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COATING MIXING, THINNING AND APPLICATION: EQUIPMENT OVERVIEW AND INSPECTION TECHNIQUES

Introduction

Transferring the coating material from the container to the surface may seem like a routine task and would hardly warrant training and inspection. Yet, next to surface preparation, it is one of most important steps to ensuring corrosion protection of structural steel. As we discussed in Module 1, coatings protect the substrate by barrier, inhibitive and/or galvanic means. If the coating material is not properly mixed, thinned and applied, then any protection afforded by the coating may be minimized or eliminated. This is why it is important to read and comprehend the project specification and the manufacturer's

written instructions for product use (product data sheet), then verify that the proper mixing and application procedures are employed. This module describes the proper methods of coating mixing, thinning and application, and discusses the associated inspection procedures. It also provides an overview of common application methods.

Methods of Coating Application

- 1 Brushes, rollers and daubers
- 2 Conventional (air) spray
- 3 High Volume Low Pressure (HVLP) spray
- 4 Airless spray
- 5 Air-assisted airless spray
- 6 Plural component spray

Module 5 Learning Outcomes

Successful completion of Module 5 on Coating Mixing, Thinning and Application: Equipment Overview and Inspection Techniques will enable the participant to:

1. Describe the inspector's role in coating mixing, thinning, and application.
2. Describe the SSPC standards for coating application and coating thickness measurements.
3. Use SDSs and product data sheets to verify safe and proper mixing, thinning, and application of coatings.
4. Describe the procedures associated with proper mixing, thinning, and application of coatings.
5. Calculate and measure wet film thickness.
6. Describe and implement the proper inspection testing procedures and processes used in coating application.

The Inspector's Role

The inspector's role related to coating mixing, thinning and application is multi-fold, and will vary from project to project (and from product to product). For example, on most projects, the inspector is typically responsible for measuring and recording ambient conditions and surface temperature, and for witnessing coating mixing, thinning and application procedures. The inspector may also be responsible for calculating the target wet film thickness and for measuring the wet and dry film thickness. Additionally, verification of the cleanliness between coats and compliance with recoat intervals are also typically monitored by the inspector. Other responsibilities may include verifying that the contractor's equipment is set-up according to the coating manufacturer's recommendations and is operating properly and productively. The inspector may also be responsible for performing pinhole or holiday detection, assessing the degree of coating cure and hardness of the film, or for measuring the adhesion of the applied coating system. Finally, in the event that it is necessary to measure the thickness of individual layers after the whole system is installed, the inspector will need to know how to use a destructive coating thickness gage. We will be discussing each of these inspection checkpoints in this module.

Review of SSPC Standards for Coating Application

SSPC: The Society for Protective Coatings has several specifications pertaining to coatings application. A brief overview of the two most commonly referenced specifications is provided below.

SSPC Paint Application Specification No. 1 (PA 1): Shop, Field and Maintenance Painting of Steel

SSPC PA 1 is the first **Paint Application** specification released by SSPC. It is a common reference in project specifications for painting of steel surfaces, and contains much of the same information as will be covered by this module. The specification contains 14 sections. Section 1 is the **Scope**, which states that PA 1 covers procedures for painting steel surfaces and is a broad document describing general and specific requirements for coating application. Section 2 (**Description**) lists the content of the standard, and Section 3 lists all of the **Referenced Standards** included in the specification. Section 4 includes the **Definitions** of key terms used throughout the document, and Section 5 (**Pre-Application Procedures**) contains information on coating material handling and use (including storage), surface preparation (general), application of chemical pretreatments, and preparation of coatings, including mixing and thinning procedures. Section 6 describes **Factors Affecting Application of Coatings**, including temperature and moisture, humidity, methods to control conditions (cover), defects, striping, continuity of the applied film, recoating intervals, tinting of successive coats, intercoat adhesion, induction time and pot life, as well as requirements for treatment of contact (mating) surfaces. Section 7 briefly describes eleven different **Application Methods** ranging from brush and roller to various spray methods. **Shop Coating** procedures are described in Section 8, and **Field Coating** procedures are listed in Section 9. Section 10 describes methods for **Repair of Damaged, Intact Coatings**, including surface preparation of the damaged areas. Section 11 describes the **Application Procedures for Generic Groups of Coatings** (some of which are rarely or no longer used), and include drying oil paints, vinyl and chlorinated rubber coatings, bituminous coatings, epoxy and coal tar epoxies, zinc-rich primers, polyurethanes, and waterborne latex coatings, and Section 12 lists requirements for **Curing and Handling of Coatings**. The specification is completed by brief sections on **Inspection** (13) and **Safety and Environmental Concerns** (14).

SSPC Paint Application Specification No. 2 (PA 2): Procedure for Determining Conformance to Dry Coating Thickness Requirements

SSPC PA 2 includes sections that cover description and use, calibration, verification and measurements procedures, required number of measurements, and accuracy. SSPC PA 2 will be described in greater detail later in this module.

Coating Manufacturer's Technical Data Bulletins/ Product Data Sheets

A coating manufacturers technical data bulletin (also called a product data sheet, or PDS) is essentially an “instruction manual” for the coating. We will be reviewing a few examples of PDS. Sometimes the label on the coating containers provide basic instructions for use, but typically they do not contain the same level of detail as that provided on a PDS. Further, container labels can become covered with paint, hiding key information. Therefore a PDS should always be made available at the work site. Note however that the information provided on a product data sheet can be revised or updated at any time. The best way to ensure that you are using the product data sheet that corresponds to the batch of coatings on the project is to contact the technical representative of the coating manufacturer and provide them with the batch or lot no. of the coating. They will direct you to the version of the product data sheet corresponding to the batch. Most coating manufacturers maintain current product data sheets on their websites, which can be downloaded and printed within minutes. In general, a PDS contains information for the specifier that includes the product brand name and number, the generic type of coating (epoxy, polyurethane, etc.), and when and where the coating can and cannot be used, as well as compatible coatings. A product data sheet will contain technical information such as the weight and volume solids content of the coating, the theoretical coverage or spreading rate of the coating (the number of square meters [square feet] that one liter [gallon] of the coating will cover), the recommended level(s) of surface preparation and the recommended dry film thickness, the Volatile Organic Compound (VOC) content of the coating as it is manufactured and the adjusted VOC content based on the type and amount of thinner added to the coating. Sometimes a PDS is used to communicate “performance data” to the specifier, such as adhesion

characteristics, accelerated weathering/corrosion resistance, hardness, abrasion resistance, etc.

The PDS contains valuable information for the applicator as well, which includes the recommended method(s) of application (brush, roller, air/airless spray, etc.), and equipment recommendations for each



Product Data Sheets

application method listed. Additionally, the PDS contains mixing and thinning instructions, and if the coating contains multiple components, the number of components to be blended together, and the pot life of the coating (how long the coating can be used once the components are blended). Some multiple component coatings require an induction (“stand-in time” or “sweat-in”) which allows the individual components to co-react or “simmer” after mixing, but before application. However, not all multiple component coatings require an induction period. If

required, the time periods for different material temperatures will be listed under the mixing instructions on the PDS, e.g., allow the mixed coating material to induct for 30 minutes at 24°C (75°F). Note that the induction time (when required) is part of the pot life of the coating. That is, if a coating has a pot life of 4 hours and a 30-minute induction at the prevailing temperature, the “usable pot life” is only 3 ½ hours. And the pot life is also dependent on the material temperature. A pot life of 4 hours at 24°C (75°F) may only be 3 hours at 32°C (90°F), but may be 5 hours at 16°C (60°F).

Drying and curing times are also listed on the PDS. These times are dependent on the air and surface temperatures, and the relative humidity (the amount of moisture present in the air). Drying times are often listed based on “dry-to-handle,” “dry-to-recoat” and “full cure.” The maximum recoat time may also be listed. Some coating manufacturers will even specify the method(s) used to verify cure of the coating. Finally, the PDS provides information on clean up of equipment, approximate shipping weights and the various sized units that the coating is available in e.g., 3.8 liter (1 gallon) kits, 19 liter (5 gallon) kits, etc. The shelf life is also indicated. The shelf life is the period of time that the coating can be used, from the

date of manufacture. For example, the shelf life of a coating may be listed as 24 months, provided it is unopened and is stored at the proper conditions of temperature and humidity. As a general rule, coatings should not be used after the shelf life has expired, even if they “appear” to be in acceptable condition. Note that some coating manufacturers consider the shelf life of a coating to begin upon receipt, rather than from the date of manufacture.

ASTM F718 provides a standardized format and lists the minimum information to be indicated on product data sheets. However, there are no requirements for the type of information that is listed. While there is certainly commonality to the type of information that is conveyed, a coating manufacturer can list any information they desire and place it anywhere on the PDS. Some manufacturers provide all of the information on two pages, while others use a six or an eight-page format. Some manufacturers publish a “Technical Bulletin” and a set of Application Instructions, rather than combining the information onto one document. Despite these limitations, the information conveyed on a PDS can be critical to the success of a coating installation. The specifier, inspector and the contractor should be familiar with the information listed on the PDS, for each product to be applied. The correct version of the PDS for each coating to be applied should be readily available on the project site, and should be supplied to the inspector(s) by the contractor.

Product data sheets contain *recommendations*. For example, the manufacturer may recommend preparing the surface to achieve “Thorough Blast Cleaning” (ISO 8501-1 Sa 2) or a “Commercial Blast” (SSPC-SP 6/NACE No. 3) with a 38-50 μm (1.5-2 mil) surface profile, while the project specification may require “Very Thorough Blast Cleaning” (ISO 8501-1 Sa 2-1/2) or a “Near-White Metal Blast” (SSPC-SP 10/NACE No. 2) and a 50-75 μm (2-3 mil) surface profile. Similarly, the manufacturer may recommend one coat at 125-175 μm (5-7 mils), while the specification may require two coats at 100-200 μm (4-8 mils) each. *In all of these cases, the specification is the governing document unless it states otherwise.* However, if there are large discrepancies between the manufacturer’s recommendations and the specification, the discrepancy should be brought to the attention of the facility/structure owner, to ensure that the variance was not an oversight. If the coating is applied in a manner that the PDS does not support (and problems arise with the coating), it may risk not being covered by the warranty. For example, if the product

data sheet states, “Do not exceed 175 μm (7 mils) dry film thickness” and the specification requires 200 μm (8 mils) dry film thickness, the contractor or the inspector should “red flag” the discrepancy and advise the owner.

Some owners will elect to invoke the product data sheets by reference in the specification. In these cases, the product data sheets become the governing document. Others state that the document that is more restrictive (specification or PDS) shall become the governing document.

Let’s review a couple examples of product data sheets/technical bulletins to see how two different suppliers of industrial protective coatings convey information on how to use their products. After reviewing these PDS, there will be a workshop (Workshop 5A) on navigating a PDS, which you will work together as a team to complete.

A coating manufacturer cannot anticipate every situation and inquiry that may arise regarding the use of their product and publish it on a data sheet. For example, the manufacturer may state the potlife of a coating at one temperature, but not multiple temperatures. And they may state the required induction time at a single temperature, which may not represent the prevailing temperature at the project site. Or they may recommend the use of a single type of thinner, but another type may work better during hot or windy conditions. In these circumstances, access to the coating manufacturer’s technical service representative can be invaluable. This representative can provide guidance on the use of their coatings on the project site where they will actually be applied. The experience and expertise of these technical representatives should be tapped whenever project-specific situations arise regarding the use of their coatings. They know them best of all.

Selection & Specification Data

Generic Type	Organic Zinc-Rich Epoxy
Description	Low VOC organic zinc epoxy steel primer with extremely fast cure-to-topcoat characteristics for in-shop applications and quick turnaround requirements in the field. ABCzinc 859 has less than 3.0 lbs/gallon VOC (thinned) and is used extensively in virtually all industrial markets.
Features	- Meets Class B slip co-efficient and creep testing criteria for use on faying surfaces - Rapid cure. Dry to recoat in 30 minutes at 75°F (24°C) and 50% relative humidity. - Complies with SSPC Paint 20 (Type II) - Low temperature cure down to 35°F (2°C) - Excellent adhesion - Protects against undercutting corrosion - Available in ASTM D520, Type II zinc version - Field proven primer that applies well by spray methods - Excellent touch-up primer by brush or roll for small areas. - VOC compliant to current AIM regulations
Color	Green (0300)
Finish	Flat
Primers	Self Priming
Topcoats	Can be topcoated with epoxies, Polyurethanes, Acrylics and others as recommended by your manufacturer's sales representative. Under certain conditions, a mist coat is required to minimize topcoat bubbling.
Dry Film Thickness	3.0-5.0 mils (75-125 microns). Dry film thickness in excess of 10.0 mils (250 microns) per coat is not recommended.
Solids Content*	By Volume: 66% ± 2% *Tested in accordance with ASTM D2697
Zinc Content	By Weight: 81% ± 2% in dry film
Theoretical Coverage Rate	1,059 mil ft ² (24.0 m ² /l at 25 microns) 353 ft ² at 3.0 mils (8.0 m ² /l at 75 microns) Allow for loss in mixing and application
VOC Values	As Supplied: 2.72 lbs./gal (326 g/l) Thinned:* 13 oz/gal w/ #2: 3.12 lbs./gal (374 g/l) 13 oz/gal w/ #33: 3.15 lbs./gal (378 g/l) These are nominal values. *Use Thinner #76 for projects requiring non-photochemically reactive solvents.
Dry Temp. Resistance	Continuous: 400°F (204°C) Non-Continuous: 425°F (218°C)

Substrates & Surface Preparation

General	Surfaces must be clean and dry. Employ adequate methods to remove dirt, dust, oil and all other contaminants that could interfere with adhesion of the coating.
Steel	SSPC-SP6 with a 1.0-3.0 mil (25-75 micron) surface profile. SSPC-SP2 or SP3 for touch-up.

Performance Data

Test Method	System	Results
ASTM D4541 Adhesion	A. Zinc B. Polyurethane C. Epoxy/Polyurethane	A. 841 psi Pneumatic B. 1,100 min, psi Pneumatic C. 602 psi Elcometer
ASTM D522 Flexibility	A. Epoxy B. Zinc/Polyurethane	A. > 6% B. > 5%
ASTM D2704 Impact	A. Epoxy B. Polyurethane Gardner Impact Tester, Direct (intrusion), inch-pounds, over 1/8" steel	A. 160 B. 100 min.
Slip Co-Efficient	Zinc A-490 bolt spec; 6 mils dry film maximum, 10% max. thinning	Meets requirements for class B rateng

Test reports and additional data available upon, written request.

Application Equipment

Listed below are general equipment guidelines for the application of this product. Job site conditions may require modifications to these guidelines to achieve the desired results.

General Guidelines:

Spray Application (General)	The following spray equipment has been found suitable and is available from manufacturers such as Binks, DeVilbiss and Graco. Keep material under mild agitation during application.
Conventional Spray	Agitated pressure pot equipped with dual regulators, 3/8" I.D. minimum material hose, .070" I.D. fluid tip and appropriate air cap.
Airless Spray	Pump Ratio: 30:1 (min.)* GPM Output: 3.0 (min.) Material Hose: 3/8" I.D. (min.) Tip Size: .017-.023" Output PSI: 2000-2200 Filter Size: 60 mesh *Teflon packings are recommended and available from the pump manufacturer.
Brush/Roller	For small areas and touch-up only. Preferred method for large areas is spray application.

Mixing & Thinning

Mixing	Power mix Part A completely. Then slowly sift in the zinc filler under agitation. Power mix Part B separately and add slowly to the mixture. Pour mixture through a 30 mesh screen. DO NOT MIX PARTIAL KITS. Tip: Sifting zinc through a window screen will aid in mixing process by breaking up or catching dry zinc lumps.		
Ratio		<u>.80 Gal. Kit</u>	<u>4.00 Gal. Kit</u>
	Part A:	.35 gallons	1.77 gallons
	Part B:	.20 gallons	1 gallon
	Zinc Filler:	14.6 lbs	73 lbs
Thinning	Normally not required but may be thinned up to 13 oz/gal (10%) with Thinner #2 or Thinner #76. In hot or windy conditions, may be thinned up to 13 oz/gal with Tinner #33. Use of thinners other than those supplied by manufacturer may adversely affect product performance and void product warranty, whether expressed or implied. Manufacturer's Thinner #236E may also be used to thin this product to minimize HAP and VOC emissions. Consult manufacturer's Technical Service for guidance.		
Pot Life	4 Hours at 75°F (24°C) and less at higher temperatures. Pot life ends when coating loses body and begins to sag.		

Cleanup & Safety

Cleanup	Use Thinner #2 or Acetone. In case of spillage, absorb and dispose of in accordance with local applicable regulations.
Safety	Read and follow all caution statements on this product data sheet and on the MSDS for this product. Employ normal workmanlike safety precautions. Hypersensitive persons should wear protective clothing, gloves and use protective cream on face, hands and all exposed areas.
Ventilation	When used in enclosed areas, thorough air circulation must be used during and after application until the coating is cured. The ventilation system should be capable of preventing the solvent vapor concentration from reaching the lower explosion limit for the solvents used. In addition to ensuring proper ventilation, appropriate respirators must be used by all application personnel. This product contains flammable solvents. Keep away from sparks and open flames. All electrical equipment and installations should be made and grounded in accordance with the National Electric Code. In areas where explosion hazards exist, workmen should be required to use non-ferrous tools and wear conductive and non-sparking shoes.

Application Conditions

Condition	Material	Surface	Ambient	Humidity
Normal	60°-85°F (16°-29°C)	60°-90°F (16°-32°C)	60°-90°F (16°-32°C)	0-90%
Minimum	40°F (4°C)	35°F (2°C)	35°F (2°C)	0%
Maximum	90°F (32°C)	120°F (49°C)	110°F (43°C)	95%

Industry standards are for the substrate temperatures to be 5°F (3°C) above the dew point. This product simply requires the substrate temperature to be above the dew point. Condensation due to substrate temperatures below the dew point can cause flash rusting on prepared steel and interfere with proper adhesion to the substrate. Special application techniques may be required above or below normal application conditions.

Curing Schedule

Surface Temp. & 50% Relative Humidity	Dry to Handle	Dry to Topcoat
35°F (2°C)	8 Hours	6 Hours
50°F (10°C)	5 Hours	2 Hours
75°F (24°C)	2 Hours	30 Minutes
100°F (32°C)	1 Hour	30 Minutes

These times are based on a 3.0 mil (75 micron) dry film thickness. Higher film thickness, insufficient ventilation or cooler temperatures will require longer cure times and could result in solvent entrapment and premature failure. **Specific topcoat products can be used in a much shorter re-coat interval. Consult manufacturer for recommendations and test results.**

Maximum Recoat: Unlimited. Must have a clean, dry surface for topcoating. "Loose" chalk or salts must be removed in accordance with good painting practice. Consult manufacturer's Technical Service for specific information.

Packaging, Handling & Storage

Shipping Weight (Approximate)	<u>.80 Gallon Kit</u> 22 lbs (10 kg)	<u>4.00 Gallon Kit</u> 105 lbs (48 kg)
Flash Point (Setaflash)	Part A: 49°F (9°C) Part B: 38°F (3°C) Zinc Filler: NA	
Storage (General)	Store Indoors.	
Storage Temperature & Humidity	40° – 110°F (4° - 43°C). 0-95% Relative Humidity	
Shelf Life	Part A: Min. 36 months at 75°F (24°C) Part B: Min. 24 months at 75°F (24°C) Part C: 24 months at 75°F (24°C)	

***Shelf Life: (actual stated shelf life) when kept at recommended storage conditions and in original unopened containers.**

*Epoxy intermediate coat***Product Data/
Application Instructions**

- High solids high build epoxy intermediate coat
- Excellent adhesion to zinc-rich primers
- Easy application
- Low VOC
- Tough and durable
- Also available with MIO pigmentation
- Can be applied direct-to-metal in selected environments

Typical Uses

ABC COAT 383H is used as an economic intermediate coating for atmospheric exposure in marine and industrial environments. ABC COAT 383H is normally applied over an inorganic zinc-silicate, zinc-rich epoxy or epoxy primer.

ABC COAT 383H is not recommended for use in continuous immersion conditions. ABCcoat 383H is normally topcoated for optimal performance.

Physical Data

Finish	Semi-gloss	
Color	Pearl gray, light buff, oxide red	
Components	2	
Curing mechanism	Solvent release and chemical reaction between components	
Volume solids (ASTM D2697 modified)	77% ± 3%	
Dry film thickness per coat	4 to 8 mils (100 to 200 microns)	
Coats	1	
Theoretical coverage	ft ² /gal	m ² /L
8 mil (200 microns)	154	3.8
4 mils (100 microns)	308	7.6
VOC	lb/gal	g/L
(Calculated)	1.9	231
Temperature resistance		
dry	°F	°C
continuous	200	93
intermittent	250	121
Flash point (SETA)	°F	°C
383H cure	117	47
383H resin	117	47
ABC COAT 65	81	27
ABC COAT 101	145	63
ABC COAT 12	2	-17

ABCcoat 383H Chemical Resistance Guide

When applied over suitable primer or intermediate coat and topcoat with ABCcoat 450 Series.

Environment	Splash and Spillage	Fumes and Weather
Acidic	F	G
Alkaline	E	E
Solvents	E	E
Salt solutions		
Acidic	G	VG
Neutral	E	E
Alkaline	E	E
Water	E	E
F-Fair G-Good E-Excellent VG-Very Good		

This table is only a guide. For specific recommendations, contact your ABCcoat representative for your particular corrosion protection needs.

Surface Preparation

Coating performance is proportional to the degree of surface preparation. Refer to specifications for the specific primer being used. Prior to coating, primed surface must be clean, dry, undamaged and free of all contaminants including salt deposits. Steel abrasive blast to SSPC SP-06 or SSPC SP-10, (ISO 8501-1 Sa 2 or Sa 2½). Round off all rough welds and remove all weld spatter.

Application Data

Substrates	Prepared or primed steel,		
Primer/s	ABCcoat 68 Series, ABCcoat 385 PA		
Method	Airless, conventional spray, brush or roller		
Mixing ratio (by volume)	1 part resin to 1 part cure		
Pot life (hours)		°F/°C	
	90/32	70/21	50/10
non-accelerated	1	2	4
accelerated (2 pts 861/10 gal)	NR	¾	2
Environmental conditions			
Temperature	°F	°C	
air	40 to 122	5 to 50	
surface	40 to 140	5 to 60	
Surface temperatures must be at least 5°F (3°C) above dew point to prevent condensation.			
Drying time (ASTM D1640) @ 6 mils, DFT (hours)			
		°F/°C	
Non-accelerated	90/32	70/21	50/10
touch	3	6	10
through	10	16	24
recoat/topcoat (min)	10	16	24
recoat/topcoat (max,days)			
383H and other epoxies	30	30	30
450H, 700, 1001	7	14	30
Accelerated (2 pts 861/10 gal)			
touch	NR	3	8
through	NR	12	20
recoat/topcoat (min)	NR	12	20
recoat/topcoat (max, days)			
383H and other epoxies	NR	14	21
450H, 700, 1001	NR	7	14
<i>Drying times are dependent on air and surface temperatures as well as film thickness, ventilation and relative humidity. Maximum recoating time is highly dependent upon actual surface temperatures - not simply ambient air temperatures. Surface temperatures should be monitored, especially with sun-exposed or otherwise heated surfaces. Higher surface temperatures shorten the maximum recoat window.</i>			
Thinners (up to 1 pt)			
above 70°F (21°C)	ABCcoat 101		
below 70°F (21°C)	ABCcoat 65		
Equipment cleaner	Thinner or Amercoat 12		

Adhere to all application instructions, precautions, conditions and limitations to obtain the maximum performance. When used over recommended primers, refer to Application Instructions for the specific primer being used for surface preparation data and application and drying procedures. For conditions outside the requirements or limitations described, contact your manufacturer representative.

Application Equipment

The following equipment is listed as a guide and suitable equipment from other manufacturers may be used. Adjustments of pressure and change of tip size may be needed to obtain the proper spray characteristics.

Airless spray – Standard equipment with 30:1 pump ratio or larger with a 0.15- to 0.027- in. (0.38 to 0.69 mm) fluid tip.

Conventional spray – Industrial equipment such as DeVilbiss MBC or JGA spray gun with 78 or 765 air cap and “E” fluid tip, or Binks No. 18 or 62 gun with a 66 x 63PB nozzle set up. Separate air and fluid pressure regulators, and a moisture and oil trap in the main air supply line are recommended.

Power mixer – Jiffy Mixer powered by an air or an explosion-proof electric motor.

Brush – Natural bristle. Maintain wet edge.

Roller – Use industrial roller. Level any air bubbles with bristle brush.

Application Procedure

ABCcoat 383H consists of two components which must be mixed together before use. It is packaged in the proper portions in 2- or 10-gallon units.

1. Flush equipment with thinner or ABCcoat 12 before use.
2. Stir each component thoroughly, then combine resin and cure and mix until uniform.
3. Thin only if necessary for workability, add ABCcoat 65 or 101 up to 1 pint (approximately 12%) per gallon of ABCcoat 383H. Use only manufacturer recommended thinners.
4. Do not mix more material than will be used within pot life. Pot life is shortened by higher temperatures.
5. For conventional spray, use adequate air pressure and volume to ensure proper atomization.
6. Apply a wet coat in even, parallel passes; overlap each pass 50 percent. If required, cross-spray at right angles to avoid holidays, bare areas and pinholes.
Note: When applying directly over inorganic zincs or zinc-rich primers, a mist coat/full coat technique may be required to minimize bubbling, especially if ABCcoat 861 accelerator is used. This will depend on the age of the primer, surface roughness, and environmental conditions during application and curing.
7. Check thickness of dry coating with a nondestructive dry film thickness gauge, such as Mikrotest or Elcometer. If less than specified thickness, apply additional material as needed.
8. Small damaged or bare areas and random pinholes or holidays can be touched up by brush. Repair larger areas by spray.
9. In confined areas ventilate with clean air during application and drying until all solvents are removed. Temperature and humidity of ventilating air must be such that moisture condensation will not form on surface.
10. Clean all equipment with recommended cleaner immediately after use or at least at the end of each working day or shift. When left in spray equipment, the product will cure and cause clogging.

