cause rework during the project, which can potentially cost the client much more in the form of premature coating failures.



Figure 3.1 DH Equipment Outside Tank

In many cases, environmental controls like heating, ventilation, protective enclosures, lighting, and dehumidification can improve the economics and quality of coatings work.

Present-day coatings reach their maximum protective potential **only** when applied to a high-quality surface. After proper removal of oil and grease, blast steel surfaces to remove old coatings, rust, and scale. Apply coatings before the surface loses its bright surface appearance and before flash-rusting begins.

A well-written coating specification requires close monitoring of the surface preparation phase of the coating operation to ensure the

full potential of the high-performance coatings.

3.2 Enclosures

3.2.1 Standards and Guides

Proper enclosures are an integral part of a successful dehumidification project (Figure 3.2, Figure 3.3). Although there are various methods to construct enclosures, there are minimal requirements to set up properly.

The enclosure must:

- Be large enough to contain the whole intended work area
- Not be larger than the performance capabilities of the dehumidification equipment
- Be sturdy enough to hold up to intended work activities, potential loads, and possible inclement weather
- Have minimal leakage to maintain proper environmental conditions and ensure the dehumidification system operates efficiently

The dehumidification system designer's responsibility is to select the proper system to fit the required enclosure.



Figure 3.2 Enclosed Bridge



Figure 3.3 Enclosed Water Tank

3.2.2 Air Turns (Air Changes)

The physical properties of air, i.e., hot air is lighter than cold air, means hot air tends to rise while cold air tends to fall. The air turnover principle eliminates air stratification, or layering, in large open spaces. It does this by recirculating the hot air that becomes trapped at the higher levels. The uniform temperature eliminates thermal barriers and the possible formation of condensation.

The number of turns it takes to destratify air is a much-discussed topic in the industry. Some manufacturers specifically suggest three air changes per hour, while others specify four air changes per hour. One to two air changes per hour are recommended because within this range, the greatest amount of operational savings exists per dollar of initial investment. Once air changes exceed two per hour, the payback ratio diminishes.

The number of air turns needed can be affected by a number of factors including:

- Time of the year (winter/summer)
- Type of dehumidification equipment (refrigerant or desiccant)
- Manufacturer of the equipment
- Client request

The number of air changes is usually a decision left up to the dehumidification system designer.

3.2.3 Corrosion and Corrosion Rate

Corrosion can occur on steel when the four elements of a corrosion cell (anode, cathode, metallic pathway, and electrolyte) are present. The most common electrolyte affecting coatings in atmospheric exposure is atmospheric moisture in the form of rain or condensation.

Steel temperature changes corrosion rates in much the same way it affects a typical chemical reaction. Higher temperatures generally create higher corrosion rates. Atmospheric humidity and pollution control the corrosion rate, first by creating an electrolyte, then by affecting the efficiency of the electrolyte. Research shows that steel exposed to *high humidity* ***and*** *high levels of atmospheric pollution*, such as in an industrial area at a sea coast site, corrodes 15 to 20 times faster than steel exposed in a rural area of high moisture and low pollution (Figure 3.4).

In a rural area, steel is frequently wet, but the film of relatively clean water produces a lower rate of corrosion. In an industrial area, atmospheric pollution such as sulfur dioxide, chlorides, and sulfates make the water acidic which improves the function of the electrolyte and accelerates the rate of corrosion.

Either way, moisture is a prime contributor to the corrosion process. However, the presence of moisture does not necessarily mean the steel *feels* wet. Contaminants on the surface can absorb moisture from the air and hold it on the steel surface in a microscopic layer of water. It is a mistake to think that keeping the surface *apparently* dry by stopping condensation is enough to stop corrosion. Rather, **to stop corrosion it is necessary to keep the air dry enough to prevent the contaminants on the steel surface from absorbing moisture.**

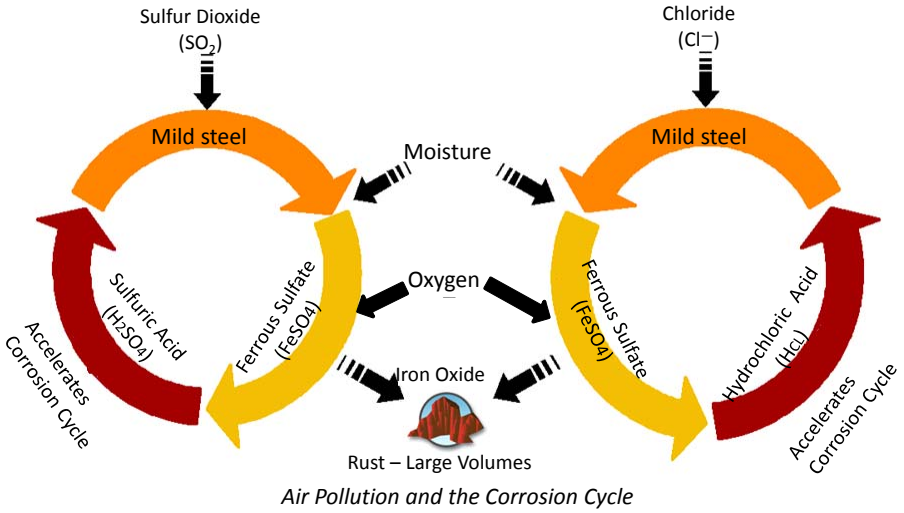


Figure 3.4 Air Pollution and the Corrosion Cycle

3.3 Moisture and Humidity

In normal conditions, all air contains some moisture, and the amount it contains depends on the temperature and pressure of the air. Generally, pressure is not a significant factor, so only temperature needs to be considered.

$$\text{Relative humidity} = \frac{\text{amount of water vapor in a given volume of air} \times 100\%}{\text{max. amount of water vapor (if air is saturated) at same temp}}$$

Air can have relative humidity in a range of 0 to 100%. At 0%, the air is perfectly dry; at 100%, it is completely saturated. Warm air can contain or "hold" more moisture than cold air. The amount of vapor held in the air in the summer is three times greater than in the winter. When the air contains the maximum amount it can hold at a given temperature, it is said to be "saturated." If it contains less, e.g., one-half as much, it is said to be partially (50%) saturated, or is said to have a relative humidity of 50%.

Air contains a given amount of moisture at a given temperature. Warm air has the ability to hold more moisture and conversely cold air has less ability to hold moisture. Visualize a sealed box of air with a specific quantity of moisture in the air. As the temperature increases, the air with greater capacity for moisture has a lower relative humidity. As the temperature decreases, the air has less capacity for moisture so the relative humidity increases.

When air is cooled, its saturation level is reduced, and the relative humidity increases toward 100% until the air finally becomes totally saturated. When the air cools further, the quantity of moisture vapor present exceeds the ability of the air to hold moisture. At that point, the excess moisture vapor condenses as a fog, mist, or dew on surfaces exposed to the air.

Whatever the humidity level, it is always possible to cool the air enough to reach saturation and produce condensation. The *dew point temperature* is when the air is cool enough to be saturated and capable of producing dew.

As relative humidity decreases, water evaporates more quickly because the air can absorb more of it. As relative humidity increases, water evaporates more slowly. The same is true of most solvents. Most coatings cannot be applied successfully when the relative humidity is greater than 90% because the solvent evaporation rate decreases at higher relative humidity and reaches zero evaporation rate at 100% relative humidity.

This condition can result in solvent entrapment in the applied coating film. When this is coupled with an impaired cure process, a subsequent coating failure in the form of blistering or severe peeling is likely to occur.

The relationship between relative humidity, temperature, and dew point are found in charts and tables, or with special slide rules or calculators. The use of the psychrometric chart (Figure 3.5) is illustrated in the presentation shown on the screen.

The chart shows 70°F (21°C), 50% relative humidity and a wet-bulb temperature of 58.5°F (16°C). The dew point is 50°F (10°C), which means this air contains the same weight of water vapor as the saturated air at 50°F (10°C).

By cooling the air from 70°F (21°C) to 60°F (16°C), the weight of vapor is not changed, so by definition the dew point is unchanged, i.e., 50°F (10°C). The relative humidity increases to 73%.

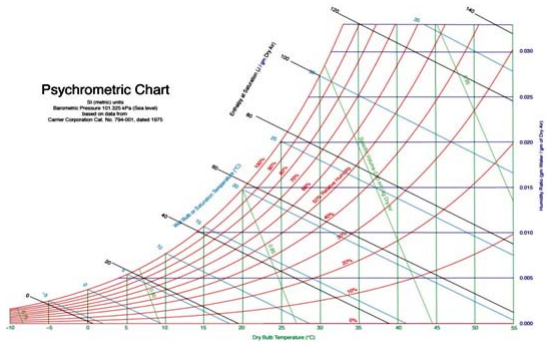


Figure 3.5 Psychrometric Chart (Mollier Diagram)

Calculate relative humidity and dew point by measuring temperatures with direct reading instruments. A practical instrument to use is the sling psychrometer, which measures the temperature using wet- and dry-bulb (thermometer) readings. Use these measurements to calculate humidity and dew point from psychrometric tables or with special slide rules or calculators.

Note, if the air is cooled to below its original dew point of 50°F (10°C), then the air is saturated at all temperatures below 50°F (10°C), and relative humidity is steady at 100%. Condensation forms as the temperature drops, so the weight of vapor the air holds steadily reduces. Increasing quantities of dew (condensation) forms on any affected surface.

3.4 Effects of Humidity on the Corrosion Rate

High humidity promotes rapid corrosion. Normal daytime humidity is typically 50 to 90%, depending on location. Studies show that corrosion slows greatly if the humidity is below 60% and virtually ceases below 50%. Hold the relative humidity to a low level (below 40% as a safety margin) in order to maintain blast cleaned surfaces for a longer time without deterioration before coating.

The relative humidity of the air in contact with the metal (steel) surface (Figure 3.6) governs the corrosion rate. This is different from the relative humidity of air only a few millimeters away from the steel surface, particularly if the surface and the air are at different temperatures. The air in close proximity to the steel is in moisture equilibrium with the metal surface unless water is evaporating from it or is actually condensing on the steel.

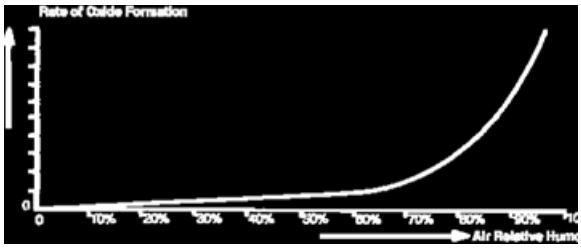


Figure 3.6 Corrosion Rate (Oxide Formation) vs. Percent of Relative Humidity

In general, it is not practical to measure air conditions this close to the steel surface, but use a psychrometer to make a measurement *close* to the substrate's surface. Measure the steel surface using a contact thermometer.

There are two ways to reduce the relative humidity of the boundary layer of air:

- Increase the surface temperature
- Reduce moisture content by dehumidification

3.4.1 Dehumidification Inspection Considerations

It is important to note that ***lack*** *of available moisture in the air* can mask surface contaminates. Without moisture, soluble salts on the surface do not initiate corrosion cells or become visible even when present; this may cause problems later in the coatings life-cycle.

3.4.2 Use of Heat to Increase Surface Temperature

There are many methods to increase surface temperature. Some are more practical and cost effective to use with small surface areas rather than large. The method chosen usually depends on relative cost.

With small work pieces, it is possible to heat surfaces using a radiant heater. This is not efficient or cost effective for large pieces or in large enclosed areas, such as tanks, unless insulation is provided. It would take many radiant heaters to combat heat losses from the steel surface to the outside air over such a large area.

Another common method is to heat the air to raise the ambient temperatures, including the steel surface temperature. This is expensive because heat transfers poorly from air to steel and also because steel has a large heat capacity. Most of the heated air goes to waste with only a small portion heating the steel.

High-velocity combustion heating is becoming more common to force cure coatings. Force-curing quickly and thoroughly dries coatings and linings of baked phenolics and epoxies to improve quality and wear while minimizing the need for reapplication. Another benefit is equipment goes back online more quickly and back into production faster. Forced curing does in hours what could take days under normal ambient conditions.

Other methods to increase surface temperature include:

- **Induction heating**, heats an electrically conducting object (usually metal) by electromagnetic induction; this allows targeted heating of specific items.
- **Resistance heating**, generates heat with electric conductors that carry current; the degree of heating for a given current is proportional to the electrical resistance of the conductor.

The heat source is a critical factor in the decision of which method to use to increase surface temperature. Gas-burning direct heaters can be unsafe and may also be counterproductive. When 1 gal (4 L) of propane burns, it produces 7.8 lb (4.5 kg) of moisture, which is exactly the opposite of what is needed (i.e., less water vapor).

3.5 Equipment Types

Dehumidification requires either refrigeration or the use of desiccants (Figure 3.7, Figure 3.8).

3.5.1 Refrigeration

Refrigeration to remove moisture vapor from air is a common and economical method of dehumidification.

Ambient air circulates over a system of refrigeration coils (Figure 3.9). The surface temperature of these coils is set at a temperature considerably lower than that of the dew point of the incoming ambient air. The air chills, reaches saturation, and condensation occurs.



Figure 3.7 Refrigeration Unit



Figure 3.8 Dehumidification Unit

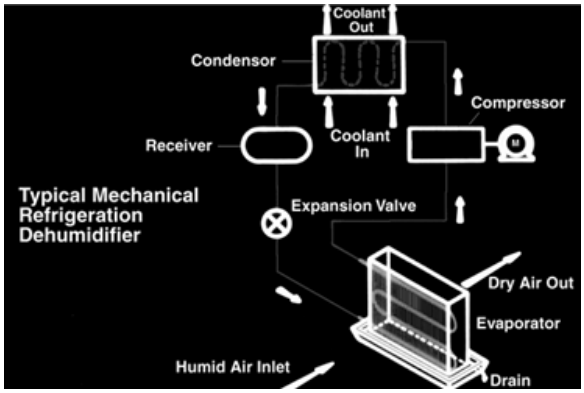


Figure 3.9 Typical Refrigeration System

The system then collects the condensation and pumps it out of the system. The air exits the cooling coil section of the dehumidifier at a reduced temperature, with a lower dew point and humidity. The system then adds dry heat to the air stream, based on the particular application's requirements.

This method works particularly well when the air is comparatively warm with high moisture content, and the outlet air dew point is above 32°F (0°C), but is less effective as temperatures and humidity levels decrease in the winter months or in northern climates. However, the cooling coil may freeze, reducing the efficiency of the dehumidifier to zero because the ice effectively insulates the coil.

An option is to use refrigeration in combination with adsorption or absorption dehumidifiers for more efficient dehumidification.

3.5.2 Desiccants

Desiccants are substances that naturally have a high affinity for water, so high that they draw moisture directly from the surrounding environment. Desiccants absorb moisture until they are saturated; then they are regenerated either with a heated air stream or a chemical process.

Most desiccants are solids in their normal state, but some are liquid, such as common sulfuric acid (used in chemical manufacturing), lithium chloride, or polymeric materials, such as triethylene glycol. These liquid materials are called ***absorbent desiccants***.

Desiccants in solid form are called ***adsorbent desiccants***. Moisture is adsorbed onto the surface of a granular material, such as silica gel, which is capable of holding large quantities of moisture. These materials dry easily, remove easily and recycle for further use.

In the coating industry, **rotating-bed silica gel adsorbent dehumidifiers** are most prevalent. The solid desiccant is put into a large rotating (10 to 12 revolutions per hour) drum or wheel that contains structured air contact media in the form of a honeycomb (Figure 3.10).

Process air (i.e., the air that needs dehumidification), passes through the open flutes in the media and releases its moisture to the silica gel desiccant contained in the media walls.

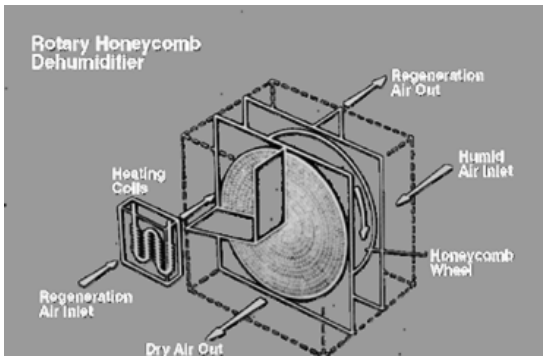


Figure 3.10 Rotary Honeycomb Dehumidifier

The moist media then rotates into a separate compartment, passing through a hot reactivation (regeneration) air stream, which removes the moisture from the silica gel. The process and reactivation air streams are separated by a partition.

The portion of the honeycomb where the moisture is removed is then exposed again to the process air stream to adsorb more moisture. This is a closed-loop continuous process, which operates automatically with little or no manpower required.

This system has some weak points to consider. Interrupting the heat source for the reactivation air stream means the honeycomb continues to operate and the silica gel desiccant becomes saturated with adsorbed moisture. At this point, the unit becomes an air handler and ceases to function as a dehumidifier. Make frequent checks to ensure the reactivation air stream is fully operable.

As a result of the heated air reactivation process, the drum (wheel) becomes heated; this heat energy transfers to the process air stream and heats the air. The normal operating temperature increase is 50°F (+28°C), which means for 80°F (27°C) ambient temperature, the process air stream outlet air temperature is about 130°F (55°C).

This temperature creates an unacceptable working environment in summer; thus requiring a refrigeration chiller downstream of the honeycomb, in the process air stream, to reduce the temperature to suitable levels.

Because large volumes of process air are often moved (Figure 3.11), ensure the silica gel is not contaminated with dirt, blasting dust, solvent vapors, or oil fumes. Once the silica gel is contaminated, it no longer adsorbs moisture.

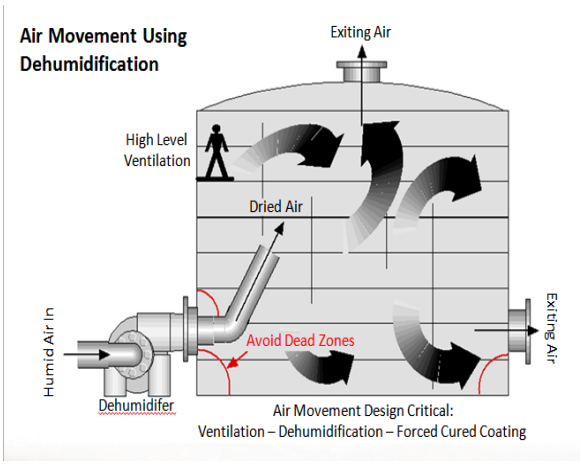


Figure 3.11 Air Movement Using Dehumidification

Protect the silica gel by installing and frequently changing filter media on both the

process and reactivation air inlets in the dehumidification unit.

3.6 Benefits of Dehumidification for Coating Contractors

Contractors benefit from using dehumidification: it dries the air (reduces dew point), permits blasting the entire surface, holds the blast with dry air, helps in cleaning the surface (i.e., helps remove the abrasive and dust), and holds the surface during coating application.

Additional benefits include:

- Crews can begin work earlier in the day and work later
- Eliminates contamination of previously applied coatings by the blasting operation
- Eliminates overlaps from one coated surface onto another (during daily blast-then-coat routine)
- All coating is done in ideal conditions
- Extended over-coating intervals are avoided
- Contractor can guarantee, with reasonable accuracy, the completion time
- Extends the coating season by many months
- Contractor can control ambient conditions despite weather and atmospheric changes

3.7 Inspection Concerns

3.7.1 Consequence of Interruption

If dehumidification is interrupted during coating, a variety of issues can result. Without proper conditions, the prepared surface begins to flash rust. During coating, loss of the surface temperature/dew point spread means coating application cannot be done. During curing, a rise in the relative humidity could potentially cause solvent entrapment. Interruption of dehumidification can ultimately cost the project a significant amount of money due to downtime and potential rework.

3.7.2 Dehumidification During Post-Application Cure

Use dehumidification equipment whenever possible during curing to ensure complete solvent release from the applied coating.

The vapor of typical solvents used in coatings are heavier than air; they tend to settle to the bottom of a structure, tank, etc., and saturate the air. Once the air at the boundary layer next to the coating is saturated, evaporation retards or stops. When this occurs, solvents remain in the film during curing. The only way to prevent this is constant ventilation of the solvent-laden air during coating operations.

If the make-up air is already at 85% relative humidity or greater, solvent evaporation does not improve or can even retard. Ensure the make-up air is dehumidified enough to increase the amount of solvent removal per cubic foot of air. The more dry air (50% relative humidity or less), the more solvent evaporates from the applied coating using the same volume of ventilation air.

Monitor post-application ventilation and dehumidification processes and record all parameters in the daily records. Document these processes to ensure a suitable coating application and cure period is maintained.

3.8 Inspection Checklist

Coating inspectors are not responsible for the design or implementation of the dehumidification system. However, with enough knowledge of dehumidification, inspectors

can watch for potential problems that could create even greater problems.

Items to look for include:

- Does equipment performance fit the requirements of the intended enclosure?
- Is the equipment installed by properly certified personnel?
- Is the size of the enclosure sufficient for the work area?
- Is the enclosure sturdy enough to hold up to intended work activities, potential loads, and possible inclement weather?
- Is the enclosure designed with minimal leakage to ensure the dehumidification system performs efficiently?
- Is there a backup system available? If not, is there a plan in case dehumidification is interrupted?

Asking questions before work begins can help avoid costly downtime, delays, and rework during the project.

Always monitor and routinely record post-application ventilation and dehumidification processes. Additionally, check the “in” versus the “out” air to provide confirmation that the equipment performs as it should.

Key Terms Definitions

Absorbent Desiccants: Desiccants in their liquid form are called "absorbent desiccants." This includes common sulfuric acid (used in chemical manufacturing), lithium chloride, or polymeric materials, such as triethylene glycol.

Adsorbent Desiccants: Desiccants in their solid form are called "adsorbent desiccants." Moisture is adsorbed onto the surface of a granular material, such as silica gel, which is capable of holding large quantities of moisture.

Dehumidification: The removal of moisture vapor from the air to lower its dew point.

Desiccants: Substances that naturally have a high affinity for water. They draw moisture directly from the surrounding environment.

Study Guide

1. Describe dehumidification:
_____
_____
_____
_____
_____

2. When planning enclosures, the following minimum requirements should be considered:
_____
_____
_____
_____
_____

3. Describe air turns (air changes):
_____
_____
_____
_____
_____

4. At and below what relative humidity does corrosion virtually cease? _____ %

5. Describe two ways to reduce the relative humidity of the **boundary layer**:
_____
_____

6. Types of dehumidification equipment include:
_____
_____

7. Describe several benefits of dehumidification:

Chapter 4: Advanced Environmental Testing Instrumentation

Objectives

When this module is complete, you will have knowledge and understanding of:

- The proper use of electronic hygrometers
- The importance and use of wind speed monitors
- Maintaining a wind data logger
- Advanced data collecting methods

Key Terms

- Electronic hygrometers
- Data loggers
- Oven data loggers
- Wind speed monitors
- Stand-alone wind data monitors

4.1 Introduction

Previous chapters presented the proper use of basic environmental (ambient) testing equipment including the sling psychrometer, surface temperature gauge (contact and infrared) and the book of psychrometric tables. Students were also introduced to some of the advanced testing equipment.

This chapter takes a deeper look into the proper use and capabilities of some of the more advanced environmental testing equipment.

The instruments include:

- Electronic hygrometers
  - — Hand held hygrometers
  - — Stand-alone data loggers
  - — Oven data loggers
- Wind speed monitors
  - — Hand held monitors
  - — Data loggers

4.2 Digital Electronic Hygrometers

4.2.1 Hand Held Hygrometers

There is a variety of electronic hygrometers available. Some are basic and designed to determine relative humidity, air temperature, and dew-point temperature. They are convenient and easy to use. There are more advanced hygrometers that deliver fast and accurate measurement of *surface temperature*, *air temperature* and *relative humidity.* From these measurements, the gauges calculate *dewpoint temperature, delta T, wet bulb temperature and dry bulb temperature*. They also store information for future use and some transfer data to computers (discussed later).

4.2.1.1 Proper Use

Users need to know and understand the proper care and use of electronic digital hygrometers (Figure 4.1). Always refer to the manufacturer's instructions that come with the instrument.



Figure 4.1 Electronic Hygrometers (Dew Point Meters)

The following section presents some basic operations (Figure 4.2) that are common to most hygrometers.

Allow time for the meter to stabilize when moving from one extreme temperature/ humidity to another. Open the sensor's protective shutter, then press the button to turn on the meter and start taking measurements. Temperature readings display in either Celsius or Fahrenheit and the user can switch between the two as needed.

Once the hygrometer is stabilized, the temperature and relative humidity display. Press the *wet bulb* button once to display dew point temperature. Press it a second time to switch to the wet-bulb temperature. Press a third time to return the meter to the ambient temperature. The display indicates when dew point and wet-bulb temperatures are selected.

Press the *hold* button to freeze the displayed readings. This also causes the meter to stop taking measurements. To continue taking readings, press *hold* again. Some instruments feature minimums and maximums, store data, save and/or print, and recall data for easier record keeping



Figure 4.2 Using a Hygrometer

Ensure that the instrument meets all NIST standards for quality and use and is in accordance with ANSI/NCSL Z540-6 (National Calibration Standard).

4.2.1.2 Calibration

Regular calibration checks over the life of the gauge are a requirement of quality management procedures, e.g., ISO 9000, and other similar standards. For checks and certification, contact the gauge's manufacturer or supplier. The hygrometer comes from the manufacturer calibrated; however some method of both certification by an independent lab and verification in the field is necessary.

4.2.1.3 Operating Parameters

Refer to the manufacturer's operating instructions for model-specific operating parameters/limits.

The accuracy and precision of the hygrometer must be near the top of its scale (i.e., close to 100% RH) because this is the critical point at which the contractor or inspector decides whether to continue work or not. Most manufacturers' guidelines state the degree of accuracy in both Celsius and Fahrenheit, as well as the range and resolution for each reading (i.e., temperature, relative humidity, dew point, and wet bulb). The repeatability of the instrument's measurements depends on its manufacturer.

Question the readings anytime the highs and lows are outside known parameters. Check the local weather predictions for the work area in the morning for a good general idea of the ambient conditions for the day; use this as a benchmark for that day.

Some of the common errors and causes are operator-based and some are equipment-based. Operator-based inaccuracies can be caused by:

- Reading taken in direct sunlight
- Instrument left in place too long
- Instrument removed before it stabilized
- Instrument was not allowed to stabilize after change of environment (office to field)

Erroneous equipment-based readings are most likely due to calibration or equipment malfunction. If it cannot be repaired or correctly re-calibrated, replacement may be needed.

4.2.2 Stand-Alone Data Loggers

Data loggers are stand-alone instruments that automatically measure and store environmental data (Figure 4.3). Users can document the saved data on location or analyze it later on a personal computer via interface and software. Fit instruments with alarms to indicate when specified limits are exceeded. Some of the more sophisticated models of hand held electronic hygrometers (dew point meters) also work as data loggers with the appropriate accessories. There are also data loggers for specific applications.

4.2.2.1 Proper Use

Always refer to the manufacturer's operating instructions for the instrument.



Figure 4.3 PosiTector DPM used as Data Logger (w/optional attachments)

4.2.2.2 Calibration

Regular calibration checks over the life of the gauge are a requirement of quality management procedures, e.g., ISO 9000, and other similar standards. For checks and certification, contact the gauge's manufacturer or supplier.

4.2.2.3 Operating Parameters

Refer to the manufacturer's operating instructions for model-specific operating parameters/limits.

The accuracy and precision of the hygrometer should be accurate near the top of its scale (i.e., close to 100% RH) because this is the critical point at which the contractor or inspector decides whether to continue work or not. Most manufacturers' guidelines state the degree of accuracy in both Celsius and Fahrenheit, as well as the range and resolution for each reading (i.e., temperature, relative humidity, dew point, and wet bulb). The repeatability of the instrument's measurements depends on its manufacturer.

Question readings any time the highs and lows are outside known parameters. Check the local weather predictions for the work area in the morning for a good general idea of the ambient conditions for the day; use this as a benchmark for that day.

Some of the common errors and causes are operator-based and some are equipment-based. Operator-based inaccuracies can be caused by:

- Reading taken in direct sunlight
- Instrument left in place too long
- Instrument removed before it stabilized

Erroneous equipment-based readings are most likely due to calibration or equipment malfunction. If it cannot be repaired or correctly re-calibrated, replacement may be needed.

4.2.3 Stand-Alone Oven Data loggers

Oven data loggers are used to measure and record oven temperature profiles. By logging both the product's surface and the air temperature in the cure oven, the instrument records the temperature profile. Oven data loggers (Figure 4.4) are used in powder coating cure ovens, wet coating ovens, batch ovens, and conveyor ovens.



Figure 4.4 Oven Data Logger

4.2.3.1 Proper Use

Refer to the manufacturer's model-specific operating instructions for information on the operating parameters/limits of the instrument. Always have the operations manual on-site and available for reference. Know the proper use of the specific data logger in use.

4.2.3.2 Calibration

Regular calibration checks over the life of the gauge are a requirement of quality management procedures, e.g., ISO 9000, and other similar standards. For checks and certification contact the gauge's manufacturer or supplier.

4.2.3.3 Operating Parameters

Refer to the manufacturer's operating instructions for model-specific operating parameters/limits.

Most manufacturers' guidelines state the degree of accuracy in both Celsius and Fahrenheit, as well as the range and resolution for each reading. The repeatability of the instrument depends on the manufacturer so consult the manufacturers' technical data sheet. Question readings anytime they are outside known parameters.

Common errors may include improper installation or using the equipment in an environment outside of its mechanical limits.

4.3 Wind Speed Monitors

Wind speed monitors (Figure 4.5) also help determine if the conditions are appropriate for coating applications.

4.3.1 Hand Held Wind Speed Monitors



Figure 4.5 Wind Speed Monitor

4.3.1.1 Proper Use

The manufacturers' instructions are the knowledge base for any instrument. Ensure that the instructions are available on the job. Always stand facing the wind with the digital dial facing the user. Hold the instrument at arm's length so the air flows though it without obstruction.

Ensure that the instrument meets all NIST standards for quality and use and is in accordance with ANSI/NCSL Z540-6 (National Calibration Standards).

4.3.1.2 Calibration

The wind speed monitor comes calibrated from the manufacturer.

4.3.1.3 Operating Parameters

Operating parameters for the wind speed monitor should include:

- Accuracy and precision: these vary, but most manufacturers indicate that the degree of accuracy is ± 3% of the indicated reading
- Repeatability of results vary depending on the individual unit

Question the readings when the instrument reading is **not** the actual speed of the wind. Make sure to learn from local weather reports the predicted general range of wind speeds for that day.

Common operator errors include:

- Not facing into the wind
- Not holding the instrument away from the body

Common equipment errors include:

- Low batteries
- Worn out roller bearings
- Poor maintenance

4.3.2 Stand-Alone Wind Data Loggers

The **stand-alone wind data logger** is a convenient way to gather wind data. Depending on the manufacturer, these instruments (Figure 4.6) may record wind speed, gusts, and direction, as well as time, date, temperature, and other important wind parameters. Some

data loggers can record wind speed from multiple anemometers. The user can set up the logger to record data at preset intervals for later data retrieval. The user can download the recorded data to a computer via manufacturer's software for use in other applications.



Figure 4.6 Wind Data Logger

4.3.2.1 Proper Use

Refer to the manufacturer's instructions for proper use of any equipment. Ensure the wind speed data logger is installed properly. Electrical connections must be made properly and the anemometer/wind vane should be in an area free of obstructions from the wind.

Ensure that the instrument meets all NIST standards for quality and use and is in accordance with ANSI/NCSL Z540-6 (National Calibration Standards).

4.3.2.2 Calibration

Wind speed monitors come from the manufacturer pre-calibrated; however, the user can calibrate the data logger's anemometer settings within its *main setup menu*. It may support a variety of anemometers, but the user provides the calibration settings.

4.3.2.3 Operating Parameters

Operating parameters vary slightly by manufacturer but wind speed data loggers generally have these functions:

- Display and log wind speed in:
  - — Miles per hour (mph)
  - — Meters per second (m/s)
  - — Kilometers per hour (kph)
- Display wind direction if so equipped, it displays from 0° to 359° or N, S, E, W
- Display temperature if so equipped, displays in °F and °C
  - — Measures 40°F to 212°F (-40°C to 100°C)
  - — Resolution: 1.8°F (1°C)
  - — Accuracy: 37.4°F (3°C) or better

Equipment generally requires a power supply of 7 to 40 volts DC.

As with the hand held wind speed monitor, question the readings when the user knows that the instrument reading is **not** the actual speed of the wind, wind direction, or temperature. Make sure to learn from local weather reports the predicted general range of wind speeds for that day.

The most common user error of wind data loggers is improper installation, which includes:

- Improper power supply
- Faulty wiring to anemometer/wind vane or data logger
- Anemometer/wind vane mounted where the wind flow is obstructed

4.4 Advanced Data Collection Methods

As mentioned previously, many of the advanced environmental testing instruments not only have the ability to quickly and accurately measure conditions, they can store the data for future use. This stored data can be transferred to a computer and other devices through various methods.

4.4.1 Equipment Connectivity

Depending on the manufacturer and instrument, there are numerous methods to transfer stored data:

- **USB** – data transfers via a high speed data transfer cable to a computer, or in some cases, connects directly to a printer
- **IR** - some models print information directly to a portable infrared printer
- **Bluetooth** – instruments with bluetooth capability means users can monitor and record data remotely, in real time; the user can download and review data on mobile devices

4.4.2 Software Systems

Some manufacturers have software available that manages stored data (Figure 4.7) for:

- Electronic hygrometers (dew point meters)
- Environmental data loggers
- Oven data loggers
- Wind data loggers

Some of the features available, depending on software include the ability to:

- Create professional reports in seconds
- Export reports to spreadsheets, text files, or save as PDF or JPEG files
- Copy and paste reports into other documents
- Combine reports to clearly compare different batches
- E-mail reports directly
- Assign batch identification tags
- Rename batches for clear identification
- Use a wide range of standard reports including:
  - Individual measurements
  - Statistics
  - Histograms
  - Individual line or bar charts
  - Log
  - Pie charts
- Fully customize reports
- Include company graphics and logos on reports
- Combine batches to compare readings or link batches together from different gauges into one comprehensive inspection file
- Quickly locate a specific file or batch

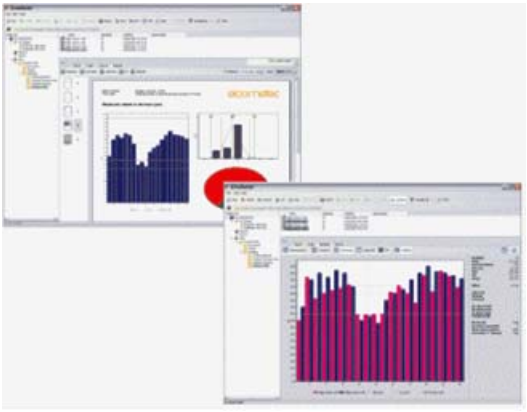


Figure 4.7 Screen-shot of Elcometer ElcoMaster™ Data Management Software

Key Terms Definitions

Data Loggers: Stand-alone instruments that automatically measure and store environmental data.

Electronic Hygrometers: Device designed to determine relative humidity, air temperature, and dew-point temperature.

Oven Data Loggers: Devices that measure and record oven temperature profiles.

Stand Alone Wind Data Monitor: Convenient way to gather wind data. Depending on the manufacturer, these instruments may record wind speed, gusts, and direction, as well as time, date, temperature, and other important wind parameters.

Wind Speed Monitor: An instrument that gathers wind data to help users decide if conditions are appropriate for coating application projects.

Study Guide

1. Electronic hygrometers determine:

   _____
   _____
   _____

2. Advanced environmental testing instruments have the ability to store data that can be transferred to a computer and other devices. Transfer methods include:

   _____
   _____
   _____

Chapter 5: Advanced Environmental Testing Instrumentation — Practice Lab

Measuring Environmental Conditions Using Advanced Testing Instrumentation

In CIP 1, participants were required to demonstrate proficiency in using a sling psychrometer, United States Weather Bureau tables (book of psychrometric tables), and a surface thermometer to determine the dew point, steel temperature, and relative humidity.

This practice lab demonstrates some of the advanced environmental testing instruments described in Chapter 4. Each student will have hands-on experience with them.

Please divide into teams and complete the attached assignment. The time allotted to complete the assignment is 45 minutes. Everyone should use the electronic hygrometer (dew point meter). Each student must understand the instrument and how to use it on the final practical examination.

Note: For guidance, consult ASTM E 337, Method A.

Procedure

1. Equipment Required:

- Electronic hygrometer (dew point meter)
- Manufacturer's instruction manual
- Infrared or contact surface temperature gauge (optional, may be part of hygrometer)
- Test panel

2. **Purpose of Practice Lab**

- Learn how to use an electronic hygrometer (dew point meter) properly
- Learn the available functions and capabilities of the electronic hygrometer
- Learn the procedure for field calibration of the electronic hygrometer

3. Task Procedure

Each team is issued the following:

- Electronic hygrometer (dew point meter)
- Infrared or contact surface temperature thermometer
- Test panel

4. Requirements

Each student must perform the following exercises:

- Properly measure surface temperature
- Measure, record, and save environmental conditions inside
- Record results in °C and °F
- Batch and save multiple sets of environmental readings
- Repeat procedure in outdoor setting

Students are to make the above determinations both *indoors* and *outdoors*.

Use equipment provided to complete inspection record on following page.

Environmental Testing Instrument Information

Note: Use table below to document information on instrument used.

Manufacturer	
Model #	
Serial #	
Last Calibration	
Due for Calibration	

Environmental Instrument Test Lab Data

Date: _____

Location: IN CLASS

Note: Use metric and imperial units

Time ⇒						
	°C	**°F**	**°C**	**°F**	**°C**	**°F**
Wet-Bulb Temperature						
Dry-Bulb Temperature						
RH (%)						
Dew Point						
Steel Temperature						
OK to work? Yes/No						

Environmental Instrument Test Lab Data *(continued)*

Date: _____

Location: OUTDOORS

Note: Use metric and imperial units

Time ⇒						
	°C	**°F**	**°C**	**°F**	**°C**	**°F**
Wet-Bulb Temperature						
Dry-Bulb Temperature						
RH (%)						
Dew Point						
Steel Temperature						
OK to work? Yes/No						

Chapter 6: Centrifugal Blast Cleaning

Objectives

When this module is complete, you will have knowledge and understanding of:

- Equipment related to centrifugal blast cleaning
- The purpose of portable and remote systems
- The standards used for centrifugal blast cleaning
- The purpose of abrasive blast cleaning
- Inspection concerns

Key Terms

- Centrifugal blast cleaning
- Tumbling mills
- Multi-table machines
- Swing table
- Blank test

6.1 Introduction

Centrifugal blast cleaning (wheel blasting) is used in a variety of cleaning, finishing, and peening operations. Coating inspectors are most concerned with centrifugal blast cleaning in shop or field operations:

- In shop operations (Figure 6.1) a variety of steel plates, pipes, and fabricated pieces are cleaned
- In field operations, new or used large, flat concrete or steel surfaces are cleaned



Figure 6.1 Monorail Centrifugal Blasting Unit – Part Before and After

6.2 Centrifugal Blast Cleaning Equipment

6.2.1 Stationary Shop Cabinets

Wheel blast shop systems, equipment, and applications generally differ only in:

- How work is conveyed through the blast
- Type of abrasive used

Although the combinations of machine types and applications are highly varied, there are several general basic setups, including:

- Tumbling mills

- Multi-table machines
- Plain table machines (most have been replaced by multi-table and swing table machines)
- Swing tables
- Custom designed systems for continuous high volume production cleaning of steel plate, fabricated beams, rolled shapes, rods, piping, etc.

Tumbling mills are systems generally used for batch loads and cleaning parts. The wheel units are usually mounted on the roof of the cabinet to blast clean parts as they tumble in the mill. Various sizes of machines are available to handle from 2 ft^2 (0.06 m^3) up to 100 ft^3 (2.8 m^3) of parts per load. These units commonly clean and de-scale castings, forgings, and heat-treated parts. Cleaning batch loads normally takes only 5–10 minutes, depending on the type of work; steel shot or grit is the usual blast media used.

Multi-table machines have a series of independent revolving work tables mounted on a rotating platform or "*spider.*" The individual tables rotate as they move beneath the blast from the abrasive throwing wheel (Figure 6.2). Models are available with varying numbers and diameters of tables, depending on the size of the pieces. Multi-tables are most commonly used for relatively flat or fragile pieces that are not suitable for tumbling action.



Figure 6.2 Multi Table Blasting Unit

Swing-table blast cleaning equipment (Figure 6.3) offers a high degree of work handling flexibility and can accommodate very large and heavy work pieces of up to 10 tons (9,000 kg). The work table rotates under the blast of one or more abrasive throwing wheels and swings out with the door as the door is opened.

This means the full table is accessible for workers to load and unload using a fork-lift, chain hoist, or overhead crane. Models are available in sizes from 4 ft (1.2 m) to 10 ft (3.0 m) in diameter. Some have a double-door design so one load cleans while the other work table unloads and reloads, a feature that permits almost continuous production cleaning.

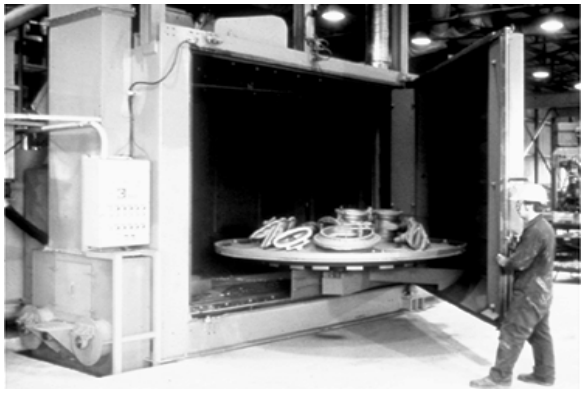


Figure 6.3 Swing Table Blasting Unit

Custom-designed systems come in a wide variety of semi-standard and special automated blast cleaning machines including spinner hanger, monorail, shot peening, straight and skewed roll conveyor, traveling work car, and continuous tumbling mills (Figure 6.4).

Some of the largest machines ever built are used to clean massive fabricated ship sub-sections. One installation utilizes 40 centrifugal wheels that propel about 30,000 lbs (13,600 kg) of abrasive per minute.

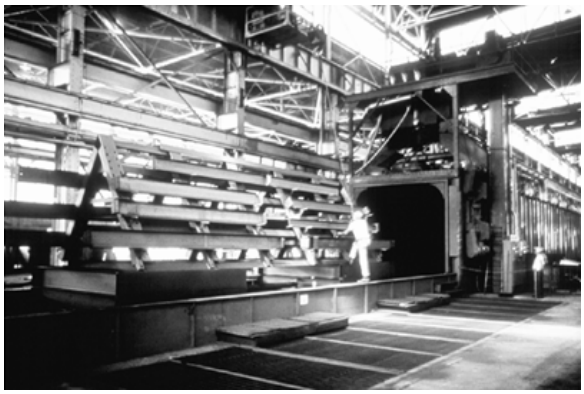


Figure 6.4 Beam Blasting Unit

Railroad cars are cleaned in enclosed rooms for new construction and repair and repainting (Figure 6.5). Blast cleaning in such cases is done with as many as twenty centrifugal wheel units (Figure 6.6, Figure 6.7, Figure 6.8).

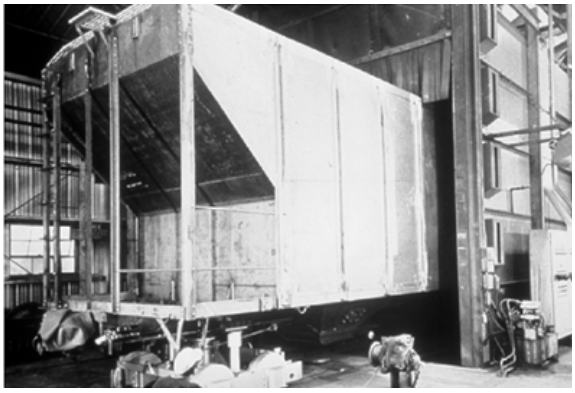


Figure 6.5 Rail Car Blasting Unit



Figure 6.6 Small Plate Unit



Figure 6.7 Large Plate Unit



Figure 6.8 Plate Blasting Unit (right to left)

Automated wheel blast systems are available for all types of hot-rolled bar stock, wire-rod castings, hot-rolled steel strip, plate and structural steel, fabricated components and weld joints needing coating (Figure 6.9).



Figure 6.9 Typical Centrifugal Blasting Unit

Four-wheel conveyor systems are commonly used for prefabrication cleaning of plate and rolled structural shapes (Figure 6.10). Larger machines, with a variety of work conveyor systems, typically using eight wheels, may be used for post-fabrication cleaning of large trusses, girders, and other large structural parts.



Figure 6.10 Small Centrifugal Blast Unit

In these machines, batches of small parts, such as gusset plates, welded joints, etc., are loaded into baskets placed on the conveyor rolls, or in larger machines, the parts are suspended from overhead crane hooks so that numerous and varied shapes of work can be cleaned. Larger parts may be hung on special racks and cleaned in batches (Figure 6.11, Figure 6.12).

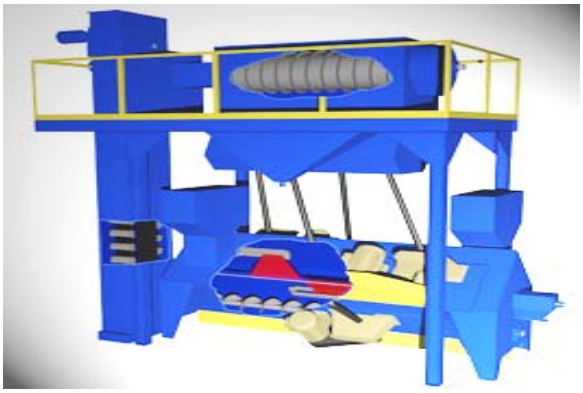


Figure 6.11 Cut-a-Way Diagram of a Unit

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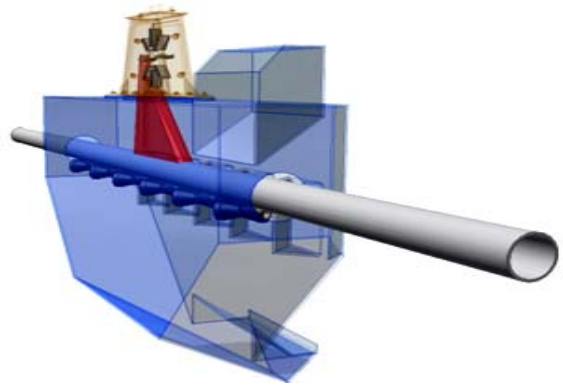


Figure 6.12 Pipe Unit - Skew Type

6.3 Portable and Remote Operated Systems

These systems make it possible to wheel blast clean on site during new construction and maintenance of steel, concrete, and wood surfaces, including:

- Ship decks, hull sides, and bottoms
- Storage tanks
- Concrete floors
- Highways and bridge decks

In these systems, the abrasive is recycled and both the material removed from the surface and the dust generated by the blast are collected for subsequent disposal (Figure 6.13).

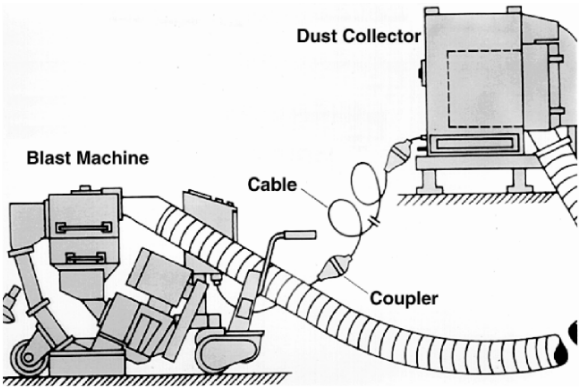


Figure 6.13 Portable Deck Unit Diagram

6.3.1 Basic Elements and Components of the Blast System

Although configurations may vary somewhat from machine to machine, centrifugal blast systems are composed of the following (Figure 6.14):

- The heart of the system, the centrifugal abrasive throwing wheel, throws the abrasive in a controlled pattern against the work to be cleaned
- The blast cabinet (enclosure) confines the abrasive as it is thrown from the wheel and prevents the fines (spent abrasives) and dust generated by the blast from escaping
- In fixed systems, a material handling system moves the work piece to the wheel(s)
- The abrasive recycling system separates and returns the good abrasive to a storage hopper for reuse through the wheel
- A dust collector and vent-pipe system to ventilate the blast cabinet and operate the air-wash separator
- Abrasives of the proper type, size, and mix for the job

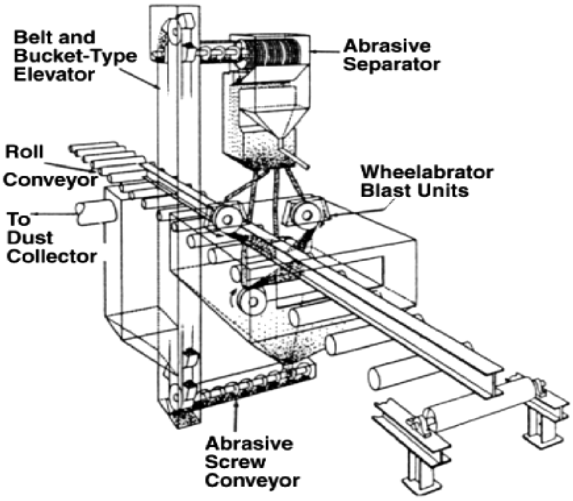


Figure 6.14 Blast Unit Diagram

6.3.2 Blast Wheel

The wheel designs (Figure 6.15) vary with individual manufacturers; however, they all function in the same manner, as described below:

- The AC- or DC-motor-driven wheel, fitted with adjustable, removable vanes, hurls the abrasive by centrifugal force onto the surface of the work piece.
- Abrasive from an overhead hopper feeds to the center of the wheel unit, which rotates at high speed.
- A cast-alloy impeller rotates with the wheel, imparts initial velocity to the abrasive particles, and then carries the abrasive to an opening in the stationary cage from which it discharges onto the wheel vanes.
- The inner ends of the vanes pick up the abrasive which rapidly accelerates as it moves to the outside edge of the wheel and onto the surface of the work piece.
- The location of the opening at the edge of the control cage establishes the direction of the blast pattern generated by the wheel. As little as 10% misalignment of the pattern location can reduce cleaning efficiency by 25% or more.

Because the wheels are central to proper functioning of the wheel blast unit, they must be properly adjusted and maintained. The efficiency of the wheels, however, depends upon other factors. Some of the following affect efficiency:

- Abrasive operating mix
- Size of the abrasive
- Velocity of the abrasive coming off the wheel
- Quantity and direction of the thrown abrasive
- Condition of the feed parts including feed spout, impeller, impeller case, and vanes (Figure 6.16)



Figure 6.15 Blast Wheel

6.3.2.1 Aligning the Wheel for Proper Blast Pattern

Unless the thrown abrasive directly strikes the work, it cannot clean. Blasting efficiency is greatly affected by the percentage of abrasive thrown onto the work, which is determined primarily by the position of the impeller case.

The impeller case is a sleeve that fits around the impeller. The impeller is cast with blades resembling those on the blast wheel, although much smaller, and is attached to the same drive shaft that powers the wheel. The impeller receives abrasive from the feed spout and propels it toward the vanes of the wheel. The abrasive feed supply to the vanes is controlled by the size and shape of the impeller case.

The concentrated area of blast is called the *hot spot*. A stationary piece of work or a target plate mounted in line with the blast will

become hot when subjected to a blast for 30 seconds or longer. To precisely target the abrasive, the operator can:

- Disengage the conveyor mechanism so target plate can remain stationary.
- Install target plate and blast it for 30 seconds.
- Stop blast and locate hot spot on target plate.
- Adjust impeller clockwise or counterclockwise as indicated by hot spot to achieve desired blast pattern.
- Remove target and re-engage conveyor.

6.3.3 Ammeter as a Performance Guide

The quality of the abrasive being thrown by the wheel is determined with an **ammeter**, which shows the loading on the drive motor. The difference between the "no-load" amperage reading and "full-load" amperage reading equals 100% of the throwing capacity of the wheel. Most wheel units are designed to run at "full load amperage."

Low amperage readings can signify:

- An abrasive-starved wheel that does not pull full amperage because it does not receive enough abrasive.
- A flooded or choked wheel that is fed abrasive at too rapid a rate, thus choking the feed spout with abrasive.

6.3.4 Effects of Part Wear on Blast Pattern

- Wear on any one of the wheel elements, i.e., impeller vanes, impeller case, or wheel vanes (Figure 6.16), can move the hot spot and reduce efficiency of the wheel (Figure 6.17).
- Wear on the impeller case opening can alter the hot spot because it allows more room for the abrasive to be thrown.
- Wear on the impeller case and the vanes affect the location and size of the hot spot.
- Badly grooved or worn wheels can lead to wheel imbalance, resulting in a deteriorating blast pattern and reduction of machine efficiency.
- If the blast stream is not directly on the work, unnecessary wear to machine components will result.



Figure 6.16 Centrifugal Blasting Unit Parts



Figure 6.17 Worn Vane from a Centrifugal Blasting Unit

6.3.5 Basic Operating Principles

In the simplest terms, the centrifugal blast system operates as follows:

- Abrasive flows by gravity from an overhead storage hopper through a feed spout then into a rotating impeller.
- Metering valves in the supply line control the quantity of the flowing abrasive.
- The impeller directs the abrasive through and opening in the impeller case onto the rotating vanes of the blast wheel.
- The motor-driven wheel throws the abrasive by centrifugal force against the work piece.
- After striking the work piece, the abrasive falls into a recovery hopper along with such contaminants as sand, scale, old coatings, etc., which are removed from the work piece as it is cleaned.
- The abrasive-handling system lifts the contaminated abrasive up into the air wash separator above the blast machine (Figure 6.18).
- The air-wash separator removes the contaminants and any abrasive particles that have become too small to be useful (Figure 6.19).
- The cleaned and sized abrasive is returned to the storage hopper for reuse, completing the cycle.

The functions of the separator are:

- To control the size of the abrasive mix, which influences cleaning efficiency
- To remove sand, fines, rust, dirt, and any other contaminants from the abrasive stream so only good, clean abrasive is fed to the blast machine
- To control abrasive consumption, which is measured by the size of abrasive pellets removed from the machine

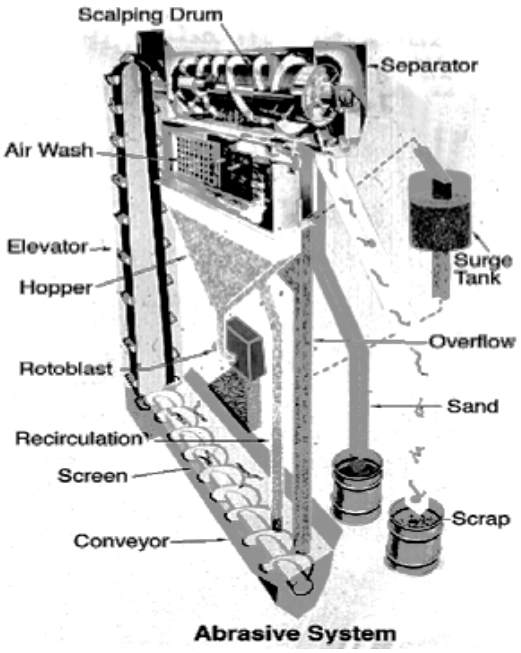


Figure 6.18 Abrasive System

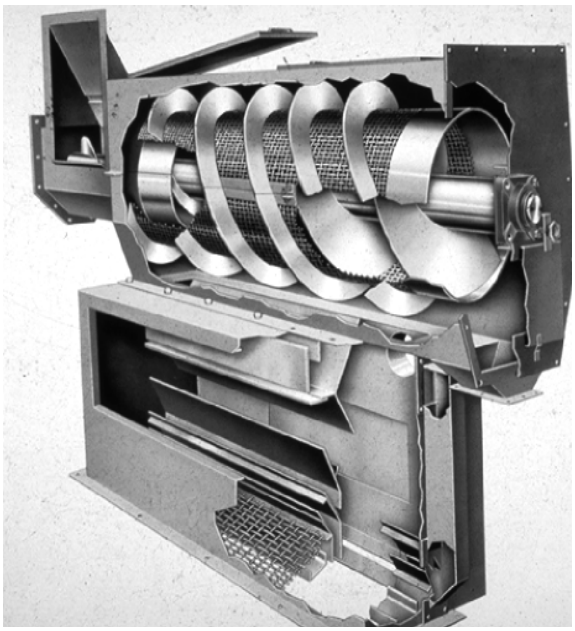


Figure 6.19 Air Wash Separator

Most separators are equipped with secondary skimmer plates (Figure 6.20) which direct some of the abrasive mixture for recirculation and permit only clean abrasive to pass to the feed hopper (Figure 6.21).

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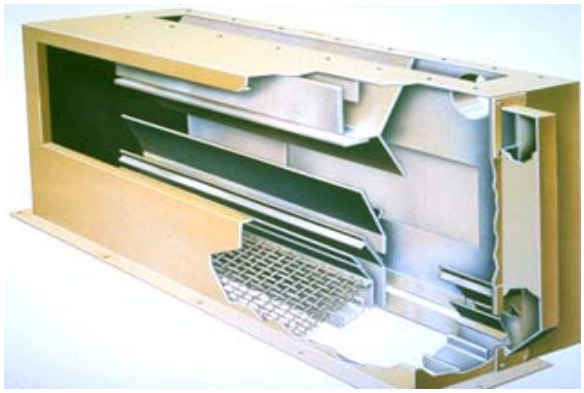


Figure 6.20 Skimmer Plates in Separator

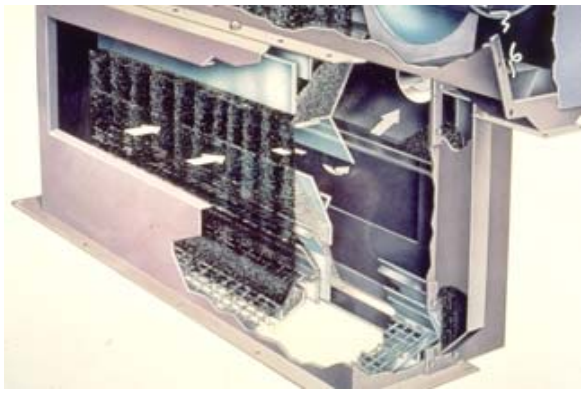


Figure 6.21 Abrasive Curtain, Air Flow, and Scrap Bypass

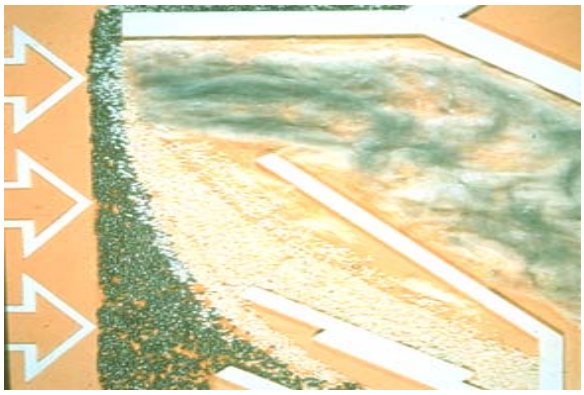


Figure 6.22 Abrasives Traveling Through Abrasive Separator

During operations, the abrasive mixture flows by gravity over the separator lip (Figure 6.22). High-velocity air flow pulls the falling mix inward, where stationary and adjustable skimmer plates skim off the contaminants, which are then diverted to a collector. A final screen tray protects the blast wheel from large foreign objects, and airborne contaminants are exhausted to a dust collection system.

An adjustable metering gate is designed to prevent contaminant overloads from entering the air wash during periods of surge. If a surge should occur, the separator's overload bypass system removes and recycles the contaminated abrasive before it can enter the air wash. A properly functioning separator assures that good, clean, properly sized abrasives fall into the hopper, ready for use.

6.4 Standards

The surface cleanliness standards used for centrifugal blast cleaning are the same as those used for air blast cleaning. They include the joint NACE/SSPC standards, which include commentary specific to centrifugal blast cleaning as well as the ISO Standards (Figure 6.23, Figure 6.24). Figures 6.23 and 6.24 list these standards.

NACE / SSPC JOINT STANDARDS	NOT	ISO STANDARDS
NACE No. 1/SSPC-SP 5 White Metal Blast Cleaning		ISO 8501-1, Sa 3 Blast-Cleaning to Visually Clean Steel
NACE No. 2/SSPC-SP 10 Near-White Metal Blast Cleaning		ISO 8501-1, Sa 2½ Very Thorough Blast-Cleaning
NACE No. 3/SSPC-SP 6 Commercial Blast Cleaning		ISO 8501-1, Sa 2 Thorough Blast-Cleaning
NACE No. 8/SSPC-SP 14 Industrial Blast Cleaning		ISO 8501-1, Sa 1 Light Blast-Cleaning
NACE No. 4/SSPC-SP 7 Brush-Off Blast Cleaning		

Figure 6.23 Abrasive Blasting Standards

Standard	Random Staining	Cleanliness
NACE No. 1/SSPC-SP 5 White Metal Blast Cleaning	None	Free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter
NACE No. 2/SSPC-SP 10 Near-White Metal Blast Cleaning	5%	
NACE No. 3/SSPC-SP 6 Commercial Blast Cleaning	33%	
NACE No. 4/SSPC-SP 7 Brush-Off Blast Cleaning	Tightly adherent mill scale, rust, and coating may remain	
NACE No. 5/SSPC-SP 14 Industrial Blast Cleaning	Traces of tightly adherent mill scale, rust, and coating residues are permitted to remain on 10 percent of each unit area	

Figure 6.24 Abrasive Blasting Standards 2

6.5 Abrasives

The abrasive blast machine (Figure 6.25) cleans best with use of **a range of abrasives**. The largest particle size is the newly added abrasive. The smallest particle size is determined by filter meshes in the recycling equipment.

Large particles impact the surface to loosen scale, sand, etc., and the smaller particles clean small irregularities and scour the surface, removing loosened particles so the work is thoroughly and uniformly cleaned.

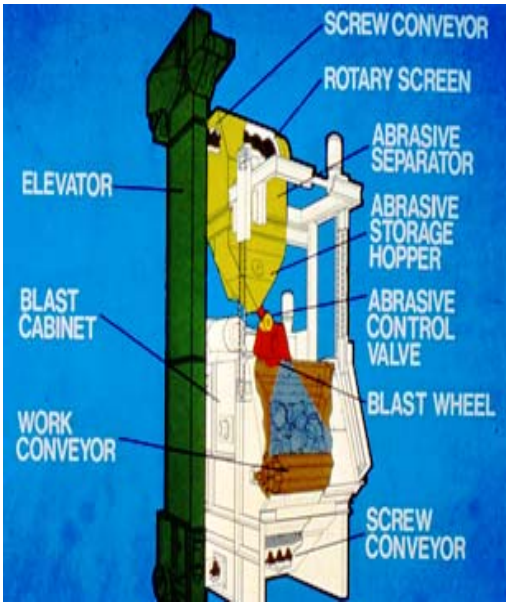


Figure 6.25 Abrasive Handling Machine Diagram

Maintaining a well-balanced operating mix (sometimes called a *working mix*) of various size abrasives will:

- Provide consistency of finish on work being cleaned
- Ensure uniform abrasive coverage of the work
- Ensure conditioning of the abrasive for optimum cleaning
- Minimize lowest abrasive and machine part-wear to reduce downtime for maintenance

Conducting a periodic sieve analysis on the abrasive can assist the operator and inspector to maintain the proper operating mix.

6.5.1 Abrasive Selection

Wheel blast operations make use of a wide variety of blast media, including agricultural products and synthetic products such as glass beads, aluminum oxide, and slags. However, steel shot and grit are used most commonly in preparing steel and concrete for coating. The items to be cleaned and the desired finish determine the use of steel shot or grit.

Steel shot (Figure 6.26) may be the best blast cleaning, peening, or de-scaling abrasive available. Shot breaks up heat treat and scales such as mill scale, or will wear sand away from castings. Because of its toughness and ideal hardness (44 to 46 Rockwell c [Rc]), steel shot does not readily fracture. Shot is round when new and, after fracturing, balls up to a round shape after repeated impacts.



Figure 6.26 Steel Shot

Steel grit (Figure 6.27) is best for etching, i.e., creating surface profile prior to coating or plating, or for cleaning hard alloys, brightening nonferrous parts, mill rolls, heat-treated parts, or any application where a roughened grit blast surface is required or desired. Angular steel grit can range in hardness from 45 to 65 Rc.

Because steel shot tends to peen rather than scour the surface, an operating mix of shot and grit frequently is used to achieve greater cleanliness and surface profile. Steel grit is

often substituted for shot. Medium hardness grits are used to obtain a sharper etch on the steel substrate or remove tenacious scale from alloy steels. The brittleness of the abrasive increases the hardness so the harder grits fracture readily, retain angularity, and result in higher abrasive consumption and wear of machine parts.



Figure 6.27 Steel Grit

Ferrous abrasives may leave trace amounts of metal on the substrate and should not be used on substrates where they could induce corrosion. For example, if a stainless steel substrate is blasted clean with an iron or steel abrasive, the stainless steel may corrode due to the loss of passivation.

6.5.2 Abrasive Replenishment

Abrasive wear creates a finer particle size (Figure 6.28), so a desirable operating mix is maintained if the mix is replenished frequently with small amounts of the coarsest abrasive used in the machine. Replenishment can be done by an automatic replenisher or by hand. If the mix is replenished by hand, make regular additions in small quantities to avoid upsetting the balance of sizes in the mix.

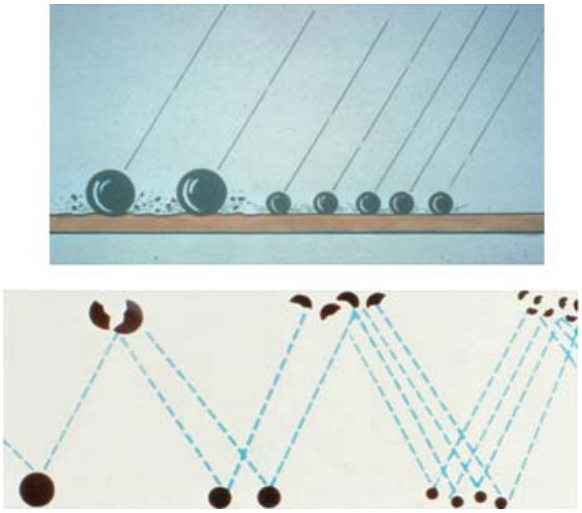


Figure 6.28 Abrasive Wear

The abrasive supply should not become so low that large additions of new material drastically alter the wheel pattern, cleaning speed, abrasive consumption, or resulting finish.

Abrasive consumption is determined by the size of abrasive being removed by the separator, not the purchased size of abrasive. Normally, the separator is adjusted to retain abrasive particles five sizes smaller than the purchased size.

6.5.3 Abrasive Contamination

Objects to be blasted are not always rigorously inspected for freedom from oil and grease prior to blasting. This can cause the abrasive to become contaminated with oil or grease. Because the oil or grease spreads as a thin film on metallic abrasives, it will adhere to the metal surface and its presence cannot be determined by the "vial test." The vial test for contamination is discussed in the inspection section.

6.5.4 Inspection

It is very important that inspectors follow a proper inspection procedure that is within the bounds of the specification.

Inspection procedures may be defined by the client or may come from the inspector's understanding of the project. Do the inspection in the proper sequence. Failure to do so can lead to time delays and cost the owner or contractor considerable time and money.

Observe, test, and verify conformance to the specification (with documentation) and report. Good reporting and inspection documentation not only provide substantial valuable information on the surface preparation process, but have a economic impact about the protection afforded when used to make future decisions about maintenance and recoating projects.

6.5.4.1 Pre-Cleaning

Be sure that all snow, ice, and standing pools of water are removed from work pieces before blast cleaning. Likewise, ensure oil, grease, and dirt are removed from the work piece before blasting to prevent contaminating the abrasive.

6.5.4.2 Additional Tests

Test for Oil and Grease Contamination on Metallic Abrasives

Place a representative sample of the metallic abrasive of about 0.5 lb (0.23 kg) in a clean glass or metal container. Cover the abrasive with a chlorinated hydrocarbon solvent 1.1.1. trichloroethane (**not** trichlorethylene) or methyl chloroform. This is the best solvent for oil or grease and has a rapid evaporation rate, which is important. This solvent is used to dry clean clothing and is sold as a solvent for removing grease spots from clothing. It is sometimes sold diluted with mineral spirits, which retards the evaporation rate.

After the solvent has been in contact with the abrasive for three to four minutes, decant into a clean shallow container such as a saucer; this provides larger area for evaporation. If the metallic abrasive is contaminated with finely dispersed rust, etc., filter the solvent during decanting with a paper towel or other filter paper.

Leave the solvent in the shallow container until the residual volume is under about 0.25 to 0.27 fluid oz (7 to 8 ml). Use unadulterated 1.1.1 trichlorethane so evaporation does not take much longer than about five minutes. Pour the remaining liquid onto a clean glass surface (a mirror is best). In a short time, all the solvent will evaporate and the oil or grease can be seen as a residual deposit on the surface of the mirror.

As with all solvents, follow precautions for safe handling and use appropriate PPE.

Blank Test

Before the above test is conducted, it is very important to conduct a **"blank" test** on the solvent. Conduct the test without any metallic abrasive and allow the solvent to reduce in volume before pouring onto the mirror.

In conducting "blank tests," it is **not** acceptable to just test a few drops of the solvent. The solvent **must** be reduced in volume by evaporation.

6.6 Special Considerations

Special considerations should include the safety issues when moving large plates, beams, etc. Do not walk under moving objects. Be aware of the working environment. For example, inspectors and blasting operators are not the only people working in the area. Vehicles, fork trucks, overhead cranes, shears, cutting tables, and pedestrian traffic is usually very heavy in the area, so look before moving.

6.7 Inspection Concerns

Inspectors should have a safe work environment to ensure the client is getting the specified cleanliness on the prepared surface:

- Constantly monitor the dust collector and make sure the vacuum is removing all the dust debris from the substrate.
- Monitor the amperage of the wheel motors and look for indications of low amperage. These indicate the wheel is not throwing the abrasive media to the substrate and is not getting the required anchor profile.
- Monitor the handling and loading of the conveyor line for contaminates, as well as discontinuities in the steel.
- Monitor the speed of the line. The speed of the line dictates whether the specified surface cleanliness is achieved.
- Most important, inspect the steel as it leaves the production line to ensure all surfaces comply with the project specification.

Inspection Checklist

- Pre-job conference.
- On-site pre-job inspection.
- Obtain specifications and data sheets. Read, understand, discuss, and compare.
- Pre-inspect equipment for obvious excessive wear (excessive wear creates a dust hazard as well as improper blast).
- Check materials for proper shot/grit mix according to the specification.
- Calibrate equipment daily before use.
- Monitor ambient conditions.
- Perform visual inspection of blasting/coating operation and machinery.
- Perform required tests on blasting/painting operation.
- Record all the functions performed.
- Report to client as required.

Key Terms Definitions

Abrasive: A solid substance that, because of its hardness, toughness, size, shape, consistency, or other properties, is suitable for grinding, cutting, roughening, polishing, or cleaning a surface by friction or high-velocity impact.

Ammeter: A device used to measure the electrical current in a circuit.

Blank Test: test that does not use metallic abrasives and allows the solvent to reduce in volume before pouring onto the mirror.

Centrifugal Blast Cleaning: An enclosed blast cleaning process that throws abrasive at the surface being cleaned.

Multi-Table Machines: A series of independent revolving work tables mounted on a rotating platform or "*spider*" in centrifugal blast cleaning.

Standards: A term applied to codes, specifications, recommended practices, procedures, classifications, test methods, and guides that provide interchangeability and compatibility. Standards enhance quality, safety, and economy; they are published by a standards-developing organization or group.

Swing Tables: Work tables used in centrifugal blast cleaning that rotate under the blast of one or more abrasive throwing wheels. The table swings out with the cabinet door when the door opens. It offers a high degree of work handling flexibility and can accommodate very large and heavy work pieces of up to 10 tons (9,000 kg).

Tumbling Mills: Mills generally used to abrasive clean batch loads and parts. The wheel units are usually mounted on the roof of the cabinet to blast clean parts as they tumble in the mill.

Study Guide

1. In general, basic centrifugal blast setups include:

_____
_____
_____
_____
_____

2. Centrifugal blast conveyor systems are commonly used for cleaning:

_____
_____
_____
_____

3. Portable centrifugal blasting systems can be used:

_____
_____
_____
_____

4. Generally, centrifugal blast systems are composed of the following elements:

_____
_____
_____
_____
_____
_____

5. The efficiency of the centrifugal blast wheels depends on several factors:

_____
_____
_____
_____
_____

6. Low amperage readings on a centrifugal blasting machine could signify:

_____
_____

7. The functions of the centrifugal blasting machine separator include:

_____
_____
_____

8. A well-balanced operating mix (working mix) of abrasive sizes will:

_____
_____
_____
_____

9. Some of the inspection concerns during centrifugal blasting include:

_____
_____
_____
_____
_____

Chapter 7: Waterjetting

Objectives

When this module is complete, you will have knowledge and understanding of:

- Standards
- Equipment and systems
- Operations
- Operator technique considerations
- Special considerations
- Inspection concerns
- Inspection checklist

Key Terms

- Waterjetting
- Non-visible contamination (NV)
- Visible surface cleanliness (VC)

7.1 Introduction

Waterjetting: *NACE No. 5/SSPC-SP 12* describes the use of a high-energy water stream to strip off existing coatings and remove contaminants on a substrate being prepared prior to coatings application. When compared to abrasive blasting, this method has certain advantages particularly for safety and environmental control. Respiratory protection requirements are less stringent and waste (abrasive) disposal is not an issue because water is the medium.

The term **waterjetting** denotes the use of "water only," without the addition of solid particles such as sand or garnet in the water stream. Modern waterjetting equipment produces pressures of up to 90,000 psig. However, as technology improves, equipment with higher operating pressures may be developed.

This cleaning method is particularly well suited to the marine, process and utility (power plants) industries, where high-performance coatings require extensive surface preparation and/or surface decontamination with minimal effect on surrounding equipment and the environment. In the marine industry, waterjetting is widely used to remove marine growth, depleted antifouling coatings, and surface preparation of tank/hold interiors. Data also proves it is effective in removing marine growth on offshore structure's jackets (submerged sections).

It is very important to remember that *while waterjetting will remove contaminants and millscale at varying pressures, it will* ***not*** *create an anchor profile*, which plays a critical role in coatings adhesion. In maintenance and repair operations, waterjetting exposes the existing anchor profile (if there is one).

While NACE standard No. 5/SSPC-SP 12 is referred to as the Waterjetting Standard, it also addresses ***water cleaning*** which is basically the same process at lower pressures. It is important for inspectors to understand these terms and the working pressures associated with them.

7.2 Standards

It has become a common practice for some specifiers and inspectors to equate the level of cleanliness achieved during waterjetting with that of abrasive blasting. This is not

accurate or appropriate since **there is no direct correlation between dry abrasive blasting standards and the capabilities and results of waterjetting**.

The joint NACE/SSPC standards for abrasive blast cleaning are complete and clearly define the surface conditions to be achieved. However, when and if specifications are being written for surface preparation utilizing waterjetting, the visual (WJ-1 to WJ-4) and the non-visual surface preparation definitions (NV-1 to NV-3) should be referenced. Keep in mind that in case of any dispute, the written standards take precedence over visual reference photographs or visual standards such as NACE VIS 7/ SSPC-VIS 4.

An example of a specification statement is: "*All surfaces to be recoated shall be cleaned in accordance with NACE No. 5/SSPC-SP 12 WJ-2/NV-1. The method of HP WJ or UHP WJ ultimately selected by the contractor will be based on his confidence in the capabilities of the equipment and its components.*"

The specifier, inspector, and contractor must agree on the test methods to determine the amount of non-visible contaminants that can be left on the prepared substrate. Consult the manufacturer of the specified coatings to determine the coating's tolerance to the surface conditions after waterjetting, commensurate with the in-service conditions.

Two terms synonymous with cleanliness after waterjetting are visible and non-visible contaminants.

Non-visible contamination (NV) is the presence of organic matter, such as very thin films of oil and grease, and/or soluble ion materials such as chlorides, ferrous salts, and sulfates that remain on the substrate after cleaning that cannot be seen with the naked eye.

Visible surface cleanliness (VC) is the visible condition of the substrate when viewed without magnification and after cleaning.

The following standards are reproduced from the joint standard NACE No.5/SSPC SP-12:

7.2.1 Visual Surface Preparation Definitions

WJ-1 Clean to Bare Substrate: *The surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible rust, dirt, previous coatings, mill scale, and foreign matter. Discoloration of the surface may be present (A, B, C).*

WJ-2 Very Thorough or Substantial Cleaning: *The surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5% of the surface (A, B, C).*

WJ-3 Thorough Cleaning: *The surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is*

limited to a maximum of 33% of the surface (A, B, C).

WJ-4 Light Cleaning: *The surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Any residual material shall be tightly adherent (C).*

The inspector and contractor should know that surfaces prepared by LP WC, HP WC, HP WJ, or UHP WJ do not exhibit the hue of a dry abrasive-blasted steel surface. After waterjetting, the matte finish color of clean steel surface immediately turns to a golden hue unless an inhibitor is used or environmental controls are employed. However, the use of any inhibitor outside of the specification requirement is never encouraged. The use of any such inhibitor without the written approval of the coatings manufacturer can result in the voiding of all performance warranties from the manufacturer. On older steel surfaces that have areas of coating and areas that are coating free, the matte finish color varies even though all visible surface material has been removed. Color variations in steel can range from light gray to dark brown/black.

Prepared steel surfaces show variations in texture, shade, color, tone, pitting, flaking, and mill scale that should be considered during the cleaning process. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type of steel or other metals, original surface condition, thickness of the steel, weld metal, mill fabrication marks, heat treating, heat-affected zones, and differences in the initial abrasive-blast cleaning or in the waterjet cleaning pattern.

The gray or brown-to-black discoloration seen on corroded and pitted steel after waterjetting cannot be removed by further waterjetting. A brown-black discoloration of ferric oxide may remain as a tightly adherent thin film on corroded and pitted steel and is not considered part of the percentage staining.

Waterjetting at pressures in excess of 35,000 psig (240 MPa) is capable of removing tightly adherent mill scale, but production rates are not always cost effective.

Mill scale, rust, and coating are considered ***tightly adherent*** if they cannot be removed by lifting with a dull putty knife (see NACE No. 4/SSPC-SP 7).

7.2.2 Flash-Rusted Surface Definitions

No Flash Rust*: A steel surface that, when viewed without magnification, exhibits no visible flash rust.*

Light (L)*: a surface which, when viewed without magnification, exhibits small quantities of yellow-brown rust layer through which the steel substrate may be observed. The rust or discoloration may be evenly distributed or present in patches, but it is tightly adherent and not easily removed by lightly wiping with a cloth.*

Moderate (M)*: A surface that, when viewed without magnification, exhibits a layer of yellow-brown rust that obscures the original steel surface. The rust layer may be evenly distributed or present in patches, but it is reasonably well adherent and leaves light*

marks on a cloth that is lightly wiped over the surface.

***Heavy (H)**: A surface that, when viewed without magnification, exhibits a layer of heavy red-brown rust that hides the initial surface condition completely. The rust may be evenly distributed or present in patches, but the rust is loosely adherent, easily comes off, and leaves significant marks on a cloth that is lightly wiped over the surface.*

7.2.3 Description of Non-Visible Surface Cleanliness Definitions (NV)

***NV-1**: An NV-1 surface shall be free of detectable levels of soluble contaminants, as verified by field or laboratory analysis using reliable, reproducible test methods.*

***NV-2**: An NV-2 surface shall have less than 7 µg/cm2 (0.0007 grains/in.^{2}) of chloride contaminants, less than 10 µg/cm^2 (0.00 1 grains /in.^{2}) of soluble ferrous ion levels, or less than 17 µg/cm^2 (0.00 17 grains/in.^{2}) of sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.*

***NV-3**: An NV-3 surface shall have less than 50 µg/cm^2 (0.005 grains/in.^{2}) of chloride or sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.*

Inspectors are required to know the recommended test procedures for extracting and analyzing soluble ferrous salts, chlorides, and sulfate contaminants of surfaces to be cleaned and/or coated. Later chapters teach and demonstrate test methods to determine the presence of and how to quantify existing soluble ferrous salts and chlorides. Keep in mind that while these procedures are generally the same, different manufacturers have slightly different guidelines for performing these tests. If the coatings specification ***does not*** require testing, the inspector ***should not*** request the contractor to do so ***or do so on his own accord*** then use the results as a benchmark for surface preparation acceptance.

The coating inspector should obtain, read, and understand all requirements of the standard before inspecting surface preparation done by waterjetting. If testing procedures are not clearly outlined in the coatings specification, all parties involved should discuss it and reach agreement before the project begins (i.e., pre-job conference). This is critical to avoid conflicts and unnecessary delays when the project gets started.

Waterjetting (WJ) is the use of water discharged from a nozzle at pressures of 10,000 psig (70 MPa) or greater to prepare a surface for coating or inspection. Waterjetting uses a pressurized stream of water with a velocity that is greater than 1,100 ft/s (340 m/s) when exiting the orifice. As stated earlier, waterjetting does not produce an anchor pattern or profile of a magnitude currently recognized by the coatings industry. Rather, it exposes the original abrasive blasted surface profile if one exists.

Water cleaning (WC) is the use of pressurized water (<10,000 psig) discharged from a nozzle to remove unwanted matter from a surface.

Standard jetting is using water of sufficient purity and quality that it does not impose additional contaminants on the surface being cleaned and does not contain sediments or

other impurities that are destructive to the proper functioning of waterjetting equipment.

In comparing water cleaning with waterjetting, these definitions apply:

- Low-Pressure Water Cleaning (LP WC): Cleaning performed at pressures below 5,000 psig (34 MPa). This is also called "power washing" or "pressure washing."
- High-Pressure Water Cleaning (HP WC): Cleaning performed at pressures of 5,000 to 10,000 psig (34 to 70 MPa).
- High-Pressure Waterjetting (HP WJ): Waterjetting performed at pressures from 10,000 to 30,000 psig (70 to 210 MPa).
- Ultrahigh-Pressure Waterjetting (UHP WJ): Waterjetting performed at pressures above 30,000 psig (210 MPa).

7.3 Waterjetting Equipment and Systems

This section introduces basic waterjetting systems and the basic equipment required to successfully accomplish the work (Figure 7.1).



Figure 7.1 Typical UHP Pump

A commercial waterjet unit can be skid, trailer, or truck-mounted and usually consists of pumps, hoses, a prime mover (diesel, electric, etc.), along with various tools such as guns, nozzles, lances, etc (Figure 7.2).

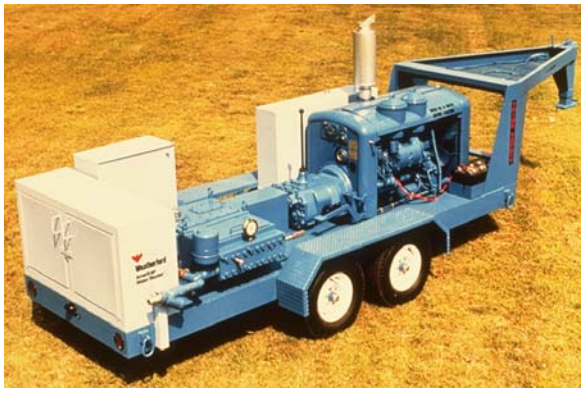


Figure 7.2 Trailer Mounted UHP Pump/Unit

The high-pressure hose, hose connections, and all other equipment, including the nozzle control valve, lance, and nozzle, should have minimum burst strength of 2½ times the capability of its maximum-rated operating strength (Figure 7.3).

High-pressure hoses are fitted with a safety device known as a **whip-lock** or **whip check**. This is a short length of cable or wire looped over each end of two hoses connected by a coupling. The whip-lock or whip check prevents the ends of the hoses from whipping around if the coupling breaks.

The section of hose next to the gun is fitted with a **hose shroud**, which usually is a short length of heavy-duty hose placed over the high-pressure hose to provide instantaneous protection if the hose bursts. A hose shroud also can be used over other hose connections. The shroud, however, does not form a permanent barrier to the flow of water from a damaged hose or broken connection.

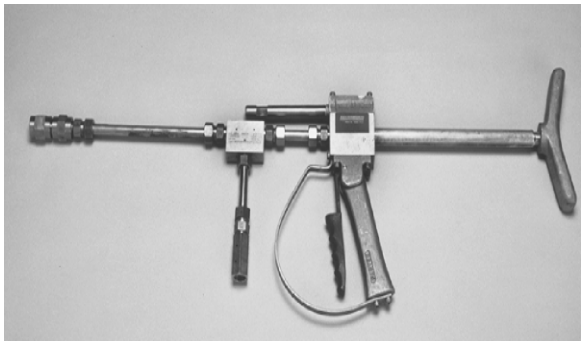


Figure 7.3 Typical Shoulder Gun w/Nozzle

7.3.1 Equipment Types

Waterjetting equipment types generally fall into one of two basic categories:

- manual
- robotic

7.3.1.1 Manual Waterjetting

The majority of waterjetting falls under the manual category and is the topic of most of this chapter. A human operator using a hand-held wand performs the surface cleaning effort.

7.3.1.2 Robotic Waterjetting

Technology is quickly improving and a new kind of equipment recently developed is a robotic water jetting unit. It is a cleaning vehicle that attaches itself, using vacuum, cables, or magnets to a vertical, horizontal or overhead surface. It is controlled by a single operator (Figure 7.4).

A unique features is that it collects in excess of 95% of the water, removed coatings and rust (waste generated). The coatings and water are transported to a filtration bag, where the waste is contained for future disposal. The water drains out at a clarity level generally acceptable for treated sewers. However, check with area authorities before disposing untreated waste in the sewage system.

A standard 40,000-psi direct-drive pump powers the unit. A vacuum system process that provides suction, attaches the Hydro-Cat® to the work surface where it conveys removed coatings and water to the filtration bag mentioned earlier.

This unit is used on vertical surfaces such as ship hulls and tanks on horizontal surfaces such as flat decks and on overhead surfaces such as the bottom of ship hulls. It also works well over weld seams, doubler plates, lap joints and riveted seams, and moves easily in and around keel blocks and other common obstructions. For straight-line work, it uses an “autopath” control feature.





Figure 7.4 Robotic Waterjetting Unit

7.3.2 How it Works

The tools can be hand held or mounted on a robot. Water is propelled through a single jet, a fan-jet, or multiple rotating jets. The jets are rotated by small air, electric, or hydraulic motors. Slightly inclined orifices in a multiple-orifice nozzle can also cause jets to rotate.

Orifices or tips come in a variety of forms and sizes. Round jets are most commonly used. A reliable round jet can produce 35,000 psig (240 MPa). Tips can be designed to produce multiple jets of water that rotate automatically to achieve higher removal rates. The round jets are cutters, and fan jets are scrapers and/or pushers. The interchangeable nozzle tips produce the desired streams (Figure 7.5). A typical water flow rate is 1 to 14 gal/min (4 to 53 L/min).



Figure 7.5 Different Guns/Tips/Hoses

The equipment sends a concentrated stream of water through the hose and nozzle at pressures of 10,000 to 60,000 psig (70 to 414 MPa). With current technology, however, the most practical pressures are 10,000 to 35,000 psig (70 to 240 MPa). Use lower pressures if appropriate. Generally, using UHP with reduced water volume produces less thrust and less operator fatigue.

Results from the use of HP WJ and UHP WJ are not necessarily similar. For example, surface oil and grease may not be removed by HP WJ at 10,000 psig (70 MPa), but will be removed completely by UHP WJ at 30,000 psig (210 MPa).

At working pressures of 4,000 psig (28 MPa) or higher, the waterjetting team consists of:

- The nozzle operator
- The pump operator
- Additional operators or workers

The nozzle operator controls the operation while waterjetting is taking place by holding the gun and lance or delivery hose and controlling the motion and direction of the waterjets.

The pump operator monitors and controls the pressurizing pump during the jetting operation, and watches the nozzle operator at all times to be able to react if any difficulty arises, or if the operator begins to show signs of fatigue. The pump operator also monitors the working area and its surroundings in case anyone tries to enter the area or if a potentially hazardous condition occurs.

In either circumstance, or as necessary, the pump operator may reduce the pressure in the supply hose until a situation is under control. The operator should use caution when rapidly reducing the system pressure; otherwise the nozzle operator may lose footing.

Depending upon the size and scope of the project, other operators or workers may be required to assist in handling a jetting gun if it is fitted with more than one jetting extension or if the hose must be fed to the work piece.

If the pump is located at some distance and out of sight of the nozzle operator, a team member may be required to monitor the jetting operation and to communicate with the nozzle operator and pump operator.

7.4 Waterjetting Operations

Waterjetting is effective for removing:

- Surface oil and grease
- Rust
- Concrete (shot-crete) spatter
- Existing coatings

Waterjetting also effectively removes deleterious amounts of water-soluble contaminants. Waterjetting removes what cannot otherwise be removed by abrasive blasting alone, especially in the bottom of pits, cracks, crevices, and craters in corroded metallic substrates such as steel.

An underwater waterjetting unit generally is used to clean the build up of barnacles or other micro-organisms off ship hulls or offshore platform legs (Figure 7.6). Take care not to use too much pressure to ensure the antifouling coating is not damaged and ensure the safety of the operator.

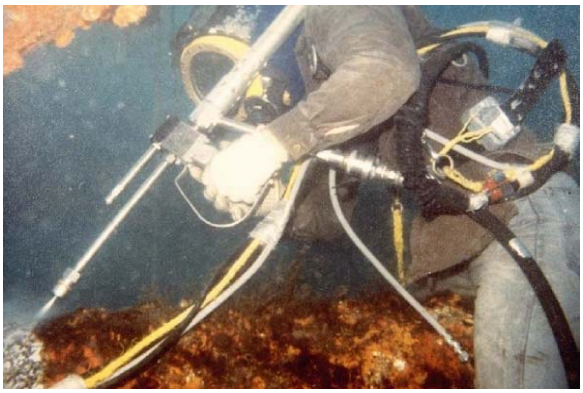


Figure 7.6 Underwater Waterjetting



Figure 7.7 Waterjetting Steel Substrate



Figure 7.8 Waterjetting Tank

7.5 Operator Technique Considerations

The type of matter that needs to be removed from the surface determines the equipment to use (HP WJ or UHP WJ), the angle at which to hold the nozzle, and the distance to hold it from the surface. Although the waterjet nozzle distance from the surface varies from 2 to 3 ft (0.6 to 1 m), typically hold the nozzle 2 to 10 in. (5 to 25 cm) from the surface. In some instances with UHP WJ, the nozzle is held only 0.25 to 0.5 in. (6 to 13 mm) from the surface.

Hold the nozzle 2 in (5 cm) from the surface when removing heavy rust scale or old coatings, i.e., virtually perpendicular (90°) to the surface. For best results when removing mastics, hold the nozzle at 45° to the surface.

One element of operator fatigue, mentioned earlier, is the back thrust from the high-pressure water. Ensure operators do not have to withstand a back thrust of more than one-third of their body weight for an extended period of time (Figure 7.9). For example, an operator working with a jet flowing at 10,000 psig (70 MPa) and 10 gpm (38 Lpm) experiences a back-thrust force of 52 lbs (23 kg). The operator should weigh at least 156 lbs (70 kg) to operate the nozzle at this pressure. Newer units operate with less back thrust than some of the earlier units.

To minimize operator fatigue and to ensure a safe operation, make sure the nozzle operators periodically alternate positions with another operator, depending upon the equipment and pressures used.



Figure 7.9 Proper Operator Position

7.5.1 Nozzles/Tips

As stated earlier, orifices or tips produce waterjets. Round jets are the most com-

monly used, but other shapes are available. A reliable round jet can produce waterjets at 35,000 psig (240 MPa). Tips are available that emit multiple jets of water that rotate to achieve higher removal rates (Figure 7.10).

The round jets are cutters, and fan jets are scrapers and/or pushers. The interchangeable nozzle tips are what produce the desired streams. A typical water flow rate is 1 to 14 gal/min (4 to 53 L/min) (Figure 7.11).



Figure 7.10 Tips/Nozzles



Figure 7.11 Fan Nozzle/Tip

7.5.2 Efficiency of Operation

Based on studies in the early 1980s, the following illustrates the overall efficiency of the HP WJ and UHP WJ.

At pressures lower than 10,000 psig (70 MPa), loose rust, debris, and material in depressions and pits are removed, but the black iron oxide Fe3O4 (magnetite) remains. A matte finish is not achieved.

At pressures of 10,000 psig (70 MPa), a uniform matte finish is obtained that quickly turns to a golden hue unless an inhibitor is added or dehumidification is used. The black oxide is removed but at a rate too slow to be considered practical.

At pressures of 20,000 psig (140 MPa), a uniform matte finish is obtained that quickly turns to a golden hue unless an inhibitor is added or dehumidification is used. Black oxide, paint, elastomeric coatings, enamel, red oxide, and polypropylene sheet lining are removed. Chemical contaminants will be removed, but with varying degrees of effectiveness.

At pressures of 34,000 to 36,000 psig (234 to 248 MPa), a uniform matte finish is obtained that quickly turns to a golden hue unless an inhibitor is added or dehumidification is used. Surface materials, including most mill scale, are removed.

Generally, *more time is required in localized jetting* to remove extremely well-bonded mill scale.

7.5.3 Stand-off Distance

Anyone working around a UHP operation should exercise extreme care. Breaches in the hoses can cause **very** serious injury. Operators may not realize anyone is in close proximity; a direct hit with the waterjet at these pressures can cause very serious injury or even death.

7.5.4 Safety

Safety systems include hose shrouds to protect from high pressure hose bursts and "deadman" controls to prevent the waterjetting system from being accidentally activated (Figure 7.12).

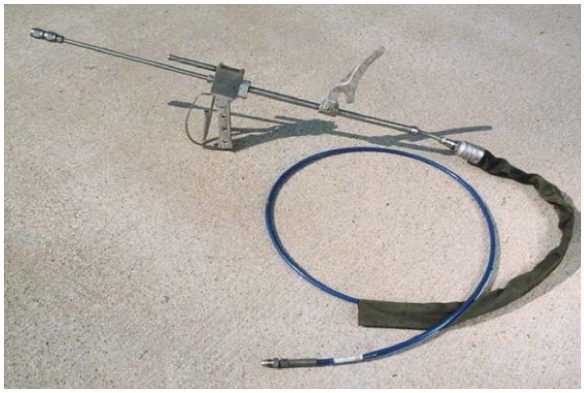


Figure 7.12 Typical Braided Hose

Before beginning work, the waterjet team should ensure that:

- The work area is properly barricaded with appropriate warning signs.
- Electrical equipment is properly covered and protected from the water.
- Electrical connections do not sit in water.
- All fittings and hoses are in good condition (not worn or damaged) and have the proper pressure rating for the working pressure to be used.
- Nozzles are open and free of obstructions.
- The complete system is flushed clean and air removed from the system before installing the nozzle.
- The dump system and all control systems are operational.
- All relevant moving equipment, such as conveyors, mixers, etc., are mechanically or electrically disabled, with appropriate lock-out provisions including the determination of confined space entry requirements.

The joint NACE No. 5/SSPC-SP 12 standard states that "all work shall be conducted in compliance with all applicable health and safety rules and environmental regulations."

As a practical matter all personnel involved with the waterjetting, washing, and cleaning operation should obtain, study, and be familiar with, all regulations and safety procedures that apply.

The waterjetting unit shall have a pressure-control relief valve (deadman valve), which immediately interrupts the flow of water when the operator releases the trigger (this is similar to the deadman valve on a typical abrasive blasting hose). The operator may use a shrouded foot valve to control the flow of water to gun.

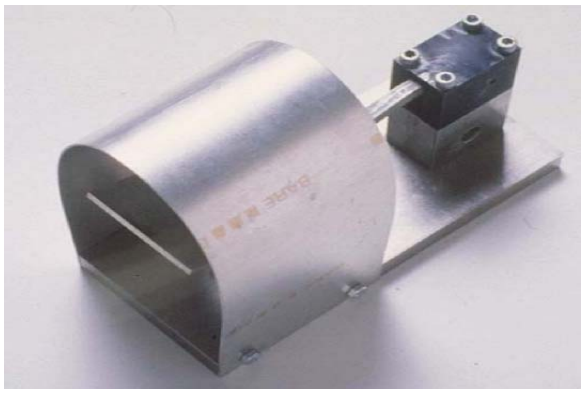


Figure 7.13 Foot Guard for Gun Trigger

Safety considerations require that only a well trained operator use the waterjetting equipment. Take the following precautions as well:

- Ensure the platform is stabilized when using swings, scaffolds, boson chairs, and similar riggings.
- Have an attendant present to monitor safety and functional conditions while the waterjetting unit is in operation.

- Ensure the operator wears the proper PPE when operating the equipment. This should include: (Figure 7.13, Figure 7.15)
  - — Head protection with full-face shield, and eye protection, such as goggles
  - — Body protection, such as waterproof or chemically resistant (if required) body suit
  - — Hand protection such as plastic-coated gloves, rubber gloves, or metal-mesh reinforced gloves
  - — Foot protection such as steel-toed boots and metatarsal guards
  - — A respirator as required, including full-face shield with supplied air

Specialized safety equipment is available for UHP waterjetting operations. One manufacturer produces a system called TurtleSkin®, which uses specialized materials to protect workers from the high water pressures of waterjetting (Figure 7.14).



Figure 7.14 TurtleSkin® Water Armor

As previously stated, injuries caused by waterjetting or water-cleaning equipment can be life-threatening. It is a good practice to require every operator to carry a medical alert card to present to medical personnel prior to any treatment. The card should have information to this effect:

"This person has been waterjetting at pressures up to 60,000 psig (414 MPa) and/or a waterjet velocity up to 2,850 ft/s (870 m/s). People injured by direct contact with high- or ultrahigh-pressure water typically experience unusual infections with microaerophilic organisms. There may be gram-negative pathogens, such as those found in sewage. Before administering treatment, the attending physician should immediately contact a local poison control center for appropriate information."

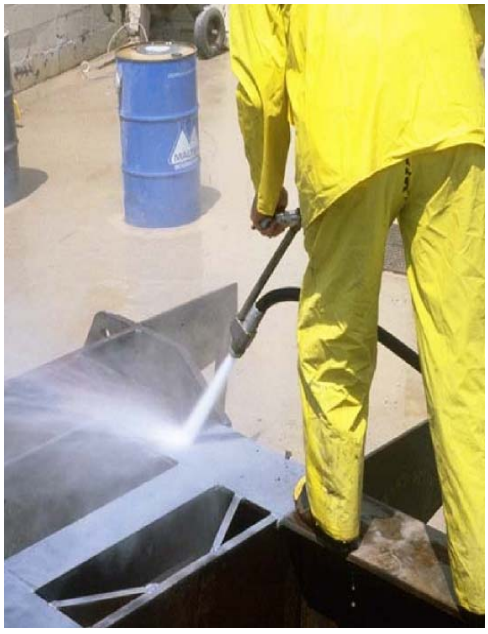


Figure 7.15 Improper PPE (notice no gloves)

7.6 Special Considerations

Some of the advantages of waterjetting over dry abrasive blasting are:

- Less dangerous for crew
- Better air quality for workers
- Respiratory requirements may be less stringent.
- No dust contamination or clean-up
- Less damaging to the environment
- Relatively cost efficient
- Requires less clean up after surface preparation

Some of the disadvantages of waterjetting over dry abrasive blasting are:

- The surface must have a prior anchor pattern or profile (waterjetting leaves no profile)
- Equipment is very expensive to purchase
- Dangers of a breached UHP hose
- Danger of water injection into the skin or serious cuts
- Collection and disposal of the contaminated water (especially in ports when working on ship decks or hulls)
- Lack of proficient operators (however as waterjetting becomes more prevalent this issue subsides).

7.7 Inspection Concerns

Coating inspectors monitor the waterjetting operations and evaluate surface cleanliness in accordance with the descriptions set forth in the joint standards.

In addition to inspection and testing, the inspector may also be required to:

- Monitor clean-up of the waterjetting area
- Ensure that the water run-off from jetting operations is collected, treated, and/or disposed of according to applicable regulations
- Document carefully (with photographs, if necessary) each phase of the waterjetting operation

7.8 Inspection Checklist

The following is a general checklist that inspectors may find helpful during a waterjetting project:

- Attend the pre-job meeting to ask questions, clarify issues, and contribute to the understanding of the specification, tools, and the methods of operation to be used.
- Read and understand the specification.
- Become familiar with the work schedule.
- Maintain all required forms of documentation, including the weekly report.
- Get a broad understanding of equipment to be used.
- Confirm that the equipment is properly sized for the job.
- Check and verify operator qualifications if required in the specification.
- Know the surface preparation requirements for the job and become familiar with the standards.
- Inspect and document the processes on the daily report.
- Ensure the job site is cleaned up on a daily basis, or as required by the contractual documents.
- Follow all safety requirements and encourage others to do the same.
- Immediately document and report all nonconformance with safety or quality.

Key Terms Definitions

Non-Visible Contamination (NV): The presence of organic matter, soluble ion materials, and/or sulfates that remain on the substrate after cleaning that cannot be seen with the naked eye.

Visible-Surface Cleanliness (VC): The visible condition of the substrate, when viewed without magnification, after cleaning.

Waterjetting: The use of standard jetting water discharged from a nozzle at pressures of 10,000 psig (70 MPa) or greater, to prepare a surface for coating or inspection.

Study Guide

1. Specifiers must note specific requirements for both of the following per NACE No. 5/ SSPC-SP 12:

2. A general description of robotic waterjetting includes:

3. A typical waterjetting team consists of:

4. Waterjetting is effective for removing:

5. Describe two of the considerations with regards to “back thrust:”

6. To ensure a safe work place before beginning the job, the waterjet team should ensure that:

7. Waterjetting advantages include:

_____
_____
_____
_____
_____
_____

8. Disadvantages of waterjetting include:

_____
_____
_____
_____
_____
_____

Chapter 8: Interpersonal Relationship Dynamics in the Workplace

Objectives

When this module is completed, you will have knowledge and understanding of:

- Behavior basics of the Johari Window
- The six principles of motivation
- The principle profile system
- How to read a personal DISC[†1] style description
- Understand your work behavioral tendencies and develop a beginning understanding of how these styles may affect others.
- Understand, respect, appreciate, and value individual differences.
- Develop strategies for working together to increase productivity.
- Enhance your effectiveness in accomplishing tasks by improving your relationships with others.

8.1 Personal Profile System Overview

Coating inspectors should recognize the vital importance of cooperation and teamwork on a coatings project. This chapter provides some guidelines to help identify methods to improve working relationships on the job.

The fundamental purpose of this chapter is to teach you how to increase your effectiveness in working relationships so that everyone benefits.

The core of this session is a self-reporting instrument called the Personal Profile System, which helps people identify their own behavioral styles, as well as the styles of others. Over 15 million profiles have been used. This is one of the most popular and successful personal and professional development instruments in the world.

This chapter has four goals, which are:

8.1.1 Facilitator's Role

The facilitator's role is not to teach so much as to be a guide throughout this session.

8.1.2 Participant's Role

The participant's role is to:

- Participate as actively as possible
- Be nonjudgmental of others in the group
- Maintain confidentiality
- Be willing to learn

Before we get into the self-assessment of the Personal Profile System, we need to focus on some basic concepts about human behavior to keep in mind.

8.2 Behavioral Basics Johari Window

Some people, for a variety of reasons, do not disclose a lot about themselves to their co-workers. They may, for example, simply feel it is not necessary or appropriate to let their co-workers know them very well.

1. Trade name

Since much of this chapter is about self-awareness and style-awareness, it is important for us to realize that some may not feel as comfortable as others talking about themselves and their personalities in a group.

Two sociologists, Joseph Luft and Harry Ingam, developed a simple model called the Johari Window that depicts basic levels of self-awareness and awareness of others (Figure 8.1). The window is divided into four sections. The sections appear to be equal, but in reality, this is rarely the case.

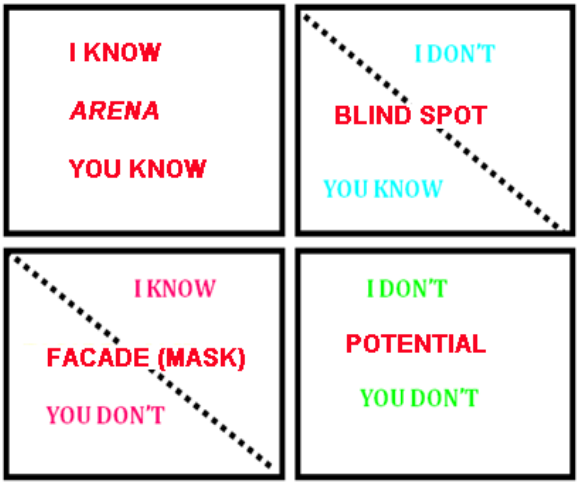


Figure 8.1 Johari Window

The upper left section is called the **Arena**. It represents the things I know about myself that you also know about me. This common knowledge that you and I know about ourselves and each other enables us to build a relationship and work together more effectively.

The lower left section is called the **Facade or Mask**. It represents things I know about myself that you do not know about me. I may be consciously concealing this information or I simply may not have disclosed it yet. If our interactions are to become more meaningful, I will need to disclose more and more information about myself. Doing this will increase the size of the Arena, which is where trust is developed and relationships deepen.

Many people find it difficult to disclose personal information. We may, for example, be shy, reserved, or concerned about losing control of a situation. But regardless of our reasons, when we finally take the initiative and begin to disclose information about ourselves, others feel safe to disclose as well. This is how relationships grow, develop, and continue.

The upper right section is called the **Blind Spot**. It represents the things you know about me, primarily from observation, that I am not aware you know. These may be things I really am aware of at a deeper level but have chosen to block out of my consciousness, or they may simply be things about me that I really have not noticed. In any case, I need to discover what you know about me if we are to develop a relationship of mutual trust.

The secret to finding out what others know about you is to encourage them to provide you with feedback. How is this accomplished?

First, you have to be receptive to **feedback**. A lot of people with **Blind Spots** tend to be so busy doing and talking that they are unaware of the effect they have on others. By taking a risk and asking questions designed to elicit feedback about the way others see you, you can find out information about yourself that others know.

Your own willingness to accept personal feedback may in turn make others more willing to accept feedback from you.

Finally, the lower right section is called **Potential** and simply represents the situation that exists when neither you nor I know each other very well. In order to work and interact effectively with each other, we need to be able to disclose information, and receive feedback about ourselves. **We need to decrease the Potential section and increase the Arena section in this model.**

From the Johari Window, you can see that self-disclosure also involves receiving and soliciting feedback from others. By completing the Personal Profile System, you are, in fact, soliciting feedback from yourself. Your responses are used to provide more complete, organized information about your natural behavioral style. This starts you on the path to enlarging your Arena and enhancing your relationships with others.

8.3 Motivating Principles

Part of learning about ourselves and others is discovering what motivates us to develop certain styles of behavior in the first place. There are **six principles of motivation**. We will look at each one in turn.

The **first motivating principle** is: *"You cannot motivate other people."* What we have to realize is that we can provide people incentives to perform better and encourage and support their efforts, but the basic motivation for their behavior must come from within. People motivate themselves.

The **second motivating principle** is: *"All people are motivated."* Research indicates that all people are motivated, no matter how they are behaving. For example, Joan is working at a slow pace. Her manager may assume Joan is lazy or "unmotivated." But she actually may be motivated by a desire to achieve perfection. If the task requires speed instead of perfection, Joan's manager needs to coach her to help her adapt her behaviors.

Another example is Tom, another employee who works at a slow pace, but for a completely different reason. Consider what other reasons or motives he could have for being a slow worker.

All of these examples support the **third motivating principle**: *"People do things for their reasons, not your reasons."* This may seem selfish, but the truth is survival is a question of self-interest.

We need to realize that even if we cannot directly motivate others, we can create an environment that encourages them to motivate themselves in ways that are desirable.

The **fourth motivating principle** is: *"A person's strength, overused, may become a limitation."* John sees his goals and drives toward them at all costs. He does not think about the affect it may have on his co-workers and associates.

The **fifth motivating principle** is: *"If I know more about you than you know about me, I can control the communication."* This brings us right back to our Johari Window, and the Mask or Facade that people erect to avoid letting people know them.

Knowledge is power, and understanding others is the key to good communication and successful and productive work relationships.

Finally, the **sixth motivating principle** is: *"If I know more about you than you know about yourself, I can control you."*

Many of us think we know ourselves pretty well, and yet we still are surprised by the way people react at times to the things we do or say. Our challenge is to recognize both our strengths and our limitations so that we remain in control of situations, particularly those situations in which we find ourselves typically uncomfortable or ineffective.

8.4 Getting Started with the Personal Profile System

8.4.1 Introducing the Personal Profile System

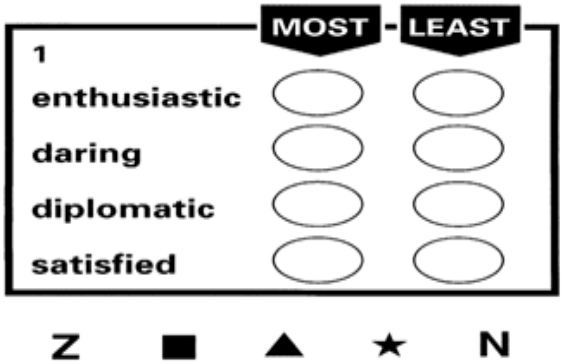
So far we have discussed being aware of how we behave, and why we behave the way we do. All of us think, feel, and act certain ways because we have developed a pattern of behavior over time. In fact, this pattern is so ingrained in most of us that we can call it a "style."

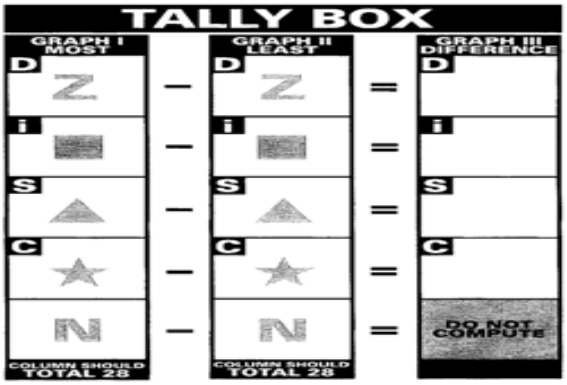
The next step is to discover how we behave — in other words, our "behavioral style" — in a work environment. This system is a simple, self-scoring instrument that helps us not only understand ourselves and others, but learn about how to work productively and harmoniously with those in our organization whose behavioral styles are different from ours.

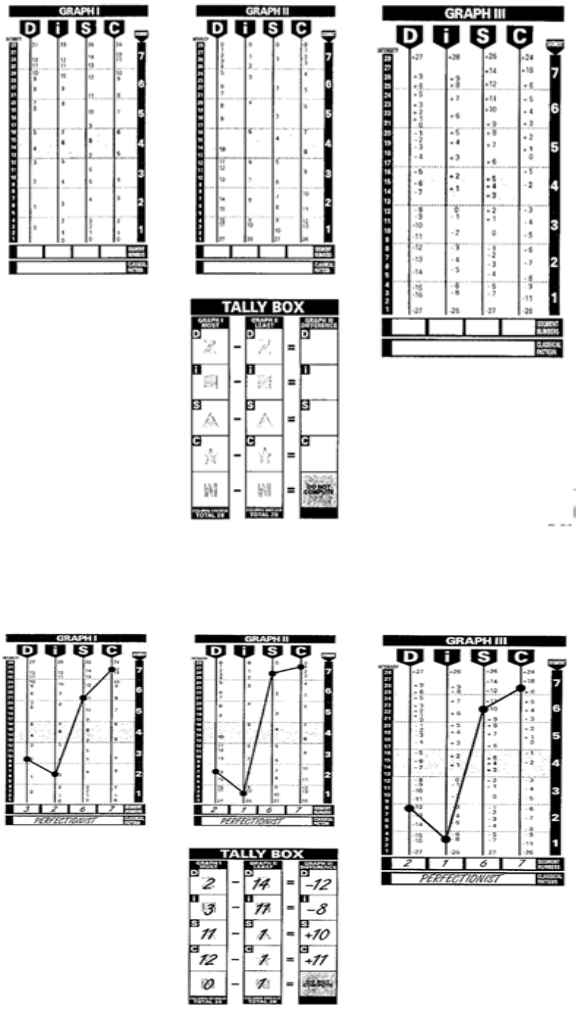
This is not a test that you can pass or fail. There is no one style or pattern that is most effective or productive in any organization. Diversity in society is not only inevitable, it is essential. We need the different temperaments and talents of artists and engineers, actors and entrepreneurs, poets and politicians. Imagine how boring it would be if we all reacted the same way to everything.

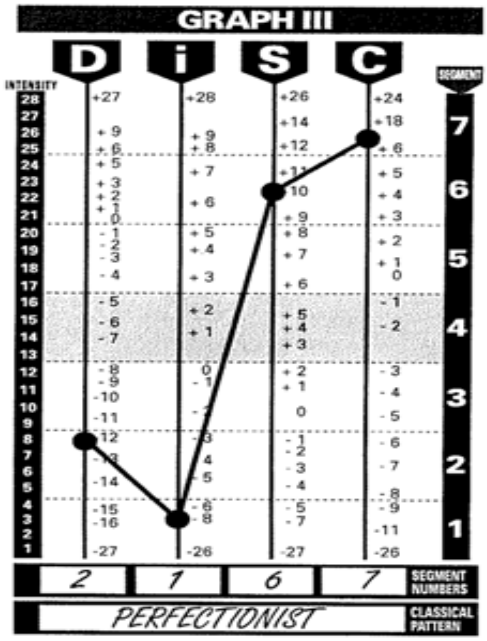
This system provides insight to the different ways we behave in work situations. Once we have identified our behavioral style, we can:

- Create a motivational environment more conducive to success
- Increase our appreciation of different work styles
- Minimize potential conflicts with others









8.5 Defining Our Personal DISC Style Description

Let us explore these four behavioral styles described on page 7 of your profile. As you can see, the four styles stand for:

- Dominance
- Influence
- Steadiness
- Conscientiousness

Take a few minutes now to read the section you circled as representing your high points on Graph III.

Underline those behaviors that you agree are natural for you. In other words, if you circled C as your highest plot point on page 7, underline all the behavioral descriptions of C behavior that you believe apply to you. Also underline the environmental descriptors that you prefer. This is your **primary behavioral style**.

When you have finished personalizing the high-point section, follow the same procedure for your second highest plot point. This is your **secondary behavioral style**. If you have a third high plot point on the graph, underline the appropriate behaviors and environmental descriptors for that behavior as well.

8.5.1 D Style Tendencies

People who display Dominance behavior shape the environment by overcoming opposition to accomplish results. They tend to get immediate results, cause action, accept challenges, make quick decisions, question the status quo, take control, manage trouble, and solve problems (Figure 8.2).

People who use **D** behavior tend to be motivated in an environment that includes prestige, challenge, power and authority, straight talk and direct answers, opportunities for advancement and individual accomplishments, freedom from direct control and supervision, new and varied activities, and a wide scope of operations.

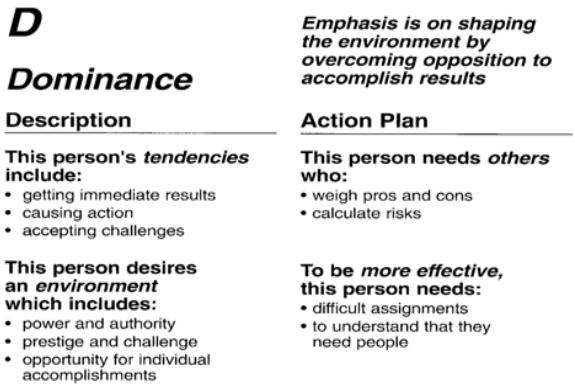


Figure 8.2 Dominance

A person who is goal-oriented will move people to action and not have much patience for small talk. People with High **D** tendencies desire change and variety and will cause change to occur in their environments. Since people with **D** behavior like to have control of the environment and the people in it, they like to take authority and use it directly (Figure 8.3).

Remember, this is an internal motivation. It is what compels people with **D** tendencies to behave the way they do. You may know people like this; you may have a High **D** style yourself. **D**'s like the challenge of getting the job done, no muss, no fuss and no chit-chat.

Fear can also motivate people with **D** tendencies, as it can motivate people with the other three behavioral tendencies. **What we observe is behavior that is designed to avoid this fear**. Think about what a person with the High **D** style would fear the most.

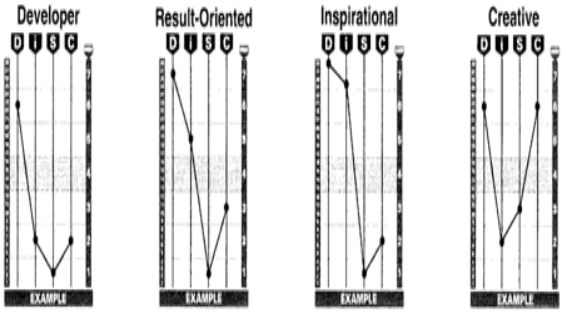


Figure 8.3 High "D" Influence

Finally, remember we previously discussed the motivating principle, *"A person's strength, overused, may become a limitation."* Consider the **D** style. Think of people you know with High **D** tendencies. Think about their strong characteristics that, when overused, can prove to be limitations. Consider the less positive aspects of their behavior.

8.5.2 I Style Tendencies

Like people with **D** behaviors, people who display **I** behaviors also enjoy shaping the environment (Figure 8.4). They do not do this by direction; however, they do it by bringing others into alliance through persuasion. In other words, people with High **I** tendencies are people-oriented. They contact people, make favorable impressions, are articulate, create motivational environments, generate enthusiasm, entertain people, and desire to help others and participate in groups.

I

Influence

Emphasis is on shaping the environment by influencing or persuading others

Description	Action Plan
This person's *tendencies* include: • contacting people • making a favorable impression • verbalizing with articulateness	**This person needs *others* who:** • concentrate on the task • seek facts
This person desires an *environment* which includes: • popularity, social recognition • public recognition of ability • freedom of expression	**To be *more effective*, this person needs:** • control of time, if D or S is low • objectivity in decision-making

Figure 8.4 Influence

People who display **I** behavior prefer environments that emphasize popularity, social recognition, public recognition of ability, group activities, democratic relationships, freedom of expression, and freedom from control and detail.

People who display High **I** behavior are socially oriented; they are often emotionally charged and love to entertain (Figure 8.5). This is because the positive motivator for High **I** behavior is social recognition. They need companionship, to be with people and to be approved of by people.

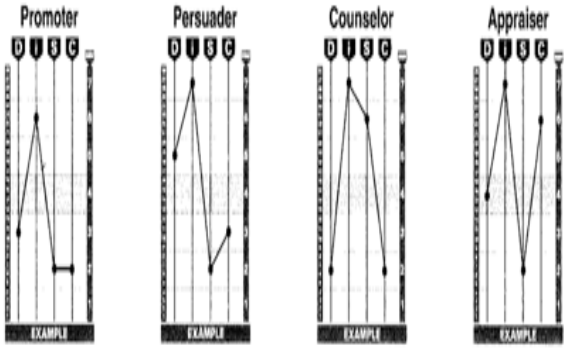


Figure 8.5 High "I" Influence

If social recognition is the positive motivation behind much **I** behavior, consider what they fear. Remember, fear is also a motivator in the sense that people behave certain ways to avoid the things they fear.

Think of those you know who take criticism of their social interactions and of their personally felt adeptness as a personal rejection of them. In their minds, they are exhibiting **I** behavior. This does not mean their behavioral style is necessarily **I**; it just means that in this circumstance they display an **I** behavior.

Consider people you know, maybe even your co-workers, who have High **I** tendencies, who are real "people persons." Consider their strengths that may prove to be limitations. Consider the less positive aspects of their behavior.

8.5.3 S Style Tendencies

S stands for Steadiness. People who display **S** behaviors are extremely predictable and reliable (Figure 8.6). They are particularly comfortable cooperating with others in carrying out tasks. People with **S** behavior demonstrate patience, show loyalty, are good listeners, and can calm excited people.

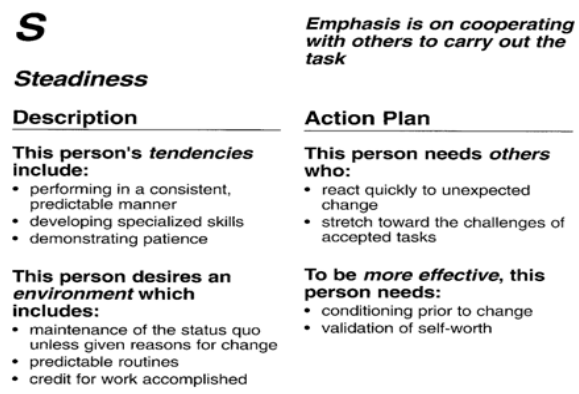


Figure 8.6 Steadiness

Like people with D tendencies, although on a different level, they are interested in consistently accomplishing tasks; because of this, they tend to concentrate on jobs, develop specialized skills, and perform accepted work patterns.

Consider the environment people with **S** behavior tend to prefer. They are motivated in safe and secure environments where:

- The status quo is the rule
- Changes are the exception
- Work does not continually infringe on home life
- Credit is given for work accomplished
- Territory is limited
- Sincere appreciation for work is provided
- The individual can identify with the group
- Traditional procedures are observed

People who display the **S** style like structured, tranquil environments with calm interactions. They are particularly uncomfortable with the unknown. They like stable settings in which proven practices are followed. A common **S** style response is likely to be: "If it works, why change it?"

Consider the basic fear of individuals with **S** tendencies. Think of people you know who have High **S** tendencies (Figure 8.7). What are some of their characteristics that prove to be limitations? Like many of the fears we have explored so far, possessiveness is just an over extension of an individual need, in this case, the person with **S** style's need for stability.

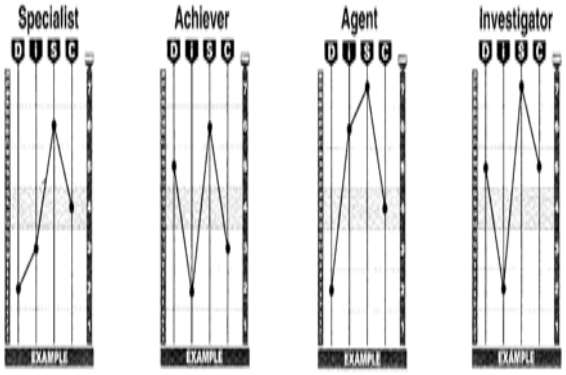


Figure 8.7 High "S" Influence

8.5.4 C Style Tendencies

C stands for Conscientiousness. People with **C** tendencies emphasize working within existing circumstances to ensure quality and accuracy (Figure 8.8). They tend to:

- Pay attention to key directives and standards
- Concentrate on details
- Think analytically
- Be diplomatic with people
- Check for accuracy
- Use subtle or indirect approaches to conflict
- Analyze performance critically

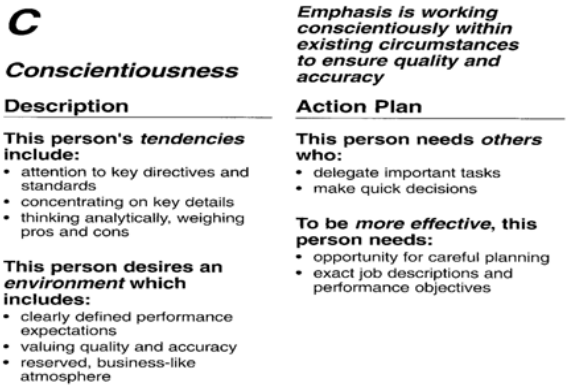


Figure 8.8 Conscientiousness

As we might expect, individuals with **C** tendencies prefer sheltered environments, those in which:

- Performance expectations are clearly defined
- Quality and accuracy are valued
- Atmosphere is reserved and business-like

A person with a High **C** style may be a natural quality-control person who tends to be precise and prize information (Figure 8.9). Rather than being oriented toward people, High **C** individuals are more task-focused.

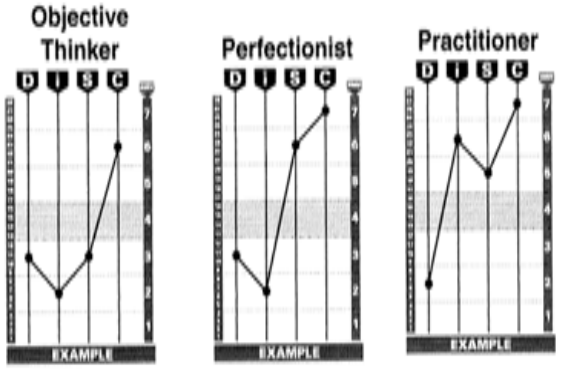


Figure 8.9 High "C" Influence

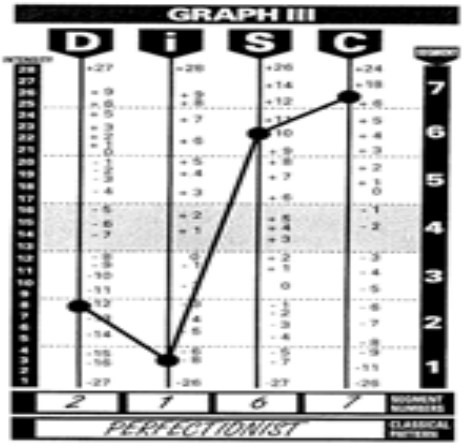


Figure 8.10 Perfectionist

Because of their precise, careful approach to things, people with High **C** tendencies are cautious with people and relationships and much more comfortable with tasks. People are often too disorderly for people with a High **C** style. They are highly disciplined, organized people, who are motivated by doing things the correct or proper way.

People with High **C** tendencies like to analyze the pros, cons, alternatives, and outcomes of things and thus remain in control of the task, process and situation. Think of people you know who have High **C** tendencies. What are some of their characteristics that prove to be limitations?

You should consider that even though we may label these characteristics "limitations" for each style, they can also be seen as opportunities for change and improvement. Limitations or overuses are characteristics or behavioral tendencies that each of us may have, given our particular style, and they can be turned into strengths if we learn how to modify them.

8.5.5 Summary

We have covered a lot of information in this chapter about our behavioral styles, tendencies, and patterns. The Personal Profile System has helped us:

- Understand our work behavioral tendencies and develop a beginning understanding of how these styles may affect others
- Understand, respect, appreciate, and value individual differences
- Understand how to enhance our effectiveness in accomplishing tasks by improving our relationships with others

Now, we are going to focus on our final goal for the seminar, which is to:

- Develop strategies for working together to increase productivity
- Develop a working plan of action to increase your effectiveness in working with people with different styles

Case Study

Plumb Creek Energy's gas platform, the Big Ten, was fabricated in a country where the use of lead-based coatings is still the norm. Unfortunately, when it arrived in its country of operations (installation), the authorities charged with its final "fit for service" approval discovered that parts of the platform were painted with lead-based coatings which is in violation of the local laws. Plumb Creek's Management was advised that unless the areas in violation (of local laws) were corrected, the installation process would not be allowed to continue.

The construction of Big Ten has already dealt a severe financial strain to the corporation due to unexpected delays and cost overruns. If the platform is not put into service within the next six (6) months, the company faces multiple legal actions that could result in tens of millions of dollars in penalties and fees.

The situation has been investigated and management, realizing the pending possible financial ramifications, has given the go ahead for repairs to meet the minimum requirements as stipulated by local laws. However, the installation date remains the same.

The coatings application contractor, ICM Painting, has been awarded the contract with I-SPY Consulting being given the inspection contract. Thomas George, the NACE Certified Coating Inspector — Level 3 who will be on the project representing I-SPY. Tony Stone, a mid-level manger with Plum Creek Energy has been appointed coatings project manager and, Donald Vincent, the OIM (Offshore Installation Manager) is responsible for the timely installation offshore.

It is four months into the painting project and all areas needing repair have been fully repainted to meet the requirements, *except* the underside of the sub-cellar deck. There is tremendous pressure on the painting crew to deliver because the platform is scheduled to sail in one week. Based on project history, it is very unlikely that ICM will be 100% complete before installation. Donald Vincent is adamant that absolutely nothing will stand in the way of a timely installation. Tony Stone, who has been stuck in his position at Plumb Creek for 20 years, realizes that this can make or break his career. He openly lends his support to Donald Vincent but does not want to upset management by putting off the remainder of the painting until after installation. He is also fully aware that Donald, as a senior manager in the operations department, is well connected with those behind the scenes.

Thomas George has been in similar situations before and understands that the primer, IOZ, has a long recoat window and that it is more cost effective to apply additional coats of paint over the primer applied to the sub-cellar deck underside than to delay the platform's ship-out date. He has a clear understanding of the coatings specification and knows that with the epoxy mid-coat and polyurethane topcoat, things can be worked out.

The owner of ICM Painting, Mr. Dave Reynolds, happens to be one of the best contractors in the area and has built his reputation on providing top-quality projects with immaculate supporting documents. A meet-

ing is called to agree on a solution. ICM's owner has no plans to suspend his work to allow for installation, because as far as he is concerned, there are too many unknowns at this time, and by all accounts, offshore can present its own set of surface preparation challenges.

Donald jumps in and states his unyielding position of timely installation regardless of the painting situation. Tony Stone sits quietly in the meeting and cannot seem to make up his mind about what direction they should go.

Thomas, on the other hand, has stated his case and informed everyone that in the end, with project planning and minor budgetary adjustments, a number of steps can be taken to ensure completion to specification with minimum impact on schedule and while meeting the coatings specification.

Summary Team Exercise:

1. Identify the personality types involved in this situation.
2. Describe what it is about the people/ materials/process that makes this a difficult situation.
3. Describe how the problem could be handled more effectively or made less difficult.
4. How would you handle the current situation based on the information presented?
5. Develop a plan of four to six action steps to take to work more effectively with the other three styles represented.
6. Select a team member to make a 5- to 10-minute presentation on your findings.

Word	Alternate words	Definition (person who .....)
accommodating	helpful	is willing to adjust or change when requested, or to be helpful
accurate	factual, correct	wants to be correct, checks all the facts
active	energetic, dynamic	rarely rests
adaptable	versatile, adjustable	can accept change
adeptness	competence, proficiency	possesses many skills
admirable	commendable, praiseworthy	is admired by colleagues
adventurous (adventuresome)	enterprising, questioning	willing to try new experiences, perhaps take risks
affable	friendly, easy-going, amiable	is a good companion
aggressive	assertive, pushy, determined	invites conflict
agreeable	amiable, friendly, nice	is co-operative, willing to agree
alert	attentive, vigilant, watchful	is wide awake and is wary
aloof	detached, distant	difficult to communicate with
amiable	friendly, pleasant, likeable	good company
analytical	logical, rational, systematic	considers the facts and seeks a solution
animated	active, energized, lively	is demonstrative, has lively body-language
antagonism	conflict, hostility, discord	actively causes contention
appealing	attractive, pleasant	likeable
arbitrary	impulsive, subjective, erratic	is not open to ideas other than own
argumentative	quarrelsome, combative	cannot see others viewpoint
assertive	forceful, confident, domineering, outspoken	pushes his or her own ideas forward
attractive	appealing, pleasant, enjoyable	attracts others
belligerent	contentious, truculent, aggressive	usually engages in conflict or aggressive behavior
bold	brave, daring, fearless	willing to take risks, make decisions
brave	unafraid, fearless, courageous	is willing to take chances
calculated risk taker	balanced activist, logical, analytical adventurer	willing to take risks, but studies options before making decisions
calm	tranquil, not agitated	is impassive, serene
captivating	charming, influential, charismatic	able to command attention
careful	cautious, takes care	attentive to detail, avoids mistakes
cautious	wary, careful	does not wish to take risks
change-oriented	likes change, seeks new experience	does not want to be in a rut and likes challenge of new things
charming	delightful, fascinating	pleasing to others
cheerful	happy, lighthearted, optimistic	sees each day as a new beginning
cognitive	aware, alert, recognizes issues	can know or perceive action from emotion
collaboration	cooperation, united effort	is willing to work with others for the common good
companionable	friendly,	enjoys company, likes fellowship with associates
competitive	aggressive, ambitious,	compares actions and achievements with other people and wants to win
complacent	indifferent, apathetic, nonchalant	is satisfied with own ideas, is not willing to make an effort
compliant	yielding, agreeable	complies with demands or requests
condescending	disdainful, patronizing	feels others are beneath them, but will tolerate them
confident	assured, secure, certain	is there own person in thinking and acting.
conscientious	painstaking, fastidious, meticulous, detailed	takes care in every detail
conservative	traditional, orthodox, moderate	likes the existing order of things

Word	Alternate words	Definition (person who .....)
considerate	kind, thoughtful, polite	thinks of other people, is aware of other's needs
contented	satisfied, comfortable	is satisfied with things as they are
controlled	reserved, regulated, managed, suppresses emotions	can regulate and direct
conventional	regular, standard, prefers customary approach	lacks originality or spontaneity
convincing	persuasive, reassuring, can cause others to agree or believe	has credibility
co-operative	agreeable, willing	willing to work together with others
cordial	friendly, congenial	has sincerity of feeling and warmth
courteous	polite, refined, gracious	has considerate regard for others
critical	crucial, important, momentous	gives careful precise evaluations
cultured	learned, cultivated	is refined in morals, mind, and taste
daring	bold, brave, fearless, courageous	willing to take risks, try new ideas
decisive	conclusive, definite	makes decisions readily
defiant	bold, insolent, rebellious	disregards authority and opposition
deliberate	calculated, considered, studied	thinks and considers carefully
demanding	insistent, exacting	asks boldly and authoritatively
demeanor	behavior, conduct	acts in a proper and suitable manner
dependent	helpless, reliant, vulnerable	is subject to outside control
determined	resolved, unwavering	has a fixed purpose
devout	dedicated, religious	is heartfelt and sincere
diligent	hard-working, industrious	shows perseverance in actions
diplomatic	tactful, suave	is skillful in dealing with people
direct	blunt, candid, frank, plain	to the point
discontented	dissatisfied, unhappy	is restless, uneasy in mind
discriminating	discerning, fastidious	can draw clear distinctions
dispassionate	calmly, objective	will be impartial and unbiased
dissension	difference of opinion	might be dissatisfied or angry
dominant	commanding, controlling	has power
domineering	taking control	demands control, uses power
eager	impatient, anxious, ready for action	shows enthusiasm or interest
easy-going	relaxed, care-free	does not get upset easily, is easy to please
easily led	no strong ideas	can be manipulated
egocentric	self-centered	has strong personality drive
emotional	impulsive	reacts with strong feelings
empathy	sympathetic	can understand without experiencing
enthusiastic	strongly attached to a cause, excited	has keen, animated interest in something particular
evasive	not direct or frank	avoids ready perception or understanding
even-tempered	calm	not excitable, slow to become angry
expressive	demonstrative, animated, flamboyant	shares ideas and thoughts freely
extroverted	out going, socializer	likes attention, likes to be seen
fact-finder	reality check	collects information correctly
factual	literal, exact	accepts only truth
fault-finding	critical, carping	is dissatisfied and finds fault
fearful	apprehensive, afraid	is filled with uneasiness
fidgety	nervous, restless	cannot sit or stand still for long

Word	Alternate words	Definition (person who .....)
firm	strong, unyielding	takes a strong view, willing to be strong
force of character	mentally strong	imposes ones opinion on someone
forceful	powerful, commanding	demands attention
friendly	showing interest and goodwill, open, cheerful	well disposed, not antagonistic is also helpful
frustrated by status quo	impatient, upset	cannot easily accept established order
fussy	finicky, particular, hard to please	wants all the details to be correct, everything to be neat and tidy
generous	unselfish, charitable	willing to share
gentle	tender, kind	refined, not harsh or rough
good-mixer	congenial, sociable	likes to be with other people
good-natured	amiable, having a pleasant, friendly disposition	others like to be associated with
gregarious	sociable	enjoys the company of others
harmonious	compatible, complimentary	shows agreement in views, feelings
helpful	kind	willing to help
high standards	yardsticks	expects others to live by own actions
high-spirited	energetic	full of energy, possibly nervous
humble	modest, unassuming	not proud
impartial	neutral, not biased	does not show any preference
impatient	lacking patience, overactive	will not wait, acts quickly
impetuous	reckless, headlong	acts on sudden impulse without forethought
impulsive	spontaneous, acts suddenly, unpredictable	acts on impulse, will make a decision and act on it very quickly and perhaps unpredictably
inactive	idle, indolent	has no desire for action
independent	self-reliant	willing to act alone, may prefer to act alone
individualistic	independent	can be self interested, no regard for others
influential	powerful, effective	wields a greater control
inquisitive	curious, searching	asks questions, wants to know the issues and facts
insistent	firm, determined	persists, will not be deflected
inspiring	encouraging, motivating	influences others
insightful	intuitive	able to see into a situation
intimidation	scare, make timid	makes others fearful by whatever means
introspective	reflective, thinker	looks inward, thinks deeply
introverted	inward looking	focuses on themselves, possibly shy
irrational	absurd, senseless	acts contrary to reason
jovial	genial, playful, humorous	makes many jokes, has good humor
joyful	happy, carefree, full of joy	has contentment and satisfaction
kind	sympathetic, nice, helpful	friendly, particularly when sympathy is needed
lenient	merciful,	is not harsh or severe when judging others
light-hearted	care-free, cheerful	not too serious
logical	wise, rational, sound	conforms to the laws of logic
loyal	dependable, reliable	faithful to friends or to the company, can be relied on
magnetic	charismatic	has ability to attract others
manipulative	skillful	can handle ideas and people shrewdly
mature	fully developed	is highly developed intellect
mild	amiable-kind	gentle and moderate in actions
mobile	movable-free flowing	can move easily from one thing to another
moderate	not extreme	avoids extremes, takes middle road

Word	Alternate words	Definition (person who .....)
modest	self-effacing, not pretentious	not boastful, plays down their own achievements
neighborly	friendly, sociable	easily makes friends
nervy	brash-impudent	is insolently assured
non-demonstrative	reserved	can not show inner feelings
nonchalant	casually indifferent	does not show interest or excitement
obedient	willing to follow orders	will obey orders or instructions
obliging	helpful	ready to help or respond
observant	watchful	sees details
observing	looking at, watching	spectator
obstinate	unyielding, stubborn	is fixed in ones purpose or opinion
open-minded	reasonable, receptive	is free from prejudiced conclusions
opinionated	close minded	obstinately attached to ones own views
optimistic	positive, bright outlook	sees the good side of any situation
original	creative, inventive	has new ideas
outgoing	friendly, sociable, open	joins in with the crowd, shares themselves
outspoken	speaks out, expresses opinion freely, bold speaker	can be very candid, gives opinions frankly
own person	confident	does not need ego satisfaction
passive	quiet, inactive	submits without resistance
patient	persevering, tolerant	has patience, can wait for results
peaceful	undisturbed	can act without hostile actions
perceptive	observant, aware	can see and recognize more detail
perfectionist	idealistic, flawless	sets high goals for self and others
persistent	unrelenting	keeps trying, will not give in
persuasive	convincing	has the ability to make you believe or agree
pessimistic	gloomy, cynical	takes a dark view of anything
pioneering	original, adventurous	willing to try something new, test new ideas
playful	frisky	likes to play or make a joke
poised	confident, polished, gracious	acts with superior confidence
polished	slick, practiced	has great style
popular	likeable	liked by many people
positive	out-going, not negative	always looks on the bright side of life
possessive	selfish	wants to dominate physically or emotionally
precise	accurate, specific	likes to have exact descriptions and definitions
predictable	consistent, unchangeable	actions can be anticipated because they rarely change
prerogatives	rights, automatic choices	demands rights hereditary or official
private	reserved, guarded	does not easily share personal thoughts or opinions
quarrelsome	argumentative,	disagrees often, picks fights
quick	sharp, intelligent	has readiness of movement or action
quiet	serene, calm	is modest, not showy
realistic	practical, down to earth	likes factual not theoretical ideas
rebellious	resentful	resists allocated duties, fights against the status quo
receptive	open minded, amenable, flexible, perceptive	is willing to listen, responds well to suggestions or new ideas
refined	cultured	behaves well, has good manners
reflective	thoughtful	gives careful consideration and thought
relaxed	at ease-unperturbed	is less formal or strict
reserved	restrained	hides or does not share emotions
resigned	submissive	reconciles oneself to the inevitable

Word	Alternate words	Definition (person who .....)
respectful	deferential	shows respect to others
responsive	reactive, supportive	quick to provide answers, act in support
restless	uneasy, not relaxed	does not rest, seeks change, needs activity
restrained	cautious	is able to hold back from quick action
reticent	silent, reserved	reluctant to speak out,
retiring	humble, unassuming	does not need social activity
ridicule	taunt – deride	makes fun at actions of another
rigid	fixed, unbending	does not easily accept change or new ideas
risk-taker (see also calculated risk-taker)	gambler	takes risks
sarcastic	mocking – scornful	uses words to conceal own failings
satisfied	contented, pleased, have wishes fulfilled	is free from doubt of anxiety, well pleased with lot in life
self-reliant	self-contained, confident	able to trust their own judgement, not dependant on others
self-assured	confident	sure of themselves
self-conscious	shy, self-aware	not confident
self-critical	harsh, judgmental (to self)	finds fault with own achievements
self-disclosure	expose ones actions	can tell of ones faults without worry
self-effacing	modest	own achievements
self-promoting	ambitious	wants to work in behalf of oneself
self-reliant	resourceful	does not need others judgements
self-righteous	formality, hypocrisy	feels morally right in own actions
sensitive	touchy	easily offended
serene	calm, regal, peaceful	not troubled, able to live without worry
sociable	gregarious, companionable	enjoys the company of others, likes to be part of a crowd
soft-spoken	mild, quiet	speaks softly
spontaneous	unrestrained	acts on own impulse
stable	steadfast	is not easily moved, shaken, overthrown
stimulating	exciting, encouraging	provides new ideas, promotes enthusiasm and new thinking
strong-willed	determined	has confidence in their own ideas and abilities, willing to push forward with projects
stubborn	unyielding, strong-willed	will not change their mind
submissive	yielding	does not resist, gives in
sulky	ill-humored – cross	is dismal and gloomy
suspicious	distrustful – skeptical	imagines something wrong without proof
sweet	agreeable, pleasant	Is gentle, pleasing and kind
sympathetic	understanding, in agreement with	is responsive to others' moods or opinions
systematic	logical, organized	follows a logical sequence in their work activities
tactful	diplomatic, discreet, inoffensive, polite	careful with words
tactless	not possessing tact, indiscrete	not careful with words
talkative	talks often, likes to talk	likes to share ones own thoughts
team-person	colleague	feels secure working with others
tenacity	constancy, persistent	holds strong opinions and rights
thorough	carry to completion, detailed	remembers all the details, misses nothing
Timid	shy, hesitant	lacking in self-confidence, may be frightened
tolerant	lenient, liberal	is willing to accept beliefs and views even if

Word	Alternate words	Definition (person who .....)
		different
trusting	confidence	relies on integrity of others
unassuming	modest, reserved	is not demanding, does not proclaim own achievements
unconquerable	proud, unyielding	is resistant to criticism
unobtrusive	modest, shy, timid	will not force opinions others without request
unsure	doubtful, uncertain	cannot be definite on some ideas
verbalize	use words	expresses oneself with words
vigorous	forceful, powerful	is energetic
weighs pros and cons	open minded sees both sides	does not take action before all avenues are considered
well-disciplined	controlled, behaves well	will comply with rules and regulations
will power	self-control	controls purpose over impulse
willing	ready to act, open	ready to contribute or help, open to suggestion
withdrawn	reserved, retiring	is unsociable, mentally detached
worrisome	irksome, annoying	sees the negative in a situation

Chapter 9: Safety Awareness

Objectives

When this module is complete, you will have knowledge and understanding of:

- Thermal spray safety
- Electrostatic spray safety
- Hot dip galvanizing safety
- Polyester coating materials safety

Disclaimer

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It is the responsibility of each person to be aware of current local, state, and federal regulations. This course is not intended to provide comprehensive coverage of regulations.

9.1 Introduction

CIP Level 1 presented basic safety information. This chapter discusses information on safety issues particular to advanced and specialized coatings.

The Occupational Safety and Health Administration (OSHA) and other similar regulatory agencies around the world are charged with enforcing worker and workplace safety. This includes the occupational safety issues in the protective coatings industry. Coatings inspectors have responsibilities in ensuring the same. Inspectors are a valuable part of a team and actively help maintain a workplace free from recognized hazards that cause serious injuries or can cause death.

"Safety First" is the battle cry for worker safety worldwide. All over the world, work sites have signs that celebrate "days since last accident" or the number of "injury-free hours," etc. Some owners have gone further and have site specific safety requirements as well as the general guidelines and regulations. Many owners have specific safety precautions required for certain application techniques and/or equipment.

While NACE International cautions inspectors against undertaking the safety officer's responsibilities, this should not be perceived as telling the inspector to avoid or ignore work place safety issues. CIP Level 1 discussed hazards and safety precautions associated with common application processes such as conventional spray, airless spray, and plural component spray.

Some of the most common hazards associated with specialized application techniques are (Figure 9.1):

- Fumes and dust inhalation
- Electrical shocks
- Burns
- Falling objects
- Falling painters
- Explosions
- Environmental contamination

In most cases, situational awareness can greatly reduce risks to the workers and the inspector in the immediate area of operation.

Too often, controls set up to ensure operator safety are ignored for faster production. Unfortunately, coatings inspectors can be influenced in these situations, not because of lack of knowledge, but rather a lack of situational awareness. Follow a few safety rules and stay conscious of potential hazards to help ensure operator and inspector safety.

The following are some of the specialized application processes and product hazards for which safety precautions are necessary when working near them.



Figure 9.1 Safety

9.2 Thermal Spray Safety

Thermal spray equipment is normally operated only in special enclosures designed to reduce noise levels and extract fumes. Thermal spray is no more or less dangerous than any other industrial equipment. Knowing the safety issues with an established set of standard operating procedures and checklists helps ensure a safe operation.

Although the OSHA standard for nonionizing radiation restricts electromagnetic radiation to only that portion of the spectrum defined as radio frequency, **thermal spray systems produce UV light, which is defined as nonionizing radiation.** Safety rules applicable to thermal spray are in OSHA standard Subpart Q — Welding, Cutting, and Brazing of 29CFR 1910.

Flame spray processes produce intense, bright flames that can have a peak temperature in excess of 5,612° F (3,100° C). Two-wire electric arc thermal spray systems produce nonionizing radiation in the electromagnetic spectrum region of 320 to 280 nanometers (nm), also called the UV-B or erythemal region. Plasma systems with much brighter arc intensity operate between 280 and 220 nm, also called the UV-C region. Plasma systems operating in this range also generate ozone. The cornea of the eye absorbs the UV from these regions easily, and can lead to a condition called **flash burn** after prolonged exposure.

The severity of flash burn depends on the duration of exposure, UV wavelengths, and the energy level at which the luminance and radiance are produced during the process. Exposure can damage eyes without any evidence or discomfort. UV from thermal spray processes can affect exposed skin, causing sunburn, tanning, and changes in skin cell growth. Repeated exposure to UV may decrease skin elasticity. The skin looks prematurely aged and can lead to a higher risk of skin cancer (Figure 9.2).

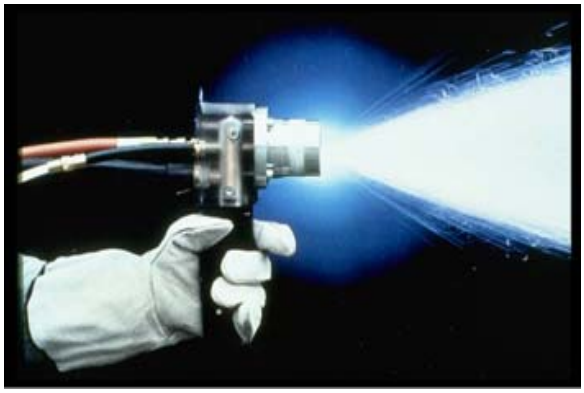


Figure 9.2 Thermal Spray Safety

It is important to install UV dark glass or shades over the windows of spray booths and enclosures. If this is not possible, operators and others in the area should wear No. 6 green welding goggles. They also should place welding screens around open spray areas and never allow the themselves or others to view the plume of a spray gun without adequate eye protection (Figure 9.3).



Figure 9.3 Thermal Spray Safety

9.2.1 Fumes and Dust

The thermal spray process atomizes molten metals, creating dust and fumes that can be dangerous to the operator and those in the immediate vicinity. Engineering controls such as dust collectors, ventilation, and air makeup units are necessary to provide good spray coatings and to protect the operator's health and safety.

All finely divided metal particles have the potential to ignite, so do not allow them to accumulate as dust in the spray environment. Materials such as aluminum, zinc, and other base metals may react with water to produce hydrogen, an explosive gas.

Other sprayed materials are also hazardous. For example, nickel and chromium are suspected carcinogens. Fumes from bronze, zinc, and copper alloys are unpleasant to smell and may cause a fever-type reaction known as brass chills.

Where engineering controls and good ventilation are not available, use a supplied-air, positive-pressure, or SCBA, respirator. If engineering controls and good ventilation are available, use a negative-pressure half-mask respirator equipped with OV/P-100 filters as a minimum. OV stands for organic vapor; the P stands for oilproof, and the 100 stands for 99.97 percent efficient against solid or liquid particles, including oil-based particles (Figure 9.4).



Figure 9.4 Fumes and Dust

These are HEPA-class filters approved for protection against dust, fumes, and mists

that have a time-weighted average of less than 2 million particles per cubic foot, or 0.05 milligram per cubic meter. These filters generally are color-coded magenta and gray with a black National Institute of Occupational Safety and Health (NIOSH) label. Filters whose elements are encased in a plastic or metal container offer more protection against the open flames and sparks generated by thermal spray processes than low-profile filters with cloth or paper exteriors. If low-profile filters are used, install a spark shield over the element.

Thermal spray equipment generally operates at high air pressures. Some commonsense safety practices for operators include:

- Use hoses rated for high pressure
- Never clean powder off equipment or clean spray cubicles with compressed air
- Do not use compressed air to clean clothing
- Do not supply plant compressed air to a breathing apparatus
- Reduce compressed air to less than 30 pounds per square inch (PSI) for cleaning purposes; use only with effective chip guarding and personal protective equipment (see 29CFR 1910.242)

Thermal spray processes use many different industrial gases, including acetylene, argon, propylene, helium, hydrogen, kerosene, and oxygen (see Subpart H — Hazardous Materials of Part 1910 OSHA standards). Prevent gas leakage, and isolate oxygen and fuel gas supplies when not in use.

Industrial gases are under pressure; operators should never work on a pressurized system. If the operator finds a leak, he should close the tank valve, blow down the system by venting to a safe place, and then repair the leak. Always use spark proof tools and explosion proof equipment, ground all equipment, and only use with adequate ventilation.

It also is important for operators to read applicable MSDSs before using gases or materials, and pressurize and leak-check any repairs to a gas line before operating the equipment.

9.3 Electrostatic Spray Safety

Electrostatic paint spray systems operate at high voltages (30 to 150 kV). Hence, worker safety is a **major** concern. Ground all items in the work area, including the operators, the paint booth, the application equipment (unless applying conductive coatings), and the conveyors. Remove ungrounded items from the work area. Workers should never wear rubber- or corked-soled shoes, instead, wear special shoe-grounding devices. Using the hand-held spray guns requires adequate skin contact. Grasp the gun with bare hands or use appropriate gloves with fingertips and palms cut out.

Static discharge is a serious concern when working in a spray booth. Most operators tend to focus on metallic objects as the threats, but overlook other conductive materials such as plastics that can become statically charged during surface preparation.

A recent study conducted by the Queensland, Australia, Department of Employment and Industrial Relations, indicates electrocution and burns are the main health risk associated with using electricity in spray painting.

Make every effort to prevent static discharge before, during, and after electrostatic spray painting. Take recommended preventive measures such as: remove metal items from the body (i.e., watches), wear antistatic or conductive footwear to stop buildup of electrostatic charge, remove paint and cleaning solvent from the spray zone, and ensure that the electrostatic spraying system is operated only by trained spray personnel. A well-ventilated spray booth is also critical to safety.

9.4 Hot Dip Galvanizing Safety

Galvanizing plants are similar to fabrication shops, and have process-specific safety challenges. Be mindful of the hot items, molten zinc, and acids (generally mild) in the area, but also stay alert to work bridge cranes, monorail hoists, etc. that are part of the operations.

The most common injuries are burns from touching galvanized work before it has cooled, and smashed fingers and toes. Chemical burns are less common; prevent these by wearing eye protection and protective clothing such as long sleeved coveralls.

Burns from molten zinc splatter do occur, so stay aware of the surroundings to avert such problems. Zinc splatter is usually caused by improper preparation of the work-piece. For example, failure to properly vent tubular work to allow entrapped moisture to escape can cause an explosion when the work is immersed in molten zinc. Know the process and its dangers, as well as typical equipment and surroundings before going on site.

Since both sulfuric and hydrochloric acid are commonly used to pickle steel prior to galvanizing, inspectors need to become familiar with the health and safety risks associated with these chemicals (Figure 9.6).

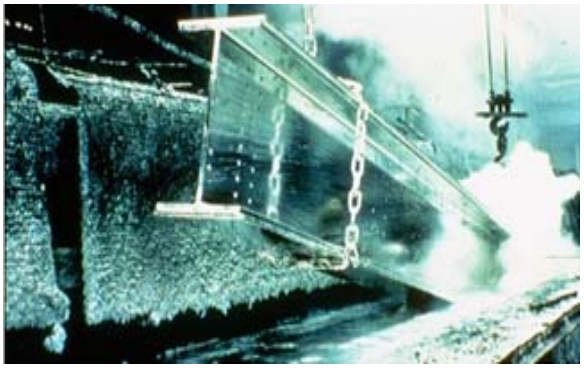


Figure 9.5 Steel Beam Leaving Bath



Figure 9.6 Acid Pickling Tank

9.5 Polyester Coating Materials

Most polyester resins contain styrene. Styrene is a solvent that may be harmful if inhaled. Reports have found repeated and prolonged occupational overexposure to solvents linked to permanent brain and nervous system damage. Extended exposure to styrene at concentrations above the recommended exposure limits may cause central nervous system depression causing dizziness, headaches, or nausea, and, if overexposure continues indefinitely, loss of consciousness, liver and kidney damage.



Figure 9.7 Applicator Wearing Proper PPE

Styrene also causes eye, skin and respiratory irritations. Inspectors and all working with this product should avoid contact with eyes, skin and clothing. Wear all of the recommended PPE, especially rubber gloves, safety eyewear, and protective clothing (Figure 9.7).

These advanced plastics are used to line storage tanks and inspectors and contractors alike come in direct contact with it at some point. **Do not** breathe or ingest vapors, spray mists, or dusts emanating from applying, sanding, grinding, or sawing polyester products. Everyone should wear an appropriate NIOSH/Mine Safety and Health Administration-approved, and properly fitted respirator during **any** use of these products until the vapors, mists, and dusts are exhausted, **unless** air monitoring demonstrates vapors, mists, and dusts are below applicable exposure limits.

The International Agency for Research on Cancer (IARC) has reclassified styrene as a Group 2B "possibly carcinogenic to humans" hazard. This new classification is not based on new health data relating to either humans or animals, but on a change in the IARC classification system. The Styrene Information and Research Center does not agree with the reclassification and has published the following statement: "Recently published studies tracing 50,000 workers exposed to high occupational levels of styrene over a period of 45 years showed no association between styrene and cancer, no increase in cancer among styrene workers (as opposed to the average among all workers), and no increase in mortality related to styrene."

Styrene is also classified by OSHA and the US Department of Transportation as a **flammable liquid**. Keep flammable polyester products away from heat, sparks, and flame. Ensure lighting and other electrical systems in the work place are vapor-proof and are protected from breakage.

Vapors from styrene may cause flash fires. Styrene vapors are heavier than air and may concentrate in the lower levels of molds and the work area. Ensure general clean air dilution or local exhaust ventilation is provided in a volume and a pattern sufficient to keep vapors well below the lower exposure limit and to keep all contaminants (vapor, mists, and dusts) below the current permissible exposure limits in the mixing, application, curing, and repair areas.

9.5.1 Isosyanates

It is possible that a protective coatings inspector may come in contact with isocyanates at some point. These compounds contain the isocyanate group (-NCO). They react with compounds containing alcohol (hydroxyl) groups to produce polyurethane

polymers, which are components of polyurethane foams, thermoplastic elastomers, spandex fibers, and polyurethane paints. Isocyanates are the raw materials that make up all polyurethane products. Some processes that may expose a person to isocyanates include: painting, foam-blowing, insulating, and the application of adhesives.

Isocyanate exposure hazards include: irritation of skin and mucous membranes, chest tightness, and difficulty breathing. Isocyanates include compounds classified as potential human carcinogens and are known to cause cancer in animals. The main effects of hazardous exposures are occupational asthma and other lung problems, as well as irritation of the eyes, nose, throat, and skin.

It is important to avoid breathing the vapor of any isocyanate, and to control limits and adhere to threshold limit values (TLVs) at all times. Isocyanate vapor also causes eye discomfort. Splashes of liquid isocyanate to the eyes cause mild to severe irritation and should be treated immediately as required by the MSDS. Handling isocyanate, particularly when drums need to be heated in order to melt the contents, must only be done by properly trained personnel. Isocyanates should not be handled in open vessels for any purpose. Although isocyanates are not particularly flammable, it is recommended that bulk storage is in a well ventilated area that is separate from the work place.

Study Guide

1. Some of the most common hazards associated with specialized applications are:

_____
_____
_____
_____
_____
_____

2. Thermal spray safety practices for operators include:

_____
_____
_____
_____

Chapter 10: Advanced Nondestructive Test Instruments

Objectives

When this module is complete, you will have knowledge and understanding of:

- Magnifiers
- Optical microscopes
- Stereo microscopes
- Digital microscopes
- pH meters
- Bench top pH meters
- Hand held pH meters
- Detection of moisture — indicators and tests
- Eddy current — DFT gauges
- Advanced data collection methods
- Ultrasonic thickness gauges

Key Terms

- Magnifiers
- Optical microscope
- Stereo microscope
- Digital microscope
- Moisture meter
- Ultrasonic thickness gauge

10.1 Introduction

In CIP Level 1, a number of basic coating inspection test instruments, used by coating inspectors worldwide, were thoroughly reviewed. This chapter introduces and demonstrates the use of more advanced nondestructive testing equipment.

The inspection tests and instruments to be discussed include:

- Magnifiers
  - — Optical microscopes
  - — Stereo microscopes
  - — Digital microscopes
- pH meters
- Blister evaluation
- Moisture Indicators/Tests
  - — Moisture meters
  - — Other moisture tests for concrete
- Eddy-current DFT gauges

10.2 Magnifiers

A closer inspection of the surface may be required to determine the exact condition of the material profile, cleanliness, etc. Magnifiers may be useful to coating inspectors. Use magnifiers to examine the surface profile, potential contamination, blisters, rust, mill scale, pinholes, and/or other surface preparation or coating defects. Remember do not use magnifiers to evaluate surface cleanliness, per NACE/SSPC standards.

There are a variety of small magnifiers available. Some fold up and can be easily carried; others have illuminated magnifying glasses that make them ideal for inspection in dark or shaded areas. These tools can be very useful to the inspector (Figure 10.1).

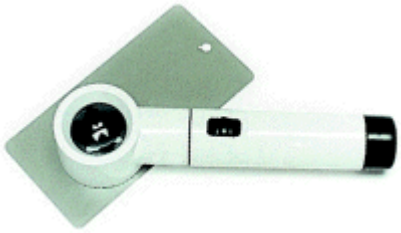


Figure 10.1 Elcometer 137 Illuminated Magnifier

10.3 Optical Microscopes

Optical microscopes use visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest and simplest microscopes. There are two basic configurations of conventional optical microscopes in use today — simple microscopes with one magnifying glass, and compound microscopes with several lenses. There are many variations available. They range from economical, simple, compact versions, to more expensive, compound versions.

There are also portable microscopes to use in field inspections. Several examples of microscopes inspectors are most likely to use are described in this section. Most of these units have some kind of battery-operated light and range in magnification from 20X to 300X (Figure 10.2).

Some are available with scales graduated in inches or millimeters and are ideal to inspect surfaces and determine crack widths. This precision is valuable; an inspector needs to evaluate the surface with a specific measurement.





Figure 10.2 Portable Surface Microscope

10.3.1 Proper Use

Always refer to the detailed operating instructions of the specific manufacturer and model. These microscopes are very easy to use. Simply hold the microscope against the surface and look through the eyepiece. The

light illuminates the surface. If there is no light provided, use a quality hand-held flashlight.

10.3.2 Calibration

The microscope does not require any field calibration since the focus can be adjusted for clearer vision. Choose an instrument with higher or lower magnification as needed. Verify scale accuracy by measuring a known length with the microscope's reticle scale.

10.3.3 Operating Parameters

Refer to the manufacturer and model-specific operating instructions for operating parameters/limits for the instrument. In general, the parameters refer to the limits of magnification.

The accuracy and precision differ from one manufacturer to another, as well as the individual model. As mentioned earlier, some microscopes are available with scales graduated in inches or millimeters.

Some common errors include not using the proper magnification or not using the appropriate lighting for a quality inspection. In general, the lower power makes it easier to focus and get the best image quality. Higher power makes it difficult to focus and limits the viewing range.

10.4 Stereo Microscope

Stereo microscopes uses two separate optical paths with two eyepieces and two objectives to provide slightly different viewing angles for the left and right eye. This view prospective produces a three-dimensional visualization adding "depth of field" to the image.

Do not confuse the stereo microscopes with compound microscopes equipped with double eyepieces or binoculars. A compound microscope allows both eyes to see the same image and binocular eyepieces provide greater viewing comfort. The image, however, is no different from that of a single monocular eyepiece microscope (Figure 10.3).



Figure 10.3 Stereo Zoom Microscope

Stereo microscopes are primarily found in lab settings and are available with magnifications up to 600X. Stereo microscopes tend to work best at lower powers because at higher powers the depth of field is severely limited. Most work with a stereo microscope is done at less than 100X.

10.4.1 Proper Use

As previously stated, since stereo microscopes are primarily used in a lab, be sure the microscope is set up on a sturdy, level surface at a comfortable working height. Some equipment may need an electrical outlet. Adjust the focus and position of the subject through the eye pieces using the multiple knobs on the instrument. For detailed operating instructions, refer to the

manufacturer and model-specific operating instructions.

10.4.2 Calibration

For checks and certification, contact the manufacturer or supplier. Periodic adjustments to lens position or other servicing maybe required. The user does normal adjustments (focusing).

10.4.3 Operating Parameters

The quality differs from one manufacturer to another and between models. As mentioned earlier, some microscope scales are graduated in millimeters and inches.

Common microscope errors may be using the wrong magnification, or not using appropriate lighting for a quality inspection. Remember, lower power makes it easier to focus and produces the best image quality. Higher power makes it difficult to focus and limits the viewing range.

10.5 Digital Microscope

A digital microscope uses optics and a charge-coupled device (CCD) camera to output a digital image to a monitor. A digital microscope differs from an optical microscope in that the user does not observe the sample directly through the eyepiece. The optical image is projected directly on the CCD camera, so the entire system is designed for a monitor image. Optics for the human eye are omitted. The magnification level is another primary difference between an optical microscope and a digital microscope (Figure 10.4, Figure 10.5).

Digital microscopes generally have both an optical zoom and a digital zoom. The image quality of an optical zoom is superior to that of a digital zoom because the actual object is magnified. The magnification for a digital microscope is determined by how many times larger the sample is reproduced on the monitor; therefore, the magnification may depend on the size of the monitor. To create a larger image, the digital microscope interpolates the pixels and fills them in based on calculations. The greater the magnification, the lower the image quality.



Figure 10.4 ProScope HR Hand-Held Digital Microscope (shown with accessories)

Some microscopes, such as the EXTECH[†1] MC108 (Figure 10.6), have a digital camera so images are viewed on the screen. It also saves the pictures for later use. Additionally, this type of microscope magnifies from 7X to 108X.

1. Trade name



Figure 10.5 MiScope® Hand-Held Digital Microscope



Figure 10.6 EXTECH MC108

10.5.1 Proper Use

As always, it is each user's responsibility to know and understand the proper use of all instruments. Always refer to the specific manufacturer and model-specific operating instructions. The next paragraphs discuss the ProScope HR[†1] Hand-Held Digital Microscope by Boldelin Technologies.

For the ProScope HR to function properly, first install the software on the computer. Once the software is installed, connect the microscope to the computer via a USB cable. The microscope is then ready for use.

There are three image capture settings:

1. Still Image – This option is located at the top-left of the main window. Use this setting to take still images, not video. It captures images in three resolutions. Click the bar to activate.
2. Video – This option is located at the top-center of the main window. Use this setting to record video. It records video in three resolutions. Click the bar to activate.
3. Time Lapse – This option is located at the top-right of the main window. Use this setting to record subjects in time lapse. It records time lapse in three resolutions and at various intervals. Click the bar to activate.

10.5.2 Calibration

Digital microscopes cannot be calibrated. Magnification can be increased using interchangeable lenses. To verify measurement systems within the microscope, measure a known standard with the microscope.

10.5.3 Operating Parameters

For specific information on the operating parameters/limits of the instrument, refer to the manufacturer and model-specific operating instructions.

Common errors that may affect the microscope's function may be incorrect installation of the microscope's software, or the USB connection to the computer. If the images are not clear, change the lens or adjust the focus.

10.6 pH Meter

As stated in CIP Level 1, the pH level is an indication of how acidic or how alkaline an aqueous solution actually is (a pH of 7.0 is neutral). The pH range of 0.0 to 7.0 is acidic, and the range from 7.0 to 14.0 is alkaline. Most people are already familiar with the pH level indicator test strips, so this section

1. Trade name

focuses on more advanced instruments to test pH levels.

10.7 Bench Top pH Meters

10.7.1 Proper Use

It is the user's responsibility to know and understand the proper use of the pH meter. Always refer to the manufacturer and model-specific operating instructions for detailed instructions; however, there are some basic operations common to the various instruments (Figure 10.7).

Place the probe of the pH meter in the aqueous solution to be tested. The probe contains two cells that produce electrical voltage in the solution. The circuitry of the meter converts this voltage to a pH reading.



Figure 10.7 Benchtop pH/Conductivity Meter

A pH meter can be used in lieu of pH paper, as described in CIP Level 1. The acidity or alkalinity of water from the surface to be coated, or water used in testing abrasives for contamination, can be determined by either method.

Many pH meters now available are multifunctional and can also measure conductivity, total dissolved solids (TDS), and temperature.

It is important to remember that manufacturers' instruments must meet all NIST standards for quality and use and be in accordance with ANSI/NCSL Z540-6 (National Calibration Standards).

10.7.2 Calibration

Regular calibration checks over the life of the instrument are required by quality management procedures (i.e., ISO 9000 and other similar standards). For checks and certification, contact the manufacturer or supplier. A pH meter is calibrated using a standard buffer solution of a known concentration at a specific temperature. Select USA or NIST buffer standards prior to calibration. (see Table 10.1).

10.7.3 Operating Parameters

Refer to the manufacturer and model-specific operating instructions for detailed information on the operating parameters/ limits of the instrument.

The accuracy, quality, and precision of pH meters differ from one manufacturer to another and between models. Most manufacturers' guidelines state the degree of accuracy and the precision (resolution) of an instrument. An example of a manufacturer's operating parameters is shown in Table 10.2.

Question readings anytime the highs and lows are outside known parameters.

Some common errors include:

- Incorrect reading due to use of the wrong buffer standard for calibration
- Incorrect reading due to damaged probes

Table 10.1: USA and NIST Buffer Standards Table

Temperature (°C)	USA Buffer					NIST Buffer				
	pH 1.68	pH 4.01	pH 7.00	pH 10.01	pH 12.45	pH 1.68	pH 4.01	pH 6.86	pH 9.18	pH 12.45
0	1.67	4.01	7.12	10.32	13.43	1.67	4.01	6.98	9.47	13.43
5	1.67	4.01	7.09	10.25	13.21	1.67	4.01	6.95	9.38	13.21
10	1.67	4.00	7.06	10.18	13.00	1.67	4.00	6.92	9.32	13.00
15	1.67	4.00	7.04	10.12	12.81	1.67	4.00	6.90	9.27	12.81
20	1.68	4.00	7.02	10.06	12.63	1.68	4.00	6.88	9.22	12.63
25	1.68	4.01	7.00	10.01	12.45	1.68	4.01	6.86	9.18	12.45
30	1.69	4.01	6.99	9.97	12.29	1.69	4.01	6.85	9.14	12.29
35	1.69	4.02	6.98	9.93	12.13	1.69	4.02	6.84	9.10	12.13
40	1.70	4.03	6.97	9.89	11.99	1.70	4.03	6.84	9.07	11.99
45	1.70	4.04	6.97	9.86	11.84	1.70	4.04	6.83	9.04	11.84
50	1.71	4.06	6.97	9.83	11.70	1.71	4.06	6.83	9.01	11.70
55		4.08	6.97	9.81			4.08	6.83	8.99	
60		4.10	6.98	9.79			4.10	6.84	8.96	
70		4.12	6.99	9.76			4.12	6.85	8.92	
80		4.16	7.00	9.74			4.16	6.86	8.89	
90		4.20	7.02	9.73			4.20	6.88	8.85	

10.8 Hand-Held pH Meters

10.8.1 Proper Use

It is the user's responsibility to know and understand the proper use of the pH meter. Always refer to the manufacturer and model-specific operating instructions for detailed instructions. Hand-held pH meters work using the same principles as the bench top meters (Figure 10.8). Hand-held meters are quick, easy, and more convenient to use because readings can be taken in the field.

Depending on needs and/or cost limitations, meters are available with a variety of capabilities. Some instruments take only individual readings but can store a number of readings to create complex reports via computer software.

Know that manufacturers' instruments must meet all NIST standards for quality and use and be in accordance with ANSI/NCSL Z540-6 (National Calibration Standards).

Table 10.2: Specification for Oakton PC150 Table

Range	pH	-2.00 to 16.00 pH
	Conductivity	0.0 to 19.99, 0 to 199.9, 0 to 1999 µS; 0 to 19.99, 0 to 199.9 mS
	TDS	0.00 to 9.99, 10.0 to 99.9, 100 to 999 ppm; 1.00 to 9.99, 10.0 to 99.9, 100 to 200 ppt
	Temperature	32 to 212°F (0 to 100°C)
Resolution	pH	0.01 pH
	Conductivity	0.01, 0.1, 1 µS; 0.01, 0.1 mS
	TDS	0.01, 0.1, 1 ppm; 0.01, 0.1, 1 ppt
	Temperature	0.1°F or °C
Accuracy	pH	±0.01 pH
	Conductivity	±1% full scale
	TDS	±1% full scale
	Temperature	±0.5°F or °C
Calibration	pH	up to 5 points (pH 1.68, 4.01, 7.00, 10.01 and 12.45)
	Conductivity	up to 5 points (one point per range)
	TDS	up to 5 points (one point per range)
	Temperature	offset in 0.1° increments
Temp compensation:		Automatic or manual
Conductivity temp coefficient:		Adjustable from 0.0 to 10% per °C
Conductivity cell constant:		Fixed at k = 1.0 cm^{-1}
Conductivity-to-TDS calibration values:		Adjustable from 0.4 to 1.0
Display:		Dual LCD shows measurement plus temperature
Power:		110 VAC
Dimensions:		9"W x 2 3/8"H x 7"D
Operating temperature:		32 to 122°F (0 to 50°C)

10.8.2 Calibration

Regular calibration checks over the life of the instrument are a requirement of quality management procedures, i.e., ISO 9000 and other similar standards. For checks and certification, contact the manufacturer or supplier. A pH meter is calibrated using a standard buffer solution of a known concentration at a specific temperature. Select USA or NIST buffer standards prior to calibration.

10.8.3 Operating Parameters

Refer to the manufacturer and model-specific operating instructions for specific information on the operating parameters/ limits of the instrument.



Figure 10.8 Hand-Held pH Meter — Oakton® pH/ mV/Temperature Basic pH 11 Meter

The accuracy and precision of pH meters differ between manufacturers and models. Most manufacturers' guidelines state the degree of accuracy and the precision (resolution) of the specific instrument.

Some common errors include:

- Incorrect reading due to use of the wrong buffer standard for calibration
- Incorrect readings due to damaged probes

10.9 Detection of Moisture — Indicators and Tests

Since moisture is one of the causes of coating failures, it is not sufficient to simply ensure that the surface is dry since the surface of the substrate is often the driest point due to evaporation.

Many substrates are coated, porous, and absorb moisture. The moisture content within the substrate needs to be measured to reduce the possibility of subsequent coating failure.

There are a number of tests and instruments available to check for and/or measure the degree of moisture content in substrates. Some of these are presented in the following sections.

10.9.1 Moisture Indicators for Wood, Plaster, and Concrete

A moisture meter indicates the degree of moisture in concrete, fiberglass or wood to a depth of 5 in. (12.5 cm), depending on the meter manufacturer and model.

An electronic, battery-operated, nondestructive moisture meter determines the moisture levels in plaster and gypsum walls, brick, concrete, and wall and roof insulation through qualitative comparative readings. It can also be used on wood. It reads wood moisture content directly as a percentage of dry weight.

Some moisture meters are hand-held with built-in electrodes; these are primarily to

measure moisture content in wood, wood by-products, and building materials such as roofing, insulation, plaster, and brick. The pins on the end of the instrument are pressed into the material. These instruments use the conductivity measurement method (Figure 10.9).

Others are non-invasive instruments to non-destructively measure moisture content. They do not use pins and do not damage the substrate (Figure 10.10). These instruments are often used to measure the degree of moisture in concrete, fiberglass, or wood.



Figure 10.9 Moisture Meter with Electrodes



Figure 10.10 Moisture Meter without Electrodes

These non-destructive gauges are very simple to use. Just turn on, press the instrument against the surface, and take the reading. Some meters are specifically calibrated and ready to use on concrete. They are available with both analogue dial and digital readouts.

10.9.2 Proper Use

Due to the variety of options available, always refer to the instrument's manufacturer and model-specific operating instructions.

Depending on model, the meter could have different settings for concrete, wood, or other substrates. Set the instrument to the proper setting for the substrate being tested.

When testing concrete, plaster, or brick, take readings using the "plaster-concrete" reference scale. Readings at the low end of the scale indicate "drier" conditions, which become progressively more "wet" as readings move toward the upper end of the scale.

Make tests on acceptable "dry" material samples. It is a good idea to use these readings as standards, or reference points, against which to compare subsequent readings.

When using gauges that operate on the principle of electrical conductivity, establish that no readings (or only very low ones) are obtained on "dry" samples. A material that, even when dry, causes the unit to read high, is in itself, conductive and makes the instrument ineffective.

10.9.3 Calibration

Regular calibration checks over the life of the gauge are a requirement of quality management procedures, i.e., ISO 9000 and

Table 10.3: Sample Specification for Elcometer 118 Surface Moisture Meter

Range - Wood 1	14% - 30% (% Moisture Content)
Range - Wood 2	15% - 30% (% Moisture Content)
Range - Plaster	8% - 20% (% Moisture Content)
Range - Concrete	5% - 14% (% Moisture Content)
Range – Linear Reference	0 - 10
Instrument Dimensions	43 x 91 x 146 mm
Resolution	1% (Not Linear Scale)
Accuracy (Using electrical resistance standards)	±2% of reading
Display	Color Coded Analogue Scale
Power	1 x 9V MN1604 PP3 Battery
Carry Case Dimensions	60 x 155 x 165mm
Instrument Weight	230g (0.5lb)

other similar standards. Typically, moisture meters are calibrated by the manufacturer. Further calibration and certification may be performed by independent labs. Some method of verification in the field is usually necessary. For checks and certifications, contact the manufacturer or supplier.

10.9.4 Operating Parameters

Refer to the manufacturer and model-specific operating instructions for detailed information on the operating parameters/ limits of the instrument.

The accuracy, quality, and precision of the moisture meters differ between manufacturers and models. Most manufacturers' guidelines state the degree of accuracy and the precision (resolution) of the specific instrument. See Table 10.3 for a sample moisture meter specification.

Always question readings if a sample that is known to be dry gives a high wet reading.

10.10 Eddy-Current DFT Gauges

Instruments based on the eddy-current principle are used to measure the Dry Film Thickness (DFT) of non-conductive films applied to conductive substrates such as aluminum, copper, brass, and stainless steel. The instrument may look exactly like the electromagnetic gauge, but it induces an eddy current in the substrate using a high frequency alternating current fed to the probe. Many manufacturers refer to eddy-current DFT gauges as N (non-ferrous) gauges (Figure 10.11).

Some instruments operate using both electromagnetic induction and eddy current. Many manufacturers refer to the equipment used to measure non-conductive coatings on

ferrous (F) substrates, using eddy-current principles (N), as either FN or FNF gauges (Ferrous/Non-Ferrous). FNF gauges typically have single probe (either separate or integral). Some gauges, however, use a different probe for each principle.

10.10.1 Proper Use

There are a wide variety of electronic gauges available; always follow the manufacturers' instructions to ensure accurate measurements are made. Although eddy-current gauges can be used to take measurements on any non-ferrous metal, the shape and size of the probe, the conductivity and surface finish of the metal substrate are significant.

Electromagnetic probes (F) cannot measure a coating over a non-ferrous (N) substrate. The eddy-current technique can give a false reading on ferrous substrates.

FNF gauges, such as the Elcometer†1 456, come with automatic substrate recognition (sometimes referred to as dual probes). These gauges first check for a magnetic field and, if it is not found, automatically switches to the eddy-current mode. These gauges generally work well; however, some compound-type metals may have just enough magnetic properties to make the probe register the metal as ferrous when in fact it is not. If readings are suspect on low grade, composite stainless steels, or nickel alloys, change the gauge to nonferrous mode to force the meter to measure in eddy-current mode. Note: linearity, and hence accuracy, on intermediate thickness values (those between the calibration points) are affected by the low conductivity of some non-ferrous metal substrates.



Figure 10.11 Eddy-Current DFT Gauges

If a user wants to measure the DFT of a material such as aluminum-pigmented mastic over a substrate like copper, do not rely on results obtained using either electromagnetic or eddy-current instruments. Instead, estimate the DFT from the WFT of the coating as applied, or, alternatively, use a paint inspection gauge (PIG) or Tooke gauge.

Standard methods for the application and performance of DFT tests using eddy-current gauges are available in ASTM B 244, ASTM D 7091-05, and ISO 2360.

1. Trade name

Users should always study and comply with the specific instructions and recommendations of the instrument manufacturer.

10.10.2 Calibration

Regular calibration over the life of the gauge is a requirement of quality management procedures, i.e., ISO 9000 and other similar standards. Certification by independent labs and some method of verification in the field is also necessary. Verify the gauge calibration on the actual substrate or on a substrate similar to that of the particular surface. Users can make calibration verification checks using thickness standards with current and traceable calibration certificates. Ensure the standards are available on the jobsite and are used to verify calibration and make day-to-day calibration adjustments.

The field calibration verification procedure is:

- Use a plastic shim of known thickness on the uncoated substrate to ensure the gauge is set up for the substrate to be measured. Choose a shim with a thickness value slightly higher than the maximum reading expected.
- Different gauges may require a minimum substrate thickness. Typically, a substrate should be a minimum of 70 mils thick.
- Make calibration verification on the prepared, uncoated surface (with the profile).
- Set instruments with multiple scales to the appropriate measuring scale.
- Gauge calibration verification procedures vary between manufactures. Verify and adjust the gauge per the manufacturer's instructions.
- For guidance purposes only, verification on smooth surfaces can be done using a shim thickness value slightly above the expected maximum DFT value of the uncoated base. Verifying on a profiled surface may require a two-point (or rough surface), so two shims are used — one with a thickness above the maximum expected DFT and the second with a thickness below the target DFT value.
- For maximum accuracy, a two-point verification should be done every time the meter is used.

Once the verification and any adjustments are made, measurements should be reasonably accurate across the scale; that is, at intermediate points between the calibration values used.

To achieve accurate results, test measurements may have to be repeated until measurements stabilize. Older instruments, in particular, may require a sequence of "zero/high/zero/high. . ." adjustments until consistent results are achieved.

10.10.3 Operating Parameters

It is the user's responsibility to know and understand the proper use of the DFT gauge. For detailed instructions, always refer to the manufacturer and model-specific operating instructions; however, there are a few basic operations that are common among the different instruments.

The accuracy and precision of the DFT gauge differs between manufacturers and models. Most manufacturers' guidelines state the degree of accuracy and the precision (resolution) of the specific instrument. In general, the gauges could have a measuring range up to 500 mils (13 mm). The most commonly used gauge has a range from 1.5 mm to 60 mil (0 to 1,500 μm) with an accuracy of ±1-3% or ±0.1mil (±1-3% or ±2.5μm). This accuracy statement applies to

the 1.5 mm to 60 mil (0 - 1,500 μm) range; however, the accuracy of gauges can be affected by many factors.

The following factors affect the accuracy of eddy-current gauge measurements:

- Magnetic and conductive properties of the substrate. Linearity and accuracy on intermediate thickness values (those between the calibration points) are affected by the low conductivity of some non-ferrous metal substrates.
- Substrate thickness. Depending on the specific instrument, the required minimum substrate thickness varies. Some instruments work over substrates as thin as a few mils.
- Edges. Generally, measurements will not be accurate when made closer than 1 in. (25 mm) to any edge. Some manufacturers have special probes to use if with a measurement requirement closer than 1 inch (25mm) to the edge.
- Curved surfaces. If this type gauge is used to measure DFT on a curved surface, hold the probe held at right angles to the surface and, if possible, make the calibration on a similar curved surface.
- Conductivity of coatings. Measurement of DFT of conductive coatings, such as aluminum pigmented coatings, almost always have problems; therefore, consult with the manufacturer for their recommendations.

The repeatability of the instrument depends on each individual instrument's manufacturer; therefore, review the manufacturer's instructions. Question the readings anytime the highs and lows are outside known parameters.

Errors that can cause inaccurate readings include:

- Failure to calibrate the gauge prior to use
- Moving the probe too quickly
- Debris on the end of the probe
- Touching the probe to a surface that is too hot
- Use of a dual gauge, but not switching to non-ferrous mode
- Damage to the probe tip, causing probe wear
- Not taking a measurement perpendicular to the surface

10.11 Advanced Data Collection Methods

Many of the advanced electronic testing instruments have the ability to store data for future use. This stored data can be transferred to a computer and other devices using various methods.

10.11.1 Equipment Connectivity

Depending on the manufacturer and model of the instrument, there are various ways to transfer stored data:

- USB – Many of the data collections devices can connect to a computer via a high speed data transfer cable. The information downloads from the device to the computer and stores for future use or, can connect directly to a printer.
- IR - Some models can print information immediately via a portable infrared (IR) printer.
- Bluetooth – Some devices are Bluetooth, which allow remote monitoring and recording. Information can be downloaded for review on mobile devices.

10.11.2 Software Systems

Some manufacturers have software available to manage stored data. The software trans-

fers data from the instrument to a computer or printer (Figure 10.12).

Some features available, depending on software manufacturer, may include the ability to:

- Create professional reports quickly
- Export reports to spreadsheets or text files, or save as PDF or JPEG files
- Copy and paste reports into other documents
- Combine reports to clearly compare different batches
- E-mail reports directly from devices
- Assign batch identification tags
- Rename batches to clearly identify the inspection batch
- Create a wide range of standard reports such as:
  - Individual measurements
  - Statistics
  - Histograms
  - Individual line or bar charts
  - Pie charts
- Customize reports
- Combine batches to compare readings or link batches together from different gauges into one comprehensive inspection file
- Quickly locate a specific file or batch

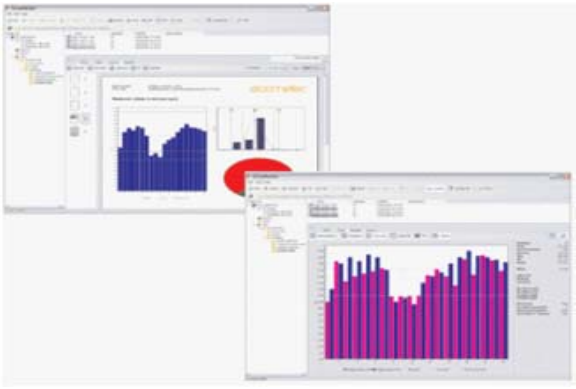


Figure 10.12 Screenshot of Elcometer ElcoMaster™ Data Management Software

10.12 Ultrasonic Thickness Gauges

The ultrasonic pulse-echo technique of ultrasonic gauges is used to measure the thickness of coatings on nonmetal substrates (plastic, wood, etc.) without damaging the coating.

The instrument probe contains an ultrasonic transducer that sends a pulse through the coating. The pulse reflects back from the substrate to the transducer, which converts it into a high-frequency electrical signal. The echo wave form is digitized and analyzed to determine coating thickness. In some instances, individual layers in a multi-layer system can be measured. Typical tolerance for this device is ±3%.

Standard methods for use and performance of this gauge are available. These instruments can be used in accordance with ASTM D 6132. This test method covers the use of ultrasonic film thickness gauges to accurately and non-destructively measure the DFT of organic coatings applied over a substrate of dissimilar material. Measurements may be made on field structures, on commercially-manufactured products, or

laboratory test specimens. These gauges can accurately measure the dry film thickness of organic coatings on concrete, wood, and wallboard substrates.

10.12.1 Calibration and Frequency

From a practical standpoint, sound velocity values do not vary greatly among the coating materials used in the concrete industry; therefore, ultrasonic coating thickness gauges usually require no adjustment to the factory calibration settings.

Verification is an accuracy check performed by the user, with known reference standards. A successful verification requires the gauge to read within the combined accuracy of the gauge and its reference standards.

10.12.2 Operating Parameters

Vibration travels through the coating until it encounters a material with different mechanical properties — typically the substrate, but perhaps a different coating layer. The vibration, partially reflected at this interface, travels back to the transducer. Meanwhile, a portion of the transmitted vibration continues to travel beyond the first interface and experiences further reflections on any material interfaces it encounters.

10.12.3 Accuracy and Precision

The accuracy of any ultrasonic measurement directly corresponds to the sound velocity of the finish being measured. Because ultrasonic instruments measure the transit time of an ultrasonic pulse, they must be calibrated for the "speed of sound" in that particular material.

10.12.4 Repeatability

Ultrasonic gauges are designed to average small irregularities in order to produce a meaningful result. On particularly rough surfaces, or substrates where individual readings may not seem repeatable, comparing a series of averaged results often provides acceptable repeatability.

10.12.5 When to Question Readings

Because a potentially large number of echoes could occur, the gauge is designed to select the maximum or "loudest" echo from which to calculate a thickness measurement. Instruments that measure individual layers in a multi-layer application also favor the loudest echoes. The user simply enters the number of layers to measure, for example three, and the gauge measures the three loudest echoes. The gauge ignores softer echoes from coating imperfections and substrate layers.

10.12.6 Common Errors and Causes

10.12.7 Operator Based

Ultrasonic testing works by sending an ultrasonic vibration into a coating using a probe (transducer) with the assistance of a couplant applied to the surface (a couplant is a liquid or gel material that maintains acoustic transmission between the transducer and the surface being tested). Know the number of coating layers applied to the substrate to avoid inaccurate readings. This is the most common operator-based failure — inputting the incorrect information into the instrument. Each instrument instruction manual addresses some of the operator errors. Be familiar with the instrument and know what to expect and how to address problems.

10.12.7.1 Equipment Based

Knowing how the coatings interface with the substrate influences the accuracy and repeatability of the ultrasonic measurement. Porosity and roughness promote adhesion, but they increase the difficulty of attaining repeatable thickness measurements using any of the ultrasonic instruments discussed. A substrate that is too rough or porous leads to irregular readings for any ultrasonic instrument. There are other errors that are instrument-based. The instrument's operational instruction manual addresses the most frequent errors. Be familiar with the issues and know how to correct them or who to contact for further instructions.

Key Terms Definitions

Digital Microscope: This device uses optics and a charge-coupled device (CCD) camera to output a digital image to a monitor.

Eddy-Current Gauge: Instruments based on the eddy-current principle are used to measure the DFT of non-conductive films applied to conductive substrates such as aluminum, copper, brass, and stainless steel.

Magnifiers: These devices are used to view surface profile, potential contamination, blisters, rust, mill scale, pinholes, and other surface preparation or coating defects.

Moisture Meter: This instrument indicates the degree of moisture in concrete, fiberglass or wood to a depth of 5 in. (12.5 cm).

Optical Microscope: This instrument uses visible light and a system of lenses to magnify images of small samples.

Stereo Microscope: This instrument uses two separate optical paths with two eyepieces and two objectives to provide slightly different viewing angles for your left and right eye.

Ultrasonic Thickness Gauge: This instrument measures the thickness of coatings on nonmetal substrates (plastic, wood, etc.) without damaging the coating.

Chapter 11: Advanced Nondestructive Test Instruments — Practice Lab

Advanced Nondestructive Test Instruments Hands-On Practical

This practice lab builds on the information learned in the previous chapter with instrument demonstrations. The instructor will show each instrument and the necessary material to perform each test. Then each student has some hands-on experience with the instruments.

Station 1: pH Meter

Equipment:

- Hand held pH meter
- USA or NIST buffer solution (for calibration)
- Test solution
- 2 beakers
- Operating instructions
- pH test strips

Assignment: Verify instrument has been calibrated. Demonstrate proper operation of the ph meter. Use the chart below to document results.

Indicate which buffer standard (USA or NIST) used: _____

Has the instrument been calibrated before use? _____

pH Meter	Temperature	Conductivity	pH
Test Solution			

pH Meter	Temperature	Conductivity	pH
Test Solution			

pH Meter	Temperature	Conductivity	pH
Test Solution			

Station 2: Moisture Meters

Equipment:

- Moisture meter with electrodes **or** moisture meter without electrodes
- Wood test subject **and/or** concrete test subject
- Operating instructions

Assignment: Use the available moisture meter to measure the moisture content of the wood and concrete test subjects. Document results in the chart below.

	Test Results	
	Wood	Concrete
Moisture with electrodes		
Moisture meter w/o electrodes		

Station 3: Eddy-current DFT Gauge

Equipment:

- Eddy-current DFT gauge (DeFelsko Positector No. 6000 N-1)
- Aluminum panel (1/3 bare metal; 1/3 primer only; 1/3 prime and topcoat)
- Package of plastic shims
- Anvil spring micrometer
- Operating instructions

Assignment:

Calibrate the gauge and measure:

- Thickness of the primer
- Thickness of the primer, plus the topcoat

Record results on worksheets below.

Worksheets:

1. Location: Primer (mils or microns)

Spots	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						

2. Location: Topcoat (mils or microns)

Spots	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						

Chapter 12: Lining and Special Coatings

Objectives

When this module is complete, you will have knowledge and understanding of:

- Linings
- Specialized coatings
- Powder coatings
- Special application equipment

Key Terms

- Lining
- Reinforced plastic
- Antifouling coating
- Ablative coating
- Cementituous
- Intumescent
- Fluidized bed
- Roto-lining
- Electrostatic spray

12.1 Introduction

In the world of industrial and marine coatings there are areas where the more common coating systems will not work. This chapter focuses on some of the specialized coatings designed for specific services as well as what a lining is and linings coating inspectors can expect to see. Linings are also covered in the next chapter, particularly non-liquid applied sheet linings such as rubber.

12.2 Linings

The coatings industry uses the word “lining” to describe a coating that is normally in immersion service (Figure 12.1). For example, the internal lining of a potable water tank, or the exterior of a structure such as a ship’s underwater hull are in immersion service. Sometimes, a coating is classified as both a lining and a coating, depending on its service environment. The most severe service for a coating is when it is used as a lining.



Figure 12.1 Linings

Linings protect the surface they are applied to, and frequently are designed to protect the cargo being carried or contained. A good example is protecting corn syrup in a rail car from picking up any odor from the car or its previous contents. Solvent certainly is not a desirable taste to have in Coca Cola[†1]! Sometimes the cargo is more valuable than the vessel containing it. For this reason, selecting the lining for a cargo-holding tank is always left up to the owner in consultation with coating manufacturers. Warrantees are

1. Trade name

used more frequently for linings than for atmospheric coating applications. When doing work under a warrantee, coating inspectors may also take direction from the organization giving the warrantee (perhaps the coating manufacturer or an insurance company).

Because of the very nature of its use, a lining often requires a more thorough inspection than an atmospheric coating. Inspectors perform holiday, adhesion, and cure tests on a tank lining that they probably would not perform on the exterior of the same tank, even if using the same coating products. A tank lining may have a different specified DFT from that specified for exterior use. The DFT requirement may be much more stringent with higher minimums or lower maximums. It is not uncommon for specifications to control the humidity and temperature to very close tolerances.

12.2.1 Types of Liquid Applied Linings

12.2.1.1 Reinforced Plastics

Standard industry terms for reinforced plastics are: fiber reinforced lining (FRL), or glass reinforced plastic (GRP), or fiberglass reinforced plastic (FRP) (Figure 12.2). All of these are *marketing* terms and essentially mean the same thing: the process of inserting a glass or other synthetic fibers (in chopped and/or mat form) into a chemically curing resin. For simplification, FRL is the term used in this course. These same materials can be made into structural members; examples are fiberglass pleasure boats, fiberglass grating, and other structural shapes. A typical industrial plant usually has a large number of fiberglass structures.



Figure 12.2 Glass-Fiber Materials

Several common resins are used in these linings; polyester, epoxy and vinyl ester are the most widely used. Each has a different generic level of resistance to chemicals, heat, impact, aging and abrasion. Individual manufacturers of these coating types may add additional features to their proprietary product (Figure 12.3).



Figure 12.3 Rolling 100% Epoxy into Glass Mat

The main feature that the reinforcing adds to the resin is strength (Figure 12.4). A reinforced coating is more resistant to movement, abrasion, and impact than a non-reinforced coating. *Polyester reinforced plastic is stronger than steel when the two weigh the same.* In other words, an FRL

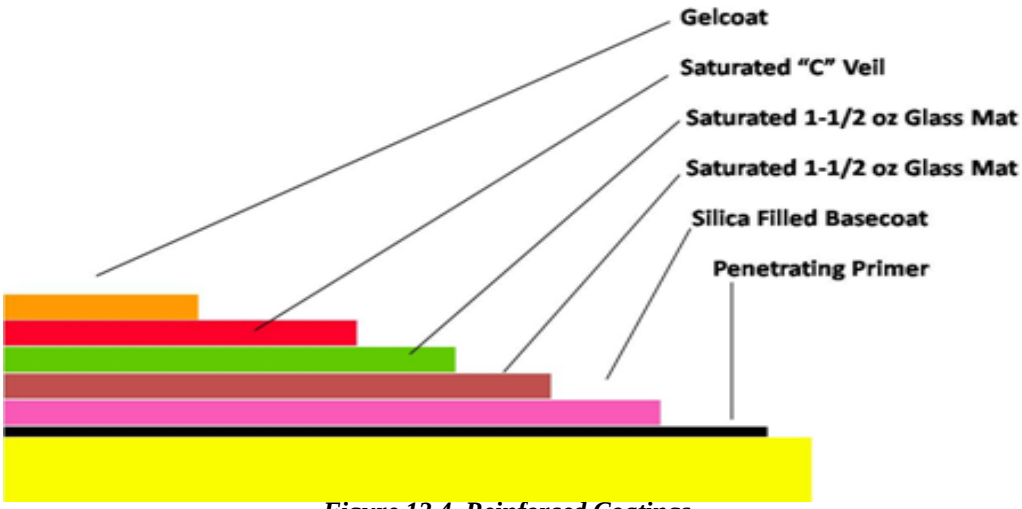


Figure 12.4 Reinforced Coatings

made into a structural member such as a beam is stronger than a steel beam that weighs the same.

The negative aspect of reinforcing a resin is that the liquid travels easily along the fiber's path, wicking the moisture, and can cause the substrate to corrode, blister, or even delaminate the system.

12.2.1.2 Conventional

Epoxies, polyurethanes, polyureas, phenolics and several other coatings are used as linings without reinforcement of any kind. They are applied in multiple coats at the film thickness required by the specification, then cured as necessary. Some, such as the phenolics, may need a baking cycle to fully cure. It is always important to ensure the lining cures; either test or wait the required time. Ventilate areas that are lined to remove solvent from the area to allow a faster cure (Figure 12.5).



Figure 12.5 Conventional Coatings

12.2.2 Lining Standards and Specifications

The following section contains a list of NACE lining standards and specifications.

NACE No. 10, SSPC PA 6, *Fiberglass Reinforced Plastic FRP Linings Applied to Bottoms of Carbon Steel Above Ground Storage Tanks*

NACE No. 11, SSPC PA 8, *Thin Film Organic Linings Applied in New Carbon Steel Process Vessels*

RP0288-2004, *Inspection of Linings on Steel and Concrete*

RP0304-2004, *Design, Installation and Operation of Thermoplastic Liners for Oilfield Pipelines*

SP0178, *Design, Fabrication, and Surface Finish Practices for Tanks and Vessels to be Lined for Immersion Service*

SP0295, *Application of a Coating System to Interior Surfaces of New and Used Rail Tank Cars*

SP0386-2007, *Application of a Coating System to Interior Surfaces of Covered Steel Hopper Railcars in Plastic Food and Chemical Service*

SP0592, 2006, *Application of a Coating System to Interior Surfaces of New and Used Rail Tank Cars in Concentrated (90 to 98%) Sulfuric Acid Service*

12.2.3 Surface Preparation, Application, and Inspection

The normal standard for surface preparation of new surfaces for linings is SA3/NACE 1/SSPC 5 White Metal Blast Cleaning. SA2.5/NACE 2/SSPC 10 Near White Metal Blast Cleaning is often specified for maintenance work. Waterjetting is only used for lining work when a surface profile already exists. However, the specification may require water washing or jetting to remove soluble contaminants followed by abrasive blasting. In some cases, it may be necessary to abrasive blast a surface, then wash it and blast it again. This cycle may repeat several times before getting an acceptable result.

During maintenance work or repainting, inspectors may be required to perform tests for soluble contaminants on the surface prior to and after initial surface preparation. The type of test depends on the service environment of the lining. Test any lining installation around salt water for soluble salts and ensure their removal; otherwise premature failure and osmotic blistering can occur. Since it is not always possible to remove all contaminants, make sure that acceptable levels and test methods are included in the project specification and agreed to by all parties prior to beginning work.

Prior to and just after surface preparation, perform a visual inspection for weld spatter and other irregularities such as temporary staging hold points, sharp edges, and other corrosion prone problems. Make sure problem areas are repaired and re-cleaned if necessary prior to application.

During application, pay particular attention to hard-to-access areas since holidays in lining work are the beginning point for coating failure and corrosion.

12.2.4 Heat Cured Linings

Some tank lining coatings require heat to cure; this can vary from 100°F to 400°F (38°C to 205°C). The temperature rise and fall is generally at a slow and measurable rate. Bring the temperature back up slowly from ambient. Hold at the max value for a determined period of time and then begin cooling at a set rate of temperature drop per time to ambient. Inspectors must confirm and document that the rate of rise and fall meets the coating manufacturer's curing chart.