Safety Precautions

Read each component's material safety data sheet before use. Mixed material has hazards of each component. Safety precautions must be strictly followed during storage, handling and use.

CAUTION – Improper use and handling of this product can be hazardous to health and cause fire or explosion. Do not use this product without first taking all appropriate safety measures to prevent property damage and injuries. These measures may include, without limitation: implementation of proper ventilation, use of proper lamps, wearing of proper protective clothing and masks, tenting and proper separation of application areas. Consult your supervisor. Proper ventilation and protective measures must be provided during application and drying to keep spray mists and vapor concentrations within safe limits and to protect against toxic hazards. Necessary safety equipment must be used and ventilation requirements carefully observed, especially in confined or enclosed spaces, such as tank interiors and buildings.

This product is to be used by those knowledgeable about proper application methods. Manufacturer makes no recommendation about the types of safety measures that may need to be adopted because these depend on application environment and space, of which manufacturer is unaware and over which it has no control.

If you do not fully understand these warnings and instructions or if you cannot strictly comply with them, do not use the product.

Note: Consult Code of Federal Regulations Title 29, Labor, parts 1910 and 1915 concerning occupational safety and health standards and regulations, as well as any other applicable federal, state and local regulations on safe practices in coating operations.

This product is for industrial use only. Not for residential use.

Warranty

Manufacturer warrants its products to be free from defects in material and workmanship. Manufacturer's sole obligation and Buyer's exclusive remedy in connection with the products shall be limited, at manufacturer's option, to either replacement of products not conforming to this Warranty or credit to Buyer's account in the invoices amount of the nonconforming products. Any claim under this Warranty must be made by Buyer to manufacturer in writing within five (5) days of Buyer's discovery of the claimed defect, but in no event later than the expiration of the applicable shelf life, or one year from the delivery date, whichever is earlier. Buyer's failure to notify manufacturer of such nonconformance as required herein shall bar buyer from recovery under this Warranty.

Manufacturer makes no other warranties concerning the product. No other warranties, whether express, implied, or statutory, such as warranties of merchantability or fitness for a particular purpose, shall apply. In no event shall manufacturer be liable for consequential or incidental damages.

Any recommendation or suggestion relating to the use of the products made by manufacturer, whether in its technical literature, or in response to specific inquiry, or otherwise is based on data believed to be reliable; however, the products and information are intended for use by Buyers having requisite skill and know-how in the industry, and therefore it is for Buyer to satisfy itself of the suitability of the products for its own particular use and it shall be deemed that Buyer has done so, at its sole discretion and risk. Variation in environment, changes in procedures of use, or extrapolation of data may cause unsatisfactory results.

Limitation of Liability

Manufacturer's liability on any claim of any kind, including claims based upon manufacturer's negligence or strict liability, for any loss or damage arising out of, connected with, or resulting from the use of the products, shall in no case exceed the purchase price allocable to the products or part thereof which give rise to the claim. **In no event shall manufacturer be liable for consequential or incidental damages.**

Due to manufacturer's policy of continuous product improvement, the information contained in this Product Data/ Application Instructions sheet is subject to change without notice. It is the Buyer's responsibility to check that this issue is current prior to using the product. For the most up-to-date Product Data/ Application Instructions always refer to the manufacturer's website.

Shipping Data

Packaging	2- and 10-gal units	
Shipping weight (approx.)	lb	kg
cure, 1 gal in 1-gal can	13	5.6
resin, 1 gal in 1-gal can	14	6.4
cure, 5 gal in 5-gal can	66	30.0
resin, 5 gal in 5-gal can	69	31.4

Shelf life when stored indoors at 40 to 100°F (4 to 38°C)
cure, resin 1 year from shipment date

Numerical values are subject to normal manufacturing tolerances, color and testing variances. Allow for application losses and surface irregularities. See application instructions for complete information and safety precautions.

The mixed product is photochemically reactive as defined by the South Coast Air Quality Management District's Rule 102 or equivalent regulations.

Material Receipt Inspection and Storage Conditions

A material receipt inspection is nothing more than verifying that what was ordered for the project was shipped to the project site, and was received in good condition. The contractor should verify the name of the manufacturer; the product name, number and color; the shelf life of the coating components (discussed earlier in this module); and the type and quantity of thinner received. In addition, the contractor should record the batch or lot number associated with each component (and thinner), in the event that a formulation problem with the batch is discovered later on. If multiple batches of the same product are used on a single project, then the contractor's QC personnel and the QA inspector should record which batch is used on which portion of the project. Without this information, batch problems can be very difficult to trace after the fact.



Likewise, the coatings inspector should record the name of the coating manufacturer, the product name and no. or code, and the batch no. or lot no. of each component. The manufacturer, product code and batch no. for any thinner brought onto the project site should also be recorded by the inspector. Some coatings are shipped to the project site with an accompanying certificate of acceptance or certificate of compliance. These documents should be properly filed and their receipt should be documented. Batch numbers or lot numbers can be found on the can label, or they may be stenciled on the side of the can or on the can lid. Interpreting a coating manufacturer's numbering/lettering scheme that comprise a batch no. can be quite challenging. For example, the manufacturer may use the first 12 letters of the alphabet to code the manufacturing month into the batch (e.g., the letter "B" may indicate a batch manufactured in February, since it is the second month of the year and "B" is the second letter of the alphabet). Or the coating manufacturer may employ other codes to indicate the batch and its manufactured date. Some manufacturers number their batches sequentially. Therefore, it is not possible to interpret when the batch was manufactured. If the batch code is not obvious, then the inspector or contractor should contact the manufacturer, as the manufacturing date is critical when determining whether the coating or

component of the coating is within the manufacturer's published shelf life. Remember, many industrial coatings are multiple component, which means they are comprised of two or even three components. All components must be blended into one container prior to application. Otherwise they will not cure, or provide protection of the underlying coating layer(s) and/or the substrate.

The contractor should not only verify that the proper components of each coating are received, but should also verify that the coatings are properly stored on the project site prior to use. The manufacturer's product data sheets will contain storage conditions of temperature and humidity. Some specifications will require the contractor to monitor the actual temperature and humidity in the storage facility using a recording temperature/humidity instrument. Most manufacturers of waterborne coatings require the contractor to protect the coatings from freezing during storage. Excessive heat or high humidity can be equally as damaging to coating materials during storage.

Contractors may elect to use chart recorders to document the temperature and relative humidity over a 24-hour or 7-day period, inside paint storage areas. Limitations to use of this type of equipment include battery life (can be somewhat limited) and the fact that someone is responsible for changing the chart daily or weekly. Also, the charts must be stored in the project file.

Palm-sized data loggers are an alternative to chart recorders. These devices are self-contained, portable recorders equipped with internal temperature and humidity sensors, memory and extended battery life (multi-year). The data loggers are placed in storage area and time-based temperature/humidity readings are acquired automatically (up to several times in one minute). The data collected by the devices can be downloaded to computer software for "paperless" recordkeeping.



Data logging devices for monitoring paint storage conditions

Inspection of Mixing, Thinning and Application of Coatings

Next to surface preparation, the inspection of mixing, thinning and coating application procedures can make or break a coatings project. Traditionally a lot of time, money and effort are expended to properly prepare a surface for coating. These efforts can be wasted very quickly if a product is mis-mixed, an inappropriate thinner or amount of thinner is used, or poor application technique is employed. These mistakes can result in complete removal of the newly applied coatings. It stands to reason then that the inspection of these procedures as they are occurring can help reduce the number of premature coating failures and the amount of rework.

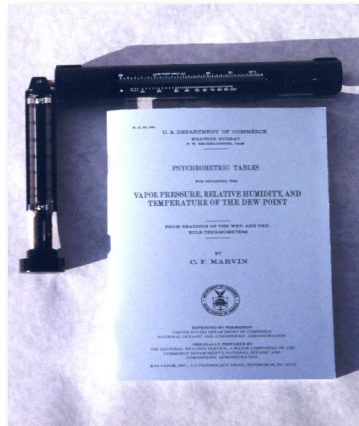
The inspection of mixing, thinning and application includes the following checkpoints. Each of these inspection checkpoints will be discussed. Verification of correct materials (coating and thinner), shelf life and material temperature are included in the list below but were described earlier in this module.

- Verifying correct materials
- Verifying shelf life
- Measuring ambient conditions and surface temperature
- Inspecting mixing procedures
- Measuring coating temperature
- Inspecting thinning procedures
- Measuring wet and dry film thickness
- Measuring individual layer thickness
- Assessing intercoat cleanliness

- Verifying recoat times and temperatures
- Detecting pinholes and holidays
- Assessing cure
- Measuring adhesion
- Measuring coating hardness

Measuring Ambient Conditions and Surface Temperature

The measurement of air temperature, relative humidity, dew point temperature, and surface temperature is required before and during coating application activities. Air or surface temperatures above/below



Sling Psychrometers

the manufacturer's specified range, as well as excessive or inadequate moisture levels in the air (relative humidity) can contribute to application challenges, inadequate curing and performance problems. As we discussed in Module 3, a surface temperature at or below the dew point temperature can result in moisture condensation on the surface. Therefore, it is important to verify that the temperature of the surfaces to be coated is at least 3°C (5°F) higher than the

temperature of the dew point*, and to verify that the air and surface temperatures, as well as the relative humidity, are all within the coating manufacturers' specified ranges and/or as required by the project specification.



Thermocouple Digital Surface Thermometer

These values (air temperature, relative humidity, surface temperature and dew point temperature) can be obtained using sling or battery-powered psychrometers in conjunction with US Weather Bureau Psychrometric Tables and surface temperature thermometers, or can be obtained using direct read-out electronic psychrometers equipped with surface temperature probes. The step-by-step use of this instrumentation was described in Module 3. It is important that the inspector not rely on prevailing weather conditions from a local service (e.g., airport weather station), as conditions at the project site can vary considerably. Ambient conditions should be measured and

**May see additional requirements (i.e., "and rising," "not falling")*



Wind Meter

recorded prior to mixing the coating materials and at 4-hour intervals thereafter, unless conditions appear to be declining. In this case, more frequent checks may be required. If coating work will be done inside a facility, tank, or inside containment, then the prevailing ambient conditions *inside* these areas (at the actual location of the work) should be assessed. The location, date, time of day and the conditions of air temperature, relative humidity, dew point temperature, and surface temperature should be recorded on forms or in log books. A wind meter can be used to monitor wind speed if required by the project specification.

Inspecting Mixing Procedures

Prior to mixing the coatings, the materials should be checked to verify that they are within the manufacturer's shelf life. Using coating materials beyond the shelf life or "expiration date" can result in mixing and application difficulties as well as poor coating performance.

The personnel responsible for mixing the coating materials should be knowledgeable in mixing procedures for various generic coating types, and should both read and comprehend the coating manufacturer's written instructions for mixing. All liquid components should be thoroughly blended using a shear-type mixing blade (e.g., "Jiffy" mixer). If the coating to be applied is multi-component, the inspector must assess whether partial kit mixing is permitted. Most of the time, the mixing of partial kits is prohibited by the manufacturer and/or the project specification. If permitted, the mixer will need to determine whether the components should be blended by weight or by volume. If by weight, then a scale is required to weigh-out the individual components. If by volume, then graduated containers are required so that the individual components can be measured out. In general, the mixing of partial kits should be discouraged, as mathematical errors and approximate measurements can lead to mixing errors. Special touch-up kits or cartridges (described earlier in this module) are available from some manufacturers and can be used to repair small areas exhibiting damage.

Mixing Zinc Primers

Zinc-rich primers containing a zinc powder component require special mixing procedures. After blending the liquid component(s), the zinc powder is slowly sifted into the liquid while under agitation. It is

important not to reverse this procedure (empty the liquid into the zinc powder). After the zinc powder is thoroughly blended into the liquid components, the mix should be strained through a fine mesh screen to remove any un-wetted zinc particles that may clog the spray tip. Straining of other coatings (non-zinc-rich) is usually not necessary unless required by the project specification.

Measuring Coating Temperature

After all of the components are thoroughly blended, the temperature of the mixed coating can be measured using a paint thermometer, which contains an 8” long stainless steel stem and a clip for attaching the thermometer to the side of the paint can. After a minimum of three minutes, the temperature of the coating can be read from the thermometer and recorded. Thermocouple-type thermometers with immersion probes reveal the coating temperature more rapidly than a paint thermometer. The temperature of the coating materials is important, since the induction time and the pot life are both based on the temperature of the coating, not the air or surface temperature.

Induction Period

Some coatings require an induction period. Also known as sweat-in, stand-in, cook time, and digestion, this represents a specific period of time (after blending of the components but before application) that the coating must chemically react or “simmer.” Without this induction time, the coating may not properly or fully cure and the applicator may encounter application difficulties (e.g., sagging, etc.). Not all coatings and not all manufacturers require an induction time. It is based on the formulation of the material. If required, the time period and material temperature will be indicated on the manufacturer’s product data sheets, typically under the “mixing” instructions. Generally, the warmer the material, the shorter the induction time that is required. Conversely cooler materials will require a longer induction time. Induction time is part of the pot life, discussed next. As stated earlier, a coating with a four-hour pot life at 25°C (77°F) and a 30-minute induction at the same temperature has a usable pot life of only 3 ½ hours.

Pot Life

The pot life of a multi-component material is the period of time (starting immediately after mixing the components together) that the coating is usable. The pot life varies depending on the manufacture and the formulation of the coating, and can range from a few minutes to 24 hours or more. Once the pot life has expired, any remaining coating should not be used.

Documentation and Reporting Procedures Relating to Inspection of Coating Mixing

Documentation of coating mixing procedures includes:

- The manufacturer and product name/number, color, and generic type of the coating material that was blended;
- The batch number(s) of the component(s);
- The number of kits mixed and the size of each kit;
- The mix ratio;
- Induction time (if required);
- The date and time the mixing occurred;
- The method used to agitate the individual components and the blended components; and
- The coating layer (primer, intermediate, finish, etc.)

In addition, the inspector should record whether or not the coating material was strained, and should document the actual coating temperature. If the project specification or coating manufacturer requires pot agitation during application, then the method used by the contractor to ensure the coating remains blended throughout the application process should be recorded.

Coating Mixing Procedures

One of the most important steps in the successful installation of a protective coating system is the proper mixing or blending of the coating materials, prior to application. The procedure for blending single component materials is straightforward and needs little instruction other than ensuring the material is homogeneous by mixing all of the settled pigment and solids materials into the liquid.

Conversely, the mixing procedures for multiple component materials can be more complex, and often requires the individual responsible for mixing the coatings and the inspector to read and comprehend the product data sheets. This section provides a step-by-step guide to the proper mixing procedures of multiple component coating materials.

Coating Mixing Step 1: Agitating the Individual Components



Before combining the individual components of the coating (if multi-component), the individual liquid components must be thoroughly mixed. Power agitation using shear-type mixing blade such as a “Jiffy Mixer” mounted into a pneumatically-operated drill or stirrer is often required. Hand stirring using wooden paddles may be acceptable for house paints, but is inadequate for mixing industrial coatings and is often prohibited by the specification. Non-liquid components like zinc powder do not require agitation.

Coating Mixing Step 2: Blending the Components and Mixing the Blended Product



Most coating manufacturers and/or the project specifications prohibit the blending of partial kits. In fact, most manufacturers require that complete kits be mixed. This is for good reason. First, many coating components may be ratioed by weight, not by volume. So in order to mix partial kits, the contractor would need to accurately weigh out a portion of each component prior to blending. In addition, there may be a critical minimum volume of material that must be blended so that the chemical curing reaction between the components occurs. This information is typically not published, but is no less critical. Many coatings are available in both larger and smaller kits. The contractor may choose to have a few smaller kits on hand, although smaller kits may be more costly. Excess mixed components cannot be saved and must be disposed of properly. Mixing instructions are provided on the manufacturer’s product data sheet.

The Bottom Line

Unless partial kit mixing is permitted by the specification and the coating manufacturer (and the ratio of components is published), the contractor should always mix complete kits. The coating manufacturer pre-measures each component to ensure the proper ratio is achieved when complete kits are used. Even if partial kit mixing is permitted and the ratio is known, the contractor must have graduated containers for blending by volume or weighing devices (scales) for blending by weight before partial mixing should even be attempted.

Once the components are combined into one container, they must be thoroughly blended by power-driven agitation using shear-type mixing blade as described earlier. Alternatively, the materials can be blended by “boxing,” which is done by dumping ½ of the material into a clean container, then alternating dumping the material back and forth, from container to container until the material is blended. This procedure is typically prohibited when mixing inorganic zinc-rich primers, moisture cured urethanes or other coating materials that react with moisture. Remember, once the coating material is blended, the “pot life clock” begins. Some manufacturers provide “touch-up” kits or cartridges, which are designed to patch or repair damaged coating without having to mix a large kit. These cartridges are typically supplied in two-component tubes. A plunger pushes the components through a built-in static mixer, which blends the components in a 1:1 ratio. Once the blended components exit the static mixer, the coating is applied to the damaged area using a brush.

Mixing Zinc-Rich Primers

Since zinc-rich primers (solvent borne) are commonly used throughout the industrial sector, it is worth spending a few minutes describing the special mixing procedures for these types of coatings.

Some zinc-rich primers are single component and cure by a reaction with airborne moisture. In this case, the zinc powder is already blended with the liquid, so the single component material mixing instructions described earlier can be employed for these types of products. In fact, over-mixing moisture-cured zinc-rich primers can entrain (bring in) moisture, which can cause the material to gel.



Multi-component zinc-rich primers can be either two or three component. In most cases, the zinc powder is one of the components that must be blended with the liquid component(s). In this case, the liquid components are thoroughly agitated, then the zinc powder is slowly and evenly dispersed into the liquid component(s) while the liquid is under power-driven agitation. Once all of the zinc powder is blended in, the coating should be power agitated for several minutes to help ensure thorough wetting of the zinc particles. Finally, the blended coating should be strained through a fine mesh cloth sieve or screen to remove any particles that may clog the spray gun tip or become lodged in the applied coating film.

Note: Any coating can be strained after mixing. Some specifications require straining of the coating material after mixing and before application.

Coating Mixing Step 3: Measure the Coating Temperature



Taking the Coating Temperature

After the components are blended and strained (if required), the temperature of the coating should be measured. A long-stem, stainless steel liquid thermometer can be used for this. The stem thermometer may be equipped with a can clip, so that that thermometer can be attached to the perimeter lip of the can. The thermometer should be allowed to stabilize for three minutes before it is read, then removed and cleaned. Thermocouple thermometers with liquid probes can also be used. It is this temperature that determines the length of the induction time and/or the pot life (both terms were described earlier) of the coating. As a general rule, the warmer the coating, the shorter the induction time and/or the pot life, since heat increases the rate of the curing reaction. A non-contact thermometer should not be used, since it will only read the temperature of the surface of the coating.

Coating Mixing Step 4: Determine Whether Pot Agitation During Application is Required

Because zinc is a dense pigment, it may settle out of the blended material during application. In this case, the original mix ratio of the product becomes distorted, and much of the protection afforded by the

primer is lying on the bottom of the pot or can. To prevent settling-out of the zinc, most coating manufacturers and project specifications require automated, constant agitation of the mixed material during application. In fact many spray systems are equipped with motor-driven agitating blades. Note however that many single component, moisture cured zinc-rich primers contain anti-settling agents and do not require pot agitation during spray-out. In fact, agitation can draw airborne moisture into the coating, causing it to gel. Therefore pot agitation is not recommended for these products, even though they contain zinc pigment. The PDS will often provide guidance as to whether or not pot agitation during application is required.

Coating Thinning Procedures

Similar to mixing, thinning of a coating material is perceived to be rather straightforward and requires little explanation. However, the type and amount of thinner added to the coating impacts the volatile organic compound (VOC) content, the target wet film thickness of the coating, and over thinning or under thinning a coating can adversely affect the application and the performance characteristics. Therefore, thinning of a coating is an important area to discuss. It is also important to verify that thinning is done properly.

Determine Whether Thinning is Permitted



Thinning

Fairly restrictive air quality regulations have caused manufacturers to reformulate coating materials with less solvent (higher solids content) and even different solvents. To this end, field addition of thinner for the purposes of reducing the viscosity of the coating material may be restricted or even prohibited. If thinning is allowed, there is oftentimes a maximum type and amount of thinner that can be added in order to maintain the volatile organic compound threshold established by Federal and/or local air quality regulations (which may be more restrictive than the Federal limit). Therefore, prior to adding thinner, the contractor must determine whether thinning is permitted. Some manufacturers prohibit thinner addition, and claim that the coatings can be applied as supplied. Conversely, while the coating manufacturer may allow the coating to be thinned, the

specification may prohibit the use of thinner. Heat may also be used to reduce coating viscosity, but may affect pot life.

Determine the Type and the Amount of Thinner to Add

Once it is determined that thinner addition is permitted and necessary, the next step is to determine the type and amount of thinner to add. This information can be gleaned from the manufacturer's product data sheet. The type of thinner to add may be dependent on the air temperature during application. Manufacturers may have a slow-evaporating thinner for warmer temperatures and a faster one for colder temperatures. Only the manufacturer's recommended thinner should be used. In fact, use of thinners other than those recommended can void the warranty on the coating, and can result in reduced coating system performance. Thinners added to coatings should be clean, new, and in their original containers. Contaminated, recycled or used thinners should never be used for reducing coatings.

The amount of thinner to add is also based on the application temperatures, the method of application and the local air quality regulations. Most coating manufacturers will indicate the VOC content of the coating material as formulated, and the adjusted VOC content based on the amount of thinner added. Any *regulated* thinner that is added to the coating in the field will increase the VOC content. Conversely, the use of a *non-regulated* solvent (e.g., water) will not increase the VOC content of the coating. But there is still a maximum amount that can be added to maintain sag resistance and performance of the coating while in service.

The permissible amount of thinner that can be added is reported on the product data sheets in various ways, including:

“Thin up to 100 mL per liter”

“Thin up to 1 pint per gallon”

“Thin up to 10%”

These three statements are phrased as the maximum amount of thinner that can be added. It may not be necessary to add the maximum amount. For example 50 mL per liter (5%) (1/2 pint per gallon) may be adequate for proper atomization and flow-out of the coating.

Calculations for converting from percentage thinner to volume thinner were described in Module 4.

Use of Viscosity Cups

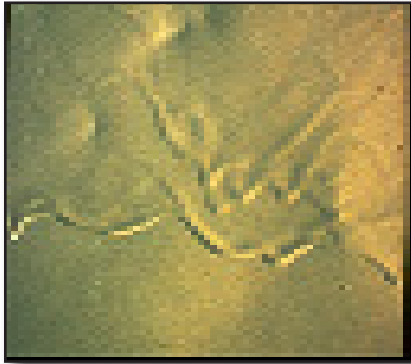
Zahn or Ford viscosity cups can be used to measure the viscosity of a coating. The viscosity cup is used to measure the adjustment made to a coating using thinner. A viscosity cup is a stainless steel cup on a long handle that holds a known volume of coating. The cup has a precise diameter hole in the bottom. The cup is filled with coating and a stopwatch is used to time how long it takes the coating to drain from the cup through the orifice. Thinner can be added to the coating to aid in adjusting the flow of the coating through the hole (the more thinner that is added, the faster the coating will drain from the cup). The inspector must know the target number of seconds that the cup is intended to drain, (based on the temperature of the coating), the manufacturer and orifice size of the viscosity cup to use, and must assure that the test is conducted out of wind, so that a true end point (stream break) can be noted. Many coatings used today will not flow through the small orifice, and the effect of temperature and other jobsite conditions are too difficult to control, making the use of viscosity cups for the purpose of determining thinner addition nearly obsolete.

Consequences of Under- and Over-Thinning Consequences of Adding Thinner to Extend the Pot Life

You may find that some contractors do not measure the amount of thinner that is added to the coating, but simply dump in thinner until the material appears or “feels” right. There are several consequences associated with this practice, some of which affect both quality and productivity.

First, by adding an unknown quantity of thinner to the coating, the effect on the VOC content of the coating is unknown, which may result in a violation of a local air quality regulation or contract requirement. Not only is the VOC content unknown, but the target wet film thickness cannot be accurately calculated, since the amount of thinner added cannot be included in the equation (shown earlier). This can result in insufficient or excessive coating layer thickness, causing potential rework. Despite what many may think, the addition of thinner does not increase the spreading rate of the coating, since the thinner is

a component of the wet film, but not the dry film layer. While the volume of material being applied to the surface increases, the resulting dry film thickness and coverage rate will not.



Sagging

The addition of excessive amounts of thinner may cause the coating to sag (downward movement of a wet film between application and setting, resulting in an uneven coating with a thick lower edge) on vertical surfaces, and if the surface of the coating dries or “skins-over” before the solvents in the body of the coating have an opportunity to escape and evaporate, a porous film filled with solvent voids can result. Conversely, under-thinning a coating may cause poor film integrity, as the applied material may dry before it has an opportunity to flow together and knit into a continuous film. This can result in exposure of the substrate or the underlying coating layers, which may not be resistant to the service environment.

As a coating approaches the end of its pot life, the material oftentimes (not always) increases in viscosity. Some believe that by adding thinner and reducing the viscosity of the coating, that they can actually extend the pot life of the coating. This is not the case. The pot life of a coating material is a defined time period that can only be extended for a short period of time (not overnight) by maintaining the material at a lower temperature. For example, if the pot life of a coating is 4 hours at 25°C (77°F), it may be possible to use the coating for up to 5 hours after it is mixed if the temperature of the material is maintained at 18°C (65°F). Therefore, the practice of adding thinner to reduce viscosity, so that the coating can be used beyond the pot life is poor practice and can result in premature failure of the applied film. Any thinner used should be added to the coating immediately after mixing, and not again until a new mix is blended.

Inspecting Thinning Procedures

With the advent of stricter air quality regulations, the type and amount of thinner that can be added to the coating may need to be monitored. If thinning is permitted by the coating manufacturer and by the project specification, then only the manufacturer’s recommended type and amount of thinner can be used. Use of alternate thinners or over-thinning a coating can result in application difficulties and premature coating failure, not to mention violation of local air quality

regulations. If thinning is permitted (and is necessary), the inspector should verify the correct type of thinner is used and should verify that graduated containers are used to measure the quantity of thinner e.g., 100 mL per liter (one pint per gallon), 10% of the total volume mixed, etc. Thinner addition for the purpose of reducing the viscosity of the coating material to “extend” the pot life is not recommended and may adversely affect coating performance. The only way to extend the pot life is to reduce the material temperature (within the range listed on the manufacturer’s product data sheet) to retard the rate of reaction.