12.3 Specialized Coatings

Specialized coatings serve specific limited markets, but are quite necessary. This is a sector of the industry where new or recently

modified materials are introduced frequently. Coating inspectors may work on a job where a new coating is tested in a small area or a portion of the project. This may mean performing additional tests and providing more detailed documentation than called for in the project specification. Specialized coatings may have more stringent governmental (international, national, or local) regulations. Keep up to date and knowledgeable about the required regulations. Regulations do change, so always acquire and follow the most current copy of regulations when jobs involve specialized coatings.

12.3.1 Antifouling Coating

Any roughness or projection on a ship's hull causes drag, even roughness only measuring microns! This drag requires more fuel to operate the vessel at the desired speed. The oceans contain countless organisms that seek permanent anchorage on firm structures. These organisms (biofouling) adhere to the bottom of anything placed into the ocean. Some of the smallest are known as micro fouling or slime; they find and adhere to a ship within minutes of launch. Whenever a ship comes close to a shoreline and slows to less than 4 knots, other larger organisms (macro fouling) adhere to the ship. Antifouling (AF) coatings either make the hull of the ship so distasteful that biofouling larva reject it, or the coating makes the hull so slick the larva cannot adhere. The toxins in most AF coatings are highly regulated by international treaties, as well as national and local regulations.

12.3.1.1 Local and International Regulations

EPA and State Approval in US

The US and many other countries have agencies that deal with environmental threats. It is the Environmental Protection Agency (EPA) in the US. Because traditional antifouling coatings contain a toxin and the general environment is exposed to this toxin, the EPA is involved and writes rules regarding the use of AFs. AF coatings that do not contain toxins, such as foul release coatings, are not regulated in the same way.

The most common toxin in AF coatings is copper, in the form of cuprous oxide. Copper leaches out of the coating film and may cause harm to bottom dwelling ocean life. Limits to the level of leaching have been discussed, but are not yet formalized. In addition to copper, many AFs contain a co-biocide, known as an herbicide, to retard the growth of marine grasses. The effective life of these AFs is limited.

The EPA must approve all products, in each available color. This approval can take many years of testing and very few newer AFs that contain toxins have been approved in the US since the 1990s. AF coatings that contain toxins are treated by regulatory agencies as pesticides, or herbicides, or both, depending on the toxins they contain.

In addition to seeking EPA approval, the coating manufacturers must register each AF product in each state where it will be used.

Country Approval

Not all port countries require the same intense study of AF coatings and those have given approval to the application of newer materials. These newer materials use the same copper and co-biocides, however, they use a different binder which depletes in a more controlled manner than the older ablative binder-containing materials.

IMO Regulations

In the late 1990s, the International Maritime Organization (IMO) authored a treaty banning the use of *organotin* as a biocide in AFs. Over a period of several years, the necessary majority of UN member countries signed it. It went into force in 2008; at this time nearly all ocean-going vessels have had organotin AFs either removed or sealed.

12.3.1.2 Types

There are three main types of antifouling coatings; they differ in the chemistry used to control bio-fouling (Figure 12.6, Figure 12.7).



Figure 12.6 Bio-Fouling

12.3.1.2.1 Ablative

The binder in an Ablative AF slowly dissolves in seawater, so it constantly presents a fresh layer of copper on the surface. Coating inspectors should know that during a repainting project, a leach layer of loose binder remains on the surface and must be removed by waterjetting or sweep blasting prior to over-coating.



Figure 12.7 Bio-Fouling

12.3.1.2.2 Self Smoothing

Self smoothing AFs are similar to ablative AFs; however, the rate of ablation is controlled and the surface of the coating system becomes smoother during use. They may each have a leach layer, but it is very thin and does not cause the same over-coating issues of a straight ablative. A tin-free version of this material is fairly new on world markets and several different chemistries are available. It is up to each coating inspector to learn from AF manufacturers the over-coating specifics of each product.

12.3.1.2.3 Foul Release

Foul release AFs do not contain certain biocides and work on the principle of a non-stick surface. Bio-fouling attaches to ship surfaces while it is in dock or traveling very slowly. As soon as the vessel reaches about

14 knots, the bio-fouling slides off. The negative aspect of this type of AF is that it damages easily. Also, micro-fouling in the form of slime can stay attached, leaving the hull with a rough finish and increasing drag. Coating manufacturers are working on newer versions of this type of material to reduce both of these negatives (Figure 12.8).

These systems require very specific primers and intermediate coats and application is a little more complicated than typical coating application. Ensure that workers follow all recommended products and steps during surface preparation and application.

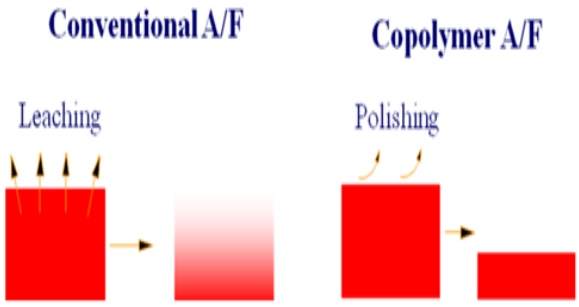


Figure 12.8 Comparison of Ablative and Self-Smoothing Coatings

12.3.1.3 Inspection Concerns

The film thickness of **each coat of AF** is **very important** to the life of the coating system, more so than with most typical coatings. Coating inspectors need to carefully measure the primer coats to ensure each coat of AF is applied at the specified thickness. In addition, any roughness in the applied coating will add drag and reduce the ship's efficiency. Watch for correct application techniques and **any** over spray on the finish coat (Figure 12.9).

12.3.1.3.1 Overcoat Times

Traditional AF coatings are single package materials that generally cure by solvent evaporation. They do not adhere well to a cured epoxy coating, which is usually an undercoat. Application must be done in a very narrow time frame, commonly within 12 hours of the final coat of epoxy. An informal test to determine if the epoxy is cured enough to overcoat, is to push your thumbnail into the coating. If this indents the surface and it is not sticky with wet paint, it may be the right time to overcoat. If the surface does not indent, then the undercoat may have cured too much, so a thin tie coat needs to be applied. If the surface is still "sticky" to the touch, it has not cured enough. Ensure the applicator waits until cure is complete before AF application. Refer to the technical data sheets for specific recoat information.



Figure 12.9 Flaking Caused by Missed Recoat Window

A few of the major AF manufacturers have a special modified epoxy that has a narrower overcoat window to use as the intermediate coat in AF systems. Read the data sheet for each coat and never assume that the "rule of thumb" of *coating while the epoxy is still soft* is always true.

12.3.1.3.2 Recoating Existing AFs

It is fairly common for a commercial vessel to dry dock needing a 20% spot blast to a commercial finish, a full sweep blast, two spot coats of epoxy on the commercially-blasted finish, and one or two full coats of AF applied. It is necessary to ensure that the spot-blasted areas are feathered in. Figure 12.10 demonstrates that it **is** possible to do, even if the contractor says it is not.



Figure 12.10 Spot and Feathered Blasted Surface

12.3.2 Fireproof Coatings

It is necessary to fireproof industrial structures to protect lives and reduce potential financial loss to owners. Industrial fireproofing materials include liquid-applied coatings and high build cementitious products. Fireproofing has two basic functions:

- Keep the fire away from living or work spaces
- Protect a building or a facility's structure from the extreme heat fires generate

The materials used to protect living and working spaces need to provide protection for 15 to 30 minutes, that is, enough time for people to escape.

The materials that protect a building or facility's structure from the extreme temperatures are heavier in nature and designed to keep steel's temperature below 1000°F (539° C) (Figure 12.11).

Fireproof coatings fall into two categories: passive, meaning they protect based on insulating the surface from the heat of a fire, or intumescent, meaning they build a thicker film when exposed to fire, thus insulating the surface.

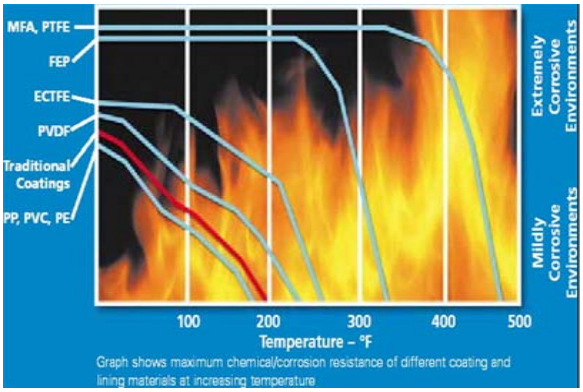


Figure 12.11 Fireproofing Resistance for Structures or Vessels

12.3.2.1 Ratings

All fireproofing materials have a fire rating, which is basically the amount of time that the material continues to protect a surface for certain types of fires. The fire ratings are directly related to the type of coating material, the application design, and the applied thickness of the material. As mentioned in the first paragraph of this section, a particular type of material, depending on its design and thickness may provide protection for as few as 15 minutes. Another material, when correctly applied, may have a rating as high as 4 hours.

When inspecting a coating project, either on an offshore oil rig or inside of a commercial ocean-going ship, IMO regulations, such as Resolution A653 (16), may govern and must be enforced.

Other federal and local regulations govern commercial building codes and cover a large variety of items in buildings, as well as the building's structure itself.

12.3.2.2 Approval Testing and Authorities

All fireproof materials should be tested and rated by a certified laboratory before use. In the US, certified laboratories include Factory Mutual and Underwriters Laboratory, as well as a number of other well respected firms. Other worldwide firms include Lloyd's Registry of Shipping and Det Norske Veritas.

The most commonly used test for industrial and marine fireproofing material is **U.L. 1709 Rapid Rise Fire Tests of Protection Materials for Structural Steel**. This test method measures the resistance of protective materials to rapid-temperature-rise fires. The method utilizes a full-scale fire exposure to evaluate the thermal resistance of a protective material applied to structural members and the protective material's ability to withstand the fire exposure. The test method also includes a small-scale fire exposure, to evaluate the ability of protective materials to withstand a variety of anticipated environmental conditions.

ASTM has over 1,000 tests concerning the fire proofing and fire resistance of materials and items. Following are just a few tests that industrial and marine coating inspectors may encounter.

ASTM E1317: *Standard Test Method for Flammability of Marine Surface Finishes*

This test method provides a means to evaluate the flammable performance of surface finish materials used to construct and outfit ships. This test method closely follows the test procedure of IMO Resolution A.653 (16).

ASTM E119 (AKA: U.L. 263, NFPA 251): *Standard Methods of Tests of Fire Resistance of Building Construction and Materials*

This test method evaluates the fire duration for different types of building construction and materials during a predetermined test exposure.

ASTM E 84-05 *Standard Test Method for Surface Burning Characteristics of Building Material*

This test method provides comparative measurements of surface flame spread, smoke density measurements, etc., for building materials under specific fire exposure conditions.

NORSOK M 501 *Surface Preparation and Protective Coatings*

Norwegian Oil Industry Association (OLF)

Relevant requirements in this standard are applicable to sprayed-on passive fire protection used in the offshore oil industry. It provides specific requirements valid for sprayed on passive fire protection.

12.3.2.3 Types

12.3.2.3.1 Cementitious

Cementitious fireproofing materials are made of lightweight cement that can be applied several inches thick. They are used in both interior and exterior applications. Concrete makes an excellent fireproofing material, but its weight can make it uneconomical in many applications. When cement

is made with lightweight additives, it does not have the compressive strength of building concrete, **but** it retains building concrete's insulation qualities.

12.3.2.3.2 Intumescent

An intumescent coating contains substances that swell or bubble up from heat exposure; they increase in volume, but decrease in density. Intumescents are typically used as passive fire protection. Industrial intumescent coatings are typically epoxy materials with additives to make them intumesce. Some intumescent coatings are made of latex emulsions.

12.3.2.4 Inspection Concerns

Coating inspectors assigned to projects that include fireproofing need to learn the requirements of that particular material; the best way is to work closely with the material manufacturer. Application is very different from thin film coating application, and in the case of cementitious materials, is similar to shotcrete application techniques. Follow the exact design shown in project drawings, and ensure applied thickness matches the thickness shown in the rating tests. Please note: some structural reinforcement may be required. Inspect edges, corners, and penetrations for conformance to the specification and drawings.

12.3.3 Fluoropolymer Coatings

First developed in 1938, fluoropolymer coatings are a family of products made from tetrafluoroethylene (TFE), which is made into polytetrafluoroethylene (PTFE), and then into various coating resins. Trade names include: Teflon®, Xylan®, Xylar®, Coraflon® and many others.

While best known for their non-stick feature, these coatings also have excellent chemical and high-temperature resistance and thus are used as linings in the chemical processing industry. They are also widely used in the commercial building industry to refinish the exteriors of large buildings.

12.3.3.1 Inspection Concerns

Fluoropolymer coatings come in powder, liquid, or sheet forms and **each requires its own inspection techniques**. Because these coatings, except the sheet form, take heat to cure, inspectors must know the heat cure cycle and ensure it is followed. Storage requirements for some of these materials are unusual, such as having to be kept at very low temperatures. It is necessary for inspectors to read and understand the product data sheets.

12.3.4 Additional Special Coatings

Because of the diversity of worldwide industry and the use of engineered materials in construction, there is a wide range of corrosion-inducing circumstances and solutions to control it. The average industrial coatings inspector does not see all conditions and products, but should know they exist.

12.3.4.1 Types

12.3.4.1.1 Thermosetting Polymers

Principally used in mining, offshore, and ocean marine applications, thermosetting polymer materials are melted and hot-spray applied to flanges, bolts, bearing housings, and other structures that have many edges and crevices. They are applied to items and locations that are hard to coat or keep a coating on. The purpose of these materials is to encapsulate the item to prevent moisture and chemicals from coming in contact with the

substrate. Make sure that all necessary areas are covered, and ensure there are no holidays. This is typically done with a visual inspection.

12.3.4.1.2 Tapes

Tapes are used in the pipeline industry to wrap and protect field joints. They are commonly self-adhesive, but some are made to heat shrink for a perfect fit. The inspector's concern is to ensure all the areas covered with the tape are adequately covered. Check the edges of the tape to ensure they adhere well.

12.3.4.1.3 Petrolatum

Pure petroleum jelly is a semi-solid mixture of hydrocarbons with a melting point usually ranging from a little below to a few degrees above 245°F (75°C). It was discovered as a by-product of drilling for oil in Pennsylvania. The critical features that make it useful in combating industrial corrosion are: it does not oxidize on exposure to the air, it is fairly impervious to chemical reagents, it is hydrophobic (repels water), and it is insoluble in water. It was first used as a skin protectant and is still available as "Vaseline."[†1]

Petrolatum is applied on surfaces by hand; it is simply smeared on the surface. Various tapes or pre-made plastic forms are available to cover it and protect it from physical abuse.

12.3.4.1.4 Underwater Coatings

Sometimes workers must apply a coating to a wet or underwater surface — this *can be done*. Specific epoxy materials can be applied to damp surfaces, some of which can also be applied to underwater surfaces. The typical procedure is to brush apply the coating (which displaces the water) so the coating then adheres. Coating inspectors (unless they are trained divers) have to inspect via camera with only an opportunity to look for holidays. Because these materials (normally solvent free), like other epoxies, are subject to temperature limitations during application. Carefully observe and document the water temperature at the application location. These materials are most often seen in marine structure maintenance work and in many industries that routinely have issues with sweating coatings. A few of these materials have acceptance for use as nuclear coatings and are used in nuclear power plants and other nuclear facilities.

12.3.4.2 Inspection Concerns

If new techniques are used on a project, find out as much as possible from the manufacturers. Contact the manufacturer of any new product to learn as much about it as possible. No matter what product is applied, or technique specified, record as much data as possible, always including the details of the coating, environmental conditions during application, surface preparation, and DFT.

12.4 Powder Coatings

Many of the commonly used generic liquid-applied coatings can be made into a powder. The powder contains the same components, but cures by baking. The two powders frequently used in the industrial and marine fields are fusion bonded epoxy and triglycidyl isocyanurate (TGIC) cured polyester.

An excellent source of information about powder coatings is the Powder Coating Institute http://www.powdercoating.org/index.php.

1. Trade name

12.4.1 Uses for Powder Coatings

Powder coatings are used in an extremely wide variety of applications — from the little red wagons children pull to parts of the Mars Rover. Any steel part that can fit in an oven can be powder coated. Many standard day-to-day items used in homes (refrigerators, washing machines, and dishwashers) and in offices (file cabinets, tables, and chairs) are powder coated since the process is highly productive. Powder coated underground gas and petroleum pipes make up one of the largest segments of the industrial and marine market. Anything that can go through an assembly line (particularly items with lots of angles) are good candidates for powder coating.

12.4.2 Powder Coatings Content

Powder coatings contain all the same components (except solvent) as liquid-applied coatings; but it is delivered to the user in powder form instead of liquid. Resins, pigments, additives, and the cure are blended together at the powder manufacturer's facility.

12.4.3 Powder Coatings Cure

Powders for coatings fall into two broad curing categories:

- **Thermoplastic**: materials that soften when heated and return to their original hardness when cooled
- **Thermosetting**: materials that harden when heated and retain their hardness when cooled

The key to the curing mechanism is the *transitional heating stage*. Once the powder is applied to a heated surface, either in a preheat or post-heat condition, the powder changes its state and temporarily resembles a liquid coating. Once cooled, it forms a homogenous film over the steel surface.

Powders pass through four distinct stages when applied to a heated surface:

1. **Flow stage**. Occurs when the particles of powder begin to flow, but are not fully liquid.
2. **Wetting stage**. Occurs when the particles of powder absorb more heat, fully liquefy, and wet the surface.
3. **Gel stage**. Occurs when the particles of the powder begin to gel, then convert into a solid.
4. **Curing stage.** Further changes take place, permitting the powder to cure completely.

The complete process — from flow stage to cure — generally takes less than three minutes, which makes this an ideal process for production-line application.

12.4.4 Generic Types of Powder

Thermoplastic materials:

- Polyvinyl chloride (PVC)
- Polypropylene
- Kynar®
- Halar®
- Polyethylene
- Teflon®

Thermosetting resins:

- Epoxy
- Urethane
- Polyester
- Acrylic

12.4.5 Powder Application Temperatures

Thermosetting powders contain partially reacted curing agents and require a heat

source to convert to a liquid state. Store powders away from **any** heat source until just before application. In warm and hot climates or during shipping in war and hot climates, store the powders in refrigerated containers.

The range of application temperatures for powder varies by manufacturer. Thermoplastic powders normally require lower application temperatures; always consult the manufacturer's data sheet for the proper temperature range.

12.4.6 Preheat

Preheat the surface or object to be coated either by a high-frequency induction coil or in a direct gas-fired oven.

12.4.7 Application Methods

Powders are applied by one of the following methods:

- Electrostatic spray
- Fluidized bed (dip method)
- Flame spray
- Roto-lining

12.4.7.1 Electrostatic Spray

The most common and efficient method to spray apply powders is using an electrostatic spray handgun (Figure 12.12). The powder is conveyed under pressure into the gun in fluidized form.

12.4.7.2 Fluidized Bed

An application method known as the fluidized bed (analogous to dipping in the liquid coatings field) was originally developed in Germany in 1953 (Figure 12.13).

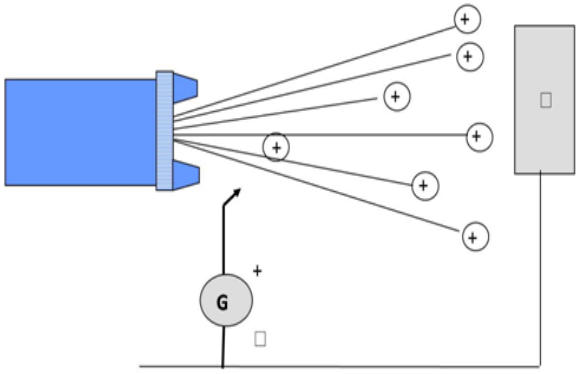


Figure 12.12 Electrostatic Spray

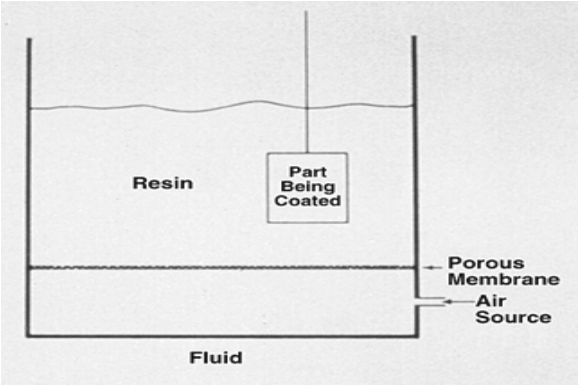


Figure 12.13 Fluidized Bed Dipping

When a finely divided stream of air passes through a powder, a solid in gas dispersion forms and behaves like a liquid. A fluidized bed is a tank with a false bottom made of porous material. Air pressure is applied from below the porous false bottom to lift the powder above it and force it into suspension.

12.4.7.3 Flame Spray

Low air pressures blow thermoplastic powder particles through a high-temperature, open-flame torch similar to an oxyacetylene blowtorch. Simultaneously, particles melt and the coating surface is heated.

12.4.7.4 Roto-lining

To roto-line, charge a pre-weighed amount of powder into a hollow mold (Figure 12.14), place the mold into a heated oven

(Figure 12.15), then rotate the mold around two axes while heating the mold and the powder. When the interior metal surface is hotter than the melting point of the powder, the powder melts on contact with the metal. Upon cooling, the powder forms a protective coating (Figure 12.16).

Examples of items that can be lined by roto-lined powder coating include: drums, carboys, storage and process vessels, pipes, pipe flanges, valves, flow meters and pumps, as well as other equipment.



Figure 12.14 Charging a Pre-Weighed Amount of Powder into a Hollow Mold



Figure 12.15 Placing a Mold into a Heated Oven

12.4.8 Inspection Concerns

Inspectors in the powder coating industry work in a relatively safe environment. Inspection criteria are similar to the liquid coating industry including the quality



Figure 12.16 The Powder Forms a Protective Coating when Cooled

of surface preparation. The requirements for surface preparation in immersion service are more critical than for atmospheric service. Ensure preparation is suitable for the powder coating and that it meets the specification requirements.

12.4.9 Inspection Checklist

Check and record:

- Ambient conditions — air and substrate temperatures, relative humidity, and dew point
- The dehumidification system — ensure it performs properly and will “hold the blast”
- Fabrication defects — such as rough welds, skip welds, pits, crevices, particularly in hard-to-reach or even inaccessible areas
- Soluble chemical salts
- Surface cleanliness
- Surface profile meets specification
- Residual abrasive dust

Carefully document each inspection item and note any potential problem areas to bring to the attention of the client for review and/or correction before coating operations proceed.

12.5 Special Application Equipment

12.5.1 Introduction

Along with the continuing development of high performance coatings there is a need for new and improved application equipment. This section discusses some of the more common specialized equipment. Keep up to date on new equipment as a member of NACE; read the monthly magazines and attend conferences where new techniques are discussed and new materials and equipment are exhibited and demonstrated.

12.5.1.1 Plural-Component Spray Systems

While plural component spray equipment is not new, it has been greatly improved in the past few years (Figure 12.17, Figure 12.18). Computerized proportioning systems have greatly improved the accuracy of the mix ratio and contractors can use the same machine with various products without have to rebuild it or change the pump legs. The machines are also much smaller and easier to maintain. A trained technician is still needed to set up and operate the equipment. Coating inspectors need to understand the ratio and heat check methods that are built into the machine.

12.5.1.2 Equipment Types

There are two basic types of plural component spray equipment: fixed- and adjustable-ratio machines. Fixed-ratio systems have two pumps that operate with a fixed throw on each leg. To change the ratio, the technician manually changes one or both of the legs (pistons) on the pump. On the variable-ratio systems, the ratio is controlled automatically by the machine (it controls the distance each piston travels in its cylinder),



Figure 12.17 Plural Component Spray System



Figure 12.18 Plural Component Spray System

thereby controlling the amount of material pushed with each movement (Figure 12.19).

Plural spray units have two types of feed mechanisms: one type that blends the components in a manifold and mixes them in an inline static mixer, and another type that mixes the components at the spray gun tip (Figure 12.20). Select the type of machine based on the pot life of the coating being sprayed. Polyureas and their hybrids, which can have only a 10 second pot life, must be

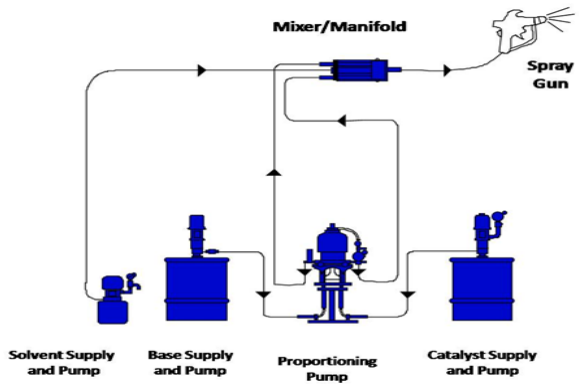


Figure 12.19 Plural Component Spray Setup

mixed just outside of the spray tip, while materials such as solvent free epoxies, with a 20 minute pot life, can be mixed in the manifold. It is important to know the correct set up of the hose connections and the necessary connections to be able to verify the system is set up properly.

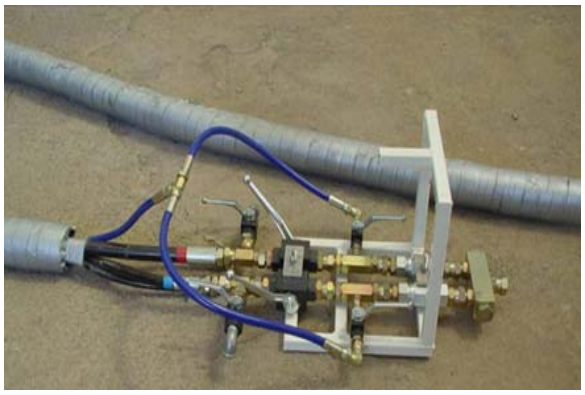


Figure 12.20 Mixing Block for Plural Component Spray Unit with Insulated Hoses

12.5.1.3 Hot-Spray Systems

Polyureas (and some other products) require temperatures of 110°F (43°C) or higher to lower the viscosity enough to make the material sprayable. A heated system uses the combination of a drum heater to preheat the product with an inline heater built into the pump mechanism to ensure the product reaches the required temperature (Figure 12.21).



Figure 12.21 Heated System with Insulated Hoses

12.5.1.3.1 Advantages and Disadvantages

Plural component spray equipment has several major advantages over single piston pumps:

- Accurate automatic material mixing
- The ability to spray apply very thick solvent-free materials without thinning
- The ability to spray materials with very short pot lives

Of course, this equipment also has disadvantages:

- The cost of the equipment is much higher than the cost of a single piston pump
- The education requirement for the mechanic is higher
- The heaters require high voltage electricity
- This type of equipment may have as many as five hot hoses attached to the gun, making the applicator's job more difficult

12.5.1.3.2 Inspection Concerns

Even though the machine controls the mix ratio, check the ratio manually at intervals during spray operations because numerous things can go wrong to cause an off-ratio situation. All modern machines have a built in method to manually check the ratio. The

usual procedure is to check at each start up and during shut down breaks. Document ratio checks to show the time and result of the test.

Also check the temperature of the material as it passes through the machine. Use either an infrared thermometer, or built in gauges. Check and document temperatures before and during spray operations.

12.5.2 Electrostatic Spray

Electrostatic spray can be used for liquid applied coatings in a manner similar to how it is used for powder coatings. However, not all coatings can be electrostatically spray applied. Coatings must be designed for electrostatic spray; the thinner is the controlling factor in the coating's ability to hold a charge. This is normally only used in shop applications for continuous coating on an assembly line. It is one of the most efficient application procedures, providing transfer efficiency of about 98%.

Electrostatic spray may be used with either conventional air spray, airless, or air-assisted airless spray equipment, with either manual or automatic settings.

The system applies an electrostatic charge to the stream of coating *at the gun itself.* This ensures that only charged materials leave the gun. Ground the item to be coated; this ensures the charged particles are attracted to its surface.

As the coating thickness builds up, it prevents loss of particle charge to the work piece. As a consequence, the outer layer of particles retain their positive charge. They repel the new positively charged particles arriving at the surface thus preventing an additional increase in thickness. This provides a very even thickness across all items being sprayed at that time. The overall thickness is controlled by the charge given to the coating.

The wrap around effect of electrostatic spray ensures full coverage of complex shapes and excellent edge coverage. In fact, an advantage of this method of application is that thickness is somewhat greater at the edges than it is on flat surfaces.

Using solvent-based coatings with electricity means a real potential for fire and explosion exists. Ground all equipment and take all safety precautions.

12.5.2.0.1 Inspection Concerns

Always follow standard coating inspection procedures, including all environmental, profile, and cleanliness specification requirements. Learn any new cleaning methods required. Since coating projects involve many areas and objects to coat, there are always some items which were manufactured on assembly lines that used chemicals to clean products. Inspectors must ensure the final part or object is clean and meets the specification's standards before coating begins, no matter what cleaning method was used. Use whatever tests are needed, including pH — the object may have been cleaned with an acid or caustic bath.

12.5.3 Centrifugal Spray for Pipe Internals

Centrifugal spray equipment uses a rapidly spinning disc, brush, or other device to atomize coatings.

Centrifugal spray equipment may be used with or without electrostatic charge (Figure

12.22). This type of equipment is used widely in lining pipes in specialized shop operations. The spray head is attached to a lance that runs through the pipe then is pulled back slowly while the material sprays.

12.5.3.1 Inspection Concerns

The inspector may need to use a camera on a lance to inspect for holidays inside of piping. Measure DFT using a long probe to check random spots inside the pipe. Carry out all other normal coating inspection steps such as environmental conditions and cleanliness. Ensure there is a system to move air through the pipes during cure if solvent-based materials are used.



Figure 12.22 Centrifugal Spray for Pipe Internals

12.5.4 Flow and Flood Coating

Flow and flood coating is the process of pumping material over the top of an item and allowing it to cover the item as it flows down the surface. Place the item in a collection pan; then hold a hose (under very little pressure) over the top and move it around as the coating pours out. The excess material is caught in the pan and re-circulated. Apply the coating until all areas are covered with the necessary film thickness. This equipment is typically custom made by a specialty contractor.

The coatings for this type of application must be specially designed, and the applicator has to be experienced in its use. The contractor modifies the viscosity by adding solvent; the final DFT of the coating depends on the viscosity.

This is an excellent method to coat items with fins such as transformers for the power industry.

12.5.4.1 Inspection Concerns

Perform and document all the normal inspection requirements, such as environmental conditions. Be aware that it is going to be difficult to perform a full visual inspection of the item for cleanliness or DFT.

Key Terms Definitions

Ablative Coating: The binder slowly dissolves in seawater, constantly presenting a fresh layer of copper on the surface.

Antifouling Coating: Coatings that make the hulls of ships so distasteful that the larva of the biofouling organisms reject it as a home, or the coatings make the hull so slick the larva cannot adhere.

Cementituous: These fireproofing materials are made of lightweight cement and can be applied several inches thick.

Electrostatic Spray: The powder is conveyed under pressure into the gun in fluidized form. This is the most common and efficient method to spray apply powders.

Fluidized Bed: An application method that consists of a tank with a false bottom made of porous material. Air pressure is applied below this false bottom so the powder contained above it is lifted and maintained in suspension.

Intumescent: A substance that swells or bubbles up as a result of heat exposure, thus increasing in volume and decreasing in density.

Lining: A coating that is normally in immersion service.

Reinforced Plastic: The process of inserting glass or other synthetic fibers (in chopped and/or mat form) into a chemically curing resin.

Roto-Lining: Application method that charges powder into a hollow mold, places the mold into a heated oven, then rotates the mold around two axes while the mold and the powder heat up. When the interior metal surface is heated above the powder's melting point, the powder melts on contact with the metal. The powder forms a protective coating upon cooling.

Study Guide

1. In the coating industry, a lining is described as:

_____
_____

2. Some resins used in reinforced linings include:

_____
_____
_____
_____

3. What is the main feature that reinforcing adds to a resin?

_____

4. Describe wicking and how it may negatively affect a coating system.

_____
_____
_____

5. Describe normal surface preparation requirements for installation of a lining.

_____
_____
_____
_____

6. What are antifouling materials used for, and how do they work?

_____
_____
_____
_____

7. The three main types of anti fouling coatings are:

_____
_____
_____

8. Name and describe the two main types of fireproofing coatings.

_____
_____
_____
_____

9. What are the best known characteristics of flouropolymer coatings?

_____
_____

10. Describe the two broad curing categories of powder coatings:

_____
_____
_____
_____

11. What are the four distinct stages powders pass through when a heat source is applied?

- _____
- _____
- _____
- _____

12. Describe the advantages and disadvantages of plural component airless spray over single piston airless spray system:

- Advantages:

  _____
  _____
  _____
  _____

- Disadvantages:

  _____
  _____
  _____
  _____

Chapter 13: Thick Barrier Linings

Objectives

When this module is complete, you will have knowledge and understanding of:

- Various polymeric sheet materials
- The purpose of various rubber sheet linings
- The purpose of various synthetic rubbers
- The application process of rubber
- Other sheet linings

Key Terms

- Rubber sheet lining
- Butyl rubber
- Chlorobutyl rubber
- Neoprene rubber
- Nitrile rubber
- Hypalon®

13.1 Introduction

This chapter examines the next group of materials — thick barrier linings. Some of the materials are:

- Reinforced plastic materials, such as fiberglass used with polyesters, vinyl esters, epoxy, novalac epoxy, etc.
- Polymeric sheet materials, including polyethylene
- Rubber linings

13.2 Polymeric Sheet Materials

A wide variety of plastic sheet materials are available (Figure 13.1), such as:

- Polyvinyl chloride (PVC)
- Polyethylene
- Polypropylene
- Proprietary materials generally known b
- rand names such as Kynar®, Halar®, Penton (Aqualon®), etc.

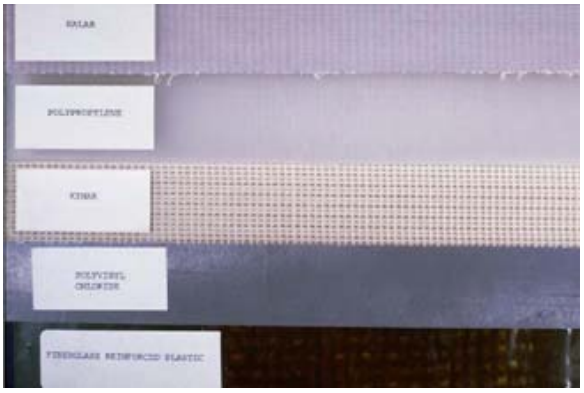


Figure 13.1 Various Mats

The application procedures for most of these materials are similar:

- Prepare surfaces according to abrasive blast cleaning to near-white to white metal.
- Pre-cut the material to fit the configuration.
- Prime and/or apply a suitable adhesive to the substrate and/or to the material itself.
- Lay-up the sheet material; correct alignment is critical.
- Heat weld or use some other method to treat seams to ensure a continuous lining. The joining process is critical to ensure there are no gaps or contamination between sheet edges. Use high-voltage spark testing for any lining to be used in immersion service.

13.2.1 Inspection Concerns

Always verify the sheet material is the specified material. Accurate and precise cutting, fitting, and alignment of the material are

critical to a successful installation. Verify the heat welding of the seams with high-voltage holiday testing.

13.3 Rubber Sheet Linings

Rubber sheet linings are made of different types of natural and synthetic rubber. These linings are not well known in the industrial coatings market, but are widely used as protective barriers in the corrosion protection market. Rubber sheet linings are also used to contain certain chemicals, non-corrosive products, and, where needed, they provide abrasion resistance (Figure 13.2). They are also vital in the storage and transportation of:

- Acids
- Certain alkalis
- Food chemicals and food products
- Selected solvents
- Specialty chemicals and other corrosive products
- Plastic pellets
- Clays, etc.

Rubber linings are used most commonly in:

- Railroad tank cars
- Truck tanks
- Barge tanks
- Membrane behind an acid brick lining systems

Rubber linings are also recommended for:

- Reaction towers
- Process tanks, vessels, etc.
- Filters
- Flue gas desulphurization (FGD) units
- Fume stacks
- Agitators
- Troughs
- Blowers and fans
- Crystallizers and sewers
- Pump shells and casings
- Rotors
- Chutes, hoppers, conveyors, screws, etc.



Figure 13.2 Section of FGD Duct, Rubber Lined

To increase effectiveness, owner/operators can tailor rubber linings with specific properties to handle particular materials. There are two classes of rubber:

- Natural
- Synthetic

Natural rubber is derived from latex obtained from hevea trees and is coagulated with acetic or formic acid. Chemically, it is an unsaturated hydrocarbon known as polyisoprene.

Synthetic rubber is any one of a group of man-made elastomers which approximate one or more of the properties of natural rubber.

13.3.1 Curing Rubber

Rubber is cured by vulcanization, a process discovered in 1846 in the US by Charles Goodyear and simultaneously by Thomas Hancock in England. Vulcanization converts rubber hydrocarbon from a soft, tacky ther-

moplastic material to a strong, temperature-stable thermoset with unique elastic modulus and tensile properties.

Vulcanization is a physicochemical (physical and chemical) change that results from cross-linking the unsaturated hydrocarbon chain of natural rubber (polyisoprene) with sulfur, and applying heat.

Vulcanization blends natural rubber with 3% sulfur, 1% organic accelerator, 3% zinc oxide, certain fillers or reinforcing agents. It cures in the presence of live steam at temperatures of 250 to 300°F (120 to 150°C).

All synthetic rubbers are vulcanized. In general, sulfur is cross-linked with unsaturated polymers, while certain saturated polymers may be cross-linked with peroxides, metal oxides, or diisocyanates.

Three factors affect the properties of the vulcanizate (vulcanized product):

- Percentage of sulfur and accelerator used
- Temperature of the curing process
- Time of cure

The sulfur content is usually 1 to 3%, but in certain cases, it may range to 50% by weight. With strong acceleration, the cure time can be as short as three minutes at high temperatures of 300°F (150°C). Vulcanization also *can* occur at room temperature with specific formulations (self-curing cements).

There are five methods used to vulcanize sheet rubber lining onto substrates of pipes, equipment, or vessels. Not all are appropriate for every rubber lining application. The specific method of vulcanization depends on design of equipment, its overall dimensions, and the facility on site.

Shielding or insulating the equipment during cure reduces the duration of the cure. The thickness of rubber affects curing time — thicker rubber takes longer to cure.

The methods of cure are:

- **Autoclave (vulcanizer) cure**: The rubber-lined equipment is placed in an autoclave and subjected to controlled steam under pressure. This method is preferred because of better heat transfer and a shorter cure cycle. This method results in the highest rubber-to-metal adhesion and yields the highest lining density useful for more corrosive media.
- **Internal steam cure**: The pressure vessel is used as its own autoclave. Workers close off all openings and fill the vessel with steam under controlled temperature and pressure.
- **Atmospheric steam cure** (also called exhaust steam cure): This is vulcanization without pressure, using atmospheric steam. The temperature of the steam and the steel skin are closely monitored. To prevent collapse of a closed vessel, take precautions against failure of steam supply or sudden cooling. This method is commonly used on vessels that are too large to transport and are therefore lined in the field.
- **Hot-water cure**: The equipment is filled with water, and steam is injected to boil the water. The temperature and water level are maintained for the required period of time.
- **Chemical cure**: Chemical cure is vulcanization at ambient temperatures. A liquid vulcanizing agent is topically applied to the surface of the rubber. Use supplementary heat to reduce the cure time. Chemical cure takes place from the rubber surface downward. This cure method produces less adhesion than other methods. This method commonly is used on tank repairs or large field-lined vessels.

13.3.2 Natural Rubber

The three categories of natural rubber are:

- Soft
- Semi-hard
- Hard

13.3.2.1 Soft Rubber

Of the three groups of rubbers (soft, semi-hard, and hard), soft rubber has the greatest flexibility, elongation, and accommodation to movement of an underlying surface.

Soft rubbers have:

- Good resistance to a number of corrosive chemicals
- Excellent abrasion resistance
- Good temperature resistance up to 140°F (60°C)

Soft rubber linings are standard for tanks that contain hydrochloric (muriatic) acid. Soft rubber is unique in that it forms a surface film that toughens slightly and retards penetration by the acid. Washing the film with water tends to disturb that film and soften the rubber.

A "tri-ply" lining construction is often used to form a sandwich film, which is a layer of a hard or a semi-hard rubber between two layers of soft rubber. Special lap seams separate the ends of the hard rubber and allow for expansion within the soft rubber. To apply to a steel substrate, coat the substrate with a special adhesive primer, then apply a soft tie gum over the primer. Apply the rubber lining over the tie gum. (Note: Tie gum is a soft backing layer of rubber used to promote bonding between two surfaces).

This sandwich film provides excellent corrosion and abrasion resistance, can be compounded for steel pickling lines, halogen acids (HCl, HBr, etc.), and offers resistance to thermal shock and fatigue from flexing. Soft rubber linings:

- Are very water resistant
- Provide the best in abrasion resistance
- Can be used with food-grade phosphoric acid

Soft rubber's hardness ranges from 35 to 70 Shore A durometer. The higher the sulfur content, the harder the rubber.

13.3.2.2 Semi-Hard Rubber

Semi-hard rubber is compounded with about 15% by weight of sulfur. Semi-hard rubber may be mixed with acid-resisting fillers, rubber dust, accelerators, and a limited amount of plasticizers to produce a workable mass which can be kneaded, extruded, and/or calendered, which can then be applied directly over tie gum or adhesive.

It is resistant to the same chemicals as soft rubber, but may be used with stronger chemical concentrations and at temperatures up to 180°F (82°C). Semi-hard rubber can be used in services that generally require hard rubber, but where the brittleness of the hard material is not acceptable.

Use semi-hard rubber in water conditioning equipment and to protect against wet chlorine gas, strong acids, and plating solutions.

Semi-hard rubber compounds:

- Are affected by temperature changes
- Become very brittle at freezing temperatures
- Are not suitable for some outdoor installations, or where there are wide temperature changes

The hardness range of semi-hard rubber is generally from 70 to 75 Shore A durometer.

13.3.2.3 Hard Rubber

Hard rubber can handle highly corrosive solutions such as concentrated HCl and wet chlorine gas at 200 to 220°F (93 to 105°C). Generally, use hard rubbers on rigid shapes of well-designed equipment that is not subject to rapid temperature changes. Because of their low permeability to moisture, hard rubbers often are used in water treatment facilities. They also have good abrasion resistance. Their hardness range is from 60 to 80 Shore D durometer.

13.4 Synthetic Rubbers

Some of the various types of synthetic rubber are:

- Butyl rubber
- Neoprene rubber
- Nitrile rubber
- Chlorobutyl rubber
- Hypalon®

13.4.1 Butyl Rubber

Butyl rubber is a very pliable and moldable material and is generally used in fittings, etc., where sheet lining is not feasible. It vulcanizes easily. Because of its cost, butyl rubber is not used as sheet lining; however, it easily reacts with chlorine to produce chlorobutyl rubber, which is used as a sheet lining.

Butyl rubber is commonly used as a component of mastics, adhesives, sealants, etc. It has excellent resistance to acid solutions such as sulfuric, dilute nitric, and dilute hydrofluoric acids at temperatures up to 200°F (93°C).

13.4.2 Chlorobutyl Rubber

Chlorobutyl rubber has very low permeability and excellent chemical resistance. It is widely used in water boxes in the power generating industry. Generally, it can be applied as thickly as 0.5 in. (12 mm) over tie gum bonded to special adhesive primers. Chlorobutyl rubber also is used in flue gas desulfurization (FGD) scrubbers, and for such chemicals as sodium hypochlorite, superphosphoric acid, and sulfuric acid.

13.4.3 Neoprene Rubber

Neoprene is a general-purpose rubber that is resistant to a wide range of chemical and physical conditions and can resist:

- Lubricating oils
- Gasoline
- Sulfuric acid 50% at 180°F (80°C)
- Strong hydrochloric and hydrofluoric acids at room temperature
- Sodium hydroxide (50 to 70%) at 200 to 230°F (93 to 110°C)
- Acid slurries

Neoprene is very resistant to ozone and oxygen, both of which can cause rubber to deteriorate. These features make neoprene useful in outdoor applications.

13.4.4 Nitrile Rubber

Nitrile rubber has good resistance to aliphatic solvents such as kerosene, naphtha, mineral spirits, etc., as well as animal, vegetable, and mineral oils. It has relatively poor resistance to acids.

Nitrile can be compounded and vulcanized to form soft, semi-hard, and hard rubber compositions. The soft form is the one most commonly used for lining applications.

13.4.5 Hypalon®

Hypalon® is chlorosulfonated polyethylene, but is regarded by industry as a form of synthetic rubber.

The material is very resistant to weathering. It is resistant to oxygen, ozone, heat, flame, tear, abrasion, oil, and grease. Hypalon has gained wide recognition in handling chromic acid (10%), hydrogen peroxide (30%) and sulfuric acid (50 to 75%). It is resistant to temperatures to 200°F (93°C).

13.5 Application Process for Rubber

The prime requirement to rubber line equipment, vessels, piping, etc., is that all vulnerable surfaces must be accessible for installation. Generally, the surface conditions and surface preparation requirements are stricter than those required by many liquid dispersion materials.

The following are some typical surface preparation requirements for a rubber-lining project:

- Make sure the steel is new, full-weight steel, free from structural defects
- Make sure the steel plate is flat, with no appreciable warp or buckle
- The steel plate should have a minimum thickness and corresponding weight per square foot: 0.25 in (6.3 mm) thick steel plate should weight 10.2 lbs/ft^2 (4.6 kg/m^2) and 0.5 in (13 mm) steel plate should weigh 20.4 lbs/ft^2 (9.2 kg/m^2)
- Ensure vessel is braced to avoid bulging
- Ensure all welds are solid and continuous, peened to eliminate porosity, and ground to remove sharp edges and high spots
- Grind edges and corners to a minimum radius of 0.125 in. (3 mm) (Figure 13.3)
- Remove all weld spatter

13.5.1 Surface Preparation

In addition to the conditions described above, ensure the surfaces to be lined are free of all oil, grease, dirt, old coatings, etc., and then abrasive blast clean with steel grit to NACE No. 1/SSPC-SP 5 white metal blast with a surface profile of 1.5 to 2.5 mils (38 to 64 µm). After blasting, ensure all surfaces are free of dust or debris before applying adhesive (primer).

13.5.1.1 Lining Installation — Plant

Linings are cut to fit the geometrical shape of the vessel to be lined. The edges of the lining material must fit precisely when they are joined, unless an overlap is done.

Apply a primer, tie coat, or adhesive, as required, to the clean, dry, bare surface and place the lining in position. After the lining is properly positioned, roll it (generally, done by hand) to remove any bubbles or wrinkles. When the installation is completed, place the item in an autoclave for curing.



Figure 13.3 Beveled Edge of Rubber Sheet

Cure linings in an autoclave with live steam at about 50 psi (345 kPa) and a temperature of 250 to 300°F (125 to 150°C). Curing is a time-temperature relationship. The lower the temperature, the slower and longer the cure time. Conversely, the higher the temperature, the faster and shorter the cure time. As indicated previously, curing also may be done by an internal steam cure or hot-water cure methods in the plant.

13.5.1.2 Lining Installation and Curing — Field

Field install a rubber lining when it is not possible to transport the item to an autoclave. A typical field installation of a closed-top tank may proceed as follows:

- After proper surface preparation, prime the tank walls, ceiling, and the floor area around the bottom corners of the tank with the appropriate adhesive. Line the walls first and the floor last.
- Apply sheet rubber to the walls with enough material to overlap onto the tank bottom. Overlap the top end of the rubber onto the roof just as at the bottom.
- Thoroughly roll the lined area by hand to remove any bubbles or wrinkles. Make the joints at the top and the bottom away from the corners. When the walls and ceiling are finished, then line the bottom.
- Once the tank is lined and ready for cure, place an exhaust steam line with a swivel elbow in the tank and shroud the tank to retain the heat. Introduce live steam into the tank. The moving elbow of the exhaust steam line circulates the steam. This field curing process is often called the exhaust cure.
- During the curing cycle, it is possible to achieve at least a 30°F (17°C) temperature differential between the outside steel wall and the inside at the rubber interface. The cure process may require up to 24 to 36 hours.
- Performing a pre-cure is optional. This method interrupts the cure to detect defects and blisters, and check hardness, etc., before final vulcanization. During a pre-cure, introduce steam for approximately two hours. The time varies according to the size of the vessel and/or the size of the steam line. Make sure the time is long enough to expand any trapped air so that it can be found and repaired, but short enough so the surface of the lining will not be cured to the point where repairs cannot be made.
- After pre-cure repair, once again introduce steam into the vessel to complete the cure.
- Make hardness measurements with a durometer, especially in the potentially colder areas, such as the bottom, outlets, nozzles, and weldments where stiffener rings could create a heat sink.

13.5.2 Inspection Criteria

Inspection of the lining may include:

- Determine required hardness with a durometer.
- Visually check for bubbles, wrinkles, or any other unusual visible physical defect.
- Checking for holidays with a high-voltage spark tester.
- Spark testing varies depending upon thickness and type of rubber. As a general guide, 15,000 V is adequate for 0.25 in. (6.4 mm) thick natural rubber. Generally, keep the probing electrode in light contact with the rubber and move it back and forth at the rate of approximately 1 ft/s (30 cm/s). Keep the electrode moving without stopping in any one position; otherwise, dielectric breakdown of the rubber is likely.

Do not inspect rubber linings without a thorough knowledge of the whole process. This

is a specialty application and requires specialized knowledge and experience (Figure 13.5).

The following list shows a sampling of acceptance criteria for a rail tank rubber lining installation. The presence of any of these items is cause for rejection:

- No pinholes in lining
- No blisters
- No loose lap seams (Figure 13.4)
- No uncured lining (hardness)
- No mechanical defects (cuts, gouges, or other surface defects)
- No evidence of poor workmanship (excessive repairs)



Figure 13.4 Loose Lap Seam in a Rubber Lining



Figure 13.5 Warning Label on Rubber-Lined Tank Car

13.5.3 Repairs

Repair procedures vary. Generally, do small repairs with a chemically cured rubber such as chlorobutyl when the lining cannot be cured by vulcanization.

13.5.4 Failures

Failures can occur with rubber linings. Some of the possible causes of failure:

- Incorrect product selected for the intended service.
- Rubber used after expiration of shelf life.
- Using a rubber lining that was not properly stored. Keep rubber cool in storage because, with heat, it can vulcanize on the roll. If this occurs, discard the material.
- Incorrect application process used.
- Inadequate cure.

13.6 Other Sheet Linings

There are other polymers, such as polyethylene and chlorinated polyethers, which are fabricated into sheet material for linings. Treat and apply these in a similar way to that used for rubber linings.

13.6.1 Chlorinated Polyether

Chlorinated polyether resins are available to apply as a powder for dispersion or solution coatings or as sheets for linings. Chlorinated polyether lends itself readily to dry powder application either by sintering or by the fluidized-bed process.

Clean the surface as specified before applying chlorinated polyether as a coating. Fuse each coat after the dispersion medium evaporates to near dryness. When chlorinated polyether is applied as a sheet, ensure:

- The bonding surfaces, both sheet and substrate, are free of oil, grease, and dirt.

- Metal surfaces are blast cleaned to white metal, vacuum cleaned, then receive a single coat of primer. Chlorinated rubber primer is often used.
- Clean the chlorinated polyether sheet with MEK and then give it a light blast, or sand by hand using fine-grade paper. Vacuum clean the abraded sheet to remove dust or grit and apply a coat of primer.
- Use rubber-based adhesives to apply chlorinated polyether sheets. Apply the adhesive either by spray, roller, or brush.

Reactivate adhesive with heat to obtain the optimum bond strength. This is sometimes done by heating through the sheet so the adhesive layer reaches about 250°F (121°C) just prior to rolling in place on the substrate.

13.6.2 Polyethylene

In general, polyethylene polymers have high-temperature resistance and have excellent resistance to chemicals. They also are resistant to creep, have high impact resistance, excellent tensile strength, and high electrical resistivity. Polyethylenes are insoluble in organic solvents and do not stress crack.

There are two forms of polyethylene: low-density and high-density. Essentially, the low-density materials have highly branched and widely spaced molecular chains, while the high-density materials have comparatively straight and closely aligned chains. The physical properties are markedly affected by increasing density.

The high-density form has a higher melting point and greater tensile strength than the low-density form. The low-density materials are used generally for wire and cable coatings and as liners for drums and other containers, etc. The high-density form is used for gasoline containers, pipes, and film and sheets.

The three methods to apply polyethylene in current use are:

- Melt the resin then extrude it onto the article to be coated.
- Heat the object to be coated to a temperature above the melting point of the polyethylene then immerse the object in a fluidized bed of powder.
- Flame spray the polyethylene directly onto a metal surface. This method requires special equipment and operator expertise.

Key Terms Definitions

Butyl Rubber: A very pliable and moldable material that is generally used in fittings, etc., where sheet lining is not feasible.

Chlorobutyl Rubber: This rubber has very low permeability and excellent chemical resistance. It is widely used in water boxes in the power generating industry.

Hypalon®: A chlorosulfonated polyethylene, that is regarded by industry as a form of synthetic rubber. The material is very resistant to weathering and oxygen, ozone, heat, flame, tears, abrasion, oil, and grease.

Neoprene Rubber: A general-purpose material that is resistant to a wide range of chemical and physical conditions.

Nitrile Rubber: A rubber that has good resistance to aliphatic solvents, such as kerosene, naphtha, mineral spirits, etc., as well as to animal, vegetable, and mineral oils; however, it has relatively poor resistance to acids.

Rubber Sheet Linings: Linings that are made in different types of natural and synthetic rubber. They are widely used as protective barriers against corrosion. They are also used to contain certain chemicals and non-corrosive products. They also provide abrasion resistance.

Study Guide

1. What are the two major classes of rubber?

2. What is vulcanization?

3. Three factors that affect the properties of the vulcanized product are:

4. List the various methods used to cure (vulcanize) rubber.

5. The three categories of natural rubber are:

6. Describe a “tri-ply” lining.

7. Some various types of synthetic rubber are:

8. Describe the typical surface preparation requirements to install a rubber lining.

_____
_____
_____
_____

9. Some of the causes of rubber lining failure may be:

_____
_____
_____

10. Three methods to apply polyethylene are:

_____
_____
_____

Chapter 14: Advanced Standards and Resources

Objectives

When this module is complete, you will have knowledge and understanding of:

- How to properly interpret and use a standard
- NACE International standards

14.1 Introduction

According to Standards Engineering Society (SES), a standard is a document that applies collectively to codes, specifications, recommended practices, classifications, test methods, and guides, which have been prepared by a standards developing organization or group, and published in accordance with established procedures.

A standard is an established norm or requirement that is put together by industry professionals. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices. Standards are meant to get industry personnel on the same level in an attempt to minimize confusion, particularly with reference to the way industry professionals do business. It enables different parties and entities to realize mutual gains, but only by making mutually consistent decisions.

Standards are not considered binding or mandatory unless they are specified or referenced in the contractual documents. In other words, inspectors with extensive knowledge and experience with a particular standard cannot force a contractor to operate under the requirements of any particular standard unless it is a contract requirement. It is always a coating inspector's responsibility to obtain and thoroughly understand each standard referred in the specification. Modifications to a given standard may only be made by an agreement between the owner, contractor, and inspector. Address and resolve any questions about a referenced standard in the pre-job conference. Because there are various organizations that write standards, each classifies them into differing sub-groups. Understand the intent of a standard and seek clarification if needed before enforcing it. Below are some general types and descriptions of standards:

Voluntary standards are generally established by private-sector bodies and are available for use by any person or organization, private or government. The term includes what are commonly referred to as "industry standards" as well as "consensus standards." A voluntary standard may become mandatory as a result of its use, reference, or adoption by a regulatory authority, or when invoked in contracts, purchase orders, or other commercial instruments.[1]

Consensus standards are developed through the cooperation of all parties who have an interest in participating in the development

1. Source: ANSI's "Standards Management: A Handbook for Profit"

and/or use of the standards. Consensus requires that all views and objections be considered, and that an effort be made toward their resolution. Consensus implies more than the concept of a simple majority but not necessarily unanimity.

Mandatory standards require compliance because of a government statute or regulation, an organization's internal policy, or a contractual requirement. Failure to comply with a mandatory standard usually carries a sanction, such as civil or criminal penalties, or loss of employment.

De facto standards are widely accepted and used, but lack formal approval by a recognized standards developing organization. Common examples of de facto standards are driving customs (right versus left side of the road) and the QWERTY keyboard.

National standards, when viewed from an "official" perspective, are adopted by a national standards body (e.g., American National Standards Institute, Standards Council of Canada, and British Standards Institution) and made available to the public. Practically speaking, however, a national standard is any standard that is widely used and recognized within a country.

Regional standards are developed or adopted and promulgated by a regional organization, e.g., European Committee for Standardization (CEN) or Pan American Standards Commission (COPANT). Regional standards are generally voluntary in nature, representing the joint action of the national standards bodies of a regional group of nations.

International standards are not easy to define. What constitutes an international standard is a subject of much discussion and disagreement. There does seem to be *some* general agreement that for a standard to be considered international it must be used in multiple nations, with its development process open to representatives from all countries. Some international standards are promulgated by multinational treaty organizations, such as the International Telecommunications Union (ITU) or the United Nations Food and Agriculture Organization (FAO). Some international standards are promulgated by multinational non-treaty organizations, such as the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).

Some international standards are written by organizations that originated as national industry associations, professional societies, or standards developers, but over time they evolved into a global presence with multinational participation. Examples are: ASTM International, SAE International and NFPA International (Source SEC).

Please note: the existence of a published standard does not imply that it is always useful or correct. For example, if an item complies with a certain standard, there is not necessarily assurance that it is fit for any particular use. The people who use the item or service (engineers, contractors, specifiers) or specify it (building codes, government, industry, etc.) have the responsibility to consider the available standards, specify the correct one, enforce compliance, and use the item correctly. It is essential to validate suitability before any standard is specified.

Standards are often reviewed, revised and updated. It is critical to always use and/or reference the most current version of a published standard. The originator or standard writing body often lists the current versions on its website.

In contrast, a custom, convention, company product or procedure, corporate standard, etc., which becomes generally accepted and dominant, is often called a de facto standard.

In most cases, standards require inspectors to perform certain tasks that, if needed, can be replicated. Any tests performed **per** the requirements, but **not** done **to** the standard must be documented accordingly. One good example is ASTM D4541, which does **not** require cutting around a dolly during an adhesion test. However, if the specification references ASTM D4541 and cutting around the dolly was done as part of the test, then the test was not done to the standard, i.e., so this process must be documented on the appropriate form.

In the case of NACE International, their standards represent a consensus of those individual members who have reviewed the document, its scope, and provisions. Its acceptance does not in any respect preclude anyone, whether they have adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with these standards. Nothing contained in NACE International's standards are to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. NACE International's standards represent minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials.

Standards are not "static" documents and as such must be reviewed, renewed, or changed, if needed. The process of ***change control*** is a formal process used to ensure that changes to any standard are introduced in a controlled and coordinated manner. This process reduces the possibility that unnecessary changes will be introduced to the system without the necessary consensus, and reduces the possibility of creating disruption industry-wide. The goals of a change control procedure usually include minimal disruption to services, reduction in back-out activities, and cost-effective utilization of the resources involved in implementing change.

In the world of standards organizations and bodies, the term national standards body (NSB) is generally used to refer to the one-per-country standardization organization, which is that country's member to ISO. However, the term Standards Developing Organization (SDO) generally refers to the thousands of industry or sector-based standards organizations which develop and publish industry specific standards. A good example of such an organization would be NACE International. Some economies feature only an NSB with no other SDOs while larger economies like the United States and Japan have several SDOs.

14.2 How to Properly Interpret and Use a Standard

Requests for official interpretations of standards are usually submitted in writing to the

originating organization for consideration. These requests usually include the following information: the standard and the essential element the request pertains to, and background information related to the request, including a rationale for why an interpretation is being requested. In addition to responding to written requests for interpretations, these organizations have the authority to issue official interpretations of the standards as they see fit.

Occasionally, questions arise regarding the meaning of portions of standards as they relate to specific applications. Such requests for interpretations should ask for clarifications of the exact nature of the contents of the standard. Questions relating to such interpretations are reviewed and evaluated in accordance with the organization's guidelines.

Interpretations are issued to explain and clarify the intent of the standard and are not intended to constitute an alteration to the original standard or to supply consulting information. A general practice during any interpretation is that new rules cannot be adopted to fit situations not yet covered in the standard, even if the investigations lead to conclusions that a requirement in a standard is incomplete or in error. Changes to a standard are made **only** through revisions or supplement within an established timeframe (5 years in most cases). It is recognized in the industry that requests are frequently received that are partially or totally requests for information rather than requests for an interpretation. It is inappropriate to issue an official interpretation to answer such requests.

14.3 NACE International Standards

NACE International standards are the most specified standards for corrosion control in the world today. NACE is one of the world's largest voluntary standards-development groups, and its standards are written and approved by industry professionals, instructors, professors, government officials, and experts from regulatory and governing bodies. NACE International is a member of the American National Standards Institute (ANSI) as an accredited standards developer. It is worth noting that although NACE is involved in all aspects of corrosion control education, approximately 50% of all NACE standards are related to protective coatings. On surface preparation, NACE has teamed up with the Society for Protective Coatings (SSPC) and developed joint standards. The standards will be discussed throughout this course.

The standards developed and published by NACE conform to the consensus principles of the association and have met the approval requirements of NACE procedures, rules, and regulations. NACE International issues a *Book of Standards* based on three classifications:

- Standard practice (SP)
- Test method (TM)
- Materials requirement (MR)

Standard Practices (SPs) include recommendations for:

- Design
- Installation
- Maintenance
- Proper use of a material or a corrosion control system

Some SPs focus on:

- Details of construction of a corrosion control systems
- Methods of treating the surface to reduce corrosion
- Requirements for using devices to reduce corrosion
- Procedures for increasing the effectiveness, safety, and economic benefits of an installation or system

14.3.1 NACE Test Methods (TMs)

Test methods (TMs) are related to corrosion prevention and control. They detail the method of conducting tests to ascertain the characteristics of a:

- Material
- Design
- Operation

14.3.2 Materials Requirements (MRs)

MRs state the necessary characteristics of a material when corrosion is a factor in the selection, application, and maintenance of the material.

The coating inspector cannot be expected to memorize all of the various standards available. However, it is the coating inspector's responsibility to know where the standards may be obtained. When a standard is referenced in a specification, the coating inspector must obtain a copy of that standard and become aware of the thrust of that standard.

If there is any part of a referenced standard that is not clear to the inspector, he or she should bring it up at the pre-job conference and seek clarification. Coating inspectors should stay abreast of changes and revisions in standards with which they may work on any given project. Coatings inspectors should also be aware of new standards created to meet the needs of industry.

As stated earlier, a number of worldwide organizations develop standards for the industry. Some of the most common ones include:

- SSPC
- ASTM
- ISO
- Committee of Industry Standards (CIS-China)
- Indian Bureau of Standard (IBS)
- National Standards Body (UK)

Regardless of which organization developed the standard, the coating inspector's responsibilities remain the same.

In the event a need for interpretation comes up, always contact the organization and make a formal request according to the established guidelines for that particular organization. Remember, give adequate time for responses.

Study Guide

1. The Standards Engineering Society (SES) description of a standard is:

   _____
   _____
   _____

2. Describe the difference between voluntary and mandatory standards:

   _____
   _____
   _____

3. Explain the difference between a National Standards Body (NSB) and Standards Developing Organization (SDO):

   _____
   _____
   _____
   _____

4. Name and define the three NACE standards classifications:

   _____
   _____
   _____

Chapter 15: Coating Concrete and Inspection

Objectives

When this module is completed, you will have knowledge and understanding of:

- How concrete is made
- The process that cures concrete
- Different concrete surfaces
- Industry standards and guidelines
- Surface preparation for concrete
- Tests for concrete
- How to check coating thickness on concrete
- When and how to check maintenance of concrete coatings.

Key Terms

- High Pressure Water Washing
- Acid Etching
- Laitance
- Efflorescence

15.1 Introduction

Coating inspectors encounter a broad range of projects including new construction and retrofit of existing structures. Therefore, it is important for inspectors to acquire a basic knowledge of concrete, its properties, and inspection needs before and during coating operations.

Concrete probably provides the largest surface area of all construction materials. While emphasis has been placed on steel as a surface for coatings, it is necessary for inspectors to know and thoroughly understand concrete as both a substrate requiring a coating, and as a coating itself.

Concrete is sometimes applied over steel to prevent corrosion. When concrete is dense and poured well, it is one of the most corrosion-resistant coatings available for steel. It provides a thick, dense, water-resistant barrier, and creates an inhibitive atmosphere that prevents steel from corroding. Concrete is, however, inherently porous and **not** impervious to water vapor transmission.

Cement mortar coatings have maintained their properties and prevented steel from corroding in water pipeline use for up to 100 years. There are few other coatings that can match that service.

Other reasons cement is used to line steel is that it is relatively inexpensive and durable. Unlike most materials that form bonded linings, cement linings often do not bond to the substrate. They may have minor cracks, but the cracks tend to "heal" themselves. There are *some* drawbacks; very pure water tends to leach and attack linings, and rocks or other abrasive materials may erode the lining very quickly. In these instances, the cement lining may require an overlay of a protective coating.

To appreciate aspects of inspecting coatings with concrete and other cementitious materials, some background about concrete itself is helpful.

One reason for the wide-spread use of concrete is that it is an extremely durable material. Some of the properties that give concrete its strength and durability are listed below:

- Concrete is **inorganic**. Essentially, it is a rock. Very few organisms, such as fungi or bacteria, attack it as they do organic materials. It does not rot in the common sense of the term. It is unaffected by sunlight, weather, moisture, dryness, or other similar conditions.
- Concrete is **hard**. It does not wear away easily. Its abrasion resistance is determined by the aggregate used. The use of hard, durable, granitic aggregates makes it very abrasion resistant even though hydrated cement alone is not a highly abrasion-resistant material.
- Concrete has **good compressive strength**, which is one of its outstanding physical properties. Few normally occurring conditions, outside of earthquakes, cause it to fail by compression.
- Concrete can **improve with age**. Underwater, crystallization continues over a long period, increasing its hardness and compressive strength. In many cases, crystallization actually heals minor cracks in a concrete structure. Because it contains considerable lime, concrete reacts with carbon dioxide from the air to form calcium carbonate or limestone. This also increases its hardness and compressive strength.

15.2 How Concrete is Made

Mix Portland cement, aggregate, and water to make concrete.

Concrete is made with many different types of aggregates, ranging from river sand to granite, including various fibrous aggregates, such as glass or asbestos (Figure 15.1). Each concrete and aggregate mix creates a different surface.

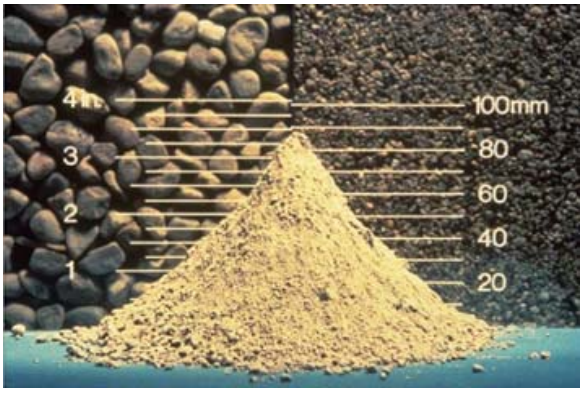


Figure 15.1 Components of Concrete

Concrete and concrete products usually are made locally because of their heavy weight and high transportation costs. This reason contributes to the wide range of aggregate materials used.

15.3 Concrete Cure Process

Inspectors must know concrete's cure process to understand the requirements for coating on concrete. At least 28 chemical reactions take place in concrete as it cures, which makes it a *very* complex process.

Hydration occurs when water is added to the cement/aggregate mixture. The water and the cement combine chemically, causing the concrete to set up and harden. The lime content of the cement is the source of concrete's high alkalinity. Concrete's pH can be as high as 13. This high alkalinity contributes to the corrosion resistance of steel coated with concrete because many grades of steel are passivated when the alkalinity reaches a pH of 11.5 or higher. This same strong alkaline condition; however, can cause problems with coatings applied over a concrete surface. It can make the concrete vulnerable to

corrosive attack from common acidic field conditions.

15.3.1 Concrete Curing Times

The hydration (curing) process begins as soon as water contacts the Portland cement and continues for an extended length of time. In general, allow poured concrete to cure for a minimum of 30 days at temperatures above 70°F (21.1°C) before coating. This helps ensure that the concrete has the desired surface pH, hardness, and tensile strength. The time also allows excess water to evaporate from the surface.

The specification states the curing times for poured or other concrete or cementitious surfaces. The inspector ensures that the surface has cured for the specified period of time prior to application of the coating.

Some coatings are designed to apply to concrete immediately after the forms are removed. These coatings can also be used on green (uncured) concrete.

Other coatings are formulated to use as curing membranes, i.e., applied immediately after the concrete is poured and forms, if any, are removed. This method helps prevent the structural problems that can occur if moisture in the concrete comes off too quickly and hydration does not proceed to the desired extent.

15.4 Concrete Surfaces

There are a wide variety of concrete and cementitious surfaces, including:

- Poured (wet-cast)
- Concrete block (poured using forms)
- Special concrete surfaces
    - — Gunite
    - — Asbestos cement
    - — Glass fiber cement products

15.4.1 Poured (Wet-Cast) Concrete

Wet-cast concrete has a high moisture content that allows it to flow into the form. Laitance, holes, and air bubbles are commonly encountered in wet-cast concrete, even on vertical surfaces. Proper placement, consolidation and vibration can help alleviate these issues.

Poured concrete can be affected by:

- **Ambient conditions**: Hot weather causes concrete to cure more rapidly than otherwise, resulting in a greater possibility for voids, and a dusty, low-strength surface. Apply a curing compound to help mitigate the effects of these conditions. The specification may require a wet burlap curing blanket to be placed over freshly poured concrete to prevent this type of “drying out.”
- **Vibration**: This is done to remove air pockets, but can cause the heavy aggregate to sink to the bottom of the form. This results in a weak, sandy surface, creating a fragile layer of sand and cement known as laitance. This condition can occur at both the upper surface and the concrete/form surface or interface.
- **Finishing operations**: A variety of finishing operations can be used on concrete:
    - — **Steel Trowelling** smooths the surface. A sand/mortar mix can be applied to the poured surface before trowelling to provide a very smooth, hard, dense surface. However, over-trowelling or overworking the concrete brings the paste to the surface and affects the long-term durability of the concrete.
    - — **Wood floating** uses a wood trowel to smooth the poured

concrete. Because the wood trowel has a relatively rough surface, sand grains are brought to the surface creating a granular surface. Wood floating may also create more laitance on the surface (Figure 15.2).

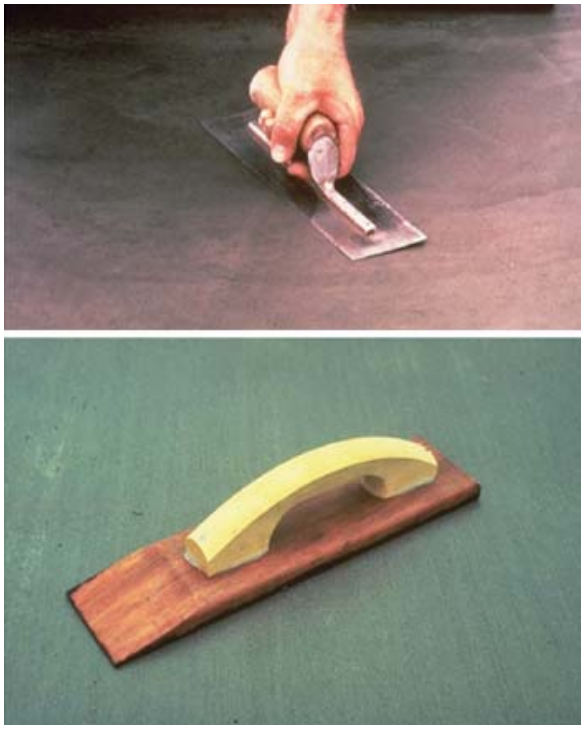


Figure 15.2 Steel and Wood Floats

— **Brooming** uses a stiff-bristle broom to provide a rough surface to the cement (Figure 15.3).



Figure 15.3 Brooming

15.4.2 Concrete Block — Surfaces Poured Using Forms

When concrete is poured using forms, the surface is quite different. Vertical pouring requires using forms that have to be removed and then the surface finished. More steps are required.

Many poured concrete surfaces have offsets at the junction between form sections or between pours. Fins may form where concrete enters the space between the forms.

Pinholes, rock pockets, air pockets, cavities, tie holes from tie wires, and other imperfections in the surface may develop (Figure 15.4).



Figure 15.4 Bugholes

In addition to these visible imperfections, hidden cavities can be just below the surface. Even light abrasive blasting is sufficient to open up such cavities. Opened or not, cavities can cause any applied coating to blister or bubble (Figure 15.5).

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Figure 15.5 Blisters in Concrete Coating

15.4.3 Special Concrete Surfaces

There are various types of concrete surfaces that inspectors should be aware of:

- Gunite
- Asbestos cement
- Glass fiber cement products

15.4.3.1 Gunite

Guniting is the process of spraying or slinging shotcrete onto a surface as a coating (Figure 15.6). Shotcrete is a dense mixture of cement and relatively small aggregate with a low moisture content. A filling agent is frequently added to help hold the shotcrete in place until it cures.

Thicknesses up to 4 in. (100 mm) are not uncommon. Depending upon the application, the thickness may be as high as 10 in. (250 mm). Unless its surface is trowelled smooth, a shotcrete surface is unusually rough and dense, but has few pinholes, air pockets, or subsurface cavities.



Figure 15.6 Guniting Equipment

15.4.3.2 Asbestos

Asbestos cement products have higher tensile strength compared to other concretes, but may be brittle.

15.4.3.3 Glass Fiber

Glass-fiber cement products contain glass fiber as reinforcement.

15.5 Coating Concrete

Concrete and other cementitious surfaces are coated for a variety of reasons. In architectural service, the color and appearance of architectural features may be an essential element of the design of a building or structure.

15.5.1 Why Coat — Environmental Protection

Coating concrete can protect it from numerous environmental hazards like:

- Water
- Freeze-thaw
- Chemical contamination

Waterproofing

Concrete may be coated, or "waterproofed" to mitigate moisture vapor transmission. Without waterproofing, concrete allows water to enter and pass through its porous structure. When concrete is relatively new,

efflorescence is highly likely. Although it is highly alkaline when first placed, the alkalinity depletes by moisture passage, and the onset of surface corrosion may be accelerated by moisture passage. Waterproofing exterior surfaces (buried or above ground) can help prevent water or moisture from passing through the concrete.

Freeze Protection

Concrete needs protection against freeze-thaw cycles that can cause it to crack and break up. Concrete, with its water and moisture content, is very susceptible to damage caused by freeze-thaw conditions. The physical forces of ice are greater than the strength of the concrete, and cause concrete to spall and shatter.

Coating is a practical way to maintain the concrete with as little contained water as possible. Design considerations that allow run-off and avoid water-entrapment in depressions or crevices, also prevent freeze-thaw damage. Today, most concrete is air-entrained (intentional creation of tiny air-bubbles within concrete) to increase its durability during freeze-thaw cycles.

Chemical Resistance

Coatings can enhance chemical resistance. This is important because concrete is a very reactive material. Chemicals, mineral acids, food acids, carbonic acid solutions, pure water, and climate all take their toll on uncoated concrete (Figure 15.7). It is essential to protect concrete from other reactive materials, either to prevent corrosion of the concrete or contamination of a chemical product.

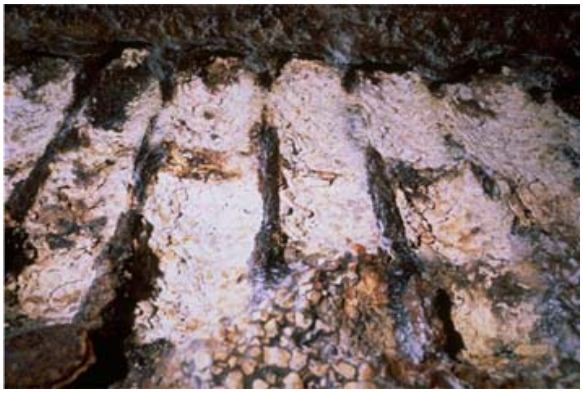


Figure 15.7 Deterioration of Concrete and Corrosion of Rebar Due to Action of Chloride Ions on Steel

15.5.2 Why Coat — Coating Benefits

In addition to environmental protection, coating concrete can have many benefits.

Steel Reinforcement

Concrete protects reinforcing steel, but that protection is seriously impaired if the concrete is so porous that chloride, sulfate, or other less common ions and oxygen permeate to the reinforcing steel.

Most of these substances, if left unchecked, cause corrosion cells (pits) to form on the reinforcing steel, which leads to broken and spalled concrete.

High-performance coatings applied to the concrete surface protect the concrete and the reinforcing steel embedded in it. It is a good practice to also coat the reinforcing steel before the concrete is poured around it. Cathodic protection is also used for this purpose.

Decontamination

Coating concrete helps prevents absorption of contaminants. As stated before, concrete is porous and tends to absorb contaminants readily. This is especially important in

nuclear power plants and other areas where radiation may be present. Surface sealers are often applied to concrete surfaces, especially floors, to prevent the concrete from dusting.

Abrasion and Erosion Protection

Coating concrete helps resist abrasion from both foot traffic and equipment traffic, and makes the concrete resistant to erosion from the flow of water or other fluids across the surface.

Color Coding

Coatings are used to color code and identify different areas for safety and to identify areas that may require frequent maintenance.

Contents Protection

Another reason to coat concrete is to protect the purity of water or other products contained in concrete vessels. Without coating, the concrete absorbs the liquids stored in the tank or vessel and can contaminate the product.

Improving Cleaning

Porous concrete is very difficult to clean unless it is sealed by either a clear or pigmented coating.

Skid Resistance

Concrete that has been steel trowelled to a smooth hard surface may be slippery when wet. Apply a specially formulated coating to make the surface skid resistant. While this makes the surface more difficult to clean, the safety concerns are more important than ease of cleaning.

15.6 Standards and Industry Guidelines

The following section lists common standards used when coating concrete.

15.6.1 ASTM

- **ASTM D 4258**, *Standard Practice for Surface Cleaning Concrete for Coating*
- **ASTM D 4259**, *Standard Practice for Abrading Concrete*
- **ASTM D 4260**, *Standard Practice for Acid Etching Concrete*
- **ASTM D 4261**, *Standard Practice for Surface Cleaning Concrete Unit Masonry for Coating*
- **ASTM D 4262**, *Standard Method for Testing pH of Chemically Cleaned or Etched Concrete Surfaces*
- **ASTM D 4263**, *Standard Tests Method for Indicating Moisture in Concrete by the Plastic Sheet Method*

15.6.2 ICRI (International Concrete Repair Institute) Technical Guidelines

- **No. 130.1R–2008** *Guide for Methods of Measurement and Contract Types of Concrete Repair Work (formerly No. 03735)*
- **No. 210.1–1998** *Guide for Verifying Field Performance of Epoxy Injection of Concrete Cracks (formerly No. 03734)*
- **No. 210.2–2002** *Guide for the Evaluation of Unbonded Post-Tensioned Concrete Structures (formerly No. 03736)*
- **No. 310.1R–2008** *Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion (formerly No. 03730)*
- **No. 310.2–1997** *Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays (formerly No. 03732)*

- **No. 310.3–2004** *Guide for the Preparation of Concrete Surfaces Using Hydrodemolition Methods (formerly No. 03737)*
- **No. 320.1R–1996** *Guide for Selecting Application Methods for the Repair of Concrete Surfaces (formerly No. 03731)*
- **No. 320.2R–2008** *Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces (formerly No. 03733)*
- **No. 320.4–2006** *Guide for the Repair of Unbonded Post-Tensioned Concrete Surfaces (formerly No. 03743)*
- **No. 330.1–2006** *Guide for the Selection of Strengthening Systems for Concrete Structures (formerly No. 03742)*
- **No. 340.1–2006** *Guide for the Selection of Grouts to Control Leakage in Concrete Structures (formerly No. 03738)*
- **No. 410.1–2008** *Guide for the Evaluation of Masonry Façade Structures*
- **No. 710.1–2004** *Guide for Design, Installation, and Maintenance of Protective Polymer Flooring Systems for Concrete (formerly No. 03741)*

15.7 Surface Preparation of Concrete/Cementitious Surfaces

When coatings are applied to concrete or cementitious surfaces, the process generally includes:

- Inspect the surface before beginning; may include pre-cleaning, steam cleaning, and/or chemical cleaning
- Inspect after pre-cleaning
- Prepare surface
- Inspect surface preparation
- Treat cracks and expansion joints
- Coating application
- Inspect after each coat in a multi-coat system
- Inspect the completed coating system

15.7.1 Inspection of the Surface

First, inspect the surface to be coated for any conditions or defects the specification requires be corrected, or that may damage the coating process. Some of the conditions coating inspectors may encounter include:

- Laitance (a weak surface layer of water-rich cement mixture on the surface of fresh concrete caused by the upward movement of water)
- Pits
- Voids
- Efflorescence (caused by moisture passing through the concrete and carrying soluble concrete salts with it to the surface. The salts react with carbon dioxide in the atmosphere creating a fluffy white crystalline deposit on the surface.)
- Projections
- Porosity
- Moisture content
- Form release oils
- Location of expansion joints:
  - Mark to uncover after coating
  - Special treatment may be required
- Visible residues of dirt, chemical salts, or other foreign substances likely to cause coatings problems (e.g., poor adhesion)
- Ice or ice crystals on the surface (require particular attention when coating outdoors in very cold weather)
- Water on the surface

15.8 Surface Preparation of Set Concrete

In order to prepare concrete or other cementitious substrates for coating, the

specification may require a number of operations:

- Pre-cleaning
- Surface preparation
- Surfacing/filling voids

15.8.1 Pre-Cleaning

Inspect all surfaces to be coated for the presence of chemical contaminants, oil, and grease. Remove these prior to surface preparation with either steam cleaning, chemical, or detergent cleaning. In cases of extreme contamination, if it is impossible or impractical to remove the contaminants, remove and replace the concrete.

15.8.2 Surface Preparation

To prepare the surface, use one of the following methods:

- Abrasive blast clean
- Hand and power tool clean
- High-pressure waterjet or blast
- Acid etch
- Stone
- Centrifugal blast
- Scarify

15.8.2.1 Abrasive Blast Cleaning

Depending on the nature of the job, use the most appropriate abrasive blast cleaning method (Figure 15.8). Abrasive blast cleaning provides a roughened, irregular surface and removes laitance. Abrasive blasting opens holes and voids so they can be sealed more effectively. Note that abrasive blasting creates an excessive amount of silica dust, a major respiratory hazard. Ensure proper respiratory protection is used during abrasive blasting.

NACE No. 6/SSPC-SP 13, *Joint Surface Preparation Standard for Surface Preparation of Concrete*, is attached at the end of the manual.



Figure 15.8 Abrasive Blast Cleaned Surface

Practical considerations for abrasive blast cleaning of concrete include:

- Hold the blast nozzle somewhat farther from the work than when blast cleaning steel.
- Use pressures lower than those used on steel.
- Move the blast nozzle as rapidly as practicable, consistent with the specified surface profile. Avoid gouging the surface or exposing large areas of bare aggregate.
- Use a finer-size abrasive than is used on steel; coarse abrasives can remove too much concrete.

Abrasive blast cleaned concrete leaves an anchor pattern different from abrasive blast cleaned steel. It is vital for inspectors to clearly understand the degree of cleanliness required in the specification.

Since abrasive blast cleaned concrete surfaces are rougher than abrasive blasted steel, more coating is required to cover the same area. Thicker coatings than those typically applied to steel are not uncommon.

The specification may call for the abrasive blast cleaned concrete to have:

- A finish coat of mortar applied by any of the methods previously discussed
- The primary coating system applied directly
- A sealer coat applied prior to application of the primary coating

15.8.2.2 Hand or Power Tool Preparation Cleaning

Many hand and power tool techniques are used to prepare concrete surfaces for coating, and they generally are time consuming and costly.

The surface resulting from hand or power tool cleaning varies from great roughness with open voids, to not much more than dust removal.

Using hand or power tools removes loose, powdery, and weak concrete at the surface, but this method is slow and does not open air pockets as well as abrasive blasting.

15.8.2.3 High-Pressure Water Washing

Power washing at 3,000 to 4,500 psi (21 to 31 MPa) is frequently used for poured concrete surfaces. However, it generally does not open up subsurface voids and pockets, or provide a profile on sound, dense concrete as well as abrasive blasting does. But, if too much pressure is used, the waterjet stream may actually cut the concrete. Wet abrasive blasting is another possible choice.

The advantages of waterjetting and wet abrasive blasting include:

- Quickly cuts the surface
- Washes dust away
- Reduces abrasive and concrete particles in air

15.8.2.4 Acid Etching (ASTM D 4260)

Acid etching uses a dilute acid solution to remove laitance and roughen the concrete surface (Figure 15.9). The procedure for acid etching requires the operator to:

- Carefully inspect for and remove any grease or other residues from the surface.
- Apply acid to the oil and grease-free concrete surface.
- Allow the acid to react with the cement until bubbling stops. The dwell time of the acid is typically 5 to 10 minutes.
- Wash the surface thoroughly to remove the acid salts; use brooming if needed with the washing and flushing process.



Figure 15.9 Acid Etching

The most common acid used is hydrochloric acid. Several etchings may be required to do the job. Unlike blasting and power tool cleaning, it is difficult for the operator to see when sound concrete has been reached.

Acid etching is difficult to use on vertical surfaces because the acid can run off before it has had time to thoroughly react. Other acids, such as phosphoric, citric, or sulfamic, may be used, but they are less widely encountered than hydrochloric. **Hydrochloric acid should not be used where chlorides are prohibited.**

Each of these acids is toxic and corrosive: do not allow them to contact skin or clothing. They rapidly disintegrate clothing and wherever acid splashes on cotton surfaces, holes form. Always use goggles, rubber gloves, and rubber boots where acid etching is in progress.

When acid etching is completed, rinse the surface to neutralize acidic deposits. Use pH paper to determine whether the surface is alkaline or acidic.

15.8.3 Smoothing Concrete Surfaces and Filling Voids

Smoothing concrete surfaces may be done at any one of these times:

- When the concrete is freshly poured, before any surface preparation
- After pre-cleaning and surface preparation

If the smoothing is done after surface preparation, carefully inspect the surface to ensure it is suitable for coating without additional surface treatment.

To surface and fill voids, use either cementitious materials (with sacking, stoning, or steel trowelling), or use synthetic putties or grouts, such as epoxies and urethanes.

15.8.3.1 Sacking

Sacking is the technique of scrubbing a mixture of cement mortar over the concrete surface using a cement sack, gunny sack, or sponge rubber float. Take great care to ensure that the mortar is correctly proportioned, mixed, and cured before coating.

Remove fins and projections before sacking when the concrete is very green (uncured). It is important to start sacking as soon as possible after the concrete is poured and the forms are removed; this allows the mortar applied by sacking to cure at nearly the same rate as the surface to which it is applied. This improves the adherence of the sack coat to the substrate.

The sacking process generally requires workers to:

- Wet down the substrate with water to prevent the concrete from sucking all the water out of the sack coat, which makes it too dry to finish correctly.
- Apply the mortar by rubbing it over the surface in a circular manner, to make sure all voids are thoroughly filled.
- Go over the surface again when it is almost dry to remove as much of the sacking material from the surface as possible, without removing it from the voids as well.

15.8.3.2 Stoning

Stoning is similar to sacking, except that the process uses a carborundum brick, or other appropriate abrasive block, to smooth the surface of the concrete (Figure 15.10).



Figure 15.10 Stoning

The brick grinds down surface imperfections, opens up surface cavities, and works the mortar into the cavities. At this point,

workers frequently rub the surface with a sack to smooth it even more.

15.8.3.3 Steel Trowelling

Use a steel trowel to move mortar over the surface to fill holes, and to provide a reasonably pore-free surface to apply coatings (Figure 15.11).

Excessive trowelling, however, can result in a too smooth, shiny surface that may need to be roughened before coating.



Figure 15.11 Steel Trowelling

When surfacing concrete with cementitious materials, it is important for these materials to cure completely and bond properly. Ensure the concrete substrate is wetted thoroughly before applying the mortar. The mortar must remain damp during its entire cure cycle.

Many coatings fail due to the loss of adhesion between the cementitious material and the concrete.

15.8.3.4 Treatment of Cracks and Expansion Joints

Cracks are classified as either:

- **Active** — these are self-made expansion joints, and because they are subject to movement, must be handled like an expansion joint.
- **Static** — these do not move, and may be filled or covered without projecting through the topcoat.

It is possible to repair some cracks by injecting 100% solid epoxies or urethane resins to help restore the monolithic character of the concrete (Figure 15.12).



Figure 15.12 Cracks in Concrete

Expansion joints in concrete are always a serious concern, and the methods of treatment depend on the severity of the service environment. Refer to the written specification for the designated method of treatment.

15.8.3.5 Inspection of Surfaces Prior to Coating

A coating inspector's responsibilities for surface preparation of concrete and cementitious surfaces may include:

- Observe surface preparation to ensure that all operations are performed as specified.
- Inspect the prepared surface prior to coating to ensure that the surface is prepared as specified.

Specific items the coating inspector may be required to inspect for, detect, record, or require correction of, may include:

- Ensure laitance removed

- Ensure projections removed
- Ensure hollow areas, voids, and other imperfections are remedied
- Ensure by-products of acid etching are removed
- Check and record pH levels
- Determine if abrasive blasting was performed as specified
- Ensure sand, dust, and other contaminants are removed
- Test the surface for complete removal of sand, dirt, etc.

15.8.4 Concrete Coating Operations

Depending on the formulation of the coating, the most common methods to apply coatings to concrete are:

- Conventional air spray or airless spray
- Hand lay up (a thick mastic-type coating trowelled or otherwise spread onto the surface with or without glass fiber reinforcing mat)



Figure 15.13 Applicator Spraying Concrete Coatings for Concrete

Coatings adhere to concrete as they penetrate the surface to create a bond (Figure 15.13). In the book, "Corrosion Protection By Protective Coatings," Charles Munger states that, "penetration is to concrete what surface profile is to steel." Coatings that penetrate the surface usually achieve an excellent bond.

15.8.5 Concrete Coating Types

Several generic types of coatings are commonly used over concrete including:

- Bituminous cutbacks
- Chlorinated rubber
- Vinyl
- Epoxy
- Novalac epoxy
- Elastomeric polyurethane
- Sheet materials (e.g., rubber)
- Glass-fiber-reinforced plastics
- Furan resins

15.8.5.1 Bituminous Cutbacks

Bituminous cutbacks are solvent solutions of coal tar or asphalt, both of which are used extensively on concrete. Apply bituminous cutbacks alone, or, when used as waterproofing for the exterior of concrete structures, apply as built-up membranes of several coats and include glass fibers as reinforcement.

Bituminous cutbacks are also used to waterproof, particularly the exterior of underground structures. It helps prevent infiltration of water from the outside of the structure. If water infiltrates the concrete, it can disbond coatings on the structure's interior.

Bituminous coatings are also available as water emulsions. Application specifications to apply bituminous emulsions on concrete may require the surface to be dampened before coating application. This helps effect deeper penetration and greater adhesion and helps mitigate the tendency of dry concrete

to “suck” in water from the coating as well as some resin along with it, leaving only a powdery, chalky film of pigment on the surface. This condition could affect adhesion of any subsequent coats applied.

15.8.5.2 Chlorinated Rubber

Chlorinated rubber coatings are used extensively for coating concrete water tanks and swimming pools. They perform well in high humidity.

Because of their resistance to ultraviolet light, chlorinated rubber coatings may be applied as a final topcoat when solvent-based bituminous coatings are applied to exterior surfaces.

15.8.5.3 Vinyl

Vinyl coatings are also used on concrete in a wide range of situations. Vinyl systems usually consist of a vinyl primer, thinned per the specification, to a point where it penetrates the concrete surface and provides a good base for subsequent applications of regular vinyl coatings.

Vinyl coatings dry rather quickly. Applicators should use caution, particularly when coating warm concrete surfaces, to avoid solvent entrapment and subsequent blistering. This occurs when the surface of the coating film dries while there are still solvents in the pores of the concrete surface.

Chlorinated rubber and vinyl have been used widely in the past, but environmental considerations now make them less attractive as currently formulated.

15.8.5.4 Epoxy

Epoxy coatings are available in several formulations and often are used for concrete. Relatively thin epoxy coatings are applied over thoroughly prepared concrete surfaces. Epoxies for concrete are usually solvent-based and use relatively high molecular weight resins similar to epoxies used for steel. These liquid epoxy-based coatings can be applied to an original concrete surface. They penetrate the surface well and serve as a base for other epoxy topcoats.

“Thin coatings” is a relative term. Because of the comparatively deep surface profile typical of concrete surfaces, a coating system that is considered relatively thick on steel, 20 mils (508 µm) for example, might barely cover the peaks of a prepared concrete surface.

Apply a thick epoxy, applied by trowel, spray, or a combination of the two, directly to a clean but otherwise unprepared concrete surface. It fills the concrete surface imperfections and can be used alone or with additional coats of epoxy topcoats fortified with sand.

15.8.5.5 Coal-Tar Epoxy

Coal-tar epoxy combines the properties of both coal, tar, and epoxy, and is one of the few coatings that withstands the corroding action of domestic wastes. Coal-tar epoxies are used extensively as coatings for concrete in waste treatment facilities.

Coal-tar epoxy is particularly useful in environments where water can permeate the concrete and cause the coating to blister.

15.8.5.6 Novalac Epoxy

Novalac epoxy is a more recent addition in the coating industry. It is comparable to an epoxy phenolic and exhibits some characteristics of both materials.

Generally novalac epoxies are 100% solids materials. Apply them using the airless spray method. These materials bond well to concrete, and develop a tight, dense film; they are also very acid-resistant.

15.8.5.7 Elastomeric Polyurethane

Apply elastomeric polyurethane coatings (100% solids) with plural-component spray equipment. Apply in multiple passes to 0.25 in. (6.3 mm), if required. These materials are usually applied over an epoxy-based primer. They are used for secondary containment and quite often to coat concrete sewer pipe.

15.9 Testing

15.9.1 Coating Thickness

Since concrete is nonmagnetic, magnetic test instruments cannot be used to measure DFT. Estimate the DFT of coatings on concrete either from WFT readings, by calculations based on the quantity of coating applied to a given area, or sometimes, by core sample (Figure 15.14). Electronic devices based on ultrasound are also used to determine the DFT of a coating on concrete.



Figure 15.14 Inspection Tools: Wet Film Thickness Gauge, Tooke Gauge, and Ultrasonic Gauge

In some cases, a Tooke gauge is specified to obtain an accurate spot determination of DFT. In this case, a repair procedure is usually specified as well.

15.10 Inspection of Coatings on Concrete

When inspecting coatings on concrete, the inspector may first be required to:

- Ensure that the concrete has cured for the specified time prior to coating
- Determine the moisture level of the concrete. The moisture level in concrete may be inspected with the plastic sheet method (ASTM D 4263).
    - Moisture detector

Some coatings are very intolerant to moisture in concrete; others may bond well to concrete that is only surface dry.

15.10.1 Inspection Procedures

During the coating operations, the inspector may be required to:

- Determine that the specified coating is used
- Ensure that the coatings are stored as specified
- Observe the mixing and thinning operations
- Observe application operations
- Monitor ambient conditions

Make a visual inspection of the coated surface after each coat has been applied to check for:

- Pinholes (detected either visually or with a holiday detector)
- Bare spots
- Runs
- Blisters

Blisters occur frequently on coated concrete since concrete is porous; it holds air which expands when the concrete heats up. Avoid the problem with:

- Use of a special primer.

- Shade to protect the concrete surface from direct sunlight.
- Use of no more solvent than necessary.
- Planned timing so the application is done when ambient temperature is decreasing. This ensures the coating is "sucked" into the pores of the cement.

The inspector should also ensure:

- There are no ridges in the coating
- The coating is cured properly by testing:
  - Hardness test (impressor)
  - Solvent wipe
- The recoat time is as specified
- Minimum and/or maximum DFT are achieved
- No overspray or damage to adjacent areas

Be alert for items that need to be coated, but that are not listed on the work schedule. If certain areas are not coated, they could lead to premature failure of the items that *are* listed on the work schedule.

For example, when a below-grade concrete basin is coated, but the lip of the basin is not, premature failure of the coated portions can result due to moisture vapor transmission. The moisture vapor can enter at the uncoated lip, migrate through the concrete, then apply hydrostatic pressure against the coated surfaces. Other items, such as uncoated concrete drains leading into or out of coated concrete structures, can have a similar effect.

It is important to perform a "water-break" test on the concrete surfaces. The way the water reacts on the surface indicates the way a coating will react with the surface. If the water penetrates into the surface, the coating should, too. If the surface repels water, it will most likely repel the coating, as well. It is not uncommon for a wax-based additive to be added to a concrete mix to make the concrete waterproof and non-porous. This additive can completely hinder coatings application since the additive prevents the coating from wetting-out and adhering.

Pinholes

The specification may require visual inspection for pinholes. Use of a holiday detector also may be specified. Use of a low-voltage wet-sponge-type holiday detector and/or high-voltage DC type may be required. A DC pulse holiday detector is not the best instrument for use over concrete.

Holiday detectors can detect pinholes in coatings on concrete and cementitious surfaces because the concrete normally contains enough moisture to be conductive.

When using a holiday detector on coated concrete, keep in mind that concrete is not a uniform, homogenous substance, and that the conductivity of the substrate can vary from point to point.

It is also very important to get a suitable ground. Do this, when using low voltage, by connecting the ground of a detector to rebar, or by placing a bag of wet sand over the ground wire positioned on the concrete surface. The concrete in contact with the ground wire should be wetted down.

15.11 Maintenance Concrete Coating

Concrete coating projects for immersion service are classified in two primary categories: coating old concrete (concrete with a service life of less than five years) or coating freshly-placed concrete. One of the major

differences between coating old concrete versus new concrete is that repairs often are necessary before top-coating old concrete.

The concrete may have degraded due to chemical attack that progressed through a pinhole or discontinuity in the original coating. If good placement techniques were utilized during the original construction, only minimal repairs need to be made before coating new concrete.

One aspect common to coating both old and new concrete is the need to pre-plan the coatings project, especially if the concrete surface area is large, concrete repairs are extensive, and/or work needs to be completed within a short time period.

Typical problems associated with coating and lining old concrete usually involve porosity including; air pockets; surface irregularities such as construction joints; expansion joints, control joints; and cracks; concrete strength; contaminants left on the concrete surface; and problems associated with ground water.

Few visual standards are available for concrete surface preparation. However, ASTM has developed several Standard Practices that may be specified.

15.12 Summary

A reasonable number of unexpected unknowns often occur during concrete coating projects. Key points in a more successful concrete coatings project include:

- Inspect the concrete and coated surface thoroughly prior to the job start
- Establish the magnitude of the project
- Schedule each work activity and establish a realistic completion date
- Select suitable products for the application
- Develop thorough specifications
- Select an experienced contractor
- Use experienced inspectors to ensure the specification has been followed

Key Terms Definitions

Acid Etching: This process uses a dilute acid solution to remove laitance and roughen the concrete surface.

Efflorescence: This condition is caused by moisture passing through the concrete and carrying soluble concrete salts with it to the surface. The salts react with carbon dioxide in the atmosphere, creating a fluffy white crystalline deposit on the surface.