Documentation and Reporting Procedures Relating to Inspection of Thinning (reducing)

Documentation of coating thinning procedures includes:

- The manufacturer of the thinner/reducer and the thinner/reducer name and/or no.;
- The batch no. of the thinner;
- The amount of thinner added (based on percentage or volume); and
- The date and time the thinner was added to the coating

Coating Application Methods

Transferring the coating materials from the can to the surface can be accomplished in a number of ways. Factors that should be considered when deciding on an application method include the size and configuration of the surfaces to be coated, the desired or required transfer efficiency, the type of coating, environmental regulations, the proximity to other operations/conditions, the specification and the coating manufacturer’s recommendations.

The six methods of coating application that we will describe in this Module include:

1. Brushes, rollers and daubers
2. Airless spray
3. Conventional (air) spray
4. High Volume Low Pressure (HVLP) spray
5. Air-assisted airless spray
6. Plural component spray

Brushes, Rollers and Daubers

The use of brushes on industrial painting projects is generally restricted to striping or “cutting in” of inside/outside corners, welds, around rivet heads and bolt/nut assemblies, etc. Striping is the



Paint Brushes

application of a layer of coating to surfaces that are relatively difficult to achieve a normal film build on. Wet striping can be done on any coating layer. After the “wet stripe” is given an opportunity to release most of the solvent (becomes tacky after 5-10 minutes), the full coat is applied. Conversely, dry striping is applied after the full coat of primer or intermediate coat, since the stripe coat in this case is allowed to *dry* for the full recoat interval (e.g., 12-16 hours), but not completely cure. Many specifications that address the application of lining systems (e.g., inside of water storage tanks) will require striping of the weld seams and other appurtenances prior to application of the full coat, since the service environment is “continuous immersion.” If striping is not specified, then it is up to the contractor as to whether he wants to apply a stripe coat.

Similar to brushes, daubers are used to coat inside crevices like back-to-back angles. There is little control of film thickness using these devices. Rollers can be used to coat large, flat surfaces, and provide the user with a high “transfer efficiency rating” (the percentage of coating



Roller Application

that reaches the surface versus waste). Careful attention must be paid to acquiring the recommended roller nap depth. Too deep of a roller nap can result in streaking and poor appearance. Additionally, roller nap can be pulled from the roller core and become embedded in the dry coating film. This can act like a small wick and draw moisture into the coating film. Also, the gloss level of the coating will be reduced as roller “stipple” is increased, and coating thickness is difficult to control. Some industrial coatings dry/cure too rapidly to be recommended for roller application.

Airless Spray

Airless spray is by far the most common method used for the application of industrial and marine coatings. If the equipment is operating properly and the applicator employs good spray technique,



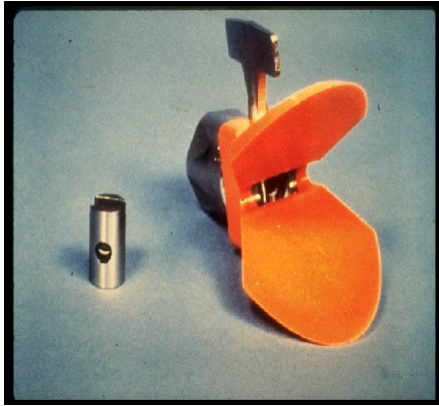
Airless Spray Gun

the finish can approach that which is created by conventional or HVLP spray, but at much higher production levels. Because airless spray does not employ compressed air to atomize the coating, the transfer efficiency is relatively higher than conventional spray, reducing airborne emissions. And because airless spray does not incorporate compressed air into the paint stream, the cleanliness of the compressed air is not critical.

Airless spray is analogous to a garden hose with a spray nozzle on the end. Both work by pressurizing a stream of fluid through a tiny orifice in the spray nozzle. This pressure is released on the opposite side of the spray nozzle as the fluid exits the nozzle. This causes the fluid to atomize, or to break-up into tiny-sized droplets. For perspective, residential water supply pressure may be 690-827 KPa (100-120 psi), while airless paint pressure is 10 to 75 times higher.

A reciprocating pump is used to siphon paint from a non-pressurized container into the pump, which puts the coating under the designated pressure. These pumps are ratioed. For every pound of pressure that is regulated into the spray pump, the pump generates a given paint pressure. For example, an airless spray pump that is ratioed at 45:1 will produce 310 KPa (45 psi) of paint pressure for every 7 KPa (1 psi) of air that is regulated into the pump. Therefore, if the coating manufacturer recommends an airless spray pressure of 25 MPa (3,600 psi), then the pressure regulator should be set at 80 psi ($80 \times 45 = 3,600$). Pumps ratioed at 74:1 and higher can be used for application of viscous coating materials that may otherwise not be able to be atomized.

The equipment itself consists of a paint pump that is operated using an air compressor (although electric pumps are available) that is equipped with a regulator. Coating manufacturers provide recommended airless spray pressures, which frequently have to be adjusted slightly based on project conditions (amount of thinner addition, temperature, etc.). A single hose containing the paint traverses to the spray gun from the pump. There are no controls on the spray gun. In fact the only way to control the shape of the spray fan is to change the spray tip. Most tips are identified using a 3-digit number; the first number is doubled to obtain the size of the spray fan at 30 cm (12 inches) from the surface, and the remaining 2 digits indicate the orifice size of the spray tip. For example, the applicator may choose a 521 tip. The orifice size of this spray tip is 0.5 mm (0.021 inches), and the fan width is 25 cm (10



Airless Spray Tip and Guard

inches) when the spray tip is maintained 30 cm (12 inches) from the surface. An airless spray gun cannot be “half-triggered” the way the conventional or HVLP guns can. sssss

The operating pressures of airless spray gun are considered dangerously high, and paint can be injected beneath the operator’s skin if fingers are held too close to the spray tip and the trigger is pulled. Use of a special guard (typically bright orange or yellow) attached to the tip and the use of a trigger lock can help prevent these types of injuries.

The distance that the airless spray gun is held from the surface is approximately 30 cm (12 inches), and varies depending on the type of coating and prevailing spraying conditions.

Conventional (air) Spray

Conventional or “air-atomized” spray uses compressed air to transport the paint from a pressurized pot to the spray gun, to atomize the coating into a fine spray, then propel the atomized coating to the surface. The ratio of air to paint is quite high (some say 600:1). Therefore, compressed air cleanliness is critical and transfer efficiency is relatively low. The major reason conventional (air) spray is used to apply industrial coatings is the ability to control both the amount of paint that exits the spray gun tip and the shape of the spray pattern.

Conventional spray equipment consists of a pressure pot equipped with two regulators. One pressure regulator is used to control the

amount of pressure in the pot itself (known as pot pressure) and the other is used to control the volume of atomization air that is used to break up the stream of paint exiting the spray tip. Coating manufacturers will provide recommended pot and atomization pressures on the PDS, which oftentimes have to be adjusted slightly based on project conditions (amount of thinner addition, temperature, etc.). Two hoses traverse to the spray gun from the pot. One hose contains the paint and the other contains the atomization air. There are two controls on the spray gun. The lower control regulates the amount of paint that comes out of the spray tip.



Air Hose



Paint Hose



Air Cap

This control essentially adjusts how far the operator can pull back the spray gun trigger (and the needle from the tip opening), which regulates the amount of paint that exits the spray tip. The upper control regulates the shape of the fan pattern from a small circle for striping of corners, etc. to a larger oval for spraying flat surfaces.

A conventional spray gun can be “half-triggered” (pull the trigger back part way), so that the atomization air (without paint) exits the spray nozzle. This compressed air can be used to perform a final blow-down of the surface immediately prior to coating application.



Half-Triggering a Conventional Spray Gun

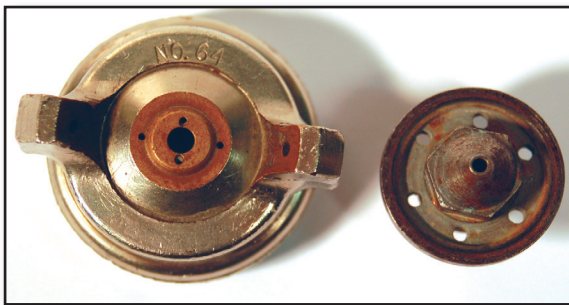
The distance that the conventional spray gun is held from the surface is 15-20 cm (6-8 inches), and varies depending on the type of coating and prevailing spraying conditions (i.e., air temperature, wind speed). We will be describing spray techniques in more depth later in this module.

High Volume Low Pressure (HVLP) Spray

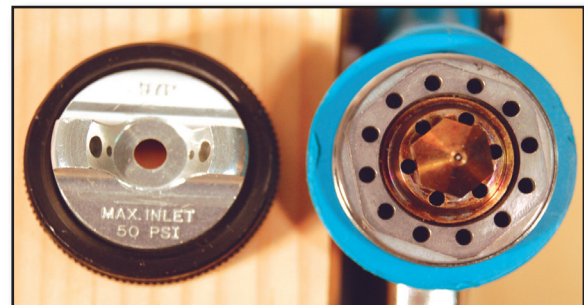
Similar to conventional spray, high volume low pressure (or HVLP) spray uses compressed air to transport the paint from a pressurized pot to the spray gun, to atomize the coating into a fine spray, then propel the atomized coating to the surface. In this case, the coating is atomized using a high volume of air under very low pressure (less than 69 KPa [10 psi], versus 345-517 KPa [50-75 psi] for conventional spray). Like conventional spray, compressed air cleanliness is critical. But unlike conventional spray, the transfer efficiency can be much higher. The major reasons HVLP spray is used to apply industrial

coatings is the ability to control both the amount of paint that exits the spray gun tip, the shape of the spray pattern and most importantly reduced blow-back (paint rebound from the surface due to the high velocity of the paint as it exits the spray tip), which increases the transfer efficiency of the paint. When the transfer efficiency is increased, less coating is used, which translates into lower volatile organic compound (VOC) emissions.

The equipment itself consists of a pressure pot equipped with two regulators (just like conventional spray). A third regulator is sometimes positioned near the spray gun, so that that atomization pressure can be finely regulated just before it enters the spray gun. Unfortunately, many coating manufacturers do not provide recommended pot and atomization pressures for HVLP on their PDS. However, the atomization air should never be set higher than 10 psi. Otherwise, the HVLP spray becomes traditional conventional spray, negating the transfer efficiencies.



Conventional Cap and Tip



HVLP Cap and Tip

The biggest noticeable difference between conventional and HVLP spray gun lies in the design of the spray tip and air cap. Compared to conventional spray, the atomization air ports around the perimeter of the spray tip and in the air cap are much larger, enabling a higher *volume* of air to pass through them. Similar to conventional spray, an HVLP spray gun can be “half-triggered” (pull the trigger back part way), so that the atomization air (without paint) exits the spray nozzle. This compressed air can be used to perform a final blow-down of the surface immediately prior to coating application. However, because of the low air pressure, the blow down may not be adequate for removal of heavy dust deposits. The distance that the HVLP spray gun is held from the surface is the same as is used for conventional spray (15-20 cm, or 6-8 inches).

Air-Assisted Airless Spray

Air-assisted airless spray combines the productivity of airless spray with some of the control of conventional spray. An “air cap” attached to the exit port of the spray gun is used to help atomize the coating and to shape the spray fan. One control knob located on the back of the spray gun is used to adjust the pattern shape. Compressed air cleanliness is once again critical to coating quality. Air-assisted airless spray operates at lower pressures than traditional airless spray.

Plural Component Spray

Plural component spray is used for coating materials with a relatively short pot life or coating materials that do not have viscosity-reducing solvents in them (e.g., 100% solids materials). Plural component spray does not require “pre-mixing” of the coating components. Rather, the individual components are pumped to a mixer/manifold at the correct ratio, then are mixed and pumped to the spray gun using a



short material hose that can be intermittently flushed with solvent using a solvent purge system. This is known as an internal mix process. There are also external mix plural component systems that send each component to the spray gun in separate material hoses. The components blend as they exit the spray tip. It is common for the material hoses to be heated for plural component spray, in order to reduce the viscosity of the components (for easier transport and improved atomization). This process is analogous to the motor oil in your vehicle's engine that reduces in viscosity as it increases in temperature.

Plural component spray can employ either fixed ratio or variable ratio proportioning pumps. Fixed ratio pumps can only proportion the components in a set ratio (e.g., 1:1), while a variable ratio pump can proportion the materials according to the required ratio (e.g., 2:1, 4:1, 8:1, 16:1 and so on...). Plural component spray equipment can be complex and typically requires a technician to set-up the equipment and to monitor the mix ratio, so that the coating materials are not applied “off-ratio.” Many plural component apparatuses now contain an off-ratio alarm that alerts the applicator when the ratio of the components is incorrect. This prevents the applicator from applying under or over catalyzed coating to the surface.

Some contractors have employed plural component spray systems even when using multi-component coatings that could be mixed prior to application and have a fairly lengthy pot life. In this case, plural component spray is being used to minimize waste and reduce material usage. That is, by keeping the components separated, the cans containing the individual components can be resealed and used another time, rather than having to discard unused material. Further, the coating will not need to be reduced, since heat can be used to reduce the viscosity of the components. Note that coatings requiring an induction time cannot be applied using plural component equipment.

SSPC's Plural Component Application for Polyureas and High-Solids Coatings training course provides additional information on plural component spray.

Spray Technique



LaserPaint Applicator Training Device

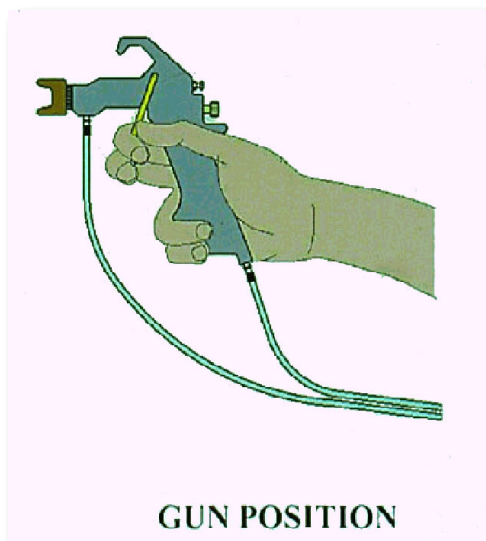
Spray technique cannot typically be taught in a classroom, but rather by practice and experience with the spray equipment and different industrial coatings. In fact, many automotive coating applicators struggle with industrial coatings application, as the techniques and equipment can vary considerably. Therefore, it is not the intent to teach application techniques here, but rather to inform the inspector of the techniques that applicators should demonstrate.

A unique laser device developed and patented by the Iowa Waste Reduction Center (IWRC) attaches to the top of a spray gun and can be used to train new applicators or correct bad habits of experienced sprayers. The applicator attaches the device to the spray gun using the mounting hardware provided with the device, then establishes the correct distance from the spray gun tip to the surface 15.2-20 cm (6-8 inches) for conventional and HVLP spray and 30.5 cm (12 inches) for airless and air-assisted airless spray). The applicator then adjusts the laser control knob so that a single laser “dot” appears on the surface. If the applicator positions the spray gun further away or closer to the surface (than the pre-set distance), or arcs the spray gun (rather than remaining perpendicular to

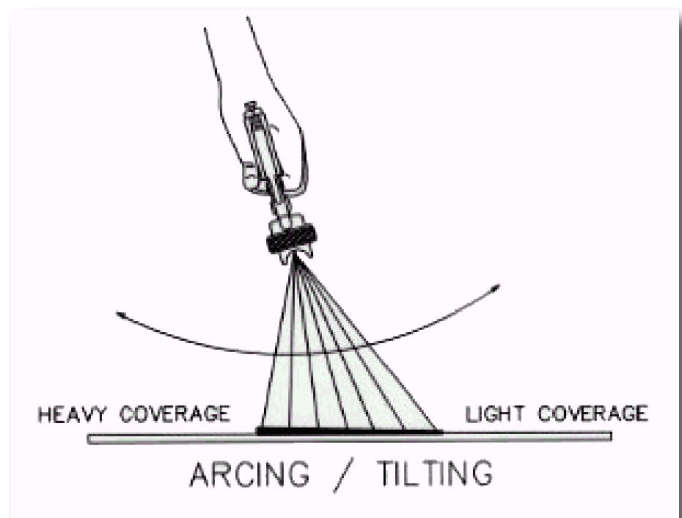
the surface) during actual application, the single laser dot will double, giving the applicator a visual signal to correct the spray gun distance/position (i.e., re-establish the correct spray gun distance/position until the laser dots converge). Also, since the laser device is positioned at the same latitude as the spray gun tip, the laser can be used to indicate the location of the middle of the spray fan, making it easier to overlap spray passes by 50% (described later in this module). The device can be removed once the applicator perfects his technique. The device was invented with the goal of reducing rework and paint waste.

Remain Perpendicular to the Surface; Maintain Proper Distance

In order to build a consistent coating layer, it is important that the spray gun be positioned perpendicular to the surface to be coated, and that the applicator maintain this position throughout the application process. If the applicator does not remain perpendicular to the surface, then light and heavy areas will likely be the result. In addition to remaining perpendicular, the applicator must maintain the proper distance from the surface, which varies depending on the application equipment (conventional, airless, etc.) Spray distances were discussed earlier in this Module.



*Correct Gun Position During Application -
Perpendicular to The Surface*



Incorrect Gun Angle

Use Spray Pass Overlapping and Crosshatch Spray Techniques

The quantity of coating material exiting the spray gun tip varies, due to the atomization air that creates a fan-shaped spray pattern. That is, the amount of material in the center of the fan is typically greater than the amount of material at the ends of the fan pattern. This variation can only be corrected by the applicator. Once the applicator makes the first pass (e.g., left to right), the applicator should overlap the previous pass by 50% when making the second pass (e.g., right to left), then overlapping that pass when making the third pass (left to right again) and so on. This overlapping technique is important. It helps to ensure an even film build and will improve the consistency of coating thickness.

In order to build an even more consistent film, the applicator can alternate between horizontal and vertical passes, overlapping each type of pass by 50% as described above. This is called a crosshatch spray technique.

Calculating Wet Film Thickness

Prior to mixing, thinning and applying the coating, the contractor should determine the target wet film thickness to apply to achieve the specified DFT. Some coating manufacturers list the wet film thickness or “WFT” on the product data sheet (many do not). Even if the target WFT is listed on the PDS, the contractor must ensure that the recommended dry film thickness or “DFT” is the same as the specified DFT for the product. Further, if the coating will be reduced (thinned), the target WFT must be adjusted based on the amount of thinner added, so the manufacturer’s target WFT will no longer be representative. The bottom line is that the contractor and/or the applicator should be knowledgeable in how to calculate a target wet film thickness. In most cases, the inspector is concerned with the dry film thickness and not the wet film thickness. But the contractor must ensure that the proper wet film thickness is applied, in order to comply with the dry film thickness requirements of the specification. If the coating is applied too thin or too thick, then rework is often required.

Calculating the Target Wet Film Thickness

Before you measure the wet film thickness, you will need to calculate the target wet film thickness for the applicator to shoot for by obtaining three values. Without these values, the target wet film thickness (WFT) remains unknown unless it is provided by the coating manufacturer. Also, attempts to determine the WFT without the help of a calculator can result in mathematical errors, so use your calculator.

Value No. 1: The target dry film thickness (DFT)

Value No. 2: The solids by volume content of the coating material

Value No. 3: The amount of thinner that will be added to the coating

Let's look at each of these a little closer to determine where the three values come from.

Step 1: Determine Value No. 1 – The Target Dry Film Thickness

The target dry film thickness (DFT) is indicated in the project specification. It is typically expressed in mils (0.001") or microns (μm). There are 25.4 μm in 1 mil. If the project specification does not provide the target DFT, then you will need to locate the recommended DFT on the coating manufacturer's application instructions. In either case, write down the target DFT. If the project specification or the manufacturer's instructions provide a range for the DFT rather than a target, then write down the range.

Example: *"The primer coat shall be applied to a dry film thickness (DFT) of 51-102 microns (2-4 mils)."*
Write down: 51-102 microns DFT
(2-4 mils DFT)

Step 2: Determine Value No. 2 – The Solids by Volume Content of the Coating Material

When the solids by volume content is indicated on the coating manufacturer's product data sheet, it is typically expressed as a percent (%). This value represents the non-volatile or non-evaporative content of a coating (e.g., the resin, pigment and additives). Often there is a solids by weight value on the product data sheet as well. Do not use this value in determining WFT requirements.

Example: *Solids by Volume: 47%*

If the solids by volume content is not listed on the coating manufacturer's product data sheet, there are two ways to determine it, depending on whether or not you are working in metric units.

Metric Example

1. Start with the standard rule of coating coverage: One liter of coating that is 100% solids by volume will cover 149 square meters if it is applied exactly 25.4 microns thick.
2. Determine coverage rate at 25.4 microns. Locate the theoretical coverage rate and dry film thickness that the coverage rate is based on using the coating manufacturer's product data sheet. Multiply the two numbers together to determine the coverage rate at 25.4 microns.

Example: *The theoretical coverage rate is
37 square meters per liter at 76 microns.
 $76 \div 25.4 = 3$
 $37 \times 3 = 111$ square meters per liter at
25.4 microns dry film thickness*

3. Calculate the solids by volume content. Divide the theoretical coverage rate at 25.4 microns by 149.

Example: *The theoretical coverage rate is
111 square meters per liter at 25.4 microns.
 $111 \div 149 = 0.74$*

4. Covert the solids content to a percentage. Multiply the volume solids value by 100.

Example: *$0.74 \times 100 = 74\%$ solids by volume*

U.S. Customary Units Example

You can use the value for the “theoretical coverage rate at 1 mil” on the product data sheet to estimate the solids by volume content of the coating. This can be a little more challenging, so you'll need to follow these next few steps carefully and you'll need to use your calculator.

1. **Start with the standard rule of coating coverage:** One US gallon of coating that is 100% solids by volume will cover 1,604 square feet if it is applied exactly 1 mil thick.

2. **Determine coverage rate at 1 mil.** Locate the theoretical coverage rate and the dry film thickness that the coverage rate is based on using the coating manufacturer's product data sheet. Multiply the two numbers together to determine the coverage rate at 1 mil.

Example: *The theoretical coverage rate is 401 square feet per gallon at 3 mils. $401 \times 3 = 1203$ square feet per gallon at 1 mil dry film thickness.*

3. **Calculate the solids by volume content.** Divide the theoretical coverage rate at 1 mil by 1,604.

Example: *The theoretical coverage rate is 1,203 square feet per gallon at 1 mil.*
 $1203 \div 1604 = 0.75$

4. **Convert the solids content to a percentage.** Multiply the volume solids value by 100.

Example: *$0.75 \times 100 = 75\%$ solids by volume*

Step 3: Determine Value No. 3 – The Amount of Thinner that will be added to the Coating

Most industrial coatings do not require thinning unless a low temperature increases the viscosity of the coating. Unnecessary thinning should be avoided. Over-thinning a coating may violate air pollution regulations.

If the project specification and the coating manufacturer permit thinner to be added to the coating, the amount of thinner that will be added must be taken into consideration when calculating a target wet film thickness. This is because the thinner is part of the wet film that is applied to the surface, but is not part of the dry film that remains on the surface (the thinner will evaporate into the air).

Coating manufacturers typically communicate the amount of thinner to add based on a percentage of the total volume of coating mixed for application (e.g., 15%), or based on a certain volume (1 pint per gallon). Ultimately, you will need a "percent thinner" value for your

calculation. If the coating manufacturer provides the percentage of thinner to add, then no further work is required. If the coating manufacturer indicates thinner addition by volume, then you will need to calculate the percentage using some very basic units of measurement.

- a) There are 4 quarts in 1 US gallon. A quart is 25% (1/4) of 1 US gallon
- b) There are 8 pints in 1 US gallon. A pint is 12.5% (1/8) of 1 US gallon

Example: *The coating was thinned 1 pint per gallon, or 12.5%*

Now that we have all three values (target DFT, percent solids by volume and percent thinner), we can calculate the target WFT.

Step 4: Select a Formula

There are two formulas. Select only one of the two formulas when calculating a wet film thickness. The formula you should select is based on whether or not the coating was thinned prior to use. Here are the two formulas. Formula A is one step, while Formula B requires two steps.

Formula A (NO thinner addition)

$\text{DFT} \div \% \text{ solids by volume} = \text{WFT}$

Formula B (WITH thinner addition)

Step 1: $\% \text{ solids by volume} \div (100\% + \% \text{ thinner added}) =$
adjusted volume solids content

Step 2: $\text{DFT} \div \text{adjusted volume solids content} = \text{WFT}$

Step 5: Enter the Values into the Formula Selected in Step 4

Once you select a formula, enter the values into the formula to arrive at the wet film thickness range. Remember, ALL percentage values must be converted to decimal format, simply by moving the decimal point two places to the left. For example, 75% is 0.75

Example 1 – DFT range of 51-102 microns (2-4 mils) with no thinner added. The solids by volume is 75%. Use Formula A:

*51 microns (2 mils) DFT ÷ 0.75 solids by volume =
68 microns (2.7 mils) WFT
102 microns (4 mils DFT) ÷ 0.75 solids by volume = 135 microns
(5.3 mils WFT)*

Therefore, the applicator should strive to apply the coating within a range of 63-140 microns (2.5-5.5 mils) WFT.

Example 2 – DFT range of 51-102 micrometers (2-4 mils) with 12.5% thinner added. Use Formula B:

(75% solids by volume ÷ 112.5%) = 67% adjusted volume solids content

*51 microns (2 mils) DFT ÷ 0.67 solids by volume =
76 microns (3.0 mils) WFT
102 microns (4 mils) DFT ÷ 0.67 solids by volume =
152 microns (6.0 mils) WFT*

Therefore, the applicator should strive to apply the coating within a range of 76-152 microns (3-6 mils) WFT. Even with the addition of 12.5% thinner, the coating should “shrink” to 51 to 102 microns (2-4 mils) DFT.

The percentage of solids by volume content of a coating remains a key component in the calculation of the wet film thickness. Unfortunately, the published value may be “theoretical” and based on the formulation. Therefore, the contractor may choose to apply a test area of the coating (thinned if appropriate), measure the wet film thickness, then after the coating dries on the test area, measure the dry film thickness. This will provide the applicators with a “practical” wet film target. If the resulting dry film thickness meets the requirements of the specification, the actual volume solids content of the coating material becomes a moot point. Conversely, if the resulting dry film thickness is too low or too high, the actual percentage of volume solids can be calculated as long as the wet film and dry film thickness is known. Then the revised target wet film thickness can be calculated. This is demonstrated below. Concurrently, the applied coating film can be evaluated for flow characteristics, resistance to sag, etc.

Target DFT (from the specification): 127 microns (5 mils)

Calculated Target WFT (based on 67% solids by volume):
203 microns (8 mils)

Actual WFT (measured): 203 microns (8 mils)

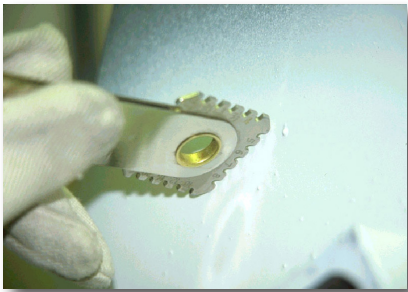
Actual DFT (measured): Only 102 microns (4 mils)

$(\text{Actual DFT} / \text{Actual WFT}) \times 100 = \text{Adjusted Percent Volume Solids Content}$

$102 \div 203 \text{ microns } (4 \div 8 \text{ mils}) \times 100 = .50 \text{ or } 50\%$

Revised Target WFT = $127 \text{ microns } (5 \text{ mils DFT}) \div 0.50 =$
254 microns (10 mils)WFT

Measuring Wet Film Thickness



Wet Film Thickness Gage

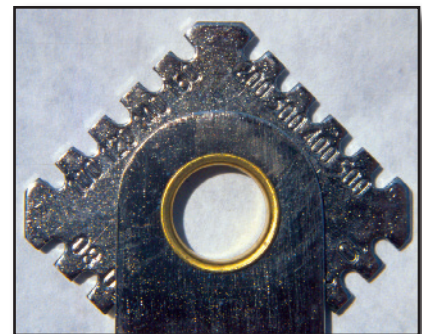
Theoretically, an accurate measurement of the wet film thickness, together with the volume solids content of the coating will correspond to the targeted dry film thickness. Applicators should routinely verify that the targeted wet film thickness of the coating is being achieved during application. That is why a wet film thickness gage should be regarded as much of an applicator's tool as a paint brush or spray gun. The industry standard for measuring wet film thickness is described in ASTM D4414, "Practice for Measurement of Wet Film Thickness by Notch Gages." Calculation of the target wet film thickness was described earlier in this module; the proper use of a wet film thickness notch gage is described in the instrument supplement at the end of this module.



*Low range WFT gage
(1/2 to 20 mils)*



*Mid-range WFT gage
(4 to 60 mils)*



*Metric range WFT gage
(10 to 500 microns)*

Measuring Dry Film Thickness

While the applicator is concerned with the wet film thickness of the applied coating, inspection personnel are much more concerned with the end result, or the dry film thickness. The measurement of wet film thickness is simply a means to an end on most metal surfaces, where measurement of the dry film is feasible. Currently there are two standards that address the nondestructive measurement of coating thickness on steel: SSPC-PA 2 "Procedure for Determining Compliance with Dry Coating Thickness Requirements," and ASTM D7091, "Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals." Each of these standards prescribes methods for verifying the accuracy of the measuring devices and for obtaining coating thickness measurements. SSPC-PA 2 also provides guidance on the frequency of measurements (number of measurements to obtain based on the size of the coated structure) and includes a table of coating thickness restriction levels that establish varying ranges of coating thickness tolerance. Coating Thickness Restriction Level 3 is the default level unless otherwise specified.

Aside from the industry standards, coating thickness measurements should be obtained after the application of each coat in a multiple coat system, not just after the final coat. The vast majority of nondestructive coating thickness gages described in SSPC-PA 2 and ASTM D7091 cannot distinguish individual coating layers, but rather measure the total "gap" between the substrate and the gage probe.

Verifying Gage Accuracy

Prior to obtaining coating thickness measurements, the user must verify the accuracy of the magnetic gage. Otherwise, the coating thickness measurements are of little value. In fact, SSPC-PA 2 requires that the gage be verified for accuracy prior to and after each period of use. You'll notice that we have not used the phrase "calibrate the gage." Typically, the only party that can truly calibrate a coating thickness gage is the manufacturer or approved laboratory. Rather, the user can verify accuracy and adjust/optimize the gage if necessary.

SSPC-PA 2 and ASTM D7091 define two types of nondestructive coating thickness gages as Type 1 (magnetic pull-off) and Type 2

(electronic). Certified traceable coated standards are typically used to verify the accuracy of Type 1 coating thickness gages, while certified non-metallic foils (also known as plastic shims) are used to verify Type 2 gage accuracy. The user must carefully read the project specification to determine which type of gage and accuracy verification are required.

Certified traceable coated standards are manufactured by thickness gage suppliers and by the National Institute of Standards and Technology (NIST). They are typically chrome-plated steel or plastic coated steel blocks. These coated standards are typically more accurate than certified measured shims. In addition, because the surface beneath the chrome or plastic-coated film is not representative of abrasive blast cleaned steel, the gage operator must measure and record the effect of surface roughness on the coating thickness gage measurement. This is called a Base Metal Reading or BMR. The BMR is deducted from any coating thickness measurement. It remains constant for the entire project (assuming the same size abrasive was used throughout) and is deducted from each measurement, regardless which coat is involved:

Measured Primer Thickness	102 microns	4 mils
BMR	13 microns	0.5 mils
Actual Primer Thickness	89 microns	3.5 mils
Measured Primer + Finish Thickness	178 microns	7 mils
BMR	13 microns	0.5 mils
Actual Total System Thickness	165 microns	6.5 mils

The step-by-step procedures for verifying the accuracy and using a variety of Type 1 and Type 2 coating thickness gages are described in the supplement at the end of this module. Briefly, gage readings are obtained on the certified coated standard or certified measured shims in the intended range of use (if the user intends to measure 203 microns (8 mils) of coating, then accuracy in the 178-229 micron (7-9 mil) range should be verified). If the gage reading does not closely match the known thickness (within the combined accuracy of the gage and calibration standard, shown below) and cannot be adjusted by the user, then the gage should be returned to the manufacturer for calibration.

For example, if the gage accuracy is +/- 5% and the standards accuracy is +/- 5%, then the combined accuracy of the gage and the standard will be +/- 7%. This is calculated

by squaring both the gage and standard accuracy values, summing them, then taking the square root of the sum.

$$\sqrt{5^2 + 5^2} = 7.071 \text{ or approximately } 7\%$$

When certified measured shims are used for verifying gage accuracy, there is no need to measure nor deduct a BMR, as the gage will only recognize the coating thickness represented by the shim from the tops of the peaks of the surface profile.

Many are confused by the BMR, its net effect on coating thickness devices and the measurements that they yield. To simplify this, it is important to recognize that the basis for whether the user should obtain a BMR or not is not based on the gage type, but rather the method chosen to verify gage accuracy. If coated standards are used, then the base metal effect must be assessed, independent of whether a Type 1 or a Type 2 gage is used. If measured shims are used AND if they are positioned on the prepared, uncoated steel, then the base metal effect is already incorporated into the measurement and no deduction is required.

Frequency of Coating Thickness Measurements

The number of areas in which to obtain coating thickness measurements can be a challenging decision. SSPC PA 2 has a recommended frequency, as described below:

The coated area is divided into 9.29 sq m (100 square foot) areas. In each area, five spots are selected – each spot is approximately 3.8 cm (1.5 inch) in diameter. Three gage readings are taken at each spot. The average of the three individual gage readings is representative of a “spot measurement.” The average of 5 “spot measurements” is representative of the area.

The size of the coated area dictates the number of areas to measure. For coated areas less than 27.9 square m (300 square feet), each 9.29 square m (100 square foot) area should be



Verify the Accuracy of a Type I Gage.

measured. For coated areas between 27.9 and 92.9 square m (300 and 1,000 square feet), three random 9.29 square m (100 square foot) areas are measured. For coated areas exceeding 92.9 square m (1000 square feet), three random areas are selected and measured in the first 92.9 square m (1,000 square feet) and one more area is selected and measured for each additional 92.9 square m (1,000 square feet). The following example is based on a coated area that is 55,000 square feet.

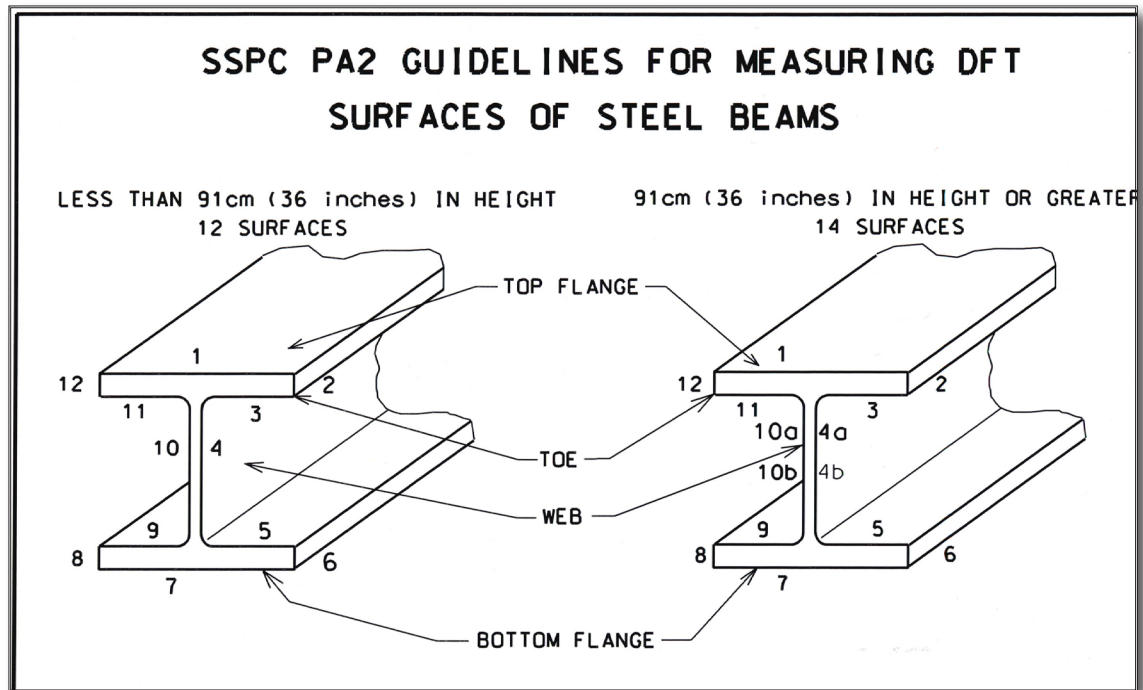
<u>Coated Area:</u>	5110 square m
No. of Areas:	$3 + 52 = 55$ areas
No. of Spots	$55 \text{ Areas} \times 5 \text{ Spots/Area} = 275$ Spots
Minimum No. of Gage Readings:	$275 \text{ Spots} \times 3 \text{ Readings/Spot} = 825$ Gage Readings

<u>Coated Area:</u>	55,000 square feet
No. of Areas:	$3 + 54 = 57$ areas
No. of Spots:	$57 \text{ Areas} \times 5 \text{ Spots/Area} = 285$ Spots
Minimum No. of Gage Readings:	$285 \text{ Spots} \times 3 \text{ Readings/Spot} = 855$ Gage Readings

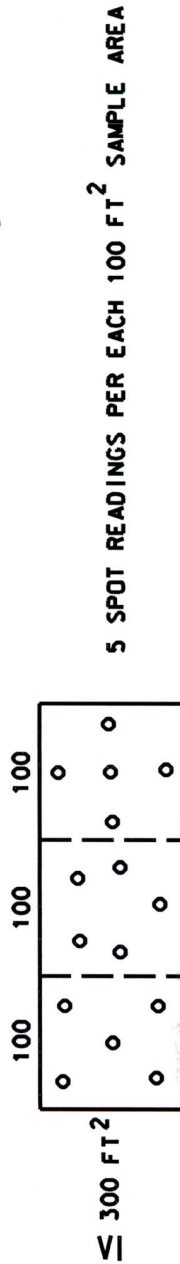
The illustrations that follow show application of SSPC-PA 2 for large, structural steel members (I-beams) and for coated flat surfaces, respectively. Note that each numbered spot is the average of a minimum of three individual gage readings.

Tolerance of Coating Thickness Measurements

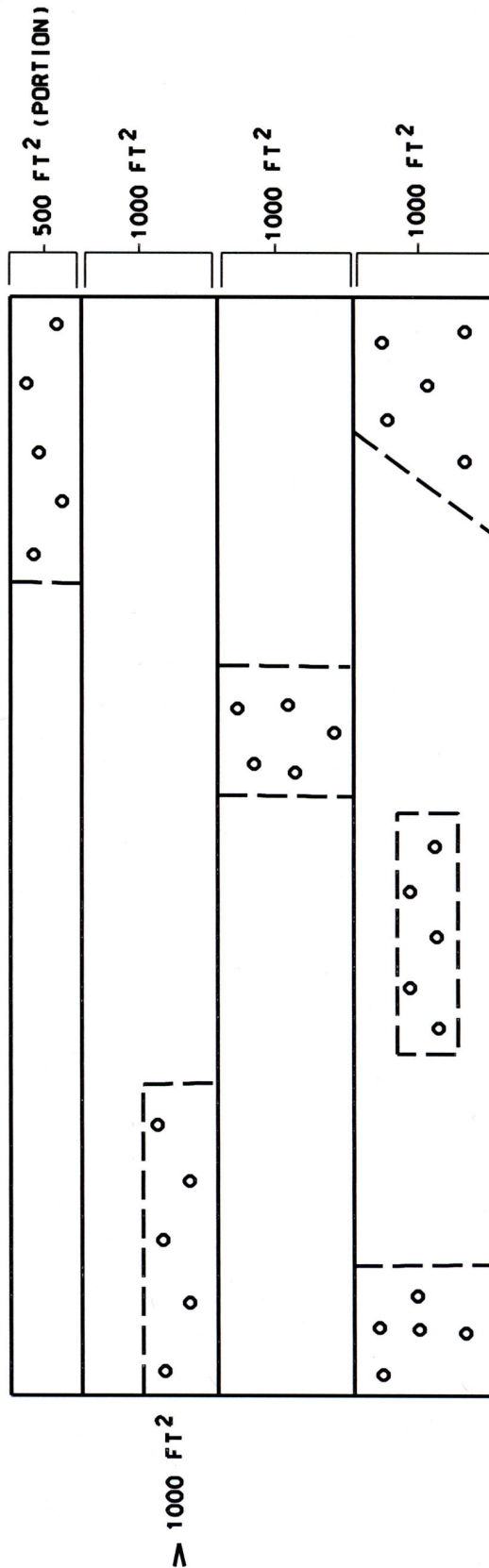
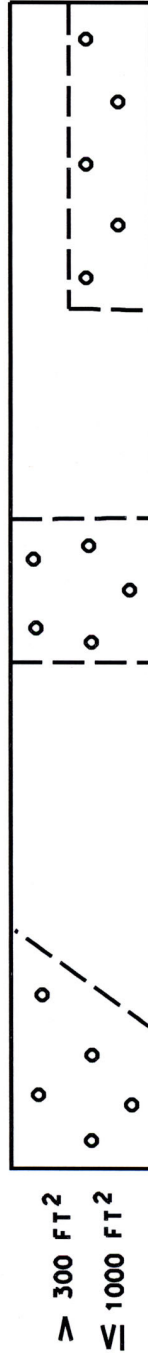
Most industrial coating specifications (and even manufacturer's technical data sheets) specify/recommend coating thickness in terms of a range (e.g., 4-6 mils/coat) rather than a single value (e.g., 5 mils). However, even given this range, it is nearly impossible for the applicator to apply the coating consistently to meet these requirements. This begs the question: Just how far out of tolerance is the coating thickness allowed to be and remain acceptable? SSPC PA 2 provides guidance here. In fact, if a specification invokes SSPC PA 2, then the contractor is limited to the tolerances stated below, depending on which level is specified.



SSPC GUIDELINES FOR MEASURING DFT LARGE STEEL PLATE SURFACES (e.g., TANK WALLS)



3 RANDOM SAMPLE AREAS 5 SPOTS PER SAMPLE



3 SAMPLE AREAS FOR FIRST 1000 FT^2
1 SAMPLE AREA FOR EACH REMAINING 1000 FT^2 OR PORTION THEREOF.

TABLE 1
COATING THICKNESS RESTRICTION LEVELS

Thickness	Gage Reading	Spot Measurement	Area Measurement
Level 1			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	As specified	As specified
Level 2			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 3			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 4			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	150% of maximum	As specified
Level 5			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	Unrestricted	Unrestricted

The individual gage readings that are averaged to generate a spot measurement are unrestricted. The user should obtain 3 readings that are truly representative of the spot, even if unusually high or low readings must be discarded. The average of the three individual readings (the spot measurement) must be within the minimum thickness and the maximum thickness percentage quoted in Table 1 of SSPC-PA 2. The average of the five spot measurements must fall within the specified thickness range.”

This tolerance concept is illustrated below, based on a target dry film thickness of 102-152 microns (4-6 mils) at Level 3:

METRIC

- 102 microns x 0.80 = 81 microns
- 152 microns x 1.20 = 183 microns
- Spot measurements must fall between 81 microns (80% of 102 microns) and 183 microns (120% of 152 micrometers) Area measurement must fall between 102 and 152 microns

US CUSTOM

- 4 mils x 0.80 = 3.2 mils
- 6 mils x 1.20 = 7.2 mils

- Spot measurements must fall between 3.2 mils (80% of 4 mils) and 7.2 mils (120% of 6 mils)]
- Area measurement must fall between 4 and 6 mils

If the coating thickness for any 100-ft² (~10-m²) area coated during a work shift is not in compliance with the contract documents, PA 2 provides a procedure to establish the magnitude of the nonconforming thickness. Additional spot measurements must be made at 5-foot (1.5m) intervals in 8 equally spaced directions radiating outward from the nonconforming area until two successive measurements in one direction are in compliance. This is illustrated on the next page.

Cumulative Thickness Measurements

As stated earlier in this module, the vast majority of nondestructive coating thickness gages for use on ferrous and non-ferrous metal surfaces cannot distinguish layers as they are applied. They simply measure the total cumulative thickness. For this reason, the inspector must understand that as each layer is applied, the range becomes somewhat wider. This concept is illustrated below.

Specification

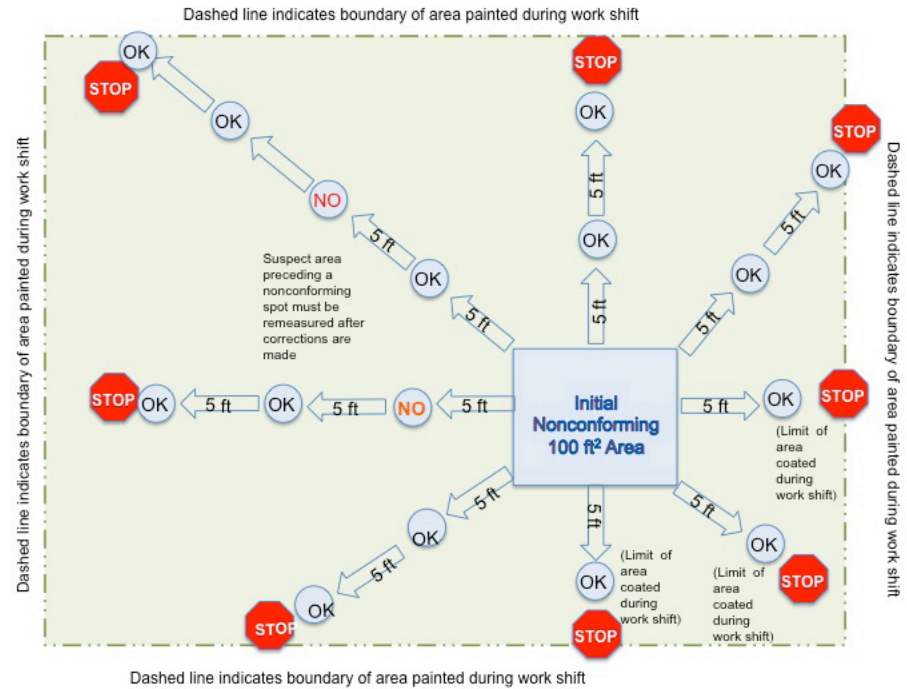
Primer Thickness:	76-127 microns	3-5 mils
Intermediate Coat Thickness:	102-152 microns	4-6 mils
Finish Coat Thickness:	51-76 microns	2-3 mils

Gage Reading

After Primer Application:	76-127 microns	3-5 mils
After Intermediate Application:	178-279 microns	7-11 mils
After Finish Coat Application:	229-356 microns	9-14 mils

Measuring the Thickness of Individual Layers Using Destructive Means

ASTM D4138, “Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means” describes the procedures used to obtain individual layer thickness data after the full system has been installed. The PIG (Paint Inspection Gage) and the Tooke Gage are frequently used. The Tooke Gage is more common and is described in this section.

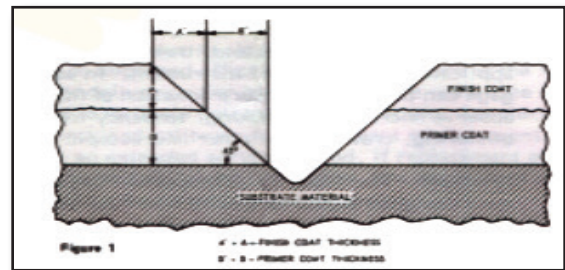


Radiating Spot Measurements to Determine Extent of Nonconforming Area

What is a Tooke Gage?

The Tooke Gage consists of a gage body (plastic or aluminum) and battery compartment, a 50 power illuminated microscope with a scale etched onto the lens, a focus adjustment for the microscope and three tungsten carbide precision cutting tips. It is perhaps the most accurate field method of measuring coating thickness. You do not have to calibrate the Tooke Gage, and it is unaffected by the type of substrate, the effect of the base metal, and surface profile. The Tooke Gage is destructive, in that it makes an incision or groove (about the width of a line drawn with a pencil) through the coating film down to the substrate. The Tooke Gage can be used to measure coating thickness up to 1270 microns (50 mils).

The Tooke Gage measures coating thickness using basic trigonometry. By cutting a precision “V” groove into the coating system using one of the tungsten carbide cutting tips, a right triangle is created. The angles of the right triangle are known. By measuring the length of one leg of the triangle, you can calculate the length of the other leg, which represents the coating thickness. If the coating layers are different or alternating in color, then each layer can be both seen and the thickness measured through the Tooke Gage lens. The good news is that you do not have to know trigonometry, nor do you actually have to calculate the third angle. The cutting tips and the scale etched on the microscope lens do the work for you.



Cross-section of groove. Right triangles are shown on left side

Documentation Procedures Relating to Inspection of Dry Film Thickness

Documentation of dry film thickness (DFT) data is a very important responsibility of a coating inspector. The following items typically comprise recordkeeping relating to coating thickness measurements:

- DFT gage manufacturer and type (Type 1 magnetic pull-off or Type 2 electronic)
- Serial No. of DFT gage
- Serial No. of calibration blocks or shims (if available)
- Date of gage calibration (typically performed annually by gage manufacturer or approved laboratory)
- Method used to verify gage accuracy prior to use
- Date measurements were acquired
- Specified DFT range (may also document the allowable spot measurement range)
- Area of structure where coating thickness was measured
- Spot measurements (the average of the 3 gage readings)
- Area measurements (the average of the 5 spot measurements)

Note that in some instances the inspector may be required to record the individual gage readings that were averaged together to generate the spot measurements.

Assessing Intercoat Cleanliness

Airborne dirt and dust is common on industrial painting sites and may become deposited onto the coated surfaces. This poses no particular problem unless the surface is scheduled to be recoated. In this case, a visual or tactile (touch) examination of the surface is required to detect the presence of dust and to help prevent intercoat contamination. Alternatively, the pressure-sensitive tape procedure (ISO 8502, Part 3) described in Module 3 can be used to assess the presence of dust on coated surfaces, in the same manner used for evaluating dust on prepared surfaces. Surface dust/debris can cause subsequent applied coatings to fisheye (inability to wet the surface) and, in sufficient quantities, can cause intercoat delamination.

Detecting Amine Exudate (Blush) On Polyamide and Polyamide-Cured Surfaces By Elevated Alkalinity

Many industrial structures are protected from corrosion using epoxy coatings, which are often regarded as the "workhorse" of today's coating systems. Epoxy coatings are multi-component, which means that the user must blend together multiple cans of material prior to application. One of these cans contains a curing agent or co-reactant, which helps the coating go from a liquid state to a solid film. Often this curing agent contains a

chemical called "Amine." Amine curing agents are water-soluble, which means they seek out moisture and can be dissolved in water.

Shop or field conditions of high humidity and/or cold temperatures during the application and/or curing stages of an amine-cured epoxy coating can produce a haze or an oily residue (oftentimes amber in color) on the surface of the coating. This is commonly referred to as amine exudate or "blush." Polyamide-cured epoxy coatings may also produce an exudate, but to a lesser extent. The residue is unreacted amine on the surface of the epoxy coating, amine which may have partially reacted with carbon dioxide and moisture in the air. This blush is intensified by cool temperatures and increased coating thickness. The presence of an amine blush may or may not be visible on the surface of the coating. If the surface amine goes undetected and a topcoat is applied over the exudate, intercoat delamination can result (provided there is enough amine on the surface to cause a problem). This oily residue interferes with the adhesion of the topcoat to the epoxy. When applying a coating over an epoxy, it is best practice to consult with the coating manufacturer in regard to determining if amine blush exists on the substrate, and, if so, what the proper removal methods may be.