High Pressure Water Washing: Power washing at 3,000 to 4,500 psi (21 to 31 MPa) that is frequently used on poured concrete surfaces.

Laitance: Weak surface layer of water-rich cement mixture on the surface of fresh concrete caused by the upward movement of water.

Study Guide

1. Some of the properties of concrete are:

_____
_____
_____
_____
_____

2. What is the process by which concrete cures?

_____

3. How do ambient conditions and vibration affect poured concrete?

_____
_____
_____
_____

4. Explain guniting:

_____
_____

5. Concrete may be coated for several reasons including:

- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____

6. Describe the difference between laitance and efflorescence.

_____
_____
_____
_____

7. Surface preparation is generally performed on concrete by:

- _____
- _____
- _____
- _____
- _____
- _____
- _____

8. What is the joint NACE No. 6/SSPC-SP 13 blast standard for surface preparation of concrete?

_____

9. The advantages of waterjetting and wet abrasive blasting on concrete include:

_____
_____
_____

10. What is the difference between sacking and stoning?

_____
_____
_____

11. Several generic types of coatings may be used over concrete including:

- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____

12. Tests for the presence of moisture in concrete include:

_____
_____
_____

Chapter 16: Test Instruments for Coating Concrete

Objectives

When this module is complete, you will have knowledge and understanding of:

- Moisture tests for concrete
- Surface profile
- Ultrasonic thickness gauges
- Holiday detection

16.1 Introduction

This chapter will examine various instruments used during the coatings of concrete, including:

- Moisture testing
- Surface profile
- Dry film thickness
- Holiday testing

16.2 Moisture Tests for Concrete

Tests for the presence of moisture in concrete include:

- **ASTM D 4263**, *Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method*
- ASTM F 1869, Calcium Chloride Test
- Electronic Testing:
  - Concrete Moisture Meter
  - **ASTM F2170-02**, *Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes"*

16.2.1 Test Procedure for Plastic Sheet Method

Tape a segment of a 4.0 mil (1.0 mm) thick, clear polyethylene sheet approximately 18 x 18 in. (457 x 457 mm) over the concrete to be tested so that the concrete is tightly sealed from the atmosphere and sunlight (Figure 16.1). Allow the test patch to remain a minimum of 16 hours.

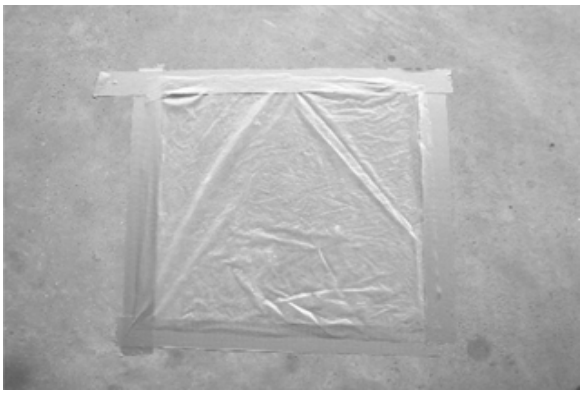


Figure 16.1 Plastic Sheet Test on Concrete Floor

After the appropriate time has elapsed, remove the plastic sheet and inspect the underside of the sheet and the concrete surface at the patch for the presence of moisture.

Samples for floors, walls, and ceilings require one test area per 50 ft^2 (46 m^2), or portion thereof, of surface area, unless otherwise specified.

The recommended practice is a minimum of one test for each 10 ft (3 m) of vertical rise in all elevations starting within 12 in. (300 mm) of the floor.

16.2.2 Calcium Chloride Test Procedure — ASTM F 1869

Apply a weighed amount of calcium chloride, which is very hygroscopic, to a measured area of the concrete surface and allow it to remain for an agreed-upon period of time. At the end of this period, remove and weigh the calcium chloride. Develop a rating scale from the differences in weight of the wet and dry calcium chloride. Use this rating scale to evaluate the condition of the concrete surface before coating (Figure 16.2).

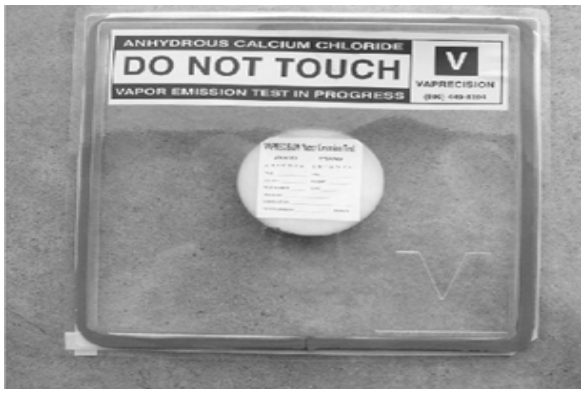


Figure 16.2 Calcium Chloride Moisture Vapor Emission Test on Concrete Floor

This test is often used by flooring contractors to develop a "disclaimer" in their warranties if the moisture vapor emission level in the concrete is considered to be too high to coat or seal.

The failure of coatings applied to floors often is a result of the slab containing too much liquid water, or the passage of water vapor through the slab. It is important to check for both before applying coatings to concrete floors.

16.2.3 Electronic Testing

16.2.3.1 Concrete Humidity Measurement System

Measuring relative humidity in a structural material such as concrete clearly indicates whether the material is dry enough. Bore a hole the required depth, clean out, and insert a plastic sleeve. At this point, push the probe into the sleeve and seal. The material at the bottom of the hole releases humidity into the space around the probe until equilibrium is reached.

Connect the humidity indicator to the probe cable and take a reading. Alternatively, plug the sleeve after insertion. When the humidity in the hole reaches equilibrium, insert the probe and leave it to stabilize for a short time before taking a reading. The supplied cover protects the probe on the construction site against the effects of the ambient conditions. Concrete dries unevenly and is usually drier on the surface. Taking only a surface measurement can give misleading information. The sleeve enables measurements to be made at the correct depth, thus giving a true picture of the humidity in the concrete.

16.2.4 Concrete Moisture Measurement System

A handheld electronic moisture meter that operates on the principle of non-destructive impedance measurement is available (Figure 16.3). It has parallel co-planer electrodes mounted on the base, which during operation, transmits low-frequency signals into the concrete floor screed to a depth of approximately 0.5 in. (12.5 mm).



Figure 16.3 Concrete Moisture Meter

Under normal conditions, concrete is never completely dry. The instrument is calibrated on acceptably dry material. In operation it compares the change in impedance caused by the presence of dampness and displays this on a clear, easy to read analog dial.

To conduct moisture tests, simply brush any dust from a smooth area of concrete and from the electrodes, switch on the concrete moisture meter, and press it firmly onto the surface. Make sure to fully compress the spring-loaded signal-enhancing contacts on the base of the instrument. Read the moisture content from the dial.

The instrument is usually calibrated to give percentage moisture content readings on a clean, bare, dust-free concrete floor slab.

16.3 Surface Profile

16.3.1 Replica Putty

One of the most important characteristics to ensure a coating bonds is the texture or "profile" of the concrete. The upper portion of a slab surface is often called the anchor profile or surface profile and is a measure of the surface roughness. In the past, the concrete surface preparation industry has not generally "measured" concrete's profile or roughness. A permanent replica tape is used to quantify the profile of steel. With current high costs for surface preparation, high performance coatings, and the preponderance for coating failure, the industry needs permanent surface profile replication with precise quantitative analysis to ensure achieved surface roughness. The Concrete Profiler (TCP) is the only product currently able to provide a permanent record of anchor profile of concrete/steel surfaces (Figure 16.4). **ASTM D 7682-10**, *Standard Test Method for Replication and Measurement of Concrete Surface Profiles using Replica Putty* is a standard for its use.



Figure 16.4 TCP Profiler kit with ICRI panels

Figure 16.5 shows examples of various surfaces replicated using The Concrete Profiler.

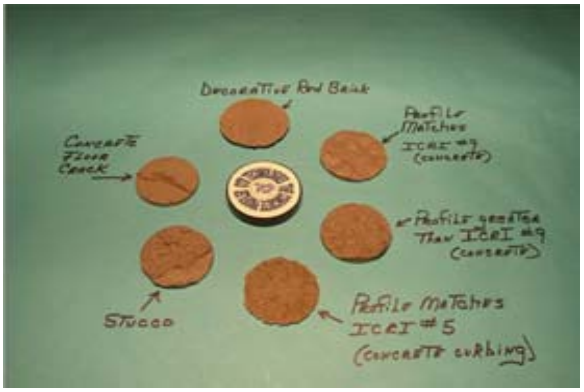


Figure 16.5 Examples of CP Putty replica panels

16.3.2 ICRI Plates

The International Concrete Repair Institute (ICRI) produces a set of comparator plates representing various surfaces of prepared concrete. Specifiers can use these to communicate the required "anchor profile" expected for a concrete surface. Inspectors can use the comparators to ensure the specification requirement is met.

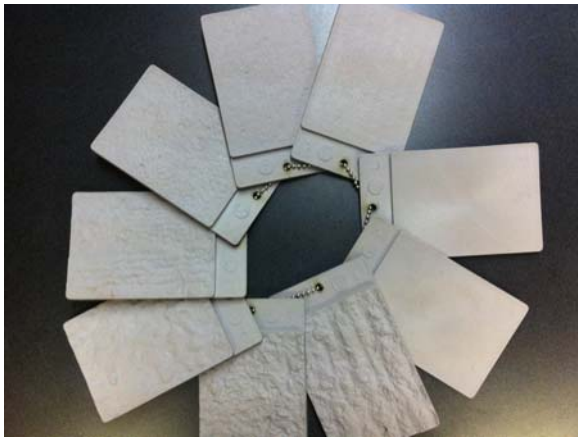


Figure 16.6 ICRI Plates

16.4 Ultrasonic Thickness Gauges

The ultrasonic pulse-echo technique of ultrasonic gages is used to measure the thickness of coatings on nonmetal substrates such as concrete without damaging the coating.

The instrument probe contains an ultrasonic transducer that sends a pulse through the coating. The pulse reflects back from the substrate to the transducer and is converted into a high frequency electrical signal. The echo wave form is digitized and analyzed to determine coating thickness. In some circumstances, individual layers in a multilayer system can be measured.

Typical tolerance for this device is ±3%. Standard methods for the use and performance of this test are available. Use these instruments in accordance with the standards listed below:

- **ASTM-D6132-97.** *Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Over Concrete Using an Ultrasonic Gage*. This test method covers the use of ultrasonic film thickness gauges to accurately and nondestructively measure the dry film thickness of organic coatings applied over a substrate of dissimilar material. Measurements may be made on field structures, on commercially manufactured products, or on laboratory test specimens. These types of gauges can accurately measure the dry film thickness of organic coatings on concrete, wood and wallboard substrates.
- **SSPC-PA 9**. *Measurement of Dry Coating Thickness on Cementitious Substrates*

16.4.1 Calibration and Frequency

From a practical standpoint, sound velocity values do not vary greatly among the coating materials used in the concrete industry. Therefore, ultrasonic coating thickness gauges usually require no adjustment to the factory calibration settings.

Verification is an accuracy check performed by the user using known reference standards. A successful verification requires the gauge to read within the combined accuracy of the gauge and the reference standards.

16.4.2 Operating Parameters

The vibration travels through the coating until it encounters a material with different mechanical properties — typically the substrate but perhaps a different coating layer. The vibration, partially reflected at this interface, travels back to the transducer. Meanwhile, a portion of the transmitted

vibration continues to travel beyond that interface and receives further reflections from any material interfaces it encounters.

16.4.3 Accuracy and Precision

The accuracy of any ultrasonic measurement directly corresponds to the sound velocity of the finish being measured. Because ultrasonic instruments measure the transit time of an ultrasonic pulse, they must be calibrated for the "speed of sound" in that particular material.

16.4.4 Repeatability

Ultrasonic gauges are designed to average small irregularities to calculate a meaningful result. On particularly rough surfaces or substrates where individual readings may not seem repeatable, comparing a series of averaged results often provides acceptable repeatability.

16.4.5 When to Question Readings

Because a potentially large number of echoes could occur, the gauge is designed to select the maximum or "loudest" echo to calculate a thickness measurement. Instruments that measure individual layers in a multi-layer application also favor the loudest echoes. The user simply enters the number of layers to measure, for example three, and the gauge measures the three loudest echoes. The gauge ignores softer echoes from coating imperfections and substrate layers.

16.4.6 Common Errors and Causes

16.4.6.1 Operator Based

Ultrasonic testing works by sending an ultrasonic vibration into a coating using a probe (transducer) with the assistance of a couplant applied to the surface. Know the number of coating layers applied to the substrate being tested so readings are not inaccurate. This is the most common operator-based failure is entering the incorrect information into the instrument. The instrument's operator instruction manual addresses some of the operator errors. Be familiar with the instrument, know what to expect, and how to address the problem.

16.4.6.2 Equipment Based

Know that how coatings interface with the substrate influences the accuracy and repeatability of ultrasonic measurement. Porosity and roughness may promote adhesion, but they increase the difficulty of attaining repeatable thickness measurements by any means. Too rough or porous a substrate leads to irregular readings for any ultrasonic instrument. There are other instrument-based errors; the operator's instruction manual addresses the most frequent errors encountered. Know the issues, know how to correct them, or know who to call for assistance.

16.5 Holiday Detection

The job specification may require visual inspection for pinholes, or it may require a holiday detector. Either a low-voltage wet-sponge-type holiday detector and/or a high-voltage DC type can be used. However, a DC pulse holiday detector is not typically the best instrument to use over concrete.

Holiday detectors can detect pinholes in coatings on concrete and cementitious surfaces because the concrete normally contains enough moisture to be conductive.

When using a holiday detector on coated concrete, keep in mind that concrete is not a

uniform, homogenous substance, and that the conductivity of the substrate can vary from point to point.

It is also very important to get a suitable ground. When using low voltage, connect the ground of a detector to rebar, or place a bag of wet sand over the ground wire positioned on the concrete surface. The concrete in contact with the ground wire should be wetted down.

16.5.1 Low-Voltage DC Holiday Detection

A number of low-voltage wet-sponge detectors are commercially available. They fit into two design categories. The first category is based on the electrical principle of an electromagnetic sensitive relay. The second category is based on the principle of an electronic relaxaciation oscillator that reacts significantly to an abrupt drop in electrical resistance between the high dielectric value of the coating and the conductive substrate. Generally this category of detector cannot be calibrated in the field.

16.5.1.1 Tinker Rasor [†1] M1 Configuration for Concrete

To configure a Tinker Rasor M1 instrument for use on concrete, verify the calibration sequence (the same as used for steel). Remove the back cover and detach the "jumper" (Figure 16.7). Replace the back cover and the unit is now ready for testing thin-film coatings applied over concrete (Figure 16.8).

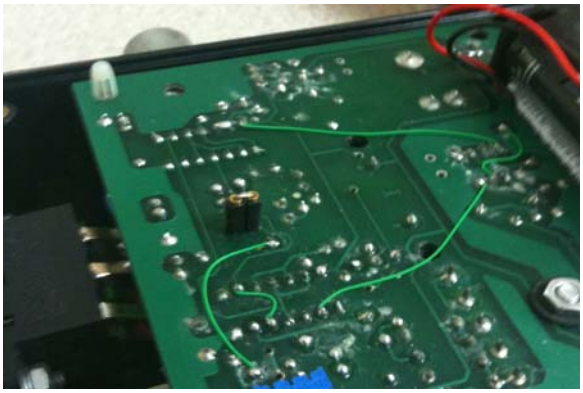


Figure 16.7 M1 Jumper In

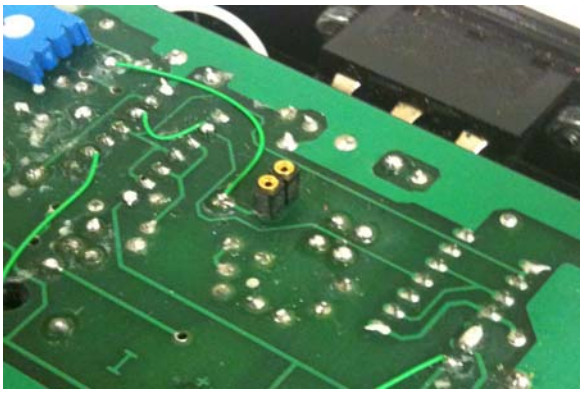


Figure 16.8 M1 Jumper Out

16.5.1.2 Standards

Standards that may need to be consulted depending on specification requirements, coating, and substrate type include:

- **NACE SP0188**, *Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates*
- **NACE TM0384**, *Holiday Detection of Internal Tubular Coatings of Less Than 250 µm (10 mils) Dry-Film Thickness*
- **ASTM D4787**, *Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates*

16.5.1.3 Operating Parameters

Low-voltage wet-sponge detectors may be used to locate holidays in nonconductive coatings applied to conductive substrates.

1. Trade name.

These holiday detectors are portable and easy to operate. They can be used on coatings up to 20 mils (500 µm) thick with reliability. The low-voltage method is preferred by some users because it cannot damage the coating film tested, however it is limited to only detecting pinholes and holidays where the substrate is uncoated. These detectors are generally not intrinsically safe so cannot be used in a hazardous environment.

16.5.1.4 Accuracy and Precision

Accuracy is generally ± 5-10% depending on the manufacturer. Some common voltages include 9, 67.5, 90, and 120 V. Different results are obtained with each voltage, so it is important to select the proper voltage. The appropriate voltages are specified in NACE, ASTM, and ISO low-voltage holiday detection standards. Ideally, a test specification cites the test method to follow for inspection.

16.5.1.5 Repeatability

Given equal conditions, repeatability of results is very high. Results depend on the operator's technique and the speed at which the user performs the test.

16.5.1.6 When to Question Readings

Make occasional checks of the detector's operation, particularly if no holidays are being found. Question results if a known discontinuity is checked and the instrument does not respond. Ensure the instrument is functioning properly and retest any areas in question.

16.5.2 Common Errors and Causes

Common operator-based errors include:

- Failure to keep the probe in contact with the surface
- Moving the electrode too quickly or too slowly across the testing surface
- Loss of connection to the substrate
- Over- or under-saturated sponge

Equipment-based errors include:

- No fault alarm; caused by low battery or bad lead/ground connection causing high electrical resistance
- Excess moisture

16.5.3 High-Voltage DC Holiday Detection



Figure 16.9 High-Voltage Holiday Detector in Use with Rolling Spring Electrode

16.5.3.1 Operating Parameters

Before high-voltage porosity testing is carried out, ensure applied coats are cured, thickness tested, and visual inspection complete and accepted. Make sure coating thickness is above 6 mils (150 µm); coatings below this thickness should be tested with a low-voltage (wet-sponge) unit. High-voltage pulse-type holiday detectors generally have a voltage output range from 800 to 60,000 V. They are designed to locate holidays in nonconductive coatings applied over conductive substrates. Generally, these devices are used on protective coating films ranging in thickness from 6 to 240 mils (150 to 6,000 µm).

On concrete structures, attach the ground to rebar in the concrete, or to a metal object that runs through the concrete (e.g., copper pipe), or, if there is no rebar or metal object, attach a metal fastener, a stub or a nail. Alternatively, lay the bare ground wire on the concrete and anchor it with a burlap (cloth) bag filled with damp sand.

Most high-voltage holiday detectors have a wide range of electrodes available for different uses, among them are:

- Flat-section rolling springs to test pipeline coatings
- Smooth neoprene flaps (impregnated with conductive carbon) to test for thin-film coatings such as fusion-bonded epoxy
- Copper-bronze-bristle brushes to test on glass-reinforced plastic (GRP) coatings

These units are not intrinsically safe and may lead to explosions if used in an explosive atmosphere.

16.5.4 Accuracy and Precision

Accuracy for voltage setting is generally ±5%. Depending on the model, the voltage range (resolution) is 10V or 100V.

16.5.5 Repeatability

Given equal conditions, repeatability of results is very high. Results depend on the operator's technique and speed at which the test is performed.

16.5.6 When to Question Readings

Make occasional checks of the detector's operation, particularly if no holidays are being found. Question results if a known discontinuity is checked and the instrument does not respond. Ensure the instrument is functioning properly and retest any areas in question.

16.5.7 Common Errors and Causes

Common operator-based errors include operator failure to keep the probe in contact with the surface and moving the electrode too quickly or slowly across the testing surface.

Equipment-based errors include:

- Lack of display (depends on model) due to low battery or bad/missing fuse.
- Continuous alarm, caused either by damp surface or moving the probe too quickly across surface. This fault can also be caused by conductive pigments in the coating or by certain types of coating that are able to hold electrical charge on the surface. This causes current flow as the probe passes across the surface.
- No alarm on fault could be caused by a low voltage/sensitivity setting or a bad ground connection. If the concrete is very dry, less than 5% moisture content, then the conductivity can be insufficient to detect flaws.
- No spark at the probe tip could be caused by a lead or connection failure.

Study Guide

1. Explain the procedure for **ASTM D 4263**, *Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method*.

2. Which organization produces a set of comparator plates for various prepared concrete surfaces?

3. DFT of coating on concrete can be measured by:

4. List standards that may be used for dry film measurement of coatings over concrete.

5. Describe the proper, safe, and accurate operating procedure for a low-voltage holiday detector.

Chapter 17: Concrete Inspection Equipment — Practice Lab

17.1 Introduction

In this practical exercise, the equipment presented in the previous chapter is used to evaluate:

- Ultrasonic thickness (UT) DFT
- Holiday testing

Note: Participants have already used the moisture meters to evaluate both wood and concrete for moisture content.

Station 1: Ultrasonic DFT gauge

Equipment:

- UT concrete DFT gauge
- Coated concrete panel
- Couplant
- Calibration materials
- Operating instructions

Assignment:

Verify the gauge calibration and measure the thickness of the coating on the panel provided using the DFT worksheet below.

Worksheets

1. Location: Primer mils / microns?

Spots	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						

Station 1 Continued(next page)

Station 1(Continued)

Spots	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						

Spots	1	2	3	4	5	Overall Average DFT at this Location
1						
2						
3						
Avg.						

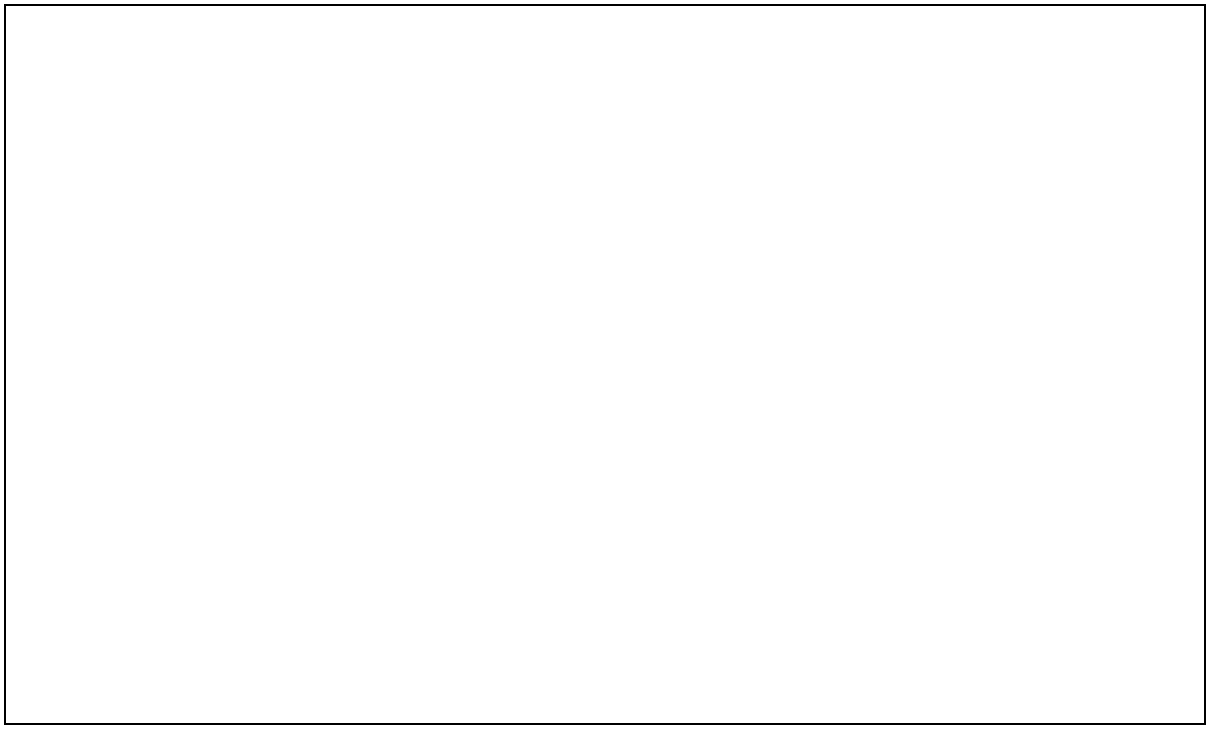
End Station 1

Station 2: Holiday Testing

Equipment:

- Low voltage holiday detector
- Coated concrete panel
- Manufacturer instructions

Evaluate the panel, and record the number of holidays, and note their locations.



Chapter 18: Pipeline Mainline and Field Joint Coatings

Objectives

When this module is complete, you will have knowledge and understanding of:

- Pipeline industry and history
- Pipeline terrain
- Materials of construction
- Pipeline integrity and consequence of failure
- Pipeline coatings — mainline
- 2-Layer PE
- 3-Layer PE
- Fusion bonded epoxy
- Tapes
- Asphalt
- Insulation
- Concrete
- Pipeline coating types — field joint
- Heat-shrink sleeves
- Insulation half shells
- Field foam
- Liquid epoxies
- Cold-applied tapes
- Hot-applied tapes
- FBE field joints
- Petrolatum (wax) tapes
- Other repair products

Key Terms

- Fusion bonded epoxy (FBE)
- 2-Layer PE
- 3-Layer PE
- Tape
- Coal tar enamel
- Heat-shrink sleeve
- Half shell insulation
- Liquid epoxy
- Cold-applied tape
- Hot-applied tape
- Petrolatum (wax) tape

18.1 Introduction

Pipelines are like highways, they are conduits that transport product from one point to another. The three main products that are transported through pipelines are oil, gas, and water. These products need to be transported from their source to their place of processing, storage, or consumption. Natural gas, for example, uses pipelines to transport gas from “well” to “burner tip.”

Gathering pipelines collect raw gas from individual gas wells and move it to the gas plants where it is processed.

Midstream pipelines transport the processed gas from gas plants to storage facilities.

Transmission pipelines transport larger quantities of gas from storage facilities to different markets across the country.

Distribution pipelines collect the gas from the transmission system so utility companies

can distribute the gas to end users i.e., the burner tip.

18.2 Pipeline Industry and History

Fusion bonded Epoxy (FBE) has been one of the primary coatings used on pipelines for many years. Starting in the mid 1970s, FBE was used on girth weld areas as a field joint coating and since that time, millions of girth welds have been coated. In the mid 1980s, FBE was used to coat heat induction bends, flanges, valves, tees, and other fittings. Advances in application technology has resulted in a low cost, high production process to eliminate corrosion on the weld seams of pipelines.

18.3 Pipeline Terrain

Pipeline construction takes place all over the world in all kinds of terrain (Figure 18.1). Modern techniques and equipment make it possible to go places with pipelines that were not previously possible. Off-shore or on-shore, pipelines continue to be laid. They go over mountains, through marshes and swamps, across deserts, or under the sea to move product.



Figure 18.1 Pipeline Terrain

18.4 Construction Materials

Pipeline construction materials vary greatly depending on the product being transported, the service use, the environment in which it is being operated, the economic circumstances, and the safety requirements (Figure 18.2).



Figure 18.2 Construction Materials

Construction materials include, but are not limited to, steel, aluminum, stainless, and plastic.

18.5 Pipeline Integrity — Consequence of Failure

Pipeline integrity is its ability to remain intact. There are three essential questions to ask about how to stop a pipeline from rusting too much:

- What is corrosion?
- What is cathodic protection?
- What role do coatings plays in pipeline integrity?

These three questions are answered in this chapter.

The consequences of pipeline failure range from environmental damage to loss of life. For examples of the extreme consequences, consider the images in Figure 18.3.

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Figure 18.3 Pipeline Rupture and Damage

18.6 Pipeline Coatings — Mainline

The majority of mainline pipes are coated at a coatings facility or plant and shipped to the installation site. To ensure field-joint coatings are properly applied, inspectors need to know:

- What mainline coating was initially applied to the pipeline
- What field-joint coating is specified to be applied
- How to visually recognize the mainline coating

This chapter explores the general characteristics and descriptions of typical plant-applied or mainline coatings. Identifying the plant-applied coating type is crucial for the proper application of field-applied coatings. When applicators and/or inspectors can identify plant-applied coatings, they then know what is required with regard to surface preparation and preheating limitations per the project specification. Coating film thicknesses and variations cannot be identified visually; measure to specifically determine the specified dry film thickness (DFT) when the coating has cured.

18.7 2-Layer Polyethylene (PE)

Two-layer polyethylene (PE) coating (**2LPE)** is the most commonly used coating for pipelines. It is usually yellow in color (Figure 18.4). It has been in use for over 40 years and is the most popular coating for nominal pipe sizes (NPS), NPS2 (2” or 5 cm) to NPS16 (16” or 40.6 cm). The base layer is applied directly to the steel substrate; it is usually black mastic (asphalt and rubber) adhesive. Ensure proper surface preparation before the coating application process begins.



Figure 18.4 2-Layer Extruded Polyethylene Coating

18.7.1 Surface Preparation

2LPE surface preparation is basically the same as used for any other air or centrifugal blasting operation. Things to do before and following the surface preparation are:

- Conduct pre-blast inspection to identify mill defects
- Pre-clean to remove contaminants
- Check ambient conditions and document

- Blast clean according to the specification
- Ensure anchor profile is as specified
- Document/report

18.7.2 2LPE Layers

The base layer or primer of 2LPE is a rubber-modified asphalt sealant that meets the requirements of the Department of Transportation (DOT) in most countries, and their environmental regulations. It bonds polyethylene to steel pipe and is rated for pipeline operating temperatures up to 140°F (60ºC). The product has cold flow and self-healing properties and also has good lap and shear strength properties to resist soil stress.

The top layer is a high-density polyethylene (HDPE) jacket. It may be either crosshead or side extruded (Figure 18.5). The jacket is tough and damage resistant, has good chemical resistance, a melting point of 266°F (130ºC), a brittleness temperature of -148°F (-100ºC), and is UV stabilized for temporary storage.

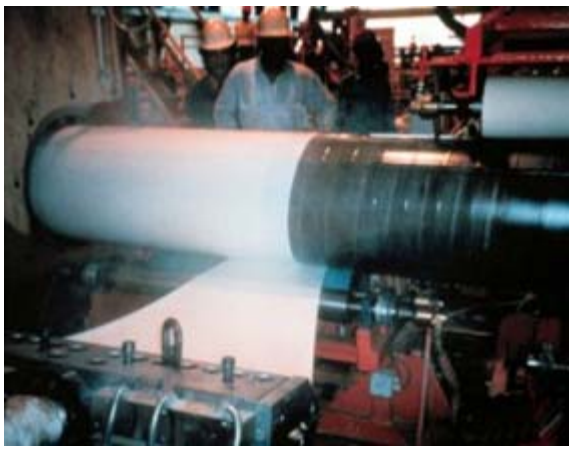


Figure 18.5 Side Extruded Coating

18.7.3 Quality Control

Inspection is just like any other air or centrifugal blasting operation. Note that side-extruded PE coatings have a very faint spiral line around the pipe. Take care not to confuse these coatings with tape coatings. Things to do before and following the application are:

- Check and document ambient conditions
- Pre-clean
- Conduct pre-blast inspection for fabrication or mill defects
- Check to ensure anchor profile matches specification
- Observe mixing of primer and its application
- Check the overlap of the side extrusion coating
- Conduct holiday test
- Ensure pipe is carefully handled
- Document/report

18.8 3-Layer PE

Three-layer polyethylene coating (**3LPE**) looks very much like 2LPE coatings (Figure 18.6). On closer inspection, a green or red layer of fusion bonded epoxy (FBE) is visible directly on the steel. This coating does not contain a black mastic layer.



Figure 18.6 3-Layer Extruded Polyethylene Coating

18.8.1 Surface Preparation

Surface preparation is the same as for 2LPE.

18.8.2 3LPE Layers

The layers are the same as for 2LPE, with the addition of an intermediate layer, which is an adhesive and is not usually visible (Figure 18.7).



Figure 18.7 Cross-head Coating

18.8.3 Quality Control

Quality control is the same as for 2LPE.

18.9 Fusion Bonded Epoxy

Fusion bonded epoxy (FBE) is typically green or red and looks like a "painted" finish (Figure 18.8). It may be a single layer or a two-layer "dual-powder" fusion bonded coating. A close visual inspection shows two distinct layers if it is a "dual-powder" system. The DFT of FBE ranges from 10 to 20 mils (250 and 500 µm).

18.9.1 Surface Preparation

The surface preparation and the coating application are a continuous in-plant process and should be followed by the steps indicated below.



Figure 18.8 Fusion Bonded Epoxy Mainline Coating

18.9.2 FBE Application

Below are the steps for FBE application to incoming pipe (Figure 18.9), which is received in-shop for a mainline coating. The application process is:

- Preheat the pipe to the specified temperature (check often)
- Grit or shot blast the area to NACE #2/ SSPC-SP10 (near white blast)
- Optional: pre-treat the area with an acid bath

- Heat the pipe to the specified temperature before applying FBE
- Apply the FBE coating (single layer FBE or dual powder). FBE is applied in powdered form by electrostatic spray
- Cure the FBE coating
- Quench the coating in a fresh water bath
- Stencil (to track and position in line)

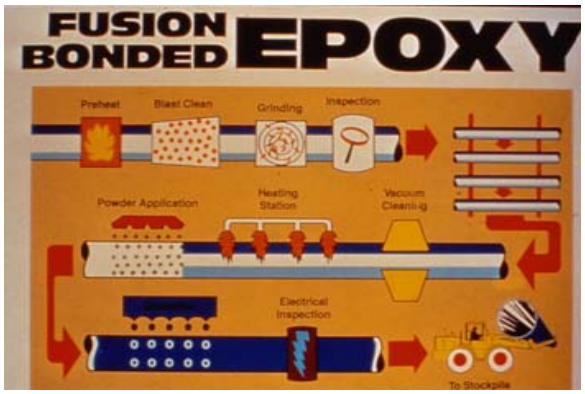


Figure 18.9 Schematic of FBE Coating Plant

18.9.3 Quality Control

Inspectors must know what to look for on FBE coatings. Include these items in the inspection:

- Check pipes for mill damage (gouges, burrs, delaminations) and ensure they are ground down or repaired
- Check that all oil, grease, dirt, or other contaminants are removed
- Ensure acid bath is proper mixture (if bath required)
- Check shot/grit mix for centrifugal blasting
- Check to ensure anchor profile matches specification
- Check pre-heated oven (flame should surround the pipe completely)
- Check the temperature of the pipe before it enters the spray booth (ensure it is in the specified temperature range)
- Ensure the specified coating is applied
- Check cool down bath to ensure the speed and distance are proper for cure
- Check DFT and make necessary repairs (Figure 18.10)
- Inspect for holidays using required voltage versus DFT (Figure 18.11)
- Document and report all processes and observations



Figure 18.10 DFT Readings

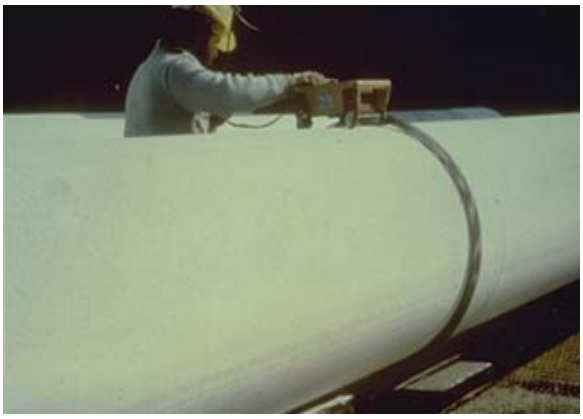


Figure 18.11 Holiday Detection

18.10 Tapes

Treat **tape** as a standalone coating on water lines or as part of an insulation system; the same as 2PLE (Figure 18.12).



Figure 18.12 Tape over Primer on Steel Pipe

18.10.1 Surface Preparation

Prepare the surface preparation of live lines with the following process:

- Pressure wash the surface to remove all contaminants
- Wipe the tape surface with solvent
- Lightly abrade the tape
- Completely remove all loose and disbonded coatings
- Abrasive blast exposed steel

18.10.2 Coatings Application

The general application process is:

- Preheat pipe to the specified temperature
- Abrasive blast clean the surface to an SSPC-SP6 (commercial blast)
- Heat the pipe after blast cleaning to the required temperature
- Apply the primer to the substrate
- Begin application of the spiral wrap tape
- Stencil (size, length, storage, pre-positioning)
- Cut back the coating; the standard is 6" (15.2 cm) or less, or remove protective end covering

18.10.3 Quality Control

Inspect the following items to ensure the tape wrap is done properly:

- Ensure the surface is pre-cleaned according to specification
- Ensure the surface preparation follows the specification
- Check the primer application to ensure compatibility with specified tape
- Check overlap for proper distance
- Check for holidays
- Document and report processes and observations

18.10.4 Coal Tar Enamel

Coal tar enamel (CTE) was used in North America through the 1970s and is still used in some international locations. It had many advantages, such as ease of application and a long life in some environments. It also had many disadvantages that made it subject to corrosion and damage from soil stress. Its use resulted in environmental and exposure concerns as well, so use of coal tar is regulated in some locations.

Technological advances have resulted in new, more economical, higher performing, more environmentally friendly coatings that have become the standard. There are still thousands of miles/kilometers of pipelines operating with CTE coatings (Figure 18.13). CTE as a standalone coating is found on existing operable live lines. Generally, these are large-diameter transmission lines.



Figure 18.13 Pipe Coated with Coal Tar Enamel/ Asphalt

18.10.5 Surface Preparation

The general surface preparation process for CTE is:

- Pressure wash and solvent wipe the coating surface
- Shot/grit blast the external surface of the steel pipe

18.10.6 Coatings Application

The general application process for CTE is:

- Prime the pipe
- Apply coal tar enamel dope
- Wrap the application with glass fiber mat
- Apply a second layer of CTE dope
- Wrap the application with a second layer of glass fiber mat (Figure 18.14)
- Apply an outer wrap of coal-tar impregnated glass fiber felt
- Cool the application



Figure 18.14 Coal-Tar Enamel being Applied with Glass Fiber Mat

18.10.7 Quality Control

Inspection concerns for coal tar enamel application are:

- Check for contaminants on the substrate
- Check the blast cleanliness and profile
- Check the mixing and application of glass layer
- Inspect for holidays and thickness
- Stencil (size, length, storage, pre-positioning)
- Cut back the coating; the standard is 6” (15.2 cm) or less, or remove the protective covers

18.11 Asphalt

Asphalt coatings are basically the same as CTE. The application, surface preparations, and quality control are the same.

18.11.1 Surface Preparation

Surface preparation is the same as for CTE.

18.11.2 Coatings Application

The coating application is the same as for CTE.

18.11.3 Quality Control

Quality control is the same as for CTE.

18.12 Insulated Pipelines

Insulated pipelines are very easy to identify, simply because of the readily apparent insulation (Figure 18.15). The pipe has 1” (2.5 cm) to 4” (5 cm) of foam insulation covered by a layer of polyethylene. A wide variety of direct-to-steel corrosion barrier coatings are available for this product.



Figure 18.15 Insulated Pipeline

18.12.1 Surface Preparation

The surface preparation process is:

- Pre-clean the surface of all contaminants
- Preheat to the specified temperature
- Prepare the surface as required by the specification

18.12.2 Coatings Application

The application process for insulation is:

- Apply the corrosion barrier to the specified requirements
- Spray polyurethane foam insulation over the corrosion barrier (Figure 18.16)
- Extrude the polyethylene outer jacket



Figure 18.16 Application of Polyurethane Foam to Pipe

18.12.3 Quality Control

- Cut back the coating. The standard cutback on steel is 4” (10.2 cm) or less. The standard cutback on foam insulation is usually 7” (17.8 cm), or to the requirement specified
- Pay particular attention to the cutback. Use of 2LPE or 3LPE as a corrosion barrier results in wider-than-standard cutbacks
- Ensure no air pockets are in the insulation
- Make sure there are no holidays (with visual inspection or a holiday detector)

18.13 Concrete

Concrete coatings are easy to recognize; the pipe is covered with concrete (Figure 18.17). Concrete coated pipe is used in conjunction with other coatings such as FBE when the lines run through wetlands or a body of water. The concrete coating enables them to sink. The actual weight of the concrete counteracts the tendency of the pipeline to float. Concrete can be applied in many thicknesses to any diameter of pipe, depending on the weight needed to submerge the pipeline.



Figure 18.17 Concrete Coated Pipe

18.13.1 Surface Preparation

Surface preparation for concrete coated pipe is simply to ensure that all the contamination is removed from the FBE before coating begins. This is usually done by water washing at low pressure. Wrap wire around the pipe as seen in the Figure 18.18.



Figure 18.18 Concrete Coated Pipe

18.13.2 Coating Application

The concrete can be applied either in a plant operation or in the field for repair. After the wire is placed with spacers between the pipe and the mesh wire, the concrete flows to the substrate and strengthens the joint. The pipe is then placed on a spiral roller system (in plants) where the concrete is then blown onto the surface, much like gunite application.

18.13.3 Quality Control

Inspection concerns for concrete coatings include:

- Ensure the pipe is clean before application; use pressure washing
- Ensure the concrete mix is the specified strength
- Check mesh wire for correct size and distance from the FBE pipe
- Check that the concrete thickness after application matches the specification
- Ensure the cure time meets requirement of specification
- Ensure handling does not damage or crack the coating

18.14 Pipeline Coating Types — Field Joints

Pipeline owner/operators normally specify the products to use on the pipeline. Studies of the construction site and operating conditions of the pipeline drive the selection of the appropriate coatings for the desired service life of the coating system. The written specification is the document that directs the application, and it should be followed.

18.15 Heat-Shrink Sleeves

Heat-shrink sleeves have a cross-linked polyethylene backing and a heat-activated adhesive. When sleeves are heated, the heat shrinks the outer backing of the sleeve and the preheated substrate melts the inner adhesive lining. The shrinking of the backing forces the molten low-viscosity adhesive into the surface profile of the pipe and holds it in place during cooling (Figure 18.19).

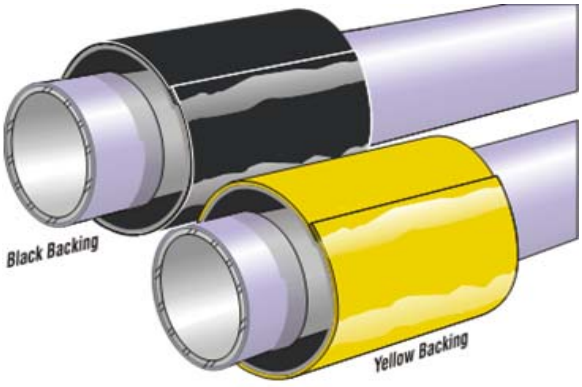


Figure 18.19 Tubular Sleeves



Figure 18.20 Surface Preparation for Sleeve Application

18.15.1 Surface Preparation

Follow the specification's surface cleanliness requirements and ensure they are carried out according to the specification and the manufacturers' product data sheets (Figure 18.20).

Two-layer heat shrink sleeves have a wide range of preheat temperatures. Check the proper temperature for each product in the specification or the appropriate product data sheet for the product in use (Figure 18.21). Verify that everywhere the product is applied is preheated and that the temperature is correct. Use a surface contact thermometer or an IR thermometer. On larger coating areas, check the pipe temperature often to ensure the temperature does not go lower than the minimum preheat required for the product in use.



Figure 18.21 Verification of Pre-Heat Temperature

18.15.2 Coatings Application

After the proper surface preparation and preheat for the sleeve are complete and verified, begin installing the sleeve.

This section details the steps to apply wrap around sleeves:

- Remove the release liner from about 6" (150 mm) from the dog-eared end and heat the adhesive until it is glossy.
- Place the heated tab onto the pipe at about the 12 o'clock position. Ensure that the sleeve is centered over the weld area. Ensure the minimum overlap onto the mainline coating is 2" (50 mm) or whatever the specification states.



Figure 18.22 Centering the Sleeve



Figure 18.23 Heat Shrink Sleeve Application

- Wrap the sleeve around the pipe leaving some slack in the sleeve (Figure 18.22). The amount of slack in the sleeve changes with the outside diameter (OD) of each pipe. The greater the OD of the pipe, the more slack should be left between the pipe and the sleeve. The sleeve overlaps itself at the top of the pipe; therefore, the overlap also changes with the pipe OD. As a general rule for an OD of less than 18" (457 mm), the overlap is 4" (100mm), and with an OD over 18" (457 mm), the overlap is 6" (150 mm). Ensure the closure seal is between the 10- and 2- o'clock position on the pipe.
- After the sleeve is wrapped around the pipe, heat the underlap/overlap area with the torch. Be sure to cover the underlap edge when heating, otherwise the edge will curl (Figure 18.23, Figure 18.24).



Figure 18.24 Shrinking the Sleeve (note the slack)

- Press the underlap/overlap area down. On a Wrapid Sleeve™, the closure seal is pre-attached to the sleeve (Figure 18.25). Canusa Wrap Sleeves have a separate closure seal. With the Wrapid Sleeve™, there are typically two types of closures.
- If a clear wrap closure (CLW) is used: heat the clear CLW from underneath until it starts to turn clear; then smooth into place. Next, heat the CLW from the outside until it turns totally clear; then roll it down into place.
- If a black bulk closure (CLH) is used: heat it from underneath until it turns slightly glossy, then pat it into position. Next, heat it from the outside until it shrinks down and then roll it into place.



Figure 18.25 Shrinking Closure

18.15.3 Quality Control

Inspection for heat-shrink sleeves is generally the same as for other wrap applications. However, there are two types of tests for heat-shrink sleeves:

- Non-destructive
- Destructive

The non-destructive tests are:

- Visual inspection to ensure the sleeve is fully recovered (cured-cooled) and is in full contact with the pipe. Ensure there is adhesive flow out beyond both edges of the sleeve, and there are no cracks or holes in the sleeve.
- Physical inspection; feel the sleeve to ensure that there is no entrapped air under the sleeve.
- Holiday detection; use proper voltage to ensure the test does not become destructive (Figure 18.26).



Figure 18.26 Holiday Testing

The destructive test is peel test.

Peel Test

Cut a 1" (25 mm) wide strip in the cool sleeve and pull it from the pipe (Figure 18.27, Figure 18.28). Look for the mode of failure:

- Cohesive failure in the adhesive = Pass
- Adhesive failure to the substrate = Fail
- Adhesive failure to the backing = Pass



Figure 18.27 Acceptable Peel Test

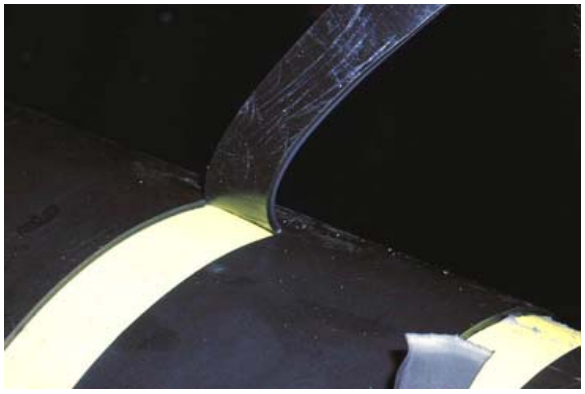


Figure 18.28 Unacceptable Peel Test

18.16 Insulation Half Shells

Polyurethane foam **half shell insulation** is made of minimum density polyurethane. It

is available in pipe diameters 1” (25 mm) to 16” (406 mm) in multiple segment shells. A multiple segment shell can be any pipe diameter a customer requests. Variable thicknesses are available, as well as side grooves and various lengths. Field repair kits are also available from various manufacturers.

18.16.1 Surface Preparation

Follow surface preparation procedures detailed in the coating manufacturer’s installation guide and the specification for minimum surface preparation standards. Note: surface preparation takes place in a smaller than usual space.

Ensure the polyurethane foam is not damaged during surface preparation. Use a shield of some kind to protect the foam.

18.16.2 Coatings Application

Ensure two things before installing the supplied half shells:

- The OD matches the OD of the pipe
- The shells are the right thickness
- The shells are dry and free of frost

To install half shells, simply measure and cut them to the cutback being worked on. Cut with either a sharp knife or a handsaw. Place them into the joint cutback and ensure they fit tightly. There should be little or no gap along the edge of the cutback or where the half shells meet. If there is a gap, fill it with either a small piece cut from the supplied material or use canned foam.

Tape around the half shells to hold them in place.

Before installing insulation:

- Prepare the cutback
- Square off the edges of the cutback (take care not to cut the corrosion coating)
- Ensure the cut is straight and enough corrosion coating is exposed for the joint coating to have the minimum required overlap
- Do not cut until the joint coating just installed is cool enough to avoid being accidentally damaged
- In the case of multi-component epoxies, wait until they are hard enough that a thumb test cannot make an impression in the epoxy with hard pressure.

18.16.3 Quality Control

Application of the half shell is the same as installing other joint coatings. However, application of this barrier has some differences that should be mentioned:

- Only two types of corrosion coatings are typically used for mainline pipes — FBE or tape.
- The foam cutback is typically 13” to 14” (33 cm to 35.5 cm).
- The width of the heat shrink sleeve is only 12” (300 mm).
- When installing the heat shrink sleeves, be careful not to burn the polyurethane (PU) foam.
- Use heat shields to protect the foam.
- Refer to the coating manufacturer’s installation guide for the proper preheat temperatures.
- Be very careful not to burn the foam during preheat. Use heat shields to avoid burning. If heat shields are not available, direct the torch tip toward the center of the cutback. This prevents the flame from directly contacting the foam.

18.17 Field Foam

Installation of injected foam is normally done by subcontractors, who have all of the equipment required to inject the foam.

18.17.1 Surface Preparation

The surface preparation for foam jackets is usually done with 80 grit sand paper. Abrade the polyethylene coating wherever the foam will contact it.

18.17.2 Coatings Application

Place a rigid mold over the joint area and inject foam into the mold via a small hole. Leave the mold on until the foam sets up, then remove the mold. Clean excess foam from the joint area before installing the outer joint coating. Applying the sleeve over the PU foam is similar to applying a sleeve over steel. Follow all of the same steps, with the following considerations:

If injected foam is used, wait at least two hours before installing the outer PE jacket sleeve because the foam will off-gas until then. If the foam is not fully set, and someone shrinks a sleeve over it, the foam can still expand, causing the foam to have a higher profile than the rest of the mainline.

When applying the outer sleeve, take care not to burn the foam during preheat. Use heat shields to avoid burning the foam. If heat shields are not available, direct the torch tip toward the center of the cutback to ensure the flame does not make contact with the foam.

Avoid inhaling the smoke from burning foam.

18.17.3 Quality Control

The outer surface of the foam PE jacket has to be prepared the same as other PE coatings.

Make sure that all excess injected foam is removed from the PE jacket prior to outer sleeve installation.

Before installation of the insulation prepare the cutback:

- Square off the edges of the cutback.
- Take care to avoid cutting the corrosion coating.
- Ensure the cut is straight.
- Ensure enough corrosion coating is exposed so the joint coating has the minimum required overlap.
- Ensure the joint coating just installed is cool enough to avoid being accidentally damaged.
- If multi-component epoxies are used, wait until they are hard enough that hard pressure with a thumb will not make an impression.

18.18 Liquid Epoxies

Liquid epoxy coatings look like FBE. They are identifiable by their distinct colors usually light blue, green, or grey (Figure 18.29). They are used for short sections of pipe, bends, and configurations. Liquid epoxy coatings are applied using a plural component pump. They are base and cure mixed at the spray nozzle, resulting in a film coating from 10 mils (250 microns) up to 60 mils (1,500 microns). Normally, the epoxy has a nominal thickness of 20 mils (500 microns). The dry and cure times depend on the temperature during cure. The temperature rating of liquid epoxy coating is 176°F (80°C) to

330°F (150°C) depending on the specific product used.

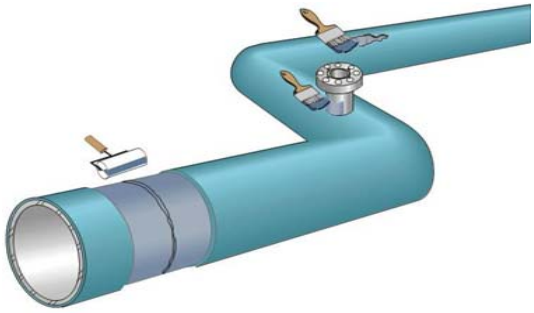


Figure 18.29 Liquid Epoxy Coating

18.18.1 Surface Preparation

To prepare the surface for application of liquid epoxy coatings on mainline pipe:

- Preheat the pipe to the specified temperature
- Grit or shot blast the area to NACE #2/ SSPC-SP10 (near white blast)
- Heat the pipe to the specified temperature
- Cut back the coating; the standard is 3" (7.6 cm) or less, or remove protective end caps

18.18.2 Coatings Application

The application process for liquid epoxy coating is: (Figure 18.30, Figure 18.31)

- Check the product and ensure it is the product specified
- Use the correct application equipment to properly apply the coating
- Perform a wet film thickness check
- Check to make sure the coating cures
- Stencil (size, length, location, positioning)



Figure 18.30 Liquid Epoxy Application - Roller



Figure 18.31 Liquid Epoxy Application — Brush

18.18.3 Quality Control

Inspection of liquid-applied epoxy to mainline should include the following:

- Ensure pre-cleaning removes all contaminates
- Ensure surface preparation is in accordance with the specification and the manufacturers' product data sheets
- Ensure ambient conditions are correct per the specification
- Ensure equipment is in good working order and operators knows how to use it
- Perform a dry film thickness check and record data

- Inspect for holidays using the required voltage for the coating thickness with the proper holiday detection device

18.19 Cold-Applied Tapes

Cold-applied wrap tape is a polyethylene adhesive tape used for corrosion protection on pipelines (Figure 18.32). It is polyethylene film, heat laminated, with an adhesive layer of butyl glue. Some of the benefits of cold-applied tape are:

- Safe to apply
- Environmentally clean
- Very good insulation characteristics
- Good anti-corrosion barrier
- Good mechanical strength
- Low water absorption rate
- Long service life
- Easy to apply



Figure 18.32 Cold-Wrap Tape Application

18.19.1 Surface Preparation

As with all the other coatings previously discussed, the cold-applied pressure sensitive and the cold laminated tapes require the surface to be cleaned to ensure the coating system adheres to the mainline coating after solvent cleaning (SSPC SP-1).

The surface preparation requirements for cold-applied pressure sensitive and cold-laminated tapes require the least amount of preparation. Remove moisture, rust, mill scale, old coatings, and dirt with a solvent saturated rag, then use hand tool cleaning. The specification may sometimes require cleaning to SP-3, but usually hand tool cleaning to SSPC SP-2 is all that is required.

Cold-applied pressure sensitive or cold-laminated tapes do not require preheating. Consult the specification for cold weather application; it may require warming the pipe with an enclosure around the application area. This protects the pipe and the area from snow, sleet, rain, or wind and keeps contamination from the work area.

18.19.2 Coatings Application

Cold-applied tapes are applied by hand while removing the release liner and spirally wrapping with a continuous overlap of the tape. The tension on the tape during wrapping should be enough to ensure the tape conforms to the surface.

A wrapping machine may be required or needed in some circumstances. The process for overlapping and spiral wrapping is the same. Make sure the machine is set according to the manufacturer's guideline for the machine in use.

18.19.3 Quality Control

There are two types of tests that can be done on cold-applied tapes:

- Non-destructive
- Destructive

The non-destructive tests are:

- Visual inspection

- Physical inspection
- Holiday detection (Note: if voltage is too high or coating is not installed properly, this test can be destructive)

For a visual inspection:

- Ensure the tape conforms to the pipe surface
- Ensure the tape overlaps and spirals as required
- Ensure there are no fish mouths defects or a kink in the tape (Figure 18.33)
- Ensure there are no cracks or holes in the tape

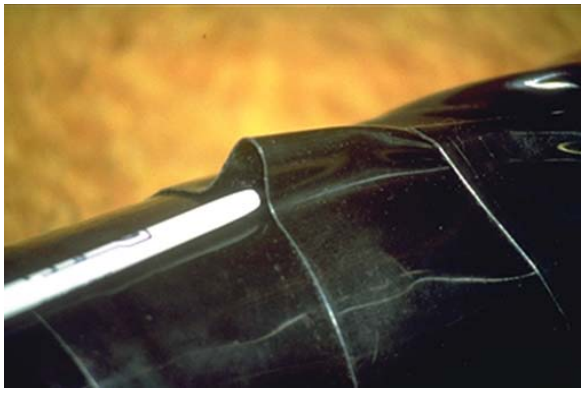


Figure 18.33 Fish Mouth

To perform a physical inspection:

- Feel the wrapped tape to ensure it is totally adhered to the pipe's surface
- For holiday detection, ensure that no holidays are present. Set the voltage properly to ensure no damage to sleeve. This test may not be required in every instance; check the specification before doing a holiday detection test

The destructive tests is a peel test.

18.20 Hot-Applied Tapes

Primer-less heat shrink tape is application friendly. It is available in various roll widths and can be used with mastic or hot melt adhesives. **Hot-applied tape** is formulated with a pliable coating completely saturated into and bonded on both sides of a high tensile strength fabric (Figure 18.34). A polyester film adheres to the coating which facilitates unwinding and acts as an outer wrap.

Some of its uses are:

- Pipeline joints and bends
- Water pipes
- Valves
- Flanges
- Steel pilings
- Marine vessel piping

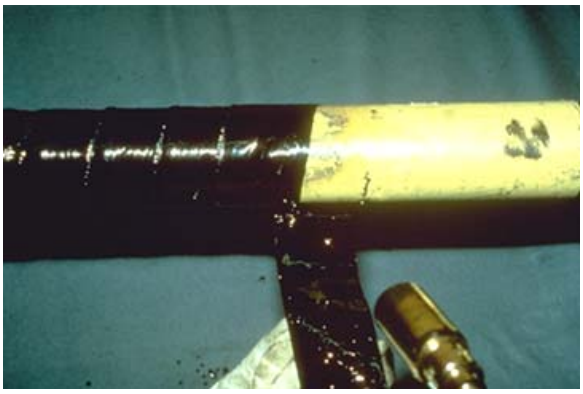


Figure 18.34 Hot-Applied Tapes

18.20.1 Surface Preparation

Surface preparation is the same as heat-shrink sleeves.

18.20.2 Coatings Application

Wrap the tape with a 50% overlap onto the previous wrap. Do not wrap the tape with any significant tension because the tape is designed to shrink to the pipe and does not need to be applied with tension.

With coating fittings or bends such as 90° bends or 45° bends, use only a 50% tape overlap on the *outside of the fitting or bend*

because the inside will overlap more than 50% on its own.

On the other side of the fitting, be sure to leave extra length. When the tape is shrunk, the overall length of the tape shortens and some of length is lost. Be sure to have a minimum overlap of 2” (50 mm) or the minimum indicated in the specification.

To anchor the end of the tape, heat the last 3” (75 mm) of adhesive until it is shiny, then place it into position. Hold it with a gloved hand until it no longer tries to move. Next shrink the Wrapid™ HCA tape.

Use an approved torch set to a medium flame. Start from the end where tape wrapping began, then slowly work along the pipe. Follow the wrapping direction of the tape, while applying heat slowly to the tape so the tape fully recovers without burning.

If there are signs of smoke or bluing on the HCA tape, remove the torch flame from the surface and allow the tape to cool slightly. It takes more heat to shrink the tape where it overlaps itself. Even more heat is needed to fully shrink the tape on the insides of bends or fittings where the HCA tape overlaps itself more than 50%.

Take care to ensure the tape completely shrinks so that it makes full contact with the pipe (Figure 18.35). **Do not trap air under the tape.**

There are two ways to determine if the HCA fully shrunk:

- The tape shrinks down tightly to conform to the pipe surface
- The adhesive flows out from its edges



Figure 18.35 Complete Wrap on Pipe Bend

After fully shrinking the tape, look for small air bubbles trapped under the tape. To remove an air bubble, use a gloved hand to move the air bubble to an edge of the tape. Keep pressure on the tape until the air bubble comes out from under the tape. Reheat the area to ensure all air is gone. If any air remains trapped under the tape, it will rise again when heat is applied to it.

18.20.3 Quality Control

After fully shrinking the HCA tape, inspect for:

- Adhesive bleed-out along the entire length of the taped area. If the steel is still hot enough, reheat any areas lacking adhesive bleed-out.
- Air pockets trapped under the entire length of the taped area. If the pipe is still hot enough, reheat and remove any entrapped air.
- Holidays at points where the tape may have come apart due to insufficient overlap, or where the tape has been burned through due to overheating. Repair all holidays per the specification, or by applying another layer of HCA over the damaged areas with a minimum overlap of 3” (75 mm) on both side of the damaged area.

- Wait for the HCA tape to cool to ambient temperature (Figure 18.36) after completing visual and hands-on tests.





Figure 18.36 Visual checks

18.21 FBE Field Joints

FBE is typically green or red (Figure 18.37). It looks and feels like a single layer of paint.

A two-layer fusion bonded coating is also called *dual powder*. On very close inspection, two distinct layers (green and brown or grey) can be seen.

18.21.1 Surface Preparation

Surface preparation to repair FBE field joints is generally the same as for the previously described repair methods, except for use of the melt stick (Figure 18.38):

- Pre-clean the area using the specified method
- Abrade the surface according to the specification
- Pre-heat the surface according to the specification
- Apply the required repair method in accordance with the specification or the manufacturers' product data sheets

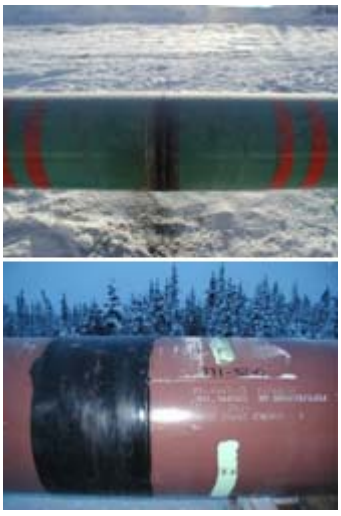


Figure 18.37 Typical FBE

Using the melt stick is **not** a method to consider for field joints. This method is used only to repair very small dings of damage to the mainline coating.



Figure 18.38 FBE Field Joint Surface Preparation

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18.21.2 Coatings Application

Use any of the following materials to repair FBE:

- Epoxy FBE melt sticks (Figure 18.39)
- Liquid epoxy
- Repair patches
- Heat shrink sleeves



Figure 18.39 Hot Melt Stick Repair

Melt sticks are heat activated adhesives supplied as rods for easy application. Use a heat source to "melt" the material and then apply it to the pipeline surface. As it cools it forms a protective film. The melt stick should **not** be used on FBE field joints.

A coating repair patch consists of a cross-linked polyolefin sheet coated with a heat activated adhesive and is designed to seal and protect a damaged pipeline coating system.

Liquid epoxy is a coating that cures into a solid film. Liquid epoxy is applied with either a brush or roller or by spray application.

Heat-shrink sleeves have a cross-linked polyethylene backing and a heat-activated adhesive. When sleeves are heated, the heat shrinks the outer backing of the sleeve and the preheated substrate melts the inner lining of adhesive. The shrinking backing forces the molten low-viscosity adhesive into the pipe's surface profile and holds it in place during cooling.

18.21.3 Quality Control

Things to consider before and during surface preparation include:

- Inspect pre-blast to identify mill defects
- Pre-clean to remove contaminants
- Check specification for required ambient conditions
- Blast clean or abrade in accordance with the specification
- Ensure anchor profile matches requirements of specification
- Ensure the specified product is used
- Verify the mixing is done in accordance with the specification
- Verify the WFT
- Verify the application procedures
- Verify the DFT
- Check for holidays
- Document and report each step of the operation

18.22 Petrolatum (Wax) Tapes

Petrolatum (wax) tape is composed of a synthetic fabric filled with a petrolatum compound, fillers, and anti-corrosion agents to protect against the corrosive environment of pipelines (Figure 18.40). Petrolatum (wax) tape creates a solid barrier against water. It has excellent strength and very good abrasion resistance, as well as good resistance to acids, alkalis, salts, and bacteria. Some of the uses for petrolatum (wax) tape systems are:

- Pipeline joints and bends
- Flanges
- Valves



Figure 18.40 Cold Petrolatum (Wax) Tape

18.22.1 Surface Preparation

Petrolatum (wax) tapes require surface cleaning to ensure adherence to the mainline coating (Figure 18.41). The surface preparation for petrolatum (wax) tapes is usually a SSPC SP1 solvent cleaning. Specifications also usually require power tool cleaning with SSPC SP 3. Remove all loose rust, mill scale, old coatings, and all other contaminants, then apply the tape to the dry surface.

Preheating is not required for the cold applied pressure sensitive or the cold laminated tapes. Consult the specification regarding cold weather application. It might require warming the pipe with an enclosure to protect the pipe and the area from snow, sleet, rain, or wind to keep contamination from the work area.

18.22.2 Coatings Application

To apply petrolatum (wax) tapes by hand, remove the release liner and wrap spirally with a continuous overlap of the tape (Figure 18.42). Apply enough tension while wrapping to ensure the tape conforms to the surface. Petrolatum (wax) tapes may require a paste primer over the surface to displace any remaining moisture and ensure proper adhesion. This is called "wetting out" the substrate. When necessary, use a mastic filler/putty to fill irregularities and help to eliminate air pockets under the tape. An outer wrap may be required to help prevent mechanical or UV damage.

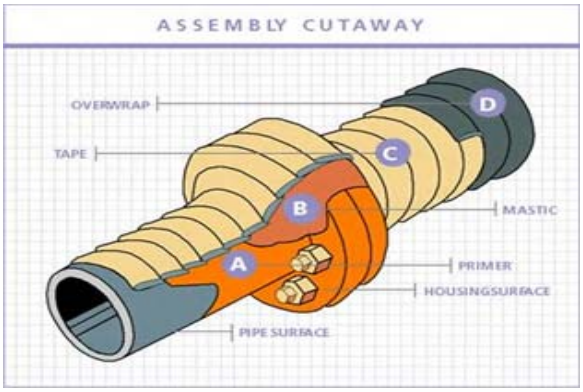


Figure 18.41 Petrolatum (Wax) Tape Surface Prep



Figure 18.42 Petrolatum/Wax Tape Application

18.22.3 Quality Control

There are two classes of tests that can be done on cold-applied tapes:

- Non-destructive
- Destructive

The non-destructive tests are:

- Visual inspection
- Physical inspection
- Holiday detection

For a visual examination:

- Ensure tape conforms to the pipe surface
- Ensure it has the required overlap and spiral application
- Ensure there are no cracks or holes in the tape

To perform a physical check:

- Feel the tape to ensure it is totally adhered to the surface of the pipe
- For holiday detection, make sure there are no holidays in the wrapped tape. Set the voltage properly to ensure there is no damage to sleeve. This test may not be required in every instance; check the specification before doing a holiday detection test.

The destructive test is the peel test.

Holiday detectors can be destructive if the voltage is set too high. Ensure that the detector is set at the specified voltage and no holidays are present.

For the peel test, cut a 1" (25 mm) wide strip in the cool sleeve and pull the strip from the pipe; inspect for mode of failure:

- Cohesive failure in the adhesive = Pass
- Adhesive failure to the substrate = Fail
- Adhesive failure to the backing = Pass

Because of the destructive nature of this test, it is rarely used in a cold tape application. Use when it is determined that the failure may extend onto the mainline coating.

18.23 Repair Products — Other

Mainline coating repair products include:

- Mastic filler
- Repair patches
- Melt sticks (Figure 18.43)

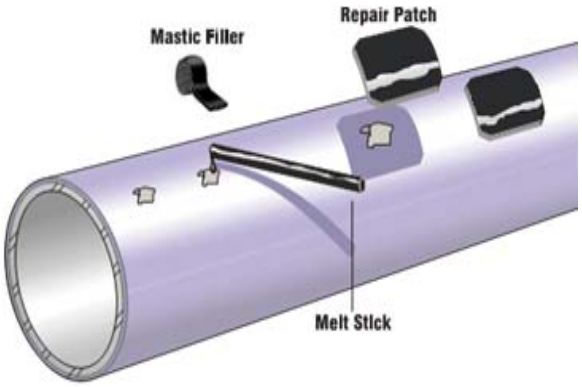


Figure 18.43 Repair Products

Use **mastic fillers** prior to applying a specified coating system. Fill all crevices with filler (typically mastic). The filler is used to fill voids before compatible material is applied. This prevents air from becoming entrapped in the void. Use for both joint coatings and/or repair coatings:

- Excellent adhesion capabilities
- Non-shrinking
- Remains flexible
- Fills surface irregularities
- Excellent water resistance

General uses for a mastic filler are on joints and bends for pipeline repair.

Repair patches consist of a cross-linked polyolefin sheet coated with a heat-activated adhesive. They are designed to seal and protect damaged pipeline coating systems. Advantages of using repair patches are:

- No special tools or equipment required

- Excellent abrasion resistance
- Inert to common acids, alkalis and solvents
- Barrier to moisture and corrosion

These are generally used on pipeline repairs to previously-applied coatings.

Melt sticks are heat activated adhesives supplied as rods for easy application (Figure 18.44). Use a heat source to "melt" the material, then apply it to the pipeline surface. As it cools, it forms the protective film that protects the substrate. Advantages of using melt sticks are:

- Flexible
- Solvent free
- No mixing or measuring
- Quick setting
- Excellent moisture resistance



Figure 18.44 Melt Stick Repair

Melt sticks are generally used for small repairs (holidays) on previously coated pipe.

18.23.1 Surface Preparation

Surface preparation for mainline coating repairs is similar to previously discussed surface preparation. Verify the surface is cleaned properly, the surface preparation is done correctly, and that the preheating is done according to the specification and/or the manufacturers' product data sheet.

There are numerous mainline coatings, each of which can be repaired in various ways. Be sure to use the correct repair procedure detailed in the specification.

Each of the coatings requires a specific surface preparation prior to installation. One requirement similar to the repair coatings is the requirements to solvent wipe (SSPC SP 1) the surface before surface preparation. However, there are some specific issues that must be addressed for different mainline coatings and their respective surface preparation.

18.23.2 Repair Application

Each of the repair methods discussed in this chapter require a specific application method. Consult the specification and manufacturers' product data sheet for the correct method of application. These methods are fully discussed in the NACE Pipeline Applicator Training Course.

18.23.3 Repair Coating Quality Control

The inspection concerns related to melt sticks and patches include destructive and non-destructive tests.

The non-destructive tests include:

- Visual inspection:
  - Ensure the melt stick fully fills the void and meets overlap requirements
  - Ensure the patch recovers and is in full contact with the pipe
  - Ensure there is adhesive flow-out beyond both edges of the patch

  - Ensure there are no cracks or holes in the patch or melt stick application
- Physical inspection:
  - Feel the patch to ensure there is no entrapped air under the patch
- Holiday detection:
  - Passes with no holidays

The destructive tests are the same used for mainline coatings which include:

- Peel Test:
  - Cut a 1” (25 mm) wide strip in the cool patch and pull it from the pipe. Look for the mode of failure:
    - Cohesive failure in the adhesive = Pass
    - Adhesive failure to the substrate = Fail
    - Adhesive failure to the backing = Pass

Though used with patches, this test is rarely done when the area is repaired with a melt stick. It is a **destructive** test, and the inspector should suspect failure of large areas around the repair for this test to be considered.

If applying an epoxy primer or using the FBE melt stick to make repairs, there are a few different tests that can be done. The non-destructive tests are:

- Visual inspection:
  - Ensure the epoxy fully covers the exposed steel area
  - Ensure the epoxy is not too far onto the mainline coating
  - Ensure there are no bubbles, sagging, or burned areas
- Physical:
  - Always check the DFT
  - Check WFT during application
- Holiday detection (Figure 18.45)



Figure 18.45 Holiday Test on Repaired Area

Key Terms Definitions

2-Layer PE (2LPE): This is the most common two-layer polyethylene coating for pipelines and is typically yellow in color. The base layer is applied directly to the steel substrate; it is usually a black mastic (asphalt and rubber) adhesive.

3-Layer PE (3LPE): A coating that looks very much like 2LPE coatings. On closer inspection, a green or red layer of fusion bonded epoxy is evident directly on the steel. This coating does not contain a black mastic layer. The intermediate layer for the three-layer system is an adhesive that is not usually visible.

Coal Tar Enamel (CTE): This coating was used in North America through the 1970s and is still used in some locations internationally. It had many advantages, such as easy application and a long life in certain environments.

Cold-Applied Tape: This tape is a polyethylene adhesive tape used for corrosion protection on pipelines.

Fusion Bonded Epoxy (FBE): This coating is typically green or red and looks like a "painted" finish. It may be a single layer or a two-layer "dual-powder" fusion-bonded coating. A close visual inspection shows two distinct layers if it is a "dual-powder" system. The dry film thicknesses of FBE ranges from 10 to 20 mils (250 to 500 µm).

Half Shell Insulation: A minimum density polyurethane. Various thicknesses are available, as well as side groves and different lengths.

Heat-Shrink Sleeve: This sleeve has a cross-linked polyethylene backing and a heat-activated adhesive. When sleeves are heated, the heat shrinks the outer backing of the sleeve and the preheated substrate melts the inner lining of adhesive.

Hot-Applied Tape: This tape is formulated with a pliable coating completely saturated into and bonded on both sides of a high tensile strength fabric. A polyester film adheres to the coating which facilitates unwinding and acts as an outer wrap.

Liquid Epoxy: Coatings that are used for short sections of pipe, bends, and configurations. Liquid epoxy coatings are applied using a plural component pump. The dry and cure times depend on temperature during cure.

Petrolatum (Wax) Tape: A coating composed of a synthetic fabric, filled with a petrolatum compound, and with fillers and anti-corrosion agents to protect against the corrosive environment of pipelines.

Tape: A standalone coating used on water lines or as part of an insulation system that can be treated the same as 2PLE.

Study Guide

1. Construction materials may include, but are not limited to:

_____
_____
_____
_____

2. The majority of the pipes coated at a coatings facility or plant and shipped to the site are called _____.

3. Typical plant-applied coatings include:

_____
_____
_____
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4. Polyethelene (PE) can be extruded by:

_____
_____

5. Common characteristics of FBE include:

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6. The FBE application process includes:

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7. The advantages of CTE pipeline coatings include:

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8. The disadvantages of CTE pipeline coatings include:

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9. The general application process for CTE includes:

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10. Concrete coating characteristics include:

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11. Pipeline coating field joints include:

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12. Non-destructive tests for heat-shrink sleeves include:

_____
_____
_____

13. Destructive tests for heat-shrink sleeves include:

_____
_____

14. The following materials can be used to repair FBE:

_____
_____
_____
_____

Chapter 19: Destructive Instruments and Tests

Objectives

When this module is complete, you will have knowledge and understanding of:

- Solvent sensitivity training
- Paint inspection gauge
- Saberg drill
- Adhesion tests
- ASTM D6677 knife/micrometer
- ASTM D3359 Measuring adhesion by tape test (Method A and B)
- Pull-off adhesion tests using portable adhesion testers
- Adhesion testing on concrete
- Hardness testing
- Pencil test
- Durometer

19.1 Introduction

Previous chapters have focused on instruments classified as non-destructive, that is, instruments and tests that do not destroy or adversely affect coatings.

CIP Level 1 discusses how a high-voltage holiday detector can damage a coating if the voltage is too high. However, this instrument is regarded as a nondestructive instrument.

Some inspection instruments or tests may deface or destroy a portion of a coating. Obviously, these tests or instruments are classified as destructive.

Do not perform any destructive tests or use any destructive instruments on coatings unless:

- The specification clearly requires specific destructive testing.
- The owner or owner's representative requires or allows such testing.
- Such tests are required in a failure analysis assignment.

Some of the tests, procedures, and instruments classified as destructive include:

- Solvent sensitivity test
- Paint inspection (Tooke) gauge
- Saberg drill
- Adhesion test:
  - 6677 knife/micrometer/microscope
  - Tape pull-off
  - Pull-off adhesion tests using portable adhesion testers:
    - Elcometer†1 106
    - Defelsko†2 Unit
    - HATE Unit
    - PATTI†3 Unit
- Hardness:
  - Pencil
  - Durometer
  - Impressor *(indentation)*

1. Trade name
2. Trade name
3. Trade name

19.2 Solvent Sensitivity Testing

This discussion focuses on the solvent sensitivity test for inorganic zinc (**ASTM D 4752**, *Test Method for Measuring MEK Resistance of Ethyl Silicate Zinc-Rich Primers by Solvent Rub*).

This standard, which uses a rub technique, was established to assess the methyl ethyl ketone (MEK) resistance of ethyl silicate (inorganic) zinc-rich primers.

The MEK resistance of some two-component ethyl silicate zinc-rich primers correlates well with the cure of the primer as determined by diffuse differential reflectance infrared spectroscopy.

Many industry users have adopted this test, or some modification of it, as an indication of the cure of polymerized (chemically induced or heat-induced) coatings. Users may develop special criteria for the coating being tested, and inspectors involved in such testing need to be aware of and understand those criteria.

19.2.1 Test Procedure

A modified test is generally used in the industry, so the inspector may be required to perform this test as follows:

- Select areas on the coating surface at least 6 in. (150 mm) long on which to run the test.
- Clean the surface with tap water or a dry cloth to remove any loose material, then measure the DFT in the selected area.
- Fold a piece of cheesecloth into a pad of double thickness.
- Saturate the cloth to a dripping condition with MEK. *Do not allow more than 10 seconds to elapse before performing the next steps.*
- Place a properly protected index finger into the center of the pad while holding the excess cloth with the thumb and remaining fingers of the same hand.
- With the *index finger at a 45° angle to the test surface*, rub a rectangular area with moderate pressure, first away from the operator and then towards the operator. One forward and back motion is one double-rub and is completed in approximately one second.
- Continue rubbing the surface with the saturated MEK, holding the pad as necessary *without lifting it from the surface* until either the metal substrate is exposed or 50 double-rubs have been completed.
- Record the number of rubs when (if) the substrate is exposed.
- Select an adjacent area as a *control*. Repeat the above steps, except use a dry cheesecloth to establish the effect of burnishing without the influence of MEK. Use this area as the control to visually show the appearance of *no effect*.

As stated, the owner may have developed proprietary acceptance criteria for using this procedure to determine coating cure or may use the scale of resistance published in ASTM D 4752 (Table 19.1).

ASTM D 5402, *Test Method for Measuring Solvent Resistance of Organic Coatings*, is performed the same way on organic coatings using an agreed-upon solvent.

In general, a chemically induced or heat-induced polymerized coating is considered fully cured if none or only a trace of the coating comes off after 50 double-rubs.

19.3 Paint Inspection (Tooke) Gauge

This paint inspection gauge (PIG) is often called the Tooke gauge after its inventor, H.

Tooke, (**ASTM D 4138**, *Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means [Method A]*).

Table 19.1: Scale of Resistance Rating

Resistance Rating	Scale for Resistance Rating
5	No effect on surface; no zinc on cloth after 50 double-rubs
4	Burnished appearance in rubbed area; slight amount of zinc on cloth after 50 double-rubs
3	Some marring and apparent depression of the film after 50 double-rubs
2	Heavy marring; obvious depression in the film after 50 double-rubs
1	Heavy depression in the film, but no actual penetration to the substrate after 50 double-rubs
0	Penetration to the substrate in 50 or fewer double-rubs

It is used to measure total coating thickness and the thickness of individual layers of coatings in multi-coat films (Figure 19.1). The direct measurement is independent of substrate characteristics and, therefore, is often used as a reference instrument.

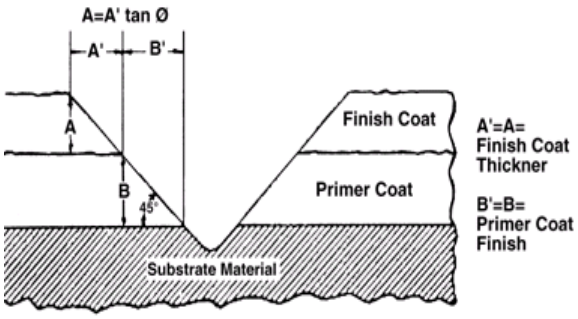


Figure 19.1 Illustration of the Measurement Principle utilized by Tooke Gauge

Use Tooke gauges to see microscopic cracking, a tendency for brittleness, blistering, or other microscopic anomalies in coatings. Use the surface microscope of the gauge to inspect the substrate under the coating for surface contamination, mill scale, and the quality of the abrasive blast. Tooke gauges are used frequently in failure analysis.

There are many different manufacturers and models of Tooke gauges available. The basic operating principles are very similar and are detailed in this section (Figure 19.2).



Figure 19.2 Elcometer 121-3

19.3.1 Equipment Description

A PIG offers a quick, versatile method to examine coatings and take destructive measurements of coating thickness and cross hatch adhesion in a portable, easy-to-use gauge.

The gauges can be used on single or multiple coats on virtually all substrates, including wood, plastics, metals, etc.

Generally, the cutting tips are mounted within the body but protrude for use. Most gauges include a built-in 50x microscope with illumination and a reticle scale in either imperial or metric units.

19.3.2 Proper Use

Make sure batteries, cutters, and cross hatch cutter are properly fitted into the instrument following manufacturer's instructions.

> Remove the batteries from the gauge if it remains unused for a long period of time. This prevents damage to the gauge in the event of malfunction.

19.3.2.1 Test Procedure

1. Mark the surface to be tested with a stroke of the black marker pen provided with the gauge. Ensure there is a distinct contrast between the color of the pen ink and the coating. Different ink colors may be required.
2. Cut the coating at right-angles to the pen mark as follows:
   - Place the gauge on the specimen with both legs or wheels in contact with the surface of the specimen (this ensures that the knife blade produces an exact vertical cut with no tilting to one side).
   - Pull the gauge toward you; as you pull, apply a little pressure.
   - Slight pressure is normally sufficient to penetrate through to the substrate. Heavier pressure may be required for very thick coatings and very hard surfaces (Figure 19.3).

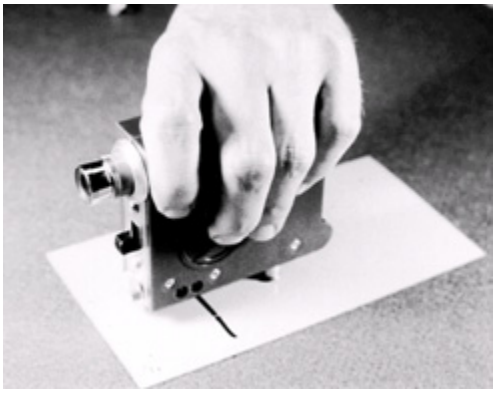


Figure 19.3 Making Cut with Tooke Gauge

3. Position the gauge so the microscope lens is over the cut.
4. Illuminate the cut.
5. Look through the microscope lens and adjust the focus until the cut is clearly visible.
6. Align the reticle scale so that the scale divisions are parallel to the cut. Note that one side of the cut has a straight edge and the other side is likely to be ragged.
7. Measure the width of the cut coating (or coatings) by counting the number of reticle divisions (Figure 19.4).

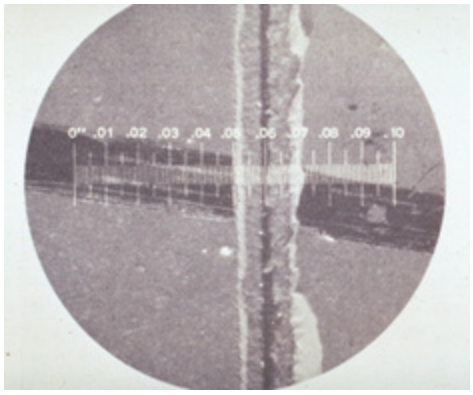


Figure 19.4 Calculating Measurement

To convert the width of the cut coating into coating thickness, multiply the number of reticle divisions by the resolution of the reticle given in Table 19.2.

Example:

A specimen is cut with a No. 4 cutter, the coating thickness is:

- 34 divisions x 2 = 68 microns

or

- 34 divisions x 0.08 = 2.7 mils

Always refer to the model-specific manufacturer's instructions for detailed testing procedures.

Use the paint inspection gauge in accordance with the following national and international standards;

- ASTM D 4138
- ASTM D 3359-B
- ISO 2808-5B
- ISO 2409

Calibration

Gauges do not contain any user-serviceable components. Original factory calibration is done by setting the guide studs in precise alignment with the cutting tip(s). Make checks with precision-applied coating film standards.

For very high-precision work, maintain painted panels of known thickness and check the instrument against these panels periodically.

In the field, verify the cutting tips are in good condition. If the coating tears or is difficult to cut through, the cutting tips may be worn. Replace immediately before further use.

Table 19.2: Paint Inspection Gauge Measurement Ranges

Paint Inspection Gauge (Tooke Gauge) Imperial Units		
Cutting Tip	Thickness Range (Mils)	1 Reticle Division Equals (Mils)
1X	Manufacturer: 20-100 ASTM D4752: 20-50	1.0
2X	Manufacturer: 3-20 ASTM D4752: 3-20	0.5
10X	Manufacturer: 0-1 ASTM D4752: 0-3	0.1
Paint Inspection Gauge (Tooke Gauge) Metric Units		
Cutting Tip	Thickness Range (Microns)	1 Reticle Division Equals (Microns)
1X	Manufacturer: 500-2500 ASTM D4752: 500-1500	20
2X	Manufacturer: 75-500 ASTM D4752: 75-500	10
10X	Manufacturer: 0-75 ASTM D4752: 0-75	2

Paint Inspection Gauge (Elcometer 121-3)					
Cutter No.	Resolution of Reticle		Range		Cutting Angle
	Microns	Mils	Micron	mills	Degrees
1	20	0.8	20 to 2000	0.8 to 70	45
2	10	0.4	10 to 1000	0.4 to 40	26.6
3	5	0.2	5 to 600	0.2 to 24	14
4	2	0.08	2 to 250	.08 to 8	5.7

19.3.3 Operating Parameters

The Elcometer 121-3 gauge measures coatings with a DFT of 0.08 mils to 70 mils (2 µm to 2000 µm). It is fitted with a 50X microscope.

The accuracy and repeatability of instruments are highly dependent on the individual performing the test and how they interpret readings.

Question readings when they are outside of known values. Be sure to use the proper conversion factor for the cutting blade used.

Common errors when performing the test may include:

- Not enough pressure applied to cut through the coating to the substrate.
- Operator pushed gauge away rather than pulling the gauge toward self.
- Read results on the wrong side of the cut line.
- Used the wrong cutting blade for applied coating thickness on the test subject.

19.4 Saberg Drill

ASTM D 4138 describes Method C, which is use of a specific angle-tip drill bit to cut a conical cavity in the coating. This is a Saberg drill, which creates a counter-sunk hole in coating and substrate (Figure 19.5).

19.4.1 Equipment Description

The device is equipped with a 50X microscope and two hand wheels to hold the cutter/drill in place and turn it. This instrument is ideal to cut brittle coatings.



Figure 19.5 Elcometer 195 Saberg Drill

19.4.2 Proper Use

Select and use appropriate handwheel:

- Heavy for hard or thick coatings use handwheel above 10 mils (250 microns)
- Light for soft or thin coatings, use handwheel below 10 mils (250 microns)

Secure the cutter on the selected handwheel. Tighten the recessed socket-head screw.

Place the drill body directly above the test area, then put the cutter into the drill hole.

Rotate the handwheel clockwise with needed pressure (for soft coatings simply rotate finger in recess) until the cutter penetrates the coating and marks the substrate.

Remove cutter assembly and drill body. View the hole with the microscope, focusing on the side of the hole.

Note the number of reticle divisions between the coating surface and the color change between the coating and either the substrate or the next paint surface.

To calculate the coating thickness (for a 20 µm/division microscope):

- Multiply the number of reticle divisions by 20 to give the coating thickness in microns
- Multiply the number of reticle divisions by 0.79 to give the coating thickness in mils

Use this instrument in accordance with ASTM D 4138-C and SAI AS 2331.1.7

19.4.3 Calibration

This instrument does not require calibration.

19.4.4 Operating Parameters

Measures coatings up to 60 mils (1,500 µm).

Accuracy and repeatability depend greatly on the operator's interpretation of the results.

Question the results when they are well outside of the expected range. Re-do the test and pay close attention to the reticle divisions; use the proper conversion factor.

Common errors include:

- Using incorrect handwheel for anticipated thickness of the coating
- Using wrong conversion factor for required unit of measure
- Using excessive pressure when rotating handwheel

19.5 Adhesion Tests

Most coatings properly applied to a well-prepared surface have good adhesion to the substrate; however, users may choose to conduct spot adhesion tests to determine the quality of the coating's bond to the substrate, as well as between coats.

Some of these adhesion tests are:

- ASTMD 6677 Knife/Micrometer/Microscope (Figure 19.6)
- ASTM D3359 Adhesion by tape pull-off test (method A & B)
- Pull-off adhesion tests using portable adhesion testers:
  - Elcometer 106
  - Defelsko Unit
  - HATE Unit
  - PATTI Unit

Adhesion tests are also used to investigate coating failures.

19.6 ASTM D 6677 Knife/ Micrometer



Figure 19.6 Measuring DFT of Paint Chip with Micrometer (ASTM D 6677)

19.6.1 Equipment Description

Use a pocket knife, a very sharp putty knife, or scraper to make a quick adhesion test.

19.6.2 Proper Use of Instrument

Use the knife to cut through the coating, and attempt to peel the coating from the substrate. Use the micrometer to check the thickness of the coating after it is peeled.

19.6.3 Operating Parameters

This is a highly subjective test, and the evaluation of bond strength is at the discretion of the user/inspector. An evaluation of the

results can be open to dispute. Obviously, if the coating is easily peeled from the surface, it could be said that the adhesive bond to the substrate is unacceptable.

If the coating is dislodged from the surface in tiny pieces by picking with the knife, then the bond may be totally acceptable. If this test is used, there must be some agreement between the parties involved about how to evaluate the test results.

19.7 ASTM D 3359 Method A & B Measuring Adhesion by Tape Test

ASTM D 3359, *Standard Test Method for Measuring Adhesion by Tape Test*, describes two methods to measure adhesion by the tape test.

19.7.1 Equipment Description

Method A

The only equipment required for Method A is a sharp knife and the special tape required to cause the pull-off.

Method B

Use a cross hatch cutter or a razor-sharp knife to score through the coating down to the substrate (Figure 19.7). Make a series of cuts at right angles to each other to form a grid of small squares. A range of cutting blades are available for different thicknesses and types of coating.

Apply the tape as required by ASTM D3359 to the surface and remove. Visually assess adhesion by comparing the grid of squares against standards.



Figure 19.7 Elcometer 107 Cross Hatch Cutter

19.7.2 Proper Use

19.7.2.1 Method A (Test Procedure)

In Method A, an X cut is made in the coating film. This method is used for coating films thicker than 5 mils or 127 µm (Figure 19.8).



Figure 19.8 X-Cut After Tape Removal

Rating Results (Method A)

The ASTM descriptions to rate adhesion by the X-cut method (Method A) are:

5A No peeling or removal

4A Trace peeling or removal along incisions or at their intersections

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3A Jagged removal along incisions up to 0.0625 in. (1.6 mm) on either side

2A Jagged removal along most of incisions up to 0.125 in. (3.2 mm) on either side

1A Removal from most of the area of the X under the tape

0A Removal beyond the area of the X

19.7.2.2 Method B (Test Procedure)

If making the cuts individually:

Make a series of cuts at right angles to each other. For films thinner than 2 mils (50 µm), make 11 cuts 1 mm apart in each direction. For coating films from 2 to 5 mils (50 to 127 µm) thick, make six cuts 2 mm apart at right angles to each other (Figure 19.9).

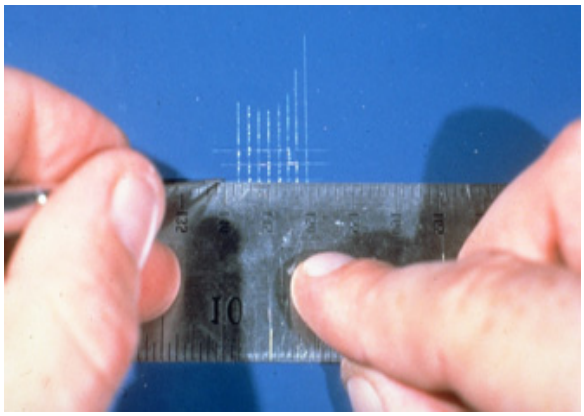


Figure 19.9 Making Cuts with X-Acto Knife for Cross-Hatch Tape Test

If using the cross hatch cutting tool:

Select the appropriate cutting blade, six or eleven, required for coating thickness. Press the blade to the surface, and pull the tool once in each direction to form a 90° angle grid (Figure 19.10, Figure 19.11).

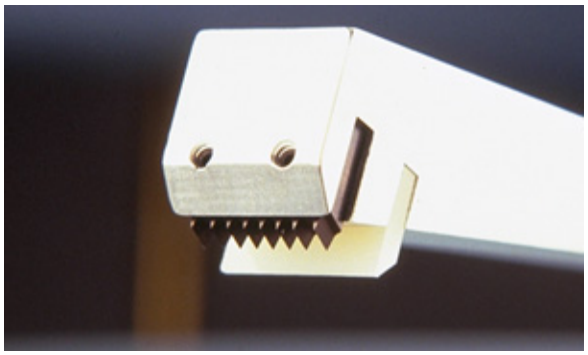


Figure 19.10 Cross-Hatch Cutter with Six Blades

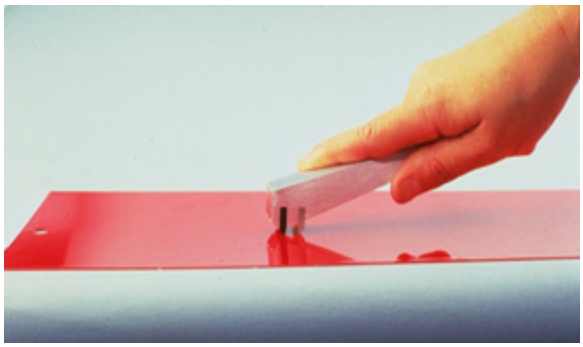


Figure 19.11 Using Cutter Tool to Make Cuts

With either method, be sure to apply sufficient pressure to cut through the coating down to the substrate.

After the cuts are made, brush the area lightly to remove dislodged coating. Remove and discard two complete laps from the roll of special tape. Place tape over the cuts, and smooth the tape firmly with an eraser to ensure good contact (Figure 19.12). After 90 (±30) seconds, pull the tape in a single smooth action at a 180° angle to the coating surface.

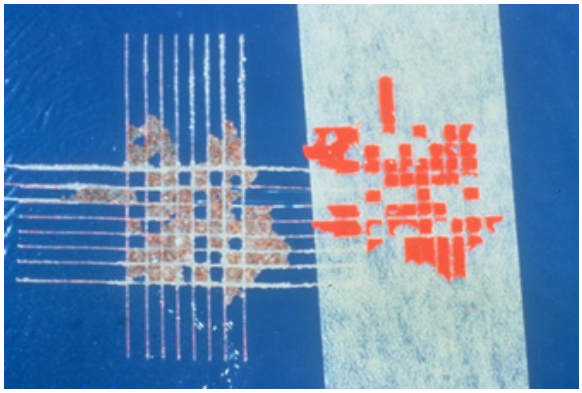


Figure 19.12 Tape after Cross-Hatch Test

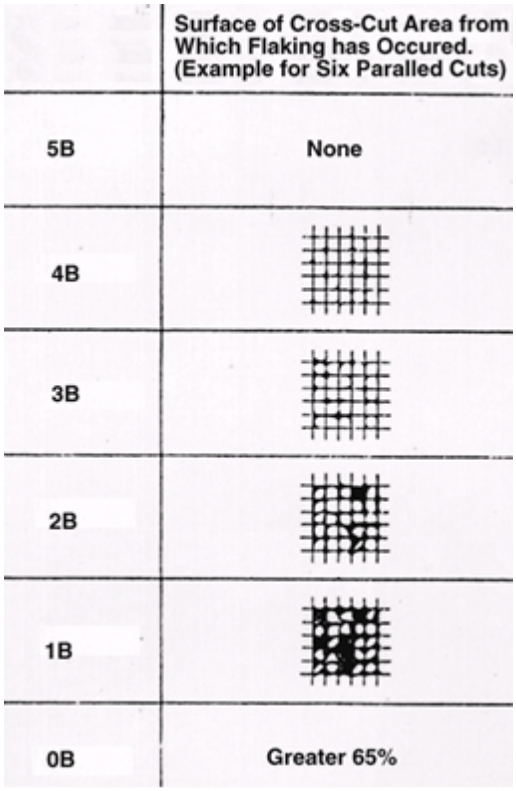


Figure 19.13 Classification of Adhesion Tape Test Results

Rating Results (Method B)

The ASTM descriptions to rate adhesion by Method B are:

5B The edges of the cuts are completely smooth; none of the squares of the lattice are detached.

4B Small flakes of the coating are detached at intersections; less than 5% of the area is affected.

3B Small flakes of the coating are detached along the edges and at the intersections of the cuts. The area affected is 5 to 15% of the lattice.

2B The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35% of the lattice.

1B The coating has flaked along the edges of cuts in large ribbons, and whole squares have detached. The area affected is 35 to 65% of the lattice.

0B Flaking and detachment worse than Grade 1B (Figure 19.13).

Perform these tests in conjunction with ASTM D 3359.

Note: some coatings with good Method A (X cut) adhesion test results do not have very good Method B (cross-hatch) adhesion test results. Brittle coatings tend to fracture badly when tested by Method B.

19.7.3 Operating Parameters

Method B can be performed on paint and powder coating adhesions up to a thickness of 5 mils (125 µm).

Accuracy and repeatability of the test depends on the technique of the user and the user's interpretation of the results.

Common errors made conducting this test include:

- Not applying enough pressure to cut to the substrate

- Using incorrect tape (not enough or too much adhesion)
- Remove tape too quickly or at the wrong angle

19.8 Pull-Off Adhesion Tests Using Portable Adhesion Testers

The X-cut and cross hatch tape tests provide a *rough indication* of a coating's adhesion to a substrate. However, a more precise method of measuring coating adhesion, particularly in multi-coat systems, is required.

A precise method is described in ASTM D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers, Annex A-2.

This test method covers the procedure and apparatus to evaluate the pull-off strength (adhesion) of a coating by determining either:

- The greatest perpendicular force (in tension) a surface can bear before a plug of material is detached
- If the surface can remain intact at a prescribed force (pass/fail)

Failure occurs along the weakest plane in the system, which comprises the:

- Test fixture
- Adhesive coating system
- Substrate

Failure is exposed by the fractured surface.

This test method minimizes tensile stress compared to the shear stress applied by other methods such as scratch or knife adhesion, and the results may not be comparable.

The ASTM D 4541 test method uses a portable adhesion tester capable of applying a concentric load and counter load to a single surface so coatings with only one side accessible can be tested.

Measurements are limited by the strength of the adhesion bonds between the loading fixture and the coating surface or the cohesive strength of the substrate. The test can be destructive and spot repairs may be necessary.

In general, to perform the pull-off adhesion test, secure a loading fixture (aluminum test dolly) with adhesive to ensure it is perpendicular to the coating surface. After the adhesive cures, attach the portable test apparatus to the test dolly, and align it to apply perpendicular tension to the test surface.

Periodically increase the force applied to the test dolly, and monitor it until either a plug of coating material detaches or a specified value is reached.