Documentation Procedures Relating to Verification of Intercoat Cleanliness and Conformance to Recoat Intervals

The inspector should record (document) the method(s) employed by the contractor to clean the surfaces of dirt or dust (if performed) and the results of the inspection of the surfaces after cleaning. Finally, the actual elapsed time between coats should be documented. If the actual recoat time exceeded the manufacturer's maximum recoat interval, then the manufacturer's recommendations for preparing the surfaces and the procedures employed by the contractor to prepare the surfaces for recoating should be recorded.

Assessing Coating Cure

Prior to application of subsequent coats, or prior to placing the lining system into service, many specifications require that the coating/lining be assessed for cure. Coatings and linings cure in a variety of ways, including solvent evaporation (air-dry), oxidation (reaction with oxygen), polymerization (chemical cross-linking) and moisture cure (reaction with moisture). We will be discussing curing mechanisms in more detail in Module 6. If a coating or lining system is placed into

service before it is fully cured, it may exhibit a reduced service life or may catastrophically fail.

ASTM has three test methods that can be employed to evaluate drying or curing of coatings. Each of these test methods is briefly described below. All of these test methods are procedural. Prior to conducting any of these tests, the inspector should carefully read the applicable ASTM test method and acquire the necessary equipment/supplies.

Coatings and linings can be evaluated for “drying” according to the procedures described in ASTM D1640, “Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature.” The standard includes test procedures for evaluating set-to-touch, dust-free, tack-free, dry-to-touch, dry-hard, dry-through and dry-to-recoat.

Each of these test procedures is briefly described below:

Set-to-Touch

Touch the coating film with the tip of a clean finger, then immediately touch the surface of a clear glass plate with the same finger. Observe the plate for any paint transfer. Set-to-touch is achieved once the film is tacky, but does not attach to the finger or transfer to the glass.

Dust Free

Cotton fibers removed from a cotton ball using tweezers are dropped from a distance of 25 mm (1 inch) onto the coated surface. The film is considered dry to a “dust-free” condition when the cotton fibers can be removed from the film by lightly blowing on the film.

Tack-Free

Tack-free testing can only be performed using a Tack Tester. Testing by this method is typically restricted to the laboratory.

Dry-to-Touch

Similar to “set-to-touch,” the film is considered dry-to-touch if it does not “rub up” when lightly rubbed with finger pressure, or does not adhere to the finger.

Dry-Hard

Hold the coated surface (e.g., coated test plate) in one hand and depress maximum thumb pressure downward on the coating film (using the opposite hand) without twisting. Lightly polish the surface with a soft cloth, then examine the tested area. The coating film is considered hard when there is no evidence of thumb pressure in the film.

Dry-Through (Dry-to-handle)

The test procedure is similar to the “dry-hard” test, except that the test surface is not held by hand, but rather is allowed to rest on a firm surface. Also, the thumb is twisted in the coating surface (once in contact) 90°. The coating film is considered dry-through when there is no evidence of loosening, detachment or wrinkling of the film.

Dry-to-Recoat

The dry-to-recoat time is assessed by recoating the film, then examining the applied coating for evidence of lifting, wrinkling or loss of adhesion from the underlying coat.

ASTM D5402, “Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs” can be used to evaluate the cure of any coating which cures by polymerization (chemical cross-linking) or by moisture cure. Briefly, it involves saturating a cloth with solvent (i.e., methyl ethyl ketone) and conducting a series of “double rubs” (one forward and backstroke is one double rub) until a specific number of double rubs is achieved, or until the coating is dissolved by the solvent.

ASTM D4752, “Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primer by Solvent Rub” describes a similar procedure, but is only intended for inorganic (ethyl silicate type) zinc-rich primers.

For both of the solvent rub methods, the number of double rubs that the coating/lining can withstand is converted to a rating scale provided by ASTM, which can then be compared to the requirements of the project specification or the coating manufacturer’s requirements. The inspector should record the method used to assess coating cure, the area(s) on the structure where the tests were conducted, and the results

of the cure tests. Also, if the solvent rub test was employed, then the type of solvent used for the testing should be recorded.

Assessing Coating Film Hardness

The hardness of a coating or lining film is sometimes used to as an alternative method to assess its level of cure. Film hardness can be assessed using a variety of methods described by ASTM, including pencil hardness, Barcol hardness and durometer hardness. Barcol and durometer hardness testing are oftentimes restricted to thick film systems. Each of these methods is described below. If hardness testing is required by the project specification, then the inspector should read the entire ASTM standard (corresponding to the type of test required) prior to conducting the inspection. Otherwise, the testing may be performed improperly and may generate misleading data.

ASTM D3363, “Test Method for Film Hardness by Pencil Test” can be used to assess the drying characteristics of a coating, as indicated by its inherent hardness. Pencils containing various hardnesses of lead (shown below), from very soft (6B) to very hard (6H) are sharpened, then blunted (dressed) using a fine sandpaper. The pencil is held at a 45° angle to the coated surface and the edge of the blunted lead is pushed into the coated film, in an attempt to scratch or gouge the coating. If the coating is scratched or gouged, a softer lead is selected and the coating film is re-tested. If the coating is not scratched or gouged, a harder lead is selected and the coating film is re-tested. The hardest pencil lead that cannot scratch the coating is recorded as the “scratch hardness;” the hardness pencil lead that cannot gouge the coating is recorded as the “gouge hardness.”

ASTM D3363 Pencil Hardness Scale

6B	5B	4B	3B	2B	B	HB	F	H	2H	3H	4H	5H	6H
<i>Soft</i>					<i>Medium</i>				<i>Hard</i>				

ASTM D2583, “Barcol Hardness” is also called “impressor hardness” and is measured using a hand held impressor. The impressor is designed to be used on aluminum, soft metals, plastics, fiberglass, rubber and leather. It is designed for use on thicker materials, and

therefore may not work on thin film coatings. If Barcol hardness is required by the project specification, the inspector will need to acquire an impressor. An impressor is easy to use, and simply requires the user to position the device so that the indenter pointer and support legs are on the same plane. The inspector should press down firmly on



the impressor handle, observe the dial indicator and record the peak reading. If a softer coating is being tested, there may be some drift from the peak value. Multiple readings should be obtained (from 3 to 9 measurements, depending on

the relative hardness of the material) and an average hardness value reported. The manufacturer of the Impressor has specific requirements for verifying the accuracy of the instrument prior to use. The inspector should carefully read the instructions provided with the instrument prior to use, and should verify the accuracy of the instrument before acquiring hardness measurements.



ASTM D2240, “Durometer Hardness” is measured using either a Shore A or a Shore D scale durometer. Similar to the Barcol impressor, position the durometer on the coated surface and set the red ancillary hand on the durometer dial just above the black needle (which indicates the hardness). Hold the durometer vertically and apply the presser foot to

the coated surface as rapidly as possible, maintaining the foot of the durometer parallel with the coated surface. Hold the durometer in place for 1 or 2 seconds, then release the downward pressure. The maximum hardness value is indicated by the red ancillary hand (the black hand returns to zero once the downward pressure is released). Obtain a minimum of five measurements and report the average hardness value. The manufacturer of the durometer has specific requirements for verifying the accuracy of the instrument prior to use. The inspector should carefully read the instructions provided

with the instrument prior to use, and should verify the accuracy of the instrument before acquiring hardness measurements.

If hardness testing is performed, the inspector should document the test method employed (pencil hardness, Barcol hardness or durometer hardness) and the manufacturer, model and serial no. of the instrument used (note that serial no's. are typically not available for the pencils used for pencil hardness, however a "lot no." may be assigned, which should be documented). The area(s) on the structure where the testing was performed and the results of the testing should be documented.

Measuring Adhesion

Some project specifications may require the inspector to measure the adhesion of the coating system after it has been applied and is cured. Or, the inspector may be required to measure the adhesion of a coating system that has been on a structure for several years, to determine its condition or whether it can be successfully overcoated. In either case, it is important to perform adhesion testing properly. Otherwise the inspector may obtain misleading results. The adhesion testing supplement at the end of this module describes the procedures for performing two different types of adhesion testing: shear or knife adhesion and tensile or pull-off adhesion (using a variety of instruments). But before conducting an adhesion test, it is important for the inspector to understand what is being measured when the adhesion of a coating is evaluated.

When performing an adhesion test, the strength of a coating at several different "planes" is being measured. First, the adhesion of the coating system to the substrate is being assessed. Secondly, the adhesion of the coating layers to each other (provided there is more than one layer of coating on the surface) is being assessed. In both of these cases, the adhesive strength of a coating, or the bond of the layers to one another and to the substrate is being tested. Lastly, when performing an adhesion test, the inner-strength of each coating layer is being tested. This is known as the cohesive strength of a coating, or the ability of each layer to hold itself together.

The adhesion of a coating system to a surface is highly variable, and can be influenced by a multitude of factors too numerous to list here. That is why there is no industry-wide standard that says that a certain type of coating must have a minimum adhesion or cohesion strength.

Standard	Test Method
ASTM D3359	"Adhesion By Tape Test"
ASTM D6677	"Knife Adhesion"
ISO 4624	"Pull-Off Test for Adhesion"
ASTM D4541	"Pull-off Strength of Coatings Using Portable Adhesion Testers"
ASTM D7234	"Pull-off Strength of Coatings on Concrete Using Portable Adhesion Testers"

However, project specifications may require a minimum adhesion value as a contract requirement, and coating manufacturers will often report an adhesion value on their technical data sheets. Sometimes this value is adopted into a project specification.

Types of Adhesion Testing

Prior to performing an adhesion test, a test method must be selected. The project specification should indicate the required method, as the various methods can generate very different results. There are three primary ways to test the adhesion of a coating system. All three methods are described in ASTM standards. The chart below summarizes the methods that are commonly used to test the adhesion of industrial coatings.

Generally the first two methods listed above (ASTM D3359 and D6677) are considered “field” test methods, since they do not require any special equipment and can be conducted rather quickly. The latter two methods (ISO 4624 or ASTM D4541 and ASTM D7234) require an instrument and the attachment of pull stubs using an adhesive that may need to cure overnight, up to 24 hours. It is common to conduct this method of adhesion testing in a laboratory; however, the instruments used to test the pull-off adhesion strength of coatings are portable and testing can and is routinely done in the field. The tests listed in the table above evaluate two different adhesion properties, and they use different testing mechanisms. The tape and knife adhesion tests (ASTM D3359 and D6677) are used to evaluate the “shear” or “peel” strength of a coating, while the pull-off test (ISO 4624 or ASTM D4541 and ASTM D7234) is used to evaluate a coating’s tensile strength, or its resistance to a perpendicular pull. Since the testing mechanisms are different (peel-back versus pull-off), the test results generated from each test should not be compared. Also, any

type of adhesion test is “destructive.” That is, the coating in the area in that the test is performed will be damaged, and oftentimes it must be repaired. Therefore, adhesion testing should not be conducted unless required by the project specification. The specification should include repair procedures for the affected areas.

If adhesion testing of the coating/lining system is performed, then the inspector will need to document the following items. The level of documentation is based on the type of adhesion testing employed, as shown below

First, the inspector should document the type of adhesion testing performed (tape, knife or pull-off)

If tape or knife adhesion is performed, then the following items should be documented:

- The manufacturer, model and serial no. of the testing equipment
- The area on the structure where the testing was performed
- The thickness of the coating in the area on the structure where the testing was performed
- The test method performed (knife or tape; if tape adhesion, Method A or B)
- If Method B was performed, the spacing between the incisions (in mm)
- The adhesion rating
- The location of break (adhesion or cohesion, if discernable)

If tape adhesion is performed, then the detached tapes should be attached to a report form, identified and stored for future reference, as necessary.

If tensile (pull-off) adhesion is performed then the following items should be documented:

- The manufacturer, model and serial no. of the testing equipment
- The area on the structure where the testing was performed
- The thickness of the coating in the area on the structure where the testing was performed
- The diameter of the pull stubs employed for the testing
- Preparation of the pull stub contact surfaces prior to attachment
- Preparation of the coated surface prior to pull stub attachment
- The type of adhesive used (manufacturer and type)

- The cure time of the adhesive used to attach the pull stubs and the ambient conditions (air temperature and relative humidity) during the adhesive curing process
- The pull-off strength (in kpa, MPa or psi)
- The location of break (adhesion, cohesion or glue, and the approximate percentage of each)

The detached pull stubs should be identified and stored for future reference, as necessary.

The adhesion testing supplement at the end of this module provides examples of documented adhesion test data.

Detecting Pinholes and Holidays

Project specifications for coating the interior of storage tanks and vessels, railcars, or for the application of coatings and linings to liquid and gas pipelines, frequently require a continuous, holiday and pinhole-free coating or lining system. Rather than relying on a visual inspection, holiday/pinhole detectors are used to determine the number and location of skips, misses, and pinholes, so that they can be repaired prior to placing the tank, vessel, railcar or pipeline into service. The pipeline industry refers to this procedure as “jeep” testing. If holiday, pinhole or “jeep” testing is not performed, and there are undetected voids in the coating or lining system, then the contents of the tank, vessel, railcar or pipeline may attack the exposed substrate and cause pitting corrosion, loss of section and eventual perforation of the substrate. In addition, the contents may become contaminated with corrosion products and coating/lining debris if deterioration occurs. Holiday testing is governed by two industry standards: ASTM D5162, “Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates” and NACE SP0188, “Standard Recommended Practice-Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates.”

What are Pinholes and Holidays?

The terms “pinhole” and “holiday” are used interchangeably. However, they can represent two different types of “breaches” in the coating/lining system. Generally, the term ***Pinhole*** is used to describe tiny

voids in the coating or lining that penetrate down through all of the layers to the substrate. These voids allow the contents of the tank, vessel or pipeline access to the metal substrate via tiny “pathways.” The term **Holiday** or discontinuity is used to describe “skips” or “misses” in the coating/lining system (just like holidays are skips in the work calendar). These uncoated areas permit easy access to the unprotected substrate.

Pinholes are usually caused by poor wetting of the coating/lining on the surface during application, or out-gassing (displacement) of air without subsequent flow-out of the coating. Holidays are areas that are missed by the applicator. They may be caused by the configuration of the structure being coated or lined (e.g., difficult to access with the application equipment), or lack of attention to detail by the applicator. Most holidays and pinholes are found on areas that are difficult to protect or access, such as edges and corners, welds, bolts, nuts and threads, behind angles and clips, inside holes, between back-to-back angles, etc. Large, flat surfaces like the walls of a tank or vessel are easier to coat, and therefore usually contain fewer pinholes and holidays.

When is Holiday Detection Performed?



Low Voltage Holiday Detector Kit

Pinhole or holiday detection is usually conducted after the final coat has been applied, but within the recoat interval (period), in case repair of the coating film is required. Some project specifications require holiday testing before the application of the final coat. If this is done, intercoat cleanliness of the surfaces must be verified prior to application of the final coat, and a wetting agent should not be used with the holiday detector, as the coated surfaces can become contaminated and may result in intercoat adhesion problems. Pinhole detection should never be performed on a coating system that has already been in service.

Selecting a Holiday Detector

There are two different types of holiday detectors. Low voltage or “wetted sponge” holiday detectors are used on coatings/linings that are less than 508 microns (20 mils) thick. High voltage holiday detectors or “spark testers” are used on coatings greater than 508 microns (20 mils) thick. Independent of coating thickness, both of these detectors will only work on non-conductive coatings applied to a conductive

substrate. For example, epoxy coatings applied to steel can be tested for holidays, while a zinc-rich coating applied to the same steel could not (zinc is a conductive metal in the coating). Most high voltage detectors can also be used on non-conductive coatings applied to concrete.

The step-by-step use of low-voltage and high-voltage holiday detectors for coatings on steel appears in the instrument supplement at the end of this module.



Holiday testing of pipeline using spring electrode

Verifying the Accuracy of High Voltage Holiday Detectors

The voltage settings on the holiday detectors are verified at the factory and at the distributor before they are sold or leased by setting the HI/LO switch and Voltage Setting Switch to a known operational voltage, then connecting the detector to a Peak Reading Voltmeter. The value displayed by the voltmeter must be within 10% of the set value.

You can verify the accuracy using the same procedure, provided that you have a Peak Reading Voltmeter. Otherwise, you will need to return the instrument to the manufacturer for verification of accuracy. If the detector is beyond the allowable tolerance, then the detector must be returned to the manufacturer, as there are no field adjustments that can be made.

The inspector should record (document) the type of pinhole detection performed (low or high voltage) and the manufacturer, model and

serial no. of the detector used. If high voltage detection is performed, then the inspector must also record the test voltage employed, and should document the method used to verify the voltage setting of the detector unit (e.g., a volt meter, including the make, model and serial no.). The area of the structure inspected and the method used to demarcate the location of any holidays or pinholes should be recorded. Finally, the method employed by the contractor to repair and recoat the areas should be recorded. If post-repair pinhole/holiday testing is performed, then the results of the retesting should be documented.

Inspecting Fluorescent Coating Systems

As an alternative to pinhole and holiday detection, fluorescent pigments or “Optically Active Additives (OAA) can be added to an existing coating formulation during the manufacturing process, similar to the process used to add a color pigment to a formulation. Once the coating is applied, it is inspected using a UVA-340 lamp (black light), which is reflected onto the coated surfaces. The inspection is performed after application of the first coat and second coat in a two-coat system and a three-coat system. In this manner, the proper application of each coating layer is verified, rather than waiting to perform a discontinuity inspection after all coats are applied. The process is described in SSPC Technology Update No. 11 (TU 11), and is summarized below.

Inspector Training

Some basic training on the use of black light fluorescence as an inspection tool is necessary if an inspector has never performed this type of inspection before. According to SSPC-TU 11, the coating manufacturer supplying the optically active coating should prepare at least five sample panels for examination by the inspector using the lamp. These panels should represent:

1. Primer applied to a flat panel with pinholes
2. Primer and finish coat applied to a flat panel; pinholes in the finish coat
3. Primer on a weld seam, with cracks in the coating
4. Primer and finish coat on a weld seam; cracking in the finish coat
5. Prime and stripe coat on an angle

In addition, the inspector should observe the safety requirements when employing the UVA lamp, including eye and skin protection

Inspecting the Coating

After donning personnel protective equipment and entering the tank or vessel, the inspector should begin a methodical inspection using the UVA lamp.

The primer (first coat) is examined for the following:

1. Holidays or undercoated areas, as indicated by black or dark spots beneath UVA 340 light.
2. High coating thickness areas, as indicated by brighter than normal luminosity beneath UVA 340 light.
3. Coating detachment or hot work damage, as indicated by a bright glow beneath UVA 340 light.
4. Organic dust or grit, as indicated by bright speckled spots beneath UVA 340 light. Note that organic dust can be produced by fabric (e.g., cotton) rags, clothing or booties.

If the coating system is limited to two coats (primer and finish), then it is common to exclude the fluorescent pigment from the finish coat. In this manner, any illumination revealed by the UVA lamp during inspection of the finish coat would indicate holidays, pinholes, cracking or low film builds.

If the coating system includes three coats, then a different (contrasting) color fluorescent pigment should be used in the intermediate coat. The inspection can then be performed as described above.

Stripe coats identical in color to the main coat (under normal lighting) will look different under UVA lamps due to the fluorescent additive. This helps where aesthetics are just as important as the additional barrier protection afforded by a stripe coat.

Summary

Next to surface preparation, coating application is one of the most crucial steps in a successful coating operation. If the coating is not properly mixed, thinned and applied, the protection of that coating may be diminished. Therefore, the study and comprehension of both the specification and the manufacturer's recommendations (known as the Product Data Sheet or PDS) are necessary to verify that proper mixing, thinning, and application procedures are followed.

The inspector's role in a coating project varies, depending on the requirements of the specification. The more common checkpoints include:

1. performing materials receipt inspection and documentation
2. witnessing and verifying (documenting) coating mixing and thinning procedures
3. measuring and documenting ambient conditions and surface temperature
4. calculating and measuring wet film thickness
5. measuring dry film thickness nondestructively
6. verifying re-coat times
7. assessing intercoat cleanliness
8. assessing cure
9. assessing coating hardness
10. performing pinhole or holiday detection
11. adhesion testing

SSPC has two main standards that pertain to coating application, including SSPC PA 1 (Shop, Field and Maintenance Painting of Steel) and SSPC PA 2 (Measurement of Dry Coating Thickness with magnetic Gages).

Coating manufacturer's technical bulletins or product data sheets (PDS) contain very useful information about the products being used on the project. However, the manufacturer is not limited to which

product information they may or may not reveal. While the PDS typically contains critical information about the content and use of the coating products, in cases where the PDS and the specification differ (say on the maximum humidity during application), the specification is the governing document, except when the owner incorporates the manufacturer's recommendations on the PDS into the specification. When that occurs, the PDS becomes part of the project specification.

Some coating manufacturers list the target wet film thickness, while others do not. But even when the targeted wet film thickness is listed on the PDS, this thickness will change if thinner is added to the product, or when the specified dry film thickness differs from that on the PDS. It is important for contractors and inspectors to know how to calculate the target wet film thickness, in order to arrive at the desired dry film thickness. There are two formulas that can be used to calculate wet film thickness; one for unthinned coatings and one for coatings that are reduced. The volume solids content of the coating and the percentage of thinner added to the coating must be known in order to calculate a wet film thickness.

Verifying that what was ordered (coating products, coating components, and thinners, if permitted) was received at the project site in good condition and in the correct amounts is called a material receipt inspection. This is typically a job for the contractor's QC and although it is not a difficult process, it can prevent a multitude of problems as the job moves forward. The contractor should also verify that the coating products are properly stored on the project site prior to use, and should record batch no's. for each component and thinner.

Mixing or blending coating products is another essential step in a successful coatings project and the correct process is geared to the individual products involved. Mixing or blending a single component coating is a straightforward process, with the main concern being that all pigments and solid materials become suspended in the mix. Yet while some single component coatings require constant agitation, there are other single component products that do not. Over-mixing moisture-cured zinc rich primers, for example, can bring moisture into the product, which can cause the material to gel in the can. (Since mixing procedures may vary from product to product, always review the PDS prior to mixing.)

The mixing of multi-component products is more complex. Remember, any time you mix different components, you are creating a “new” product, so following directions is imperative. Before combining individual components, the individual liquid components must be thoroughly mixed. Power agitation using a shear-type mixing blade is often required for industrial coatings.

In the case of multi-component zinc-rich primers, the liquid components are blended, and then the zinc powder is slowly blended in while the entire mix is under power-driven agitation. A final step is the straining of the blend, to remove any zinc particles that did not thoroughly blend into the product and might clog the tip of the spray gun or become lodged in the applied coating film.

Most specifications, as well as coating manufacturers, prohibit the blending of partial kits. This is to prevent the combination of product components in the wrong ratios. (Also, there may be a critical minimum volume of material that must be blended so that the anticipated chemical reaction between the components actually occurs.) Once the multi-component coating material is blended, the “potlife clock” begins.

Once the components are blended (and strained, if required), the temperature of the coating should be measured. Some products require an induction or “sweat-in” time, which is necessary to initiate a chemical reaction. As a general rule, the warmer the coating the shorter the potlife time, since heat increases the rate of the chemical reaction. Induction time (which is part of the potlife time) is also based on the temperature of the coating material.

The next step in the mixing process is to decide whether the product will need constant agitation during application. Reminder: there are products that need constant agitation and products that could be damaged by the process. The need for constant agitation will be addressed by the PDS.

Thinning a coating product impacts the VOC content and the targeted wet film thickness. Even when thinning is permitted, it must be done according to the specification and with the products and ratios recommended on the PDS. There are times when the manufacturer will permit thinning, but the specification will not. Since the

specification is the governing document, the product is not reduced in these instances.

Adding an unknown quantity of thinner to reduce viscosity or to extend the potlife is poor painting practice; a practice that can result in a variety of consequences. First, this practice does not extend the pot life (it can only be extended by maintaining the product at lower temperatures). Secondly, the addition of unknown quantities of thinner alters the VOC content, and the target wet film thickness. The end result of such a practice may be excessive or inadequate coating thickness. Excessive thinning can cause the coating to sag on vertical surfaces. If the coating should dry or “skin-over” before the solvents have an opportunity to escape, a porous film filled with solvent voids can result. Undo-thinning the coating can have equally negative consequences, including poor film integrity and/or exposure of the substrate or underlying coating layers (which may not be resistant to the service environment).

The method of coating application depends on any number of factors: the size and configuration of the surfaces to be coated, the proximity to other structures, environmental regulations, and, of course, the specification and the coating manufacturer’s recommendations. And there are other issues for the contractor/applicator to consider when choosing an application method, including speed and control.

The use of brushes for industrial projects is typically limited to striping: the application of a layer of coating to surfaces where it is difficult to achieve a normal film build. Brushes are also used around rivet heads, welds, bolt-nut assemblies and to “cut-in” inside and outside corners. Daubers are often used to coat inside crevices such as back to back angles. Rollers have a high coating transfer efficiency and can be used to coat large flat surfaces, but there are limitations. Roller nap can become embedded in the dry coating film and pull moisture into the coating, and film thickness is hard to control.

With conventional (air) spray the applicator can control both the amount of paint that exits the gun and the shape of the spray pattern. Another advantage is that the gun can be half triggered so that compressed air (without paint) can exit the gun and blow-down the surface to remove dust and debris. Compressed air cleanliness is critical for the operation of conventional spray equipment, and

verification of clean, dry compressed air using the blotter test is an inspection checkpoint any time compressed air is used in the atomization process.

High Volume Low Pressure (HVLP) Spray is similar to conventional spray, but uses much lower air pressures. The result is excellent control and a much higher transfer efficiency during application. In addition, the reduced blowback from HVLP results in lower VOC emissions. Like conventional spray, HVLP can also be half-triggered to blow-down the surface, but since pressures are low, the blow down may not be adequate to remove heavy deposits of dust.

Airless spray is a very productive method to apply industrial coatings, but it operates using dangerously high fluid pressures. To prevent injuries to applicators, a special guard attached to the tip of the airless gun and a trigger lock are built-in safety features. If the equipment is operating correctly, a skilled applicator can create a finish similar to finishes created by conventional spray, but at much higher production rates. Since airless spray does not employ compressed air to atomize the coating, the transfer efficiency rate is higher than conventional spray, which also lowers VOC emissions. Airless spray is the most common method used to apply industrial coatings.

Air-assisted airless spray is an adaptation of airless spray. The addition of atomization air helps control the shape and quality of the spray pattern. The atomization air, as well as the operation of the equipment at lower pressures gives the applicator some of the control of conventional spray.

Good spray technique and the consistency of the coating thickness go hand in hand. Unfortunately, classroom teaching has its limitations as a job-training tool. Experience with the equipment and with a variety of industrial coatings has proven to be the “best teacher.” One technique that applicators must learn is to keep the spray gun perpendicular to the surface. The distance of the gun from the surface will vary according to the type of spray system used, but the angle of the gun will remain the same. Overlapping technique is also important, because whenever a fan pattern is created, the paint will be thicker at the center of the fan. Only the operator and an appropriate technique (crosshatch) can correct this problem. A special device that is attached to a spray gun uses a laser to train applicators on maintaining proper distance, angle and to use proper overlapping techniques.

Inspection of the mixing, thinning and coating application, whether by the contractor (QC), the owner/owner's representative (QA), can make or break a coatings project.

Prior to the mix, it is important for the QC personnel to verify that all necessary materials/products/ and equipment necessary for the job are on hand, are within the manufacturer's shelf life (check the expiration dates), and are properly stored.

Prior to the mix and throughout the application process, the measurement of ambient conditions (relative humidity, dew point, air temperature, wind conditions) helps determine whether or not the application of the coating can move forward. Often, both the specification and the PDS will contain information on the conditions required to apply each specific coating product. If the requirements listed in the project specification differ from that listed on the PDS, the specification is the governing document. The right weather conditions for the coating products open the way to a successful application of the coating. If a coating must have moisture to cure, too little moisture in the air becomes a problem. Conversely, for some coatings, too much moisture in the air creates a problem. Warm versus cold air temperature ranges are also important issues. And wind conditions are important, especially in areas where strong winds are frequently a problem.

Ambient conditions should be measured at regular intervals both before and throughout the application process, and anytime the weather conditions appear to be declining. Perhaps the single most important temperature relationship is the relationship between the dew point and the surface temperature. To prevent applicators from coating a "wet surface," the surface temperature should be at least 3°C (5°F) higher than the dew point temperature. An inspector should not depend on national or regional weather service information for weather conditions. Those conditions must be measured at the correct time at the exact location where the coating application will take/is taking place.

Both the individual responsible for mixing the coating and the inspector(s) responsible for verifying proper mixing procedures should first read the coating manufacturer's instructions for mixing. Required documentation of the mix may vary, but typically includes: the

manufacturer, product number and product name, batch numbers, time of the mix, amount of each component blended, type of agitation used, and the coating temperature once blended. Storage conditions should also be verified and documented. It should also be noted if full kits were mixed. If partial kits were permitted, the measured amounts of each component should be recorded. If a product requires an induction time, the amount of time needed and the amount of time actually allowed for the induction to take place should be recorded. Potlife should also be noted. Remember: potlife includes the induction time (when applicable), so the induction time must be subtracted from the potlife to assess the actual time the coating is available for application to the substrate. Potlife can range from a few minutes to 24 hours or more, and is based on the temperature of the coating.

When agitation of the coating mix is required by the manufacturer or project specification the equipment used should be documented. The type of agitation and when the agitation took place (at the beginning of the mix only, intermittently, or continually throughout the application process) should also be documented.

If thinning is permitted, the type and amount of thinner added should be monitored and documented. If a contractor uses an alternate thinner or exceeds the amount of thinning recommended by the PDS, the details of this action also need to be recorded.

Measurement of wet film thickness is typically performed by the applicator, although an inspector should spot-check and record the measured wet film thickness. A notch-type wet film thickness gage can be used for this purpose.

There are three standards that apply to the measurement of dry film thickness (DFT). The specification should state which standard applies, but the dry film thickness of each layer in a multi-coat system should be assessed after the application and before the next layer is applied. All coating thickness gages, whether Type 1 (magnetic pull-off) or Type 2 (electronic), must be verified for accuracy before and after each period of use. Typically, calibration blocks are used to verify the accuracy of magnetic pull-off gages, while plastic shims are used to verify electronic gages. However, the inspector should always check the specification to determine which type of gage to use and the method to verify the gage's accuracy. Some specifications for example may prohibit the use of Type 1 gages.

Surface profile or roughness affects dry film thickness gages. If a gage is verified for accuracy on smooth steel blocks (and the coating will be applied to roughened steel) the amount the gage is affected (called the Base Metal Reading or BMR) must be measured and deducted from each cumulative coating layer. If a gage is verified for accuracy by placing shims of known thickness on top of the peaks of the roughened steel (the same surface the coating will be applied to), then there is no BMR to measure or deduct.

Frequency of dry film thickness measurements is another inspection concern. SSPC-PA 2 has specific requirements for the number of readings that are taken and the number of areas measured according to the coated area of the structure. SSPC-PA 2 requires obtaining a minimum of three gage readings at each spot. These gage readings are averaged to create a spot measurement and there is no restriction placed on the individual gage readings (relating to thickness tolerance). SSPC-PA 2 places a tolerance on the five spot measurements that comprise an area measurement. Unless another coating thickness restriction level is specified, the spot measurements must be within 80% of the minimum specified thickness and 120% of the maximum specified thickness. The average of the five spot measurements (the area measurement) must fall within the specified thickness range established by the project specification.

Once all the coatings of a multi-coat system have been applied, the only way to assess the thickness of each coat is through the use of a destructive thickness gage. One type of destructive thickness gage is the Tooke Gage, which cuts a groove through the coating layers all the way down to the substrate using one of three precision cutting tips. By using the microscope on the gage, an inspector can examine the coating to determine the thickness of each layer. The Tooke Gage can be used to examine different or alternating colored layers in a multi-coat system up to 50 mils thick.

Documentation of coating thickness is critical and includes recording the gage manufacturer and type; the serial no. of the gage and calibration blocks/shims; the date the gage was last calibrated by the manufacturer and the method used to verify accuracy prior to and after use. The date(s) the coating thickness data was acquired; the specified DFT range; the area where the coating thickness data was collected; and the spot and area measurements complete the documentation activities. The acceptability of the area should be recorded prior to application of subsequent coating layers.

Dirt, dust, debris or amine exudate (caused by curing of epoxy coatings under cool, damp conditions) on surfaces to be recoated can cause intercoat delamination. Inspection of surfaces for intercoat cleanliness can be visual, tactile or chemical, in the case of amine exudate (blush) detection. The inspection procedures used to verify intercoat cleanliness (and the results) should be clearly documented.

Since coating materials typically have both a minimum and maximum recoat time, the inspector must verify that the coating has been allowed to dry or cure the recommended minimum amount of time and verify that the next coat is applied before the maximum recoat time has expired. The inspector should document the actual recoat interval.

Some coatings must perform in very challenging service environments: for example, the coatings applied to the interior of storage tanks, railcars, and liquid and gas pipelines. Visual inspection of these coatings for pinholes, skips or missed areas would not be adequate, therefore holiday or pinhole detectors are used to determine the location of skips, misses, and pinholes. This testing is performed so the coating or lining can be repaired before the vessel is put into service. Holidays are skips or misses in the coating system. Pinholes are tiny voids in the coating that penetrate all the way to the substrate. The type of pinhole detection employed (low or high voltage) is based on the coating system thickness. This type of inspection can only be performed on nonconductive coatings applied to electrically conductive substrates. In general, the test voltage for high voltage holiday detection is 100-125 volts/25 μ m (1 mil), however the manufacturer of the coating system should provide the proper test voltage.

The inspector may be required to verify that a coating has adequately dried or cured prior to application of subsequent coats, or prior to placing the coating system into service (i.e., filling up the tank/vessel). ASTM has three test methods for evaluating or assessing the degree of coating drying or curing. These methods include drying tests (set-to-touch, tack-free, dry-to-touch, dry-to-handle, dry-to-recoat, etc) per ASTM D1640 and two solvent rub tests (one for organic coatings [ASTM D5402] and one for ethyl silicate type inorganic zinc-rich primers [ASTM D4752]).

The hardness of a coating can also be an indicator of the degree of cure, and an inspector may be required to test the hardness of a coating film using the pencil hardness test (ASTM D3363), or an impresser/indenter test (Barcol hardness [ASTM D2583] or Durometer hardness [ASTM D2240]).

Some specifications require the measurement of the adhesion of the applied coating system after it has cured. Adhesion assessments may include: the adhesion of the coating to the substrate, the adhesion or the bond of one layer of the coating to another, or the inner-strength of the coating, also known as cohesive strength.

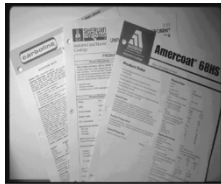
Different adhesion tests measure different coating adhesion mechanisms (peel back versus pull-off). Two tests that are common for the field are the "Adhesion by Tape Test" (ASTM D3359) and the "Knife Adhesion Test" (ASTM D6677). These two tests are used to evaluate the coating's "shear" or "peel" strength. The third test measures tensile strength and is governed by ISO 4624 "Pull-off Test for Adhesion," or ASTM D4541, "Pull-off Strength of Coatings Using Portable Adhesion Testers," or ASTM D7234, "Pull-off Strength of Coatings on Concrete Using Portable Adhesion Testers." Pull-off tests are used to evaluate the coating's resistance to a perpendicular force on a pre-attached pull stub. All adhesion tests are destructive to the coating film and should not be conducted unless required by the specification. The specification should include repair procedures for the affected areas.

	Module Five
	Coating Mixing, Thinning and Application: Equipment Overview and Inspection Techniques

	Module Five Learning Outcomes
	■ Successful completion of Module Five on Coating Mixing, Thinning and Application: Equipment Overview and Inspection Techniques will enable the participant to: ■ Describe the inspector's role in coating mixing, thinning, and application ■ Describe the SSPC standards for coating application and coating thickness measurement ■ Use SDSs and product data sheets to verify safe and proper mixing, thinning, and application of coatings

	Module Five Learning Outcomes
	■ Describe the procedures associated with proper mixing thinning, and application of coatings ■ Calculate and measure wet film thickness ■ Describe and implement the proper inspection and testing procedures and processes used in coating application

	SSPC Standards for Coating Application
	■ SSPC Paint Application Specification No. 1 (PA 1) ■ SSPC Paint Application Specification No. 2 (PA 2)

	Product Data Sheets
	■ Coating Manufacturer's Product Data Sheets (PDS) ➢ An "instruction manual" for the coating ➢ Technical information about the coating ➢ ASTM F718 provides standardized format ➢ No standardized content 

	Product Data Sheets
	■ The specifier, the inspector(s), and the contractor should be familiar with the information on the PDS.

Product Data Sheets Contain Recommendations

- When the PDS and the project specification differ, the specification is the governing document.
- Note discrepancies between the PDS and the specification and advise the owner.

Material Receipt Inspection and Storage Conditions

- Verifying that what was ordered for the project was shipped to the project site and received in good condition
- Verify and document:
 - Manufacturer
 - Product name & No.
 - Shelf life
 - Manufacturer, type & quantity of thinner
 - Batch No. of each component and thinner
 - If multiple batches of same product, record what batches were used where
 - Products may have Certificates of Acceptance/ Compliance

Material Receipt Inspection

- Verify coatings and thinners are properly stored
- Manufacturer publishes storage conditions on PDS
- May require monitoring of storage area
- Protection from freezing and extreme heat/high humidity



Data Loggers for Paint Storage Area

- Self-contained recording instruments
- Download to computer software



Inspecting Mixing, Thinning and Application

- Verify correct materials
- Verify shelf life
- Measure ambient conditions
- Witness mixing and thinning
- Measure coating temperature
- Measure WFT and DFT
- Assess intercoat cleanliness
- Verify recoat intervals
- Detect pinholes/holidays
- Assess cure
- Measure adhesion
- Measure hardness

Ambient Conditions

- Measure ambient conditions:
 - Prior to mixing the coating materials and at 4-hour intervals
 - Whenever conditions appear to be changing
 - At the location where the coating will be applied (outside or inside)
- Document:
 - Date and time
 - Air and surface temperatures
 - Relative humidity and dew point temperature
 - Temperature spread between surface & dew point temperatures
 - Wind speed (if required)

	Measuring Wind Speed
■ Wind meters ➢ Analog (floating ball) ➢ Digital ➢ Rotating Vane Anemometers ➢ Feet/minute or MPH ➢ Can convert to Km/Hr	

	Inspecting Mixing Procedures
■ Verify coatings are within the shelf life ■ Check PDS for mixing instructions ■ Measure coating temperature after all components are thoroughly blended	

	Induction
■ Also known as sweat-in, stand-in, cook time or digestion ■ Required of some coatings ■ Period of time when components chemically co-react ■ Part of the pot life (but not the usable pot life) ■ Generally, the warmer the material, the shorter the required induction time	

	Pot Life
■ The period of time (after mixing) that multiple component coatings are usable ■ Ranges from a few minutes to 24 hours ■ Once pot life has expired, any remaining coating should not be used	

	Documenting Coating Mixing Procedures
■ Manufacturer, product name & no., color & generic coating type ■ Batch No' s. of the components ■ Number of kits mixed and kit sizes ■ Mix ratio ■ Date and time mixing occurred ■ Method used to agitate individual and blended components ■ Whether straining was employed ■ Elapsed time of induction (if required) ■ Whether pot agitation was employed ■ The coating layer (primer, intermediate, finish, etc.)	

	Coating Mixing Procedures
■ Mixing single component materials ➢ Ensure the material is homogeneous by mixing all of the settled pigments and solid materials into the liquid	

Coating Mixing Procedures	
■ Before mixing two-component coatings, individual liquid components must be thoroughly mixed ➢ Power agitation often required – use shear mixing blade ➢ Non-liquid components (zinc powder) do not require agitation	

Partial Kit Mixing	
■ Prohibited by most manufacturers and specifications ■ Off-ratio blends won't cure properly ■ Some coatings are ratioed by weight, not by volume ■ May be a critical minimum volume for chemical reaction ■ Remedy: Order larger & smaller kit sizes	

Coating Mixing Procedures	
■ Once combined: ➢ Thoroughly blend - use power agitation ➢ Alternative – blend by “boxing” (prohibited for mixing inorganic zinc-rich primers and any coating that reacts with moisture) ➢ Once materials are blended, the pot life begins	

Touch-up Kits/Cartridges	
■ Designed to patch/repair damaged coatings ■ Supplied in two component tubes ■ Product blended through static mixer ■ Product brushed onto surfaces	

Mixing Zinc-Rich Primers	
■ Single component – cure by reaction with airborne moisture (zinc powder already blended with the liquid; should not be over-mixed)	

Mixing Zinc-Rich Primers	
Multi-component: ■ Mix liquid components ■ Slowly disperse zinc powder into the mix while under power agitation) ■ Keep agitating to ensure the wetting of the dry zinc particles ■ Strain through a fine mesh cloth, sieve or screen	

	Pot Agitation
	■ Zinc may settle-out ➢ Original mix ratio becomes distorted ➢ Protection lying at the bottom of the can ➢ Most specifications require constant agitation during application ➢ Single component, moisture cured zinc-rich primers should not be agitated during application

	Measuring Coating Temperature
■ After mixing and straining ■ Attach thermometer to lip of can ■ Allow 3 minutes to stabilize, then read ■ Temperature determines length of induction time and/or pot life ■ Thermocouples also available	

	Coating Thinning Procedures
	■ Amount of thinner added impacts: ➢ volatile organic compound (VOC) content ➢ the target wet film thickness ■ Over or under thinning can adversely affect application and performance characteristics ■ Thinners should be clean, new and in their original containers ■ Contaminated, recycled, or used thinners should not be used for thinning coatings ■ Thinner addition does not extend pot life

	Coating Thinning
	■ Determine if thinning is permitted: ➢ If allowed, there is often a maximum amount that can be added ➢ Federal/state/local air quality regulations ➢ The coating manufacturer may permit thinning, but the specification may not

	Coating Thinning
	■ Determine the type and amount of thinner to add: ➢ Check the product data sheet ➢ Type thinner may depend on air temperature and wind during application ➢ Use of thinners not recommended by the PDS can void the coating warranty ➢ Heat can reduce viscosity without thinner, but may impact pot life ➢ Use of viscosity cups

	Thinners: Contribution to VOC Content
	■ In the field: ➢ The addition of regulated thinner will increase VOC content ➢ The use of non-regulated solvent (e.g., water) will not increase VOC content (there is still a maximum amount that can be added to maintain sag resistance)

	Thinning Consequences
	■ Excessive thinner may cause: ➢ Coating to sag on vertical surfaces ➢ Coating “skin-over” entrapping solvents, resulting in a porous film filled with solvent voids 

	Thinning Consequences
	■ Under thinning may cause poor film integrity: ➢ Can result in exposure of the substrate or the underlying coating layers ➢ Substrate and/or underlying coating may not be resistant to the service environment

	Thinning Consequences
	■ Thinner addition will not extend pot life ■ Pot life can only be extended by reducing the material temperature ■ Applying coatings beyond the pot life can result in failure ■ Thinner addition after mixing only

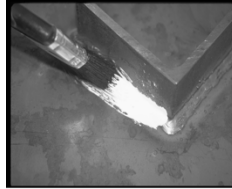
	Inspecting Thinning Procedures
	■ Inspector should verify: ➢ Correct type of thinner is used ➢ Graduated containers are used to measure thinner 

	Documenting Thinning Procedures
	■ Manufacturer, thinner name & number ■ Batch Number of the thinners ■ Amount of thinner added ■ Date and time thinner was added

	Six Methods of Coating Application
	■ Brushes, rollers and daubers ■ Airless spray ■ Conventional (air) spray ■ High Volume Low Pressure (HVLP) spray ■ Air-assisted airless spray ■ Plural component spray

Brushes

- Brushes –
 - Cutting in outside/inside corners
 - Welds
 - Around rivet heads
 - Bolt and nut assemblies
- Brushes – stripe coating
 - Wet stripe coating
 - Dry stripe coating
 - SSPC-PA Guide 11



Wet Stripe Coating

- Done on any coating layer
- Once it becomes tacky (about 5-10 minutes), the full coat is applied

Dry Stripe Coating

- Applied after the full coat of primer or intermediate coat, since the stripe coat is allowed to dry for the full recoat interval (e.g., 12-16 hours), but not completely cure

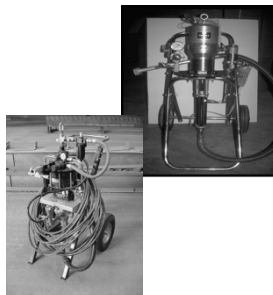
Daubers and Rollers

- Daubers
 - Used to coat crevices
- Rollers
 - Large flat surfaces
- Rollers problems:
 - Nap too deep – streaking
 - Roller nap can become embedded in dry coating film – can draw moisture into the coating film
 - Coating thickness difficult to control
 - Roller stipple can reduce gloss

Airless Spray

- Most common method used to apply industrial/marine coatings
- Fast, high production levels
- No compressed air in the paint stream
- Operates under high fluid pressures

**Airless pressures 10 to 75 times higher than residential water supply pressure*



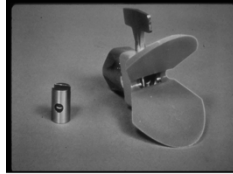
Airless Spray Equipment

- One hose containing the paint goes from the pump to the spray gun
- Paint pump may be operating using an air compressor (or electric pump)
- No controls on the spray gun (cannot be half-triggered)
- Change the spray tip to change the shape of the fan



Airless Spray Tips

- Tip Nomenclature
 - 3-Digit number
 - Double 1st number for fan width @ 30 cm (12")
 - Last 2 numbers indicate orifice size (.001")
 - Example: 521
 - 10" fan; .021" orifice



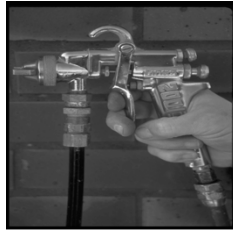
Airless Operating Pressures & Distance

- Pumps are ratioed
 - 60:1 (1 psi input = 60 psi fluid pressure)
 - 80 psi input = 4,800 psi fluid pressure
- Fluid pressures are dangerous
 - Injection hazard
 - Use of a special tip guard and trigger lock prevent injection
- Gun distance from surface: 30 cm (12 inches)



Conventional (Air) Spray

- Compressed air transports coating from pressurized pot to gun, atomizes coating into a fine spray
- Compressed air cleanliness critical
- Operator has good control over paint that exits the gun tip
- Problem: transfer efficiency is relatively low



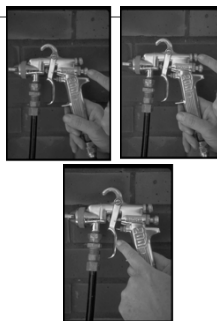
Conventional Spray Equipment

- Pressure Pot
 - Two regulators:
 - Controls pot pressure
 - Controls volume of atomization air



Conventional Spray Equipment

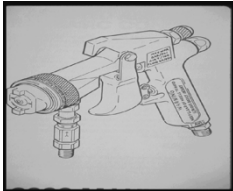
- 2 controls
 - Lower control – regulates the amount of paint that comes out of the spray tip
 - Upper control – regulates the shape of the fan pattern
- Spray gun can be "half-triggered" – air (without paint) exits the nozzle
- Gun held 15-20 cm (6-8 inches) from the surface

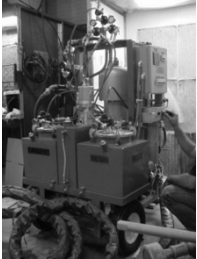


High Volume Low Pressure (HVLP) Spray

- Similar to conventional spray
- Uses a high volume of air under low pressure (less than 69 KPa [10 psi])
- Compressed air cleanliness is critical
- The transfer efficiency can be higher than conventional spray
- Operator can control the amount of paint, the shape of the spray pattern

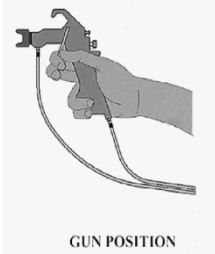


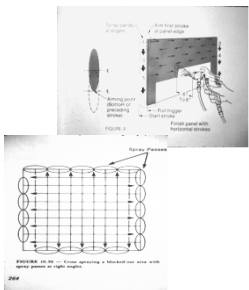
	Air-Assisted Airless Spray
- Combines the productivity of airless spray with the control of conventional spray - An "air cap" attached to the exit port of the spray gun atomizes the coating and shapes the spray fan - Operates at lower pressures than traditional airless spray	

	Plural Component Spray
- Plural component spray used for: - Short pot life materials 100% solids materials - Heated material hoses - Internal mix systems - External mix systems - Fixed and variable ratio pumps - Many systems have "off-ratio" alarms	

	Spray Technique
- Spray technique is best learned through practice and experience - Coating application not part of this course - Inspection personnel should report poor application technique	

	Spray Technique
- Laser Paint Device - Teaches applicators to: - Maintain proper distance - Maintain perpendicular gun position - Overlap spray passes	

	Spray Technique (arcing/tilting)
- Position the spray gun perpendicular to the surface - Avoid Arcing/Tilting	 GUN POSITION

	Use Overlapping and Crosshatch Techniques
- The amount of coating in the center of the fan is greater than the amount at the ends - Can only be corrected by the applicator - Applicator overlaps each previous pass by 50% - Vertical and horizontal passes (cross-hatch)	

Measuring Wet Film Thickness

- Inspectors should verify the target wet film thickness is being achieved
- ASTM D 4414 – “Practice for Measurement of Wet Film Thickness by Notch Gages”



Documenting Wet Film Thickness

- May not be necessary if dry film thickness will be measured
- Attempts to measure fast dry coatings may generate inaccurate WFT readings
- If required:
 - Actual WFT applied
 - Type of gage (stainless steel, aluminum, plastic)
 - Serial No. of gage (if available)

Measuring Dry Film Thickness

- Three common standards that address the nondestructive measurement of coating thickness:
 - SSPC-PA 2 (most common reference)
 - ASTM D7091 (coating thickness on ferrous and nonferrous metal surfaces)
 - ASTM D6132 (concrete and other non-metal surfaces)

Measuring Dry Film Thickness

- Standards provide guidance on:
 - Frequency of calibration
 - Frequency of verifying gage accuracy
 - The frequency of measurements (number of measurements to obtain based on the size of the coated structure)
- SSPC-PA 2 places limits on thickness readings vs. specified thickness

Measuring Dry Film Thickness

- SSPC-PA 2 – requires gage accuracy verification before and after each period of use
- Read the specification to determine type of gage and method used to verify accuracy
- Two types of nondestructive coating thickness gages
 - Magnetic pull-off (Type 1)
 - Electronic (Type 2)

Verifying Gage Accuracy

- Magnetic pull-off (Type 1) gages: Use Certified Traceable Coated Standards
 - NIST
 - Proprietary
 - See supplement for step-by-step procedures



The Base Metal Reading

- Surface roughness affects dry film thickness gages
- The amount the gage is affected is the Base Metal Reading or BMR
- The BMR:
 - Remains constant for the entire project
 - Is deducted from each cumulative coating layer measurement



BMR Compensation for Multiple Coat Systems

Measured Primer Thickness:	4.0 mils
BMR:	0.5 mils
Actual Primer Thickness:	3.5 mils
Measured Primer + Finish Thickness:	7.0 mils
BMR:	0.5 mils
Actual Total System Thickness:	6.5 mils

Verifying Type 2 Gage Accuracy

- Using certified traceable coated standards:
 - Adjust gage to match thickness standard
 - Measure BMR
 - Measure coating thickness
 - Deduct BMR



Gage Adjustment

- Using certified shims:
 - Place certified shim on prepared surface
 - Adjust gage to match certified shim thickness
 - Measure coating thickness
 - No BMR compensation



Frequency of Coating Thickness Measurements

- SSPC-PA 2 and ASTM D7091
- Test area size: 9.29 square meters (100 square feet)
- Five spots per test area (each spot is 3.8 cm (1.5") in diameter)
- Minimum three gage readings per spot (average becomes the "spot measurement")

Dividing Coated Areas into Test Areas Per SSPC-PA 2

- If the coated area is less than 300 square feet, each 100 square feet should be measured
- If the coated area is between 300 and 1000 square feet, select 3 random 100 square foot test areas and measure

Dividing Coated Areas into Test Areas Per SSPC-PA 2

- If the coated area is less than 300 square feet, each 100 square feet should be measured
- If the coated area is between 300 and 1000 square feet, select 3 random 100 square foot test areas and measure

Dividing Coated Areas into Test Areas Per SSPC-PA 2

- For coated areas exceeding 1000 square feet, select 3 random 100 square feet test areas for the first 1000 square feet, and select 1 random 100 square foot test area for each additional 1000 square feet

SSPC-PA 2 Example

Structure Size: 55,000 square feet

No. of Areas: $3 + 54 = 57$ areas
 No. of Spots: $57 \text{ Areas} \times 5 \text{ Spots/Area} = 285$ Spots
 Minimum No. of Gage Readings: $285 \text{ Spots} \times 3 \text{ Readings/Spot} = 855$ Gage Readings

SSPC-PA 2 Example

Structure Size: 5110 square meters

No. of Areas: $3 + 52 = 55$ areas
 No. of Spots: $55 \text{ Areas} \times 5 \text{ Spots/Area} = 275$ Spots
 Minimum No. of Gage Readings: $275 \text{ Spots} \times 3 \text{ Readings/Spot} = 825$ Gage Readings

Coating Thickness Tolerance (PA 2 only)

- Individual gage readings within spot are unrestricted (unusually low or high readings are discarded)
- Spot measurements (average of 3 gage readings) must be within specified thickness range
- Coating Thickness Restriction Level 3 is default unless otherwise specified
- Area measurement must be within specified range

PA 2 Options for Specifier

Thickness	Gage Reading	Spot Reading	Area Measurement
Level 1			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	As specified	As specified
Level 2			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 3 DEFAULT (same as former PA 2 requirement)			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 4			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	150% of maximum	As specified
Level 5			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	Unrestricted	Unrestricted

Coating Thickness Tolerance

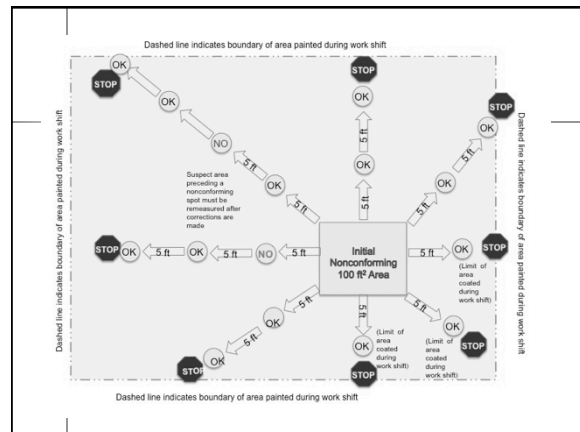
- Target DFT: 4-6 mils
- Individual gage readings unrestricted
- According to Level 3, spot measurements must be between 3.2 mils ($4 \text{ mils} \times 0.80 = 3.2 \text{ mils}$) and 7.2 mils ($6 \text{ mils} \times 1.20 = 7.2 \text{ mils}$)
- Area measurement must be between 4 mils and 6 mils
- If spot or area measurements out of tolerance, measure each 100 sq. ft area coated during the work shift to demarcate the deficient area (Independent of structure size)

Coating Thickness

- Specifications should indicate the range of coating thickness (e.g., 5-7 mils), not as a single value (e.g., 5 mils)
- Nearly impossible for an applicator to achieve a single thickness value
- The coatings inspector should not have to assume a range
- SSPC-PA 2 establishes range at +/-20% if unspecified (by spec/manuf.)