When a plug of material detaches, the exposed surface represents the plane of limiting strength within the system. The nature of failure is qualified by the percent of adhesive and cohesive failures at the interfaces and layers involved. The pull-off strength (adhesion) of the coating is reported in pounds per square inch (psi) or kilograms per square centimeter (kg/cm2).

19.8.1 Pull-Off Adhesion Tester

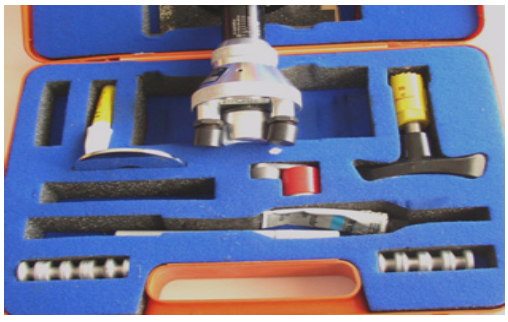


Figure 19.14 Elcometer 106 Adhesion Tester

19.8.1.1 Equipment Description

Adhesion testers are designed to measure the bond strength of applied coatings (Figure 19.14). A wide range of coatings can be tested, including paint, plastic, sprayed metal, epoxy, wood veneers, and laminates on wood, metal, or plastic.

The Elcometer 106 Scale 6 adhesion tester determines the bond strength of coatings applied to concrete surfaces, and tests the tensile strength of hardened concrete on site.

19.8.1.2 Proper Use

The Elcometer 106 and the Elcometer 106 Scale 6 operate in much the same manner with very minor differences. Always refer to the model-specific manufacturer's operating instructions. For purposes of instruction, this section focuses on the Elcometer 106 tester.

Testing areas should be flat surfaces large enough to accommodate the specified number of replicate tests. Usually, a minimum of three replications is required to statistically characterize the test area.

The selected testing areas must also have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force.

Lightly roughen the surface of the dolly with a light abrasive-coated paper (400 grit or finer) as well as the coating where the dolly is to be applied (Figure 19.15). Be careful not to affect the integrity of the coating. Then de-grease these areas with a suitable solvent (MEK or xylol) to clean both surfaces.



Figure 19.15 Roughening Dolly

Mix the adhesive (specified and/or agreed upon) in accordance with the manufacturer's recommendation. The adhesive supplied with the instrument is Regular Araldite which is a two-component epoxy paste. Other adhesives available include acrylics with much faster setting times. Determine the suitability of the adhesive before use. Some coatings are adversely affected by adhesives, and some adhesives are contaminated by coating environments, solvents, etc.

There are two dolly sizes available for the Elcometer 106: 20mm (standard dolly) and 40mm (large dolly). Coatings on concrete, cementatious layers and uneven surfaces can be tested more effectively with a large dolly. This has twice the diameter and 4 times the area of the standard dolly. The scale readings of the Elcometer 106 must be divided by 4 to compensate. The large dolly is taller than the standard dolly. A special base ring is used to support the instrument to enable correct operation.

Apply an even film of adhesive to the roughened dolly surface. Place the dolly onto the prepared test surface and apply pressure to squeeze out excess adhesive.

Carefully remove the excess adhesive from around the dolly. Caution: movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute discontinuities during testing.

Allow enough time for the adhesive to set up and reach the recommended cure. Maintain a constant contact pressure on the dolly during adhesive setup and the early cure stage. Use magnetic or mechanical clamping systems, but take care with clamping systems such as masking tape, which depend on tack. Ensure they do not relax with time, and allow air to intrude between the dolly and the test area.

Do not score around the dolly; this violates the fundamental in-situ criterion that only an *unaltered coating* can be tested (see ASTM D 4541). Report if the coating is scored.

> Cutting around the base of the dolly is only necessary when lateral bonding in the coating is greater than adhesion, for example, elastomeric coatings.

Use a bearing ring if the substrate is thin, less than 0.25 in. (6.4 mm) thick. Place the ring so it centers around the dolly on the coated surface.

After the adhesive is cured and the area is ready to test, position the adhesion tester over the dolly to ensure it lies flat on the surface. Slacken the hand wheel or nut, then set the dragging indicator on the scale to zero (0) and carefully engage the dolly with the claw (Figure 19.16, Figure 19.17).

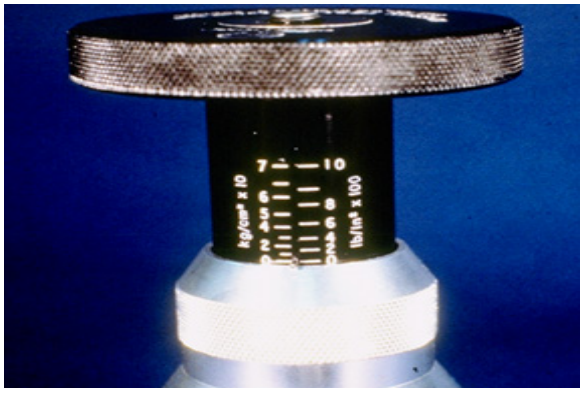


Figure 19.16 Close Up of Indicator

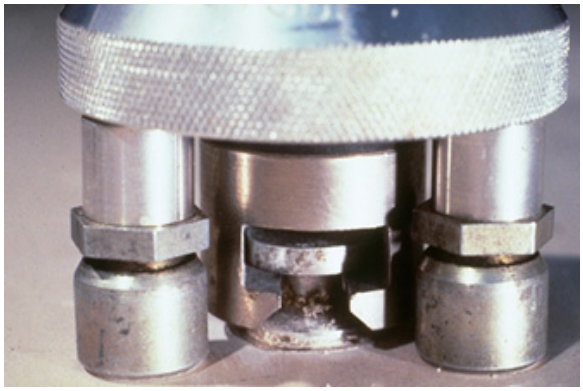


Figure 19.17 Placing Claw Over Dolly

Hold the adhesion tester steady with one hand to prevent rotation then tighten the hand wheel or nut slowly and evenly (Figure 19.18) to apply increasing force to the dolly and to the coating. Increase the load in a smooth continuous manner at a rate of no more than 150 psi/s (1 MPa/s).

Continue increasing the load until the coating fails and the dolly parts from the surface or until the specified test force is reached. Ensure this occurs in about 100 seconds or fewer. (Figure 19.19). Read the force indicator scale to determine the highest value attained at failure, or the maximum force applied.

Slacken the hand wheel or nut to remove all the force from the unit immediately after the test is complete and the pull-off force has been recorded.



Figure 19.18 Turning Hand Wheel

If a plug of material is detached, label and store the dolly for qualification of the failed surface (Figure 19.20).



Figure 19.19 Close Up of Dolly after Pulling



Figure 19.20 Dollies with Various Amounts of Adhered Coating

For all tests-to-failure, estimate the percent of adhesive and cohesive failures according to their respective areas and locations within the test system comprising the coating and adhesive layers. One way to make this determination is:

- Describe the test specimen as substrate A, upon which successive coating layers B, C, D, etc., are applied, including the adhesive Y, which secured the dolly Z to the topcoat.
- Designate cohesive failures by the layers within which they occur as B, C, etc., and the percent of each.
- Designate adhesive failures by the interfaces at which they occur as A/B, B/C, C/D, etc., and the percent of each.

As with all instruments, know the proper operating procedure. Refer to the manufacturer's operations manual for more detailed instructions.

19.8.1.3 Calibration

All manufacturers' instruments should meet all NIST standards for quality and use and be in accordance with ANSI/NCSL Z540-6 (National Calibration Standard).

Table 19.3: Adhesion Tester Ranges

	Scale	Range		
		N/mm2 (MPa)	kg/cm2	lb/in2
Elcometer 106/1	1	0.5 to 3.5	5 to 35	100 to 500
Elcometer 106/2	2	1 to 7	10 to 70	200 to 1000
Elcometer 106/3	3	3 to 15	30 to 150	500 to 2000
Elcometer 106/4	4	5 to 22	50 to 220	500 to 3200
Elcometer 106/5	5	0.05 to 0.2	0.5 to 2.0	5 to 30
Elcometer 106 Scale 6 (for concrete)	6	0 to 3.5		0-500

For checks and certification, contact the gauge's manufacturer or supplier. Periodic calibration checks are needed to ensure that the correct load being applied to the dolly is required.

19.8.1.4 Operating Parameters

There are five different ranges available for Elcometer 106 (Table 19.3). With the Elcometer 106 Scale 6, each range is expressed in imperial and metric units and is directly related to the area of the standard dolly.

The accuracy of the Elcometer 106 is ±15% of the actual reading. The repeatability of testing results is very high.

Common Errors:

- Using an adhesive with a lower bond strength than the target range
- Turning the hand wheel too fast or using jerking motions can cause false readings
- Not setting the indicator to zero

19.8.2 Defelsko Positest AT

19.8.2.1 Equipment Description

The Defelsko Positest AT measures the force required to pull a specified test diameter of coating away from its substrate using hydraulic pressure (Figure 19.21). It is available in either a manual or automatic version. This section focuses on the manual version.

The Positest AT Manual has a heavy-duty manual hydraulic pump to apply smooth and continuous pull-off pressure, and a pull rate indicator to manually monitor and adjust the rate of pull.

The Positest AT Automatic uses an electronically controlled hydraulic pump to automatically apply pull-off pressure at a user-specified rate.



Figure 19.21 Defelsko Positest AT Manual and Automatic

19.8.2.2 Proper Use

Refer to the model-specific manufacturer's instructions for detailed operating instructions.

Choose the appropriate dolly size for the anticipated bond strength range. This has 10, 14, 20, or 50 mm dollies with capability and measurement resolution across a wide range of bond strengths.

19.8.2.2.1 Dolly Preparation

To remove oxidation and contaminants, place the abrasive pad (included with equipment) on a flat surface and rub the base of the dolly across the pad 4-5 times. As required, remove residue left from abrading with a dry cloth or paper towel.

19.8.2.2.2 Coating Preparation

Lightly roughen the coating with the abrasive pad.

> Coating abrasion may introduce flaws, so only use it if necessary to remove surface contaminants or when the bond strength between the adhesive and the coating is insufficient for pull testing.

To promote the bond between the dolly and the coating, degrease the coating test area with alcohol or acetone to remove oil, moisture, or dust.

> Ensure that alternative abrasion techniques, degreasers, or adhesives do not alter the properties of the coating. Test by applying a small amount of degreaser or adhesive to a sample area and observe effects.

19.8.2.2.3 Adhesive Selection

The adhesive in the PosiTest Adhesion Tester kit is included because of its versatility. This adhesive has minimal impact on a variety of coatings and has a tensile strength exceeding the maximum performance capabilities of the pressure system under ideal conditions. Choose an adhesive based on requirements such as cure time, coating type, working temperature, and pull-off strength. Quick curing one-part cyanoacrylates (super glues) may be sufficient for painted surfaces, but two-part epoxies are often preferred for porous or rough coatings.

19.8.2.2.4 Dolly Application

Mix the adhesive per manufacturer's instructions, then apply a uniform film to the

base of the dolly, approximately 2-4 mils (50-100 microns) for best results. Attach the dolly to the prepared coating test area.

> If the coated test surface is overhead or vertical, use some means to hold the dolly in place during the cure time, i.e., removable tape.

Gently push down on the dolly to squeeze out excess adhesive. Do not twist or slide the dolly back and forth on the coating because the movement can generate air bubbles.

Carefully remove excess adhesive from the edges of the dolly with cotton swabs. Allow to cure per the adhesive manufacturer's instructions.

> Many adhesives cure faster and provide a stronger bond when heat cured. Similarly, cold environments may cause a longer cure time and weaker bond strength.

19.8.2.2.5 Pull Off Test

The PosiTest AT powers-up and displays dashes when the "zero" button is pressed. To preserve battery life, the instrument powers down after 5 minutes of no activity.

Ensure the pressure relief valve (Figure 19.22) on the pump is completely open (turn counter clockwise).

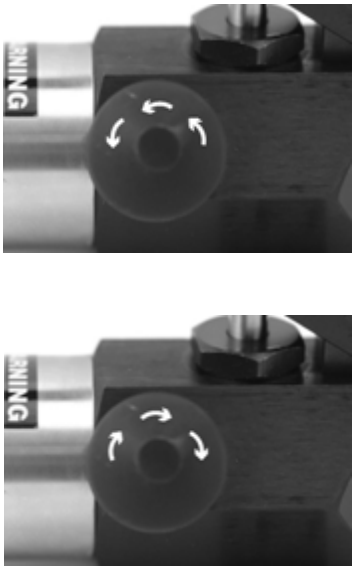


Figure 19.22 Pressure Relief Valve

Push the actuator handle completely down into the actuator assembly. Place the actuator assembly over the dolly head. Attach the quick coupling to the dolly by reaching through the holes in the actuator assembly to lift the quick coupling. Release the quick coupling when the dolly head is completely engaged.

Close the pressure relief valve on the pump completely (turn clockwise).

To verify and adjust the dolly size, press the "dolly" button. Select the pressure units by pressing the "psi/mpa" button. The instrument will maintain these adjustments even after the "zero" button is pressed.

Zero the instrument ***before*** pumping by pressing the "zero" button. This clears the display, zeroes the instrument, and prepares it for the test.

Prime the pump slowly until the displayed reading approaches the priming pressure. The priming pressure is the point at which the instrument begins to calculate and display the pull rate. It is also the pressure at

which the ability to store readings is enabled. Priming pressures for the various dolly diameters are:

10 mm	400 psi	2.8 MPa
14 mm	200 psi	1.4 MPa
20 mm	100 psi	0.7 MPa
50 mm	50 psi	0.4 MPa

For optimum results, prior to exceeding the priming pressure, return the pump handle to its full upright position then complete a single stroke at the desired pull rate until the actuator separates the dolly from the coating.

Open the pressure relief valve and remove the dolly from the actuator assembly.

Store readings into memory by pressing the "memory" button.

Input the stored readings into Defelsko's PosiSoft software, (Figure 19.23), which has a variety of functions including:

- Displays pressure, rate, test duration, and dolly size for up to 200 pulls
- Calculates max, min, mean, and standard deviation
- Prints and displays basic charts and histograms
- Performs real time graphing of individual pulls for a more detailed analysis of applied pressure over time
- Allows entry of notes and annotations
- Exports to a document or spreadsheet
- Has multi-language support, including English, German, Italian, Spanish and French



Figure 19.23 Screenshot of PosiSoft Software

Use the Positest AT in accordance with national and international standards including:

- ASTM D 4541/D 7234
- ISO 4624/16276-1
- AS/NZS 1580.408.5

19.8.2.3 Calibration

The PosiTest is shipped with a certificate of calibration showing traceability to a national standard. Return the PosiTest at regular intervals, typically one year, for calibration.

19.8.2.4 Operating Parameters

The PosiTest Adhesion Tester pressure system is calibrated and certified to ± 1% accuracy using an NIST traceable load cell. The instrument has a resolution of 1 psi (0.01 MPa). Measurements obtained are highly repeatable.

Always question readings when measurements are outside known parameters. Also, question readings if the digital readout does not show a steady, consistent rise the test, or if the gauge was not zeroed prior to use.

Common errors that may occur using this instrument include:

- Pumping up pressure too quickly at the beginning of a test can cause a sudden

pressure pulse, fooling the tester into thinking the test is complete and causing it to freeze.

- Using improper adhesive; applying too little or too much adhesive; and/or not allowing the adhesive to cure properly.

19.8.3 Hydraulic Adhesion Tester (HATE) Unit

19.8.3.1 Equipment Description

The Elcometer 108 Hydraulic Adhesion Tester (HATE) is used to measure the adhesion between a coating and its substrate (Figure 19.24). The tester is a reliable, simple gauge. There are two versions of the Elcometer 108; one is fitted with a dial pressure gauge and the other is fitted with a digital pressure gauge.



Figure 19.24 Elcometer 108

19.8.3.2 Proper Use of Instrument

Identify the dolly test surface and wipe it and the sample area with a solvent to remove oil and grease. Apply a thin, even coat of adhesive to the dolly test surface. Press dolly on to sample for about 10 seconds. Leave dolly undisturbed and allow the adhesive to harden for the amount of time required per the adhesive instructions.

Turn the handle fully counter-clockwise to release any pressure in the instrument. Use a thumb or finger to push the pin fully upward toward the coupling. Pull coupling sleeve up and insert pin into centre of dolly. Release the coupling sleeve. The instrument should grip the dolly firmly. If the coupling does not grip the dolly firmly, there may be excess adhesive in the center of the dolly. Remove any excess adhesive.

To zero the pressure gauge:

Dial pressure gauge:

- Rotate knob on front of gauge to turn the red drag indicator to 0 (zero).

Digital pressure gauge:

- Press on/off button to turn gauge on.
- Press 0 (zero) button to zero the gauge.
- Press **MAX** button to set gauge to store the maximum force recorded during the test. The display indicates MAX and holds the maximum value until the button is pressed a second time. The MAX feature is switched off when the gauge is switched off.

Increase pressure by turning the handle clockwise, slowly and smoothly, until either of the following occurs:

- For destructive testing: the dolly and coating pull off the substrate
- For non-destructive testing: the minimum specified pressure value is reached.

If possible, complete the test within 90 seconds of starting. This is in accordance with some adhesion-testing standards.

Record the results of the test including the following information:

- Pressure (indicated by the gauge)
- Test location
- Type of adhesive
- Coating system details
- Duration of tests

- Appearance of breaks, e.g., clean between coating and substrate, separation of coating layers, jagged edges, etc.

After the test decrease the pressure to zero by turning handle fully counter-clockwise.

Cyanoacrylate adhesives are normally recommended to glue dollies to the sample area because of their relatively quick curing time. However, there are a number of coatings that cyanoacrylate adhesives may not be suitable for. These include:

- Thermoplastics, celluloses, vinyl, chlorinated rubbers and some acrylics, because the glue can possibly react with the coating
- Porous coatings, e.g. metal sprayed, whose adhesion could be compromised by the glue. The glue has a low viscosity enabling it to travel into the coating and possibly stick coating particles together.

Use a two-pack epoxy such as Araldite™, or a modified acrylic gel-type adhesive, with the coatings described above.

If in doubt about the type of adhesive to use, please contact the coating manufacturer for advice.

Use the HATE unit in accordance to:

- ASTM D 4541
- ISO 16276-1
- NF T30-606

19.8.3.3 Calibration

Verify the calibration of the gauge in the field with the Elcometer 1970 PFCV (Portable Field Calibration Verification Unit). It connects to Elcometer 108 Gauges. Turn the handle of the Elcometer 108 to apply pressure, then compare the reading on the gauge with that of the gauge on the Elcometer 1970 PFCV.

Regular calibration checks over the life of the gauge are a requirement of quality management procedures, such as ISO 9000. For checks and certification contact Elcometer or your local Elcometer supplier.

19.8.3.4 Operating Parameters

Dial Pressure Gauge:

- Operating range: 0 PSI - 2,600 psi (0 MPa - 18 MPa)
- Scale range: 0 PSI - 3,500 psi (0 MPa - 25 MPa)
- Scale resolution:
  - Metric (black) 1 division = 1 MPa
  - Imperial (red) 1 division = 100 psi
  - Accuracy: Metric (black) 0.5 MPa
  - Imperial (red) 50 psi

Digital Pressure Gauge:

- Operating range: 0 psi - 2,600 psi (0 MPa - 18 MPa)
- Scale range: 0 psi - 5,000 psi (0 MPa - 34 MPa)
- Scale resolution: 7 psi (0.05 MPa)
- Accuracy: ±1%

Always question readings when measurements are either outside known parameters, or if the readout does not show a steady, consistent rise during the test.

Common errors may include:

- Using the incorrect type of adhesive or not allowing the adhesive to cure properly.

19.8.4 Pneumatic Adhesion Tensile Testing Instrument (PATTI) Unit



Figure 19.25 Elcometer 110 PATTI ® Adhesion Tester

19.8.4.1 Equipment Description

The Elcometer 110 Pneumatic Adhesion Tensile Tester (PATTI) is a simple-to-use instrument that measures the bond strength between a coating and a substrate (Figure 19.25).

The tester uses a pneumatically operated piston to apply a tensile force along the axis of a pull stub that has been glued to the coating. The tester measures the pressure in the piston during the test and records the pressure at the point of coating failure or at the point when the test is stopped.

The values obtained provide a quantitative measure of the strength of the bond between a coating and its substrate or the strength of an adhesive.

19.8.4.2 Proper Use of Instrument

Use Araldite™ epoxy resin to attach the pull stub to the coating. Use of another adhesive may require different surface preparation and/or application techniques. Please refer to the relevant manufacturer's recommended procedures.

To ensure good adhesion, make sure the pull stub and test surface are clean and free from debris and contaminants e.g., skin oils, etc.

Clean the pull stub; use any recognized method to clean and degrease aluminum.

Mix the epoxy. Apply to the blast cleaned end of the pull stub and to an area the size of the pull stub on the test surface; press epoxy into the roughened surfaces of the pull stub to fill the voids.

> Ensure no epoxy gets onto the threaded part of the pull stub.

Press the epoxied end of the pull stub to the epoxied area of the test surface and maintain pressure for approximately 1 minute. Use suitable clamps if required.

Do not rotate, tilt or slide the pull stub on the test surface as this will create voids in the epoxy.

While holding the stub in place, press the cut-off ring (knife edge down) around the pull stub and onto the test surface. This displaces any excess epoxy away from the pull stub.

When the epoxy is fully cured (24 hours minimum is recommended) remove the cut-off ring by gently squeezing the sides of the ring, twist and lift it off. Remove any clamps.

Prepare the control module, pressurize the system, and insert the proper piston into the piston housing according to the manufacturer's instructions.

Ensure the cut-off ring is removed from the pull stub.

Ensure the metal protection washer inside the piston body is in place.

With the felt-coated side downward, place the selected piston over the pull stub.

Thread the reaction plate onto the pull stub until light contact is made with the piston. Make note of this orientation.

Unscrew the reaction plate through 90° from the point of contact. This allows the gasket to seal and aligns the reaction plate perpendicular to the pull stub axis.

The digital piston pressure gauge should read 00.0. If not, adjust the zero setting by holding in the *Reset* button and at the same time turn the *Zero* reset control on the back panel of the control module. Then release *Reset*.

Press and hold *Run* until the piston assembly (with attached pull stub) detaches from the surface (pull-off point), or 100 psig is attained.

Release *Run*.

Use the PATTI unit in accordance with ASTM D 4541, AS/NZS 1580.408.5, and ISO 16276-1.

19.8.4.3 Calibration

All manufacturers' instruments should meet all NIST standards for quality and use in accordance with ANSI/NCSL Z540-6 (National Calibration Standard). Regular calibration checks over the life of the gauge are a requirement of quality management procedures. For checks and certification, contact the gauge's manufacturer or supplier. A traceable calibration certificate can be supplied after any repairs are carried out. The tester does not contain any user-serviceable components.

19.8.4.4 Operating Parameters

A wide range of interchangeable pistons is available, providing the user with a maximum adhesion tester of 10,000 psi / 70 MPa with a link to an external air supply or CO2 canister. The tester is adjustable to a pull rate of up to 150 psi/second.

This instrument has an accuracy of ±1%. Due to the controlled force being applied, the resulting adhesion value is highly repeatable.

Question readings when measurements are outside of known parameters. Also question readings if the digital readout does not show a steady, consistent rise during the test or if the gauge was not zeroed prior to use.

Common errors when performing this test might include:

- Air supply pressure may be too low to properly perform test
- Selecting the wrong piston for the target range
- Incorrect selection or improper application of the adhesive

19.9 Adhesion Testing on Concrete

The Elcometer 106 Scale 6 and the Defelsko Positest AT are two examples of instruments that test adhesion on concrete. The testing procedures for conducting adhesion tests on concrete may be the same, but very often a dolly with a larger surface testing area is required and/or different conversion factors may have to be used. Consult the model-specific owner's manual for detailed information about adhesion testing on concrete.

19.10 Hardness Testing

The hardness of a coating is as an indication of its cure and, hence, its expected performance. There are several methods to determine the hardness of a coating, but only two are explored in this course:

- Pencil hardness test
- Indentation (impressor) hardness test

Determining the film hardness of an organic coating by the pencil hardness test is rapid and useful in developmental work and to establish performance criteria for various coatings.

This hardness test is best performed under laboratory conditions but it may be performed in the field. It is essential to be familiar with this test procedure and to be able to perform it in field conditions.

Indentation (impressor) hardness is useful to rate coatings or rigid substrates for their resistance to mechanical abuse such as blows, gouges, and scratches.

19.11 Pencil Test



Figure 19.26 Elcometer 501 Pencil Hardness Tester

19.11.1 Equipment Description

The pencil test for film hardness is based on *ASTM D 3363, Standard Test Method for Film Hardness by Pencil Test*.

This standard describes the procedure to determine the film hardness of an organic coating on a substrate in terms of drawing leads or pencil leads of known hardness (Figure 19.26).

The purpose of the test is to determine the hardness of a coating as required by the specifications, or determine performance data for the coating material furnished. The hardness values are often correlated as a function of a coating's cure.

Many coating manufacturers use this test method in developmental work, production control testing, and as an indication of the performance of a given coating. Within reason, the harder the coating, the more complete the cure and the better performance of the coating.

Because results vary between different operators and between different laboratories, make every effort to use the standardized hardness of the lead specified, and to follow the technique precisely as described in the standard.

If used as a basis for a purchase agreement, this method achieves maximum precision if a given set of reference pencils is agreed upon by the purchaser and the seller.

19.11.2 Proper Use

The test should be carried out at 73.5° F ± 3.5°F (23°C ± 2°C) and 50% ± 5% relative humidity, unless otherwise agreed.

Use drawing leads or equivalent calibrated wood pencils from the same manufacturer

that meet the following scale of hardness: 6H, 5H, 4H, 3H, 2H, H, F, HB, B, 2B, 3B, 4B, 5B, 6B (hardness ranges from 6H as the hardest to 6B as the softest).

Prepare the pencil using the special pencil sharpeners supplied with the kit. If special sharpeners are not available, peel the wood or paper away from the point of the pencil for 0.19 to 0.25 in. (5 to 6 mm) to expose an undisturbed smooth cylinder of lead.

Hold the pencil at 90° to the abrasive paper and rub the lead until a flat, smooth and circular cross-section is achieved. Ensure that the edge is free of chips or nicks.

When performing this test, hold the pencil firmly at a 45° angle to the coating film, with the point away from the operator. Push away from the operator in a 0.25 in. (6.5 mm) stroke.

Some test kits, like the Elcometer 501 Pencil Hardness Tester, come with a tester designed to hold the pencils in the proper position.

Start with the hardest pencil (6H) and continue down the scale (6H to 6B) to either of two results:

- A pencil that will not cut into or gouge the coating film (**gouge hardness** [often termed as pencil hardness])
- The pencil that will not scratch the film (**scratch hardness**)

Exert enough uniform pressure downward and forward either to cut the film, or to crumble the edge of the lead.

Repeat the process down the hardness scale until a pencil is found that will either not cut through the film to the substrate or to the previous coat for a distance at least 0.13 in. (3 mm). This is the gouge hardness.

Continue the process until a pencil is found that will neither cut through nor scratch the surface. This is the scratch hardness. Any defacement of the film other than a cut (gouge) is considered a scratch.

In some cases, the gouge and scratch results may be the same.

Conduct a minimum of two tests for gouge hardness or scratch hardness for each pencil or lead.

Record each result (if applicable) for gouge and scratch hardness, the make and grade of lead or pencil, and any deviations from standard conditions, including roughness in the finish.

Ensure manufacturer's operating instructions are always available for reference when performing this procedure.

Use the Pencil hardness test in accordance with the following standards:

- ASTM 3363
- BS 3900 E19
- ISO 15184.

19.11.3 Calibration

The Pencil hardness test cannot be calibrated.

19.11.4 Operating Parameters

As stated earlier, use drawing leads or equivalently calibrated wood pencils from the same manufacturer that meet the following scale of hardness: 6H, 5H, 4H, 3H, 2H, H, F,

HB, B, 2B, 3B, 4B, 5B, 6B (hardness ranges from 6H as the hardest to 6B as the softest).

Ambient conditions, operator technique, such as differences in the angle of the pencil, and the pressure exerted on the pencil may affect the accuracy and reproducibility of the test.

Common errors include:

- Not using the proper procedure for the pencil lead
- Holding the pencil at the wrong angle
- Misinterpretation of the results

19.12 Durometers (Hardness Testers)



Figure 19.27 Elcometer 3120 Shore Durometer

These instruments are widely used to test soft materials: rubber, various resins, wood, leather, formica, and others (Figure 19.27).

A point or a ball penetrates the material under spring pressure, with varying force, depending on the model. A direct reading is displayed on the dial, which is graduated from 0 to 100 shore hardness units.

19.12.1 Proper Use

The instrument is put on the specimen vertically so that the complete measuring surface is in contact with the specimen.

Take the contact value from the corresponding standards and keep a record accordingly.

Read the measured value after 3 seconds. The hardness test is then finished. Read the measured value of the specimens of very flowing material after 15 seconds.

If the surface of the hardness tester is not kept parallel with the specimen, there may be measuring uncertainties.

Use the shore durometer in accordance with ASTM 2240, and DINISO 7619.

19.12.2 Calibration

Check the precision of the hardness tester regularly to ensure reliable measuring results. A special control plate is required to do this. Press the hardness tester against the plate. The measuring distance is acceptable if the gauge indicates “100” (for Shore A).

Check with the manufacturer to get model-specific instructions to check the accuracy of the durometer.

Ensure calibration is verified and documented by a manufacturer test certificate or an official DKD – calibration certificate.

19.12.3 Operating Parameters

The tester has a graduated dial which measures from 0 to 100 shore hardness units. It

is available in a wide range of versions designed for different types of hardness (Shore A, B, C, D, DO, O, OO). There is an accuracy of ±1 shore.

Question measurements anytime they are outside known values. Check the precision of the instrument using the control plate, then re-administer the test.

Common errors include:

- Using a gauge with the wrong hardness range for the test subject.

19.13 Barcol Impressor

There are several hand-held, portable hardness testers available for field use. Most rely on the indentation (or impression) of a plunger or pin into soft metals, sheet materials such as rubber, and reinforced or nonreinforced rigid plastics. One such instrument is the Barcol impressor (Figure 19.28).

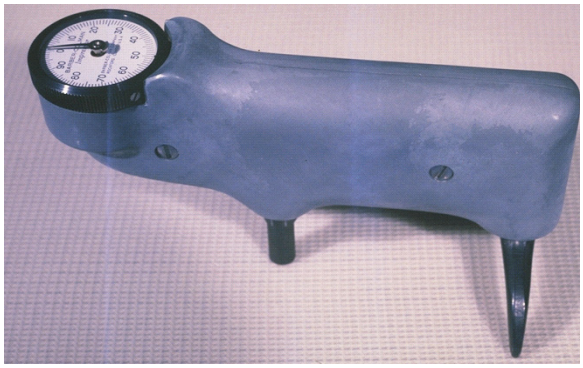


Figure 19.28 Barcol 934

Use the Barcol impressor according to **ASTM D 2583**, *Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor.* This test method covers the indentation hardness of both reinforced and nonreinforced rigid plastics.

This test method may be specified for many materials, but always follow the procedural modifications that take precedence when adhering to the specification.

Always refer to the specification before using this test method. The ASTM Classification System D 4000 lists the ASTM materials standards that are pertinent.

Inspectors must be fully aware of the client's requirements when specifying an indentation hardness test and must thoroughly review the standard or the adaptation under consideration.

Some users consider hardness a function of coating cure and coating performance; that is, within limits, the harder the chemically-induced or heat-induced polymerized coating, the more complete the cure and the better the performance of the coating.

Many users specify this type of test method for coatings such as glass-filled polyesters, vinyl esters, and epoxies, etc., for an indication of their cure. However, some instruments, such as the Barcol impressor, are better to use on homogeneous materials.

When applied to reinforced plastic (non-homogeneous) materials, the Barcol impressor produces greater variations in hardness readings than readings from non-reinforced (homogeneous) materials.

These variations may be caused mainly by the differences in hardness between resin and filler materials in contact with the small diameter 0.0062 in. (0.157 mm) indenter. There is less variation in hardness readings on harder materials in the range of 50 Barcol and higher, and considerably more variation in readings of softer materials.

Table 19.4: Sample Hardness Readings

Brinell	Vickers	Rockwell B	Rockwell E	Rockwell H
73	81	39	81	101

In general, hardness readings by a given test method are affected by:

- Type of coating, sheet, or filled material
- Cure
- Ambient temperature
- Thickness of material to be tested
- Size of test sample

Indentation hardness readings are numeric. These readings correspond to reference standards established by the manufacturer of the test equipment, or by consensus of industry experts. There are several manufacturers of hardness testers, including:

- Rockwell
- Vickers
- Brinell
- Barcol

There is no direct relationship between the hardness scales; however, one scale may be correlated with another by use of an appropriate conversion chart.

These charts enable the inspector to correlate one manufacturer's hardness scale with another. For example, a review of a Barcol conversion chart shows that a reading of 73 on a Brinell scale would compare with other manufacturer's values as shown in Table 19.4.

19.13.1 The Impressor

The indenter of the impressor consists of a hardened steel truncated cone, with an angle of 26° with a flat tip 0.0062 in. (0.157 mm) in diameter. The indenter fits into a hollow spindle and is held down by a spring-loaded plunger.

The indicating dial has 100 divisions, each representing a penetration depth of 0.0003 in. (0.0076 mm). The higher the reading, the harder the material.

19.13.1.1 Calibration

Hard and *soft* aluminum alloy disks supplied by the instrument manufacturer are the standards used to calibrate the instrument.

With the upper plunger guide backed out until it just engages the spring, place the impressor on a glass surface, and press down until the point is forced all the way into the lower plunger guide (Figure 19.29).

The indicator should now read 100. If it does not, loosen the lock-nut and turn the lower plunger guide in or out to obtain a 100 reading. Next, read the *hard* calibration disk. If necessary, adjust the device so the reading is within the range marked on the disk. Read and adjust the *soft* disk readings, if needed. If these readings cannot be made, then any subsequent readings will not be valid.

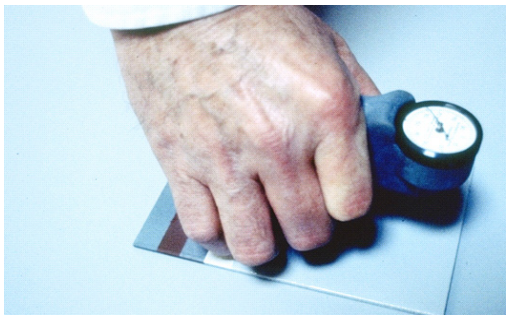


Figure 19.29 Testing with Barcol Impressor

19.13.1.2 Test Procedure

According to the manufacturer, to take accurate readings, the test specimen should be at least 0.03 in. or 32 mils (0.79 mm) thick and large enough to ensure a distance of 0.13 in. (3 mm) in any direction from the indenter point to the edge of the specimen.

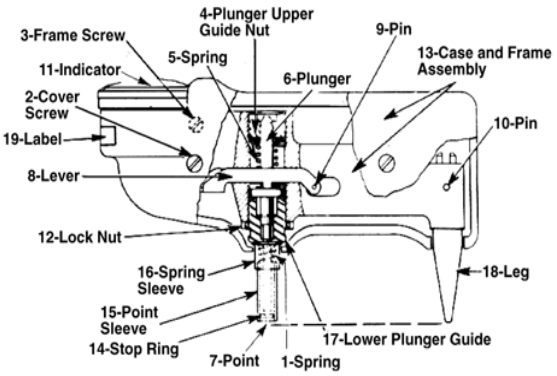


Figure 19.30 Cross Section of Barcol 934

- Place the impressor, the calibration disks, and the test material on a smooth, hard supported surface.
- Set the point sleeve (Figure 19.30) (indenter housing) on the test surface.
- Set the legs on the same surface, or on solid material of the same thickness so the indenter is perpendicular to the test surface.
- Grasp the instrument firmly between the legs and point sleeve.
- Quickly, by hand, apply increasing force on the case until the dial indication reaches a maximum (note: drift-in readings from the maximum may occur in some materials).
- Record this *maximum* reading.

When using a hardness tester, a phenomenon known as *cold flow*, or *creep,* is sometimes seen. This happens when the hardness tester is held in contact with the test material for a period of time. The indenter continues to penetrate the material and the indication dial drifts lower.

This occurs because some materials are more plastic than others. A plastic material, if deformed, will more or less stay deformed when the force is released. An example is putty, which has a high degree of plasticity.

An elastic material will more or less return to its original shape when force is reduced. Examples are a tennis ball or rubber ball.

Without regard to the elasticity or plasticity of the test material, in accordance with this test method, the maximum reading is recorded as the hardness rating of the material being evaluated.

Perform the Barcol impressor hardness test on glass-reinforced materials, such as polyester, before the gel coat is applied to avoid damage to the seal coat. The gel coat must be repaired if indentation or impressor hardness tests are performed after the gel coat is applied, or a potential failure point is created.

Chapter 20: Destructive Instruments and Tests — Practice Lab

Destructive Instruments and Tests Hands On Practical

This practice lab builds on the information in Chapter 19 with demonstrations of some of the instruments covered. The instructor shows each instrument along with the necessary material required to perform each test. All students will then have hands-on experience with the instruments.

Station 1: Paint Inspection Gauge (Tooke Gauge)

Equipment:

- Tooke gauge
- DFT gauge (Type 1 or Type 2)
- Operating instructions
- Test panel

Assignment: Use the Paint inspection gauge (Tooke gauge) to determine the thickness of the individual layers of the coating system applied to the test panel. Document the results on the chart below.

Show correct procedures to:

- Turn instruments on/off
- Check/change batteries
- Set focus adjustment
- Determine the proper tip/changing tip
- Make cut with instruments
- View and evaluate cut made with instruments

What is the approximate coating thickness? _____

What is the proper cutting blade to perform the test? _____

Record your results here:

		Mils/Microns	
		Panel #1	Panel #2
1	Thickness of primer		
2	Thickness of intermediate coat		
3	Thickness of topcoat		
4	Total dry-film thickness		

Extra Table for Practice:

		Mils/Microns	
		Panel #1	Panel #2
1	Thickness of primer		
2	Thickness of intermediate coat		
3	Thickness of topcoat		
4	Total dry-film thickness		

Station 2: Measuring Adhesion by Tape Test

Equipment:

- Razor-sharp knife
- Metal ruler
- Cross hatch cutters with 6 and 11 teeth
- Special tape
- Classification of adhesion test results (X-Cut & Cross Hatch)
- Operating instructions
- Coated test panel

Assignment: Perform adhesion test of the coating on the test panel using the X-cut and cross hatch (cutter & knife) tape test methods. Document the results on the chart below.

Test	Panel:	Panel:
X-Cut		
Cross hatch (with cutter)		

Station 3: Pull-Off Adhesion Test

Equipment:

- Elcometer 106 Adhesion Tester
  - — Test dollies
  - — Operating instructions
- Defelsko PosiTest AT with test dollies
  - — Test dollies
  - — Operating instructions
- Light grit sand paper
- Adhesive
- Photos of dollies pulled from coated surface (4) numbered 1 through 4
- Test panel

Assignment: Perform adhesion test using the two portable adhesion test instruments provided. Perform these tests on the sample panels provided and document observations in the chart below. Describe location of failure using the key below:

A = Substrate
B = First Coat
C = Second Coat
D = Third Coat (etc.)
Y = Adhesive
Z = Dolly

Apply test dollies (1 for Elcometer 106 and 1 for the Defelsko AT) to the test panel using supplied adhesive; allow to cure before performing test. Use proper procedure to apply test dollies.

Pull-Off Adhesion Test Results

Location of Test	Test Type	Value (psi)	Adhesion % Failure	Cohesion % Failure	Glue % Failure	Location of Failure
Test Panel #1	Elcometer 106					
Test Panel #2	Defelsko PosiTest AT					

Extra Table for Practice:

Location of Test	Test Type	Value (psi)	Adhesion % Failure	Cohesion % Failure	Glue % Failure	Location of Failure
Test Panel #1	Elcometer 106					
Test Panel #2	Defelsko PosiTest AT					

Station 4: Hardness Testing

Equipment:

- Barcol Hardness Tester Model No. 934
- 2 Aluminum Discs (1 No. 87 and 1 No. 89)
- Pencils

Assignment:

1. Show correct procedures for:
   - Pencil hardness test: Shape pencil lead to smooth cylinder
     - — Push pencil across surface
     - — Interpret results
   - Impressor hardness test: change point
     - — Use instrument
     - — Interpret results
2. Evaluate the coated sample panels provided with both the pencil hardness and impressor hardness tests and record observations in the chart provided below.
3. Evaluate the unknown test panels by means of the impressor hardness test only and record observations in the chart provided below.

	Panel:	Panel:
Pencil Hardness		
Impressor Hardness		

Panel Number	Hardness	Creep Observed: Yes	Creep Observed: No
1			
2			
3			
4			
5			
6			
7			
8			

Chapter 21: Surface Preparation, Coating and Inspection of Special Substrates

Objectives

When this module is complete, you will have knowledge and understanding of:

- Special metal substrates
- Protective oxide film
- Protection for non-ferrous metals
- Wood substrates
- Polymeric materials

21.1 Introduction

The CIP Level 1 course covered two general types of substrates:

- Carbon steel
- Concrete and other cementitious surfaces

From time to time, other substrates are coated, including:

- Special metal substrates:
  - Copper
  - Aluminum
  - Lead
  - Galvanized
- Other substrates:
  - Wood
  - Polymeric materials (plastics)

These substrates are coated for a variety of reasons, including:

- Enhance corrosion resistance based on the NACE definition of corrosion in its broadest sense, namely, the deterioration of a substance or its properties, because of a reaction with its environment
- Decoration
- Marking or identification

Little has been written specifically about these substrates compared with the information published about steel and concrete. Consequently, inspectors must be particularly careful to develop a complete understanding of the coating specification and manufacturers' data sheets for specific job.

21.2 Special Metal Substrates

Coating inspectors occasionally encounter the requirement to coat nonferrous metals such as copper, nonferrous alloys such as brass, and alloys of ferrous and nonferrous metals such as stainless (or corrosion-resistant) steel. These metals include:

- Stainless steel
- Nickel
- Copper/nickel alloys
- Aluminum
- Aluminum bronzes
- Copper
- Bronzes
- Brass
- Tin
- Cadmium
- Lead
- Magnesium

- Zinc (hot-dip galvanizing and thermal spray)

Although a number of nonferrous metal substrates can be coated, inspectors are not likely to encounter most of these metals and alloys, except in unusual circumstances or when the surface areas to be coated are small. However, coating inspectors must be aware of problems arising from coating any of the above substrates.

21.2.1 Protective Oxide Film

Many of the metals and alloys mentioned above react with the atmosphere to produce an oxide film. The oxide film is an essential part of corrosion protection, such as with stainless steel.

If a substantial oxide film forms, there is the danger that a subsequent organic coating may adhere well to the oxide film, but the oxide film may be too thick to allow the coating to penetrate to the surface of the metal. Also, the oxide film may have low strength so the paint film and part of the oxide film detach easily. Generally, the protective oxide films of stainless steel, nickel, tin, and cadmium are tough and adherent. After degreasing and water washing, they are ready to prime.

Some types of stainless steel tend to become rust-spotted when exposed to an unsuitable environment. If this occurs, it may be necessary to either totally or partially remove the rust. Use dry or wet abrasive blasting (with a nonmetallic abrasive), waterjetting, power tool cleaning, or scrub vigorously with water and a stiff-bristle brush or scrubber.

Use a vinyl wash primer on these films. Coating suppliers may offer specific primers for particular metals or alloys.

21.2.2 Protection for Nonferrous Metals

Certain nonferrous metals in constant contact with some building materials must be protected. Protect non-ferrous metals from:

- Concrete
- Cement and cement mortar
- Lime mortar
- Brickwork

To protect the nonferrous metal, coat it with an appropriate alkali-resistant coating. Protect aluminum and lead from direct contact with alkaline metals such as:

- Magnesium
- Zinc
- Cadmium
- Copper

The specification may require insulating spaces to prevent formation of a galvanic couple.

Some hardwoods, such as oak, chestnut and tung, release acidic materials. Protect lead and tin if they are in contact with these materials.

Clean Joints

Where joints are soldered, welded, or brazed, take care to remove flux before coating.

21.2.3 Standards

Several standards established about surface preparation of nonferrous metals include:

- **ASTM D1730**. *Preparation of Aluminum and Aluminum Alloy Surfaces for Painting*
- **ASTM D1731**. *Preparation of Hot Dip Aluminum Surfaces for Painting*
- **ASTM D1732**. *Preparation of Magnesium Surfaces for Painting*

21.2.4 Aluminum

Aluminum can develop a protective oxide film with low adhesion to the substrate. If coated with an organic coating, oxide film may detach from the substrate.

However, on anodized aluminum, the oxide film adheres strongly to the substrate. Lightly abrade the surface, then apply the organic coating.

Surface preparation of aluminum varies with different circumstances. Sometimes, only degreasing and water rinsing are needed. At other times, wet or dry abrasive blasting with a fine-particle sand or plastic abrasive may be necessary after degreasing. Avoid creating a high surface profile.

Use a vinyl wash primer or other special primers (such as a two-pack epoxy) before top-coating with an organic coating.

21.2.5 Copper

Copper and various copper alloys that required coating usually are seen only in small surface areas. Degrease and water rinse the surface, then abrade with wet or dry abrasive-coated paper of an appropriate grit size.

Copper frequently is used architecturally, so that protection (such as a roof) and appearance are important. In some cases, soft copper is used, which develops a greenish oxide called “patina.”

To prepare certain copper alloys used for architectural purposes, degrease, rinse, acid etch, then treat with a special solution to help develop the patina. Do not top-coat surfaces with the patina.

21.2.6 Lead

Lead usually does not require a top-coating. Usually, only small surface areas are encountered, so surface preparation is straight-forward. Degrease, water rinse, then abrade lightly with wet or dry abrasive paper before coating.

21.2.7 Galvanizing

Galvanized zinc surfaces react with moisture and carbon dioxide in the atmosphere to form a passive film of zinc carbonate, zinc oxide, and zinc hydroxide. This passive film, which develops even in corrosive environments, can inhibit further corrosion of the zinc underneath.

Zinc can be attacked by acids and alkalis. In an acid environment, such as in hydrochloric acid, zinc reacts to form the acid salt, zinc chloride. In an alkaline environment, such as in sodium hydroxide, zinc reacts to form an alkaline salt, zinc hydroxide. Some of these salts are water-soluble and must be removed before top-coating.

Top-coating galvanized surfaces with organic coatings presents many problems. Generally, newly-galvanized surfaces are allowed to weather. They remain unprotected in the atmosphere for a period of months before top-coating. This weathering process allows the slick zinc surface to

develop a tightly bonded passive film before being top-coated. Some users simply wash this passive film thoroughly then apply a wash primer or special tie coat before applying a topcoat.

Sometimes, it is appropriate to treat galvanized zinc surfaces with a mordant solution (normally a weak acid solution containing other chemicals such as copper salts).

The process includes degreasing the zinc surface, rinse and swabbing down with the mordant solution. If the zinc surface is properly cleaned, the mordant solution reacts with the zinc to create a dark-brown color. If this color does not develop, it could signify that the surface is not adequately clean. Rinse off the mordant solution with clean water. After the surface is dry, apply the topcoat.

Ensure all people involved wear the proper personal protective clothing, including a respirator and eye protection. This is required whenever a mordant solution is used.

21.3 Other Substrates

21.3.1 Wood

Wood is coated for numerous reasons, such as:

- Decoration
- Protection
- Sealing
- Stabilization
- Preservation
- Flame retardance

21.3.1.1 Decoration

Coating and finishing wood is often done for decorative and protective purposes. Wood is one of few substrates that is treated with transparent finishes that allow the substrate to be seen. Many finishes enhance the appearance of the wood because the finishes are absorbed (to varying extents) into the surface, thus enhancing the wood grain.

21.3.1.2 Protection

Wood is also coated for protection:

- **Sealing**: Untreated wood surfaces can absorb liquids, stain readily, and be difficult to clean.
- **Stabilizing**: Moisture-content causes wood to not only change dimensions; it changes to a different extent in each of the three grain directions, so it changes *shape* as well as *size*. Coatings best help stabilize wood against dimensional change when applied to all surfaces. Give particular attention to protecting end grain surfaces.
- **Protection**: A coating helps prevent water absorption and slows water vapor passage.
- **Preservation**: Not all special coatings designed to preserve wood are wood preservatives in the strictest sense; that is, they are not toxic to wood-destroying organisms and do not prevent the decay of damp wood. Coating *damp* wood can trap moisture and encourage decay. Moisture entering open joints or unprotected end grain can be trapped in the wood by a coating, resulting in a blistered coating film and/or wood decay. But an intact coating on all surfaces of *dry* wood may help prevent wood from becoming damp enough to swell or warp or support fungal growth. An intact coating may also help prevent wood surface erosion which can lead to mold, soft rot, and/or algae.
- **Flame Retardance**: Coatings designed to raise performance in flame spread tests are applied to wood or other combustible surfaces.

- **Seasoning**: Season wood that is to be coated to an appropriate moisture content, if it is to be used in building. The moisture content at time of coating should not exceed the amount specified. Without proper seasoning, the coating may not adhere properly, or may subsequently blister. The substrate may also warp and/or shrink.

Wood for construction falls into two basic categories:

- Hardwood
- Softwood

Some hardwoods are difficult to coat due to their inherent oil content.

21.3.2 Polymeric Materials

The term polymeric materials (plastics), encompasses a wide variety of materials; it is not always possible to identify a precise type of polymeric material by simple examination. Plastic materials are widely used in buildings, tanks, rainwater goods, claddings, wall and floor coverings, pipes, decorative panels, and in expanded form, as insulating linings, and wall and ceiling tiles.

Some polyvinyl chloride (PVC) articles used in buildings present difficulties, particularly when they are **new** and **not weathered**. These materials often suffer surface degradation on exposure, particularly to sunlight. Other forms of plastic materials accept coatings more readily after a period of exposure.

21.4 Inspection of Special Substrates

The same general inspection principles for steel and concrete apply to the special substrates as well. The inspector should:

- Read and understand the specification
- Read and understand reference standards
- Read and understand manufacturers' product data sheets
- Ensure proper surface preparation
- Ensure correct application procedures
- Inspect each coat after application, and inspect the finished job
- Keep records and submit reports as required by the specification or the owner's representative

Study Guide

1. Describe common reasons that wood is coated.

2. Non-ferrous substrates include:

3. Special substrates that have tightly adherent oxide films include:

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Chapter 22: Maintenance Coating Operations

Objectives

When this module is complete, you will have knowledge and understanding of:

- The basic economics of coatings
- The elements of maintenance coating operations

Key Terms

- Feathering
- Curling

22.1 Introduction

This chapter discusses some of the important special conditions and items encountered in maintenance coatings operations. Maintenance coating operations are defined as "*applying coatings over a substrate that has been installed in its final environment and has been placed in service*." The maintenance operation can be a substrate with an existing coating, or it can be replacing a section of the equipment or structure (Figure 22.1). Often the structure or equipment to be recoated or repaired is in a hostile environment and has been subjected to all types of contaminants, such as, but not limited to, oil, grease, chemicals, water, etc. This chapter elaborates on material already covered.

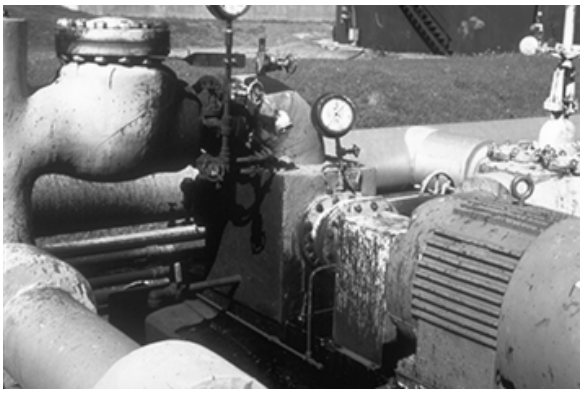


Figure 22.1 Typical Process Equipment

22.2 Economics of Coatings

Replacement is a long term solution and costly solution, with both direct and indirect costs. The direct costs, or replacement costs, include materials, man-hours, and installation. These direct costs eat up most of the budget. This chapter focuses on only a part of replacement costs.

22.2.1 Maintenance

Coating application usually has lower manpower costs; **but** if a surface needs to be specially treated or prepared, the manpower costs for coating are comparable to the costs of replacement. Coating material costs are usually far lower than replacement costs. Indirect costs are lower as well. Always try to schedule maintenance coating around the production schedule to minimize downtime. This saves the company a small fortune in indirect costs. This is a very cost-effective part of a company refurbishment strategy.

Whether completing emergency repairs on a major project, industrial operations require owners, contractors, and inspectors who get the job done quickly, use innovative methods to resolve previously-unforeseen problems and roadblocks at a competitive price and minimize disruptions of day-to-day facility operation.

22.2.2 Coatings Inspection Projects

As with other projects for coating inspection, maintenance coatings require the same diligence from the inspector. Inspectors are vital members of the team who get the job done. All safety, environmental, inspection processes, and teamwork remain the same. As always, read and understand the specification requirements and the manufacturers' product data sheets. Know the inspector's duties and responsibilities inside and out. Remember, it is critical inspectors attend the pre-job meeting. The scope of the project is clarified at the prejob conference, as are the inspector's responsibilities and those of other team members. This meeting can ensure an inspector does a acceptable job for the client.

22.2.3 Life Cycle Costs

Numerous options are available to coat steel in a maintenance coatings project. Several factors **must** always be considered. Remember, the "cheapest" system based on initial costs may wind up being the most expensive over the life of the project.

To determine the coating system life cycle costs, consider the following factors:

- The steel to be coated and its condition
- The coating system chosen (benefits and drawbacks)
- The service environment
- The initial material costs
- The initial labor costs
- Time until first maintenance coating
- Maintenance intervals
- Maintenance costs over the life of the coating system
- The length of time the coating system will last
- The yearly maintenance costs
- Evaluating the coating system

22.3 Elements of Maintenance Coating Operation

A typical maintenance coating operation ranges from a carefully scheduled system of industrial maintenance to random hit-or-miss activities.

Elements of a good maintenance coating operation follow the same general steps as new construction coating. These practices include:

- Coating selection
- Pre-job conference
- Pre-inspection of the structure to be coated
- Surface preparation
- Application
- Inspection and reporting

22.3.1 Coating Selection

Due to the potential difficulties that can arise during maintenance coating projects, all parties should commit to very focused consideration and attention to selecting the coating system. The maintenance coating selection process should examine the following factors.

Maintenance coating must be compatible with the existing coating system. If the existing coating is an alkyd, use a tie-coat if the top-coat contains hot solvents. The top-coat could degrade the alkyd. Ask the following questions: What if there is not enough time to add a topcoat? What if additional cost to apply a topcoat is prohibitive? If the company does not have records that detail the coating history, it may be necessary to test the existing coating to determine its basic composition in order to choose a compatible topcoat. This can be done with a field-test kit or by a more sophisticated instrumental analysis (ASTM 5064).

Surface preparation needs of existing coatings. If the existing coating has a hard, impervious surface, it may be necessary to solvent wipe to soften the surface or use abrasive-coated sand paper to roughen the surface. It may be necessary, if and where allowed, to perform a light abrasive blast to create an anchor pattern for the maintenance coating to adhere to. Otherwise, a tie coat may be necessary.

If a light abrasive blasting (brush off) is permitted and is economically feasible, the inspector must be diligent during inspection after the brush-off. Since the existing surface could be fractured rather than merely roughened by blasting at too high a velocity or holding the nozzle too close to the surface, inspectors need to pay close attention.

Surface preparation may be limited to hand- or power-tool cleaning. In this case, the owner may select a coating with good wetting properties or can be applied over a hand-cleaned or power-tooled surface.

It is a good practice for the owner to **check with the coating manufacturer regarding the appropriateness of the maintenance coating selected.** It is also wise to patch test the coatings to determine its suitability for the specific service.

22.3.2 Pre-Job Conference

A successful coating project begins with the pre-job conference. It is critical to review the specifications to ensure there is a common understanding among the project team members. Specifications for maintenance coating operations vary from job to job, depending on:

- Condition of surface to be repaired
- Plant shutdown
- Effect on plant personnel at the site
- Budget constraints
- Use of in-house or contract labor
- Accessibility to area
- Results desired by owner

A maintenance coating specification may call for anything to hand-clean and spot-recoat of failed areas, or to clean the entire surface down to white metal and apply a totally new coating system. As always, ensure all parties involved read and understand the coating specification and have a unified understanding of the intent of the specification and its expected results.

It is a good idea for all parties to visit the job site to review points in the specification that may require judicious interpretation and common agreement such as:

- Spot repair requirements
- Feathering
- Appearance of repaired areas

22.3.3 Pre-Inspection

Before any other work is performed and specified, inspect the surface to locate and mark any failed areas, including:

- Blistering
- Loss of adhesion
- Under-film corrosion
- Chalking areas that may have been contaminated by grease, chemical salts, dirt, or other substances

If the coating specification calls for spot repair, **it is very important for the owner, contractor, and inspector to have a common understanding of the degree of failure that requires spot repair**. For example, if the specification calls for *"spot repair of blistered areas,"* does this mean that *every blister*, no matter how small, regardless of location, should be repaired? Does it mean that *any blister* of a certain size or larger, or *a cluster* of some number of blisters in a certain area, are to be repaired?

A rather spirited discussion could result if the owner holds the former view and the contractor holds the latter. **A common understanding of these points** is very important in the minds of the owner's representative, contractor, and coating inspector.

22.3.4 Surface Preparation

Once the repair areas have been located and marked, surface preparation operations can begin. There can be many obstacles to achieving the desired degree of surface cleanliness, such as:

- A heavy build-up of contaminants: grease, oil, dirt, chemical salts, corrosion products, etc., to remove before the final surface preparation by abrasive blasting or power tool cleaning begins (Figure 22.2).
- Clean and coat an area while equipment is still in service.
- Inability to remove a work piece to a clean and dry work area.



Figure 22.2 Heavy Contaminant Buildup

- Protective covers over dial faces and gauges (Figure 22.3). Live gauges, dial faces, and other sensitive equipment must be protected during cleaning and coating operations.

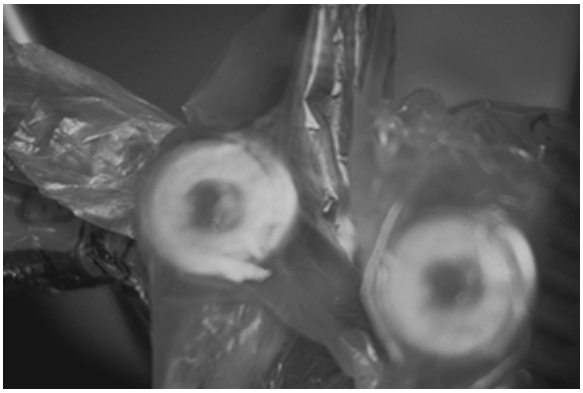


Figure 22.3 Gauges and Dial Face Protection

Generally, the same tools, equipment, and techniques used in surface preparation of new construction are used in maintenance coating operations.

Use solvent/emulsion cleaning, waterjetting, or water blasting to remove chalky, friable portions of the old coating systems and

grease, dirt, chemical salts, and other gross contaminants.

Hand- or power-tool clean and/or abrasive blast to open blisters, chip off cracked and peeling paint, remove tightly adhered mill scale, and provide an anchor pattern. One technique required in maintenance coating operations that is not generally encountered in new work is called ***feathering*** (Figure 22.4).

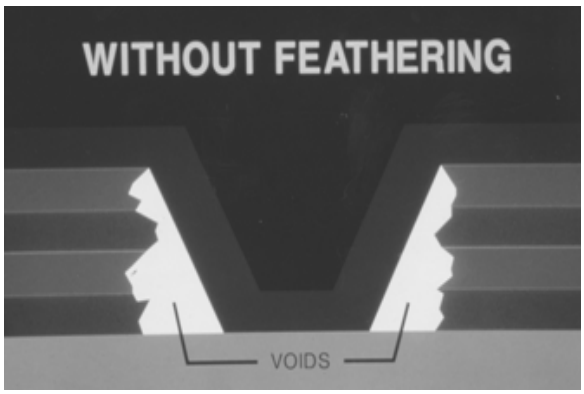


Figure 22.4 Without Feathering

Frequently, a maintenance coating specification requires *spot* abrasive blast cleaning of areas with visible corrosion and light abrasion (*feathering*) of the adjacent coated areas (Figure 22.5).



Figure 22.5 With Feathering

Be aware that the processes of spot blast cleaning and/or feathering the coating can damage the adjacent coating and cause unseen coating cracks, ultimately resulting in loss of adhesion (Figure 22.6).

Generally, when applicators spot blast, they use a straight-bore nozzle to reduce the velocity of the abrasive and maintain better control of the blast pattern. The applicator also uses reduced blast pressures to minimize damage to the adjacent coating.

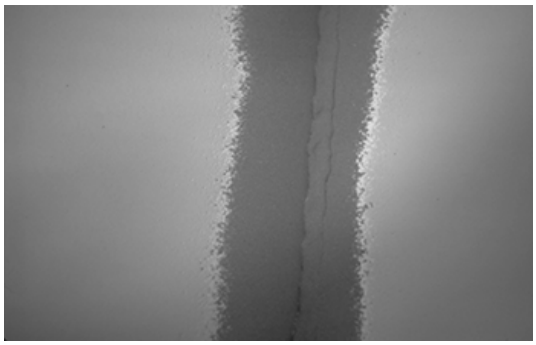


Figure 22.6 Spot Blast on Weld Seam (Feathered Edge)

Feathering works back the edges of the repaired area to achieve a fairly smooth transition from the repair area to the sound coating (Figure 22.7). An alternative is to use abrasive paper to avoid fracturing the adjacent coating. It is helpful for the owner's representative, contractor, and inspector to go to the job site for the contractor to demonstrate feathering.

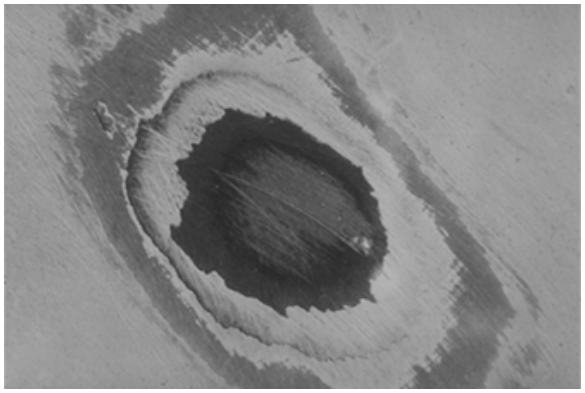


Figure 22.7 Spot Blasted and Feathered

They should work and confer together until they achieve an example that is representative of the owner's and contractor's agreed-upon feathered repair. This example serves as a reference sample for the coating inspector (Figure 22.8).

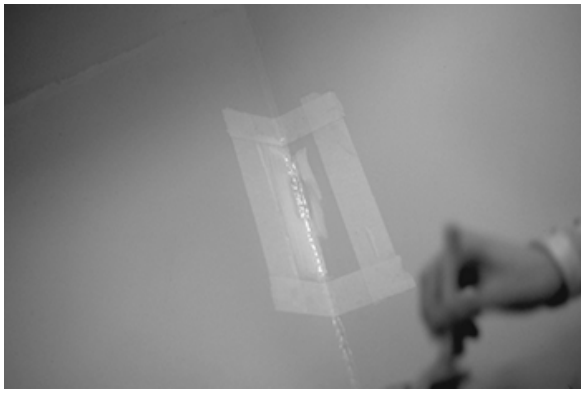


Figure 22.8 Corner Cleaned and Ready for Coating

The maintenance coating may, to some degree, be incompatible with part or all of the existing coating system. If so, ***curling*** may occur. Curling is the expansion, lifting, softening, or other deformation of the existing coating in reaction to the applied coating (Figure 22.9). The specification describes precisely what should be done to prevent or treat curling. If not, it may be necessary for the owner's representative and the contractor to develop a procedure that meets with the owner's approval.

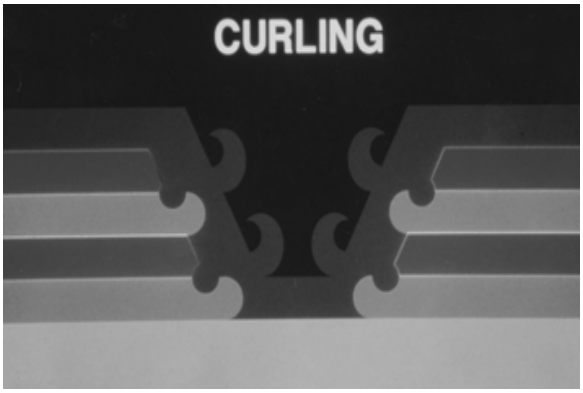


Figure 22.9 Spot Repair – Curling

Before maintenance coating work actually begins, the owner, contractor and coating inspector must have a clear/common understanding of the specified surface preparation cleanliness standard. For example, the definitions of blast cleaning standards are the same, whether it is new work or maintenance work.

The surface color of an abrasive blasted surface varies according to the degree of rust. Inspectors must be familiar with SSPC-VIS 1 and VIS 3 pictorial standards, which show different degrees of surface preparation performed on various steel surface conditions. These standards were thoroughly discussed in CIP Level 1.

It may be extremely difficult to remove all traces of corrosion, etc., from severely pitted surfaces. It is very helpful for the owner, contractor, and inspector to meet at the job site for the contractor to demonstrate their interpretation of the specified degree of surface preparation.

If this sample area is not agreed upon, do additional work until an example **is** representative of the acceptable degree of surface preparation. Remember that certain factors, such as ambient conditions, can influence

how long the surface will retain the desired standard appearance. These factors are very similar to the factors affecting new coating operations, including:

- Relative humidity
- Airborne contaminants
- Contaminants due to service

Another factor sometimes found in maintenance coating is the *permeation* of the steel with contaminants caused by the service environment. Some of these service environments include:

- Sour crude storage tanks
- Cooling towers
- Fertilizer plants

At this point, it is essential to subject the surface to an exacting evaluation. Soluble chemical salts, sulfates, and chlorides of various descriptions may permeate the steel. These contaminants **are not removed** by abrasive blast cleaning to bare metal. If these contaminants remain, the "cleaned" surface tends to ***turn*** much more quickly.

The inspector may be required to run tests to determine the presence of soluble chemical salts on the surface. This is particularly useful to determine whether to use high-pressure waterjetting to remove the contamination prior to abrasive blast cleaning.

Once the surface is prepared, coat it within the specified time period. If the surface *turns* from the specified condition, it is likely to be unsuitable for application of the protective coating. In this case, it is a good idea to hold a conference between the contractor and the owner to determine the next steps.

22.3.5 Application

The general safety and workmanship requirements for application, inspection, and reporting are the same for maintenance and new work.

22.3.6 Inspection Checklist

This is also true of tools, techniques, and requirements. However, some variations in technique can be useful. To properly use a nondestructive magnetic thickness gauge to determine the thickness of the newly-applied coating, it is necessary to:

- Take initial readings of the old coating after surface preparation is finished.
- Take readings of the surface after coating application, taking care to take the readings in the same location as the first readings.
- Subtract the initial thickness readings from the final readings to obtain an estimate of the thickness of the newly applied coating.

Another method to estimate the thickness of the newly-applied coating is to use the wet-film gauge and perform WFT/DFT calculations, as previously discussed (Figure 22.10).



Figure 22.10 WFT Reading

If allowed, take adhesion tests (pull-off, ASTM D 4541 (Figure 22.11) and/or cross-hatch, ASTM D 3359), to determine the adhesive strength of the:

- Existing coating to the substrate
- Bond between the new and old coatings

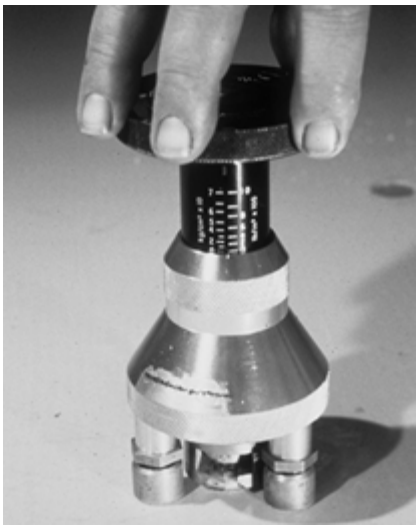


Figure 22.11 Pull-Off Adhesion Testing

As is clear, there are many similarities between maintenance and new coating work, but as noted in the first part of this chapter, there are additional important considerations including:

- Choose coating compatible with existing coating (ASTM D 5064, Standard Practice for Conducting a Patch Test to Assess Coating Compatibility)
- Patch tests
- Surface preparation and application
- Time constraints
- Heavy contamination from service conditions
- Feathering spot repairs
- Work done while facility is in operation

NACE technical committee reports that have value for the owner, contractor and the inspector, include:

- 6H194, Combating Adhesion Problems When Applying New onto Existing Finish Coats of Paint
- 6H188, Coatings Over Non-Abrasive Cleaned Steel
- SSPC-PA 1, Part 10, a publication devoted to maintenance paints

22.4 Case Study

An inspector arrives at the jobsite, No Trees Texas Tank Farm (NTTTF), and is handed the specification below. The inspector reads the specification and realizes there are many problems with it. A three coat system, Zinc, Epoxy, and Urethane, was applied on the exterior. Read the specification carefully and:

- Discuss some of the requirement issues
- Identify the problems
- Explain how to correct the problems
- Identify when these problems should be addressed

NTTTF Painting Specification

No Trees Texas Tank Farm Painting

No painting shall be done above 85% humidity conditions unless adjusting and lowering by dehumidifier. Temperature and humidity shall be measured at designated place(s).

Surface Preparation

- Surface preparation shall be made by power tools (disc-sander, power brush).
- Quality of the each preparation shall be according to “Standard-SIS” (as shown below):
  - Shell: ST2.5 (SIS)
  - Roof: ST2.5 (SIS)
  - Ladder: ST2.0 (SIS)
  - Piping: ST2.0 (SIS)
  - Apertures: ST2.0 (SIS)
- Power-tool treatment shall not done on surface where shop-primer still intact.
- On welding bead where coating is still intact, power-tool shall not be applied.
- Removing existing coating shall be limited to the extent removable by usual disc sander or power brush operation at the time of surface preparation. Specific removal works by other tools shall not be done.
- The surface cleaning shall be done by vacuum-power tools only.
- Visible water, oil, and salt shall be removed. Oil shall be removed by wiping with solvent, however, any trace left, upon dried up, shall not be treated further.
- Those areas exposed to water shall be washed by freshwater, but no chloride test shall be conducted.

General

- All surface preparations, on edge corners and welding beads by power-tool, shall be completed during the surface preparation process. No additional treatment shall be carried out at the time of surface preparation for the coating.
- In general, coating shall be applied at joints and some hard-to-apply areas, by reason of the coating schedule, etc.
- Light metals shall be coated as per the painting specification.
- Pipes and fittings in tank shall be coated with same tank coating paint.

Painting

- Painting works shall be done mainly by brush or roller.
- One advance coating (stripe coat) to be applied on inner side and edges of any small holes in the tanks.

Film thickness

Measurement of total film thickness shall be made in principle upon completion and dried (DFT). No measurement on each layer shall be conducted.

- Each measuring point shall be chosen as follows:

- Tank exterior: one-spot/20m2
- Tank Roof: one-spot/10m2
- Ladder: one-spot/20m2
- Piping: one-spot/20m2
- Apertures'
- Spots within 15mm from edges, and difficult-to-measure spots such as welding beads and fitting items are excluded from the measuring.
- Below result of the measurement shall be accepted as satisfactory:
    - — Any measured DFT shall not below 90% of specified thickness.
    - — Numbers of the "under-spec" points shall be less than 10% of total measured points.
    - — All the measurement data shall be submitted to Owners before delivery.

22.4.1 Inspections

Owners' inspections as follows:

- Below areas shall be inspected by owners own:
    - — Tank Shell
    - — Tank Roof
    - — Ladder
    - — Piping
    - — Apertures
    - — Other area except specified on above
- Any minor defect which had been overlooked and found at pre-painting inspection shall be treated as follows:
    - — Tiny pin-holes shall be filled up by putty
    - — Other defects except above shall be treated as follows:
        - Mark the spot
        - Paint all over except the marked spot
        - Treat the spot with power tool etc.
        - Touch up by brush

Your Team's List

Key Terms Definitions

Curling: The expansion, lifting, softening, or other deformation of an existing coating in reaction to an applied coating.

Feathering: Technique accomplished repaired areas by working the edges of the area back to achieve a fairly smooth transition from the repair area to the sound coating.

Study Guide

1. Maintenance coating operations are defined as:
_____
_____

2. Life cycle of a coating system can be affected by:
_____
_____
_____
_____

3. When determining the coating system life cycle, the following should be considered:
_____
_____
_____
_____
_____
_____

4. Maintenance coating selection process should take the following into consideration:
_____
_____
_____

5. With regards to maintenance coatings all parties should agree on:
_____
_____
_____

6. _____ is performed at the repaired area by working the edges of the repaired area back to achieve a fairly smooth transition from the repair area to the sound coating.

7. If a maintenance coating to be applied is incompatible with the existing coating system, _____ may occur.

8. Some service situations where permeation may occur include:

_____

_____

_____

Chapter 23: Non Liquid Coatings

Objectives

When this module is complete, you will have knowledge and understanding of:

- Hot-dip galvanizing

Key Terms

- Hot-dip galvanizing

23.1 Hot Dip Galvanizing

23.1.1 Introduction

Hot-dip galvanizing coats iron or steel with a thin zinc layer by passing the steel through a molten bath of zinc at a temperature of around 820-860°F (460°C). The process results in a metallurgical bond between zinc and steel with a series of distinct iron-zinc alloys.



Figure 23.1 Hot-Dip Galvanizing Kettle

Hot-dip galvanized coatings usually have three distinct layers, each consisting of different amounts of zinc and iron. The ETA or outer surface which contains 100% zinc is not considered a separate layer (Figure 23.1). Below are the various layers and the zinc/iron content breakdown:

- ZETA (94% Zn 6% Fe)
- Delta (90% Zn 10% Fe)
- Gamma (75% Zn 25% Fe)

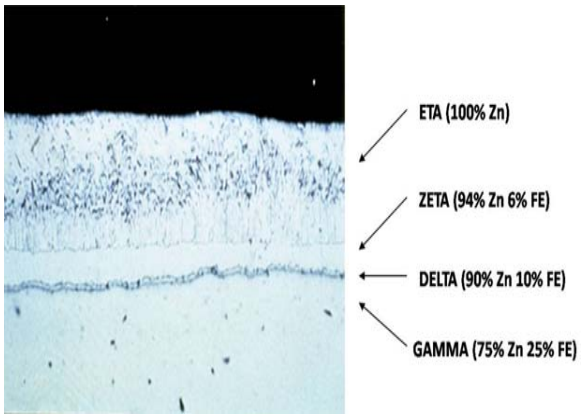


Figure 23.2 Various Layers of Hot-Dip Galvanizing

Like many other protective coatings, galvanized steel is widely used in applications where extended corrosion resistance is needed. It is easy to identify by the crystallization pattern on the surface (often called a “spangle”). A common misconception is that galvanized steel lasts for a lifetime. This is totally incorrect; the life cycle for any installed protective coatings system depends on a number of variables, including service environment, which is one of the most important.

Because the hot-dip process uses molten metal, the coating inspector and all other workers should use special safety precautions when working around the hot-dip kettle. Listed below are some safety precautions that inspectors must remember:

- Hot-dipped articles stay hot for some time. Do not touch or put a gauge on it until the article thoroughly cools.
- Molten metal can splash quite far from the kettle. For example, when pipe is galvanized and is dipped too quickly, water vapor in the pipe expands rapidly, causing molten zinc to shoot out the end of the pipe and travel for some distance.
- Nascent hydrogen, picked up by steel during pickling (if the galvanized surface area is large enough, such as with grating), may be released fast enough and in a great enough quantity to burn in the air above the kettle. Immersion in the molten zinc changes this moisture into steam that causes miniature explosions in the zinc bath. This produces uncoated areas adjacent to the unsealed areas, *and* creates a potentially hazardous condition.

23.1.2 Standards

There are a number of specifications for hot-dip galvanizing to ensure a quality product. While coating inspectors are not expected to remember all of this verbatim, it is essential to become familiar with the standards referenced in any specification. Listed below are some of the most common standards used in the industry today:

- **CAN/CSA G 164**: *Hot-Dip Galvanizing of Irregularly Shaped Articles*
- **ISO 1461**: *Hot-Dip Galvanized Coatings on Fabricated Iron and Steel Assemblies Specifications and Test Methods*
- **ASTM A 123/A 123M**: *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*
- **AS/NZS 4680**:*1999 Hot-dip galvanized (zinc) coatings on fabricated ferrous articles*
- **ASTM A 153/A 153M**: *Standard Specification for Zinc Coating (Hot-Dip) on Iron and Hardware, fasteners and small products that are centrifuged after galvanizing to remove excess zinc*
- **AS/NZS 1397-2001**: *Steel sheet and strip – Hot-dip zinc coated or aluminum/zinc-coated*
- **ASTM A 767/A 767M**: *Standard Specification for Zinc-Coated (Galvanized) steel bars for Concrete reinforcing steel or rebar*
- **ASTM A 780**: *Standard practice for repair of damaged and uncoated areas of hot-dip galvanized coatings and touch-up procedures for coating bare spots on an existing hot-dip galvanized product*
- **ASTM B 6**: *Standard Specification for Zinc*
- **ASTM D 6386**: *Standard practice for preparation of zinc (Hot-Dip Galvanized) coated iron and steel product and hardware surfaces for paint*
- **ASTM E 376**: *Standard practice for measuring coating thickness by magnetic-field or eddy-current (Electromagnetic) examination methods*

It is clear that there are many standards in the galvanizing business as well as various organizations involved in writing these standards. ISO, ASTM and the Australian Galvanizers Association are in the forefront of writing hot-dip galvanizing standards.

Two terms coatings inspectors are most likely to hear about galvanizing are:

- **Heavy galvanizing** which is also referred to as *batch, heavy duty* or *after-fabrication galvanizing*. Heavy galvanizing gives a complete coating of heavy zinc, both externally and internally, if required by specification.
- **Light galvanizing** is also referred to as *continuous, ILG* (in-line galvanizing), or *zinc electroplated*. This application process is different from the kettle hot-dip

process. Light galvanizing has a significantly lower level of protection in corrosive environments, and often requires supplementary coatings for outdoor exposure.

23.1.3 Process

There are several major stages in the hot-dipping process. The three main steps are: surface preparation, galvanizing, and post-treatment, each of which is discussed in these sections.

The first step, surface preparation, is to obtain the cleanest possible steel surface by removing all of the oxides and other contaminants. This is achieved in various ways based on the project specification.

23.1.3.1 Surface Preparation

Solvent cleaning (SSPC-SP1) and abrasive blasting are frequently specified. This is good for hot-dip galvanizing because it not only covers the cleanliness desired but also creates a measurable anchor profile. Therefore, either abrasive blasting or caustic cleaning are likely to be the first step based on the specification and/or the plant equipment set-up:

- Caustic cleaning immerses steel in an acid bath or caustic solution to remove the dirt, oil, and grease from its surface. Rinse the steel with water after degreasing.
- Pickling immerses the item in an acid tank, filled with either hydrochloric or sulfuric acid, to remove oxides and mill scale. Once these are removed, it is rinsed again with water (Figure 23.3).



Figure 23.3 Acid Picking Tank

- Fluxing cleans the steel of any oxidation developed after pickling, which creates a protective coating to prevent oxidization before the steel reaches the galvanizing kettle. Generally, the fluxing process is one of two types:
  - — Combination of zinc chloride and ammonium chloride. It is contained in a separate tank and is slightly acidic.
  - — Top flux floats on top of the liquid zinc in the galvanizing kettle but serves the same purpose.

After degreasing, pickling, and fluxing tanks, the surface of the steel is considered free of oxides or other contaminants. The steel is ready for dipping into the kettle.

23.1.3.2 Zinc Bath (Hot-Dip Medium)

The galvanizing kettle contains zinc specified to ASTM B 6 (or a similar standard), that specifies one of three different grades of zinc that are each at least 98% pure. Sometimes other metals are added to the zinc melt to promote certain desirable properties in the galvanized coating. The inspector must not make recommendations on bath composition.

Most galvanizers prefer to keep the kettle temperatures a little cooler to prolong the life of the kettle. This, however, can ulti-

mately affect the quality of the coating. The galvanizing kettle is essentially a high-grade steel plate firebox, 1 to 1.5 in. (30 to 35 mm) thick that usually lasts from two to five years.

Galvanizing kettles typically operate at temperatures ranging from 820-860°F (438-460°C), at which point the zinc is in a liquid state. The steel products are immersed into the galvanizing kettle and remain until the steel's temperature reaches the temperature required to form a hot-dip galvanized coating (Figure 23.4).



Figure 23.4 Fabricated Piece Being Dipped into the Zinc Bath

Once the inter-diffusion reaction of iron and zinc is complete, the steel is withdrawn. Usually, the entire dip lasts fewer than ten minutes, but this depends on a number of factors, including the steel's thickness. When alloying is complete, the steel is removed and air- or quench-cooled (Figure 23.5).

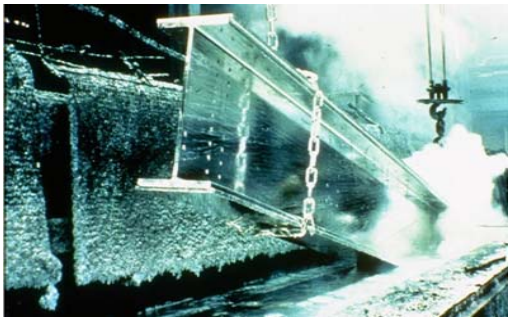


Figure 23.5 Steel Beam Leaving Bath

23.1.3.3 Post Treatments

Once the steel is removed from the galvanizing kettle, it may receive a post-treatment to enhance the coating. Post treatments are done to produce one or more of the following:

- **Reduce coating thickness**. This is done by reducing the amount of molten metal that adheres as the article leaves the bath (Figure 23.6). Roll, wipe, centrifuge- or air-blast the steel to accomplish this. Do this while the coating is still molten. Chromate, phosphate, or light-roll and/or roller-level the steel to improve the properties or appearance of the coating.



Figure 23.6 Fabricated Steel Leaving Galvanizing Bath

- **Change the properties of the coating**. Annealing hot-dipped zinc coatings converts the whole of the coating into an alloy.

23.1.4 Inspection

Inspection and test methods for hot-dip galvanizing are specified in standards such as:

- ASTM A 123/A 123M
- ASTM A 153/A 153M
- ASTM A 767/A 767M

This chapter focuses on the simpler, more common inspection issues.

23.1.4.1 Visual Inspections

The basic finish requirements for galvanized coating include:

- Smooth
- Continuous
- Lustrous
- Free of gross imperfections:
  - Cracking
  - Peeling
  - Bare spots
  - Lumps
  - Blisters
  - Flux, ash, or dross inclusions

The term “smoothness” is relative, so it is the job specification that sets the tolerances for smoothness (Figure 23.7).

The galvanized coating must be continuous to provide optimum corrosion protection. Handling techniques for galvanizing often require use of chain slings, wire, or other holding devices to immerse materials into the galvanizing kettle. The techniques can easily mar a continuous surface.

Differences in the luster and color of galvanized coatings do not significantly affect corrosion resistance and the presence of spangle or “zinc crystals” (Figure 23.7) has no effect on the coatings performance. However, a company highly concerned with aesthetics may specify the appearance as a criteria for acceptance. Inspectors must be aware that the cooling rate has a direct effect on surface brightness and spangle size. Faster cooling usually results in a brighter coating with smaller spangles. Alloy composition of the base metal also may affect appearance.



Figure 23.7 Typical Galvanized Surface

Some of the common problems seen during visual inspections are discussed below. Although some are not grounds for rejection, keep in mind that the owner can stipulate grounds for rejection that are not a part of any standard.

Articles in Contact: The zinc in the galvanizing bath needs free access to all surfaces. Keep articles entering and passing through the galvanizing bath out of tight contact with each other.

Rough Coatings: Rough, heavy coatings means galvanized components with markedly rough surfaces. This includes coatings with just a rough surface or those with a groove-type surface. A rough coating usu-

ally is caused by excessive growth or unevenness of the alloy layer. This results from either the chemical composition of the steel, or its original surface condition. The irregularity of an alloy layer tends to increase as its thickness increases; thus, heavy coatings are usually rougher than light ones. Where the galvanizing is thick, some degree of roughness is usually unavoidable (Figure 23.8).



Figure 23.8 General Roughness

Excess Aluminum: This condition (sometimes called *black spots*) may occur if the aluminum content of a bath, over which a flux blanket is used, is too high. Avoid by keeping aluminum content below 0.01%.

Dross Protrusions: Dross protrusions and stipple are small, hard lumps on an otherwise normal galvanized surface (Figure 23.9). The protrusions result from agitation of the dross layer at the bottom of the bath or from dragging the item through the dross layer. A clean kettle is less likely to produce this defect. The dross that incorporates in the coating prevents good drainage in the immediate area of the dross and a buildup occurs. Some think that because the dross consists of the same iron-zinc alloy as the coating, it may provide the same corrosion protection as a normal galvanized coating. However, this may not be true.



Figure 23.9 Dross Protrusions

Lumpiness and Runs: A lumpy and uneven coating results when the item is withdrawn too quickly or the bath temperature is too low to allow surplus zinc to run back into the bath. Runs can also be caused by delayed drainage from bolt holes, folds, seams, and other pockets where zinc collects. These are a direct consequence of product design.

Uneven Drainage: Drips are removed by filing or other means, if required. Look for voids where drips have been carelessly removed or knocked off (Figure 23.10).

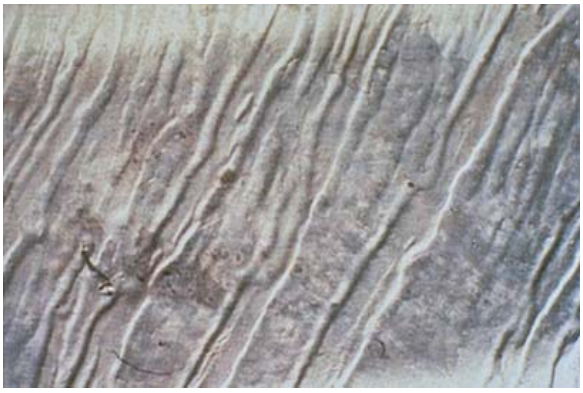


Figure 23.10 Uneven Drainage

Flux Inclusions: Flux inclusions originate in several ways. Stale or spent kettle flux tends to adhere to the steel instead of sepa-

rating cleanly when dipped. This occurs even with active flux if residual grease, scale, or other surface contaminants resist the cleansing action of the flux blanket. Either way, the inclusions are associated with bare spots in the coating. Black spots formed by flux inclusions are distinguishable from dirt smuts, splash marks, and other less harmful types of contamination by their tendency to pick up moisture (Figure 23.11).



Figure 23.11 Flux Inclusions

Ash Inclusions: Ash inclusions are zinc ash, an oxide film that sometimes develops on the surface of the galvanizing bath (Figure 23.12). As with flux, ash may burn onto the steel during dipping, or be picked up from the top of the bath during withdrawal. Ash inclusions often occur on work pieces that are cumbersome and require slow withdrawal from the bath.



Figure 23.12 Ash Inclusions

Dull-Gray Galvanized Coating: This gray or mottled appearance develops during cooling and is caused by diffusion of the zinc-iron alloy phase to the surface of the coating. It usually appears as a localized dull patch on an otherwise normal surface, although in extreme cases, it may extend over the entire surface of the steel. Dull coatings (usually more brittle) can occur on steels with silicon, phosphorus, and/or high carbon. A gray coating is most frequently found on heavy sections that cool slowly. Certain types of steel (those with relatively high silicon or phosphorus content or severely cold-worked steel) may exhibit abnormally rapid alloy growth (Figure 23.13).

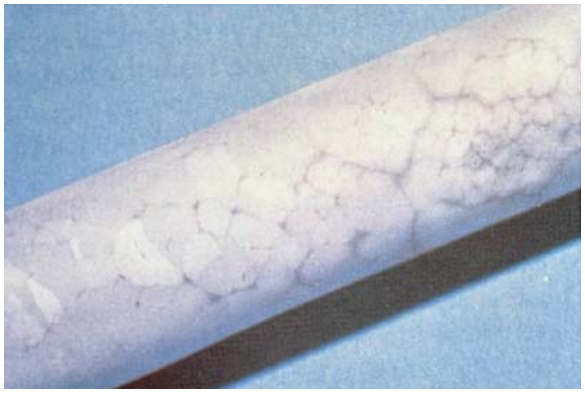


Figure 23.13 Dull-Gray Galvanized Coating

Rust Stains: Rust stains can be caused by seepage from joints and seams after galva-

nizing or by storing galvanized materials under or in contact with rusty steel. Certain high-silicon-content steels may form a slight rusty appearance on the surface after a period of exposure. This is not a failure of the galvanizing, but simply a phenomenon peculiar to this type of steel (Figure 23.14).



Figure 23.14 Rust Stains

A copy of the TPC-9 *Users Guide to Hot-Dip Galvanizing for Corrosion Protection in Atmospheric Service* is provided with this course for future reference.

23.1.5 Repairs

All project specification should provide guidelines on repairs. Some specifications also reference a standard such as **ASTM A-780** *Standard Practice for Repair of Damaged Hot Dip Galvanized Coatings*.

23.1.6 Storage

There are a few issues with storing hot-dipped galvanized items. Inspectors need to be aware of them and understand the issues are not generally cause for rejection:

- **Rust Stains**: As mentioned in an earlier section, these are caused by seepage from joints and seams after galvanizing or when galvanized materials are stored under or in contact with rusty steel. Please note that rust stains of this type are superficial and are not failure of the underlying coating. Rust stains caused by seepage from an assembly *can* indicate the need for a design modification. Surface rust stains are **not** cause for rejection of the galvanized product.
- **Wet Storage Stains**: Wet storage stains are a buildup of zinc oxide and zinc hydroxides on a galvanized surface. As the name implies, wet storage stains occur when the steel is exposed to a humid or moist environment without freely circulating air. Tightly stacked or nested galvanized items are particularly vulnerable to wet storage stain, especially if they are stored as unopened bundles for more than a few weeks. Although in extreme cases, the protective value of the coating may be impaired, generally the attack is superficial, despite the relative bulkiness of the zinc hydroxide. A medium to heavy buildup of white corrosion products must be removed; otherwise, the essential protective film of basic zinc carbonates cannot form in affected area. Remove light deposits by brushing with a stiff bristle (not wire) brush. Perform a coating thickness check on the affected areas to ensure sufficient zinc coating remains after removal of the wet storage stain (Figure 23.15).



Figure 23.15 Wet Storage Stain (White Rust)

In advanced stages of wet storage stain, the typical white or gray corrosion product may blacken. When this occurs, *a significant amount of coating has been lost to corrosion* and the service life is decreased.

In extreme cases, when heavy white deposits or red rust have formed as a result of prolonged storage under poor conditions, remove the corrosion products and repair the damaged area according to ASTM A 780 or other referenced standards. If the affected area is extensive or if the wet storage stain would impair the use of the article for its intended service, it may be necessary to re-galvanize.

Unless wet storage stains are present before shipment, their development is generally not cause for rejection. Those responsible for storage and transportation must be sure their processes prevent wet storage stains.

23.1.7 Special Considerations

23.1.7.1 Faying Surfaces

Surfaces that depend on friction to hold structural elements in place **should not be hot-dip galvanized**. Hot-dip galvanizing greatly reduces the possible coefficient of friction between the surfaces (Figure 23.16).

23.1.7.2 Alteration of Substrate Properties

Quenching ceases all further reaction between the steel and the zinc. Quenching can also alter the properties of the base steel. Inspectors must ensure the cooling process described in the specification is followed.

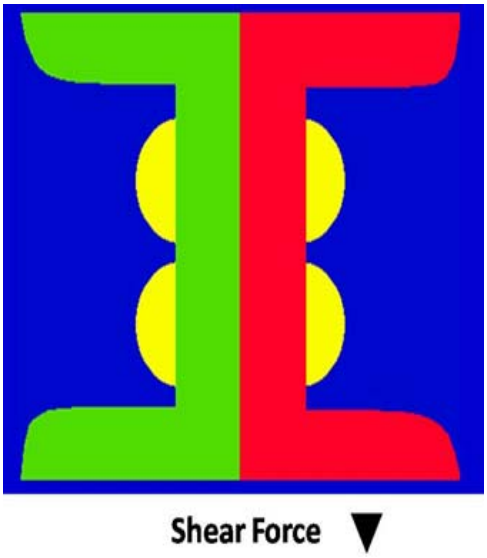


Figure 23.16 Faying Surfaces

23.1.7.3 Work Piece Design and Fabrication

Design and fabrication of the work piece affects quality in a variety of ways. Pay close attention to the following factors:

- Skip welds, crevices, and/or other areas can trap pickling acid.
- Areas where pockets or air bubbles can form and prevent molten zinc from contacting those areas.
- The length of the items need to be compatible with the size of the kettle.
- Thickness of items being dipped must be consistent with the specification.

23.1.7.4 Dissimilar Metals

Ideally, a work piece to be hot-dip galvanized should be made of the same steel alloy throughout. Different steel alloys have different galvanizing characteristics.

23.1.7.5 Coating Thickness and Service Life

Service life is directly associated with coatings thickness. With hot-dip galvanizing, thickness is dependent on the thickness of

the substrate. ISO 1461 (2) and ASTM A 123 both contain tables detailing the values appropriate for the particular article to hot-dip. Before taking any thickness readings, inspectors must have the referenced standard for guidance.

Measure the coatings thickness of hot-dipped galvanized items with one of four methods:

- Magnetic thickness gauge
- Stripping
- Weighing (before and after galvanizing process)
- Optical microscopy

The most common and easiest method to determine DFT in the field is to use a magnetic DFT gauge. These gauges are very effective when compared to other methods. DFT gauges and weighing the item are non-destructive methods; stripping and optical microscopy are destructive tests. Inspectors must have the standards referenced in the specification and understand them thoroughly before conducting any of these tests.

23.2 Spray Metalizing/Thermal Spraying

23.2.1 Introduction

Spray metalizing (thermal spraying) is the general term used for the process of coating metal onto the surface of non-metallic objects. However, this term has grown to include applying a coating by spraying molten metal on steel substrates as a form of corrosion protection.

In thermal spray, wire or powder is melted by a flame or electricity and sprayed onto a work piece. During the actual process, the spray gun makes successive passes across the work piece to produce a coating.

23.2.2 Surface Preparation

In spray metalizing, as in coating, surface preparation is critical. Surface preparation for thermal spraying generally requires a minimum NACE 2/ SSPC-SP10 or ISO SA 2.5 with an angular profile. In addition, the white-blasted surface must be dry before application. To help drying, use the spray metalizing gun. Release the metal-feed trigger and dry the desired section with the gas flame.

Some highly experienced operators prefer to heat the surface from 175 to 200°F (79.4 to 93.3°C) before starting application. This creates an improved bond.

23.2.3 Application Process

This section presents the four application processes inspectors need to know.

23.2.3.1 Flame Spraying

Flame spraying is part of the wider group of coating processes known as thermal spraying systems. To flame-spray, feed oxygen and a fuel gas, such as acetylene, propane, or propylene, into a torch and ignite to create a flame. Inject either powder or wire into the flame where it is melts. Spray the atomized material onto the surface. This creates the layer of protective coating.

Flame spray guns typically require very little additional equipment. Most powder-fed guns have a hopper built into the gun body; others have a small external powder feed unit. Wire-fed guns usually have a mechanism built into the gun body to feed the wire and regulate its speed. Typically, only sup-

ply lines for oxygen, fuel, and, occasionally, compressed air are required. The two forms of the coating material match the two process variants:

- Powder-flame spraying
- Wire-flame spraying

In either case, the gun melts and atomizes, or softens the material as it is fed into the flame, and ejects the soft or molten particulate in a directed stream through the gun's nozzle.

In the powder-flame spraying process, a stream of compressed air or inert gas (argon or nitrogen) feeds the powder directly into the flame. In some basic systems, the powder is drawn into the flame using the venturi effect, which is sustained by a flow of fuel gas. The carrier gas feeds the powder into the center of an annular combustion flame where it heats. A second outer annular gas nozzle feeds a stream of compressed air around the combustion flame, which accelerates the spray particles toward the substrate and focuses the flame.

In the wire flame spray process, the operator balances the wire feed rate and flame settings so the wire melts continuously to produce a fine particulate spray. The annular compressed air flow atomizes and accelerates the particles towards the substrate.

Flame spraying requires very little equipment and is done in a shop or on site. The process is fairly inexpensive and is generally used to apply metal alloys. The relatively low particle velocity of the flame spray process leaves a coating of moderate, but not outstanding density. As a result, flame sprayed coatings of self fluxing alloys are often candidates for spray and fuse processes where the additional fusing stage allows the coating to flow more freely and fill many of the voids that the spray process may have left.

23.2.3.2 Arc Spraying

The arc spray process inserts two wires into the torch so they contact each other at the nozzle. Placing an electrical load on the wires causes the tips of the wires to melt when they touch. A carrier gas such as compressed air or nitrogen strips the molten material off the wires and transports it to the surface. Arc spraying is relatively inexpensive, easy to learn, portable, and fairly simple to maintain. Low particle velocities yield a high maximum coating thickness for a given material. Recent advancements in nozzle and gun configurations provide greater control over the coating quality and the spray pattern. With the right equipment, it is possible to produce an elongated spray pattern or to spray components with very small internal diameters. A drawback, however, is that arc spraying is limited to electrically-conductive solid wires and cored wires.

23.2.3.3 Plasma Spraying

The plasma spray process is considered the most versatile of all the thermal spray processes. During operation, gases such as argon, nitrogen, helium, or hydrogen pass through a nozzle. An electric arc disassociates and ionizes the gases. Beyond the nozzle, the atomic components recombine, and give off a tremendous amount of heat. In fact, the plasma core temperatures are typically greater than 18,032°F (10,000°C), well above the melting temperature of any material. The process injects powder into the

flame, where it melts and is accelerated to the surface.

Plasma spraying was initially developed to spray ceramics and is still the primary process to apply them. This technique also sprays metals and plastics. The particle velocities in plasma spraying are higher than flame or arc spraying. The result is coatings that are typically denser and have a finer "as-sprayed" surface roughness. The trade-off for increased density, however, is that it reduces the maximum coating thickness for a given material. Both metals and ceramics spray effectively with the technique, so plasma spraying lends itself to automation and reduces process steps.

23.2.3.4 High-Velocity Oxyfuel Spraying

The high-velocity oxyfuel (HVOF) process was introduced only 20 years ago. This process expands application possibilities for thermal spraying into areas previously not possible. HVOF spraying injects a combination of process gases (such as hydrogen, oxygen, propylene, air, or kerosene) into the spray gun's combustion chamber at high pressure where it ignites. The gas velocities achieve supersonic speeds, so the melted powder also accelerates to supersonic speeds. The results are the densest thermal spray coatings available.

The HVOF process is the preferred technique to spray wear-resistant carbides and is also suitable to apply wear-and/or corrosion-resistant alloys like Hastelloy, Triballoy, and Inconel®. The HVOF process imparts high kinetic energy and low thermal energy to the spray materials, so HVOF coatings are very dense with less than 1% porosity. They have very high bond strengths, fine "as-sprayed" surface finishes, and low oxide levels.