Coating Thickness Nonconformities

See illustration on the next slide.



Cumulative Thickness Measurements

- **Nondestructive coating thickness gages cannot distinguish coating layers.**
- **They measure the total cumulative thickness**



Cumulative Thickness Measurements

Specification

Primer thickness:	3-5 mils
Intermediate Coat Thickness:	4-6 mils
Finish Coat Thickness:	2-3 mils

Target After -

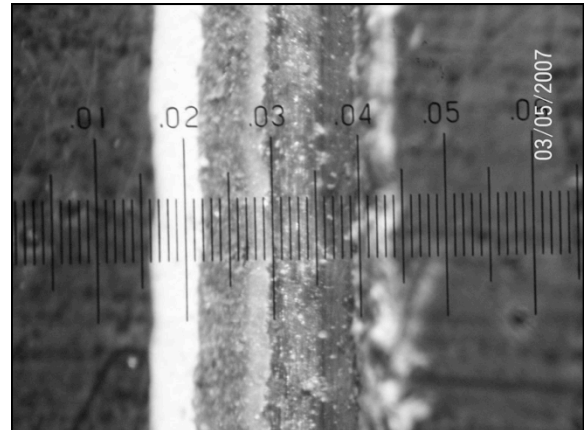
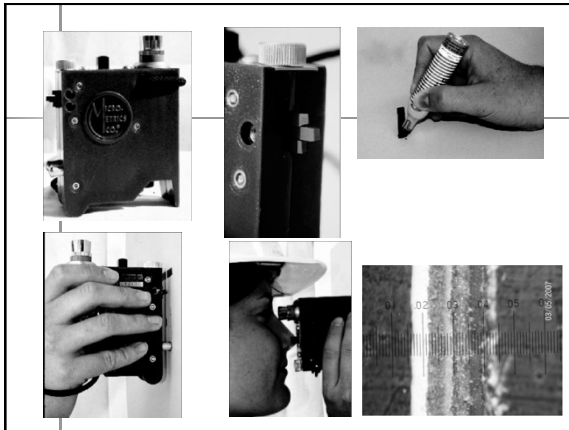
Primer Application:	3-5 mils
Intermediate Application:	7-11 mils
Finish Coat Application:	9-14 mils

Destructive Coating Thickness

- Gages used to measure individual layer thickness when all layers have been applied
- Substrate independent
- Paint Inspection Gages (PIG)
- Tooke Gages (shown)

Destructive Coating Thickness

- Gage body and battery compartment
- 50 power illuminated microscope with a scale etched onto the lens
- A focus adjustment
- Three tungsten carbide precision cutting tips



Documentation of Dry Film Thickness Data

- Gage manufacturer, model and type (1 or 2)
- Serial No. of gage
- Serial No. of calibration blocks/shims
- Date of gage calibration
- Method used to verify gage accuracy
- Date measurements were acquired
- Specified DFT range
- Area of structure measured
- Spot measurements
- Area measurements

Assessing Intercoat Cleanliness

- Airborne dirt and dust deposited on coated surfaces
- Problem if surface is to be recoated
- Can cause fisheyes in the coating and intercoat delamination
- Requires visual or tactile (touch) examination of the surface
- Can employ ISO 8502, Part 3 (pressure sensitive tape) described in Module 3

	Amine Exudate (Blush)
	■ Epoxy coatings can produce haze and/or oily residue on the coated surface during cure. ➢ High humidity and/or cool temperatures. ■ Haze and/or oily residue must be detected and removed ➢ Consult with coating manufacturer.

	Verifying Recoat Times/ Temperatures
	■ Applied coatings may have a minimum and a maximum recoat time ■ Inspector verifies: ➢ Coating has been allowed to dry or cure the minimum amount of time ➢ The next coat is applied before the maximum recoat time expires

	Documentation of Intercoat Cleanliness and Recoat Intervals
	■ Method(s) used to remove dirt and dust ■ Results of inspection after dirt removal ■ Elapsed time between coats ■ Manufacturer's remedy and methods employed by the contractor to prepare surfaces when the maximum recoat time is exceeded

	Assessing Coating Cure
	■ ASTM Methods: ➢ ASTM D1640, "Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature" ➢ ASTM D5402, "Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs" ➢ ASTM D4752, "Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc Rich Primer by Solvent Rub"

	Assessing Coating Cure
	■ ASTM D1640 includes 7 procedures for testing: 1. Set-to-touch time 2. Dust free time 3. Tack-free time 4. Dry-to-touch 5. Dry-hard 6. Dry-through (Dry-to-handle) 7. Dry to recoat

	Assessing Coating Cure
	■ ASTM D5402 and D4752 employ solvent rub testing ("double rubs") ■ No. of double rubs is converted to rating scale ■ Rating compared to coating manufacturer's PDS or the project specification

	Documenting Drying/Curing Testing
	■ Date and time of testing ■ Method used to assess cure ■ Areas on the structure tested ■ Results of cure tests ■ If solvent rub testing employed, the type of solvent used

	Assessing Coating Hardness
	■ Alternative methods to assess cure ➢ ASTM D3363 (Pencil Hardness) ➢ ASTM D2583 (Barcol Hardness) ➢ ASTM D2240 (Durometer Hardness)

	Pencil Hardness
	■ Pencils containing various lead hardness values (6B to 6H) ■ Sharpen pencil, then blunt point ■ Hold pencil at 45° angle and attempt to scratch and gouge the coating ■ Move up/down the hardness scale ■ Hardest pencil lead that will not scratch the coating is the scratch hardness ■ Hardest pencil lead that will not gouge the coating is the gouge hardness

	ASTM D3363 Pencil Hardness Scale 6B 5B 4B 3B 2B B HB F H 2H 3H 4H 5H 6H Soft Medium Hard
--	--

	Barcol Hardness
	■ "Impressor hardness" ■ Designed for thick materials ■ Position tester so legs and pointer on same surface ■ Press firmly downward ■ Read hardness from indicator scale ■ Multiple measurements required 

	Durometer Hardness
	■ Shore A or Shore D scale ■ Designed for thick materials ■ Position tester so base and pointer on same surface ■ Press firmly downward, hold in place 1-2 seconds ■ Read hardness from indicator scale (red hand) ■ Obtain 5 measurements 

Documenting Hardness Testing

- Date and time of testing
- Method used to assess hardness
- Manufacturer, model, serial no. of instrument (lot no. for pencils)
- Areas on the structure tested
- Results of hardness tests

Measuring Adhesion

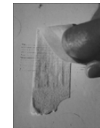
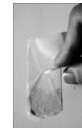
- Assessing coating adhesion characteristics:
 - The adhesion of the coating system to the substrate
 - The adhesion of the coating layers to one another
 - The inner-strength of each coating layer (cohesion properties)
 - No "industry standard" for minimum adhesion/cohesion strength (based on specification requirements)

Adhesion Test Methods

Standard	Title
D3359	Adhesion by Tape Test
D6677	Knife Adhesion
D4541	Pull-off Strength of Coatings Using Portable Adhesion Testers
D7234	Pull-off Strength of Coatings on Concrete Using Portable Adhesion Testers

Field Testing for Adhesion

- Adhesion by Tape Test, ASTM D3359
- Up to 50 μm (2 mils) = 1 mm spacing
- 50-125 μm (2-5 mils) = 2 mm spacing
- >125 μm (5 mils) – Use Method A (X-cut)
- See *adhesion testing supplement for step-by-step procedures*



Method A

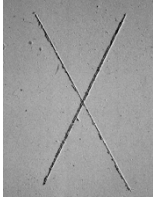
Method B

ASTM D3359 Method A Rating

- 5A No peeling or removal
- 4A Trace peeling or removal along the incisions
- 3A Jagged removal along the incisions up to 1/16" (1.6mm) on either side
- 2A Jagged removal along most of the incisions up to 1/8" (3.2mm) on either side
- 1A Removal of most of the coating from the area of the "X" under the tape
- 0A Removal of coating beyond the area of the "X"

ASTM D3359 Method B Rating

CLASSIFICATION OF ADHESION TEST RESULTS		
CLASSIFICATION	PERCENT REMOVED	CLASSIFICATION OF ADHESION TEST RESULTS (FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGES IN PERCENT)
5B	0% None	
4B	Less than 5%	
3B	5 – 15%	
2B	15 – 35%	
1B	35 – 65%	
0B	Greater than 65%	

Field Testing for Adhesion	
■ Knife Adhesion, ASTM D6677 ■ Generate X-Cut ■ Probe intersection with knife blade tip ■ Assign rating (10-0 scale) ■ See <i>adhesion testing supplement for step-by-step procedures</i>	

Evaluating Tensile Adhesion Strength	
■ Resistance to a perpendicular pull, ■ ISO 4624, ASTM D4541 & D7234 ■ Requires the attachment of pull stubs ■ Pulling mechanisms ➢ Spring ➢ Pneumatic ➢ Hydraulic ■ See <i>adhesion testing supplement for step-by-step procedures</i>	

Documenting Tape/Knife Adhesion Testing	
■ Date and time of testing ■ Manufacturer, model, serial no. of equipment ■ Areas on the structure tested ■ Thickness of the coating in the areas tested ■ Test method conducted (knife adhesion; tape adhesion [methods A/B]) ■ Spacing between incisions (if method B) ■ Adhesion rating ■ Location of break (if discernable)	

Documenting Tensile Adhesion Testing	
■ Date and time of testing ■ Manufacturer, model, serial no. of equipment ■ Areas on the structure tested ■ Thickness of the coating in the areas tested ■ Diameter of the pull stubs employed ■ Preparation of pull stub contact surfaces ■ Preparation of coated surfaces prior to pull stub attachment ■ Type of adhesive used (manufacturer & type) ■ Adhesive cure time and curing conditions ■ Pull-off strength (KPa, MPa or PSI) ■ Location of break and percentage of each	

Pinholes and Holidays	
■ Holiday and pinhole-free linings are critical for: ➢ Interior of storage tanks, vessels and railcars ➢ Liquid and gas pipelines ■ The pipeline industry refers to testing for pinholes and holidays as "jeep testing"	

Holiday Testing Standards	
■ ASTM D5162, "Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates" ■ ASTM D4787, "Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates" ■ NACE SP0188, "Standard Practice-Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates"	

	Pinholes and Holidays
	■ Holidays/Discontinuity – skips or misses in the coating/lining system ■ Pinholes – tiny voids in the coating or lining that penetrate to the substrate

	Pinholes and Holidays
	■ Caused by: ➢ areas missed by the applicator (holidays) ➢ outgassing of the coating; poor wetting of the coating/lining on the surface during application (pinholes) ■ Typically found on difficult access areas/ non-uniform surfaces (behind angles, corners, welds, bolt threads, inside holes, between back-to-back angles, etc.)

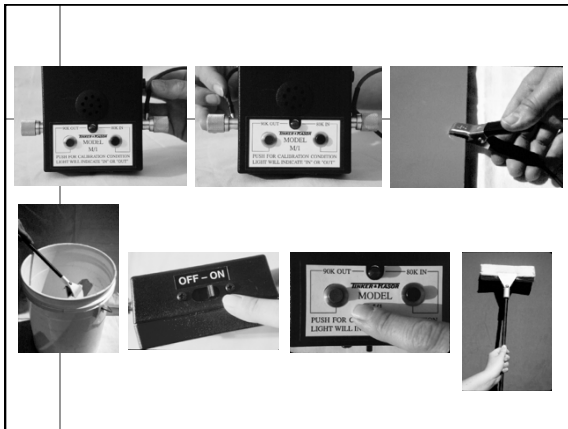
	When is Holiday Detection Performed?
	■ After final coat has been applied, but within the recoat period/interval ■ Specifications may require holiday testing after the application of each coat ■ Cannot use wetting agent in water for “between coat” pinhole detection ■ Cannot perform pinhole detection on a coating already in service

	Selecting a Holiday Detector
	■ Two types: ➢ Low voltage (wet sponge) – coatings that are less than 20 mils thick ➢ High voltage (spark testers) – coatings that are greater than 508 microns (20 mils) thick



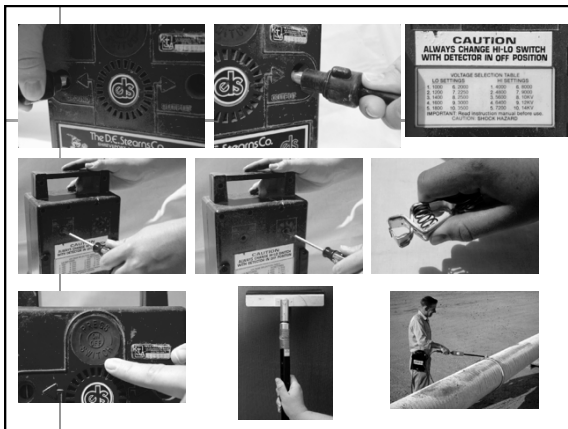
	Holiday Detection
	■ Coating must be nonconductive ■ Substrate must be conductive ■ High voltage (spark) testing requires voltage setting ➢ 100 to 125 volts/mil (per 25 µm) ➢ Obtain recommended test voltage from coating manufacturer ➢ ASTM D5162 provides voltage chart & formula

	Low Voltage Pinhole Detection
	1. Attach ground wire to detector unit 2. Attach sponge wand wire to detector 3. Attach ground wire to bare substrate 4. Saturate sponge with tap water. May use wetting agent in water if coating thickness is 250-500 µm (10-20 mils) 5. Power-up detector 6. Verify unit is operational (correct sensitivity) 7. Test surfaces (move wand 30 cm [1 foot]/second) 8. Mark pinholes with chalk or other marker that is removable



High Voltage Holiday Detection

1. Attach ground cable to detector unit
2. Attach electrode cable to detector
3. Select test voltage
4. Verify accuracy of test voltage setting using a peak reading voltmeter
5. Attach ground wire to bare substrate
6. Power-up detector
7. Test surfaces (move wand 30 cm [1 foot]/second)
8. Mark holidays with chalk or other marker that is removable
9. Only re-inspect repaired areas



Documenting Pinhole/Holiday Detection

- Type of inspection (low or high voltage)
- Manufacturer, model No. and serial No. of detector
- If high voltage, the test voltage used and the method used to verify test voltage
- Area of structure inspected
- Location of holidays/pinholes
- Methods used to repair coating/lining
- Results of retesting (if performed)

Inspecting Fluorescent Coating Systems

- Optically Active Additives (OAA) added to coatings during formulation
- Inspection performed using UVA-340 light
- Processed described in SSPC-TU 11
- Inspector training recommended if not previously performed



Inspecting Fluorescent Coating Systems, con't.

- Holidays/undercoated areas:
 - Black or dark spots under UV light
- High coating thickness
 - Brighter luminosity under UV light
- Coating detachment or hot work damage
 - Bright glow under UV light
- Organic dust/grit
 - Bright "speckled" spots under UV light
 - Can be caused by cotton fibers

	Summary
	■ Coating mixing thinning & application critical to coating system success ■ Inspection includes: ➢ Material receipt inspection ➢ Witnessing mixing/thinning procedures ➢ Measuring ambient conditions & surface temperature ➢ Calculating & measuring WFT ➢ Measuring DFT ➢ Verifying recoat times ➢ Assessing intercoat cleanliness ➢ Assessing coating cure and/or hardness ➢ Detecting pinholes/holidays ➢ Measuring adhesion ➢ Documentation of inspections

	Summary
	■ Coating application standards include SSPC-PA 1 and PA 2 ■ Product data sheets contain critical mixing, thinning and application information ■ Target WFT can be calculated based on volume solids content, thinner addition and target DFT ■ Methods of coating application include, brush, roller, airless spray, conventional spray, HVLP spray, air-assisted airless spray and plural component spray

	Summary
	■ Spray technique includes maintaining gun distance, position, overlapping passes and consistent movement ■ Measure and record ambient conditions and surface temperature prior to mixing ■ Air and surface temperatures, and relative humidity must be maintained within the allowable ranges. ■ Surface temperature must be maintained at least 3°C (5°F) higher than dew point temperature ■ Wind speed may be restricted by the project specification

	Summary
	■ Coating mixing includes proper agitation, correct ratios, correct batches, material temperature, induction consideration, pot life monitoring, material temperature, thinning amount and ratio ■ Measurement of wet film thickness is performed using notch-type WFT gages ■ SSPC and ASTM categorize Type 1 DFT gages as "magnetic pull-off" and Type 2 DFT gages as "electronic"

	Summary
	■ DFT gages must be verified for accuracy before and after each period of use ■ Type 1 & 2 gages are verified for accuracy using traceable coated standards ■ Type 2 gages can be adjusted over prepared surfaces using measured shims ■ Surface roughness affects gage readings. BMR is required if traceable coated standards are used ■ The frequency of DFT measurements and the tolerance of spot measurements are described in SSPC-PA 2

	Summary
	■ Individual layer thickness data can be acquired using a Tooke Gage ■ Documentation of DFT data is a critical responsibility of an inspector ■ Intercoat cleanliness is critical for adhesion of coating layers to one another ■ Coatings typically have minimum and maximum recoat intervals ■ Pinhole/holiday testing may be required on lining systems ■ Fluorescent pigments (Optically Active Additives) can be added to coatings for "visual" holiday detection

	Summary
	■ Coatings can be tested for degree of cure using solvent rub or other "drying" tests ■ Coating can be assessed for degree of cure using hardness tests ■ Tests can be performed to evaluate the adhesion of the coating layers to one another and the coating system to the substrate (steel or other) ■ Adhesion testing can include: ➢ Tape adhesion (Methods A or B) ➢ Knife adhesion ➢ Tensile (pull-off adhesion)

	Module 5 Workshops
	■ Inspection Case Study ■ Navigating a PDS Workshop (A) ■ Identifying coating defects (B) ➢ Classroom-interactive ■ Inspection Instrument Use Workshop (C) ■ Documentation of Workshop (C) Answers ■ Work in your teams

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INSTRUMENT USE SUPPLEMENT

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Participants are responsible for learning the information in this supplement.

DETECTING HOLIDAYS AND PINHOLES IN COATING AND LINING SYSTEMS

10

Project specifications for lining the interior of storage tanks, vessels, and railcars, and specifications for coating and lining of liquid and gas pipelines frequently require a continuous, holiday and pinhole-free coating or lining system. Rather than relying on a visual inspection, holiday/pinhole detectors are used to determine the number and location of skips, misses and pinholes, so that they can be repaired prior to placing the tank, vessel, railcar or pipeline into

service. The pipeline industry refers to this procedure as “jeep” testing. If holiday, pinhole or “jeep” testing is not performed, and there are undetected voids in the coating or lining system, then the contents of the tank, vessel, railcar or pipeline may attack the exposed substrate and cause pitting corrosion, loss of section and eventual perforation of the substrate. In addition, the contents may become contaminated with corrosion products and coating/lining debris if deterioration occurs. Holiday testing is governed by two industry standards: ASTM D5162 and NACE SP0188.

- ✓ A holiday is a skip or miss in the coating/lining system
- ✓ Low voltage (wet sponge) testing is for coating systems less than 20 mils thick
- ✓ High voltage (spark) testing is for coating systems greater than 20 mils thick

What are Pinholes and Holidays?

The terms “pinhole” and “holiday” are used interchangeably. However, they represent two different types of “breaches” in the coating/lining system. **Pinholes** are tiny voids in the coating or lining that penetrate down through all of the layers to the substrate. These voids allow the contents of the tank, vessel or pipeline access

to the metal substrate via tiny “pathways.” **Holidays** are considered “skips” or “misses” in the coating/lining system (just like holidays are skips in the work calendar). These uncoated areas permit easy access to the unprotected substrate.

Pinholes are usually caused by poor wetting of the coating/lining on the surface during application, or out-gassing (displacement) of air without subsequent flow-out of the coating. Holidays are areas that are missed by the applicator. They may be caused by the configuration of the structure being coated or lined (e.g., difficult to access with the application equipment), or lack of attention to detail by the applicator. Most holidays and pinholes are found on areas that are difficult to protect or access, such as edges and corners, welds, bolts, nuts and threads, behind angles and clips, inside holes, between back-to-back angles, etc. Large, flat surfaces like the walls of a tank or vessel are easier to coat, and therefore usually contain fewer pinholes and holidays.

When is Holiday Detection Performed?

Pinhole or holiday detection is usually conducted after the final coat has been applied, but before it has achieved complete cure, in case repair of the coating film is required. Some project specifications require holiday testing prior to application of the finish coat. If this is the case with your project, you will need to verify intercoat cleanliness of the surfaces prior to application of the next layer. Also, you should not use a wetting agent in the water (discussed in Step 3 under low voltage testing), as the coated surfaces can become contaminated and may result in intercoat adhesion problems.

Selecting a Holiday Detector

There are two different types of holiday detectors. The one you select is based on the total thickness of the coating/lining system. Low voltage or “wet sponge” holiday detectors are used on coatings/linings that are less than 20 mils thick. High voltage holiday detectors or “spark testers” are used on coatings/linings greater than 20 mils thick, and in some cases down to 10 mils. If you do not know the thickness of the coating system, you will need to measure the thickness before you perform holiday testing. You can use one of the instruments described in Module 6.

Independent of coating thickness, both of these detectors will only work on non-conductive coatings applied to a conductive substrate. For example, epoxy coatings applied to steel can be tested for holidays, while a zinc-rich coating applied to the same steel could not (zinc is a conductive metal in the coating). Some high voltage detectors can be used on non-conductive coatings applied to concrete. For this application, you should carefully review the instrument manufacturer's instructions. This module discusses holiday testing of coatings and linings on steel only.

Holiday Tester	Coating/Lining System Thickness
Low voltage (wet sponge)	Less than 20 mils
High voltage (spark)	Greater than 20 mils*

*Some cases down to 10 mils

Using a Low Voltage (wet sponge) Holiday Detector

There are several manufacturers of low voltage or wet sponge holiday detectors. In this module, we will only be discussing the proper calibration verification and use of the Tinker-Razor Model M-1 low voltage holiday detector. However, all of these detectors operate on a similar principle. A sponge is clamped to the end of a wand and is wetted with water. The holiday detector unit is grounded to the structure using a ground wire clip. Both the wand and the ground wire are attached to the detector. The wetted sponge is dragged across the coated surface. If a pinhole or holiday is present, the water from the sponge will pass through the pinhole, contact the steel, complete the circuit or "loop" and cause the detector to signal using a visible and an audible alarm.