23.2.4 Sealers

In service, corrosion products of zinc or aluminum develop as the porous coatings begin to corrode. In time, porous coating essentially seals itself with its own corrosion products. To remedy this, the specification often calls for application of a sealer or sealer plus top coat after the application. Sealers for thermal spray coatings (TSC) are low-viscosity, clear or pigmented paints formulated to flow over and absorb into the natural pores of the TSC. Successful sealers include thin coats of vinyl, PVBA etch primers (generally followed by at least one more coat), and aluminum-pigmented silicone sealers. Keep in mind that the addition of one or more layers of paint "topcoats" are not necessary for corrosion control. If done, it is usually a matter of aesthetics or the need for additional abrasion resistance. A topcoated system has shorter maintenance intervals since the paint requires more frequent maintenance than the underlying metallic coating. Inspectors must ensure that requirements are met before final acceptance.

23.2.5 Spray Metalizing Inspection

Coatings inspectors on thermal spray projects perform inspections and documentation just like conventional coatings. Major concerns are:

- Surface preparation (cleanliness and profile)
- Substrate pre-heating
- Moisture-free substrate verification
- Application procedures and techniques

- Application of sealers and topcoats when specified
- DFT measurements (DFT gauges)
- Handling and storage of finished products

23.3 Sherardizing

Sherardizing is a method of galvanizing also referred to as vapor galvanizing. This process applies a layer of zinc to the metal substrate by heating the object in an airtight container with zinc powder to approximately 572-752°F (300-400°C), the temperature at which the zinc diffusion bonds with the substrate.

Sherardizing is ideal for small parts, and parts that have inner surfaces to coat. In this process, the temperature that the parts reach does not exceed the melting point of zinc, which makes this a dry process.

23.4 Aluminizing

Aluminizing or aluminum diffusion alloying is a high temperature chemical process in which aluminum vapors diffuse into the surface of the substrate and forms a new metallurgical aluminide alloy. It is an economical way to inhibit corrosion of steels, stainless steels, and nickel alloys that operate in severe high temperature environments. The aluminide alloys formed during the process contain a minimum of 20% aluminum.

Another method to aluminize is hot-dip aluminizing. The compositions vary among manufacturers and much of the work is proprietary. It is similar to the galvanizing process except the hot-dip bath contains aluminum.

Key Terms Definitions

Arc Spray: Arc spraying is relatively inexpensive, easy to learn, portable, and fairly simple to maintain. Low particle velocities enable high maximum coating thicknesses for a given material.

Flame Spray: All flame spray guns perform the same essential function: heat and project the coating material with an oxy-fuel flame and a pressurized carrier gas jet.

Hot-Dip Galvanizing: The process of coating iron or steel with a thin zinc layer. The steel passes through a molten bath of zinc at temperatures around 820-860°F (460°C).

Plasma Spray: This process is considered to be the most versatile of the thermal spray processes. During operation, gases such as argon, nitrogen, helium, or hydrogen pass through a gun. An electric arc disassociates and ionizes the gases. Beyond the nozzle, the atomic components recombine, giving off a tremendous amount of heat.

Thermal Spray: In thermal spray, wire or powder is melted by a flame or electricity and sprayed onto the substrate.

Study Guide

1. What is hot-dip galvanizing?

   _____
   _____
   _____

2. The usual layers of a galvanized coatings consists of:
   - _____
   - _____
   - _____
   - _____

3. A few safety issues the inspector should know when working around hot dip galvanizing are:
   - _____
   - _____
   - _____

4. List the several major stages of the hot-dip process:
   - _____
   - _____
   - _____
   - _____
   - _____

5. Explain the purpose of both caustic cleaning and acid pickling.
   - Caustic cleaning

     _____
     _____
   - Pickling

     _____
     _____

6. What is the temperature range for a typically operated galvanizing kettle?
   - _____

7. Name some of the post-treatments that may be performed and why.
   _____
   _____
   _____
   _____

8. List some common problems seen during the visual inspections of hot-dip galvanized items.
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____

9. What are faying surfaces and why not galvanize them?
   _____
   _____
   _____

10. What are the different methods of thermal spray application?
    - _____
    - _____
    - _____
    - _____

Chapter 24: Coating Surveys

Objectives

When this module is complete, you will have knowledge and understanding of:

- What coating surveys are
- Why coating surveys are performed
- Who performs coating surveys
- Coating survey steps
- Coatings condition assessment surveyor
- Offshore Corrosion Assessment Training
- Shipboard Corrosion Assessment Training
- Advanced collection data and storage

24.1 What is a Coating Survey?

A coating survey is done to gather information on the performance of the previously coated protective coatings system in an organized, rational manner on assets such as bridges, offshore platforms, chemical plants, refineries, paper mills, etc. (Figure 24.1, Figure 24.2). Do not confuse coating surveys with the more in-depth corrosion survey. Corrosion surveys go beyond the scope of coatings system performance.



Figure 24.1 Offshore Platform

Coating is a major maintenance item and accounts for huge annual expenditures. A coatings survey is a vital part of the in-service inspections done on a regular basis. Management requests these coating surveys (condition assessments) for a variety of simple or complex reasons. Individuals or teams of qualified people (depending on the agreed-upon scope) conduct these surveys.



Figure 24.2 Refinery

Coating surveys provide baseline information needed to plan maintenance coating programs. To be meaningful, ensure knowledgeable professionals conduct the survey. The survey must provide information the company needs to plan maintenance coating programs. In the past, some companies were less than thorough in their approach to coating. Now, there is increasing recognition that planning and performance monitoring is beneficial to the company.

Companies now look more closely at their facilities because of the increased attention paid to environmental protection and safety (employees and public). Accidents caused by corrosion can lead to significant profit

loss, dissatisfaction in the work force, and bad publicity.

24.2 Why are Surveys Performed?

Some of the primary reasons to perform coating surveys include:

- Helps plan future maintenance
- Easier prioritization of work
- Budgetary concerns
- Helps determine value of assets
- Legal compliance

24.3 Who Performs Coating Surveys?

Knowledgeable, experienced, and trained professionals conduct coating surveys. A team effort yields better results in a more timely manner when an in-depth survey is required. If the team leader is suitably qualified, then support members are only responsible for clearly defined tasks which do not require extensive individual skills. The survey participants must be able to follow the survey plan and gather meaningful information. Team members may have to be:

- A NACE O-CAT Technician or NACE S-CAT Technician (most qualified)
- A certified NACE Coating Specialist
- A NACE Certified Coating Inspector — Level 3
- A coating inspector qualified by field experience
- A coating manufacturer's technical representative with adequate field experience
- A maintenance engineer with extensive knowledge of the plant or facility

24.4 Coatings Survey Steps

Ensure the coatings surveyor understands the scope of the survey and stays within those guidelines. This is extremely important especially when the survey is driven by legal requirements. Any participant must also understand the legal ramifications if anyone falsifies information to make an individual or company happy. In others words, do not act as a rubber stamp for anyone; these actions may be grounds for prosecution where legally applicable. Below is a step-by-step process to conduct simple coating survey:

- Get a clear understanding of the scope (objective and goals)
- Gather the team (if needed)
- Develop a survey plan
- Review standards that may be used for performing required tests
- Agree on a format to present collected data
- Delegate various tasks to team members if necessary
- Evaluate the existing coating (overall and by “paintable items”)
- Gather additional information per the survey plan
- Summarize the data and ensure the data is accurate, factual, and corresponds to the appropriate standards
- Prepare plans to perform the maintenance work required, based on the survey results (if required)
- Prepare reports and input data in a database
- Submit final survey reports

Because of the importance a coatings survey is for owner/operators, attention centers on qualifications of the persons performing the surveys. Trained coatings inspectors are valuable assets on a coatings condition assessment team but may not be able to per-

form a detailed condition assessment survey on their own. Conducting a condition assessment is very complex so experience, knowledge, and a clear understanding of scope is essential. The next section of this chapter looks at the definition of a *coatings condition assessment surveyor.*

24.5 Coatings Condition Assessment Surveyor

A person whose knowledge, experience, and qualifications mean he is deemed capable to perform a coatings condition assessment.

Until recently, there was no formal training for coatings condition assessment surveyors. However, NACE International working closely with various industries, recognized the need to formalize coating condition assessment training. As a result, there are now two coating assessment certification programs:

- O-CAT
- S-CAT

24.5.1 Offshore Corrosion Assessment Training (O-CAT)

This intensive five-day course addresses the elements of in-service inspection and maintenance planning for fixed offshore structures. It also addresses the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), A-B-C facility evaluation grading system requirements for Level I (Topsides) inspection reporting. The course is valuable to anyone in the corrosion control facet of integrity management for fixed offshore structures. It is also a great benefit to personnel with management/planning responsibilities, including field inspectors conducting in-service inspections of a facility. It provides offshore platform operations personnel a better understanding of corrosion prevention systems used on offshore structures.

24.5.2 Shipboard Corrosion Assessment Training (S-CAT)

This course provides a foundation of coatings, corrosion, and corrosion control knowledge to assess the condition of tanks and other structures on ships, and determine the required actions to effectively maintain fully operational status. The course equips assessors with practical guidelines to survey and evaluate the condition of the protective coating systems on specific areas of a marine vessel. The desired end result is that assessors use a consistent, orderly, and repeatable process of evaluation trusted by those involved in the maintenance cycle.

24.5.3 Advanced Data Collection and Storage

Outside of the general steps listed at the beginning of this section, the most important step in a condition survey is **data collection**. When the survey is complete, the data gives management a clear picture. It is difficult for some surveyors to evaluate coating condition without veering into areas that extend beyond their responsibilities and expertise. If a surveyor notes severe metal loss, it should be properly passed on to the correct people. Do not make blanket statements like “such and such must be replaced.” Condition surveyors should never “interpret” data outside of their responsibilities.

There are a number of database software programs developed to give managers the tools to implement, monitor and continuously improve enterprise-wide corrosion control programs. These programs can:

- Prioritize work based on collected data
- Provide rapid access to data and generate reports from multiple locations
- Organize maintenance work by focusing on logical work actions
- Calculate coating condition over time
- Recommend progression of maintenance work steps
- Calculate costs of deferring maintenance work

Data collection and reporting are critical, as well as storage and management of the data for future reference. Surveyors should research the various software systems to be able to recommend effective systems to owners.

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Study Guide

1. What is the definition of a coating survey?

   _____
   _____
   _____

2. List some of the primary reasons surveys are performed.

   - _____
   - _____
   - _____
   - _____
   - _____

3. Outline steps to perform a simple coating survey:

   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____

4. List individuals who may be qualified to perform coating surveys.

   - _____
   - _____
   - _____
   - _____
   - _____
   - _____

Chapter 25: Specialized Tests and Test Equipment

Objectives

When this module is complete, you will have knowledge and understanding of:

- Coating performance tests and qualification tests
- Collecting samples for failure analysis
- Other laboratory tests

25.1 Introduction

This course has explored tests and test equipment that coating inspectors can expect to encounter and use in the field. Next, this chapter briefly reviews frequently performed laboratory tests and test equipment related to a coating's performance, such as:

- Pre-qualification and performance tests
- Special laboratory test instruments
- Collecting samples for failure analysis

These tests help determine a coating's suitability for a project.

25.2 Performance Tests and Pre-Qualification

To ensure a coating chosen for a project is best suited to successfully meet the targeted life-cycle, performance and pre-qualification tests are done to verify that it meets certain physical and performance characteristics.

In-situ tests to qualify coatings may take many years to evaluate results. Generally accelerated lab tests (wet-dry cyclic, salt-fog, and other test methods) can generate results in a timely manner.

25.2.1 Industry Qualification Methods and Standards

Many standards delineate the tests that determine the physical properties of coatings such as flexibility, impact resistance, and adhesion. Standards to test and qualify coatings are available from the following groups:

- ASTM
- NACE
- ISO
- SSPC
- IMO PSPC

25.2.2 Cathodic Disbondment Test

Cathodic disbondment (CP) tests are the most common performance test. They are accelerated procedures to determine how easily a coating loosens from a substrate, or develops holidays as a result of normal soil potentials and/or impressed current cathodic protection. **ASTM Standard G 8**, "*Standard Test Methods for Cathodic Disbonding of Pipeline Coatings*," describes in detail how a cathodic disbondment test is performed (Figure 25.1).

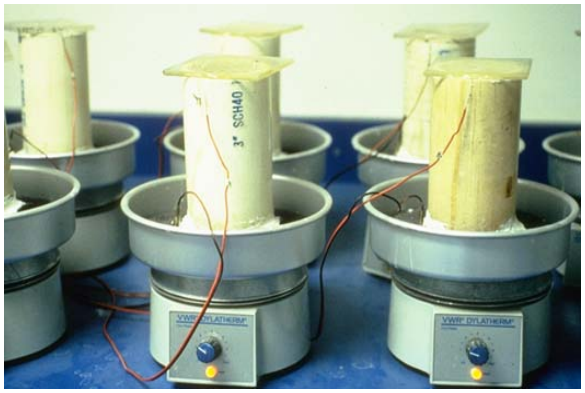


Figure 25.1 ASTM G 95 Cathodic Disbondment Test

25.2.3 Test Methods

Various test methods have been developed and generally include:

- Preparing a sample consisting of a substrate and the applied coating
- Creating an artificial holiday in a coating
- Immersing a sample in a solution of water (preferably distilled) with:
  - Sodium chloride (NaCl)
  - Sodium sulfate (Na2SO4)
  - Sodium carbonate (Na2CO3)
- Electrically connect a sample to an anode or, if an impressed current method is used, to a DC voltage source
- Examine the specimen at specified intervals for loosened coating around the artificial holiday, new holidays, or other required conditions

25.3 Special Laboratory Test Instruments

Coating inspectors may encounter sophisticated tests and test equipment, particularly if involved in investigating coating failures. When the inspector sends coating samples to the lab, detailed information about the sample should also be provided to the lab.

The sample information is used to choose the proper test instrument. Most of these instruments require frequent tuning and calibration. It is important to recognize that in many cases, samples require laborious preparation before the instrument analyzes them. Instrument results typically require expert interpretation as well.

Some of these test instruments are:

- Atomic Absorption/Emission (AA/AE) and Induction Coupled Plasma (ICP) Spectrophotometers
- Gas Liquid Chromatographs (GLC)
- Infrared Spectrophotometers (IR and FTIR, and FTIR-ATR)
- Differential Scanning Calorimeters (DSC)

The following section briefly discusses these instruments.

25.3.1 Atomic Absorption/Emission and Induction Coupled Plasma Spectrophotometers

These instruments quantify concentrations of metallic compounds (Figure 25.2). Examples are:

- Hazardous heavy metals in spent abrasives
- Lead concentration in paints
- Titanium dioxide pigment in coatings
- Silicon concentration in silicone/alkyd resins

ICP instruments are replacing AA/AE instruments for routine high-volume analysis because the ICP instruments operate more quickly.

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Figure 25.2 AA/AE Spectrophotometer

25.3.2 Gas Liquid Chromatograph

Gas liquid chromatography (GLC) analyzes the composition of an organic liquid when its chemical composition is in doubt.

It can also identify and quantify solvents retained in coating films. Some instruments are so sensitive that they can identify residual solvents in paint films over 100 years old.

The test injects a sample into a heated packed column. The sample separates into its individual chemical components. A detector measures the individual components when they leave the other end of the column.

The molecules will take different amounts of time (called the retention time) to come out of, or elute from, the gas chromatograph. The mass spectrometer downstream captures, ionizes, accelerates, deflects, and detects the ionized molecules separately.

There are many different types of GLC instruments and detectors. One is a mass spectroscope (MS). The GC-MS identifies individual components by fragmenting their molecules and measuring their respective molecular masses (Figure 25.3, Figure 25.4).



Figure 25.3 Interior of a GC-MS.

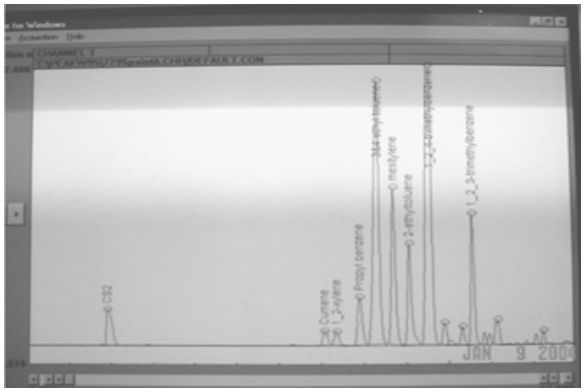


Figure 25.4 GLC Output Screen

25.3.3 Infrared Spectrophotometer

These instruments analyze the composition of a coating or identify many chemical compounds using infrared radiation that interacts with the material analyzed. The wave numbers at which the radiation is absorbed, and the intensity of the absorption, reflects the molecular structure of the material.

Figure 25.5 shows the infrared spectrum of the binder resin from the epoxy component of a coating. The infrared spectra are often very complex, and correct interpretation of them requires specialized training and thorough knowledge of the material being analyzed. Computer software assists in interpreting the spectra.

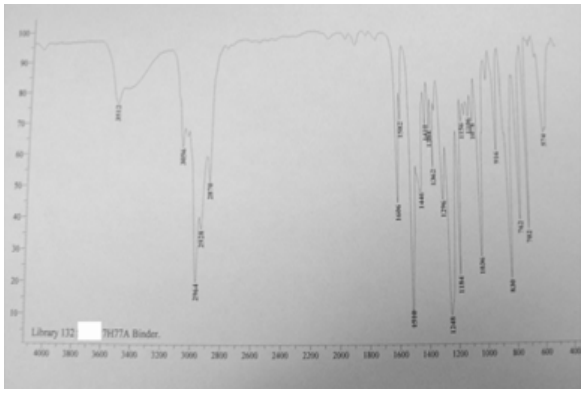


Figure 25.5 Infrared Spectrum



Figure 25.6 FT-IR Spectrophotometer

More recent infrared spectrophotometers generate digital signals using interferometers and fourier transform circuitry. These fourier transform infrared spectrophotometers (FT-IR) are more powerful and operate faster than the older dispersive instruments. Figure 25.6 shows an FT-IR instrument equipped with an infrared microscope that can analyze particles too small to be seen with unaided vision (Figure 25.7).

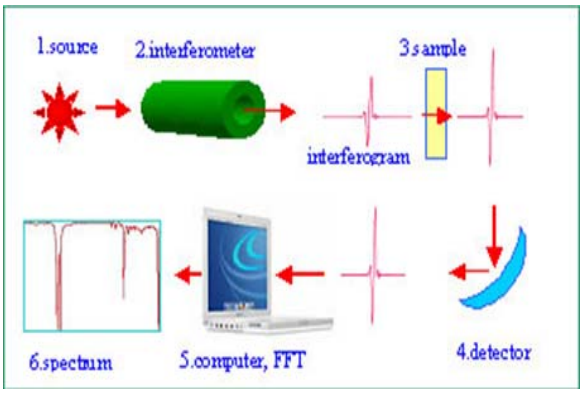


Figure 25.7 How FT-IR Spectrophotometer works

Attenuated total reflection infrared (ATR-IR) spectroscopy is used to analyze the surface of materials. It is also suitable to characterize materials which are either too thick or too absorbent to be analyzed by transmission spectroscopy. No sample preparation is required for ATR analysis of bulk materials or thick films.

25.3.4 Differential Scanning Calorimeter

The differential scanning calorimeter (DSC) measures heat gained or lost in a chemical reaction (Figure 25.8). They are quality-control instruments for powder coatings such as fusion-bond epoxies. They also measure the degree of cure for chemically-cured coatings such as epoxies, and they monitor the quality of plastics such as polyethylene and polypropylene.



Figure 25.8 Differential Scanning Calorimeter (DSC) for thermo-analysis

Another use for the DSC is to measure the amount of metallic zinc in a zinc primer. This test is described in ASTM D 6580.

25.4 Collecting Samples for Failure Analysis

Coating inspectors may be required to collect coating samples to send to a laboratory for further testing and analysis. The collection procedure and the documentation of the collection process are extremely important to ensure acceptable samples arrive at the laboratory. It is essential for the chain of custody during transportation to be verified.

Information provided to the laboratory enables the lab technician to select the best instrument. The information should include each of these items:

- Identity of materials to be analyzed
- Properly packed and labeled samples
- A chain-of-custody form should accompany the samples (the inspector retains a copy)
- Type of analysis required:(Examples)
  - — Leachable lead in spent abrasives
  - — Type and concentration of retained solvents in coating chips
  - — Generic identification of coating type
- Expected concentrations or concentrations of interest: (Example)
  - — Lead in paint is of interest in parts per million
  - — Lead in potable water in parts per billion

25.5 Other Laboratory Tests

Many laboratory tests that establish coating performance criteria are in reference books, including:

- ASTM Standards, Volume 6.01 and 6.02
- "*Paint Testing Manual*," by Gardner and Sward
- ASTM STP 500: "*Paint Testing Manual*"

These standards detail many additional field and laboratory coating tests for:

- Permeability
- Hardness
- Penetration
- Melting point
- Adhesion
- Abrasion resistance
- Color retention
- Gloss retention
- Bend
- Salt spray
- And other coating characteristics

Study Guide

1. What is a cathodic disbondment test?

   _____
   _____
   _____
   _____

2. List some of the specialized tests or equipment that coating inspectors may encounter:
   - _____
   - _____
   - _____
   - _____

3. What information should be included when sending samples to a laboratory?

   _____
   _____
   _____
   _____

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Chapter 26: Coating Types, Failure Modes, and Inspection Criteria

Objectives

When this module is complete, you will have knowledge and understanding of:

- Curing mechanisms
- Solvent-evaporation (Nonconvertible) Coatings
- Polymerization-cured coatings

26.1 Introduction

Earlier chapters discussed various coatings and their methods of curing. This chapter deals with the unique problems coating inspectors need to understand. Each cure type has unique inspection concerns inspectors need to understand to know what to look for and how and when to test the coating. If the cure type is not on the product data sheet, inspectors should contact the coating manufacturers' technical service department.

26.2 Curing Mechanisms

As stated previously, there are two categories of curing, each with several sub categories. The two major curing mechanism categories are: **non-convertible** (no chemical change during the cure cycle) and **convertible** (some chemical change during the cure cycle).

26.3 Solvent-Evaporation Cure (Nonconvertible) Coatings

Solvent-evaporation cured coatings simply harden as the solvent evaporates. In countries with active clean air programs solvent-evaporation cure materials are in limited supply since they contain a large amount of solvent that dissolve resins.

26.3.1 Chlorinated Rubber Coatings

These single-package coatings were once commonly used in both the chemical process industry and the marine industry because of their excellent petro-chemical, water, and UV resistance.

26.3.1.1 Failure Modes

Inspectors should ensure that existing chlorinated rubber coatings should never be overcoated with a convertible coating such as an epoxy mastic during maintenance projects.

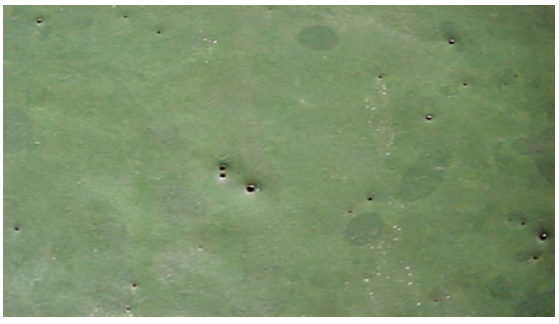


Figure 26.1 Pinholes

Overcoat chlorinated rubber only with chlorinated rubber, a single package waterborne material, or possibly a solvent-free chemical cured coating. To determine if the existing coating is solvent sensitive (as most evaporative cure coatings are) simply rub the surface with a solvent soaked rag. If this affects the existing coating, it is safe to assume that it should not be overcoated with a convertible coating. If a coating containing solvent is applied to a hot surface, the coating will not flow out and will leave an uneven surface with pinholes and low adhesion. Solvent entrapment can cause in-service blistering (Figure 26.1).

26.3.1.2 Inspection Criteria

DFT, surface temperature, and the overcoat window are all necessary inspection points with chlorinated rubber coatings. Follow the overcoat window and DFT recommended by the manufacturer to avoid solvent entrapment. Also monitor the surface temperature during application to ensure it does not exceed the recommended maximum and cause too-rapid solvent evaporation.

26.3.2 Vinyl Coatings

Vinyl coatings have the same issues as chlorinated rubber coatings. Vinyl coatings are commonly used in water tanks and as interior linings in water pipes. When used as a lining they are applied in multiple coats with very thin DFTs for each coat. Vinyl coatings can have a solids content as low as 25%, so safety is major concern when working around them. A big concern is also the large amount of solvent that moves off into the surrounding atmosphere.

26.3.2.1 Failure Modes

Solvent blistering is a common form of failure in vinyl coatings (Figure 26.2). This is usually caused by poor ventilation during application, excessive DFT per coat, or failure to follow the recommended recoat window.

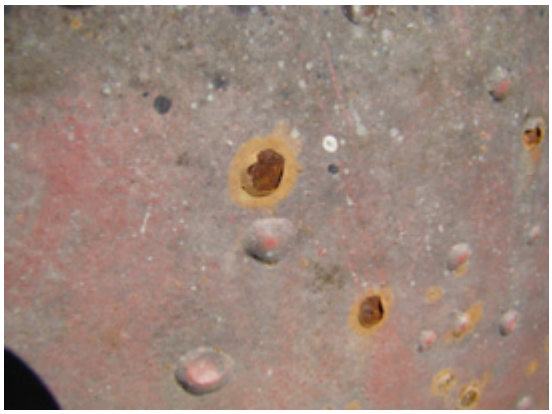


Figure 26.2 Blistering

26.3.2.2 Inspection Criteria

DFT, surface temperature, and the overcoat window are all necessary inspection points with vinyl coatings. Follow the overcoat window and the DFT recommended by the manufacturer to avoid solvent entrapment. Also monitor the surface temperature during application to ensure it does not exceed the recommended maximum and cause a too-rapid solvent evaporation.

26.3.3 Acrylic Coatings

Acrylic resins are commonly blended with other resins because of their excellent resistance to UV degradation. Additionally, they are used as the main, or singular resin, in water-borne coatings with very low VOC.

26.3.3.1 Failure Modes

When a single acrylic resin is the only resin in an acrylic coating, the most common fail-

ure modes are the failure to fully cure, and the failure to adhere when used as a primer. These failures are caused by either exceeding the recommended DFT or applying the material in hot and/or windy conditions. If the co-solvent evaporates too quickly from the surface of the coating film, it traps solvent in the lower layers of the film and retards or stops the coalescence process. Applying the primer to a hot surface can prevent it from flowing out, which reduces adhesion (Figure 26.3).



Figure 26.3 Delamination from Substrate

26.3.3.2 Inspection Criteria

DFT, surface temperature, wind speed, and the overcoat window are all necessary inspection points with acrylic coatings.

26.3.4 Bituminous Coatings

Both hot-melt and cold-applied bituminous coatings are used in the pipe coating industry, and at times, for other industries around the world. These coatings are normally shop applied.

26.3.4.1 Failure Modes

Long periods of sunlight exposure cause embrittlement of bituminous coatings and cracking (Figure 26.4) and delamination. Holidays are the most common problem when they are shop-applied.

26.3.4.2 Inspection Criteria

The coating inspector needs to follow the inspection criteria for the particular product and the facility applying it. A close inspection for holidays is necessary, paying careful



Figure 26.4 Cracking (Coating shown is not bituminous)

attention to the bottom side and the areas where the application equipment has difficulty reaching.

26.4 Polymerization-Cured Coatings

Temperature affects all coatings that cure through a chemical reaction. This is a positive heat-cured material, but this is generally a negative. There are a few single-package materials in this group, such as alkyds and moisture cures, however most polymerization-cured coatings come in two or more containers that cannot be mixed until just prior to use. These two facts are also the leading cause of failure for polymerization-cured coatings.

26.4.1 Oxygen-Induced Polymerization Coatings

26.4.1.1 Alkyds

Alkyds absorb oxygen from the surrounding atmosphere and uses the 0_2 molecule to react with the alkyd molecule in a process called oxidation.

26.4.1.1.1 Failure Modes

The most common problem with alkyds is wrinkling and/or a soft film caused from applying the coating too thickly. The top surface cures and seals the lower levels of the film from the oxygen they need to cure. The other common issue is putting the coating into service before it has time to fully cure.

26.4.1.1.2 Inspection Criteria

Ensure WFT readings are taken frequently by the applicator. Generally, any WFT over 3 to 4 mils (75 or 100 microns) in a single coat is too thick. The inspector should also confirm the applied material is cured before another coat is applied. Since oxygen-induced polymerization coatings normally have a long cure time before they are ready for service, inspectors should make sure owners know not to package or use alkyd-coated assemblies until the coating has reached its cure-to-handle stage.

26.4.2 Chemically Induced Polymerization Coatings

When two compounds are mixed together to form another compound, it is called chemically-induced polymerization. Most of the industrial and marine coatings in use today are chemically-induced polymerization coatings.

26.4.2.1 Epoxy Two-Component (Co-Reactive) Coatings

Epoxy coatings are the most widely used industrial/marine coatings. They come in a variety of types, however the most common failure modes are similar across all types.

26.4.2.1.1 Failure Modes

The following failure modes and their causes are usually apparent:

- Failure to cure – caused by improper mixing including a too short induction time, or temperatures above or below the recommended maximum and minimum
- Cracking – caused by applying too thickly
- Pinholes – caused by applying too thinly
- Sagging – caused by applying too thickly, over-thinning, or a too long pot life
- Delamination from previous coat – caused from exceeding the overcoat widow, coating on a dirty surface, or applying over amine blush (Figure 26.6, Figure 26.7)
- Chalking – caused by UV (sunlight) exposure or other radiation (Figure 26.5)



Figure 26.5 Chalking

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Figure 26.6 Amine Blush



Figure 26.7 Amine blush in removal process

26.4.2.1.2 Inspection Criteria

Inspectors need to keep a careful watch on the person mixing; this job is sometimes performed by the newest person on the team. It is too easy to leave the cure component out of one can by mistake, particularly if the mixer is inexperienced. Ensure mixing is done correctly, using the correct equipment, for sufficient time for the type of coating, and for the size of the unit. Ensure the entire cure is poured from its container into the base. The cure component is frequently a thick material and may not pour easily.

In a fast-paced production job the mixer may not allow the necessary induction time. Note the time the material is mixed, and mark each can with the time the mixer came out of it. Use this to calculate the necessary induction time based on the material's temperature. Mark the container with the time it can be used.

Inspectors need to also watch the environmental conditions, especially the dew point in the early hours of the day. For most epoxy coatings, moisture on the surface is a potential cause of delamination. Cooler temperatures in the evenings retard an epoxy's cure time. Check the temperatures during cure at least every 4 hours. Some situations may require using a data logger to track temperatures every few minutes during the cure cycle. Only count the hours of cure when the surface is at the curing temperature. For most epoxy paints this temperature is above 40°F (4.5°C).

Because epoxies and epoxy blends work well on a broad range of applications, inspectors need to know the exact surface preparation required for each project. When white metal is specified, the inspector must ensure the requirement is met. Specification requirements vary widely; sometimes a lower level of cleaning is required, or sometimes the specification requires epoxy to be applied over damp, oil contaminated surfaces, or underwater.

All epoxy coatings can be applied too thinly, and many can be applied too thickly without sagging. Inspectors must ensure the applicator uses a WFT gauge and follows the DFT reading standard specified, as well as check DFT in hard to reach areas.

When using epoxies, each case is different, so the inspector's most difficult task is ensuring the specified epoxy is used and

applied following all the required steps and conditions for the material and the project.

26.4.2.2 Zinc-Rich Epoxy

This epoxy coating has powdered zinc added to it. It is supplied as either a two-component material with the zinc already in the base, or as a three-component material with the zinc to be added by the applicator at the time of mixing.

26.4.2.2.1 Failure Modes

Failure modes are the same as with a standard epoxy. Use this material only as a primer. If it is applied over another coating, it **will not** provide the advertised protection to the surface.

26.4.2.2.2 Inspection Criteria

Due to the high load of zinc, zinc-rich epoxies are more difficult to mix. Because of this difficulty, inspectors must know the proper mix ratio and ensure all of the zinc supplied in the kit is used. They must also verify that the pump is constantly agitated to keep the zinc in suspension.

As always, ensure all mixing and application criteria in the specification are followed.

26.4.2.3 Polyester/Vinyl Ester Coatings

Polyester and vinyl ester coatings are used in special situations when a chemical or abrasion-resistant coating is required. A high degree of surface preparation is commonly specified.

26.4.2.3.1 Failure Modes

Failure to cure is one of the most common problems. Hardness testing may be required to determine if the proper cure is achieved before returning the surface to service. Ensure the surface is totally oil and contaminant free, or blisters can form.

Because many of these products have glass fiber included with the resin (either mixed in or added during application), wicking can be a problem. Each glass fiber must be completely wetted out to prevent moisture wicking into the film and the substrate. Wicking causes underfilm corrosion, blistering and/or delamination (Figure 26.8).



Figure 26.8 Blistering

26.4.2.3.2 Inspection Criteria

Perform all of the standard tests for these products, and possibly a hardness test if required.

26.4.2.4 Moisture-Cured Urethane

These materials are used in areas of high humidity where other materials generally cannot be used. They are frequently single package materials but must be applied in strict accordance with the owners' and manufacturers' requirements.

26.4.2.4.1 Failure Modes

Moisture-cured urethane is prone to failure to cure if used in areas of low humidity. This coating **must** be able to absorb moisture from the surrounding atmosphere. Do not

permit flooding with water. With a low humidity environment, the only proper treatment is to increase the local humidity by misting the area.

Moisture-cured urethane will blister and delaminate if applied to surfaces not cleaned in accordance with the specification.

26.4.2.4.2 Inspection Criteria

This standard inspection technique requires an extra careful watch on the humidity during the cure cycle.

26.4.2.5 Two-Component Thin Film Urethane Coatings

These products are most commonly used as topcoats over epoxies due to their good-to-excellent UV resistance and their wide availability in different colors.

26.4.2.5.1 Failure Modes

Common failure modes include:

Delamination, often due to application after the overcoat window (Figure 26.9).

Color and gloss differences. These occur in finished film and are caused by using two or more different batches of material, or from using two or more application techniques in adjoining areas. Changes in appearances are also seen if the DFT is uneven across the surface.

Blushing. This can be caused by moisture on the surface during the cure.

Failure to cure. This can happen if thinner added during application contains any moisture. Please note that bulk thinners purchased at low cost may contain some level of water.

26.4.2.5.2 Inspection Criteria

Use the required standard inspection techniques and closely watch the DFT. Ensure that if any thinner is used, the coating supplier approves in writing.



Figure 26.9 Cracking

26.4.2.6 Thick Film Polyurethane, Polyureas and Their Hybrids

These products are applied by heated plural airless spray. They have a very short pot life, sometimes as short as 9 seconds. Although grouped as a single family of materials, the individual products often have very different use and application characteristics. Inspectors must understand how the specialized spray equipment works and understand the unique mixing at the tip of the gun.

26.4.2.6.1 Failure Modes

Delamination. Dehumidification is caused by an improper specification. Polyureas are normally applied over an epoxy primer when used on steel, but this is not required when applied over concrete. Polyurethanes and *some* polyurea hybrids are commonly applied directly to steel, but they sometimes require an epoxy primer on concrete.

Failure to cure. Generally caused by the failure of the equipment to heat or pump proper amounts of each material to the gun,

or caused by the gun failing to spray both sides in the proper ratio.

26.4.2.6.2 Inspection Criteria

Follow standard inspection techniques.

26.4.2.7 Siloxanes

These can come as single-package or two-component materials and are normally blended with other resins such as acrylic, epoxy or polyurethane.

26.4.2.7.1 Failure Modes

Delamination. One coat may delaminate from the previous coat; this is caused by application over a non-compatible product (Figure 26.10).

Cracking. This is usually caused by an improper formula, and delamination (Figure 26.11).

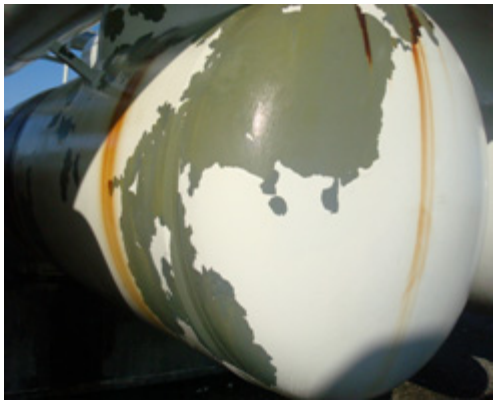


Figure 26.10 Delamination



Figure 26.11 Cracking

26.4.2.7.2 Inspection Criteria

Follow standard inspection procedures. In addition, pay close attention to the film thicknesses. Confirm that each product in the system is applied in its proper order. Also, ensure that the products in the system are compatible and meet the specified requirements.

26.4.2.8 Silicone Coatings

These high-temperature materials are applied over IOZ or applied directly to steel. These materials require a two-step cure process. At first, they react like any solvent-evaporation material — they harden within a very short time. However, they do not reach a fully cured state or adhere properly until heated. In many cases, the heating is done in service and increases incrementally over a set period of time.

26.4.2.8.1 Failure Modes

Delamination. Generally due to an improper heat cure cycle (Figure 26.12).



Figure 26.12 Delamination

26.4.2.8.2 Inspection Criteria

Carefully read the specification and the product data sheet. Pay close attention to requirements to slowly and incrementally raise the heat the first time these materials are placed in service.

26.4.3 Solvent-Borne Inorganic Zinc Coatings

These coatings cure both by solvent evaporation, and a chemical reaction from absorbing moisture from the surrounding atmosphere. This may take several days to happen, although it *appears* to cure within minutes or seconds of application. These can be used as preconstruction primers, but must be applied at only.75 mils (19 microns).

26.4.3.1 Failure Mode

Failure to cure. Caused by overcoating too soon.

Mud cracking. Caused by an excessively thick application — typically over 5 mils (125 microns).

26.4.3.2 Inspection Criteria

Pay careful attention to the curing cycle of these materials. The inspector must ensure they are **fully cured** prior to overcoating or packaging.

26.4.4 Water-Borne Inorganic Zinc Coatings

These coatings cure by water evaporation and absorbing carbon dioxide from the atmosphere. The cure may take days, but the coating appears to cure within minutes of application. This has use as a pre-construction primer if applied at .75 mils (19 microns).

26.4.4.1 Failure Modes

Failure to cure. Caused by overcoating too soon.

Mud cracking. This is caused by applying an excessively thick coating, typically 5 mils (over 125 microns).

26.4.4.2 Inspection Criteria

Pay careful attention to the curing cycle of these materials. The inspector must ensure they are **fully cured** prior to overcoating or packaging.

26.4.5 Water-Borne Coatings

Many coatings use water as a thinner or diluent. The major concern is preventing freezing during shipping and storage.

26.4.5.1 Failure Modes

Failure to cure is caused by the water evaporating too rapidly due to excessive heat on the surface, or excessive air flow over the surface.

26.4.5.2 Inspection Criteria

Use standard inspection criteria, paying particular attention to surface temperatures if high heat is expected, particularly to the tops of structures in full sunlight.

26.5 Case Study

The exterior of a 20-year-old carbon steel ground storage petroleum tank located in an arid desert climate was being blasted and coated with a three-coat single package water-borne acrylic coating system. After airless spray application of the primer and intermediate coating on the top and 50% of the sides, the application contractor called the coating manufacturer and told them the material was not curing, ever after several days at 100°F (38°C) plus temperatures.

26.6 Details

The specification called for:

- Abrasive blast in accordance with NACE 3/SSPC SP10 Near White Blasting Cleaning
- Application of a water-borne acrylic primer at 3 to 5 mils (75 to 125 microns)
- Application of a water-borne acrylic intermediate coat at 4 to 6 mils (100 to 150 microns)
- Application of a water-borne acrylic finish coat at 2 to 3 mils (50 to 75 microns)

No inspection requirements were included in the specification except the statement that the coating manufacturers recommends procedures be followed and that the contractor follow industry standard inspection procedures.

Application and cure times between coats and final cure were the same for all three products and were listed on their data sheets as:

26.6.1 Application Conditions

Review Table 26.1 for application conditions.

26.6.2 Curing Schedule

These times are based on a 2.0-3.0 mils (50-75 micron) DFT. Higher film thickness, insufficient ventilation, high humidity, or cooler temperatures will require longer cure times (Table 26.2).

Table 26.1: Application Conditions

Condition	Material	Surface	Ambient Temperature	Humidity
Normal	60-90°F (16-32°C)	65-85°F (18-29°C)	65-90°F (18-32°C)	10-80%
Minimum	50°F (10°C)	50°F (10°C)	50°F (10°C)	0%
Maximum	105°F (40°C)	130°F (54°C)	110°F (43°C)	85%

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Table 26.2: Curing Schedule

Surface Temp and 50% RH	Dry to Handle	Dry to Topcoat
50°F (10°C)	3 hours	3 hours
75°F (24°C)	2 hours	2 hours
90°F (32°C)	1 hour	1 hour

A note on the data sheets stated: "Dry Film Thickness 2.0-3.0 mils (50-75 microns); do not exceed 3.0 mils (75 microns) in a single coat."

26.7 Pertinent Notes

When the manufacturer's technical service person arrived on site, he first reviewed the contractor's and inspector's notes of the project.

26.7.1 Contractor's Notes

- The start of the project coincided with the beginning of the summer season.
- The owner did not have a coating inspector on the project and relied on the contractor who provided a part time non-certified coating inspector.
- This was a single shift job and all work took place between 7 a.m. and 5 p.m. each day.
- Environmental conditions, including: ambient and surface temperature, dew point and %RH, were taken and recorded at the beginning of the day about 8 a.m., around noon, and at the end of the work-day about 5p.m. On some days, the noon and end of shift readings were not recorded.
- On some days no environmental readings were recorded.
- Wind speed was not recorded and the inspector did not have a wind velocity meter.
- The material temperature was not taken or recorded.
- There was a verbal comment from the inspector to the manufacturer's technical service person that since this was the desert, every day was just the same as the previous day as far as the weather went. He also proudly commented that they had to stop painting and hold off until the next morning on several occasions, since the wind was blowing so hard in the afternoon that the man-lifts they worked out of started to swing too much.
- The abrasive blasting was performed with silica sand and was accepted by the coating inspector as being compliant with the specification. There were no photographs or any recorded test results such as the ISO 8503-3 Dust Tape test to verify his claim. When asked if he had a copy of SSPC Vis-1 he said he did not.
- No testing for soluble contaminants was required by the specification or performed by the contractor.
- Blasting was performed from the beginning of the shift until about 3 p.m. when the blasted area was blown down and coated with the primer.
- There were no records of WFT being taken. When questioned about it the painting supervisor said that all of his painters checked WFT constantly while applying the coating, but they did not record.
- The material was thinned with clean water, but no record of the amount of thinner was kept. The painting supervisor claimed they followed the manufacturer's data sheet exactly. There was no evidence of any liquid measuring devices at the job site.

26.7.2 Inspector's Daily Log

The project had been in progress for 7 days when the coating manufacturer's technical service person showed up. The daily notes

recorded by the contractor's inspector were as follows:

26.7.2.1 Day One and Two

Moved on job, brought in equipment, paint, and grit, and covered with tarp.

Bright sun, no rain in forecast.

Ambient temperature was 90°F (32°C) in the morning, and 110°F (43°C) at 5 p.m. when leaving the job site. Did not have tool to measure RH but was really hot and dry feeling; must have been pretty low humidity. Sure a lot of sand blowing around in the afternoon!

26.7.2.2 Day Three

Set up and started to blast on roof of tank, three blasters on roof starting in the middle and working out.

Ambient temperature was 90°F (32°C) at 8 a.m., clear and sunny.

Ambient temperature was 97°F (36°C) at 12 noon, still clear and sunny, wind starting to pick up.

Ambient temperature was 110°F (43°C) at 4 p.m., sunny but with a dust cloud from the wind, too windy to paint.

26.7.2.3 Day Four

Checked blasting from previous day, still looked good, will complete blasting and prime the roof today.

Ambient temperature was 90°F (32°C) at 7:30 a.m., clear and sunny.

Noon: Blasting on roof completed, looks good, painters setting up. Air temp 99°F (37°C), RH 15%, tank surface on roof 105°F (40°C).

1 p.m. — wind picked up too much to paint, tarps blowing off stored materials.

2 p.m. — put away materials and left job site.

26.7.2.4 Day Five

Inspector not available due to a different project today. Supervisor reported that everything went well, all temperatures were good to go and the roof was painted with the primer, and two drops were made on the side by the blasters.

26.7.2.5 Day Six

9 a.m. arrived at job site, blasting on sides.

Ambient temperature was 90°F (32°C) at 9 a.m., clear and sunny, RH 12%.

Ambient temperature was 97°F (36°C) at 12 noon, still clear and sunny, RH 12%.

Ambient temperature was 110°F (43°C) at 4 p.m., clear and sunny.

Checked DFT of primer on roof and sides, took 25 or 30 readings on roof and another 10 or 15 on the sides, average was 4 mils (100 microns).

Primer on roof still a little soft, but not sticky. Gave approval to apply intermediate coat based on the fact the primer had been on for two days and must be cured by now. Told painters to wear booties so they would not get the primer dirty. They used the blast hoses to blow down the roof before spraying on the next coat.

3 p.m. — Blasting on sides completed with all areas blown down, looks like a good near white blast, only a very few spots of paint visible on the surface, really clean looking.

3:30 p.m. — Intermediate coat being applied to roof and portion of the sides. Primer being applied to bare steel portion of the sides and the ladder.

5 p.m. — One of the painters had to come down off the roof since he burned his hand when he touched the steel with his bare hand. It did not seem bad enough to send him to the hospital so we had him soak it in cold water. I guess I should check that temperature up there, but access is limited.

6 p.m. — today's painting completed, looks good!

26.7.2.6 Day Seven

Ambient temperature was 90°F (32°C) at 9 a.m., clear and sunny, RH 12%.

Ambient temperature was 97°F (36°C) at 12 noon, still clear and sunny, RH 12%.

Ambient temperature was 110°F (43°C) at 4 p.m., clear and sunny.

7 a.m. — Material on roof still soft to the touch, but not sticky. Soft on the sides also, except on the north side of the tank where it has gotten hard like I think it should be. Checked the batch numbers on the paint and there were several different numbers for each product. Must be we got some bad paint!

Stopped the job and called the coating manufacturer's technical service department; they said they would send someone out that afternoon.

26.8 Coating Manufactures Results

The manufacturer's representative confirmed that the coating was still fingernail soft. He measured several places for DFT and found a film thickness (used plastic shim to measure through and subtracted shim DFT) ranging from 2 to 8 mils (50 to 200 microns) of primer and where the primer had been overcoated the DFT was 3 to 16 mils (75 to 400 microns). The surface temperature of the roof was 140°F (60°C) at 3 p.m. and the wind speed was 24 knots.

26.8.1 Questions

Your team represents the coating manufacturer. Answer the following questions:

1. List three things the inspector did wrong or neglected to do that should been have done.
2. List three things the owner's specification writer could have done to improve the specification.
3. What could the application contractor have done to improve the quality of the job?
4. Why does your team think the coating was still soft to the touch on most of the tank and hard on the north-facing wall of the tank? What do you think can be done to fix it?

Study Guide

1. What are the two categories of curing and their definitions?
   - _____
   - _____

2. List some examples of non-convertible coatings.
   - _____
   - _____
   - _____
   - _____

3. What is a polymerization-cured coating?
   _____

4. List some examples of convertible-cured coatings.
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____

5. What is the cause of chalking in an epoxy coating?
   _____

6. When using a solvent-borne inorganic zinc, what would be one common reasons for a failure to cure?
   _____

Chapter 27: Peer Review

27.1 Peer Review Procedure

Peer Review preparation includes:

- Review the CIP Level 1 materials. Take advantage of the time allowed for review this week to ask questions on any items that need clarification.
- Relax — try not to worry about the Peer Review. NACE has made the Peer Review as fair and straightforward as possible. The review itself has a maximum time duration of 2 hours. The review is divided into two (2) parts: technical and practical.

The review is an opportunity to demonstrate mastery of technical and practical knowledge. Be a willing participant in that demonstration.

The question set drawn is representative of a body of knowledge that is consistent with the other question sets. The question set drawn is used only once.

The integrity of the process is based upon the integrity of the candidate. Honor the hard work and the program by not repeating the questions given in the review to anyone for any reason.

Mentally move into the role of a NACE inspector throughout the review. Arrive at least 1 hour early. The schedule has a tendency to shift, so do not be alarmed. Be ready and stay flexible. The lead peer may make contact to give an update, especially if the reviews are running ahead of schedule.

A copy of the Peer Review Procedure is in the notebook. Take a few minutes to read over it and then questions will be answered.

Provisional time slots for the Peer Review are assigned by NACE staff. The time slots first accommodate those who are taking both Level 2 and the Peer Review. These assignments are provisional because the final determinations are made by the Peers when they arrive.

If you want a slot that someone else in class has, get with that person and work out a swap if you can. Make that change on the posted schedule, or check with the NACE staff representative.

This outline describes the procedure and questions to be used in the NACE Coating Inspector Certification Peer Review.

The Peer Review board shall consist of three persons appointed by NACE.

27.1.1 Expectations

The technical portion of the review consists of 6 technical questions, each with a maximum time allotment of 10 minutes.

- Take time to focus on the question, and take time to thoroughly formulate your response.
- When you give an answer, stay focused on what the question is asking, do not stray from the boundaries of the question.
- If you are unsure of what the question is asking, you may request clarification from the Peers. They will assist as much as possible.
- Leave time at the end of each question for Peers to ask clarifying questions, if necessary. Peers “suggest” that a response should begin when you have formulated

an answer. If you receive a notice of 5 minutes you should start your answer.

- Some questions require only a short answer, while others require a more developed response. In all cases, there are no trick questions.
- All questions are drawn from CIP courses and reading material that you have been exposed to at some point during the CIP Program.
- The practical portion of the review consists of 4 practical questions, each having a maximum time allotment of 15 minutes.
- Review and understand the Attestation and Code of Ethics. Much of what NACE inspectors do is based upon the ideals that are contained in the Attestation and Code of Ethics.
- The practical portion of the review requires you to apply your technical knowledge, field experiences, and logic, in order to satisfy the scenario.
- Each practical question is a scenario in which you are the NACE inspector. The scenario presents a situation that needs facilitation to resolution. It is quite possible that there may be more than one correct response, so think through the scenario and fully develop your response.
- The scenario may be amended and the Peers may take on roles in order to see how you would respond to a modified situation.

27.2 Evaluation

After both parts of the review are completed, the applicant will be asked to leave the room, and to wait nearby.

The Peers will vote, without discussion, on whether, in each Peer's judgment, the applicant's answers are satisfactory to the extent that the applicant should be judged to have passed the Peer Review, or the applicant's answers are unsatisfactory to the extent that the applicant should be judged to have failed the Peer Review.

Two passing votes are required for the applicant to pass the Peer Review. If the applicant does not receive a unanimous vote (pass or fail), the Peers may discuss the applicant's answers, and vote a second time.

In any case, the final results will be noted on a standardized form that will be forwarded to NACE Headquarters.

Each Peer voting negative must document negative comments on the second page of the form.

27.3 Peer Review Results Notification Procedure

When a decision is reached, the candidate shall be called to the Peer Review room by the Lead Peer.

The candidate shall be presented with the decision of the Peer Board by means of the Lead Peer presenting the candidate with a properly executed copy of the appropriate PASS or FAIL letter.

The Peer Board may be available to briefly answer questions, but if the candidate wishes to discuss the Board's decision in detail, the candidate must make arrangements for a formal appointment with the Peer Board through NACE staff. It will be the responsibility of the Lead Peer to immediately communicate the results of the Peer Board to NACE staff.

Candidates who fail the Peer Review on their first attempt must wait a minimum of one week before attempting to retake the

Peer Review. Candidates failing on second and subsequent attempts must wait a minimum of six months between attempts.

SSPC
the society for protective coatings

NACE INTERNATIONAL

Item No. 21076

Joint Surface Preparation Standard

NACE No. 5/SSPC-SP 12
Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating

This NACE International (NACE)/SSPC: The Society for Protective Coatings standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. It is intended to aid the manufacturer, the consumer, and the general public. Its acceptance does not in any respect preclude anyone, whether he has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not addressed in this standard. Nothing contained in this NACE/SSPC standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents current technology and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. NACE and SSPC assume no responsibility for the interpretation or use of this standard by other parties and accept responsibility for only those official interpretations issued by NACE or SSPC in accordance with their governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

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Foreword

This joint standard describes the surface preparation technique known as waterjetting. This technique provides an alternative method of removing coating systems or other materials from metal surfaces, including lead-based paint systems, prior to the application of a protective coating or lining system. This standard is intended for use by coating or lining specifiers, applicators, inspectors, or others whose responsibility it may be to define a standard degree of surface cleanliness. Since publication of NACE Standard RP0172,[1] surface preparation using waterjetting equipment has found acceptance as a viable method.

Waterjetting can be effective in removing water-soluble surface contaminants that may not be removed by dry abrasive blasting alone, specifically, those contaminants found at the bottom of pits of severely corroded metallic substrates. Waterjetting also helps to remove surface grease and oil, rust, shot-creting spatter, and existing coatings and linings. Waterjetting is also used in areas where abrasive blasting is not a feasible method of surface preparation.

The use of a high-pressure water stream to strip existing coatings and clean the surface has advantages over open dry abrasive blasting with respect to worker respiratory exposure and work area air quality. Respiratory requirements for waterjetting may be less stringent than for other methods of surface preparation.

Waterjetting does not provide the primary anchor pattern on steel known to the coatings industry as “profile.” The coatings industry uses waterjetting primarily for recoating or relining projects in which there is an adequate preexisting profile. Waterjetting has application in a broad spectrum of industries. It is used when high-performance coatings require extensive surface preparation and/or surface decontamination.

This standard was originally prepared by NACE/SSPC Joint Task Group TGD. It was technically revised in 2002 by Task Group 001 on Surface Preparation by High-Pressure Waterjetting. This Task Group is administered by Specific Technology Group (STG) 04 on Protective Coatings and Linings—Surface Preparation, and is sponsored by STG 02 on Protective Coatings and Linings—Atmospheric, and STG 03 on Protective Coatings and Linings—Immersion/Buried. This standard is issued by NACE International under the auspices of STG 04, and by SSPC Group Committee C.2 on Surface Preparation.

Joint Surface Preparation Standard

NACE No. 5/SSPC-SP 12
Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating

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Section 1: General

1.1 This standard describes the use of waterjetting to achieve a defined degree of cleaning of surfaces prior to the application of a protective coating or lining system. These requirements include the end condition of the surface plus materials and procedures necessary to verify the end condition. This standard is limited in scope to the use of water only.

~~1.3~~1.2 This standard is written primarily for applications in which the substrate is carbon steel. However, waterjetting can be used on nonferrous substrates such as bronze, aluminum, and other metals such as stainless steel. This standard does not address the cleaning of concrete. Cleaning of concrete is discussed in NACE No. 6/SSPC SP-13.[2]

~~1.4~~1.3 Appendices A, B, and C give additional information on waterjetting equipment, production rates, procedures, and principles.

1.4 Visual Reference Photographs: NACE VIS 7/SSPC-VIS 4, "Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting,"[3] provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The latest issue of the reference photographs should be used.

Section 2: Definitions

2.1 This section provides basic waterjetting definitions. Additional definitions relevant to waterjetting are contained in the WaterJet Technology Association's[(1)] "Recommended Practices for the Use of Manually Operated High-Pressure Waterjetting Equipment."[4]

2.1.1 **Waterjetting (WJ):** Use of standard jetting water discharged from a nozzle at pressures of 70 MPa (10,000 psig) or greater to prepare a surface for coating or inspection. Waterjetting uses a pressurized stream of water with a velocity that is greater than 340 m/s (1,100 ft/s) when exiting the orifice. Waterjetting does not produce an etch or profile of the magnitude currently recognized by the coatings industry. Rather, it exposes the original abrasive-blasted surface profile if one exists.

2.1.2 **Water Cleaning (WC):** Use of pressurized water discharged from a nozzle to remove unwanted matter from a surface.

2.1.3 **Standard Jetting Water:** Water of sufficient purity and quality that it does not impose additional contaminants on the surface being cleaned and does not contain sediments or other impurities that are destructive to the proper functioning of waterjetting equipment.

2.1.4 **Low-Pressure Water Cleaning (LP WC)**: Water cleaning performed at pressures less than 34 MPa (5,000 psig). This is also called "power washing" or "pressure washing."

2.1.5 **High-Pressure Water Cleaning (HP WC):** Water cleaning performed at pressures from 34 to 70 MPa (5,000 to 10,000 psig).

2.1.6 **High-Pressure Waterjetting (HP WJ):** Waterjetting performed at pressures from 70 to 210 MPa (10,000 to 30,000 psig).

2.1.7 **Ultrahigh-Pressure Waterjetting (UHP WJ):** Waterjetting performed at pressures above 210 MPa (30,000 psig).

2.1.8 **Nonvisible Contamination (NV):** Nonvisible contamination is the presence of organic matter, such as very thin films of oil and grease, and/or soluble ionic materials such as chlorides, ferrous salts, and sulfates that remain on the substrate after cleaning.

2.1.9 **Visible Surface Cleanliness (VC):** Visible surface cleanliness is the visible condition of the substrate, when viewed without magnification, after cleaning.

Section 3: Surface Cleanliness Requirements

~~3.1~~3.1 Table 1 lists four definitions of surface cleanliness in terms of visible contaminants. A surface shall be prepared to one of these four visual conditions prior to recoating.

3.1.1 As part of the surface preparation, deposits of oil, grease, and foreign matter must be removed by waterjetting, by water cleaning, by steam cleaning, by methods in accordance with SSPC-SP 1,[5] or by

[1] WaterJet Technology Association, 917 Locust Street, Suite 1100, St. Louis, MO 63101-1419.

another method agreed upon by the contracting parties.

3.1.2 NOTE: Direct correlation to existing dry media blasting standards is inaccurate or inappropriate when describing the capabilities of water cleaning and the visible results achieved by water cleaning.

3.1.3 The entire surface to be prepared for coating shall be subjected to the cleaning method.

3.1.4 For WJ-4 (see Table 1) any remaining mill scale, rust, coating, or foreign materials shall be tightly adherent. All of the underlying metal need not be exposed.

3.1.5 Photographs may be specified to supplement the written definition. In any dispute, the written standards shall take precedence over visual reference photographs or visual standards such as NACE VIS 7/SSPC-VIS 4.[3]

3.2 Table 2 lists definitions of flash rusted surfaces (See Section 4). When deemed necessary, a surface should be prepared to one of these flash rusted surface conditions prior to recoating.

3.3 The specifier shall use one of the visual surface preparation definitions (WJ-1 to WJ-4 in Table 1) and, when deemed necessary, one of the flash rust definitions.

3.3.1 The following is an example of a specification statement:

"All surfaces to be recoated shall be cleaned to NACE No. 5/SSPC-SP 12, WJ-2/L, Very Thorough or Substantial Cleaning, Light Flash Rusting."

3.4 Appendix A contains information on nonvisible surface contaminants. In addition to the requirements given in Paragraph 3.1, the specifier should consider whether a surface should be prepared not to exceed the maximum level of nonvisible surface contamination prior to recoating. A suggested specification statement for nonvisible contaminants is given in Appendix A.

Table 1: Visual Surface Preparation Definitions

Term	Description of Surface
WJ-1	**Clean to Bare Substrate:** A WJ-1 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible rust, dirt, previous coatings, mill scale, and foreign matter. Discoloration of the surface may be present.[A, B, C]
WJ-2	**Very Thorough or Substantial Cleaning:** A WJ-2 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5% of the surface.[A, B, C]
WJ-3	**Thorough Cleaning:** A WJ-3 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 33% of the surface.[A, B, C]
WJ-4	**Light Cleaning:** A WJ-4 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Any residual material shall be tightly adherent.[C]

[A] Surfaces cleaned by LP WC, HP WC, HP WJ, or UHP WJ do not exhibit the hue of a dry abrasive blasted steel surface. After waterjetting, the matte finish color of clean steel surface immediately turns to a golden hue unless an inhibitor is used or environmental controls are employed.[6] On older steel surfaces that have areas of coating and areas that are coating-free, the matte finish color varies even though all visible surface material has been removed. Color variations in steel can range from light gray to dark brown/black.

Steel surfaces show variations in texture, shade, color, tone, pitting, flaking, and mill scale that should be considered during the cleaning process. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type of steel or other metals, original surface condition, thickness of the steel, weld metal, mill fabrication marks, heat treating, heat-affected zones, and differences in the initial abrasive blast cleaning or in the waterjet cleaning pattern.

The gray or brown-to-black discoloration seen on corroded and pitted steel after waterjetting cannot be removed by further waterjetting. A brown-black discoloration of ferric oxide may remain as a tightly adherent thin film on corroded and pitted steel and is not considered part of the percentage staining.

[B] Waterjetting at pressures in excess of 240 MPa (35,000 psig) is capable of removing tightly adherent mill scale, but production rates are not always cost effective.

[C] Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife. (See NACE No. 4/SSPC-SP 7[7]).

Section 4: Flash Rusted Surface Requirements

4.1 Table 2 lists four definitions of flash rusted surface requirements. *Flash rust* or *water bloom* is a light oxidation of the steel that occurs as waterjetted carbon steel dries. With the exception of stainless steel surfaces, any steel surface may show flash rust within 0.5 to 2 hours, or longer depending on environmental conditions, after cleaning by water. Flash rust quickly changes the appearance. Flash rust may be reduced or eliminated by physical or chemical methods. The color of the flash rust may vary depending on the age and composition of the steel and the time-of-wetness of the substrate prior to drying. With time, the flash rust changes from a yellow-brown, well adherent, light rust to a red-brown, loosely adherent, heavy rust.

4.2 It is a common practice to remove heavy flash rust by low-pressure water cleaning. The visual appearance of steel that has heavily flash rusted after initial cleaning and is then recleaned by low-pressure water cleaning (up to 34 MPa [5,000 psig]) has a different appearance than the original light flash rusted steel depicted in NACE VIS 7/SSPC-VIS 4.

4.3 The coating manufacturer should be consulted to ascertain the tolerance of the candidate coatings to visual cleanliness, nonvisible contaminants, and the amount of flash rust commensurate with the in-service application. These conditions should be present at the time of recoating.

4.4 The following is an example of a specification statement concerning flash rust:

"At the time of the recoating, the amount of flash rust shall be no greater than moderate (M) as defined in NACE No. 5/SSPC-SP 12."

Table 2: Flash Rusted Surface Definitions

Term	Description of Surface
No Flash Rust	A steel surface which, when viewed without magnification, exhibits no visible flash rust.
Light (L)	A surface which, when viewed without magnification, exhibits small quantities of a yellow-brown rust layer through which the steel substrate may be observed. The rust or discoloration may be evenly distributed or present in patches, but it is tightly adherent and not easily removed by lightly wiping with a cloth.
Moderate (M)	A surface which, when viewed without magnification, exhibits a layer of yellow-brown rust that obscures the original steel surface. The rust layer may be evenly distributed or present in patches, but it is reasonably well adherent and leaves light marks on a cloth that is lightly wiped over the surface.
Heavy (H)	A surface which, when viewed without magnification, exhibits a layer of heavy red-brown rust that hides the initial surface condition completely. The rust may be evenly distributed or present in patches, but the rust is loosely adherent, easily comes off, and leaves significant marks on a cloth that is lightly wiped over the surface.

Section 5: Occupational and Environmental Requirements

5.1 Because waterjet cleaning is a hazardous operation, all work shall be conducted in compliance with all applicable occupational health and safety rules and environmental regulations.

Section 6: Cautionary Notes

6.1 Waterjetting can be destructive to nonmetallic surfaces. Soft wood, insulation, electric installations, and instrumentation must be protected from direct and indirect water streams.

6.2 Water used in waterjetting units must be clean and free of erosive silts or other contaminants that damage pump valves and/or leave deposits on the surface being cleaned. The cleaner the water, the longer the service life of the waterjetting equipment.

6.3 Any detergents or other types of cleaners used in conjunction with waterjetting shall be removed from surfaces prior to applying a coating.

6.4 Compatibility of the detergents with the special seals and high-alloy metals of the waterjetting equipment must be carefully investigated to ensure that WJ machines are not damaged.

6.5 If inhibitors are to be used with the standard jetting water, the manufacturer of the waterjetting equipment shall be consulted to ensure compatibility of inhibitors with the equipment.

6.6 The coatings manufacturer shall be consulted to ensure the compatibility of inhibitors with the coatings.

6.7 If effluent jetting water is captured for reuse in the jetting method, caution should be used to avoid introducing any removed contaminants back to the cleaned substrate. The effluent water should be treated to remove suspended particulate, hydrocarbons, chlorides, hazardous materials, or other by-products of the surface preparation procedures. The water should be placed in a clean water holding tank and tested to determine the content of possible contamination prior to reintroduction into the jetting stream. If detergents or degreasers are used prior to surface preparation, these waste streams should be segregated from the effluent jetting water to avoid contamination and possible equipment damage.

References

1. NACE Standard RP0172 (withdrawn), "Surface Preparation of Steel and Other Hard Materials by Water Blasting Prior to Coating or Recoating" (Houston, TX: NACE). (Available from NACE as an historical document only.)

2 NACE No. 6/SSPC-SP 13 (latest revision), "Surface Preparation of Concrete" (Houston, TX: NACE, and Pittsburgh, PA: SSPC).

3. NACE VIS 7/SSPC-VIS 4 (latest revision), "Guide and Visual Reference Photographs for Steel Cleaned by Waterjetting" (Houston, TX: NACE, and Pittsburgh, PA: SSPC).

4. "Recommended Practices for the Use of Manually Operated High-Pressure Waterjetting Equipment," (St. Louis, MO: WaterJet Technology Association, 1987).

5. SSPC-SP 1 (latest revision), "Solvent Cleaning" (Pittsburgh, PA: SSPC).

6. NACE Publication 6A192/SSPC-TR 3 (latest revision), "Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces" (Houston, TX: NACE, and Pittsburgh, PA: SSPC).

7. NACE No. 4/SSPC-SP 7 (latest revision), "Brush-Off Blast Cleaning" (Houston, TX: NACE, and Pittsburgh, PA: SSPC).

8. NACE Publication 6G186 (withdrawn), "Surface Preparation of Contaminated Steel Structures" (Houston, TX: NACE). (Available from NACE as an historical document only.)

9. SSPC-TU 4 (latest revision), "Field Methods for Retrieval and Analysis of Soluble Salts on Substrates" (Pittsburgh, PA: SSPC).

10. ISO[2] 8502-5 (latest revision), "Preparation of Steel Substrates Before Application of Paints and Related Products—Test for the Assessment of Surface Cleanliness—Part 5: Measurement of Chloride on Steel Surfaces Prepared for Painting (Ion Detection Tube Method)" (Geneva, Switzerland: ISO).

11. FHWA[3]-RD-91-011 (latest revision), "Effect of Surface Contaminants on Coating Life" (McLean, VA: U.S. Department of Transportation, Federal Highway Administration). Also available as SSPC Publication 91-07. (Pittsburgh, PA: SSPC).

12. ISO 8502-6 (latest revision), "Preparation of Steel Substrates Before Application of Paints and Related Products—Tests for the Assessment of Surface Cleanliness—Part 6: Extraction of Soluble Contaminants for Analysis—The Bresle Method" (Geneva, Switzerland: ISO).

13. ISO 8502-2 (latest revision), "Preparation of Steel Substrates Before Application of Paints and Related Products—Tests for the Assessment of Surface Cleanliness—Part 2: Laboratory Determination of Chloride on Cleaned Surfaces" (Geneva, Switzerland: ISO).

14. ASTM[4] D 516-02 (latest revision), "Standard Test Method for Sulfate Ion in Water" (West Conshohocken, PA: ASTM).

15. J.J. Howlett, Jr., R. Dupuy, "Ultrahigh Pressure Waterjetting (UHP WJ): A Useful Tool for Deposit Removal and Surface Preparation," CORROSION/92, paper no. 253 (Houston, TX: NACE, 1992).

16. L.M. Frenzel, R. DeAngelis, J. Bates, Evaluation of 20,000-psi Waterjetting for Surface Preparation of Steel Prior to Coating or Recoating (Houston, TX: Butterworth Jetting, 1983). Also available in L.M. Frenzel, The Cleaner, February (1992) (Three Lakes, WI: Cole Publishing, Inc.).

[2] International Organization for Standardization (ISO), 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland.
[3] Federal Highway Administration (FHWA), 400 7th St. SW, Washington, DC 20590.
[4] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

17 G. Kuljian, D. Melhuish, "Evaluating the Productivity of Waterjetting for Marine Applications," Journal of Protective Coatings and Linings (JPCL) 16, 8 (1999): pp. 36-46.

18. R.K. Miller, G.J. Swenson, "Erosion of Steel Substrate when Exposed to Ultra-Pressure Waterjet Cleaning Systems," 10th American Waterjet Conference, paper 52 (St. Louis, MO: WJTA, 1999), page 661.

19. R. Lever, "A Guide to Selecting Waterjet Equipment for Coating Installation Surface Preparation," NACE Infrastructure Conference, Baltimore, MD. (Houston, TX: NACE, 1995).

20. D.A. Summers, WaterJetting Technology (London, UK: Chapman and Hall, 1995).

Bibliography

Ablas, B.P., and A.M. van London, "The Effect of Chloride Contamination on Steel Surfaces: A Literature Review." Paint and Coatings Europe, Feb. (1997); pp.16-25.

Appleman, B.R. "Painting Over Soluble Salts: A Perspective." *JPCL* 4, 6 (1987): pp. 68-82.

Calabrese, C., and J.R. Allen. "Surface Characterization of Atmospherically Corroded and Blast Cleaned Steel." *Corrosion* 34, 10 (1978): pp. 331-338.

Cathcart, W.P. "Non-Visible Contaminants in Railcar Interiors: Their Significance and Removal." *JPCL* 4, 12 (1987): pp. 6, 8-10.

Ferry, K.W. "Cleaning Lined Tank Cars and Unlined Tank Cars for Lining Application." *Materials Performance (MP)* 30, 5 (1991): pp. 34-37.

Flores, S., J. Simancas, and M. Morcillo. "Methods for Sampling and Analyzing Soluble Salts on Steel Surfaces: A Comparative Study." *JPCL* 11, 3 (1994): pp. 76-83.

Frenzel, L.M., M. Ginn, and G. Spires. "Application of High-Pressure Waterjetting in Corrosion Control." In *Surface Preparation: The State of the Art*. Eds. B.R. Appleman and H.E. Hower. Pittsburgh, PA: SSPC, 1985.

Frenzel, L.M., and J. Nixon. "Surface Preparation Using High-Pressure Water Blasting." CORROSION/89, paper no. 397. Houston, TX: NACE, 1989.

Frondistou-Yannas, S. "Effectiveness of Nonabrasive Cleaning Methods for Steel Surfaces." *MP* 25, 7 (1986): pp. 53-58.

Johnson, W.C. ASTM Special Publication 841. West Conshohocken, PA: ASTM, 1984.

McKelvie, A.N. "Can Coatings Successfully Protect Steel, What Are the Ingredients of Success?" *MP* 19, 5 (1980): p. 13.

McKelvie, A.N. "Steel Cleaning Standards-A Case for Their Reappraisal." *Journal of the Oil and Colour Chemists' Association* 60 (1977): pp. 227-237.

NACE Standard TM0170 (withdrawn). "Visual Standard for Surfaces of New Steel Airblast Cleaned with Sand Abrasive." Houston, TX: NACE. Available from NACE as an historical document only.

Rex, J. "A Review of Recent Developments in Surface Preparation Methods." *JPCL* 7, 10 (1990): pp. 50-58.

Systems and Specifications: Volume 2, *Steel Structures Painting Manual.* 7th ed. Pittsburgh, PA: SSPC, 1995.

Trimber, K.A. "An Investigation into the Removal of Soluble Salts Using Power Tools and Steam Cleaning." In *The Economics of Protective Coatings*: *Proceedings of the Steel Structures Painting Council Seventh Annual Symposium*. Pittsburgh, PA: SSPC, 1988.

Trimber, K.A. "Detection and Removal of Chemical Contaminants in Pulp and Paper Mills." *JPCL* 5, 11 (1988): pp. 30-37.

Weldon, D.G., A. Bochan, and M. Schleiden. "The Effect of Oil, Grease, and Salts on Coating Performance." *JPCL* 4, 6 (1987): pp. 46-58.

NOTE: Appendices A, B, and C provide explanatory notes. They provide additional information on waterjetting.

Appendix A: Surface Cleanliness Conditions of Nonvisible Contaminants and Procedures for Extracting and Analyzing Soluble Salts

A1.1 For the purpose of this appendix, the list of non-visible contaminants is limited to water-soluble chlorides, iron-soluble salts, and sulfates. The contracting parties should be aware that other nonvisible contaminants may have an effect on the coating performance.[8] The specifier should determine whether, and to what condition, nonvisible chemical contaminants should be specified. Section 3 contains additional information on surface cleanliness conditions.

A1.2 The level of nonvisible contaminants that may remain on the surface is usually expressed as mass per unit area, for example, $\mu g/cm^2$ (grains/in.^{2}) or mg/m^2 (grains/yd^2) (1 $\mu g/cm^2$ = 10 mg/m^2 = 0.0001 grains/in.^{2} = 0.13 grains/yd^2).

A1.3 Coatings manufacturers should be consulted for recommendations of maximum surface contamination allowed. The specification should read as follows:

> "Immediately prior to the application of the coating, the surface shall not contain more than xx $\mu g/cm^2$ (grains/in.^{2}) of the specific contaminant (e.g., chloride) when tested with a specified method as agreed upon by contracting parties."

A1.4 The contracting parties shall agree on the test method or procedure to be used for determining the level of nonvisible contaminants.

Note: NACE and ISO committees are currently (2002) developing recommendations for the level of nonvisible contaminants that may be tolerated by different types of coatings in various services.

Table A1: Description of Nonvisible Surface Cleanliness Definitions[(A)] (NV)

Term	Description of Surface
NV-1	An NV-1 surface shall be free of detectable levels of soluble contaminants, as verified by field or laboratory analysis using reliable, reproducible test methods.
NV-2	An NV-2 surface shall have less than 7 $\mu g/cm^2$ (0.0007 grains/in.^{2}) of chloride contaminants, less than 10 $\mu g/cm^2$ (0.001 grains/in.^{2}) of soluble ferrous ion levels, or less than 17 $\mu g/cm^2$ (0.0017 grains/in.^{2}) of sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.
NV-3	An NV-3 surface shall have less than 50 $\mu g/cm^2$ (0.005 grains/in.^{2}) of chloride or sulfate contaminants as verified by field or laboratory analysis using reliable, reproducible test methods.

[(A)] Additional information on suitable procedures for extracting and analyzing soluble salts is available in NACE Publication 6G186,[8] and SSPC-TU 4.[9]

A2.1 Procedure for Extracting Soluble Salts by Swabbing

The following procedures may be used to extract the soluble salts from the surface:

(a) SSPC Swabbing Method[9]
(b) Procedure described in ISO 8502-5, Section 5.1, "Washing of the Test Area"[10]
(c) Any suitable controlled washing procedures available and agreed to by the contracting parties. During the washing procedure, clean plastic or rubber gloves should be worn to ensure that the wash water is not accidentally contaminated.

A2.2 Procedure for Extracting Soluble Salts by Surface Cells

(a) Limpet Cell Method[11]
(b) Surface Conductivity Cell Method[9,11]
(c) Nonrigid Extraction Cell Method[9,11,12]

A2.3 Procedure for Field Analysis of Chloride Ions

The extract retrieved using the procedures in Paragraphs A2.1 and A2.2 may be analyzed using one of the following methods:

(a) Chloride Chemical Test Strips[9]
(b) Chloride Chemical Titration Kit[9]
(c) Ion Detection Tube Method[9,10]

The following laboratory method is available as a referee method:

(a) Specific Chloride Ion Electrode[9,11,13]

A2.4 Procedure for Field Analysis of Sulfate Ions

The extract retrieved using the procedures in Paragraphs A2.1 and A2.2 may be analyzed using one of the following methods:

(a) Turbidity Field Comparator Methods[9, 11]
(b) Turbidity Method[9,11]
(c) Standard Test Method for Sulfate Ion in Water[14]

A2.5 Procedure for Field Analysis of Soluble Iron Salts

The extract retrieved using the procedures in Paragraph A2.1 or A2.2 may be analyzed using one of the following methods:

(a) Ferrous Chemical Test Strips[9,11]
(b) Semiquantitative Test for Ferrous Ions[8]
(c) Field Colorimetric Comparator Methods

A2.5.1 Papers treated with potassium ferricyanide may be used for the qualitative field detection of ferrous ions.[8,9]

Appendix B: Waterjetting Equipment

B1.1 The commercial waterjet unit can be mounted on a skid, trailer, or truck; can be equipped with various prime movers (diesel, electric motor, etc.); and usually consists of a pump, hoses, and various tools. The tools can be hand-held or mounted on a robot (or traversing mechanism). Water is propelled through a single jet, a fan jet, or multiple rotating jets. Rotation is provided by small electric, air, or hydraulic motors, or by slightly inclined orifices in a multiple-orifice nozzle.

B1.2 The units operate at pressures up to 240 to 290 MPa (35,000 to 42,000 psig), using a hydraulic hose with a minimum bursting strength of 2.5 times the capability of its maximum-rated operating strength.

B1.3 A water flow rate of 4 to 53 L/min (1 to 14 gal/min) is typical.

B1.4 Pressure loss is a function of the flow rate of the water through the hose and the inside diameter of the hose. The manufacturer should be consulted for specific information on potential pressure loss for each type of equipment.

B1.5 Waterjets are produced by orifices, or tips, that can have different forms. The higher the pressure, the more limited is the choice of forms. Round jets are most commonly used, but orifices of other shapes are available. Tips can be designed to produce multiple jets of water that are normally rotated to achieve higher material removal rates. Interchangeable nozzle tips should be used to produce the desired streams. The manufacturer shall be consulted for specific recommendations.

B1.6 The distance from the nozzle to the work piece substrate (standoff distance) is critical for effective cleaning with any of the water methods. Excessive standoff does not produce the desired cleaning.

Appendix C: Principles of Waterjetting

NACE No. 5/SSPC-SP 12 is a performance specification, not a process specification. Appendix C is not intended to be used as an equipment specification.

C1 Commentary on Production Rates

C1.1 Operator skill and the condition of the steel surface affect waterjetting production rates.[15,16,17] Regardless of the surface conditions, production rates usually improve when:

(a) The operator gains additional experience with high- and ultrahigh-pressure waterjetting; or

(b) Mechanized, automated waterjetting equipment is used.

C1.1.1 New metal with tightly adhering mill scale requires the highest level of operator skill and concentration to produce a clean surface by waterjetting. Older, more corroded, or previously coated surfaces require an average level of skill and concentration to achieve desired results. This is the opposite of abrasive blasting, when poor surface conditions require the highest levels of operator skill and concentration.

C1.2 As a general rule, production and ease of removal increase as the waterjetting pressure increases.

C1.3 Cleanup time to remove waste material should be considered when determining the overall production rate.

C2 Commentary on Waterjetting Parameters

C2.1 The specifier should describe the final condition of the substrate. Depending on the initial condition of the area and materials to be cleaned, the method to achieve Visible Conditions WJ-1, WJ-2, WJ-3, or WJ-4 may be LP WC, HP WC, HP WJ, or UHP WJ. The method of water cleaning or waterjetting ultimately is based on the capabilities of the equipment and its components. Dwell time, transverse rate, pressure, flow, stand-off distances, the number of nozzles, and rotation speed all interact in determining what material will remain and what will be removed.

C2.2 There are two thoughts on increasing production rates during the removal of materials by pressurized water. First, determine the threshold pressure at which the material will just be removed. The user can then either increase the flow to achieve adequate production rates or increase the pressure by a factor no greater than three over the threshold pressure. These two methods do not necessarily yield the same result.[18]

C2.3 Details of the calculations in Table C1 are standard to the waterjetting industry and are beyond the scope of this standard.[19]

C2.4 Removal of degraded coating is coupled to thorough stressing of the remaining coating. The jet energy is the work done when the jet stream vertically impacts the coating surface. Energy is normally measured in kilojoules. The shear stress is developed against the vertical pit walls and larger fractures created on the eroded coating surface. This can, in gross terms, be thought of as a hydraulic load.

C2.5 Flexure stressing is induced by repetitive loading and unloading of the coatings systems by the jet streams as they pass over the surface. The rapid loading and unloading is vital to finding areas of low adherence and nonvisible adherence defects in the coating system.[19]

C2.6 Characteristics of typical pressurized water systems are included in Table C1.

Table C1: Typical Pressurized Water Systems

Pressure at Nozzle	70 MPa (10,000 psig)	140 MPa (20,000 psig)	280 MPa (40,000 psig)
Number of Tips	2	2	5
Diameter	1.0 mm (0.040 in.)	0.69 mm (0.027 in.)	0.28 mm (0.011 in.)
Flow	12.9 L/min (3.42 gpm)	8.3 L/min (2.2 gpm)	2.0 L/min (0.52 gpm)
Cross-Sectional Area	0.81 mm^2 (0.0013 $in.^2$)	0.37 mm^2 (0.00060 $in.^2$)	0.065 mm^2 (0.00010 $in.^2$)
Jet Velocity	360 m/s (1,180 ft/s)	520 m/s (1,700 ft/s)	730 m/s (2,400 ft/s)
Impact Force (per tip)	8.1 kg (18 lb)	7.7 kg (17 lb)	2.4 kg (5.3 lb)
Jet Energy	141 kJ (134 BTU)	189 kJ (179 BTU)	89 kJ (81 BTU)
Energy Intensity (energy/ cross-sectional area)	175 kJ/mm^2 (107,000 $BTU/in.^2$)	513 kJ/mm^2 (314,000 $BTU/in.^2$)	1,401 kJ/mm^2 (857,000 $BTU/in.^2$)

C2.7 In field terms, the 70-MPa (10,000-psig) jets may not significantly erode the coatings. Therefore, they are typically used for partial removal or for cleaning loose detrital material. The 140-MPa (20,000-psig) jets erode the coatings fairly rapidly and are typically used for partial removal. The 280-MPa (40,000-psig) jets erode and destroy coatings very fast and are typically used when most or all of the coating is to be removed (WJ-1 or WJ-2).

C2.8 Application judgment is employed by operators or users who make the decisions concerning which type of jetting water to use:

(a) HP WC (the water's flow rate is the predominant energy characteristic);

(b) HP WJ (pressure [i.e., the velocity of the water] and flow rate are equally important); or

(c) UHP WJ (the pressure [i.e., the velocity of the water] is the dominant energy characteristic).

C2.9 As water passes through the orifice, potential energy (pressure) is converted to kinetic energy. The energy increases linearly with the mass flow, but increases with the square of the velocity, as shown in Equation (C1).

$$Kinetic\ Energy = \frac{1}{2} mv^2 \qquad \text{(C1)}$$

where

m = mass (derived from water volume)
v = velocity (derived from pressure)

In order to calculate the kinetic energy from flow rates and velocity, a time period must be selected. A time period of 10 milliseconds is used for Equation (C1).

C2.10 The threshold pressure[5] of a coating must also be determined. In general, the tougher or harder the coating (i.e., the more resistant to testing by a pocket knife), the higher the threshold pressure; the softer and more jelly-like the coating, the lower the threshold pressure.

C2.10.1 Once the threshold pressure is achieved or exceeded, the production rate increases dramatically. Therefore, waterjetting production rates are affected by two conditions:

(a) Erosion at pressures lower than the threshold pressure, and

(b) Waterjet cutting and erosion at pressures greater than the threshold pressure.

[5] *Threshold pressure* is defined as the minimum pressure required to penetrate the material.[20]

SSPC
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NACE INTERNATIONAL
THE CORROSION SOCIETY

Item No. 21082

Joint Surface Preparation Standard

NACE No. 6/SSPC-SP 13
Surface Preparation of Concrete

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Foreword

This standard covers the preparation of concrete surfaces prior to the application of protective coating or lining systems. This standard should be used by specifiers, applicators, inspectors, and others who are responsible for defining a standard degree of cleanliness, strength, profile, and dryness of prepared concrete surfaces.

This standard was originally prepared in 1997 by NACE/SSPC Joint Task Group F on Surface Preparation of Concrete. It was reaffirmed in 2003 by NACE Specific Technology Group 04 on Protective Coatings and Linings—Surface Preparation and SSPC Group Committee C.2 on Surface Preparation. This standard is issued by NACE International under the auspices of STG 04, and by SSPC Group Committee C.2.

Joint Surface Preparation Standard

NACE No. 6/SSPC-SP 13
Surface Preparation of Concrete

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Section 1: General

1.1 This standard gives requirements for surface preparation of concrete by mechanical, chemical, or thermal methods prior to the application of bonded protective coating or lining systems.

1.2 The requirements of this standard are applicable to all types of cementitious surfaces including cast-in-place concrete floors and walls, precast slabs, masonry walls, and shotcrete surfaces.

1.3 An acceptable prepared concrete surface should be free of contaminants, laitance, loosely adhering concrete, and dust, and should provide a sound, uniform substrate suitable for the application of protective coating or lining systems.

1.4 When required, a minimum concrete surface strength, maximum surface moisture content, and surface profile range should be specified in the procurement documents (project specifications).

1.5 The mandatory requirements of this standard are given in Sections 1 to 7 as follows:

Section 1:	General
Section 2:	Definitions
Section 3:	Inspection Procedures Prior to Surface Preparation
Section 4:	Surface Preparation
Section 5:	Inspection and Classification of Prepared Concrete Surfaces
Section 6:	Acceptance Criteria
Section 7:	Safety and Environmental Requirements

1.6 Appendix A does not contain mandatory requirements.

Section 2: Definitions

Coating: See *Protective Coating or Lining System*.

Concrete: A material made from hydraulic cement and inert aggregates, such as sand and gravel, which is mixed with water to a workable consistency and placed by various methods to harden and gain strength.

Curing (Concrete): Action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration so that potential properties of the mixture may develop.

Curing Compound (Membrane Curing Compound): A liquid that can be applied as a coating to the surface of newly placed concrete to retard the loss of water.[1]

Efflorescence: A white crystalline or powdery deposit on the surface of concrete. Efflorescence results from leaching of lime or calcium hydroxide out of a permeable concrete mass over time by water, followed by reaction with carbon dioxide and acidic pollutants.[2]

Fin: A narrow linear projection on a formed concrete surface, resulting from mortar flowing into spaces in the form work.[1]

Finish: The texture of a surface after consolidating and finishing operations have been performed.[1]

Finishing: Leveling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce desired appearance and service.[1]

Hardener (Concrete): A chemical (including certain fluorosilicates or sodium silicate) applied to concrete floors to reduce wear and dusting.[1]

High-Pressure Water Cleaning (HP WC): Water cleaning performed at pressures from 34 to 70 MPa (5,000 to 10,000 psig).[3]

High-Pressure Waterjetting (HP WJ): Waterjetting performed at pressures from 70 to 210 MPa (10,000 to 30,000 psig).[3]

Honeycomb: Voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.[1]

Laitance: A thin, weak, brittle layer of cement and aggregate fines on a concrete surface. The amount of laitance is influenced by the type and amount of admixtures, the degree of working, and the amount of water in the concrete.[2]

Lining: See *Protective Coating or Lining System*.

Placing: The deposition, distribution, and consolidation of freshly mixed concrete in the place where it is to harden.[1]

Porosity: Small voids that allow fluids to penetrate an otherwise impervious material.

Protective Coating or Lining System (Coating): For the purposes of this standard, protective coating or lining systems (also called *protective barrier systems*) are bonded thermoset, thermoplastic, inorganic, organic/inorganic hy-

brids, or metallic materials applied in one or more layers by various methods such as brush, roller, trowel, spray, and thermal spray. They are used to protect concrete from degradation by chemicals, abrasion, physical damage, and the subsequent loss of structural integrity. Other potential functions include containing chemicals, preventing staining of concrete, and preventing liquids from being contaminated by concrete.

Release Agents (Form-Release Agents): Materials used to prevent bonding of concrete to a surface.[1]

Sealer (Sealing Compound): A liquid that is applied as a coating to a concrete surface to prevent or decrease the penetration of liquid or gaseous media during exposure. Some curing compounds also function as sealers.

Soundness: A qualitative measure of the suitability of the concrete to perform as a solid substrate or base for a coating or patching material. Sound concrete substrates usually exhibit strength and cohesiveness without excessive voids or cracks.

Spalling (Concrete): The development of spalls which are fragments, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the larger mass.[1]

Surface Porosity: Porosity or permeability at the concrete surface that may absorb vapors, moisture, chemicals, and coating liquids.

Surface Preparation: The method or combination of methods used to clean a concrete surface, remove loose and weak materials and contaminants from the surface, repair the surface, and roughen the surface to promote adhesion of a protective coating or lining system.

Surface Profile (Texture): Surface contour as viewed from edge.

Surface Air Voids: Cavities visible on the surface of a solid.

Section 3: Inspection Procedures Prior to Surface Preparation

3.1 Concrete shall be inspected prior to surface preparation to determine the condition of the concrete and to determine the appropriate method or combination of methods to be used for surface preparation to meet the requirements of the coating system to be applied. Inherent variations in surface conditions seen in walls and ceilings versus those in floors should be considered when choosing surface preparation methods and techniques. For example, walls and ceilings are much more likely than floors to contain surface air voids, fins, form-release agents, and honeycombs.

3.2 Visual Inspection

All concrete surfaces to be prepared and coated shall be visually inspected for signs of concrete defects, physical damage, chemical damage, contamination, and excess moisture.

3.3 Concrete Cure

All concrete should be cured using the procedures described in ACI[(1)] 308.[4] Curing requirements include maintaining sufficient moisture and temperatures for a minimum time period. Surface preparation performed on insufficiently cured or low-strength concrete may create an excessively coarse surface profile or remove an excessive amount of concrete.

3.4 Concrete Defects

Concrete defects such as honeycombs and spalling shall be repaired. The procedures described in NACE Standard RP0390,[5] ICRI[(2)] 03730,[6] or ACI 301[7] may be used to ensure that the concrete surface is sound prior to surface preparation.

3.5 Physical Damage

3.5.1 Concrete should be tested for soundness by the qualitative methods described in NACE Publication 6G191[8] or Paragraph A1.4.3.

3.5.2 When qualitative results are indeterminate, or when a quantitative result is specified, concrete shall be tested for surface tensile strength using the methods described in Paragraph A1.6.

3.5.3 Concrete that has been damaged because of physical forces such as impact, abrasion, or corrosion of reinforcement shall be repaired prior to surface preparation if the damage would affect coating performance. Repairs should be made in accordance with ACI 301,[7] NACE Standard RP0390,[5] or Paragraph A1.4.

3.6 Chemical Damage

3.6.1 Concrete is attacked by a variety of chemicals, as detailed in ACI 515.1R[9] and PCA[(3)] IS001.[10]

(1) American Concrete Institute International (ACI), 38800 International Way, Country Club Drive, Farmington Hills, MI 48331.
(2) International Concrete Repair Institute (ICRI), 3166 S. River Road, Suite 132, Des Plaines, IL 60018.
(3) Portland Cement Association (PCA), 5420 Old Orchard Rd., Skokie, IL 60077.

3.6.2 All concrete surfaces that have been exposed to chemicals shall be tested and treated for contamination as described in Paragraph 3.7.

3.6.3 Concrete that has been exposed to chemicals shall be tested for soundness by the qualitative methods described in NACE Publication 6G191[8] or Paragraph A1.4.3.

3.7 Contamination

3.7.1 Contamination on concrete surfaces includes all materials that may affect the adhesion and performance of the coating to be applied. Examples include, but are not limited to, dirt, oil, grease, chemicals, and existing incompatible coatings.

3.7.2 Contamination may be detected by methods described in NACE Publication 6G191[8] and Paragraph A1.5. These methods include, but are not limited to, visual examination, water drop (contact angle) measurement, pH testing, petrographic examination, and various instrumental analytical methods. Core sampling may be required to determine the depth to which the contaminant has penetrated the concrete.

3.7.3 Concrete surfaces that are contaminated or that have existing coatings shall be tested by the method described in Paragraph A1.6.3 to determine whether the contamination or existing coating affects the adhesion and performance of the coating to be applied. Concrete surfaces that have existing coatings shall also be tested by the method described in Paragraph A1.6.3 to determine whether the existing coating is sufficiently bonded to the concrete.

3.7.4 In extreme cases of concrete damage or degradation, or thorough penetration by contaminants, complete removal and replacement of the concrete may be required.

3.8 Moisture

Moisture levels in the concrete may be determined by the methods described in Paragraph 5.6.

Section 4: Surface Preparation

4.1 Objectives

4.1.1 The objective of surface preparation is to produce a concrete surface that is suitable for application and adhesion of the specified protective coating system.

4.1.2 Protrusions such as from burrs, sharp edges, fins, and concrete spatter shall be removed during surface preparation.

4.1.3 Voids and other defects that are at or near the surface shall be exposed during surface preparation.

4.1.4 All concrete that is not sound shall be removed so that only sound concrete remains.

4.1.5 Concrete damaged by exposure to chemicals shall be removed so that only sound concrete remains.

4.1.6 All contamination, form-release agents, efflorescence, curing compounds, and existing coatings determined to be incompatible with the coating to be applied shall be removed.

4.1.7 The surface preparation method, or combination of methods, should be chosen based on the condition of the concrete and the requirements of the coating system to be applied.

4.1.8 All prepared concrete surfaces shall be repaired to the level required by the coating system in the intended service condition.

4.2 Surface Cleaning Methods

4.2.1 The surface cleaning methods described in Paragraphs 4.2.2 and 4.2.3 shall not be used as the sole surface preparation method of concrete to be coated as they do not remove laitance or contaminants or alter the surface profile of concrete. These methods shall be used as required, before and/or after the mechanical and chemical methods described in Paragraphs 4.3 and 4.4.

4.2.2 Vacuum cleaning, air blast cleaning, and water cleaning as described in ASTM[(4)] D 4258[11] may be used to remove dirt, loose material, and/or dust from concrete.

4.2.3 Detergent water cleaning and steam cleaning as described in ASTM D 4258[11] may be used to remove oils and grease from concrete.

4.3 Mechanical Surface Preparation Methods

4.3.1 Dry abrasive blasting, wet abrasive blasting, vacuum-assisted abrasive blasting, and centrifugal shot blasting, as described in ASTM D 4259,[12] may be used to remove contaminants, laitance, and weak concrete,

[(4)] ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

to expose subsurface voids, and to produce a sound concrete surface with adequate profile and surface porosity.

4.3.2 High-pressure water cleaning or waterjetting methods as described in NACE No. 5/SSPC-SP 12,[2] ASTM D 4259,[12] or "Recommended Practices for the Use of Manually Operated High Pressure Water Jetting Equipment,"[(5)13] may be used to remove contaminants, laitance, and weak concrete, to expose subsurface voids, and to produce a sound concrete surface with adequate profile and surface porosity.

4.3.3 Impact-tool methods may be used to remove existing coatings, laitance, and weak concrete. These methods include scarifying, planing, scabbling, and rotary peening, as described in ASTM D 4259.[12] Impact-tool methods may fracture concrete surfaces or cause microcracking and may need to be followed by one of the procedures in Paragraphs 4.3.1 or 4.3.2 to produce a sound concrete surface with adequate profile and surface porosity. The soundness of a concrete surface prepared using an impact method may be verified by one of the surface tensile strength tests described in Paragraph A1.6.

4.3.4 Power-tool methods, including circular grinding, sanding, and wire brushing as described in ASTM D 4259,[12] may be used to remove existing coatings, laitance, weak concrete, and protrusions in concrete. These methods may not produce the required surface profile and may require one of the procedures described in Paragraphs 4.3.1 or 4.3.2 to produce a concrete surface with adequate profile and surface porosity.

4.3.5 Surface preparation using the methods described in Paragraphs 4.3.1 through 4.3.4 shall be performed in a manner that provides a uniform, sound surface that is suitable for the specified protective coating system.

4.4 Chemical Surface Preparation

Acid etching, as described in ASTM D 4260[14] and NACE Standard RP0892,[15] may be used to remove laitance and weak concrete and to provide a surface profile on horizontal concrete surfaces. This method requires complete removal of all reaction products and pH testing to ensure neutralization of the acid. Acid etching is not recommended for vertical surfaces and areas where curing compounds or sealers have been used. Acid etching shall only be used where procedures for handling, containment, and disposal of the hazardous materials are in place. Acid etching with hydrochloric acid shall not be used where corrosion of metal in the concrete (rebar or metal fibers) is likely to occur.

4.5 Flame (Thermal) Cleaning and Blasting

4.5.1 Flame cleaning using a propane torch or other heat source may be used to extract organic contaminants from a concrete surface. To remove the extracted contaminants this type of cleaning may need to be followed by the cleaning methods described in ASTM D 4258.[11]

4.5.2 Flame cleaning and blasting using oxygen-acetylene flame blasting methods and proprietary delivery equipment may be used to remove existing coatings, contaminants, and laitance and/or create a surface profile on sound concrete.

4.5.3 The extent of removal when employing flame methods is affected by the rate of equipment advancement, the flame adjustment, and the distance between the flame and the concrete surface. Surface preparation using flame methods shall be performed in a manner that provides a uniform, sound surface that is suitable for the specified protective coating system.

4.5.4 High temperatures reduce the strength of or damage concrete; therefore, surfaces prepared using flame methods shall be tested for soundness and surface tensile strength. Concrete surfaces found to be unsound or low in tensile strength shall be repaired or prepared by other mechanical methods described in Paragraph 4.3.

4.6 Surface Cleanliness

After the concrete surface has been prepared to the required soundness and surface profile, surfaces may still need to be cleaned by one of the methods described in Paragraph 4.2 to remove the residue created by the surface preparation method or to remove spent media.

4.7 Moisture Content

If the moisture level in the concrete is higher than the specified limit tolerable by the coating, the concrete shall be dried or allowed to dry to the level specified in the procurement documents before inspection and application of the coating (see Paragraph 5.6).

4.8 Patching and Repairs

4.8.1 Prior to proceeding with patching and repairs, the prepared concrete surface shall be inspected according to Section 5. After the patching and repairs of the concrete surface are completed, the repaired areas shall be reinspected according to Section 5.

4.8.2 All gouges, surface air voids, and other surface anomalies shall be repaired to a level required by the coating system as specified in the procurement documents.

[(5)] WaterJet Technology Association, 917 Locust, Suite 1100, St. Louis, MO 63101-1419.

4.8.3 All repair materials, both cementitious and polymeric, should be approved or recommended by the coating manufacturer as being compatible with the coating to be applied. Repair materials not recommended or approved by the coating manufacturer shall be tested for compatibility prior to their application.

4.8.4 The repair material shall be cured according to the manufacturer's published instructions.

4.8.5 The repaired section may require additional surface preparation prior to coating application.

Section 5: Inspection and Classification of Prepared Concrete Surfaces

5.1 Surface Tensile Strength

5.1.1 All prepared concrete surfaces should be tested for surface tensile strength after cleaning and drying but prior to making repairs or applying the coating.

5.1.2 Surface tensile strength should be tested using a method agreed upon by all parties. (See Paragraph A1.6 for commentary on these methods.)

5.2 Coating Adhesion

5.2.1 If specified in the procurement documents and accepted by all parties, a test patch shall be applied to determine the compatibility of and adhesion between the prepared surface and the coating system. (See Paragraph A1.6.3 for commentary on this method.)

5.2.2 Coating adhesion should be tested using one of the methods agreed upon by all parties. (See Paragraph A1.6 for commentary on these methods.)

5.3 Surface Profile

5.3.1 If a specific surface profile is required for the performance of the coating system to be applied, the profile shall be specified in the procurement documents.

5.3.2 The surface profile of prepared concrete surfaces should be evaluated after cleaning and drying but prior to repairs or application of the coating.

5.3.3 The surface profile may be evaluated by comparing the profile of the prepared concrete surface with the profile of graded abrasive paper, as described in ANSI[(6)] B 74.18,[16] by comparing the profile with the ICRI Guideline No. 03732[17] (surface profile chips), or by another agreed-upon visual comparison.

5.4 Surface Cleanliness

5.4.1 All prepared concrete surfaces shall be inspected for surface cleanliness after cleaning and drying but prior to making repairs or applying the coating. If the concrete surfaces are repaired, they shall be reinspected for surface cleanliness prior to applying the coating.

5.4.2 Prepared concrete surfaces may be inspected for surface cleanliness by lightly rubbing the surface with a dark cloth or pressing a translucent adhesive tape on the surface. The test method and acceptable level of residual dust shall be agreed on by all parties.

5.4.3 The method used to verify compatibility of the coating to be applied over a contaminated surface or over contaminated surfaces that have been cleaned and prepared should be approved by the coating manufacturer and specified in the procurement documents.

5.5 pH

5.5.1 If a specific pH range is required for proper performance of the coating system to be applied, the pH of the concrete shall be specified in the procurement documents.

5.5.2 The pH of concrete surfaces prepared by acid etching should be tested after etching and rinsing but before the prepared surface has dried.

5.5.3 ASTM D 4262[18] should be used to determine pH.

5.6 Moisture Content

5.6.1 If a specific moisture content is required for proper performance of the coating system to be applied, the moisture content of the concrete shall be specified in the procurement documents.

5.6.2 Prepared concrete surfaces should be tested for residual moisture after cleaning and drying but prior to the application of the coating.

5.6.3 ASTM D 4263,[19] ASTM F 1869,[20] or ASTM F 2170[21] should be used to determine the residual moisture content in concrete.

5.6.4 If required or accepted by all parties, any of the methods described in Paragraph A1.8.4 may be used to determine the moisture content of the concrete surface.

[(6)] American National Standards Institute (ANSI), 1819 L Street NW, Washington, DC 20036.

Section 6: Acceptance Criteria

6.1 The acceptance criteria for prepared concrete surfaces shall be specified in the procurement documents.

6.2 The procurement documents may refer to the specifications in Table 1.

Table 1:
Suggested Acceptance Criteria for Concrete Surfaces After Surface Preparation

Property	Test Method	Light Service[A]	Severe Service[B]
Surface tensile strength	See Paragraph A1.6	1.4 MPa (200 psi) min.	2.1 MPa (300 psi) min.
Surface profile	Visual comparison[16]	Fine (150) abrasive paper min.	Coarse (60) abrasive paper min.
Surface cleanliness	Visible dust[11]	No significant dust	No significant dust
Residual contaminants	Water drop[15,22]	0° contact angle	0° contact angle
pH	ASTM D 4262[18]	(pH of rinse water) -1, +2[C]	(pH of rinse water) -1, +2[C]
Moisture content[D]	ASTM D 4263[19]	No visible moisture	No visible moisture
Moisture content[D]	ASTM F 1869[20]	15 g/24 hr/m^2 (3 lb/24 hr/1,000 ft^2) max.	15 g/24 hr/m^2 (3 lb/24 hr/1,000 ft^2) max.
Moisture content[D]	ASTM F 2170[21]	80% max.	80% max.

[A] Light service refers to surfaces and coatings that have minimal exposure to traffic, chemicals, and changes in temperature.
[B] Severe service refers to surfaces and coatings that have significant exposure to traffic, chemicals, and/or changes in temperature.
[C] The acceptance criterion for ASTM D 4262 is as follows: The pH readings following the final rinse shall not be more than 1.0 lower or 2.0 higher than the pH of the rinse water (tested at the beginning and end of the final rinse cycle) unless otherwise specified.
[D] Any one of these three moisture content test methods is acceptable.

Section 7: Safety and Environmental Requirements

7.1 Disposal of contaminants, old coatings, acid from etching, and contaminated water and blasting media shall comply with all applicable facility, local, state, and federal regulations.

7.2 Handling of hazardous materials, machinery operations, worker protection, and control of airborne dust and fumes shall comply with all applicable facility, local, state, and federal health and safety regulations.

References

1. ACI 116R (latest revision), “Cement and Concrete Terminology” (Farmington Hills, MI: ACI).

2. SSPC-Guide 11 (latest revision), “Guide for Coating Concrete” (Pittsburgh, PA: SSPC).

3. NACE No. 5/SSPC-SP 12, “Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating” (Houston, TX: NACE, and Pittsburgh, PA: SSPC).

4. ACI 308 (latest revision), “Standard Practice for Curing Concrete” (Farmington Hills, MI: ACI).

5. NACE Standard RP0390 (latest revision), “Maintenance and Rehabilitation Considerations for Corrosion Control of Existing Steel-Reinforced Concrete Structures” (Houston, TX: NACE).

6. ICRI Guideline No. 03730 (latest revision), “Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion” (Des Plaines, IL: ICRI).

7. ACI 301 (latest revision), “Specifications for Structural Concrete” (Farmington Hills, MI: ACI).

8. NACE Publication 6G191 (withdrawn), “Surface Preparation of Contaminated Concrete for Corrosion Control” (Houston, TX: NACE). (Available from NACE as an historical document only).

9. ACI 515.1R (latest revision), “Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete” (Farmington Hills, MI: ACI).

10. IS001 (latest revision), "Effects of Substances on Concrete and Guide to Protective Treatments" (Skokie, IL: PCA).

11. ASTM D 4258 (latest revision), "Standard Practice for Surface Cleaning Concrete for Coating" (West Conshohocken, PA: ASTM).

12. ASTM D 4259 (latest revision), "Standard Practice for Abrading Concrete" (West Conshohocken, PA: ASTM).

13. "Recommended Practices for the Use of Manually Operated High-Pressure Water Jetting Equipment" (latest revision) (St. Louis, MO: WaterJet Technology Association).

14. ASTM D 4260 (latest revision), "Standard Practice for Acid Etching Concrete" (West Conshohocken, PA: ASTM).

15. NACE Standard RP0892 (latest revision), "Coatings and Linings Over Concrete for Chemical Immersion and Containment Service" (Houston, TX: NACE).

16. ANSI B74.18 (latest revision), "Specifications for Grading of Certain Abrasive Grain on Coated Abrasive Products" (Washington, DC: ANSI).

17. ICRI Guideline No. 03732 (latest revision), "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays" (Des Plaines, IL: ICRI).

18. ASTM D 4262 (latest revision), "Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces" (West Conshohocken, PA: ASTM).

19. ASTM D 4263 (latest revision), "Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method" (West Conshohocken, PA: ASTM).

20. ASTM F 1869 (latest revision), "Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride" (West Conshohocken, PA: ASTM).

21. ASTM F 2170 (latest revision), "Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes" (West Conshohocken, PA: ASTM).

22. F.S. Gelfant, "Contaminated Concrete—Effect of Surface Preparation Methods on Coating Performance," Journal of Protective Coatings and Linings (JPCL) 12, 12 (1995): pp. 60-72.

23. T.I. Aldinger, B.S. Fultz, "Keys to Successfully Preparing Concrete for Coating," JPCL 6, 5 (1989): pp. 34-40.

24. T. Dudick, "Concrete Standards for Resinous Toppings," SSPC 93-06: Innovations for Preserving and Protecting Industrial Structures, November 13-18, 1993 (Pittsburgh, PA: SSPC, 1993).

25. R. Boyd, "Quality Control in Cleaning and Coating Concrete," SSPC 91-19: Protective Coatings for Flooring and Other Concrete Surfaces, November 10-15, 1991 (Pittsburgh, PA: SSPC, 1991), pp. 5-7.

26. L.D. Vincent, Corrosion Prevention by Protective Coatings, 2nd ed. (Houston, TX: NACE, 1999).

27. NACE 6G197/SSPC-TU 2 (latest revision), "Design, Installation, and Maintenance of Coating Systems for Concrete Used in Secondary Containment," (Houston, TX: NACE, and Pittsburgh, PA: SSPC).

28. ASTM PCN: 03-401079-14, "Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities" (West Conshohocken, PA: ASTM, 1979), pp. 114-119.

29. H.H. Baker, R.G. Posgay, "The Relationship Between Concrete Cure and Surface Preparation," JPCL 8, 8 (1991): pp. 50-56.

30. F. Hazen, "Repairing Concrete Prior to Lining Secondary Containment Structures," JPCL 8, 1 (1991): pp. 73-79.

31. ASTM PCN: 03-401079-14, "Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities" (West Conshohocken, PA: ASTM, 1979), pp. 120-123.

32. C.T. Grimm, "Cleaning Masonry: A Review of the Literature," Publication #TR 2-88, Construction Research Center, (Arlington, TX: University of Texas at Arlington, November 1988).

33. S. Lefkowitz, "Controlled Decontamination of Concrete," Concrete: Surface Preparation, Coating and Lining, and Inspection (Houston, TX: NACE, 1991).

34. R.A. Nixon, "Assessing the Deterioration of Concrete in Pulp and Paper Mills," Concrete: Surface Preparation, Coating and Lining, and Inspection, January 28-30, 1991 (Houston, TX: NACE, 1991).

35. IS214 (latest revision), "Removing Stains and Cleaning Concrete Surfaces," (Skokie, IL: PCA).

36. J. Steele, "Testing Adhesion of Coatings Applied to Concrete," Materials Performance (MP) 33, 11 (1994): pp. 33-36.

37. ASTM D 4541 (latest revision), "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers" (West Conshohocken, PA: ASTM).

38. ACI 503R (latest revision), "Use of Epoxy Compounds with Concrete" (Farmington Hills, MI: ACI).

39. T.K. Greenfield, "Dehumidification Equipment Reduces Moisture in Concrete During Coating Application," MP 33, 3 (1994): pp. 39-40.

40. L. Harriman, "Drying and Measuring Moisture in Concrete—Part I," MP 34, 1 (1995): pp. 34-36.

41. L. Harriman, "Drying and Measuring Moisture in Concrete—Part II," MP 34, 2 (1995): pp. 34-36.

42. W.H. Riesterer, "Hydrostatic, Capillary, Osmotic and Other Pressures," Innovations for Preserving and Protecting Industrial Structures," November 13-18, 1993 (Pittsburgh, PA: SSPC, 1993).

43. ASTM E 1907 (latest revision), "Standard Practices for Determining Moisture-Related Acceptability of Concrete Floors to Receive Moisture-Sensitive Finishes" (West Conshohocken, PA: ASTM).

44. N.C. Duvic, "Surface Preparation of Concrete for Application of Protective Surfacing or Coating," Concrete: Surface Preparation, Coating and Lining, and Inspection (Houston, TX: NACE, 1991).

45. P.J. Fritz, "The Use of Captive Shot (Roto-Peening) for Preparing the Surface of Concrete," SSPC 93-06: Innovations for Preserving and Protecting Industrial Structures, November 13-18, 1993 (Pittsburgh, PA: SSPC, 1993), pp. 144-147.

46. K. Pashina, "Planning, Proper Surface Preparation Essential for Successful Coatings," Concrete Repair Bulletin 7, 1 (1994): pp. 4-8.

47. ASTM PCN: 03-401079-14, "Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities" (West Conshohocken, PA: ASTM, 1979), pp. 124-127.

48. T.I. Aldinger, "Coating New Concrete: Why Wait 28 Days?" SSPC 91-19: Protective Coatings for Flooring and Other Concrete Surfaces, November 10-15, 1991 (Pittsburgh, PA: SSPC, 1991), pp. 1-4.

49. J. Steele, "Effective Sealing, Priming and Coating of New and Uncured Concrete," Concrete: Surface Preparation, Coating and Lining, and Inspection, January 28-30, 1991 (Houston, TX: NACE, 1991).

Appendix A: Comments
(This section does not contain any mandatory requirements.)

A1.1 General[23,24,25,26]

A1.1.1 This standard does not recommend surface preparation methods or differentiate levels of surface preparation that are specifically required for various protective system designs, types, thicknesses, and end-use requirements. These specifications should be decided and agreed upon by all parties (the specifier, facility owner, coating manufacturer, and contractor).

A1.1.2 Concrete and its surfaces are not homogeneous or consistent and, unlike steel, cannot be discretely defined. Therefore, visual examination of a concrete surface is somewhat subjective. The acceptance or rejection of a prepared concrete surface should be based on the results of specific tests, including, but not limited to, tests for surface tensile strength, contamination, and moisture.

A1.1.3 Joints, cracks, and curing shrinkage of concrete should be considered in the design of the protective coating system; however, these topics are beyond the scope of this standard. See NACE Standard RP0892,[15] ACI 515.1R,[9] and NACE 6G197/SSPC-TU 2[27] for more information.

A1.1.4 When a significant amount of weak, deteriorated, or contaminated concrete is removed during the course of surface preparation to achieve a sound surface, the profile of the remaining concrete is often too rough for the intended coating system. In these cases, and where form voids and surface air voids must be filled, patching or grouting materials are specified to repair or level the concrete surface. See NACE Standard RP0892,[15] ACI 515.1R,[9] NACE Standard RP0390,[5] NACE 6G197/SSPC-TU 2,[27] and Paragraph A1.4.4 for more information about patching materials.

A1.2 Concrete Finishing and Surface Characteristics[23]

A1.2.1 The method used to finish concrete surfaces affects the concrete's surface profile, composition, porosity, and density. These surface properties affect the adhesion and performance of concrete coatings. Typical surface properties obtained using the most common finishing methods are given in Table A1. These properties are evaluated prior to surface preparation.

A1.2.2 No preferred method of finishing concrete to accept coatings has been established by the concrete coating industry. The surface cure, surface preparation method, and type of coating system to be applied are all factors in determining the suitability of any specific concrete finishing method. For example, broom finishing is sometimes used because it gives a profile for the coating; however, most of the profile may be removed during surface preparation if the surface is not properly cured, negating this inherent advantage of the broom finish. When sacking is used to fill voids in formed concrete surfaces, subsurface voids are created, and the added cement is usually removed during surface preparation due to improper cure of the added cement paste.

Table A1:
Typical Surface Properties of Finished Concrete

Method	Profile[A]	Porosity[A]	Strength[A]	Problems
Formed concrete	Smooth to medium	Low to medium	Medium	Voids, protrusions, release agents
Wood float	Medium	Medium	Medium	
Metal trowel	Smooth	Low	High	
Power trowel	Smooth	Very low	High	Very dense
Broom finish	Coarse to very coarse	Medium	Medium	
Sacking	Smooth	Low to medium	Low to high[B]	Weak layer if not properly cured
Stoning	Smooth to medium	Low to medium	Low to high[B]	Weak layer if not properly cured
Concrete block	Coarse to very coarse	Very high	Medium	Pinholes
Shotcrete[C]	Very coarse	Medium	Medium	Too rough for thin coatings

[A] These surface properties are based on similar concrete mix, placement, and vibration and prior to surface preparation.
[B] Strength depends on application and cure.
[C] Shotcrete may be refinished after placement, which would change the surface properties given in this table.

A1.2.3 Use of a metal trowel is gaining acceptance as the preferred finishing method for horizontal surfaces to be coated, provided the surface is not excessively trowelled, the concrete is cured properly, and the laitance is removed prior to coating.

A1.2.4 Photographic examples of concrete finishes are shown in ASTM PCN:03-401079-14.[28]

A1.3 Concrete Cure[29]

A1.3.1 Maintaining sufficient moisture and proper temperature in concrete in the early stages of cure is important to ensure development of the designed strength. Keeping the surface moist until sufficient strength has developed at the surface is important to ensure formation of sufficient surface strength, to reduce curling, and to reduce surface cracking.

A1.3.2 ACI 308[4] recommends seven days of moist curing for Type I portland cement concrete and three days for Type III portland cement concrete, if the temperature is above 10°C (50°F). ACI 308 also recommends numerous methods to properly cure concrete, including the use of sealing materials and other methods to keep concrete moist.

A1.3.3 ACI 308[4] also gives recommendations on the use of curing compounds, which are commonly used immediately after placement and finishing of concrete surfaces to reduce moisture loss and improve surface cure. The curing compound should either be compatible with the coating or be removed during surface preparation.

A1.4 Identification and Repair of Surface Defects and Damage[30]

A1.4.1 Physical and Chemical Damage

A1.4.1.1 Existing concrete structures that have been subjected to mechanical damage (caused by impact or abrasion), chemical attack, or rebar corrosion are restored to provide a uniform, sound substrate prior to coating application.

A1.4.1.2 In order to best receive and hold the patching material all deteriorated concrete should be removed and the surrounding sound concrete cut using the procedures described in ICRI 03730.[6] Some contaminants have a detrimental effect on the rebar or the applied coating if they are not completely removed.

A1.4.1.3 A number of polymeric grouts and patching materials can be used, especially when the coating is to be applied immediately. These materials should be compatible with the coating to be applied.

A1.4.2 Other Defects and Imperfections

A1.4.2.1 Defects such as honeycombs, scaling, and spalling do not provide a sound, uniform substrate for the coating. These defects are repaired by removing all unsound concrete and then patching the concrete prior to surface preparation. NACE Standard RP0390[5] and ICRI 03730[6] describe removal and repair procedures for concrete

that is spalled because of rebar corrosion.

A1.4.2.2 Surface air voids, pinholes, or excessive porosity may affect the application or performance of the coating. The maximum substrate void size or surface porosity that can be tolerated depends on the coating system under consideration. If voids are not filled before the coating is applied, the trapped air vapor expands and contracts and may affect the performance of the coating. For liquid-rich coatings, excess porosity at the surface may result in pinholes in the coating. Voids are usually filled after surface preparation and prior to coating application.

A1.4.2.3 Protrusions such as form lines, fins, sharp edges, and spatter may cause holidays or thin sections in the coating if they are not removed. Protrusions and rough edges are usually removed during surface preparation.

A1.4.3 Testing for Surface Soundness

A1.4.3.1 NACE Publication 6G191[8] describes the following commonly used methods for determining surface soundness:

A screwdriver, file, or pocket knife is lightly scratched across the concrete surface. If the metal object rides over the surface without loosening any particles and leaves no more than a shiny mark, the surface is sound. If this process gouges the surface, the surface is not sound.

The concrete surface is lightly struck with the edge of a hammer head. If the hammer rebounds sharply with no more than a small fracture at the impact area, the surface is sound. If it lands with a dull thud and leaves powdered dusts in the indentation, the surface is not sound.

A chain is dragged across horizontal concrete surfaces. Differences in sound indicate unsound concrete and holes or pockets within the concrete.

A1.4.4 Patching of Concrete Surface Imperfections

A1.4.4.1 Materials such as grouts, putties, and sealers are used to repair, patch, smooth, or seal the concrete surface to provide a substrate that is suitable for the coating system to be applied. These materials are applied after surface preparation and require the following characteristics:

(1) good adhesion;

(2) adequate strength;

(3) low volumetric and linear shrinkage;

(4) compatibility with the coating to be applied; and

(5) proper consistency for the application.

In addition, the patching material is often required to cure sufficiently, be traffic bearing, and be ready to recoat in a short time frame (usually within 24 hours).

A1.4.4.2 Shrinkage of the patching material may reduce the adhesion of that material to the concrete substrate. Differences in thermal expansion between the concrete, patching material, and coating system cause stresses during thermally induced movement that may reduce adhesion between these layers.

A1.4.4.3 The most common types of patching materials are cementitious, polymer-modified cementitious (usually acrylic), and polymeric (usually epoxy). Cementitious materials are lower in cost than polymeric materials, but polymeric materials generally cure faster and have higher strengths, better adhesion, and increased chemical resistance.

A1.4.4.4 Patching materials are available in a range of consistencies for application to vertical or horizontal surfaces by a variety of methods. The amount of filler also varies. For example, grouts for deep patching are typically highly filled, while porosity sealers may be minimally filled or unfilled. Numerous proprietary materials are low-shrinking, nonshrinking, or expanding.

A1.4.4.5 Additional surface preparation may need to be performed on cured patching materials to ensure that the laitance is removed and/or that the patched surface meets the profile requirements of the coating system.

A1.4.4.6 Photographic examples of patched concrete surfaces are shown in ASTM PCN:03-401079-14.[31]

A1.5 Identification and Removal of Contaminants[22,32,33,34]

A1.5.1 Hydrophobic Materials

A1.5.1.1 Hydrophobic materials such as form-release agents, curing compounds, sealers, existing coatings, oil, wax, grease, resins, and silicone may be detected by a simple water drop test. Analytical techniques such as infrared analysis or gas chromatography may also be used to detect and identify these contaminants.

A1.5.1.2 Oils and greases can be removed by steam cleaning, flame blasting, baking soda blasting, or using degreasers and absorbents.

A1.5.1.3 If they are incompatible with the coating to be applied, existing curing compounds, sealers, form-release agents, and coatings should be removed by the least destructive, most practical, economical, and safe method that is successful. Methods such as grinding, abrasive blasting, wet abrasive blasting, waterjetting, scarifying, flame blasting, or paint stripping may be used.

A1.5.2 Salts and Reactive Materials

A1.5.2.1 Salts and reactive materials such as laitance, efflorescence, acids, alkalis, and by-products of chemical attack of concrete can sometimes be detected by pH testing, soundness testing using the screwdriver test, or visual examination (see PCA IS214).[35] When these methods are not successful, chemical analysis techniques are required.

A1.5.2.2 Residual acids and alkalis are first neutralized and then removed by high-pressure water cleaning. Salts and efflorescence can be removed by abrasive blasting, high-pressure water cleaning, or applying a weak acid or alkali solution and then high-pressure water cleaning.

A1.5.3 Microorganisms

A1.5.3.1 Microorganisms such as fungus, moss, mildew, algae, decomposing foods, and other organic growths can sometimes be detected by visual examination (see PCA IS214).[35]

A1.5.3.2 Microorganisms are removed by washing with sodium hypochlorite (household bleach) and rinsing with water. High-pressure water cleaning or abrasive blasting may also be used.

A1.6 Adhesion Testing[36]

The two commonly used methods for testing adhesion of coatings to concrete substrates are ASTM D 4541[37] (modified for concrete substrates as discussed in Paragraph A1.6.1) and ACI 503R.[38] Testing for surface tensile strength consists of scoring (core drilling) the concrete surface, bonding a test fixture with an adhesive, pulling the fixture with an adhesion tester, and noting the pull-off strength or adhesion value. Testing for coating adhesion is performed using the same procedure, noting the adhesion value, and noting the adhesion failure mode (see Paragraph A1.6.4).

A1.6.1 The procedure described in ASTM D 4541[37] may be used to determine pull-off strength or coating adhesion strength using a portable adhesion tester, typically either a manual tester with a 20-mm (0.78-in.)-diameter loading fixture (test dolly) or a pneumatic adhesion tester with a 13-mm (0.5-in.) loading fixture. ASTM D 4541 states that "Scoring around the fixture violates the fundamental in situ criterion that an unaltered coating be tested," but it also states that scoring should be noted in the results when employed.[37] The procedure in ASTM D 4541 should be modified for use on concrete substrates by scoring or core drilling prior to attaching the loading fixture. Scoring around the test fixture ensures that the pulling force is applied only to the area directly beneath the fixture. Without scoring, stress is transferred through the coating film beyond the area of the test fixture. This could result in significant error when testing thick or reinforced coatings. A water-lubricated diamond-tipped core bit should be used for scoring to reduce the possibility of microcracks in either the coating or the concrete substrate. The procedure may also be modified by using a larger (5-cm [2-in.] or more) loading fixture. A larger test fixture typically yields more accurate results than a smaller fixture because the greater surface area reduces the effect of inconsistencies, such as a piece of aggregate or a void, in the substrate.

A1.6.2 ACI 503R[38] discusses the process of applying a coating or adhesive coring to the substrate, bonding a 5-cm (2-in.) pipe cap to the coating, and applying tension with a mechanical testing device attached to a dynamometer. As with ASTM D 4541,[37] the tensile load and mode of failure are noted.

A1.6.3 A test patch involves applying the coating system to a small section (with the minimum size to be specified) of prepared concrete and testing for tensile strength and adhesion by either of the methods described in Paragraphs A1.6.1 and A1.6.2. The prepared concrete substrate—at least the portion to be patched—should meet the acceptance criteria as detailed in Section 6. The coating system should be applied in accordance with the coating manufacturer's published instructions. The last coat of the coating system serves as the adhesive for the loading fixture, or, when this is not recommended (e.g., for solvent-based topcoats), the loading fixture is attached to the coating system by an adhesive. If agreed by all parties, the primer alone may suffice as the test patch and the adhesive for the loading fixture.

A1.6.4 The acceptable adhesion strength and mode of failure may vary depending on the type of coating tested. The coating manufacturer should be consulted to determine the preferred test method, the suitability of that method, and acceptance criteria for the specified coating. When adhesion testing is performed, the mode of failure should be noted. The failure can be described using one or more of the following terms.

(1) Concrete (substrate) cohesive failure: This failure mode is defined as failure within the concrete, below the concrete/coating interface. This result, if the adhesion value is sufficient, is considered to be the most desirable for coatings applied to concrete. If concrete cohesive failure occurs but the adhesion value is low, the failure may be because of low concrete strength or microcracking from scoring. If only a thin layer of concrete is pulled with the fixture and the adhesion value is

low, it may be because of a weak concrete surface layer or laitance.

(2) Coating adhesive failure: This failure mode is defined as failure directly at the concrete/coating interface. For most coating systems, failure in this mode indicates a problem with surface preparation, residual contamination, or the coating.

(3) Coating cohesive failure or coating intercoat adhesion failure: This failure mode is defined as failure within the coating system, above the concrete/coating interface. This mode of failure indicates a problem with the coating material or with the coating application.

(4) Fixture adhesive failure: This failure mode is defined as failure within the fixture adhesive or at the fixture adhesive/coating interface. When this failure mode is encountered, the test should be repeated.

A1.7 Surface Profile

A1.7.1 In addition to removing laitance, weak concrete, and contamination at the concrete surface, surface preparation usually opens the pores and/or creates a profile on the concrete surface. Profile increases the surface area available for bonding between the concrete and the coating, enhances adhesion at the concrete/coating interface, and helps the coating resist peeling and shear forces.

A1.7.2 The depth of surface profile required depends on:

(1) tensile and shear strength of the concrete and the coating system;

(2) adhesion of the coating system to the concrete;

(3) internal stresses in the coating system created during application (e.g., from shrinkage);

(4) difference in the coefficient of thermal expansion between the coating and the concrete;

(5) modulus or stress-relaxation properties of the coating system;

(6) thermal and chemical exposure environment; and

(7) coating thickness.

A1.7.3 At this time, no recognized testing equipment or method is used to quantify the surface profile of concrete that is analogous to the replica tape method used on steel. The profile can be subjectively compared to the standard classification for coated abrasive paper as described in ANSI B74.18,[16] or by comparing the profile with the ICRI Guideline No. 03732[17] (surface profile chips). For extremely coarse prepared concrete surfaces (assuming that the coating system can cover and perform over such a substrate), the profile may be estimated as an average distance between peaks and valleys on the concrete surface and quantified in mm (mils).

A1.8 Moisture in Concrete[39,40,41,42]

A1.8.1 The movement of moisture in concrete during the curing process and after application of the coating is important to consider in the design of the concrete structure. Concrete is normally placed with water levels in excess of that required to completely hydrate the cement. Excess free water in the concrete can adversely affect the application and cure of many coatings. Pressure caused by excess moisture in the concrete or from ground water may be substantial and, in some instances, may be sufficient to disbond barrier coating systems that appear to be well bonded. These pressures are commonly referred to as hydrostatic, capillary, and osmotic pressures.

A1.8.2 Concrete has traditionally been coated no sooner than 28 days after concrete placement (see Paragraph A1.10). In addition to allowing the concrete to sufficiently cure (see Paragraph A1.3), this waiting period allows excess moisture to evaporate prior to applying a barrier coating system. The waiting period is especially important if a vapor barrier (or positive-side waterproofing) is installed, which prevents moisture from exiting into the ground.

A1.8.3 The drying rate of concrete is a function of the concrete temperature, thickness, porosity, and initial free-water content. The drying rate is also a function of the velocity and dew point of the drying air. Excess free water can be removed by dehumidifiers, surface air movers, or surface heaters provided that (1) the forced drying does not begin until sufficient concrete strength is developed and (2) it does not adversely affect the concrete properties. Dehumidifiers lower the air dew point, can increase the air temperature, and perform best when the area is enclosed. Surface air movers direct low-dew point air across the concrete surface at high velocities, but they should be periodically repositioned to ensure uniform drying over the entire surface. Surface heaters increase the mobility of free water; they work best if the heat penetrates the concrete and if they do not raise the dew point of the drying air.

A1.8.4 Moisture Test Methods[40,41]

The following are some of the common methods used to identify or quantify the free moisture in concrete prior to the application of coatings.

ASTM D 4263, Plastic sheet method[19]

ASTM F 1869, Calcium chloride test[20]

ASTM F 2170, Relative humidity test[21]

ASTM E 1907, Conductivity test[43]

ASTM E 1907, Calcium carbide method[43]

ASTM E 1907, Capacitance-impedance method[43]

A1.8.5 Use and Interpretation of Moisture Test Methods

A1.8.5.1 The plastic sheet method[19] and the calcium chloride test are commonly used and accepted in the United States. The hygrometer and conductivity tests are cited in numerous British standards and are accepted in the United Kingdom, while the carbide method is accepted in other parts of Europe.

A1.8.5.2 All of these methods are quantitative except the plastic sheet method.[19] The plastic sheet, calcium chloride, and capacitance-impedance methods are nondestructive, while the hygrometer, conductivity, and calcium carbide methods involve drilling into the concrete.

A1.8.5.3 Testing duration is 16+ hours for the plastic sheet method[19] and 72 hours for the calcium chloride and relative humidity tests. The other methods give results immediately if the testing equipment has been calibrated.

A1.8.5.4 The plastic sheet method may indicate whether excess moisture is present at the time of the test. However, because the method depends on a moisture differential—a higher relative humidity in the concrete than in the air above the concrete surface—during the test span, potential problems are not always evident at the time the test is performed.

A1.8.5.5 Information on the tolerance of a specific coating system for free water or moisture migration should be provided by the coating manufacturer. A free water content of less than 5% by weight is acceptable for most coatings. Alternatively, concrete with a relative humidity of less than 80% or a moisture transmission rate of less than 15 g/24 hr/m^2 (3 lb/24 hr/1,000 ft^2) has proved acceptable for most coatings.

A1.8.5.6. Occasionally, despite moisture testing, a problem is not identified until after a low-permeability coating is applied.

A1.9 Surface Preparation Methods[17,32,44,45,46]

The surface preparation methods described in this standard are listed in Table A2 with their intended use, profile created, typical problems encountered when using each method, and solutions to those problems.

A1.9.1 Photographic examples of prepared concrete surfaces are shown in ASTM PCN:03-401079-14.[47]

A1.10 The 28-Day Waiting Period[48,49]

A1.10.1 The traditional 28-day waiting period after concrete placement and prior to coating installation is a controversial topic that involves all parties. Although the waiting period is not usually required for surface preparation, it affects the timing of surface preparation because many coatings are applied within 24 hours after surface preparation.

A1.10.2 The 28-day waiting period originated from the structural benchmark to test concrete strength at 28 days after placement to verify that the tested strength met the design strength. The 28-day benchmark became the industry standard to identify the point in time when the concrete was considered fully cured. The 28-day waiting period was adopted by the coating industry because it usually allows sufficient time for concrete surface strength to develop and for excess moisture to evaporate.

A1.10.3 Many factors can reduce or increase the time required for strength and moisture levels to be acceptable. In addition, many construction schedules do not allow for a 28-day waiting period. For these reasons, quantifying surface requirements as in Paragraph A1.12 are preferred over the traditional 28-day waiting period.

A1.10.4 NACE Standard RP0892[15] and ACI 515.1R[9] do not recommend a specific cure period but do address surface dryness, surface strength requirements, and other surface quality issues.

A1.11 Temperature Considerations

The temperature of the surface at the time of the coating application and the temperature progression during the application are both important. Rising concrete temperatures during the application of the coating systems may cause blistering and pinhole problems in the coating caused by out-gassing from the concrete. Coating application during periods of falling temperatures may be required to prevent this problem. Although controlling the ambient temperature in outdoor installations is difficult, concrete is often shaded from direct sunlight during coating application. In addition to potential problems from moisture in the concrete as described in Paragraphs A1.8.1 and A1.8.2, monitoring the dew point during periods of changing weather is often recommended to ensure that coatings are not applied over moisture that has condensed on the concrete surface.

Table A2:
Surface Preparation Methods

Preparation Method	When Used	Profile Created[A]	Problems	Solutions
Dry abrasive blasting	Removal, profile, cleaning	Fine (150) to extra coarse (40)	-Dust on surface -Airborne dust -Noise	-Vacuum cleaning -Vacuum attachments -None
Wet abrasive blasting	Removal, profile, cleaning	Fine (150) to extra coarse (40)	-Wets concrete -Creates sludge	-Let concrete dry -Cleaning
High-pressure water cleaning	Removal, cleaning	Fine (150) to extra coarse (40)	-Wets concrete -Creates sludge	-Let concrete dry -Cleaning
Waterjetting (with or without abrasive)	Removal	Rougher than extra coarse	-Creates sludge -Wets concrete -Coarse profile	-Cleaning -Let concrete dry -None[B]
Impact tools	Removal, profile, cleaning	Rougher than extra coarse	-Airborne dust -Fracturing -Coarse profile	-Vacuum attachments -Other methods -None[B]
Power tools	Removal	Smooth (no grit equivalent)	-Airborne dust -Fine profile	-Vacuum attachments -Other methods
Flame blasting	Removal, profile, cleaning	Rougher than extra coarse	-Excess removal -Damages concrete	-Experience[B] -Remove damaged concrete
Acid etching	Profile, cleaning	Fine (150) to coarse (60)	-Hazardous -Not for vertical or overhead surfaces -Neutralization -Wets concrete -Curing membrane	-Other acids -Other methods -pH testing -Let concrete dry -Other methods

[A] Profile is described using graded abrasive paper sizes. These are typical surface profile values only. Results may vary significantly because of concrete properties and surface preparation practices.
[B] For coating systems that do not perform over a coarse profile, refinishing the concrete or an underlayment may be required.

A1.12 Recommendations for Procurement Documents (Project Specifications) for Concrete Surface Preparation

Because of the wide range of concrete types, existing concrete conditions, ambient conditions, types of protective coatings to be applied, and project scheduling, producing a comprehensive standard that can be used as a project specification is not possible. Therefore, the following is a checklist of items that should be included in a comprehensive procurement document.

A1.12.1 NACE No. 6/SSPC-SP 13

A1.12.2 Contaminants

A1.12.2.1 Types anticipated

A1.12.2.2 Detection methods

A1.12.2.3 Preferred removal method

A1.12.2.4 Other acceptable removal methods

A1.12.3 Surface Preparation

A1.12.3.1 Preferred method

A1.12.3.2 Other acceptable methods

A1.12.4 Surface Tensile Strength

A1.12.4.1 Minimum allowable

A1.12.4.2 Test method and mode of failure

A1.12.5 Surface Profile

A1.12.5.1 Minimum and maximum allowable

A1.12.5.2 Test method or visual comparison

A1.12.6 Surface Uniformity

A1.12.6.1 Maximum allowable void size

A1.12.7 Repairs and Patching

A1.12.7.1 Preferred materials

A1.12.7.2 Other acceptable materials

A1.12.8 Cleanliness

A1.12.8.1 Maximum allowable residual dust level

A1.12.8.2 Test method or visual comparison

A1.12.9 Moisture Content

A1.12.9.1 Maximum allowable

A1.12.9.2 Test method and when to test (e.g., before or after surface preparation, or immediately before coating)

A1.12.10 Surface Flatness and Levelness

A1.12.10.1 Minimum and maximum slope allowed

A1.12.10.2 Minimum flatness allowed

A1.12.10.3 Test method or visual comparison

Item No. 21100

Joint Standard

NACE No. 12/AWS C2.23M/SSPC-CS 23.00 Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

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Foreword

This "Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, Their Alloys, and Composites for the Corrosion Protection of Steel" is issued to meet a critical industry and government need.

Thermal spray coatings (TSCs) are used extensively for the corrosion protection of steel and iron in a wide range of environments. The corrosion tests carried out by the American Welding Society[1] and the marine-atmosphere performance reports of ASTM[2] and the LaQue Center for Corrosion Technology[3] confirm the effectiveness of flame-sprayed aluminum and zinc coatings over long periods of time in a wide range of hostile environments. The British Standards Institution "Code of Practice for the Corrosion Protection of Steel"[4] specifies that only TSCs give protection for more than 20 years to first maintenance for the 19 industrial and marine environments considered and that only sealed, sprayed aluminum or zinc gives such protection in seawater immersion or splash zones.

This standard may be used by owners, and design, fabrication, and maintenance engineers to detail and contract for the application of TSCs for the preservation and maintenance of steel structures. This standard may also be used by TSC inspectors and TSC applicators to develop and maintain application procedures, equipment inventory, and an operator-training program.

This standard presents the basic need-to-know information for the application of quality TSCs. Appendixes present amplifying information. The Table of Contents gives an overview of this standard and may be used to find specific information.

This standard was prepared by the AWS C2B Subcommittee on Thermal Spray Coatings for Corrosion Protection, SSPC C.1.2.B Committee on Thermal Spraying, and NACE Task Group (TG) 146 on Thermal Spray Coatings. TG 146 is administered by Specific Technology Group (STG) 02 on Protective Coatings and Linings—Atmospheric, and is sponsored by STG 39 on Process Industry—Materials Applications.

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[1] AWS C2.14-74, "Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report" (Miami, FL: AWS). AWS standards can be obtained from Global Engineering, 15 Inverness Way East, Engelwood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www .global.ihs.com

[2] R.M. Kain, E.A. Baker, "Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Spray Coatings on Steel," ASTM STP 947 (West Conshohocken, PA: ASTM, 1987). Available from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

[3] S.J. Pikul, "Appearance of Thermal Sprayed Coatings After 44 Years Marine Atmospheric Exposure at Kure Beach, North Carolina," LaQue Center for Corrosion Technology, Inc, February 1996. Available from the LaQue Center for Corrosion Technology, Inc., 702 Causeway Drive, Wrightsville Beach, NC 28480.

[4] BS 5493, "Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion" (London, UK: British Standards Institution). Available from the American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036-8002, USA; and the British Standards Institution (BSI), British Standards House, 389 Chiswick High Rd., London W4 4AL, UK.

Joint Standard

NACE No. 12/AWS C2.23M/SSPC-CS 23.00

Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

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Section 1: General

1.1 General

This standard is a procedure for the application of metallic thermal spray coating (TSC) of aluminum, zinc, and their alloys and composites for the corrosion protection of steel. Required equipment, application procedures, and in-process quality control (QC) checkpoints are specified. This standard may be used as a procurement document. Appendix A presents a fill-in-the-blanks model procurement specification. The flow diagram in Figure 1 provides an overview of the thermal spray coating process presented in this standard.

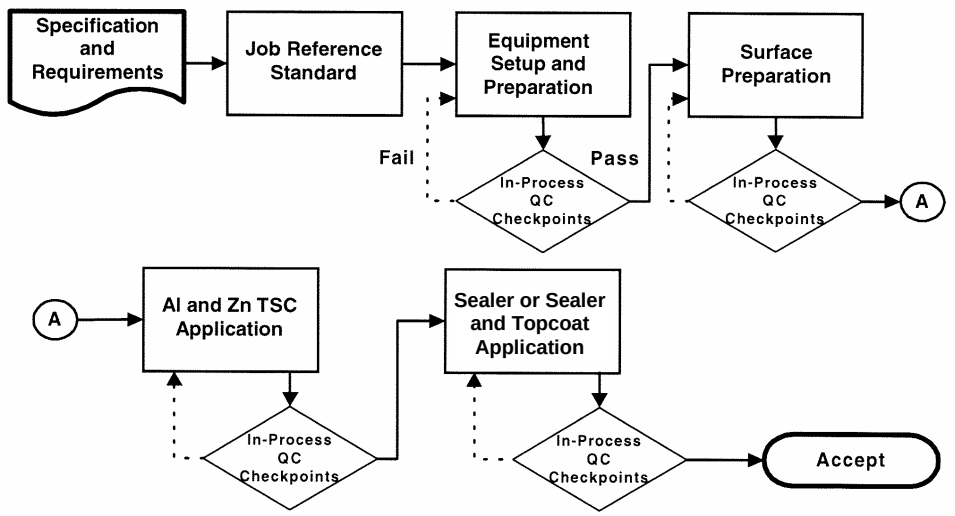


Figure 1: Thermal Spray Coating Process

Not included in this standard are requirements for design and fabrication, thermal spray equipment qualification, coating selection, and operator and inspector certification. For successful thermal spray application, the steel structure and components should be designed and fabricated according to NACE Standard RP0178.[5] Additional consideration should be given to weldments whose oxyfuel cut edges may affect hardness which may preclude adequate profile depth.

1.2 Safety

The basic precautions for thermal spraying are essentially the same as for welding and cutting. Information on safety can be found in the Safety Chapter in AWS *Thermal Spraying: Practice, Theory, and Application*; ANSI Z49.1, *Safety in Welding, Cutting; and Allied Processes*; and NFPA 58,[6] *Standard for the Storage and Handling of Liquefied Petroleum Gases*. Safety precautions can also be found in the manufacturer's equipment technical instructions and manuals and the feedstock Material Safety Data Sheet. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Potential thermal spraying hazards include exposure to vapors, dust, fumes, gases, noise (from the spray gun), and arc ultraviolet (UV) radiation. Additionally, improperly used thermal spray equipment can create potential fire and explosion hazards from the fuel and carrier gases and a potential electrical shock hazard from the electrical and electronic equipment and charged wire spools. To minimize hazards, proper safety precautions shall be followed. Operators shall comply with the procedures in the safety references, the manufacturer's technical manuals, and the material safety data sheets.

Thermal spraying can be a completely safe process when performed by an operator who follows the recommended precautionary measures, has a proper understanding of thermal spraying practices, and has knowledge, skill, and exercises care in using thermal spray equipment.

1.3 Units of Measure

This specification makes use of both the International System (SI) and U.S. Customary units. The measurements are not exact equivalents; therefore each system must be used independently of the other without combining in any way.

[5] NACE standards can be obtained from NACE International, 1440 South Creek Drive, Houston, TX 77084-4906.
[6] Available from the National Fire Protection Association (NFPA), 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

The specification ANSI/AWS C2.23M/NACE No. 12/SSPC-CS 23.00 uses SI units. U.S. Customary units are shown in appropriate columns in tables or within parentheses when used in the text. Suitable conversions encompassing standard sizes of both can be made, however, if appropriate tolerances are applied in each case.

Section 2: Referenced Documents

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS/NACE/SSPC standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this AWS/NACE/SSPC standard are encouraged to investigate the possibility of applying the most recent editions of the documents shown below. For undated references, the latest edition of the standard referred to applies

ASTM B 833, *Standard Specification for Zinc and Zinc Alloy Wire for Thermal Spraying (Metallizing)*[7]

ASTM C 633, *Standard Test Method for Adhesion or Cohesive Strength of Flame-Sprayed Coatings*

ASTM D 4285, *Method for Indicating Oil or Water in Compressed Air*

ASTM D 4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*

ASTM D 4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

ASTM D 4940, *Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives*.

ASTM E 3*, Standard Practice for Preparation of Metallographic Examination*

ANSI/AWS C2.18, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*

ANSI/AWS C2.25/C2.25M, *Specification for Solid and Composite Wires, and Ceramic Rods for Thermal Spraying*

ISO 8502-3, *Preparation of steel substrates before application of paints and related products—Tests for the assessment of surface cleanliness—Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)*[8]

NACE No. 1/SSPC-SP 5, *White Metal Blast Cleaning*

NACE No. 2/SSPC-SP 10*, Near-White Metal Blast Cleaning*

NACE Standard RP0178, *Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion Service*

NACE Standard RP0287, *Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape*

SSPC-AB 1, *Mineral and Slag Abrasive*[9]

SSPC-AB 2, *Specification for Cleanliness of Recycled Ferrous Metallic Abrasives*

SSPC-AB 3*, Newly Manufactured or Remanufactured Steel Abrasives*

SSPC-PA 1, *Shop, Field, and Maintenance Painting of Steel*

SSPC-PA 2, *Measurement of Dry Coating Thickness with Magnetic Gages*

SSPC-SP 1, *Solvent Cleaning*

SSPC-VIS 1, *Guide and Visual Reference Photographs for Steel Surfaces prepared by Dry Abrasive Blast Cleaning*

Section 3: Definitions

3.1 Aluminum MMC TSC: Aluminum metal matrix composite (MMC) TSC is a coating that contains a composite material in an aluminum matrix. It is produced by flame or arc spraying a solid or cored wire that contains the composite material.

3.2 Bend Test: The bend test (180° bend on a mandrel diameter based on the TSC thickness) is a qualitative test of the ductility and tensile bond of the TSC. The bend test is a macro-system test of surface preparation, equipment setup, spray parameters, and application procedures.

[7] ASTM standards can be obtained from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.
[8] ISO standards can be obtained from American National Standards Institute (ANSI), 11 W. 42nd Street, New York, NY 10036-9002.
[9] SSPC standards can be obtained from SSPC: The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656.

3.3 Bond Test: A test to determine the tensile strength of a thermal spray coating.

3.4 Companion Coupon: A small rectangular metal sample surface prepared and coated concurrently with the workpiece, used for inspection.

3.5 Contract Pre-Award Validation: The purchaser's contract pre-award evaluation of the thermal spray coating applicator includes (a) written procedures for and (b) demonstration of surface-preparation and thermal spray materials, equipment capabilities, and application process proposed for the contract work.

3.6 Cut Test: The TSC cut test shall consist of a single cut 40 mm (1.5 in.) long through the TSC to the substrate without severely cutting into the substrate. All cuts shall be made with sharp-edge tools. The chisel cut shall be made at a shallow angle. The cutting tool shall be specified in the contract.

3.7 Holding Period: Holding period is the time between the completion of the final anchor-tooth blasting, or final brush blasting, and the completion of the thermal spraying. The holding period, by definition, ends with the onset of rust bloom.

3.8 Job Control Record (JCR): The JCR is a record form that enumerates the essential job information and the in-process QC checkpoints required by this standard. The JCR includes information on safety precautions, and the equipment, parameters, and procedures for surface preparation, thermal spraying, and sealing or sealing and topcoating. Appendix B is a model JCR.

3.9 Job Reference Standard (JRS): The JRS is a job site pass/fail reference standard representative of the whole job or major sections of the job. See Paragraph 13.2 and Figure 2.

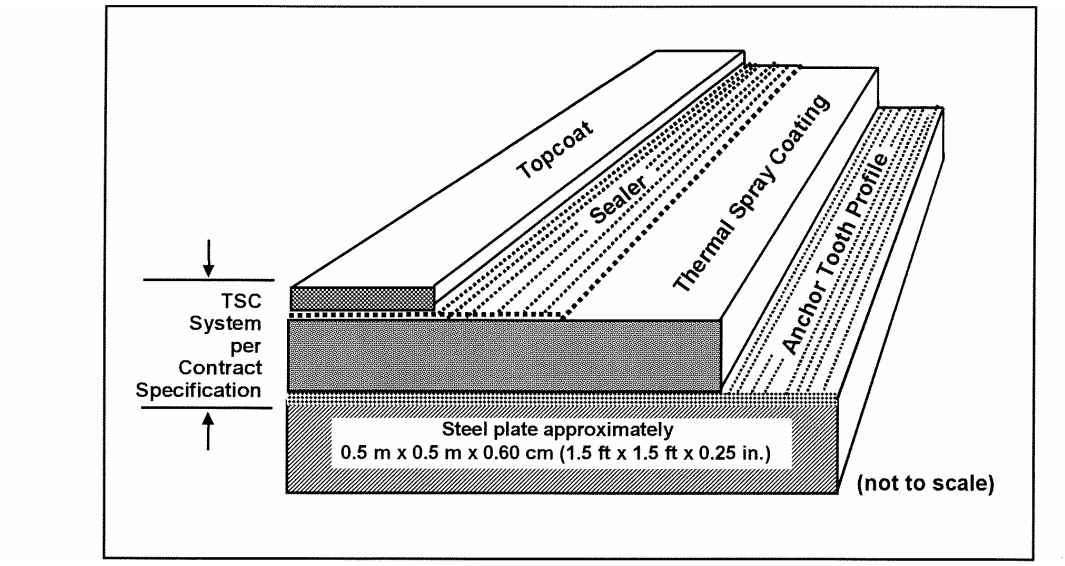


Figure 2: Job Reference Standard Illustration

3.10 Overspray: The portion of the thermal spray deposit that is not deposited on the desired area of the workpiece.

3.11 Rust Bloom: Discoloration indicating the beginning of rusting. For the purpose of this standard, rust bloom is rusting that occurs after specified surface preparation.

3.12 Sealer: The sealer is a thin paint coat about 38 μm (1.5 mils) thick that is absorbed into the pores of the TSC. Aluminum and zinc TSCs have porosities ranging up to 15%. Interconnected porosities may extend from the surface to the substrate. Sealing extends the service life. Sealing is accomplished (a) naturally by the oxidation of the sprayed aluminum or zinc filling the pores with a tightly adherent oxide layer or (b) by applying thin paint sealer coatings that penetrate and are absorbed into the pores of the TSC.

3.13 Soluble-Salt Contaminants: These water-soluble salts are inorganic compounds (such as chlorides and sulfates) that contaminate a product. If soluble salts are present on a prepared steel surface, they may cause rust bloom and premature coating failure.

3.14 Topcoat: The topcoat is a paint coat over the seal coat. Note: Paint topcoats should never be applied over an unsealed TSC.

Section 4: Summary of Practice

4.1 The procedure for application of TSCs for the corrosion protection of steel includes (a) proper surface preparation of the substrate steel, (b) proper application of the TSC, and (c) proper application of the sealer or sealer and topcoat. The procedure includes the use of suitable abrasive blasting, thermal spraying, sealing/topcoating equipment, and in-process QC checkpoints. Table 1 summarizes the TSC system requirements and the inspection and acceptance tests for shop and field applications. The TSC system material, thickness, adhesion strength, and sealer or sealer and topcoat should be related to the required service.

Section 5: Surface Finish Requirements

5.1 Surface Finish

5.1.1 The steel substrate shall be prepared to:

(1) White metal finish, NACE No. 1/SSPC-SP 5, for marine and immersion service, or

(2) The minimum of near-white metal finish, NACE No, 2/SSPC-SP 10, for other service applications.

(3) The level of soluble-salt contamination on the surface shall conform to the contract specifications.

5.1.2 Surface finish and cleanliness shall be confirmed according to SSPC-VIS 1.

5.2 Angular Profile Depth

5.2.1 The steel substrate shall have, at a minimum, an angular profile depth ≥65 μm (2.5 mils) with a sharp angular shape.

5.3 Angular Profile Depth Measurement Schedule

5.3.1 The profile depth shall be measured according to NACE Standard RP0287 or ASTM D 4417, Method C (replica tape, x-coarse, 38 to 113 μm [1.5 to 4.5 mils]), or Method B (profile depth gauge), or both.

(1) Manual Blasting. At a minimum, take one profile depth measurement every 1 to 2 m^2 (10 to 20 ft^2) of blasted surface.

(2) Automated Blasting. At a minimum, take one profile depth measurement every 100 to 200 m^2 (1,000 to 2,000 ft^2) of blasted surface.

(3) Angular Blast Media. Use clean dry angular blasting media. Mineral and slag abrasives shall be selected and evaluated per SSPC-AB 1, recycled ferrous metallic abrasives per SSPC-AB 2, and steel grit per SSPC-AB 3. The absence of oil contamination shall be confirmed using the test for oil in the appropriate abrasive specification (no oil film or slick). The soluble salt contamination shall be measured by ASTM D 4940. The suitability of the angular blast media, blasting equipment, and blasting procedures shall be validated according to Section 14, Contract Pre-Award Evaluation, Demonstration, and Validation. Table 2 indicates blasting media and mesh size found suitable for TSCs on steel substrates.

Section 6: TSC Requirements

6.1 Feedstock and TSC Thickness

6.1.1 The TSC feedstock material and thickness should be selected according to intended service environment and service life. (See ANSI/AWS C2.18)

6.1.2 The TSC feedstock material shall be specified according to ANSI/AWS C2.25/C2.25M or ASTM B 833.

6.1.3 The minimum and maximum TSC thickness shall be measured with an SSPC-PA 2, Type 2 fixed probe gauge or equivalent. The thickness scheduled is specified in Paragraph 6.3.

Table 1: TSC System Requirements and Acceptance Tests

TSC System Requirements			Acceptance Tests
Surface Preparation	**TSC**	**Sealer or Sealer and Topcoat**	
NACE No. 2/SSPC-SP 10 minimum [A]	Smooth and uniform. No blisters, cracks, loose particles, or exposed steel.	Smooth and uniform. No runs, sags, lifting, pinholes, or overspray.	Per the contract surface preparation standard.
Angular-profile depth ≥65 µm (2.5 mils)	---	---	Profile tape according to NACE Standard RP0287 or micrometer depth gauge according to ASTM D 4417
Specify blasting media	Specify feedstock	Specify paint(s)	Manufacturer's certificate[B] and MSDS
---	Coating Thickness[C] Minimum: ____µm (____mils) Maximum: ____µm (____mils)	Coating thickness Minimum: ____µm (____mils) Maximum: ____µm (____mils)	SSPC-PA 2 Type 2 Fixed Probe Gauge
---	Portable tensile bond (≥ Table 3 values) Minimum: ____MPa (____psi)	---	ASTM D 4541[D]
Companion coupon bend/tensile-bond test[E]:		---	Bend/tensile-bond test
Condition of substrate surface preparation and TSC interface and morphology (structure)[F]		---	Metallographic examination of companion coupon
---	No peeling or delimitation	---	TSC Cut Test [G]
	Other as specified by the Contract		Other as specified by the Contract

[A] For critical surfaces and marine and underwater service, clean to a white metal finish (NACE No. 1/SSPC-SP 5) with ≥65 µm (2.5 mils) angular profile. The owner should specify the minimum required blast quality and its validation according to Section 5, Job Reference Standard. The angularity of the blast profile can be determined by a metallographic analysis of a companion coupon according to ASTM E 3 using a specimen cut from a successful bend coupon prepared and thermal sprayed per the contract specifications and tested according to Paragraph 6.5.

[B] Verification that the manufacturers or suppliers provide a certificate or affidavit that (1) the blasting media conforms to SSPC-AB 1 for mineral and slag abrasive, SSPC-AB 2 for recycled ferrous metallic abrasives, or SSPC-AB 3 for newly manufactured or remanufactured steel abrasive; (2) the TSC-feedstock chemical composition, obtained from a representative sample of each heat during the pouring or subsequent processing, conforms to ANSI/AWS C2.25; and (3) the sealer and topcoat paints are formulated for the contract-specified thermal spray coating. The Material Safety Data Sheets (MSDS) provide supporting physical and chemical information.

[C] Measure the TSC thickness according to SSPC-PA 2. Calibrate the instrument using a calibration wedge near the contract-specified thickness placed over a representative sample of the contract-specified abrasive blasted steel, a prepared bend coupon, or both.

[D] Specify the ASTM D 4541 self-adjusting portable tensile instrument to be used and its minimum acceptable value for the Job Reference Standard and the job work surfaces.

[E] As an alternative to the portable tensile-bond test, which may be considered potentially destructive on a finished part, a companion coupon may be bend tested, or a companion tensile test specimen may be tested in accordance with ASTM C 633 to validate the coating adhesion strength. The bend test is a macro system test for proper surface preparation, equipment set-up, and spraying parameters.

[F] Metallographic analysis of a companion coupon may be specified to establish the suitability of the surface preparation, TSC application, and/or porosity of the TSC.

[G] TSC cut test should be made by a tool cutting through the TSC to the steel surface. The TSC is defective if any part of the coating lifts off the surface.

Table 2: Blasting Media and Mesh Size Found Suitable for TSCs on Steel Substrates

Thermal Spray Material	Process	Blasting Media	Size[A]
Al, Zn, 85/15 Zn/Al, 90/10 Al-Al_2O_3 MMC	Flame wire and arc wire	Aluminum oxide	10-30 mesh
		Angular steel grit	G-16 to G-40
		Copper and nickel slag	G-16 to G-24
		Almandite garnet	G-16 to 30/40
		Chilled iron grit	G-16 to G-40
Al, Zn	Flame powder	Aluminum oxide	10-30 mesh
		Angular steel grit	G-16 to G-40
		Chilled iron grit	G-16 to G-40

[A] Mesh size shall be selected as appropriate to the anchor-tooth depth requirement and the blasting equipment used.

6.2 TSC Thickness

6.2.1 Thickness Less Than Contract Specification

6.2.1.1 If upon later inspection, and prior to sealer application, the TSC thickness is less than the contract requirement, the applicator shall apply additional TSC to meet the thickness requirement.

6.2.2 Thickness Greater Than Contract Specification

6.2.2.1 If the TSC thickness is greater than the contract specification, information shall be recorded in the JCR and the inspector shall be notified immediately. The inspector should then notify the purchaser for resolution of this discrepancy. The TSC applicator and the purchaser should record all areas in excess of 150% of the acceptable coating thickness. If these areas are damaged during shipping, loading/unloading, or erection, they should be repaired in accordance with maintenance repair procedures as outlined in ANSI/AWS C2.18.

6.3 TSC Thickness Measurement Schedule

6.3.1 For flat surfaces a measurement line shall be used. The average value of five readings taken in line at 2.5-cm (1.0-in.) intervals shall be determined. The line measurement measures the peaks and valleys of the TSC.

6.3.2 For complex geometries and geometry transitions a measurement spot shall be used. The measurement spot should have an area of approximately 10 cm^2 (1.6 $in.^2$). The spot measurement may not measure the peaks and valleys of the TSC.

6.3.3 Figure 3 illustrates the line and spot measurements.

6.3.4 Measurement Schedule: One line or spot measurement shall be taken every 10 to 20 m^2 (100 to 200 ft^2) of applied TSC.

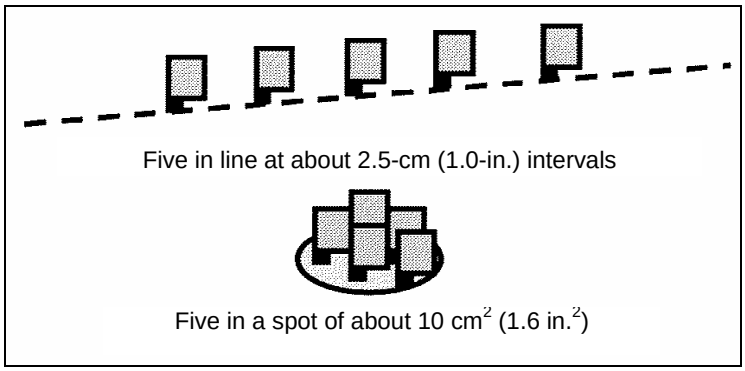


Figure 3: Line and Spot Measurements

6.4 TSC Tensile Bond and Measurement Schedule

6.4.1 The TSC tensile bond shall be measured according to ASTM D 4541 using a self-aligning adhesion tester or approved equivalent.

6.4.1.1 The minimum TSC tensile bond value shall be specified according to Table 3. Higher values may be specified.

Table 3: Minimum Tensile Bond Requirements (According to ASTM D 4541 using self-aligning adhesion tester)

Feedstock	MPa (psi)
Zn	3.45 (500)
Al	6.89 (1,000)
85/15 Zn/Al	4.83 (700)
90/10 Al_2O_3 MMC	6.89 (1,000)

6.4.1.2 One portable tensile-bond measurement shall be made every 50 m^2 (500 ft^2). If the tensile bond is less than the contract specification, the degraded TSC shall be removed and reapplied.

6.4.1.3 For nondestructive measurement: Tensile force shall be measured to the *contract-specified tensile.* The tensile force shall then be reduced and the tensile fixture removed without damaging the TSC.

6.4.2 Note: The tensile-bond measurement of the portable test instrument may be calibrated according to the ASTM C 633 test method as described in Appendix C.

6.5 Bend Test

6.5.1 The bend test (180° bend on a mandrel) is used as a qualitative test for proper surface preparation, equipment setup, and spray parameters. The bend test puts the TSC in tension. The mandrel diameter for the threshold of cracking depends on substrate thickness and coating thickness.

6.5.2 Table 4 summarizes a very limited bend-test cracking threshold for arc-sprayed zinc TSC thickness on steel coupons 1.3 mm (0.05 in.) thick versus mandrel diameter.

Table 4: Bend-Test Cracking Threshold: Mandrel Diameter vs. TSC Thickness
For steel coupons 1.3 mm (0.05 in.) thick

TSC Thickness, μm (mils)	≥250 (10)	≥380 (15)	≥640 (25)
Mandrel Diameter, mm (in.)	13 (0.50)	16 (0.63)	<25 (1.0)[A]

[A] Confirm diameter with JRS.

6.5.3 Bend-Test Procedure for TSC Thickness Range 175 to 300 μm (7 to 12 mils)

(1) Five corrosion-control bend coupons shall be sprayed and shall pass the following bend test:

(a) Carbon steel coupons of approximate dimensions 50 x 100 to 200 x 1.3 mm (2 x 4 to 8 x 0.050 in.) shall be used.

(b) Surface shall be prepared according to contract specification.

(c) The TSC shall be sprayed 175 to 300 μm (7 to 12 mils) thick. The TSC should be sprayed in crossing passes laying down approximately 75 to 100 μm (3 to 4 mils) in each pass.

(d) Coupons shall be bent 180° around a 13-mm (0.50-in.) diameter mandrel.

(2) *Bend test passes* if, on the bend radius (see Figure 4), there is

(a) no cracking or spalling, or

(b) only minor cracking that cannot be lifted from the substrate with a knife blade.

(3) *Bend test fails* if the coating cracks with lifting from the substrate.

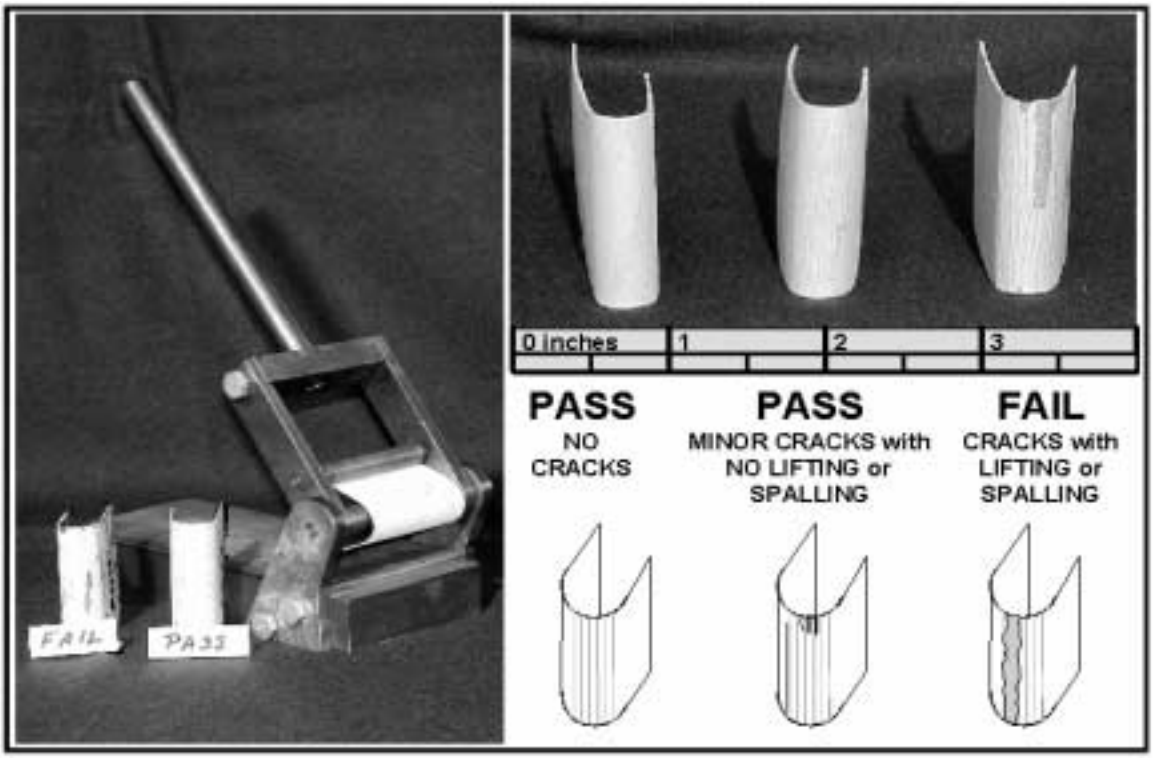


Figure 4: TSC Bend Test: Pass and Fail Samples

6.6 TSC Finish

6.6.1 The deposited TSC shall be uniform without blisters, cracks, loose particles, or exposed steel as examined with 10x magnification.

6.7 TSC Porosity

6.8.1 If required by the purchaser, the maximum allowable porosity and the metallographic measurement method to be used for the evaluation shall be specified. Note: Porosity measurements are not used for in-process quality control in metallizing for corrosion protection of steel. However, porosity measurements may be used to qualify thermal spray application processes and spray parameters.

6.8 TSC QC Measurement Procedures and Instruments

6.8.1 The suitability of the TSC thickness, portable tensile bond, bend test, and cut-test measurement procedures and instruments shall be validated during the Contract Pre-Award Validation according to Section 14.

Section 7: TSC Application Procedure

7.1 General

7.1.1 Appendix D details the key production and quality control checkpoints for applying TSCs.

7.2 Thermal Spray Equipment Setup

7.2.1 Thermal spray equipment shall be set up, calibrated, and operated (1) according to the manufacturer's instructions and technical manuals or the TSC applicator's refinement thereto, and (2) as validated by the JRS (See Paragraph 13.2).

7.2.2 Spray parameters and thickness of each crossing pass shall be set for spraying the specified thermal spray material and, at a minimum, be validated with the bend test.

7.2.3 The thermal spray equipment spray-parameter set-up shall be validated with a bend test at the beginning of each shift or crew change.

7.2.4 A copy of the spray parameters used shall be attached to the JCR.

7.3 Post-Blasting Substrate Condition and Thermal Spraying Period

7.3.1 Steel Surface Temperature

7.3.1.1 The steel surface temperature shall be at least 3°C (5°F) above the dewpoint of the ambient air temperature.

7.3.2 Holding Period

7.3.2.1 Time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying should be no greater than six hours for steel substrates with the following exceptions:

(1) In high-humidity and damp environments, shorter holding periods shall be used. If rust bloom or a degraded coating appears at any time while spraying, spraying shall be stopped. (See Paragraph 8.2.4.)

(2) In low-humidity environments or in controlled environments with enclosed structures using industrial dehumidification equipment, it may be possible to retard the oxidation of the steel and hold the surface finish for more than six hours. The TSC applicator, with the concurrence of the purchaser, can establish a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons, tensile-bond specimens, or both. The following method shall be used for bend-test coupons: (a) establish, measure, and record the low-humidity environment; (b) prepare four bend-test coupons according to contract specifications; (c) place bend-test coupons in the low-humidity environment; (d) after target holding period duration, apply the contract-specified thermal spray coating; (e) perform the bend test according to Paragraph 6.5; (f) the low-humidity environment and holding period are satisfactory if the four bend coupons meet the requirement of Paragraph 6.6.3 (2). Alternately, tensile-bond specimens can be similarly tested.

(3) For small and movable parts, if more than 15 minutes is expected to elapse between the completion of surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface should be protected from moisture, contamination, and finger/hand marks. Wrapping with clean ink-free paper is normally adequate.

7.4 TSC Flash Coat

7.4.1 Application Time

7.4.1.1 A 25- to 50-µm (1- to 2-mil) flash coat of the TSC may be applied within six hours of completing surface preparation to extend the holding period for up to four more hours beyond the complete application of the flash coat. The final TSC thickness, however, shall be applied within four hours of the completion of the application of the flash coat provided the TSC can be maintained free of contamination.

7.4.2 Validation Procedure

7.4.2.1 The use of a flash TSC to extend the holding period shall be validated with a tensile-bond measurement, bend test, or both. The use of a flash TSC shall be validated by:

(1) Cleaning and abrasive blasting a representative job area for a portable tensile-bond measurement, a bend-test coupon, or both.

(2) Applying a flash TSC.

(3) Waiting the delay period and applying the final TSC thickness.

(4) Measuring the tensile bond, performing the bend test, or both.

7.4.2.2 The flash TSC and holding period are acceptable if the tensile bond, bend tests, or both, are satisfactory.

Section 8: TSC Application

8.1 Preheat

8.1.1 Preheating the starting area has been common practice for flame spraying and should be continued until proven not to be a benefit or inconsequential. The initial 0.1- to 0.2-m^2 (1- to 2-ft^2) starting-spray area shall be preheated to prevent water in the flame from condensing on the substrate.

8.1.1.1 For flame spraying, the initial starting area shall be preheated to approximately 120°C (250°F).

8.1.1.2 Preheating requirements shall be validated with the JRS and the bend test, tensile test, or both.

8.2 Thermal Spraying

8.2.1 Crossing Passes

8.2.1.1 The specified coating thickness shall be applied in several crossing passes. The coating tensile-bond strength is greater if the spray passes are kept thin. Laying down an excessively thick spray pass increases the internal stresses in the TSC and decreases the ultimate tensile-bond strength of the total TSC. The suitability of the crossing-pass thickness shall be confirmed with a bend test, tensile-bond measurement, or both.

8.2.2 Manual Spraying

8.2.2.1 For manual spraying, right-angle crossing passes shall be used to minimize the thin areas in the coating.

8.2.3 Mechanized Spraying

8.2.3.1 For mechanized spraying (mechanized movement of the gun, workpiece, or both), overlapping and crossing passes shall be programmed to eliminate thin spots and stay within the coating thickness specification.

8.2.4 Rust Bloom

8.2.4.1 If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC or flash TSC, the following procedure applies:

(1) Stop spraying.

(2) Mark off the acceptable sprayed area.

(3) Re-prepare the unsatisfactory areas to the required degree of surface cleanliness and surface profile, including any areas where the TSC was applied to unsatisfactory surfaces.

(a) Blast the edges of the TSC to provide for a 5.0- to 7.5-cm (2.0- to 3.0-in.) feathered-area overlap of the new work into the existing TSC.

(b) Apply TSC to the newly prepared surfaces, and overlap the existing TSC to the extent of the feathered edge so that the overlap is a consistent thickness.

8.2.5 TSC Thickness

8.2.5.1 The TSC thickness shall be that specified in Table 1 and Paragraph 6.1.3.

8.2.6 Low-Temperature Spraying

8.2.6.1 Thermal spraying in low-temperature environments (below freezing) must:

(1) Meet the substrate surface temperature and holding period specified in Paragraphs 7.3.1 and 7.3.2. No moisture condensation on the surface is permissible during thermal spraying.

(2) Be qualified with a bend test, portable tensile-bond test, or both.

Note: TSCs are mechanically bonded to the substrate. Preheating may be required to improve the TSC tensile bond to the substrate and reduce internal stresses.

Section 9: Application of Sealers and Topcoats

9.1 General

9.1.1 Thermal sprayed steel should be sealed and/or topcoated under any of the following conditions:

(1) The environment is very acidic or very alkaline (normal pH range for pure zinc is 6 to 12 and for pure aluminum, 4 to 11).

(2) The metallic coating is subject to direct attack by specific chemicals.

(3) A particular decorative finish is required.

(4) Additional abrasion resistance is required.

(5) Frequent saltwater spray, splash, or immersion service.

(6) Frequent freshwater spray, splash, or immersion service, excluding potable water.

9.1.2 Sealers and topcoats shall meet the local restrictions on volatile organic compound (VOC) content. Sealer and topcoats shall be applied according to the paint manufacturer's instructions for use with a TSC, or as specified by the purchaser.

9.2 Sealer

9.2.1 The seal coat, if applied, shall be thin enough to penetrate into the body of the TSC and seal the interconnected surface porosity. Typically the seal coat is applied at a spreading rate resulting in a theoretical 38-μm (1.5-mil) dry-film thickness (DFT).

9.2.2 For shop and field work, sealers should be applied as soon as possible after thermal spraying and preferably within eight hours.

9.2.3 If a sealer cannot be applied within eight hours, it shall be verified that the TSC (a) has not been contaminated by visual inspection, and (b) is dust-free using the clear cellophane tape test per ISO 8502-3 before applying the sealer.

9.3 Topcoat

9.3.1 A topcoat is essentially a full coat of paint. Topcoats shall be chemically compatible with the sealer and shall be applied according to the paint manufacturer's instructions for a topcoat on a sealed TSC, or as specified by the purchaser. Full topcoats greatly reduce or entirely diminish the cathodic protection effects of the TSC in immersion or underground service.

9.3.2 A paint topcoat shall only be applied to an unsealed TSC if the compatibility of this (sealer-topcoat) painting system has been demonstrated.

9.4 Applying Paints

9.4.1 All paint coatings shall be applied according to SSPC-PA 1 and the paint manufacturer's recommendations for use of the product with a TSC system.

Section 10: Records

10.1 The TSC applicator shall use a JCR to record the production and QC information and other information required by the purchasing contract. Additionally, the TSC applicator shall have its own Quality Assurance Program. The TSC applicator shall keep records for a time period consistent with the TSC applicator's quality assurance and records program and as required for regulatory compliance and the purchasing contract. Records should be kept a minimum of one year.

Section 11: Debris Containment and Control

11.1 The TSC applicator and the purchaser shall coordinate the specific requirements, responsibilities, and actions for the containment, collection, and removal of the debris produced by the TSC applicator and its subcontractors.

Section 12: Work Procedures and Safety

12.1 The purchaser shall provide its standard operating and safety procedures and compliance requirements to the TSC applicator. The TSC applicator shall follow all appropriate procedures and meet all appropriate regulatory requirements.

Section 13: Documentation

13.1 TSC Applicator's Application Procedure

13.1.1 The TSC applicator shall submit its application procedure proposed for the contract work. The application process shall include information on the equipment capabilities, materials, and process or application procedures, and in-process quality control checkpoints for (a) surface preparation, (b) thermal spraying, and (c) paint work (sealer or sealer and topcoat).

13.2 Job Reference Standard (JRS)

13.2.1 A job site pass/fail JRS representative of the whole job or major sections of the job shall be prepared by the TSC applicator. The JRS shall be used as a "comparator" to evaluate the suitability of the application process.

(1) The JRS shall be made on a steel plate approximately 46 x 46 x 0.60 cm (18 x 18 x 0.25 in.) (see Figure 2). *For structural steel, the reference standard does not need to be more than 0.60 cm (0.25 in.) thick because steel does not thermally distort when TSC is applied.* If the actual work is less than 0.60 cm (0.25 in.) thick, the JRS should be made from material of a representative thickness.

(2) The JRS shall be made with the actual field equipment and the process parameters and procedures (surface preparation, thermal spraying, sealing or sealing

and topcoating in-process QC checkpoints) that shall be used for the contracted work.

(3) The JRS shall be made in representative environmental conditions spraying with or without enclosure as appropriate.

(4) Thickness and tensile-bond measurements shall be made according to Figure 5.

(a) Four "five in-line" thickness measurements.
(b) Four portable tensile-bond measurements according to Paragraph 6.4.
(c) The JRS is unsatisfactory if any measurements are less than the contract-specified value.

(5) The JRS is used as a pass/fail reference for the applicator's in-process QC and the purchaser's inspector.

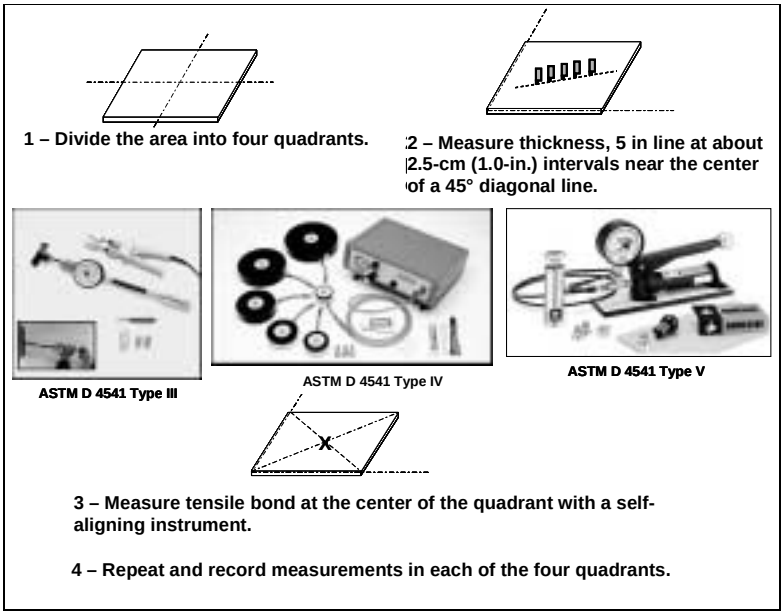


Figure 5: Thickness and Tensile-Bond Measurements for JRS Qualifications

Section 14: Contract Pre-Award Evaluation, Demonstration, and Validation

14.1 The purchaser shall evaluate the suitability of the TSC applicator's application process submitted according to Paragraph 13.1.

14.2 The purchaser, as an option for physically validating the TSC applicator's application process, may schedule, witness, and evaluate a contract pre-award demonstration of the TSC applicator's application process for the surface preparation, thermal spraying, sealing, and topcoating, using the equipment, materials, and process procedures proposed for the contract work. The JRS should be made during this demonstration and witnessed by the purchaser or his designated representative.

Section 15: TSC Applicator Warranty

15.1 TSC Applicator Warranty

15.1.1 The TSC applicator shall warrant the quality of its workmanship as mutually agreed to by the purchaser and the TSC applicator.

15.2 Materials Used

15.2.1 The TSC applicator shall provide the purchaser with a Certificate of Materials Used to include:

(1) For angular blasting media: Media type, grit size range, chemical composition, and MSDS.

(2) For TSC spray feedstock: Alloy type/designation, lot number, wire diameter, chemical composition of the wire lot, and MSDS.

(3) Sealer and topcoat: Manufacturer's product and application data sheets for application on the TSC system and MSDS.

Further Reading

ANSI Z49.1. "Safety in Welding, Cutting, and Allied Processes." Washington, DC: ANSI.[10]

AWS C2.14. "Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report." 1974.[11]

BS 5493. "Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion." London, UK: BSI.[12]

Kain, R.M., and E.A. Baker. "Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Spray Coatings on Steel." ASTM STP 947. 1987.

NFPA 58. "Standard for the Storage and Handling of Liquefied Petroleum Gases." Quincy, MA: NFPA.[13]

Pikul, S.J. "Appearance of Thermal Sprayed Coatings after 44 Years Marine Atmospheric Exposure at Kure Beach, North Carolina." LaQue Center for Corrosion Technology Report.[14]

SSPC Publication. *Inspection of Coatings and Linings: A Handbook of Basic Practice for Inspectors, Owners, and Specifiers.* B.R. Appleman, R. Drisko, J. Neugebauer, eds.

SSPC-TU 4. "Field Methods for Retrieval and Analysis of Soluble Salts on Substrates." Pittsburgh, PA: SSPC.

Thermal Spraying: Practice, Theory, and Application. Miami, FL: AWS, 1985.[15]

[10] Available from the American National Standards Institute, 1819 L Street NW, 6th floor, Washington, DC 20036.
[11] AWS publications can be obtained from Global Engineering, 15 Inverness Way East, Engelwood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www .global.ihs.com.
[12] BSI standards can be obtained from the British Standards Institution (BSI), British Standards House, 389 Chiswick High Rd., London W4 4AL, UK.
[13] Available from the National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.
[14] Available from the LaQue Center for Corrosion Technology, Inc., 702 Causeway Drive, Wrightsville Beach, NC 28480.
[15] AWS publications can be obtained from Global Engineering, 15 Inverness Way East, Engelwood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www .global.ihs.com

Appendix A: Model Procurement Specification

This Appendix is not a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, but is included for informational purposes only.

Appendix A is included to illustrate how this standard may be used to specify a thermal spray job.

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	**Instructions/Rationale**
1. Scope of Work **1.1 Application Procedure** **The TSC system (surface preparation, thermal spraying, and sealing or sealing and topcoating) shall be applied in accordance with Sections 4, 5, and 6 of this specification.**	The major production and quality control (QC) steps for applying a TSC coating system are summarized in Appendix D. Appendix D should be appended to the procurement specification to inform the TSC applicator of the application requirements.
1.2 Items/Areas to Be Thermal Sprayed. **Apply TSC systems to:** _____ _____ _____ _____	Specify the item(s) and surface(s) to be (and not to be) thermal sprayed. Reference and append engineering drawings or other technical documents that quantitatively describe the job.
2. Codes and Standards **This specification takes precedence in event of conflict with cited Codes and Standards.** The following codes and standards (latest issue) apply: ASTM B 833, Standard Specification for Zinc Wire for Thermal Spraying (Metallizing). ASTM C 633, Test Method for Adhesive/Cohesive Strength of Flame Sprayed Coatings. ASTM D 4285, Method for Indicating Oil or Water in Compressed Air. ASTM D 4417, Test Method for Field Measurement of Surface Profile of Blasted Steel. NACE Standard RP0287, Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape. ASTM D 4541, Test Method for Pull-Off Strength of Coating Using Portable Adhesion Testers. ANSI/AWS C2.18, Guide for the Protection of Steel with Thermal Spray Coatings of Aluminum, Zinc, and Their Alloys and Composites. NACE No. 12/AWS C2.23M/SSPC-CS 23.00, Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel. SSPC Publication, The Inspection of Coatings and Linings: A Handbook of Basic Practice for Inspectors, Owners, and Specifiers. SSPC-AB 1, Mineral and Slag Abrasives. SSPC-AB 3, Ferrous Metallic Abrasives. SSPC-PA 1, Shop, Field, and Maintenance Painting of Steel. SSPC-PA 2, Measurement of Dry Coating Thickness with Magnetic Gages. NACE No. 1/SSPC-SP 5, White Metal Blast Cleaning. NACE No. 2/SSPC-SP 10, Near-White Metal Blast Cleaning. SSPC-VIS 1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning.	List the Codes and Standards cited in this procurement specification. Add other standards as required.

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
3. TSC System Requirements	
3.1 Surface Preparation Requirement.	
3.1.1 Surface Finish. Degrease according to SSPC-SP 1 if oil/grease contaminated. The steel substrate shall be abrasive blasted to _____(a)_____. Using SSPC VIS 1, confirm that the blast cleaned finish meets NACE No. 1/SSPC-SP 5 or NACE No. 2/SSPC-SP 10.	(a) Specify either white metal finish, NACE No. 1/SSPC-SP 5, for marine and immersion service; or near-white metal finish, NACE No. 2/SSPC-SP 10, for other service applications.
3.1.2 Blasting Media Requirement. Use ____(a)____ angular blasting media to produce the angular profile depth specified by Paragraph 3.1.3. Mineral and slag abrasives shall be selected and evaluated per SSPC-AB 1; recycled ferrous metallic abrasives per SSPC-AB 2; and steel grit per SSPC-AB 3.	(a) Specify abrasive basting media type and size. See Table 2 of this NACE No. 12/AWS C2.23M/SSPC-CS 23.00 standard.
3.1.3 Blast Angular Profile Depth. The steel substrate shall have an angular profile depth ≥65 µm (2.5 mils) with a sharp angular shape per NACE Standard RP0287 or ASTM D 4417, Method B or C.	
3.1.4 Blast Profile Measurement Schedule. Measure the angular profile depth in a measurement spot approximately every ____(a)____ blasted surface. Take three measurements for each spot in an area approximately 10 cm^2 (1.5 $in.^2$). Average the measurements and record in the JCR.	(a) Specify the minimum area, e.g., 10 to 20 m^2 (100 to 200 ft^2)
3.2 TSC Requirement.	
3.2.1 Thermal Spray Feedstock Requirement. **Use ___(a)___ thermal spray wire.**	(a) Specify wire according to ANSI/ AWS C2.25 or ASTM B 833.
3.2.2 TSC Thickness Requirement and Measurement Schedule **(a) Thickness** **(1) The minimum TSC thickness shall be _____(a)_____.** **(2) The maximum TSC thickness shall be _____(b)_____.** **(3) Measure TSC thickness using a SSPC-PA 2 Type 2 fixed probe gauge or equivalent.** **(b) Measurement Schedule** **One portable tensile-bond measurement shall be made every 50 m^2 (500 ft^2). If the tensile bond is less than the contract specification, the degraded TSC shall be removed and reapplied.**	(a) Specify the minimum thickness. (b) Specify the maximum thickness.
3.2.3 TSC Tensile-Bond Requirement. **(a) The TSC shall have a minimum tensile bond of __(a)__ MPa (____ psi) according to ASTM D 4541 using the Type __(b)__ self-aligning portable test instrument for coating thickness specified in Paragraph 3.2.2.** **(b) Use adhesive recommended by the instrument manufacturer, or equivalent. Attach adhesive manufacturer's instructions to the JCR.**	(a) Specify the minimum tensile bond. (b) Specify either the Type III or IV portable self-aligning test instruments.

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
3.2.4 Bend Test. **Conduct a bend test at the beginning of each work shift or crew change:** **(1) Use carbon steel coupons of approximate dimensions 50 x 100 to 200 x 1.3 mm (2 x 4 to 8 x 0.050 in.).** **(2) Surface preparation according to contract specification.** **(3) Spray 200- to 250-µm (8- to 10-mil) thick TSC in crossing passes laying down approximately 75 to 100 µm (3 to 4 mils) for each pass.** **(4) Bend coupons 180° around a 13-mm (0.5-in.) diameter mandrel.** **(a) Bend test passes if there is no cracking or only minor cracks with no spalling or lifting (by a knife blade) from the substrate.** **(b) Bend test fails if the coating cracks with lifting (by a knife blade) from the substrate.**	The bend test (180° bend on a mandrel) is used as a qualitative test for proper surface preparation, equipment setup, and spray parameters. The bend test puts the TSC in tension. The mandrel diameter for the threshold of cracking depends on substrate thickness, coating thickness, and mandrel diameter.
3.2.5 TSC Porosity Requirement. *The TSC shall have a porosity ≤ __(a)__ % for each metallographic analysis of a bend coupon made during the Contract Pre-Award Evaluation, Demonstration, and Validation.*	*Flame and arc spraying aluminum and zinc for the corrosion protection of steel generally have porosity ≤15%. The TSC thickness should be selected so there is no interconnected porosity to the substrate. A lower-porosity TSC requires less thickness. Porosity measurements are not used for in-process quality control in metallizing for corrosion protection of steel. However, a metallographic sample must be used to evaluate TSC porosity and confirm the TSC nonporous thickness for the contract-specified thickness. If required, the porosity metallographic sample should be taken from the bend coupon made during the purchaser's witnessing of the preparation of the JRS.*
3.3 Sealers and Topcoats *All paint coatings shall be applied according to SSPC-PA 1 and the paint manufacturer's instructions for use of the product with a thermal sprayed coating system.* ***Use a heat-resistant silicone alkyd aluminum paint or equivalent sealer on components whose operating temperatures are greater than 80°C (175°F).***	*Specify use of sealer if (a) the service environment precludes effectiveness of the natural oxidation to "fill and seal" the pores or (b) a paint topcoat (cosmetic and/or functional purpose) is specified. Long delay times will preclude adequate penetration of the sealer into the pores of the TSC. The sealer must be chemically compatible with the TSC material and the topcoat.*

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
3.3.1 Sealer *(1) Use the sealer _____(a)_____ manufactured by_____(b)_____.* *(2) Follow paint manufacturer's application instructions for applying the sealer on TSCs. The seal coat shall be thin enough to penetrate into the body of the TSC and seal the porosity. Typically the seal coat is applied at a spreading rate resulting in a theoretical 38-μm (1.5-mil) DFT.* *(3) Sealer Application* *For shop work, apply the sealer immediately after thermal spraying.* *For field work, apply the sealer as soon after thermal spraying as possible but preferably within eight hours.* *If sealer cannot be applied within eight hours, verify that the TSC (a) has not been contaminated by visual (10x) inspection and (b) is dust-free using the clear cellophane tape test (ISO 8502-3).*	*(a) Specify formula or other unique identification.* *(b) Specify manufacturer.*
3.3.2 Topcoat. *(1) Use the topcoat _____(a)_____ manufactured by_____(b)_____.* *(2) Apply the topcoat to a dry-film thickness (DFT) of ____(c)____ according to manufacturer's instructions.* *(3) Measure DFT using an SSPC-PA 2 Type 2 fixed probe gauge.*	*(a) Specify formula or other unique identification.* *(b) Specify manufacturer.* *(c) Specify thickness from similar successful applications or manufacturer's recommendations for topcoating sealers on TSCs.*
4. Surface Preparation. **Use blasting equipment, materials, and procedures that will produce the Paragraph 3.1 metal finish and an angular profile ≥65 μm (2.5 mils).** **The suitability of the blasting, media, procedures, and equipment shall be validated in the contract pre-award evaluation, demonstration, and validation.**	Blasting media is specified in Paragraph 3.1.2.
5. TSC Application.	
5.1 Thermal Spray Equipment Setup. **5.1.1 Thermal spray equipment shall be set up, calibrated, and operated according to the manufacturer's instructions and technical manuals or the TSC applicator's refinement thereto and as validated by the JRS.** **5.1.2 Spray parameters shall be set for spraying the specified thermal spray material and, at a minimum, be validated with the bend test. A bend test shall be satisfactorily performed at the beginning of crew and shift change.** **5.1.3 A copy of the spray parameters used shall be attached to the JCR.**	

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
5.2 Post-Blasting Substrate Condition and Thermal Spraying Period **5.2.1 Steel Surface Temperature.** **(1) the steel surface temperature shall be at least 3°C (5°F) above the dew-point.**	
5.2.2 Holding Period. **(1) Time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying should be no greater than six hours for steel substrates. In high-humidity and damp environments, shorter holding periods shall be used. If rust bloom or a degraded coating appears at any time within the six-hour window, Paragraph 5.5.4 of this model specification applies.** **(2) In low-humidity environments or in enclosed spaces using industrial dehumidification equipment, it will be possible to retard the oxidation of the steel and hold the surface finish for more than six hours. The TSC applicator, with the concurrence of the purchaser, can validate a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons, tensile-bond coupons, or both.** **(3) For small and movable parts, if more than 15 minutes is expected to elapse between completion of surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface should be protected from moisture, contamination, and finger/hand marks. Wrapping with clean print-free paper is normally adequate.**	
5.3 TSC Flash Coat *5.3.1 A 25- to 50-µm (1- to 2-mil) flash coat of the TSC may be applied within six hours of completing surface preparation to extend the holding period for up to four further hours beyond the complete application of the flash coat. The final TSC thickness, however, shall be applied within four hours of the completion of the application of the flash coat provided the TSC can be maintained free of contamination.*	*Specify the use of a flash TSC if there is a requirement to extend the time-based holding period beyond that specified in Paragraph 5.2.2.*
5.3.2 Validate the use of the flash TSC holding period with a _____(a)_____. *Clean and abrasive blast a representative job area and three bend-test coupons.* *Apply a flash TSC to the representative job area and the three bend coupons.* *Wait the delay period in representative environmental conditions and apply the final TSC thickness.* *Flash TSC and holding period are acceptable if the tensile bond specified in Paragraph 3.2.3, or bend test, or both, are satisfactory.*	*(a) Specify validation method, i.e., with a tensile-bond measurement, bend test, or both.*

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
5.4 Preheating **For flame spraying, preheat the initial starting area to approximately 50°C (120°F) to prevent condensation of moisture in the flame onto the substrate. Validate preheating and non-preheating requirements with a _____(a)_____.**	Specify the preheating requirement for flame spraying. Preheating is not normally required for arc spraying. (a) Specify validation method, i.e., with a tensile-bond measurement, bend test, or both.
5.5 Thermal Spraying **5.5.1 Apply the specified coating thickness (Paragraph 3.2.2) in overlapping passes. The coating tensile-bond strength is greater when the spray passes are kept thin. Laying down an excessively thick spray pass increases the internal stresses in the TSC and decreases the ultimate tensile-bond strength of the total TSC. Confirm the suitability of the crossing-pass thickness with _____(a)_____ measurement.**	(a) Specify validation method, i.e., with a tensile bond measurement, bend test, or both.
5.5.2 For manual spraying: **On non-fixtured components, spray perpendicular crossing passes to minimize thin (below contract-specified thickness) areas.** **On fixtured rotating components, spray perpendicular overlapping passes to obtain the contract-specified thickness as the spray gun is advanced over the rotating component.** **5.5.3 For mechanized spraying, program overlapping or crossing passes, or both, to eliminate thin spots and stay within the coating thickness specification.** **5.5.4 If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following procedure applies:** **(1) Stop spraying.** **(2) Mark off the satisfactorily sprayed area.** **(3) Repair the unsatisfactory TSC (i.e., remove degraded TSC and reestablish the minimum near-white metal finish and anchor-tooth profile depth).** **(4) In the JCR, record the actions taken to resume the job.** **(5) Call the TSC inspector to observe and report the remedial action to the purchaser.**	
5.6 Thermal spraying in low-temperature environments (below freezing). *No moisture or condensation is permissible on the surface during surface preparation and thermal spraying.* *Qualify TSC period with a _____(a)_____.* *Meet the tensile bond and metallographic requirements of the purchasing contract.*	*Include Paragraph 5.6 for thermal spraying in low-temperature environments (below freezing).* *(a) Specify validation method, i.e., with a tensile-bond measurement, bend test, or both.*

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
5.7 TSC Measurement Schedule. **(1) The TSC dry film thickness (DFT) shall be measured using a SSPC-PA 2 Type 2 fixed probe gauge.** **(2) Use a measurement line for flat surfaces. Take the average value of five readings taken in line at 2.5-cm (1.0-in.) intervals. The line measurement measures the peaks and valleys of the TSC.** **(3) Use a measurement spot approximately 10 cm^2 (1.5 $in.^2$) for complex geometries and geometry transitions. Do not measure the peaks and valleys of the TSC.** **(4) Record in the JCR.**	
6. Sealer or Sealer and Topcoat. *The sealer and topcoat shall be applied according to SSPC-PA 1 and the paint manufacturer's recommendations for use of the product with a TSC system.*	*Include this section if a sealer is specified.*
6.1 Apply sealer as specified in Paragraph 3.3.1.	*Include this section if a sealer is specified.*
6.2 Apply topcoats as specified in Paragraph 3.3.2.	*Include this section if a topcoat is specified.*
7. TSC Applicator's Detailed Procedure. **The TSC applicator shall submit the detailed procedures conforming to Section 5 (Surface Preparation), Section 7 (TSC Application), and Section 9 (Sealer or Sealer and Topcoat) of the specification. The procedures shall detail the equipment, application process, in-process quality control, and JCR to be used for the contract work. The information shall include:** **(1) Detailed procedures for surface preparation, thermal spraying, sealing or sealing and topcoating, and the in-process quality control checkpoints.** **(2) Equipment (surface preparation, thermal spraying, sealing or sealing and topcoating, and the in-process quality control) to be used and for which the detailed procedures apply.** **(3) Blasting media, thermal spray feedstock, and sealing or sealing and topcoating materials.** **(4) JRS.** **(5) JCR. See Appendix B.** **(6) Repair defective TSCs per ANSI/AWS C2.18.**	Specify the requirements for the following information as required: safety, thermal spray operator qualification, TSC applicator work performance history, and customer contact references for validation.
8. Contract Pre-Award Evaluation, Demonstration, and Validation. **8.1 Data Requirements.** **The TSC applicator shall submit the detailed information cited in Section 7. This information shall be submitted prior to contract approval and at least ____(a)____ days prior to Contract Pre-Award Evaluation Demonstration and Validation.**	(a) Specify lead time.

The Model Specification **(Bolded text is the model specification.** *Scripted text is optional and if used, should match the format and style used in the final specification.***)**	Instructions/Rationale
8.2 Equipment and Process Demonstration and Validation. **The actual equipment and processes to be used for the contract work shall be demonstrated and validated to produce the specified TSC. This demonstration and validation shall be scheduled _____(a)_____ days after delivery of the data requirements. See Paragraph 8.1.**	(a) Specify lead time.

Appendix B: Model Job Control Method

This Appendix is not a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, but is included for informational purposes only.

Model Job Control Record (JCR) (Add steps specified in the contract if not specified in the model JCR. Delete steps not specified in the contract.)			
TSC Applicator: JCR#: Date:			
TSC Applicator Point of Contact: Tel:			
Customer/Contract #			
Customer POC: Tel:			
Spray Equipment Data: Spray machine mfg.:_____ Model: _____ Feedstock:_____ TSC minimum/maximum thickness, µm (mils):_____min./_____max. Thickness/pass:_____µm (mils) Standoff Distance:_____mm (in.) Other:_____			
DAILY PRODUCTION RECORD DATE:_____ **Work Item/Area**			
	Environmental Requirements		**Initials for Check-Off**
	1—The steel surface temperature shall be at least 3°C (5°F) above the dewpoint.		
Step	**Production Process**		
	Requirement	**In-Process QC Checkpoint**	
	Surface Preparation—NACE No. 2/SSPC-SP 10 with ≥65-µm (2.5-mil) angular profile. (NACE No. 1/SSPC-SP 5 finish required for marine, immersion, and other critical service.)		
1	Degrease to remove oil, salts, and other contamination.	1.1—Dust/dirt: Clear tape pull-off and visual/10x magnification	
		1.2—Oil/grease: solvent evaporation test.	
		1.3—Na and S salts: Potassium ferrocyanide filter paper test.	
2	Validate clean blasting air and media.	2.1—Clean blasting media using the test oil in the appropriate abrasive specification (No oil film or slick. No fines.).	
		2.2—Clean blasting air according to ASTM D 4285 (air discharge on absorbent or nonabsorbent collector).	
3	Blast to specified finish with >64-µm (2.5-mil) angular profile.	3.1—Angular profile depth: Profile tape according to NACE Standard RP0287 or depth-gauge measurement according to ASTM D 4417 and contract sampling schedule.	
4	Clean and dust-free surface.	4.1—Clean and dust-free surface according to visual/10x magnification and the clear-tape pull-off test.	

Step	Requirement	Thermal Spraying	Initials for Check-Off
5	Holding period between completion of surface preparation and completion of thermal spraying.	5.1—Holding periods shall be no more than six hours for steel substrates if there is no flash rusting prior to completion of thermal spraying. See Paragraph 8.2.4.	
		5.2—In low-humidity environments or in enclosed spaces using industrial dehumidification equipment, a holding period > six hours shall be validated using bend coupons, a portable tensile-bond test, or both according to Paragraph 7.3.2.1 (2).	
		5.3—Small and movable parts shall be protected if more than 15 minutes is expected to elapse between surface preparation and the start of thermal spraying or if the part is moved to another location.	
6	TSC Flash Coat	6.1—A 25- to 50-µm (1.0- to 2.0-mil) flash coat of the TSC may be applied within six hours of completing surface preparation to extend the holding period for up to a further four hours beyond the complete application of the flash rust coat.	
		6.2—The final TSC thickness shall be applied within four hours of the completion of the application of the flash coat provided the TSC can be maintained free of contamination.	
7	Preheating	7.1—For flame spraying, the initial starting area shall be preheated to approximately 120°C (250°F) to prevent water in the flame from condensing on the substrate. Preheating and non-preheating equipment shall be validated using a bend test, tensile-bond measurement, or both.	
8	Thermal Spraying	8.1—The specified coating thickness,_____ (insert value from the specification) in overlapping passes. Confirm the suitability of the inter-pass thickness with a bend test, tensile-bond measurement, or both.	
		8.2—If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following process shall be followed: (a) Stop spraying. (b) Mark off the acceptable sprayed area. (c) Call the TSC inspector to observe and evaluate the error, report the deficiency to the purchaser for remedial action, and record the deficiency and actions taken to resume the job.	
9	TSC Measurement Schedule	Measurements shall be taken according to the contract and recorded in the JCR.	
		9.1—The TSC shall be measured in accordance with a SSPC-PA 2 Type 2 gauge.	
		9.2—The average value of five readings for each measurement line or spot shall be determined.	
		9.3—A measurement line shall be used for flat surfaces. The average value of five readings taken in line at 2.5-cm (1.0-in.) intervals shall be determined. The line measurement measures the peaks and valleys of the TSC.	
		9.4—A measurement spot shall be used for complex geometries and geometry transitions. The measurement spot should be approximately 10 cm^2 (1.6 $in.^2$). The spot measurement may not measure the peaks and valleys of the TSC.	

Step	Requirement	Sealing or Sealing and Topcoating	Initials for Check-Off
10	If sealer is specified:	10.1—The seal coats shall be applied as soon as possible after the TSC has been applied and before visible (10x magnification) oxidation of the TSC occurs: < 8 hours for zinc and zinc-alloy TSCs and < 24 hours for aluminum and aluminum alloys.	
		10.2—The seal coat shall be applied according to manufacturer's instructions or the purchasing contract and only to clean dry TSC surfaces.	
11	If topcoat is specified:	11.1—The topcoats shall be applied according to manufacturer's instructions or the purchasing contract.	
Remarks:			
Thermal Sprayer (or QC Inspector) print name:_____ Signature:_____ Date:_____			

Appendix C: Procedure for Calibration of Portable Test Instruments to the ASTM C 633 Test Method

This Appendix is not a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, but is included for informational purposes only.

General. ASTM C 633 is the standard laboratory method for the measurement of the adhesion of TSCs to the substrate and forms the basis of the "literature." ASTM D 4541 is a method for portable tensile measurements and when compared to the C 633 method, gives a means of "calibrating" the portable to the laboratory measurements.

This proposed procedure is based on spraying a steel plate that has holes drilled to accept the ASTM C 633 tensile-bond test specimens, inserting the C 633 tensile specimen 0.65 cm (0.25 in.) above the calibration fixture, preparing the surface, and thermal spraying according to the application standard or contract specifications. Note: This procedure has not been validated experimentally or adopted by any standards-writing organization. It is, however, presented as a logical and simple method to relate D 4541 tensile bonds to the C 633 tensile bonds.

Procedure. Using the calibration fixture similar to Figure C1:

(1) Degrease calibration fixture and the ASTM C 633 and the ASTM D 4541 portable tester tensile-bond test specimens.

(2) Mount the ASTM C 633 tensile specimens about 0.65 cm (0.25 in.) above one face of the holding plate to prevent the thermal spray coating from bridging the holding plate. Use a release agent on the cylindrical surface of the tensile specimen to ease removal after thermal spraying. Use brackets or masking tape to firmly hold the tensile-test specimen in place during the blasting and spraying.

(3) Prepare the surface (angular grit blast) and apply TSC according to contract specifications. Prepare at the same time the JRS is being prepared. Use the same personnel, equipment, materials, and procedures to be used during the production work.

(4) Remove C 633 specimens and measure according to ASTM C 633 method. Designate the average value as C_c.

(5) Use ASTM D 4541 portable tensile-testing instrument and measure the tensile bond on the three locations on the steel plate. Designate the average value as D_c.

(6) The calibration ratio (p) of the portable tensile-instrument measurement to the laboratory tensile measurement is C_c/D_c.

(7) The portable ASTM C 633 equivalent tensile measurement, $P_{C\,633}$, is estimated by Equation (C1):

$$P_{C633} = pD4541_{avg} \quad \text{(C1)}$$

Where

P_{C633} is the D 4541 tensile bond equivalent to the C 633 tensile bond

p is the calibration ratio of the portable-tensile measurement instrument to the laboratory C 633 measurement

$D\,4541_{avg}$ is the average of a set of measurements on a specimen using the ASTM D 4541 tensile testing instrument.

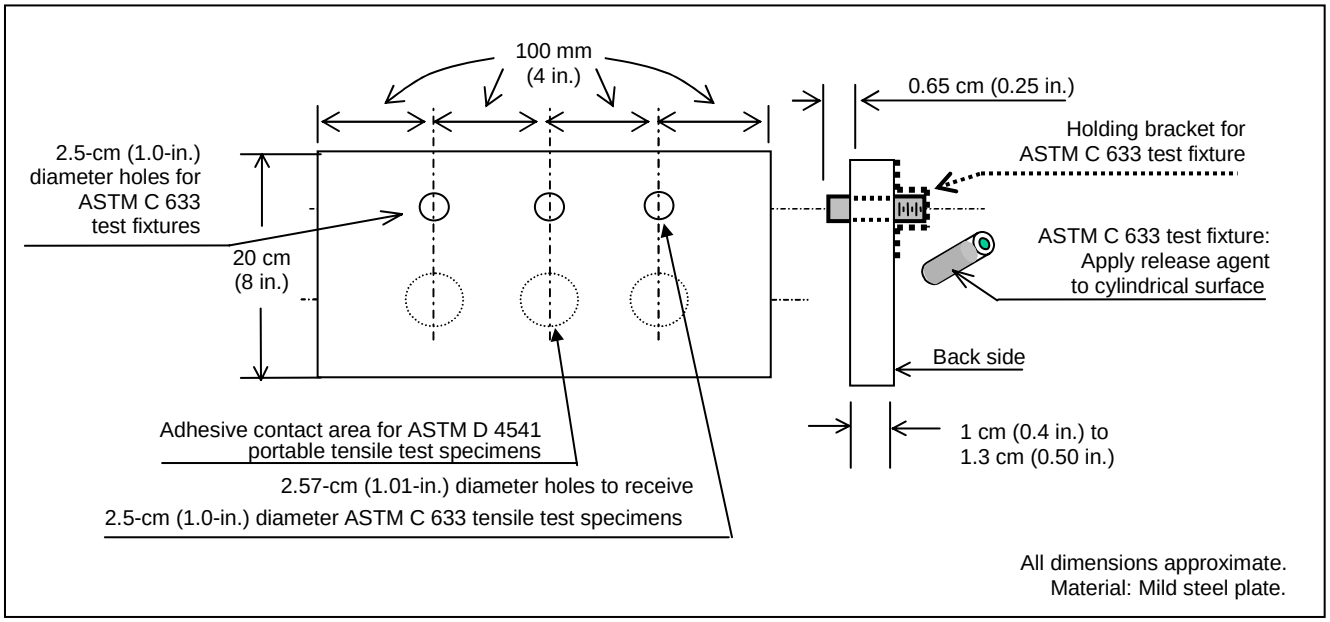


Figure C1: Calibration Fixture

Appendix D: Application Process Method

This Appendix is a part of NACE No. 12/AWS C2.23M/SSPC-CS 23.00, and includes mandatory requirements for use with this standard.

The major production and QC activities are shown in Figure D1. The applicable Section and Quality Control Checkpoint (QCCP) numbers are noted in the lower right-hand corner of each process action.

Section D1: Surface Preparation

Proper surface preparation is a critical and necessary step for successful thermal spray applications.

D1.1 Criteria

The steel substrate shall be prepared to at least a near-white metal finish according to NACE No. 2/SSPC-SP 10. Marine service requires white metal finish according to NACE No. 1/SSPC-SP 5.

Abrasive or centrifugal blast with a sharp angular abrasive to a ≥65-µm (2.5-mil) angular profile so as to mechanically anchor the TSC.

D1.2 Procedure

Surface preparation should be accomplished in one abrasive blast cleaning operation whenever possible. Steel substrates require approximately 0.6 to 0.7 MPa (87 to 100 psi) air-blasting pressure at the nozzle. Air pressures and media size should be reduced and adjusted to preclude damage/distortion to thin-gauge materials. The blasting time on the workpiece should be adjusted to only clean the surface and cut the required anchor-tooth with minimum loss of metal. Blast angle should be as close to perpendicular as possible but in no case greater than ± 30° from the perpendicular to the work surface. Do not overblast; this forces the peaks back into the valleys. Only angular and clean blasting media of suitable mesh size should be used to cut the ≥65-µm (2.5-mil) anchor-tooth profile. The blasting media must be free of debris, excessive fines, hazardous materials, and contamination such as sodium chloride and sulfur salts.

Section D2: New Steel Substrate

D2.1 Degreasing

The substrate shall be degreased according to SSPC-SP 1. Use QCCP #1 to validate absence of oil and grease contamination.

D2.2 Masking

The following shall be masked for protection:

(a) All fit-and-function surfaces.
(b) Overspray-control areas.
(c) Areas not to be thermal sprayed.

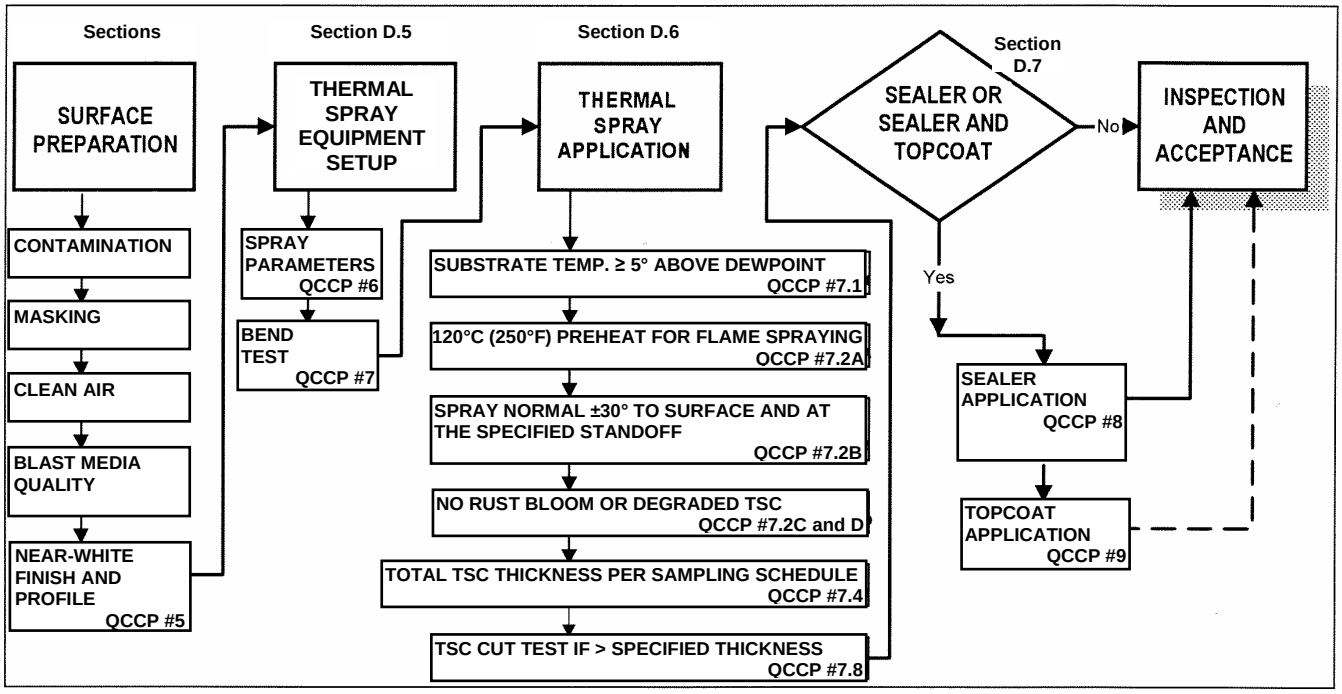


Figure D1: Key Production and Quality Control Checkpoints (QCCPs) for Applying Thermal Spray Coatings

QCCP #1: Oil and Grease

Inspect for the absence of oil and grease contamination by the following:

1.1 Visual inspection during removal of oil/grease contamination. Continue degreasing until all visible signs of contamination are removed.

1.2 Conduct the UV-light test, the qualitative-solvent evaporation test, or the heat test.

(a) Use a UV lamp to confirm the absence of oil or grease contamination.

(b) Conduct a solvent evaporation test by applying several drops or a small splash of a residue-free solvent such as trichloromethane on the areas suspected of oil and grease retention (e.g., pitting and crevice-corrosion areas, depressed areas, especially those collecting contamination, etc.). An evaporation ring forms if oil or grease contamination is present.

(c) Conduct a heat test by using a torch to heat the degreased metal to about 110°C (225°F). Residual oil/grease contamination is drawn to the metal surface and is visually apparent.

1.3 Continue inspection and degreasing until the test is passed.

The fit-and-function areas must be protected from the blast cleaning, thermal spraying, and sealing or sealing and topcoating operations.

Overspray-control areas have complex geometry where overspray cannot be eliminated. Use QCCP #2 to validate masking suitability.

QCCP #2: Masking

2.1 All fit-and-function surfaces and those other surfaces and areas specified by the purchaser not to be abrasive blasted or to be thermal sprayed shall be visually inspected.

2.2 Covers and masking shall be inspected to ensure they are attached securely to survive the blasting and thermal spraying operations.

2.3 Complex geometries (e.g., pipe flanges, intersections of structural beams, and valve manifolds) shall be masked to eliminate or minimize overspray. *Overspray is that TSC applied outside the authorized parameters, primarily the gun-to-substrate standoff distance and spray angle (perpendicular ±30°).*

2.4 Potential overspray surfaces should be protected with clean, metal masks or clean, removable masking materials to prevent overspray from depositing on surfaces not already sprayed to the specified parameters.

D2.3 Blast Equipment

The TSC applicator shall use mechanical (centrifugal wheel) and/or pressure-pot blast-cleaning equipment and procedures. Suction-blasting equipment shall not be used. QCCP #3 shall be used to validate clean and dry air.

QCCP #3: Clean and Dry Air

When pressure-pot blast cleaning is used, the air used for final anchor-tooth blasting and brush blasting or blow-down prior to thermal spraying shall be clean and dry and without moisture and oil. The compressed air shall be checked for oil and water contamination per ASTM D 4285:

3.1 Slightly open a valve downstream from the filter or dryer. Allow the air to vent with a slightly audible flow into an open, dry container for one minute. Any wetting or staining indicates contamination.

3.2 If moisture or contamination is detected, correct any deficiency before going further.

3.3 Repeat step 3.1 above, but place a clean, white cloth over the valve outlet. Any wetting or staining indicates contamination.

D2.4 Surface Finish and Profile

The surface shall be blast cleaned to NACE No. 1/SSPC-SP 5 for marine and immersion service or to at least NACE No. 2/SSPC-SP 10 for other service both with a ≥65-µm (2.5-mil) sharp angular profile. The substrate should be thick enough to preclude damage to the workpiece or deformation from the abrasive blasting. QCCP #4 shall be used to validate clean-blasting media. QCCP #5 shall be used to validate metal finish and profile depth.

Section D3: Contaminated Steel Substrate

Steel contaminated with deicing salts, oil, grease, bird droppings, etc., and corroded and pitted steel requires more intensive surface preparation than new steel. To produce the minimum required near-white metal finish with a ≥65-µm (2.5-mil) profile, the surface preparation schedule should be tailored for the specific steel surfaces to be cleaned. High-pressure water cleaning, heat cleaning, chemical washing (followed by water flushing), steam cleaning, and abrasive-blast cleaning, singly and in combination, may be required to clean contaminated steel.

D3.1 Degreasing

The surface shall be degreased as required according to contract specifications (e.g., hydroblast, steam clean, solvent wash, or detergent wash).

QCCP #4: Clean Blasting Media

Prior to the use of the abrasive-blasting media for final anchor-tooth blasting or brush blasting:

4.1 The blasting media shall be visually inspected for the absence of contamination and debris using 10x magnification.

4.2 Inspection for the absence of oil contamination shall be conducted using the test for oil in the appropriate abrasive specification (no oil film or slick) and/or the following procedure:

(1) Fill a small, clean 100- to 200-mL (4- to 6-oz) bottle half-full of abrasive particles.

(2) Fill the remainder of the bottle with potable water.

(3) Cap and shake the bottle.

(4) Inspect water for oil film/slick. If any oil film/slick is observed, do not use the blasting media.

(5) Clean blasting equipment, especially the pot and hoses, then replace blasting media and retest.

QCCP #5: Near-White Finish and Anchor-Tooth Profile

5.1 Using SSPC-VIS 1, the surface shall be visually inspected for conformance with NACE No. 2/SSPC-SP 10 or NACE No. 1/SSPC-SP 5 if specified in the contract. The clear-cellophane-tape test shall be used to confirm absence of dust as required. The frequency of use of the cellophane tape test shall be determined by the specifier.

5.2 The anchor-tooth profile shall be measured with profile tape (NACE Standard RP0287) or a depth-gauge micrometer. At least one measurement shall be taken every 10 to 20 m^2 (100 to 200 ft^2) or as otherwise specified by the purchaser.

5.3 If the profile is <65 µm (2.5 mils) blasting shall continue until a ≥65-µm (2.5-mil) profile is obtained.

5.4 Information shall be recorded on sketches or drawings or as required by the purchasing contract.

D3.2 Thermal Cleaning

SAFETY AND PROCEDURE PRECAUTION: This procedure shall be used only if there is no danger of an explosion or fire and no degradation of the metal temper. Temperatures shall not exceed 300°C (570°F) on steel alloys.

(1) The contamination shall be baked out or burned off (the dark brown or black surface areas) in an oven or with a rosebud torch. The substrate temperature shall be kept between 250 and 300°C (480 and 570°F) for the time necessary to bake out or burn off the oil and grease contamination.

(2) The substrate area to be thermal sprayed within the next six hours or longer according to Paragraph D4.2 shall be blasted to a minimum near-white metal finish with >65 µm (2.5 mils) anchor-tooth.

(3) Repeat steps (1) and (2) above as required until the thermal spray job is completed.

D3.3 Removal of Soluble Salts:

If required by owner specifications, the surface should be tested for the presence of soluble salts. Methods for testing are described in SSPC-TU 4. The acceptable levels and methods of removal of soluble salts shall be determined by the specifier.

D3.4 Rust Bloom

The thermal spray coating shall be applied within six hours after blast cleaning. If rust bloom (i.e., the visual appearance of rust on the blast-cleaned surface) appears on the blasted surface before thermal spraying, the rust bloom shall be removed and the TSC applicator shall wait 24 hours to observe for any recurrence before spraying. Under very dry conditions, a longer waiting period may be necessary.

D3.4.1 Light Rust Bloom

If there is light rust bloom (light in color and greater than 10% of the surface area), the substrate area that will be thermal sprayed within the next six hours shall be reblasted to achieve the specified level of cleanliness.

D3.4.2 Heavy Rust Bloom

If there is heavy rust bloom (dark brown or black color), other cleaning methods shall be continued (e.g., wet-abrasive, high- and ultra high-pressure water, or thermal cleaning singly or in combination) to remove the contamination.

Section D4: Post-Blasting Substrate Condition and Thermal Spraying Period

D4.1 Steel Surface Temperature and Cleanliness

The steel surface temperature shall be at least 3°C (5°F) above the dewpoint. The surface shall be cleaned to NACE No. 2/SSPC-SP 10 finish as a minimum.

D4.2 Holding Period

(1) The TSC shall always be applied to white metal NACE No. 1/SSPC-SP 5 or near-white metal finish (NACE No. 2/SSPC-SP 10), free of visible and invisible contaminants. It is common practice in field work to apply the TSC during the same work shift as the final blast cleaning is preformed. The logical end point of the holding period is when the surface cleanliness degrades or a change in performance (bend or tensile test) occurs.

(2) As a general guide, however, the time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying shall be no greater than about six hours for steel substrates. In high-humidity and damp environments, shorter holding periods shall be used. If rust bloom or a degraded coating appears at any time while spraying, Paragraph D4.2 (6), shall be strictly observed.

(3) In low-humidity environments or in controlled environments with enclosed structures using industrial dehumidification equipment, it may be possible to retard the oxidation of the steel and hold the near-white metal finish for more than six hours. The TSC applicator, with the concurrence of the purchaser, can validate a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons, tensile-bond coupons, or both.

(4) If specified by the purchasing contract, a flash coat of TSC equal to or greater than 25 µm (1.0 mil) may be applied within six hours of completing the surface preparation to extend the holding period for up to four hours beyond the complete application of the flash coat. The final TSC thickness, however, shall be applied within four hours of the completion of the application of the flash coat. This procedure shall be validated with a tensile-bond measurement, bend test, or both, by spraying a flash coat and waiting the delay period before applying the final coating thickness.

(5) For small and movable parts, if more than 15 minutes is expected to elapse between the surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface should be protected from moisture, contamination, and finger/hand marks. Wrapping with clean print-free paper is normally adequate.

(6) If rust bloom, blistering, or degraded coating appears at any time during the application of the TSC, the following procedure applies:

(a) Stop spraying.
(b) Mark off the satisfactorily sprayed area.
(c) Repair the unsatisfactory TSC (i.e., remove degraded TSC and re-establish the minimum near-white metal finish and anchor-tooth profile depth).
(d) Record the actions taken to resume the job in the JCR.
(e) Call the TSC inspector to observe and report the remedial action to the purchaser.

Section D5: Thermal Equipment Set-Up and Spraying Sequence

D5.1 Thermal Spray Equipment Set-Up

(1) Thermal spray equipment shall be set up, calibrated, and operated according to the manufacturer's instructions

and technical manuals, or the TSC applicator's refinement thereto, and as validated by the JRS.

(2) Spray parameters shall be set for spraying the specified thermal spray material and, at a minimum, be validated with the bend test of QCCP #6.

(3) A copy of the spray parameters shall be attached to the JCR.

QCCP #6: Macro-System Bend Test (Required at beginning of each work shift or crew change)
6.1 The equipment parameter settings shall be in accordance with those used for the validated JRS. 6.2 The successful surface preparation shall be observed, spraying the specified TSC thickness in crossing passes, and performing a bend test of at least one bend coupon at the beginning of each work shift. This is a macro- or overall-systems check. 6.3 If the bend test fails, problems shall be identified and fixed before continuing. 6.4 Results shall be recorded, identification noted, and the bend-test coupons retained in the JCR.

D5.2 Plan the Thermal Spraying Sequence

Thermal spraying should be started as soon as possible after the final anchor-tooth or brush blasting and completed within six hours for steel substrates subject to the temperature to dewpoint and holding-period variations in Section D4.

(1) The surface geometry of the item or area to be sprayed should be inspected. The spraying pass or sequence should be planned according to the following:

(a) Maintain the gun as close to perpendicular as possible and within ±30° from the perpendicular to the substrate.

(b) Use the manufacturer's recommended standoff distance for the air cap installed or the TSC applicator's refinement thereto. See Table D1 for nominal standoff and spray-pass width values.

(2) For complex geometries where overspray cannot be eliminated, an overspray-control area should be established. Clean, metal masks or clean, removable masking materials should be used to prevent overspray from depositing on surfaces not already sprayed to the specified thickness.

Table D1: Flame- and Arc-Spray Standoff Distances and Spray Widths, Nominal

Thermal Spray Method	Perpendicular Standoff, mm (in.)	Spray-Pass Width, mm (in.)	
		Air Cap	
		Regular	Fan
Flame wire	130 to 180 (5 to 7)	20 (0.75)	Not Available
Flame powder	200 to 250 (8 to 10)	50 (2)	75 to 100 (3 to 4)
Arc wire	150 to 200 (6 to 8)	40 (1.5)	75 to 150 (3 to 6)

Section D6: TSC Application

D6.1 Preheating

Preheating the starting area has been common practice in the past and should be continued until proven inconsequential. Preheating the initial 0.1- to 0.2-m^2 (1- to 2-ft^2) starting-spray area prevents water in the flame from condensing on the substrate.

(1) For flame spraying, the initial starting area shall be preheated to approximately 120°C (250°F).

(2) Preheating requirements shall be validated with the JRS and the bend test, tensile test, or both.

D6.2 Startup and Adjustment

Start-up and adjustment of the spray gun shall be made from the workpiece (or surface to be thermal sprayed). In an enclosed space, the spray shall be applied to a scrap-metal sheet. Spray coating shall not be sprayed until it is validated.

D6.3 Specification Thickness

The specified coating thickness shall be applied in several perpendicular overlapping passes. The coating tensile-bond strength is greater when the spray passes are kept thin. Laying down an excessively thick spray pass increases the internal stresses in the TSC and decreases the ultimate tensile-bond strength of the TSC.

(1) For manual spraying, crossing passes shall be used to minimize thin spots in the coating.

(2) For mechanized spraying, overlapping and crossing passes shall be programmed to eliminate thin spots and stay within the coating thickness specification. The auto-

mated spraying parameters and spraying program shall be validated with tensile-bond, metallographic analysis, or both.

(3) Use spray-gun extensions to reach into recessed spaces and areas.

D6.4 Rust Bloom

If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following procedure applies:

(1) Stop spraying.

(2) Mark off the satisfactorily sprayed area.

(3) Repair the unsatisfactory TSC (i.e., remove degraded TSC and reestablish the minimum near-white metal finish and anchor-tooth profile depth).

(4) In the JCR, record the actions taken to resume the job.

(5) Call the TSC inspector to observe and report the remedial action to the purchaser.

D6.5 TSC Requirement

The TSC shall meet the system requirements and acceptance tests cited in Section 6, main body of this standard.

The QCCP #7 shall be used to validate proper TSC application process.

Section D7: Low-Temperature Spraying

Thermal spraying in low-temperature environments, less than 5°C (40°F) must:

(1) Meet the substrate surface temperature and holding period of Section D 4.1 and D 4.2. Moisture condensation on the surface is not permissible during thermal spraying.

(2) Be qualified with a bend test, portable tensile-bond test, or both.

TSCs are mechanically bonded to the substrate. Substrate preheating may be required to improve the TSC tensile bond to the substrate and reduce internal stresses. The preheating requirement, or non-requirement, shall be validated during the preparation of the JCR (see Paragraph D6.1).

Section D8: Sealer or Sealer and Topcoat

D8.1 General

The sealer or sealer and topcoat shall meet the requirements of this standard. Sealers or sealers and topcoats for TSCs shall be applied in accordance with SSPC-PA 1, the paint manufacturer's instructions for sealing or sealing and topcoating the contract-specified TSC, and/or the purchasing contract.

If moisture is present or suspected in the TSC pores, the steel may be heated to 50°C (120°F) to remove the moisture prior to the seal coat application. If possible, the steel from the reverse side of the TSC shall be heated to minimize oxidation and contamination of the TSC prior to sealing.

D8.2 Sealer Application

If applied, the seal coat shall be thin enough to penetrate into the body of the TSC and seal the porosity. Typically, the seal coat is applied at a spreading rate resulting in a theoretical 38-µm (1.5-mil) dry-film thickness.

For shop and field work, sealers should be applied as soon as possible after thermal spraying and preferably within eight hours.

If sealer cannot be applied within eight hours, it shall be verified that the TSC (a) has not been contaminated, using visual inspection and (b) is dust-free using the clear cellophane tape test (ISO 8502-3), before applying the sealer.

QCCP # 8 shall be used to validate proper application.

QCCP #7: TSC Application

7.1 Substrate surface temperature shall be measured/confirmed with a contact pyrometer to be ≥3°C (5°F) above the dewpoint:

(a) Air temperature ___°C (___°F).
(b) Relative Humidity (RH) ___ %.
(c) Dewpoint ____°C (___°F).
(d) Substrate surface temperature ____°C (___°F).
(e) Surface temperature (d) ≥3°C (5°F) above the dewpoint (c): (Yes/No) ____
(f) If Yes ➔ Continue.
(g) If No ➔ STOP. Wait for proper conditions and/or adjust the work-area space temperature and humidity conditions so that the steel temperature is ≥3°C (5°F) above the dewpoint.

7.2 The spraying process shall be observed as specified in Section D6:

(a) Preheat to 120°C (250°F) when flame spraying.
(b) Proper spray-gun adjustment and spraying process (±30° from the perpendicular, thickness/pass, and crossing passes). (See Figure D2.)
(c) No rust bloom on prepared steel during spraying.
(d) No degraded TSC.

7.3 Specified TSC thickness. Proper coating thickness in the contour-transition areas (see Step 7.5) shall be ensured.

7.4 The total TSC thickness shall be measured according to Figure D3 using a SSPC-PA Type 2 gauge:

QCCP #7: TSC Application
(a) One measurement line or spot every 10 to 20 m^2 (100 to 200 ft^2) of applied TSC. (b) Take the average value of five readings for each measurement line or spot. (c) Use a measurement line for flat surfaces. Take the average value of five readings taken in line at 2.5-cm (1.0-in.) intervals. The line measurement will measure the peaks and valleys of the TSC. (d) Use a measurement spot for complex geometries and geometry transitions. The measurement spot should be approximately 10 cm^2 (1.6 $in.^2$). The spot measurement does not measure the peaks and valleys of the TSC. 7.5 The TSC thickness in surface plane changes and attachments (brackets, angles, plates, studs, etc.) welded or permanently attached to the substrate shall be measured. 7.6 If the TSC is too thin, spraying shall continue until the specified thickness range is achieved. 7.7 If the TSC is within the contract specified thickness range, the applicator shall proceed to Step 7.9. 7.8 If the TSC is too thick: (a) Record the areas that are over 150% of the maximum contract-specified thickness in the JCR. (b) Notify the purchaser. If these areas are damaged during shipping. loading/unloading, or erection, they should be repaired in accordance with maintenance repair procedures as outlined in ANSI/AWS C2.18. 7.9 The locations and values of the TSC-thickness measurements shall be recorded in the JCR.

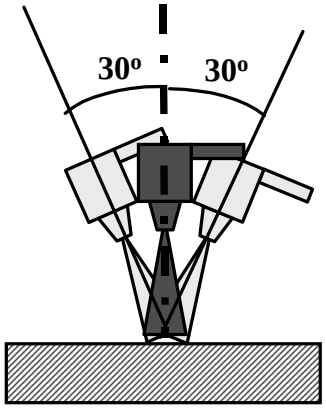


Figure D2: Proper Spray Gun Adjustment

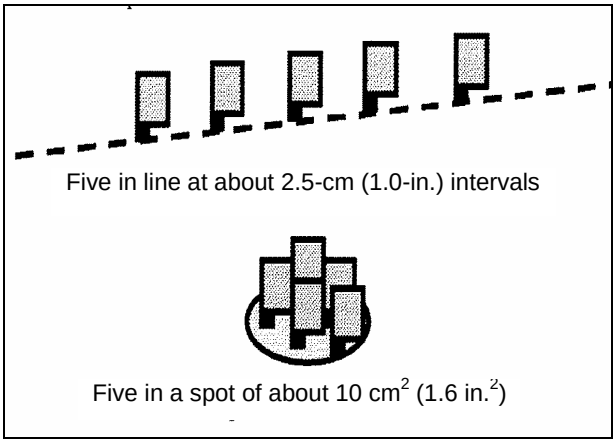


Figure D3: Line and Spot Measurements

QCCP #8: Sealer Application
8.1 During application of the seal coat, complete coverage shall be visually validated. If applied, the seal coat shall be thin enough to penetrate into the body of the TSC and seal the porosity.

D8.3 Topcoat Application

Topcoats shall be applied according to manufacturer's instructions or as specified in the purchasing contract. A paint coating shall not be applied over an unsealed TSC.

Use QCCP #9 to validate proper application.

QCCP #9: Topcoat Application and Thickness
9.1 During application of the topcoat, complete coverage shall be visually validated. 9.2 If required by the contract, the thickness of the topcoat shall be measured according to SSPC-PA 2 using a Type 2 fixed-probe gauge. The measurement may be made on (a) the companion coupon or (b) the sealed TSC if the TSC thickness has been previously measured.

Chapter 2 – Advanced Corrosion

1. *Passivation is the formation of a protective oxide film on the surface reducing its chemical activity and its ability to corrode*.

2. Describe the following factors and how they affect corrosion:

   Oxygen: Oxygen increases the rate of corrosion.
   Temperature: Corrosion usually accelerated with increasing temperature
   Chemical Salts: Increase the rate of corrosion by increasing the efficiency of the electrolyte.
   Humidity (or Wetness): The wetter the environment, the more corrosion is likely to occur.
   Pollutants and Acid Gases: Acid rain, chemical byproducts and chlorides all promote corrosion.

3. Two broad categories of corrosion can be described as:

   General
   Localized

4. ***Galvanic corrosion*** *is an electrochemical action of two dissimilar metals in the presence of an electrolyte and an electron conductive path, which occurs when dissimilar metals come into contact.*

5. ***Cathodic protection*** *is the reduction or elimination of corrosion by making the structure to be protected a cathode by means of an impressed current or attachment to a galvanic anode.*

6. The two primary types of cathodic protection are:

   Impressed Current
   Galvanic (Sacrificial)

7. Impressed current power sources include:

   Rectified commercial power
   Solar cells
   Generators
   Fuel cells
   Wind-powered cells
   Thermoelectric cells

8. ***Cathodic disbondment*** *is the separation of the coating from the surface through hydroxyl (OH–) formation due to increased (made more negative) potential.*

Chapter 4 – Advanced Environmental Testing Instrumentation

1. Electronic hygrometers can be used to determine:

   Relative humidity
   Air temperature and
   Dew-point temperature

2. Advanced environmental testing instruments have the ability to store data that can be transferred to a computer and other devices Transfer methods include:

   USB

IR (infrared)
Bluetooth

Chapter 6 – Centrifugal Cleaning

1. Some general basic centrifugal blast setups include:
   - Tumbling Mill
   - Multi Table
   - Plain Table
   - Swing Table
   - Custom designed systems

2. Centrifugal blasting conveyor systems are commonly used for cleaning of:
   - Plate
   - Rolled structural shapes
   - Large trusses
   - Girders

3. Portable centrifugal blasting systems can be used on:
   - Ship decks, hull sides, and bottoms
   - Storage tanks
   - Concrete floors
   - Highways and bridge decks

4. Generally centrifugal blast systems are composed of the following elements:
   - Centrifugal abrasive throwing wheel
   - The blast cabinet (or enclosure)
   - In fixed systems, some type of material handling system
   - Abrasive recycling system
   - A dust collector and vent-pipe system
   - Abrasives

5. The efficiency of the centrifugal blast wheel(s) depends on several factors.
   - Abrasive operating mix
   - Size of the abrasive
   - Velocity of the abrasive coming off the wheel
   - Quantity and direction of the thrown abrasive
   - Condition of the feed parts

6. Low amperage readings on a centrifugal blasting machine could signify:
   - An abrasive-starved wheel
   - A flooded or choked wheel

7. The functions of the centrifugal blasting machine separator include:
   - To control the sizing of the abrasive mix
   - To remove sand, spent abrasives (fines), rust, dirt, and any other contaminants from the abrasive stream
   - To control abrasive consumption

8. A well-balanced operating mix (***working mix***) of abrasive sizes will:
   - Provide consistency of the finish.
   - Ensure uniform abrasive coverage.

Ensure conditioning of the abrasive for optimum cleaning.
Minimize lowest abrasive and machine part-wear and reduce downtime for maintenance.

9. Some of the inspection concerns during centrifugal blasting include:
   Monitor the dust collector
   Monitor the amperage of the wheel motors /low amperage
   Monitor the handling and loading of the conveyor line for contaminates/ possible discontinuities in the steel.
   Monitor the speed of the line.
   Inspect the steel as it leaves the production line

Chapter 7 – Waterjetting

1. Specifiers must note specific requirements for both of the following per NACE 5/ SSPC SP12:
   Visual definition (WJ-1 to WJ-4)
   Nonvisual definition (NV-1 to NV-3)

2. A general description of Robotic waterjetting includes:
   Attaches using vacuum, cables, or magnets
   Vertical, horizontal or overhead surface
   controlled by single operator
   collects in excess of 95% of the water, removed coatings and rust (waste generated)

3. A typical waterjetting team consists of:
   The nozzle operator
   The pump operator
   Additional operators or workers

4. Waterjetting is effective for removing:
   Surface oil and grease
   Rust
   Concrete (shot-crete) spatter
   Existing coatings
   water-soluble contaminants that cannot otherwise be removed by abrasive blasting
   An underwater unit used to clean barnacles or other micro-organisms for ship hulls or off-shore platform legs.

5. Describe two of the considerations with regards to “back thrust”:
   Causes fatigue
   Should be no more than 1/3 of operators body weight

6. To ensure a safe work place, before commencing the job, the waterjet team should ensure that:
   The work area is properly barricaded
   Electrical equipment protected from the water.
   Electrical connections are not allowed to sit in water.
   All fittings and hoses are in good condition/proper pressure rating
   Nozzles free of obstructions.
   System is flushed clean and air removed
   The dump system and all control systems are operational.
   Proper LOTO provisions/Confined Space Entry Requirements

7. Waterjetting advantages include:
   - Worker safety
   - Worker air quality
   - Respiratory requirements may be less stringent
   - No dust contamination or clean-up
   - Friendly to the environment.
   - Relatively cost efficient
   - It requires less clean up

8. Disadvantages lf waterjetting include:
   - The surface must have a profile (water-jetting leaves no profile)
   - Equipment is very expensive
   - Danger of UHP hose breaking
   - Danger of injection into the skin or serious cuts
   - Collecting and disposing of the contaminated water
   - Proficient operators

Chapter 9 – Safety Awareness

1. Some of the most common hazards associated with specialized application are:
   - Fumes and dust inhalation
   - Electrical Shocks
   - Burns
   - Falling objects
   - Explosions
   - Environmental contamination

2. Thermal Spray safety practices for operators include:
   - Use hoses rated for high pressure.
   - Never clean powder off equipment or clean spray cubicles with compressed air.
   - Do not use compressed air to clean clothing.
   - Do not supply plant compressed air to a breathing apparatus.
   - Reduce compressed air to less than 30 pounds per square inch (PSI) for cleaning purposes

Chapter 12 – Linings and Special Coatings

1. The word "lining" is used to describe a coating that is normally in immersion service.

2. Some come resins used in reinforced linings include:
   - Polyester
   - Epoxy
   - Vinyl Ester

3. The main feature that reinforcing adds to a resin is strength.

4. The negative effect reinforcing has on a resin is the ability of a liquid to travel along the fibers path (wicking) and cause corrosion to the substrate, blisters or delamination of the system.

5. With a lining the normal requirement for surface preparation for new surfaces is cleaning in accordance to SA3/NACE 1/SSPC 5 White Metal Blast Cleaning. You may see the requirement for SA2.5/NACE 2/SSPC 10 Near White Metal Blast Cleaning when performing maintenance work. Water Jetting is only used for lining work when a profile already exists. However you may see a requirement to water wash or jet to remove soluble contaminants and then abrasive blast. In some cases you may find it necessary to abrasive blast a surface then wash it and blast it again, this could be repeated several times, before an acceptable result is achieved.

6. The purpose of antifouling (AF) paints is to either make the hull of the ship so distasteful the larva of the biofouling reject it as a home or they make the hull so slick the larva cannot adhere.

7. The three main types of anti fouling paints are:
   Ablative
   Self Smoothing
   Foul Release

8. Types of Fireproofing Coatings:
   Cementitious - Made of lightweight cement and can be applied several inches thick.
   Intumescent - A substance that swells or bubbles up as a result of heat exposure, thus increasing in volume, and decreasing in density.

9. Flourpolymer coatings are best known for their non-stick feature and also have excellent chemical and high temperature resistance.

10. Powders fall into two broad curing categories:
    Thermoplastic: materials that soften when heated and return to their original hardness when cooled
    Thermosetting: materials that harden when heated and retain their hardness when cooled

11. Powders applied to a heat source pass through four distinct stages:
    1. **The flow stage**, which occurs when the particles of powder begin to flow, but are not fully liquid
    2. **Wetting stage**, which occurs when the particles of powder absorb more heat, fully liquefy, and wet the surface
    3. **Gel stage**, which occurs when the particles of the powder begin to gel, converting into a solid
    4. **Curing stage** allows for further changes to take place, permitting the powder to cure completely

12. Advantages and Disadvantages of plural component airless spray over single piston airless spray system:

Advantages:

Accurate mixing of materials without human element
Ability to spray very thick solvent free materials without thinner
The ability to spray materials with very short pot life

Disadvantages:

Cost is much higher than cost of single piston pump
Higher education requirement for the mechanic
High voltage electricity is required for the heaters
Applicator's job more difficult with multiple hoses

Chapter 13 – Thick Barrier Linings

1. Two major classes of rubber:

   Natural

   - Derived from latex obtained from Hevea trees and is coagulated with acetic or formic acid
   - Unsaturated hydrocarbon known as polyisoprene

   Synthetic

   - any one of a group of manmade elastomers with one or more of the properties of natural rubber

2. Vulcanization is a physicochemical (physical and chemical) change resulting from the cross-linking of the unsaturated hydrocarbon chain of natural rubber (polyisoprene) with sulfur, and the application of heat.

3. Three factors affect the properties of the vulcanizate (vulcanized product):
   - Percentage of sulfur and accelerator used
   - Temperature of the curing process
   - Time of cure

4. Methods used to cure (vulcanize) rubber are:
   - Autoclave (vulcanizer) cure
   - Internal steam cure
   - Atmospheric steam cure (also called exhaust steam cure)
   - Hot-water cure
   - Chemical cure

5. The three categories of Natural Rubber are:
    - Soft
    - Semi-hard
    - Hard

6. A “tri-ply” lining construction is used to form a *sandwich* which is semi-hard, or hard, rubber between two layers of soft rubber.

7. Some various types of synthetic rubber are:
    - Butyl Rubber
    - Neoprene Rubber
    - Nitrile Rubber
    - Chlorobutyl Rubber
    - Hypalon Types

8. Typical surface preparation requirements:
    1. Steel shall be new, full-weight steel, free from structural defects
    2. Steel plate shall be flat with no appreciable warp or buckle
    3. Steel plate should have a minimum thickness and weight as specified
    4. Vessel must be braced to avoid bulging
    5. All welds to be continuous, peened, and ground to remove sharp edges and high spots
    6. Edges and corners should be ground to a minimum radius as specified
    7. All weld spatter should be removed
    8. Blast cleaned to NACE No. 1/SSPC-SP 5 White Metal with a surface profile of 38 to 64 µm (1.5 to 2.5 mils).

9. Some of the causes of failure with rubber linings may be:
    - Incorrect product selected for the intended service.
    - Using rubber after the shelf life has expired.
    - Using rubber lining that was not properly stored. Rubber must be kept cool in storage because, with heat, it can vulcanize on the roll. If this occurs, the material should be discarded.
    - Incorrect application process.
    - Inadequate cure.

10. Three methods for applying polyethylene are:
    - Melting the resin and extruding it onto the surface of the article
    - Heating the work piece and then immersing it into a fluidized bed
    - Flame spraying

Chapter 14 – Advanced Standards and Resources

1. The Standards Engineering Society (SES) describes a standard as:
   A document that applies collectively to codes, specifications, recommended practices, classifications, test methods, and guides, which have been prepared by a standards developing organization or group, and published in accordance with established procedures.

2. Voluntary standards are standards established generally by private-sector bodies and that are available for use by any person or organization, private or government.

   A mandatory standard is a standard that requires compliance because of a government statute or regulation, an organization internal policy, or contractual requirement.

3. Explain the difference between:
   National Standards Body (NSB)
   Used to refer to the one-per-country standardization organization which is that country's membership to International Organization for Standardization (ISO).

   Standards Developing Organization (SDO)
   Refers to the thousands of industry or sector-based standards organizations that develop and publish industry specific standards.

4. Name and define the three NACE standards classifications.
   - Standard Practice (SP)
   - Test Method (TM)
   - Materials Requirement (MR)

Chapter 15 – Coating Concrete

1. Some of the properties of Concrete are;
   - Extremely durable.
   - Inorganic.
   - Hard.
   - Has good compressive strength.
   - Improves with age.

2. Concrete cures by a process called hydration

3. Poured concrete can be affected by:
   Ambient conditions: Hot weather causes concrete to cure more rapidly than otherwise, resulting in a greater possibility for voids, and a dusty, low-strength surface. Applying a curing compound can help mitigate the effects of these

conditions. Many entities require a wet burlap curing blanket to be used over freshly placed concrete to prevent this type of "drying out".
Vibration: This is done to remove air pockets, and can cause the heavy aggregate to sink to the bottom of the form. This results in a weak, sandy surface, creating a fragile layer of sand and cement known as laitance. This condition can occur both at the upper surface and at the concrete/form surface or interface

4. Guniting is the process of spraying or slinging shotcrete onto a surface as a coating to restore concrete to its original grade.

5. Concrete may be coated for several reasons including:
    - Decoration
    - Waterproofing
    - enhancing chemical resistance
    - protection from freeze-thaw cycles
    - protection of reinforcing steel
    - decontamination
    - surface sealer
    - protection against abrasion and erosion
    - color coding
    - protecting purity of water or other products contained
    - improving and simplifying cleaning
    - skid resistance

6. Describe the difference between laitance an efflorecences.
    - **Laitance** is a weak surface layer of water-rich cement mixture on the surface of fresh concrete caused by the upward movement of water
    - **Efflorescence** is caused by moisture passing through the concrete and carrying soluble concrete salts with it to the surface. The salts react with carbon dioxide in the atmosphere creating a fluffy white crystalline deposit on the surface.

7. Surface preparation is generally performed on concrete by:
    - Abrasive blast cleaning
    - Hand and power tool cleaning
    - High-pressure water-jetting or blasting
    - Acid etching
    - Stoning
    - Centrifugal blasting
    - Scarifying

8. NACE No. 6/SSPC-SP 13, Joint Surface Preparation Standard for Surface Preparation of Concrete

9. The advantages of waterjetting and wet abrasive blasting on concrete include:
    - Fast cutting of the surface
    - Washing dust away
    - Reducing abrasive and concrete particles in air

10. **Sacking** consists of scrubbing a mixture of cement mortar over the concrete surface using a cement sack, gunny sack, or sponge rubber float.
    Stoning is similar to sacking, except that a carborundum brick, or other appropriate abrasive block, is used to smooth the surface of the concrete.

11. Several generic types of coatings may be used over concrete including:
    - Bituminous cutbacks
    - Chlorinated rubber
    - Vinyl
    - Epoxy
    - Novalac epoxy
    - Elastomeric polyurethane
    - Sheet materials (e.g., rubber)
    - Glass-fiber-reinforced plastics
    - Furan resins
12. Tests for the presence of moisture in concrete include:
    - ASTM D 4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
    - ASTM F 1869, Calcium Chloride Test
    - Electronic Testing: Concrete Moisture Meter

Chapter 16 – Test Instruments for Coating Concrete

1. **ASTM D 4263, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method**
   A segment of a 1.0 mm (4.0 mil) thick, clear polyethylene sheet approximately 457 x 457 mm (18 x 18 in.) is taped over the concrete to be tested so that the concrete is tightly sealed from the atmosphere and sunlight. The test patch is allowed to remain a minimum of 16 hours.

2. International Concrete Repair Institute (ICRI) produces a set of comparator plates for various surfaces of prepared concrete

3. DFT of coating on concrete can be measured by:
    - estimated from WFT
    - estimated from quantity of coating used
    - verified by a paint inspection gauge (Tooke)
    - determined by a modified gauge based on ultrasound

4. List Standards that may be used for dry film measurement of coatings over concrete.
    - ASTM-D6132-97 Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Over Concrete Using an Ultrasonic Gage
    - SSPC - PA 9 - Measurement of Dry Coating Thickness on Cementitious Substrates

5. Describe the proper safe accurate operating procedure for a low voltage holiday detector.
    - Ground cable is attached directly to substrate
    - Sponge saturated with a solution of tap water/wetting agent
    - Maximum rate of 30 cm/s (1 linear ft/s) double stroke
    - Used on coatings up to 500 µm (20 mils)
    - May be used on concrete.

6. What are some of the errors that may occur while using a High Voltage DC Holiday detector?
    - Failure to keep the probe in contact with the surface and
    - Moving electrode too fast or slow across surface.
    - low battery or bad/missing fuse
    - Continuous alarm - damp surface or moving the probe to fast
    - No alarm - too low voltage/sensitivity or bad ground
    - No spark at the tip caused by bad lead or connection

Chapter 18 - **Pipeline Mainline and Field Joint Coatings**

1. Construction materials may include, but not be limited to:
    Steel
    Aluminum
    Stainless
    Plastic.

2. The majority of the pipe (mainline) will have been coated at a coatings facility or plant and shipped to the site.

3. Typical plant-applied or mainline coatings include:
    2-Layer PE
    3-Layer PE
    Fusion Bonded Epoxy
    Tapes
    Coal Tar Enamel
    Asphalt
    Insulated
    Concrete

4. Polyethelene (PE) can be extruded by:
   - Side extrusion for large diameter pipe
   - Crosshead extrusion

5. Common characteristics of FBE include:
   - Typically green or red and looks like a “painted” finish
   - May be a single layer or a two-layer “dual-powder”
   - DFT from 250 and 500 microns (10 to 20 mils)

6. The FBE application process includes:
   - Preheating the pipe
   - Grit or shot blast the area to NACE #2/ SSPC-SP10
   - Optional – pre-treat the area with an acid bath.
   - Heat the pipe to the specified temperature.
   - Apply the FBE coating
   - Curing the FBE coating application.
   - Quench the coating in a fresh water bath.
   - Stencil

7. The advantages of coal tar enamel pipeline coatings include:
   - Ease of application
   - Long life in some environments

8. The disadvantages of coal tar enamel pipeline coatings include:
   - Subject to corrosion and damage from soil stress
   - Environmental and exposure concerns
   - Use of coal tar is regulated in some locations

9. The General application process for coal tar enamel includes:
   - Prime the pipe
   - Apply coal tar enamel dope
   - Wrap the application with glass fiber mat
   - Apply a second layer of CTE dope
   - Wrap the application with a second layer of glass fiber mat
   - Apply an outer wrap of coal-tar impregnated glass fiber felt
   - Cool the application

10. Concrete coating characteristics include:
    - Used in conjunction with other coating such as FBE
    - Used to reduce buoyancy so pipe will sink
    - Can be applied in many thicknesses
    - Can be applied to any diameter of pipe

11. Pipeline coatings field joints include:
    - Heat Shrink Sleeves
    - Insulation Half Shells
    - Field Foam
    - Liquid Epoxies
    - Cold Applied Tapes
    - Hot Applied Tapes
    - FBE Field Joints
    - Petrolatum (Wax) Tapes

12. Non-destructive tests for heat shrink sleeves includes:
    - Visual inspection
    - Physical inspection
    - Holiday Detection

13. Destructive tests for heat shrink sleeves includes:
    - Holiday Detection (if the voltage set too high)
    - Peel Test. A 25 mm (1") wide strip cut, pulled from the pipe

14. The following materials can be used to repair FBE:
    - Epoxy FBE melt sticks
    - Liquid epoxy
    - Repair patches
    - Heat shrink sleeves

Chapter 21 - Surface preparation, Coating and Inspection of Special Substrates

1. Describe common reasons that wood might be painted
    - Decoration
    - Protection
    - Sealing
    - Stabilization
    - Preservation
    - Flame retardance

2. Non-ferrous substrates include:
    - Stainless steel
    - Nickel
    - Copper/nickel alloys
    - Aluminum
    - Aluminum bronzes
    - Copper
    - Bronzes
    - Brass
    - Tin
    - Cadmium
    - Lead
    - Magnesium
    - Zinc (includes hot-dipped galvanizing and thermal spray)

3. Special substrates that have tightly adherent oxide films include:
    - stainless steel
    - Nickel
    - Tin
    - cadmium

Chapter 22 - Maintenance Coating Operations

1. Maintenance coating operations are defined as ***applying coatings over a substrate that has been installed in its final environment and has been placed in service***.

2. Life cycle of a coating system can be affected by :
    - The steel in question
    - Costs
    - The service atmosphere
    - Product
    - Maintenance

3. When determining the coating system life cycle, the following should be considered:
    - The particular coating system to be used
    - The initial cost
    - Time until first maintenance coating will be applied
    - Maintenance cost during the life of the coating system
    - The length of time the product will last
    - The maintenance cost per year
    - The cost over the life of the system

4. Maintenance coating selection process should take the following into consideration:
    - Compatible with the existing coating system
    - Condition of existing coating
    - Limitations on surface preparation
    - Manufacturers recommendation

5. With regards to maintenance coatings all parties should agree on:
    - Spot repair requirements
    - Feathering
    - Appearance of repaired areas

6. **Feathering** is performed at the repaired area by working the edges of the repaired area back, to achieve a fairly smooth transition from the repair area to the sound coating.

7. If a maintenance coating to be applied is incompatible with the existing coating system, ***curling*** may occur.

8. Some service situations in which permeation may occur include:
    - Sour crude storage tanks
    - Cooling towers
    - Fertilizer plants

Chapter 23 – Non Liquid Coatings

1. Hot-dip galvanizing is the process of coating iron or steel with a thin zinc layer, by passing the steel through a molten bath of zinc at a temperature of around 820- 860 °F (460 °C).

2. The usual galvanized coating consists of three distinct iron-zinc compounds:
    - Gamma 75% zinc and 25% iron
    - Delta 90% zinc and 10% iron
    - Zeta 94% zinc and 6% iron
    - Eta (Outer layer) 100% zinc (not considered separate layer)

3. A few safety issues the inspector should know when working around hot dip galvanizing are:
    - Hot-dipped articles stay hot and to make sure the article is cool before touching it
    - Molten metal can splash out of the kettle and travel some distance
    - Nascent hydrogen may burn off in the air above the

4. List the several major stages of the hot-dip process:
    - Surface preparation
    - Fluxing
    - Dipping
    - Post treatments
    - Inspection

5. Explain the purpose of both caustic cleaning and acid pickling.
    - Caustic cleaning – the steel is immersed in caustic solution to remove the dirt, oil, and grease from the surface of the steel
    - Pickling – The process where the item being prepared is immersed in a tank filled with either hydrochloric or sulfuric acid, which removes oxides and mill scale

6. The galvanizing kettle, is typically operated at a temperature ranging from 820-860 F (438-460 C).

7. Name some of the post treatments that may be performed and why.
    - Reduction of coating thickness by reducing the amount of molten metal adhering to the article as it leaves the bath. This may be done by rolling, wiping, centrifuging, or air blasting. These operations must be done while the coating is still molten. Improvement of the properties or the appearance of the coating may be accomplished by such treatments as chromating, phosphating, light rolling and roller leveling
    - Change in the properties of the coating. Hot-dipped zinc coatings are sometimes annealed to convert the whole of the coating into an alloy. Aluminum coatings intended for heat resistance may be converted into an alloy in the same way. Aluminum can be anodized and dyed attractive colors.

8. List some of the common problems which may be noted during the visual inspections of hot dip galvanized items.
    - Articles in Contact
    - Rough Coatings
    - Excess Aluminum
    - Dross Protrusion
    - Lumpiness and Runs
    - Uneven Drainage
    - Flux Inclusions
    - Ash Inclusions
    - Dull-Gray Galvanized Coating
    - Rust Stains
    - Wet Storage Stain

9. Faying Surfaces
   Surfaces that depend on friction to hold the structural elements in place should not be hot-dip galvanized, because this treatment greatly reduces the possible coefficient of friction between the surfaces.

10. What are the different methods of thermal spray application?
    - Flame Spraying
    - Arc Spraying
    - Plasma Spraying
    - High-Velocity Oxyfuel

Chapter 24 – Coatings Survey

1. What is the definition of a Coating Survey?
   A Coating Survey is a task performed in an organized, rational manner on assets (bridge, oil rig, chemical plant, refinery, paper mill etc) that have been previously painted/coated to gather information on the performance of the installed protective coatings system.

2. List some of the primary reasons surveys are performed.
    - Aid in planning future maintenance
    - Work prioritization
    - Budgetary purposes
    - Aid in determining asset's value
    - Legal compliance

3. Outline step in the process for performing a simple coating survey:

- Have a clear understanding of the scope
- Gather the team
- Develop a survey plan
- Review required standards for tests
- Agree on format
- Delegate various tasks to team members if necessary
- Evaluate the existing coating
- Gather additional information per the survey plan
- Summarizing the data and ensure that they are accurate, factual and correspond to reference/appropriate standards
- Preparing plans for performing the maintenance work required,
- Prepare reports/ input data in database
- Submit final survey reports

4. List individuals who may be qualified to perform coating surveys.
    - NACE Certified Offshore Corrosion/Coatings Assessment Training (OCAT) or Shipboard Corrosion/Coatings Assessment Training (SCAT) Technician (most qualified)
    - Certified NACE Coating Specialist
    - NACE-Certified Coating Inspector—Level 3
    - Coating inspector, not Level 3 but qualified by field experience
    - Coating manufacturer's technical representative with adequate field experience
    - Maintenance Engineer with extensive knowledge of the plant or facility

Chapter 25 – Specialized Tests and Test Equipment

1. Cathodic disbondment tests are accelerated procedures to determine the comparative degree to which the tested coating may be loosened from the substrate, or may develop holidays as a result of the action of normal soil potentials and/or impressed current cathodic protection.

2. List some of the specialized test or equipment that may be encountered by the coating inspector, particularly if involved in the investigation of coating failures.
    - Atomic Absorption/Emission (AA/AE) and Induction Coupled Plasma (ICP) Spectrophotometers
    - Gas Liquid Chromatographs (GLC)
    - Infrared Spectrophotometers (IR and FTIR, and FTIR-ATR)
    - Differential Scanning Calorimeters (DSC)

3. What information should be included when providing a sample for the laboratory?
    - The identity of the materials to be analyzed.

- The inspector should ensure that the samples are properly packed and labeled. A chain-of-custody form should accompany the samples. A copy of this should be retained by the inspector.
- The type of analysis required.
  For example, leachable lead in spent abrasive; Type and concentration of retained solvents in coating chips; Generic identification of coating type.
- Expected concentrations or concentrations of interest.
- For example, lead in paint is of interest in parts per million, but in potable water this changes to parts per billion. This enables the lab technician to select the best instrument for the job.

Chapter 26 – Coating Types, Failure Modes and Inspection Criteria

1. What are the two categories of curing and their definitions?
   - Non-convertible - no chemical change during the cure cycle
   - Convertible - some chemical change during the cure cycle

2. List some examples of non convertible coatings.
   - Chlorinated Rubber
   - Vinyl Coatings
   - Acrylic Coatings
   - Bituminous Coatings

3. What is a polymerization cured coating?
   Coatings that cure through a chemical reaction

4. List some examples of convertible cured coatings?
   - Alkyds
   - Epoxy Coatings
   - Polyester/Vinyl Ester Coatings
   - Polyurethane
   - Polyureas
   - Silicone Coatings
   - Inorganic Zinc

5. What is the cause of chalking in an epoxy coating?
   - Caused by exposure to UV (sunlight) or other radiation.

6. When using a solvent borne inorganic zinc, what would be one common reasons for a failure to cure?

Low humidity. These coatings cure by solvent evaporation and chemical reaction by absorption of moisture from the surrounding atmosphere.

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Report of NACE Technical Unit Committee T—6D* on Application and Use of Coatings for Atmospheric Service. Prepared by Task Group T-6D-12** on Industrial Maintenance Painting Terminology.

Glossary of Terms used in Maintenance Painting

This glossary is a compilation of terms commonly used in the maintenance painting field, with generally accepted definitions of those terms. Although many of the terms used are generally understood, some are interpreted in several different ways: others are not commonly used because of lack of clear definitions. The purpose of this glossary is to eliminate misunderstanding resulting from conflicting interpretations of these terms and to improve communications between users, applicators, and manufacturers of industrial maintenance coatings.

The asterisks preceding some of the words in this glossary indicate the definition varies from the definition of the word as given by the Standard Definitions and Terminology Subcommittee of the NACE Publication Committee, published on pages 79-80 of this issue.

A

ASTM Cups—standard laboratory test cups for measuring viscosity.

abrasion resistance—resistance to mechanical wear.

abrasive *(see NACE Task Group T-6G-1k Report on "Surface Preparation Abrasives for Industrial Maintenance Painting"[1])*—the agent used for abrasive blast cleaning, for example, sand, grit, etc.

absorption—process of soaking up, or assimilation of one substance by another.

accelerator—catalyst; a material which accelerates the hardening of certain coatings.

acetone—dimethyl ketone: solvent.

acid number—a numerical index of free acid in an oil or resin.

acoustic paint—paint which absorbs or deadens sound.

acrylic resin—a clear resin polymerized from acrylic acid and methacrylic acid.

activator—catalyst or curing agent.

adaptors—connectors for joining parts of different sizes.

adduct curing agent—a curing agent combined with a portion of the resin.

adhesion—bonding strength; the attraction of a coating to the substrate.

adsorption—process of attraction to a sur face attachment, the retention of foreign molecules on the surface of a substance.

agglomeration—random attachment of single units to form groups; formation of masses of pigments, not dispersed.

aging—remaining undisturbed.

agitator—stirrer: mixer.

air adjusting valve—spray gun valve con trolling input air.

air bubble—dry bubble in paint film caused by entrapped air.

air cap *(or air nozzle)*—perforated housing for atomizing air at head of spray gun.

air drying—dries by oxidation or evaporative drying by simple exposure to air without heat or catalyst.

air entraining agents—natural wood resins, fats, inorganic materials, sulfonated compounds, and oils for air entrapment in concrete up to 10%.

air entrapment—inclusion of air bubbles in paint film.

air hose—hose of air supply quality, usually red.

airless spraying—spraying without atomizing air, using hydraulic pressure.

airjet *(sandblasting)*—a type of sand blasting gun in which the abrasive is conveyed to the gun by partial vacuum.

air manifold *(pig)*—common air supply for several lines.

air transformer—device for controlled reduction in air pressure.

air valve—control valve in air line system.

air volume—quantity of air in cubic feet (usually per minute) at normal (atmospheric) pressure.

alcohol—a flammable solvent, miscible with water: alcohols commonly used in painting are ethyl alcohol (ethanol) and methyl alcohol (methanol, wood alcohol)

aldehydes—chemical compounds containing R-CHO grouping.

aliphatic hydrocarbons—"straight chain" solvents of low solvent power, derived from petroleum.

alkali—caustic, inorganic compounds which release hydroxyl groups in aqueous media.

alkyd resins—resins prepared by reacting alcohols and acids.

alligatoring—surface imperfections of paint having the appearance of alligator hide.

allyl resins—resins prepared from allyl alcohol.

ambient temperature—room temperature or temperature of surroundings.

American gallon—231 cubic inches.

amides—compounds containing oxygen and amino (NH_2) groupings.

amine adduct—amine curing agent combined with a portion of the resin.

* C.W. Sisler, Monsanto Company, St. Louis, MO, chairman.

** P.E. Weaver, Dow Chemical Company, Houston, TX, chairman.

amines—organic substituted ammonia; organic compounds having an NH_2 group.

amino resins—those containing reactive NH_2 groups.

amyl phenol resins—particular group of organic film formers. See phenolic resins.

anchor pattern—profile, surface roughness.

angle blasting—blast cleaning at angles less than 90°.

angle or degree *(airless spray cap)*—orifice angle, controls width of spray pattern angle.

anhydride—compound not containing water.

anhydrous—dry; free of water in any form.

***anion**—negatively charged ion.

annular orifice—circular opening.

***anode**—the electrode at which corrosion (oxidation) occurs .

applicator—one who applies; tool for applying .

arcing—swinging spray gun away from perpendicular.

argillaceous—clay containing.

aromatic hydrocarbons—ring compounds; strong solvents.

asphalt—residue from distilling petroleum also a natural complex hydrocarbon find in Trinidad, the United States, and else where.

asphalt cut back—asphalt plus thinner, asphalt solution; asphalt coating formed by dissolving asphalt.

asphalt emulsion—asphalt dispersion, not a solution; a water emulsion of asphalt.

asphalt impregnated—containing absorbed asphalt.

atomize—break stream into small particles.

Aurand Scaler—proprietary cleaning tool using cutter wheel bundles.

B

baking finish—finish requiring heat cure.

banding—identifying with strips of tape.

barrier—shielding or blocking device.

base—substrate.

binder—resin, film former vehicle.

bitumen—product of asphalt or coal tar origin.

bituminous coating—coal tar or asphalt based coating.

blast angle—angle of nozzle with reference to surface, also angle of particle propelled from wheel with reference to surface.

blast cleaning—cleaning with propelled abrasives.

bleaching—removing color.

bleeder gun—a spray gun with no air valve; trigger controls fluid flow only.

bleeding—surface flotation of color from under coats.

blistering—bubbling in dry or partially dry paint film.

block coat *(barrier coat or transition primer)*—tie coat *(adhesive)* between non-compatible paints.

blooming—whitening; moisture; blush; blushing.

blow-back *(spray term)*—rebound.

blushing—whitening and loss of gloss due to moisture blooming.

body—viscosity; middle or under *(coat)*.

boilers *(solvent)*—solvents of particular evaporation rate.

Bonderizing—a five-step proprietary custom process for phosphatizing

bonding—adhesion.

boomerang *(Mikrotest Gauge)*—a single magnet Proprietary direct reading, dry film thickness gauge.

bounce-back—spray rebound.

boxing—mixing by pouring from one container to another.

bridging—forming a skin over a depression.

bright blast—white blast.

brittleness—degree of resistance to cracking or breaking by bending.

bronze tools—non-sparking tools.

bronzing—formation of metallic sheen on a paint film.

brushability—ease of brushing.

brush-off blast—see NACE No. 4 in this alphabetical listing.

bubbling—a term used to describe the appearance of bubbles on the surface while a coating is being applied.

bulking value—volume per unit weight, usually expressed as gallons per pound.

C

caking—hard settling of pigment from paint.

calcareous—lime containing.

calcimine—pigment used in white wash.

casein paint—water thinned paint with vehicle derived from milk.

catalyst—accelerator; curing agent, promoter.

cat-eye—hole or holiday shaped like a cat's eye; cratering.

***cathode**—the electrode at which corrosion (oxidation) usually does not occur.

***cathodic protection**—corrosion prevention by sacrificial anodes or impressed current.

***cation**—positively charged ion.

***cavitation**—undercutting, crevice forming may be caused by fluids at high velocities and by flashing from liquid to gaseous state.

cellulose resins—those prepared from cellulose derivatives.

cement finishes—coatings containing Portland cement.

centipoise—a metric unit of viscosity.

centrifuge—device for separating solids from liquids by centrifugal action.

***chalking**—powdering of surface.

champagne finish (effervesence)—rapid escape of solvent visible by bubbling.

check—shallow crack of short length.

checking—formation of checks.

chipping—(1) cleaning steel using special hammers. (2) type of paint failure.

chlorinated rubber—a particular film former used as a binder, made by chlorinating natural rubber.

cleaner—(1) detergent, alkali, acid or other cleaning material; usually water or steam borne. (2) solvent for cleaning paint equipment.

clean surface—one free of contamination.

coal tar—black residue remaining after coal is distilled.

coal tar epoxy paint—paint in which binder or vehicle is combination of coal tar with epoxy resin.

coal tar urethane paint—paint in which binder or vehicle is combi-

nation of coal tar with polyurethane resin.

coatings—surface coverings; paints: barriers.

coat of paint—one layer of dry paint, resulting from a single wet application.

cobwebbing—premature drying causing a spider web effect.

cohesion—property of holding self together.

cold-checking—checking caused by low temperature.

cold-cracking—cracking occuring at low temperature.

color dynamics—scientific use of action colors.

color-fast—non-fading.

color retention—ability to retain original color.

commercial blast—*see NACE No. 3 in this alphabetical listing.*

compatibility—ability to mix with or adhere properly to other components.

composition—analysis: makeup.

continuity—degree of being intact or pore free .

contrast ratio—the coefficient of reflection of the black surface area divided by the coefficient of reflection of the white area.

converter—that which causes change to different state catalyst: curing agent promoter.

copolymers—large molecules resulting by simultaneous polymerization of different monomers.

copper sulfate test *(for mill scale)*—copper color indicates absence of mill scale when steel swabbed with 5% to 10% solution .

***corrosion**—decay: oxidation; deterioration due to interaction with environment: eaten away by degrees.

***corrosion fatigue**—loss of strength caused by corrosion.

coumarone—indene resins, particular type of organic binder or resin, coal tar resins.

coverage—milage, usually in square feet per gallon for a given dry film thickness.

cracking—splitting: disintegration of paint by breaks through film.

cratering—formation of holes or deep depressions in paint film.

crawling—shrinking of paint to form uneven surface.

crazing—development of nonuniform surface appearance of myriad tiny scales or cracks.

creepage—see crawling.

cross-linking—a particular method by which chemicals unite to form films.

cross-spray—spraying first in one direction and second at right angles.

crystalline structure—a structure in which components have a regular pattern of planes.

curing—setting up; hardening.

curing agent—hardener; promoter.

curtaining—sagging.

curtains—sags having a draped effect.

cycling *(of pump)*—interval between strokes.

D

damp—wet not dry.

deadman valve—shut-off valve at blast nozzle, operated by remote control.

decorative painting—architectural painting; aesthetical painting.

degreaser—chemical solution (compound) for grease removal.

delamination—separation of layers.

density—weight per unit volume.

detergent—cleaning agent.

deterioration—decay.

dew point—temperature at which moisture condenses.

diluent—a liquid which lowers viscosity and increases the bulk but is not necessarily a solvent for the solid ingredients: a thinner.

discoloration—color change.

dispersion—suspension of one component in another.

distensibility—ability to be stretched.

distillation—purification or separation by volatilizing and condensing.

doctor blade—knife applicator.

dolomite—carbonate of calcium and magnesium.

double regulation—regulation of both pot and gun air pressure.

drier—chemical which promotes oxidation or drying of paint.

drift *(overspray)*—sprayloss.

drop *(scaffold)*—one vertical descent of the scaffold.

drop cloth—protective cover.

dry spray—overspray or bounce back, sand finish due to spray particle being partially dried before reaching the surface.

drying oil—an oil which hardens in air.

drying time—time interval between application and final cure.

dry to handle—time interval between application and ability to pick up without damage .

dry to recoat—time interval between application and ability to receive next coat satisfactorily.

dry to touch—time interval between application and tack—free time.

dulling—loss of gloss or sheen.

E

edging—striping.

efflorescence—deposit of soluble white salts on surface of brick and other masonry.

eggshell—semi-gloss, dull.

elasticity—degree of recovery from stretching.

Elcometer—a two-prong proprietary magnetic direct reading dry film thickness gauge.

***electrolysis**—decomposition by means of an electrical current.

***electrolyte**—a substance which disassociates into ions when in solution or a fused state and which will then conduct an electric current. Sodium chloride and sulfuric acid are common examples.

electrostatic spray—spraying in which electric charge attracts paint to surface.

elongation—stretch.

emulsion paint—water base paint with an emulsified resin vehicle.

enamel—pigmented varnish; any hard, glossy coating.

endothermic—a change or process which takes place with absorption of heat.

epoxy resins—film formers usually made from bisphenol and epichlorohydrin.

epoxy amine—amine cured epoxy resin.

epoxy adduct—epoxy resin having all of the required amine incorpo-

rated by requiring additional epoxy resin for curing.

epoxy ester—epoxy modified oil; single package epoxy.

erosion—wearing away of paint films; heavy chalking tends to accelerate erosion

ester—reaction product of alcohol and acid, an organic salt.

estimate—compute, calculated cost of a job.

etch—surface attack by chemical means.

evaporation rate—rate of solvent release.

evaporation rate, final—time interval for complete evaporation of all solvents.

evaporation rate, initial—time interval during which low boiling solvent evaporates completely.

exothermic—a change or process in which heat is given off.

explosion—cratering from release of solvent after surface is dry: also see blistering.

explosive limits—a range of the ratio of solvent vapor to air in which the mixture will explode if ignited. Below the lower or above the higher explosive limit the mixture is too lean or too rich to explode. The critical ratio runs from about one to seven percent of solvent vapor by volume at atmospheric pressure.

extender—filler; cheapener.

extension gun—pole gun.

external mix—spray equipment in which fluid and air join outside of aircap.

F

FDA—see Food & Drug Administration.

fadeometer—device for measuring color retention or fade resistance.

fading—reduction in brightness of color.

fallout *(spray)*—overspray.

false body—thixotropic.

fanning *(spray gun technique)*—arcing.

fan pattern—geometry of spray pattern.

fast drying—dry for recoat in less than two hours, quick hardening paint.

fat paint—too much oil.

fatty acid—a component of certain drying oils, vegetable oil derivative feather edge—tapered edge.

feathering—(1) flickering a gun at the end of each stroke (2) tapering edge.

federal specifications—government specifications for formulations, raw material components, or performance.

ferrous—iron containing.

field painting—painting at the job site.

filler—extender; bulking agent; inert pigment.

film build—dry thickness characteristics per coat.

film former—a substance which forms a skin or membrane when dried from a liquid state.

film integrity—degree of continuity of film.

film thickness gauge—device for measuring film thickness above substrate: dry or wet film thickness gauges are available.

filter—strainer; purifier.

fineness of grind—measure of particle size or roughness of liquid paint, degree of dispersion of pigment in the binder.

fingers *(airless)*—broken spray pattern; fingerlike.

fire retardant paint—a paint which will delay flaming or overheating of substrate.

fish eye—*see cratering.*

flaking—disintegration in small pieces or flakes.

flammability—measure of ease of catching fire, ability to burn.

flame cleaning—method of surface preparation of steel using flame.

flash point—the lowest temperature at which a given flammable material will flash if a flame or spark is present.

flat finish—dull finish, no gloss.

flatting agent—paint ingredient causing low gloss.

flexibility—ability to be bent without dam age.

floating—separation of pigment colors on surface.

flocculation—see agglomeration.

flocking—a coating process producing velvet—like surfaces.

flooding—see floating.

flow—a measure of self spreading ability; spread.

fluid adjusting screw—a screw on a spray gun which controls the amount of fluid entering the gun.

fluid flow—a measure of flow through a gun with atomizing air shut off.

fluid hose—specially designed hose for paint materials, usually black.

fluid nozzle—fluid tip or orifice; in a broader sense it connotes needle and tip combination.

fluid tip—orifice in gun into which needle is seated.

foaming—frothing.

fogging—misting.

Food & Drug Administration (FDA)—agency involved with linings for food or pharmaceutical service.

forced drying—acceleration of drying by increasing the temperature above ambient temperature accompanied by forced air circulation.

Ford Cup—a proprietary viscosity measuring device.

frothing—foaming.

fungicide—a substance poisonous to fungi; retards or prevents fungi growth.

fungus—any of a group of plants, such as molds, mildew, mush rooms, smuts, etc.

furane resins—dark chemical resistant resins made from furfuryl alcohol, furfural and phhenol.

furfural—a particular type of aldehyde used to make furane resins.

G

galvanic corrosion—corrosion of dissimilar metals in electrical contact.

galvanized steel—zinc plated steel applied in a molten bath of zinc.

gas checking—fine checking; wrinkling, frosting under certain drying conditions; said to be caused by rapid oxygen absorption or by impurities in the air.

gel—a jelly—like substance.

gelling *(gelation)*—conversion of a liquid to a gel state.

generic—belonging to a particular family.

Gilsonite—a special bitumen, an asphalt found in Utah, one of the purest of natural bitumens.

glazing *(paint term)*—application of transparent or translucent pigment on a painted surface to produce certain blended effects.

glazing *(puttying)*—setting glass.

gloss—sheen; ability to reflect; brightness; lustre.

gloss meter—device for measuring sheen or lustre.

gloss retention—ability to retain original sheen.

grain—surface appearance, usually of wood.

gray blast—commercial blast.

grind gauge *(Hegeman)*—proprietary instrument for measuring smoothness of liquid paint.

grit—an abrasive obtained from slag and various other materials.

ground wire *(airless)*—a wire attached to dissipate electrostatic charge.

grooving *(roofing term)*—formation of shallow channels.

guide coat—a coat similar to the finish or color coat but of a different color to as sure good coverage.

gun distance—space between tip of gun and work.

H

halide—a compound containing fluorine, bromine, chlorine or iodine.

halogen—bromide, chlorine, fluorine or iodine.

hardener—curing agent; promoter, catalyst.

hardness—the degree a material will with stand pressure without deformation or scratching.

hazing—clouding.

Hesiometer—proprietary device for measuring cohesion and adhesion.

heavy-centered pattern—spray pattern having most paint in center, less at edges.

hiding power—able to obscure substrate.

high-boiling solvent—a solvent with an initial boiling point above 302°F (150°C) .

high build—producing thick dry films per coat.

high flash naptha—an aliphatic solvent having a high flash point, (1131°, 45°C).

hold out—ability (or property) to prevent soaking into substrate.

holiday—pinhole, skip, discontinuity, voids.

holiday detector—device for detection of pinholes or holidays.

honeycombing—lack of vertical film integrity, formation of cell structure; voids.

hose cleaner—mechanical device promoting a beneficial swirling action to cleaning solvent.

hose restriction—impediment; reduced diameter.

hot spray—spraying material heated to reduce viscosity.

hot surface—above 120°F (48.9°C).

humidity—measure of moisture content; relative humidity is the ratio of the quantity of water vapor in the air to the greatest amount possible at the given temperature. Saturated air is said to have a humidity of 100.

hummocking *(roofing term)*—formation of raised islands.

hydraulic spraying *(see airless)*—spraying by hydraulic pressure.

hydrophilic—having an affinity for water; capable of uniting—with or dissolving in water.

hydrophobic—having an antagonism for water; not capable of uniting or mixing with water.

hydroxyl—chemical radical; OH; basic nature.

hygroscopic—having a tendency to absorb water .

I

impact resistance—a measure of resistance to a blow; ability to resist deformation from impact.

incompatibility—inability to mix with or adhere to another material.

indicator (pH) paper—a vegetable dyed paper indicating relative acidity or basicity.

inert—not reactive.

inert pigment—a non-reactive pigment; filler.

inflammability—measure of ease of catching fire: ability to burn: use of the word flammability is preferred to inflammability due to the possible misinterpretation of the prefix "in" as a negative.

inhibitive pigment—one which retards corrosion process.

***inhibitor**—an agent added to retard corrosion.

inorganic—containing no carbon.

inorganic coatings—those employing inorganic binders or vehicles.

insulation—thermal, electrical, or sound barrier material; a poor conductor.

intercoat contamination—presence of foreign matter between successive coats.

intermediate coat—middle coat, guide coat.

internal mix—a spray gun in which the fluid and air are combined before leaving the gun.

intumesce—to form a voluminous char on ignition; foaming or swelling when exposed to flame.

***ion**—an electrically charged atom or group of atoms.

iron phosphate coating—conversion coating; chemical deposit.

isocyanate resins—resins characterized by CNO grouping; polyurethane resins.

J

japan—dark colored glossy varnish.

japan drier—weak mixture of driers.

jeep test—continuity test using low voltage circuit.

K

KB Value—measure of solvent power.

KTA Panel—a proprietary paint test panel with unique configuration and markings.

KTA Rating System—10 for no failure, 0 for complete failure, proprietary method of measuring paint disintegration over KTA Panels.

kauri reduction—test for solvent power of petroleum solvents.

ketones—organic solvents containing CO grouping; commonly used ketones an acetone, dimethyl ketone;

MEK, methyl ethyl ketone; and MIBK, methyl isobutyl ketone.

kreb units—units of viscosity.

L

lacquers—coatings which dry by evaporation of solvent.

laitance—milky white deposit on new concrete; effloresence.

laminar scale—rust formation in heavy layers.

lap—see overlap.

latex—rubber like a common binder for emulsion *(water)* paints, there are natural and synthetic latexes.

leaching—the process of extraction of a soluble component from a mixture with an insoluble component by percolation of the mixture with a solvent, usually water.

leafing—orientation of pigment flakes in horizontal planes.

levelling—Rowing out to films of uniform thickness; loss of brush marks in paint.

lifting—softening and raisins of an under coat by application of a top coat.

linings—internal barriers; linings may be coated or sheet type.

livering—curds or gelling formation.

long oil—a resin having a large quantity of oil cooked per 100 pounds of resin *(25 gallons or more per 100 pounds of resin)*.

loose flake *(mill scale)*—thin, easily—removed scale.

low boiling solvent—a solvent with an initial boiling point below 302°F (150°C).

low pressure spraying—conventional air spraying.

M

MAC *(maximum allowable concentration)*—maximum allowable concentration in parts of solvent vapor to one million parts of air in which a worker can work not more than eight consecutive hours without an air fed mask; the lower the MAC number, the more toxic the solvent.

MEK—*see methyl ethyl ketone.*

MEK—*see methyl isobutyl ketone.*

MVT—*see moisture vapor transmission.*

maintenance painting—(1) repair painting any painting after the initial paint job in a broader sense it includes painting of items installed on maintenance; (2) all painting except that done solely for aesthetics.

maleic resins—a class of resins obtained from polymerization of maleic acid or maleic anhydride with alcohols; rosins; etc.

mandrel test—a physical bending test for adhesion and flexibility.

masking—covering areas not to be painted.

mass tone—base covering.

mastic—a heavy-bodied coating of high build.

melamine resins—synthetic resins which are condensate products of formaldehyde and melamine, they require baking.

metallizing—mechanical deposition of one metal on another.

methyl ethyl ketone *(MEK)*—a strong solvent.

methyl isobutyl ketone *(MIBK)*—a strong solvent.

Mikrotest Gauge—a proprietary single magnet dry film thickness gauge.

mil—one one-thousandth of an inch, .001".

milage—coverage rate; square feet per gallon at a given thickness.

mild steel—structural steel, SAE 1020.

mildew—fungus.

mildewcide—substance poisonous to mildew: prevents or retards growth of mildew.

***mill scale**—oxide layer formed on steel by hot rolling.

mill scale binder—gray oxide layer between mill scale and steel.

mill white—one-coat, high-hiding power interior paint.

mineral spirits—aliphatic solvent with solvency similar to turpentine.

miscible—capable of mixing or blending uniformly.

misses—holidays, skips, voids.

mist—coat-thin tack coat; thin adhesive coat.

moisture and oil separator—trap on air compressor or in air lines.

moisture vapor transmission *(MVT)*—moisture vapor transmission rate through a membrane: also see perm.

monomer—composed of simple molecules; a basic chemical used to make polymers.

mopping—swabbing, as with roofing asphalt.

mottling—speckling; an uneven color on paint.

mud-cracking—irregular cracking, dried mud puddle.

multicolor finishes—speckled finishes, paints containing flecks of colors different from the base color.

N

NACE No. 1 White Metal Blast Cleaned Surface Finish[2]—this finish is defined as a surface with a gray-white, uniform metallic color, slightly roughened to form a suitable anchor pattern for coatings: this surface shall be free of all oil, grease dirt, visible mill scale rust, corrosion products, oxides, paint or any other foreign matter; the surface shall have a color characteristic of the abrasive media used: photographic or other visual standards of surface preparation may be used to further define the surface.

NACE No. 2 Near White Blast Cleaned Surface Finish[2]—this finish is defined as one from which all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint or other foreign matter have been removed from the surface except for very light shadows, very slight streaks or slight discolorations, at least 95% of the surface shall have the appearance of a surface blast cleaned to a white metal surface finish and the remainder shall be limited to the light discoloration mentioned above, photographic or other visual standards of surface preparation may be used to modify or further define the surface.

NACE No. 3 Commercial Blast Cleaned Surface Finish[2]—this finish is defined as one from which all oil, grease, dirt, rust scale, and foreign matter have been completely removed from the surface and all rust, mill scale, and old

paint have been completely removed except for slight shadows, streaks, or discolorations, if the surface is pitted, slight residues of rust or paint may be found in the bottom of pits, at least two—thirds of the surface area shall be free of all visible residues and the remainder shall be limited to light discoloration, slight staining or light residues mentioned above: photographic or other visual standards may be used to further define the surface.

NACE No. 4 Brush-Off Blast Cleaned Sur face Finish[2]—this finish is defined as one from which oil grease dirt rust scale loose mill scale, loose rust, and loose paint' or coatings are removed completely, but light mill scale and tightly adhered rust, paint and coatings are permitted to remain provided they have been exposed to the abrasive blast pattern sufficiently to expose numerous flecks of the underlying metal fairly uniformly distributed over the entire surface; photographic or other visual standards of surface preparation may be used to further define the surface.

Naphtha—an aliphatic solvent cut; hydro carbons of the $C_nH_{2n}+2$ series.

near-white blast cleaning—*see NACE No. 2 in this alphabetical listing.*

needle *(spray gun)*—fluid metering pin.

neoprene—a rubber-like film former; a type of elastomers based on polymers of 2 chloro-butadiene-l, 3.

nondrying oil—one which will not harden in air.

nonferrous—containing no iron.

nonflammable—incombustible.

nontoxic—not poisonous.

nonvolatile—solid: non-evaporating; the portion of a paint left after the solvent evaporates.

nozzle—orifice; sandblast nozzle; spray gun nozzle.

nylon resins—a particular group of film formers having recurring amide groups: CONH, as an integral part of the main polymer chain; polyamide resins.

O

oil absorption—a measure of the ability of pigments to absorb oil.

oil color—coloring *(pigment or dye)* dispersed in oil.

oil length—gallons of oil reacted with 100 pounds of resin.

oleoresinous—film former containing oil and resin.

opacity—hiding power.

orange peel—dimpled appearance of dried film: resembling orange peel.

organic—containing carbon.

organosol—film former containing resin plasticizer and solvent; colloidal dispersion of a resin in plasticizer containing more than 5% volatile content.

orifice—opening; hole.

osmosis—transfer of liquid through a paint film or other membrane.

osmotic blistering—formation of blisters containing liquid.

overatomize—dispersed too finely by use of excessive atomizing air pressure.

overcoat—second coat top coat.

overlap—portion *(width)* of fresh paint covered by next layer.

overspray—sprayed paint which did not hit target, waste.

***oxidation**—combination with oxygen; drying; burning; rusting.

oxide—chemical compound of an element, usually a metal, with oxygen.

P

PVA—see polyvinyl acetate.

PVC—see pigment volume concentration or polyvinyl chloride.

paint heater—device for lowering viscosity of paint by heating.

paint program—comprehensive painting plan. *(see NACE Task Group T-6D-3 Report "Industrial Maintenance Painting Program"[3]).*

paint project—single paint job.

paint system—the complete number and type of coats comprising a paint job. In a broader sense, surface preparation, pretreatments, dry film thickness, and manner of application are included in the definition of a paint system.

particle size distribution—percentages of particles of different screen sizes.

pass *(spray)*—motion of the spray gun in one direction only.

***passivation**—act of making inert or unreactive.

pattern length—spray pattern height.

pattern width—width of spray pattern at vertical center.

peeling—failure in which paint curls from substrate.

perm—a unit for expressing MVT rate; a perm-inch = 1 grain of water per hour per square foot per one inch thickness (except where otherwise noted) per one inch difference in mercury vapor pressure on each side of membrane.

permeability—quality or state of being permeable.

phenolic resins—particular group of film formers, phenol—formaldehyde type.

phosphatize—form a thin inert phosphate coating on surface usually by treatment with H_3PO_4 (phosphoric acid).

phthalic resins—a particular group of film formers, alkyds.

pH value—measure of acidity or alkalinity; pH 7 is neutral, the pH value of acids ranges from 1 to 7, and of alkalis (bases) from 7 to, and including, 14.

***pickling**—a dipping process for cleaning steel and other metals; the pickling agent is usually an acid.

pig—*see air manifold.*

pigment grind—dispersion of pigment in a liquid vehicle.

pigments—solid coloring agents.

pigment volume concentration *(pvc)*—percent by volume occupied by pigment in dried film.

pig tail—finger-like spray pattern.

***pitting**—formation of small, usually shallow depressions or cavities.

pin-holing—formation of small holes through the entire thickness of coating; see cratering.

plasticizer—a paint ingredient which imparts flexibility.

plastisol—film former containing resin and plasticizer with no solvents.

pock marks—pits: craters.

pole-gun—spray gun equipped with an extension tube.

polymerization—formation of large molecules from small ones.

polymer—the product of polymerization; large molecules.

polyvinyl acetate *(PVA)*—a synthetic resin used extensively in emulsion *(water)* paints; produced by the polymerization of vinyl acetate.

polyvinyl chloride *(PVC)*—a synthetic resin used in solvent type coatings and fluid bed coatings, produced by the polymerization of vinyl chloride, PVC is also used in emulsion *(water)* paints..

polyvinyl chloride acetate—a combination of PVA and PVC used in coatings.

porosity—hole; degree of integrity or continuity.

pot-life—time interval after mixing during which liquid material is usable with no difficulty.

precipitation—settling out of solid material.

pressure balance—in spray painting, relationship of pot pressure to atomizing air pressure.

pressure drop—loss in pressure due usually to length or size of line or hose.

pressure feed—fluid flow caused by application of air or hydraulic pressure on paint.

pressure feed paint tank *(pressure pot)*—fluid container in which fluid flow is caused by air pressure.

preventive maintenance painting—spot repair painting; touch up or full coats of paint before rusting starts.

prime coat—first coat.

primer—material used for prime coat.

production rate *(sq. ft./day)*—measurement of surface area cleaned or coated in one working day by one man.

profile—surface contour as viewed from edge.

profile depth—average distance between tops of peaks and bottom of valleys on the surface.

proprietary—available on open market under brand name.

protective life—interval of time during which a paint system protects substrate from deterioration.

pulsation—surging.

pump bypass—recirculating line which returns fluid to container.

pump ratio—multiplier of input pressure which indicates output pressure: ratio of air piston area to fluid piston area.

Q

quick release fittings—snap-lock fittings.

R

reaching *(spray gun)*—extending spray stroke too far.

rebound—paint spray deposit bounced back.

recoat time—time interval required between application of successive coats.

red label goods—flammable or explosive materials with flash points below 302°F (26.7°C).

reducer—a material which lowers viscosity but is not necessarily a solvent for the particular film former; thinner.

reflectance—degree of light reflection.

repainting—repetition of a complete painting operation including surface preparation.

resin—a material, natural or synthetic contained in varnishes, lacquers, and paints; the film former.

respirator—safety breathing mask.

reticulation—a surface defect of net-like appearance.

rise—height.

roller coating—the act of, or the material, applied with a roller.

round pattern—circular spray pattern.

runs—curtains, sags.

***rust**—corroded iron: red iron-oxide; also other metal oxides formed by corrosion.

rust bloom—discoloration indicating the beginning of rusting.

S

SSPC—Steel Structures Painting Council.

safety valve—pressure release valve preset to safe operating limit.

sags—runs.

salt spray—a salt fog test environment.

sandblast—blast cleaning using sand as an abrasive; for different grades of blast cleaning finishes *see NACE No. 1, NACE No. 2, NACE No. 3, and NACE No. 4 blast cleaned finishes in this alphabetical listing.*

sandy finish—a surface having the appearance of sandpaper overspray.

saturant—that substance, usually a liquid, which saturates something else.

saturated—holding the maximum amount of saturant it is capable of holding.

scale—laminar rust.

scaler—a hand cleaning chisel.

***scaling**—process of delamination.

sealer—a low viscosity (thin) liquid applied before priming wood or masonry.

seeding—formation of small agglomerates.

separation—division into components or layers by natural causes.

settling—caking; sediment.

shade—degree of gray tone in a color.

shelf life—maximum interval in which a material may be stored in usable condition.

shellac—a resin secreted by insects, a lacquer; resin in alcohol.

shielding—protecting; protective cover against mechanical damage.

shop coat *(prime, see NACE Task Group T-6D-3 report on "Industrial Maintenance Painting Program")*—first coat applied in fabricating shop.

short oil—a varnish prepared by cooking a relatively small quantity of oil with 100 pounds of resin, quick drying; brittle, less than 25 gallons of oil per 100 pounds of resin.

shot blasting—blast cleaning using steel shot as the abrasive.

shrinkage—decrease in volume on drying.

silicate paints—those employing silicates as binders.

silicone resins—a particular group of film formers; used in water proof and high temperature paints; organosiloxane polymers: semi-organic polymers containing silicon.

silking—a surface defect characterized by parallel hairlike striations in coated films.

skinning—formation of a solid membrane on top of a liquid.

skips—holidays ; misses; uncoated area; voids.

slow drying—requiring 24 hours or longer before recoating.

slug—surge of material; blob.

solid—non-volatile portion of paint.

solids volume—percentage of total volume occupied by non-volatiles.

solubility—degree to which a substance may be dissolved.

solution—a liquid in which a substance is dissolved.

solvency—measure of ability to act as solvent.

solvent—a liquid in which another substance may be dissolved.

solvent balance—ratio of amounts of different solvents in a mixture of solvents. solvent pop—blistering caused by entrapped solvent.

solvent power—see solvency.

solvent release—ability to permit solvents to evaporate.

solvent wash—cleaning with solvent.

***spalling**—the cracking, breaking or splintering of materials, usually due to heat.

spark testing—detection of holidays (flaws) using electric spark.

spark-proof tools—bronze beryllium tools.

specific gravity—ratio of weight of a given volume to weight of an equal volume of water at the same temperature.

specular gloss—mirror-like reflectance.

spewing—irregular or intermittent surging with liquid spillage.

Spider *(power staging)*—a proprietary mechanical boat swain's chair or platform.

spit—sputter.

spot repair—preventive maintenance; repainting of small areas.

spray cap—front enclosure of spray gun equipped with atomizing air holes.

spray head—combination of needle, tip and air cap.

spray pattern—configuration of spray, gun held steady.

spreading rate—coverage, milage, usually at specified dry thickness.

sputtering flow—spitting, surging.

squeegee—rigid bar applicator.

static wire—ground wire.

steam clean—a cleaning process using live steam.

strain—to filter.

streaks—a surface defect characterized by essentially parallel lines of different colors or shades.

striping—edge painting prior to priming.

stroke *(spray)*—a single pass in one direction.

styrene-butadiene—resin; copolymer of styrene and butadiene.

substrate—surface to be painted.

suction feed *(sandblaster)*—one in which the abrasive is siphoned to the nozzle.

suction feed *(spray gun)*—one in which the fluid Is siphoned to the spray head.

surface tension—cohesive force on liquid surface.

surfacer—a paint used to smooth the surface before finish coats are applied.

surge—see spewing; noncontinuous flow.

surge chamber *(airless spray)*—a device to eliminate uneven fluid flow.

sweating—condensing moisture on a surface.

swelling—increasing in volume.

swivel fitting—one capable of being moved in any direction.

swivel head—spray head adjustable to deliver spray in many directions.

synthetic—manufactured; not occuring naturally.

T

tack—degree of stickiness.

tail *(solvent evaporation)*—highest boiling solvent fraction.

tail line—short piece of blast hose smaller than the main hose to permit better maneuverability.

tails *(airless spray)*—finger-like spray pattern.

tank whites—good hiding, self cleaning white paints; usually alkyds.

tapered pattern—elliptical shaped spray pattern; a spray pattern with converging.

tape test—a particular type of adhesion tenacity—ability to stick together, cohesiveness; adhesiveness.

tensile strength—resistance to elongation the greatest longitudinal stress a sub stance can bear without rupture or remaining permanently elongated.

terpene resins—a particular group of film formers, prepared from isomeric hydrocarbons such as turpentine or similar oleoresins.

test pattern—spray pattern used in adjusting spray gun.

thermoplastic—mobile or softens under heat.

thermosetting—becomes rigid under heat and cannot be remelted.

thinners—volatile organic liquids for reducing viscosity; solvents.

thixotropic—false-bodied, a gel which liquefies with agitation but gels again on standing.

Tinsley Gauge—a proprietary pencil-like single magnet, dry film thickness gauge.

tint—degree of white in a color; a color produced by the mixture of white paint or pigment with a non-white colored paint or pigment.

toner—a color modifier.

tooth—profile; mechanical anchorage; sur face roughness.

top coating—finish coat.

touch-up painting—spot repair painting usually conducted a few months after initial painting.

toxic—poisonous.

toxicity—degree of poisonous or harmfulness.

transition primer *(block or barrier coat)*—coating compatible with primer and also with a finish coat which is not compatible with primer.

trigger—operating lever of spray gun.

triggering—intermittent squeezing and releasing of trigger.

tubercule—nodule; pimple.

two-component gun—one having two separate fluid sources leading to spray head.

U

underatomized—not dispersed or broken up fine enough.

unit cost—cost per given area.

urea resins—a particular group of film formers; (amino resins).

urea formaldehyde—a particular group of film formers; usually re-

quires baking; produced by reacting urea with formaldehyde.

urea melamine—see melamine.

urethane resins—a particular group of film formers; isocyanate resins.

V

VM&P naptha—varnish and paint manufacturers naptha, an aliphatic solvent.

vapor degreasing—a cleaning process utilizing condensing solvent as the cleaning agent.

vaporization—conversion from liquid or solid to a gaseous state, phase change

varnish—liquid composition of oil, resin; thinners and driers, which is converted to a transparent or translucent solid film after application as a thin layer or coat.

vehicle—liquid carrier; binder; anything dissolved in the liquid portion of a paint is a part of the vehicle.

veiling—curtaining, sagging.

venturi—a tube having a restriction to promote velocity increase.

vertical pattern—a spray pattern whose longest dimension is vertical.

vinyl acetate—a particular resin monomer: obtained by reaction of acetylene and acetic acid; see PVA, polyvinyl acetate.

vinyl choride—a particular resin monomer: obtained by reaction of acetylene and hydrochloric acid, cracking of ethylene dichloride, or reaction of ethylene dichloride and caustic soda; see PVC, polyvinyl chloride.

vinyl coating—one in which the major portion of binder is of the vinyl resin family.

vinyl copolymer—resins produced by copolymerizing vinyl acetate and vinyl chloride.

vinyl resins—a particular group of film formers, see PVA and PVC.

viscosity—a measure of fluidity.

viscosity cup—a device for measuring viscosity.

voids—holidays, holes, skips.

volatiles—fluids which evaporate rapidly.

volatile content—percentage of materials which evaporate.

W

washing—erosion of a paint film after rapid chalking.

wash primer—a thin inhibiting paint usually chromate pigmented with a polyvinyl butyrate binder.

water blasting—blast cleaning using high velocity water.

water spotting—a surface defect caused by water droplets.

weatherometer—a testing device intended to simulate atmospheric weathering.

weld joints—beads of weld joining two members.

weld slag—amorphous deposits formed during welding.

weld spatter—beads of metal left adjoining a weld.

weld splatter—see weld spatter.

wet edge—fluid boundary.

wet film gauge—device for measuring wet film thickness.

wet film thickness—thickness of liquid film immediately after application.

wet spray—spraying so that surface is covered with paint that has not started to dry.

wetting strength—the maximum distance or penetration the vehicle is capable of livering the paint or coating assembly in a vertical or horizontal direction on a specific substrate.

wetting time—the time required for a vehicle to reach the end point of distance and penetration on a metal.

whipping *(spray gun)*—arcing, waving.

whip blast—*see NACE No. 4 in this alphabetical listing.*

whip line—*see tail line.*

white blast—*see NACE No. 1 in this alphabetical listing.*

whiting—Paris white, gliders white, fine ground, naturally occurring calcium carbonate, $CaCO_3$, about 98% pure. Used as an inexpensive filler and extender.

wicking—absorption of liquid by capillary action.

wire brush—a hand cleaning tool comprised of bundles of wires; also the act of cleaning a surface with a wire brush including power brushes.

wrinkling—a surface defect resembling the skin of a prune.

wrist action *(spraygun)*—swiveling of wrist without arcing forearm.

Y

yellowing—development of yellow color or cast, in whites, on aging.

zinc phosphate coating—a thin, inorganic deposit formed on zinc treated with phosphoric acid.

zinc silicate—inorganic zinc coating.

zinc yellow—zinc chromate.

References

1. Surface Preparation Abrasives for Industrial Maintenance Painting. A Report of NACE Technical Unit Committee T-6G, Surface Preparation for Protective Coatings. Prepared by Task Group T-6G-1 on Abrasive Blast Cleaning Media for Surface Preparation in conjunction with Task Group T-6D-13 on Surface preparation Media Materials Protection, 3, 76 (1964) July.
2. Proposed Definitions of Sandblast Cleaned Surfaces. A Report of NACE Technical Committee T-6G, Surface Preparation for Protective Coatings. Prepared by Task Group T-6G-2 on Definitions of Degrees of Blast Cleaning Surface Preparation for Organic Coatings. To be published soon.
3. Industrial Maintenance Painting Program. Report of NACE Technical Unit Committee T-6D. Corrosion, 16, 301t (1960) June.