Step 1: Assemble the Detector

The Tinker-Razor Model M-1 low voltage holiday detector contains five basic components:

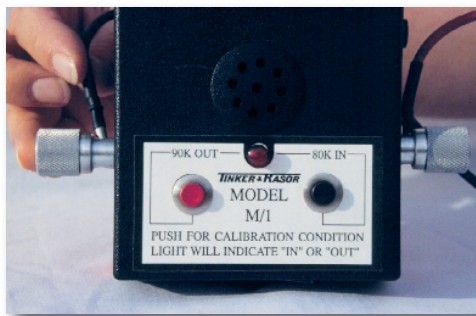
1. A 24" insulated wand containing a silver-colored, metal clamp on one end and a red insulated wire on the other end.
2. A 6" sponge.
3. A 25' black insulated ground wire with a spring-loaded, copper-colored clamp on one end (maximum of 75' allowed).



Low voltage holiday detector kit

4. A 67.5 volt detector unit that operates on 6-AA batteries.
5. A 4 ounce bottle of wetting agent.

The detector unit contains two posts: one post on either side of the unit. Connect the ground wire to one of the posts (it does not matter which one) by loosening one of the knurled posts, inserting the exposed metal tip of the black ground wire into the small hole and retightening the post (hand-tighten only). Loosen the opposite post and



Connect the ground wire to the detector



Connect the wand wire to the detector

insert the exposed metal tip of the red wire from the wand into the small hole and retighten the post. The ground wire and the wand should now be connected to the detector unit.

Loosen the wing nut on the silver-colored, metal clamp at the end of the wand and insert the sponge into the clamp. You may need to dampen the sponge slightly, so it becomes more pliable prior to inserting it into the clamp. Hand-tighten the wing nut. The unit is now assembled.



Insert sponge into wand clamp

Step 2: Attach the Ground Wire to the Structure

Attach the copper-colored, spring-loaded clamp on the end of the ground wire to the structure that you are inspecting. It is *very* important that the clamp is in contact with the bare steel. This means that you may have to remove a small section of coating to properly ground the detector. If the detector is not properly grounded, then no pinholes or holidays will be detected, even if they are there.



Attach ground wire clamp through coating to substrate

Step 3: Saturate the Sponge

Saturate the sponge with tap water. Do not use distilled or deionized water, as pure water does not conduct electricity as efficiently as tap

water. If you are inspecting a coating system that is less than 10 mils thick, plain tap water is adequate. If you are inspecting a coating system that is between 10 and 20 mils thick, you will need to add wetting agent to the tap water before you saturate the sponge. The wetting agent makes it easier for the water to penetrate down through the pinholes, rather than bridging across them. The Tinker-Rasor M-1 comes with a 4 ounce bottle of wetting agent. Add the 4 ounce bottle to 3 gallons of tap water. If you want to use less water, add 3 to 6 bottle caps of the wetting agent to one gallon of tap water. Larger bottles of wetting agent are available. Also, photograph-developing fluid (e.g., Eastman Kodak® Photo-Flo) can be used if you run out of the wetting agent. After saturating the sponge, gently squeeze out the excess water. The sponge should be thoroughly wetted, but should not be dripping water.



Saturate the sponge

Step 4: Power-up the Detector and Verify Calibration and Continuity

4-1 The “On/Off” switch is located on the bottom of the detector unit. Turn the switch to the “On” position. You will hear a constant tone. If you do not hear a tone, the batteries inside the detector may need to be replaced.



Turn the detector unit “ON”



Verify detector is “IN” calibration

4-2 Next, verify that the detector unit is operating at the proper sensitivity (greater than 80,000 ohms, but less than 90,000 ohms). There are two push buttons on the front of the detector unit. One is black and says “IN” while the other is red and says “OUT.” If you depress the black button and the detector unit signals, the unit is “IN” calibration.



Verify detector is not “OUT” of calibration

4-3 If you depress the red button and the detector unit signals, the unit is “OUT” of calibration. If the unit is out of calibration, you can either open the detector unit and adjust the potentiometer using a small screwdriver (then retest the calibration using the red and black buttons), or return it to the manufacturer for adjustment.

4-4 Prior to inspecting the coated surfaces, you should verify continuity by ensuring that the detector unit is properly grounded. To do this you will need to touch the wetted sponge to an uncoated section of the structure, or even create an intentional pinhole. Drag the wetted sponge over the uncoated substrate or the intentional pinhole. If the detector signals (a higher pitch tone is generated and the red light on the front of the detector illuminates) the ground is adequate. If the detector does not signal, touch the wetted sponge to the grounding clamp. If you hear a signal, the detector is operating properly, it's just that the ground contact is not adequate. In this case, you will need to improve the ground wire contact with the structure. If the detector does not signal when you touch the wetted sponge to the grounding clamp, the detector is not operating properly and should not be used.

Step 5: Inspect the Coated Surfaces

After you have verified that the detector is operational and the ground contact is adequate, inspect the coated surfaces by dragging the wetted sponge across the coated surfaces at a speed of approximately one linear foot per second, using a systematic, overlapping method. Maneuver the sponge as necessary and even use the ends of the sponge to check non-flat surfaces, such as inside corners and around bolt heads and nuts. Check the wetness of the sponge frequently and re-wet the sponge as necessary. The detector unit has both an audible (higher-pitch ringing) and a visual alarm (red signal light on the front of the detector) that will signal if a pinhole or a holiday is detected. The visual alarm is for noisy environments, where you may not be able to hear the higher-pitch ringing (optional head phones are also available). If the detector unit signals, turn the sponge on end and determine the exact location of the pinhole or holiday. Circle the defective area with chalk or other non-grease/non-wax marker that can be removed after the pinhole or holiday is repaired.



Inspect the coated surfaces for pinholes/holidays

Using a High Voltage (spark) Holiday Detector

There are several manufacturers of high voltage or “spark” holiday detectors. In this module, we will be only be discussing the proper use of the D.E. Stearns Model 14/20 Voltage-Regulated holiday detector. However, all of these detectors operate on a similar principle. An electrode is attached to the end of a wand. The holiday detector unit is grounded to the structure using either a ground wire clip, or by allowing the ground wire to drag along the earth (provided the

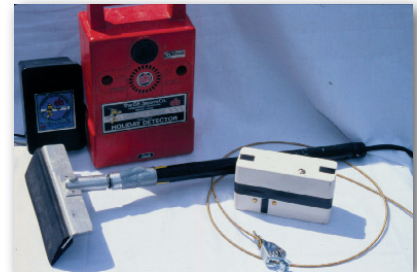
structure itself is grounded to earth). Both the wand and the ground wire are attached to the detector. The electrode is dragged across the coated surface. If a pinhole or holiday is present, the electrode will throw a spark through the air gap and cause the detector to signal using an audible alarm.

CAUTION: These detectors operate at high voltage, low amperage. Electrical shock can occur if you come in contact the electrode during use.

Step 1: Assemble the Detector

The D.E. Stearns Model 14/20 Voltage-Regulated holiday detector contains seven basic components:

1. A 24" insulated wand.
2. A black insulated cable.
3. An electrode (neoprene rubber [shown], brass brush, or spring coil).
4. A non-insulated ground wire with clip.
5. An adjustable, voltage-regulated detector unit that operates on a rechargeable battery.
6. A spare battery and battery charger unit.
7. A carrying case (not shown).



High voltage holiday detector kit

Before you proceed further, make sure the detector power switch is in the “OFF” position. Do not turn the detector “ON” until you reach Step 4. If you perform Step 2 with the Detector “ON” you will damage the detector unit.



Insert ground wire connector into detector port “GROUND”



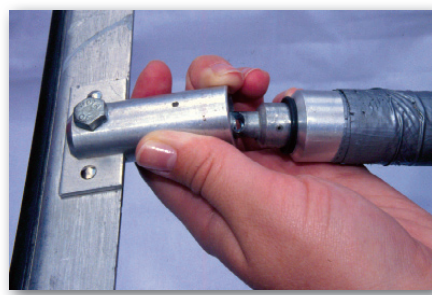
Insert electrode cable connector into detector port “OUTPUT”

The detector unit contains two ports on the front side: one port is for attaching the ground wire and the other port is for attaching the electrode. Connect the ground wire to the “GROUND” port by inserting and twisting the connector clockwise.

Connect the electrode cable to the “OUTPUT” port by inserting and twisting its connector clockwise. The ground wire and the electrode cable should now be connected to the detector unit.



Next, attach the wand to the free end of the electrode cable (insert and twist to lock).



Finally, attach the electrode (neoprene rubber, brass wire brush or spring coil) to the end of the wand (insert and twist to lock). The unit is now assembled.

Step 2: Select the Voltage Setting

Selecting the voltage setting is one of the most important steps when using a high voltage holiday detector. If the voltage selected is too low, the detector will not locate any pinholes or holidays, even if they are there. If the voltage is set too high, you could damage the coating. You should obtain the correct voltage setting from the project specification or from the manufacturer of the coating system.

In lieu of this information, ASTM D5162, “Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates” contains a suggested formula for calculating voltage settings:

$$V = M \sqrt{T_c}$$

Where: V = test voltage in volts

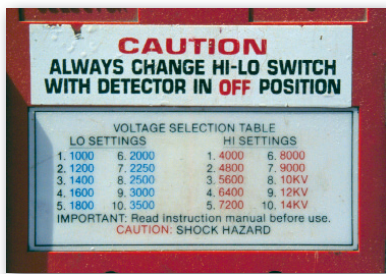
T_c - coating thickness in mils

M = a constant dependent on thickness range as follows:

<u>Thickness Range, mils</u>	<u>M Value</u>
< 40 mils	525
>40 mils	1250

The table to the right presents a list of voltages that have been calculated for coating thicknesses in the range of 20 to 95 mils using the equation.

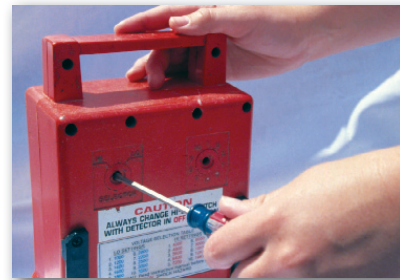
Thickness, Mils	Test Voltage	Thickness, Mils	Test Voltage
20	2,348	45	8,385
22	2,462	50	8,839
24	2,572	55	9,270
26	2,678	60	9,682
28	2,778	65	10,078
30	2,875	70	10,458
32	2,970	75	10,825
34	3,061	80	11,180
36	3,150	85	11,524
38	3,236	90	11,858
40	3,320	95	12,183



CAUTION ALWAYS CHANGE HI-LO SWITCH WITH DETECTOR IN OFF POSITION			
VOLTAGE SELECTION TABLE			
LO SETTINGS		HI SETTINGS	
1. 1000	6. 2000	1. 4000	6. 8000
2. 1200	7. 2250	2. 4800	7. 9000
3. 1400	8. 2500	3. 5600	8. 10KV
4. 1600	9. 3000	4. 6400	9. 12KV
5. 1800	10. 3500	5. 7200	10. 14KV

IMPORTANT: Read instruction manual before use.
CAUTION: SHOCK HAZARD

*Voltage setting table
(on detector unit)*



*Adjust the detector to HI or LO
setting*

2-1 Locate the “Voltage Setting Table” on the back side of the detector unit. Select the range (HI/LO) and the voltage setting from the table.

2-2 Unscrew the protective cap on the “SELECTOR” port and turn the switch to HI or LO (from the table) using a screwdriver. Replace the protective cap.



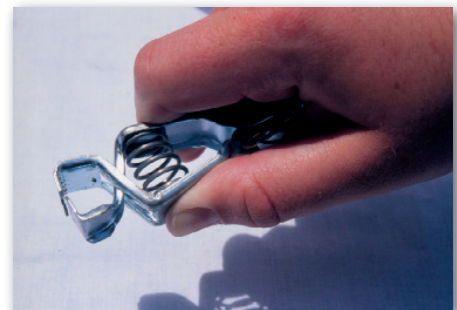
*Adjust the voltage setting on the
detector*

Example: If you wanted the test voltage to be 9,000 volts, set the HI/LO switch to “HI” and the voltage setting switch to “7.”

2-3 Unscrew the protective cap on the “Voltage Setting” port and turn the switch to the desired voltage (from the table) using a screwdriver. Replace the protective cap.

Step 3: Attach the Ground Wire to the Structure or to Earth

Attach the non-insulated ground wire to the structure that you are inspecting. It is *very* important that the wire remains in contact with the bare steel. This means that you may have to remove a small section of coating to properly ground the detector. If the detector is not properly grounded, then no pinholes or holidays will be detected, even if they are there. For pipeline inspection, or if attaching the ground wire is not practical, you can simply allow the ground wire to drag across the earth, provided that the pipeline or structure is grounded to earth.



Attach ground wire to substrate



Turn detector unit "ON"



Inspect coated surfaces for pinholes/holidays

Step 4: Power-up the Detector and Verify Continuity

The "On/Off" switch is located on the front of the detector unit. Push the switch to the "On" position. You will hear a buzzing tone. If you do not hear a tone, the battery inside the detector may need to be recharged or replaced.

Prior to inspecting the coated surfaces, you should verify continuity by ensuring that the detector unit is properly grounded. To do this you will need to touch the electrode to an uncoated section of the structure, or even create an intentional holiday. Drag the electrode over the uncoated substrate or the intentional holiday. If the detector signals (a higher pitch tone and spark are generated) the ground is sufficient. If the detector does not signal, touch the electrode to the ground wire. If you hear a signal, the detector is operating properly, it's just that the ground contact is not adequate. In this case, you will need to improve the ground wire contact with the structure or the earth. If the detector still does not signal when you touch the electrode to the ground wire, the detector is not operating properly and should not be used.

Step 5: Inspect the Coated Surfaces

After you have verified that the detector is operational and the ground contact is adequate, inspect the coated surfaces by dragging the electrode across the coated surfaces at a speed of approximately one linear foot per second, using a systematic, overlapping method. Do not hold the electrode stationary at any time while in contact with the surface, or you may damage the coating. The detector unit has an audible (high-pitch ringing) alarm that will signal if a pinhole or a holiday is detected. Also, a spark will be generated providing a visual indication of the location of the void. Circle the defective area with chalk or other non-grease/non-wax marker than can be removed after the pinhole or holiday is repaired.



*Holiday testing of pipeline using
spring electrode*

Verifying the Accuracy of High Voltage Holiday Detectors

The voltage settings on the holiday detectors are verified at the factory and at the distributor before they are sold or leased by setting the HI/LO switch and Voltage Setting Switch to a known operational voltage, then connecting the detector to a Peak Reading Voltmeter. The value displayed by the voltmeter must be within 10% of the set value.

You can verify the accuracy using the same procedure, provided that you have a Peak Reading Voltmeter. Otherwise, you will need to return the instrument to the manufacturer for verification of accuracy. If the detector is beyond the allowable tolerance, then the detector must be returned to the manufacturer, as there are no field adjustments that can be made.

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MEASURING THE ADHESION OF COATINGS

9

Some project specifications will require you to measure the adhesion of the coating system after it has been applied and is cured. Or, you may be required to measure the adhesion of a coating system that has been on a structure for several years, to determine its condition or whether it can be successfully overcoated. In either case, it is important for you to perform adhesion testing properly. Otherwise you may obtain misleading results. In Module 9, you will learn how to perform two different types of adhesion testing: shear or knife

adhesion and tensile or pull-off adhesion. But before we describe how to conduct an adhesion test, it is important for you to understand what you are measuring when you test the adhesion of a coating.

Adhesion Testing Evaluates:

- ✓ Adhesive coating strength
- ✓ Cohesive coating strength

Adhesion Test Methods Include:

- ✓ Tape adhesion
- ✓ Knife adhesion
- ✓ Tensile (pull-off) adhesion

When you perform an adhesion test, you are measuring the strength of a coating at several different “planes.” First, you are testing the adhesion of the coating system to the substrate. Secondly, you are testing the adhesion of the coating layers to each other, if there is more than one layer of coating on the surface. In both of these cases, you are testing the adhesive strength of a coating, or the bond of the layers to one another and to the substrate. Lastly, when you perform an adhesion test, you are also testing the inner-strength of each coating layer. This is known as the cohesive strength of a coating, or the ability of each layer to hold itself together. We will describe each of these in more detail later.

The adhesion of a coating system to a surface is highly variable, and can be influenced by a multitude of factors too numerous to list here. That is why there is no industry-wide standard that says that a certain type of coating must have a minimum adhesion or cohesion strength. However, project specifications may require a minimum adhesion value as a contract requirement, and coating manufacturers will often report an adhesion value on their product data sheets. Sometimes this value is adopted into a project specification.

Selecting an Adhesion Testing Method

Prior to performing an adhesion test, you must select a test method. The project specification should indicate the required method, as the various methods can generate very different results. There are three primary ways to test the adhesion of a coating system. All three methods are described in ASTM standards. The chart below summarizes the methods that are commonly used to test the adhesion of industrial coatings.

ASTM Standard	ASTM Test Method
D3359	"Adhesion By Tape Test"
D6677	"Knife Adhesion"
D4541	"Pull-off Strength of Coatings Using Portable Adhesion Testers"
D7234	"Pull-off Strength of Coatings on Concrete Using Portable Adhesion Testers"

Generally the first two methods listed above (ASTM D3359 and D6677) are considered more suitable for the field, since they do not require any special equipment and can be conducted rather quickly. The third and fourth methods (ASTM D4541 and D7234) require instruments and take longer to perform, as you will see below. While it is common to conduct this method of adhesion testing in a laboratory, the instruments used to test the pull-off adhesion strength of coatings on steel and concrete are portable and testing can and is routinely done in the shop and in the field.

The tests listed in the table above evaluate two different adhesion properties, and they use different testing mechanisms. The tape and knife adhesion tests (ASTM D3359 and D6677) are used to evaluate the "shear" or "peel" strength of a coating, while the pull-off tests (ASTM D4541 and D7234) are used to evaluate a coating's tensile strength, or its resistance to a perpendicular pull. Since the testing mechanisms are different (peel-back versus pull-off), the test results

that you obtain from each test can not be compared. Also, any type of adhesion test is “destructive.” That is, the coating in the area in which you perform the test will be damaged, and oftentimes it should be repaired. Therefore, you should not conduct an adhesion test unless you are required to by the project specification, or have been directed to perform the test by your supervisor.

Measuring Adhesion by the Tape Test (ASTM D3359)

If the project specification or other document requires you to perform an adhesion test according to ASTM D3359, “Adhesion by Tape Test,” you will need the following testing equipment. A kit is available that contains most of the equipment listed below.



Tape adhesion test kit

Item	Purpose
Steel Ruler or Guide	To generate straight cuts using a knife blade
Utility Knife With a New Razor Blade	To generate incisions (cuts) through the coating system to the underlying substrate
Small Brush (not in kit)	To remove the debris generated by the cutting process
Adhesive Tape	To apply to the cut area and test the peel strength of the coatings
Pencil Eraser (not in kit)	To ensure the adhesive tape is pressed against the cut area
ASTM Test Method	To define the test procedure and rate the adhesion

Step 1: Select a Test Area

Selecting a test area is perhaps the most difficult part of testing adhesion, particularly if you are evaluating an older coating system that has been maintained by spot or area touch-up painting over many years. It is beyond the scope of this module to provide direction on where to test and how many tests to perform. However, you should test several areas and perform replicate tests in each area to ensure you are obtaining representative adhesion data. If you are testing the adhesion of a new coating system, you may want to minimize the number of locations that you test to reduce the amount of touch-up required. However, replicate testing (at least 3) in each area selected is always a good idea. Ensure the areas you select are free of grease, oil, dirt, chalking, or water that will interfere with the adhesion of the tape.

Step 2: Determine the Thickness of the Coating System

Before you test the adhesion of the coating system using this procedure, you will need to determine how thick the coating system is. This will enable you to select a testing “method” in Step 3. This will be explained later in this module. The thickness of the coating system can be measured using any of the coating thickness gages described in Module 6.

Step 3: Select a Testing Method

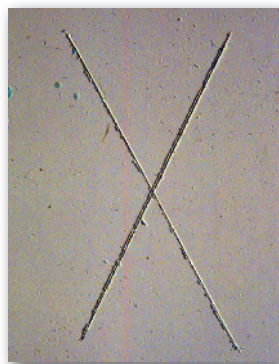
Based on the thickness of the coating system, select a test method (A or B). Method A is called an “X-Cut” and is used to test the adhesion of a coating system that is greater than 5 mils thick. Method B is called a “Cross-cut” and is used to test a coating system that is less than, or equal to 5 mils thick. ASTM allows you to use Method B for a coating system that is greater than 5 mils thick, provided that you make some adjustments to the testing procedure, and that the project personnel all agree to the deviation from the standard test method. If you select Method A (X-Cut), proceed to Step 4 below. If you select Method “B,” proceed to Step 5.

Step 4: Measure the Adhesion using Method A (X-Cut)

If you selected the X-Cut method of testing the adhesion of the coating system, follow steps 4-1 through 4-8 below. Repeat these steps for each test area selected in Step 1.



Use a straight edge to make cuts

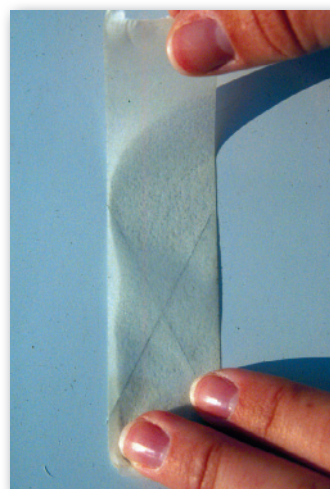


4-1 Mount a new razor blade in a utility knife holder and extend the blade outward. Use a straight edge (one side of the KTA Cross-Cut Guide works well) and make a 1.5” long cut through the coating system (down to the substrate). Now make a second 1.5” long cut across the first cut to form an “X.”

The legs at the top and bottom of the “X” should be approximately 1” apart. The intersection of the “X” should be close to a 30-45° angle.

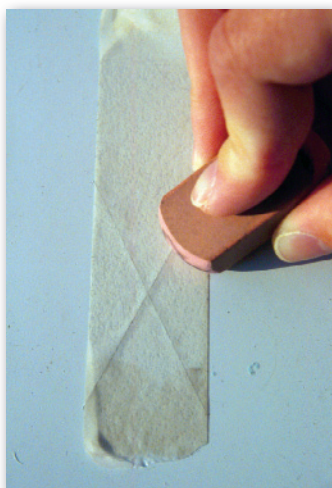


4-2 Remove any debris from the “X” area using a soft brush (a new 1” paint brush works well).



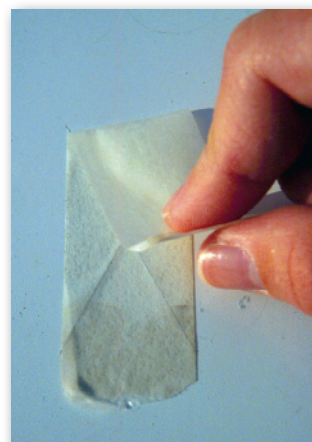
Apply tape to X-Cut area

4-3 Remove two complete wraps of adhesive tape and discard. Carefully remove a piece of the adhesive tape and apply it to the “X” area. Since the total length of the “X” is approximately 1.5”, you will need a piece of tape that is at least 2” long. Because the tape and the “X” cut area are both 1” wide, the tape should cover the entire X-Cut. If it does not, you have made the “X” cut too wide.



Ensure tape is adherent

4-4 Using a soft pencil eraser, rub the tape over the X-Cut. This step will help ensure good contact between the tape and the coating surface. Since you will generate some friction here, allow the tape to remain on the surface for a few seconds (to cool) before removing it in Step 4-5.



Remove tape 180° to the surface

4-5 Within 90 (+/- 30) seconds, remove the tape from the X-cut smoothly and rapidly, 180° back across the X-Cut (i.e., peel back, do not pull upwards).

4-6 Examine the X-Cut area for coating delamination. Since there will be shavings of coating down in the grooves of the cuts, it is not a good idea to rate the adhesion based on what appears on the tape. The tape will almost always have coating debris on it. Instead, look at the X-Cut area on the coated surface and rate the condition of it according to the table below.

Rating	Description
5A	No peeling or removal
4A	Trace peeling or removal along the incisions
3A	Jagged removal along the incisions up to 1/16" (1.6mm) on either side
2A	Jagged removal along most of the incisions up to 1/8" (3.2 mm) on either side
1A	Removal of most of the coating from the area of the "X" under the tape
0A	Removal of coating beyond the area of the "X"

4-7 Classify the location of the delamination as "adhesion" or "cohesion" according to the definitions provided in the table below. Usually this can only be done if the adhesion is rated 3A or lower.

Location of Delamination	Description
Adhesion	A distinct break between coating layers or a distinct break between the substrate and the first coating layer
Cohesion	A split within a coating layer

4-8 If possible, you should also record the identity of the coating layers where the delamination occurred (e.g., Adhesion: Primer/Topcoat). The table below illustrates an example of how to record the adhesion data. You can use an 8X or 10X magnifier or "loop" to view the cut area, if needed.

Example using Method A from ASTM D3359:

Location	Test No.	Adhesion Rating	Location of Delamination
Area 1	1	3A	Cohesion: Within the primer layer
Area 1	2	2A	Cohesion: Within the topcoat layer
Area 2	1	1A	Adhesion: Between the substrate and the primer
Area 2	2	2A	Adhesion: Between the primer and the topcoat
Area 3	1	5A	Not applicable
Area 3	2	4A	Cannot distinguish location of delamination

Step 5: Measure the Adhesion using Method B (Cross-Cut)

If you selected the Cross-Cut method of testing the adhesion of the coating system, follow Steps 5-1 through 5-8 below. Repeat these steps for each test area selected in Step 1.

5-1 Mount a new razor blade in a utility knife holder and extend the blade outward. Use a straight edge or the KTA Cross-Cut Guide and make a series of 6 or 11 parallel knife blade cuts through the coating system (down to the substrate). The number of cuts and the amount of space between the cuts is based on the total thickness of the coating system you measured in Step 2. Using the chart below, determine the number of cuts and the spacing between the cuts.



Cutting parallel incisions into coating film

Coating Thickness	Number of Cuts	Spacing Between Cuts
Up to 2 mils	11	1 mm
2-5 mils	6	2 mm
>5 mils	6	5 mm or X-Cut (Method A)



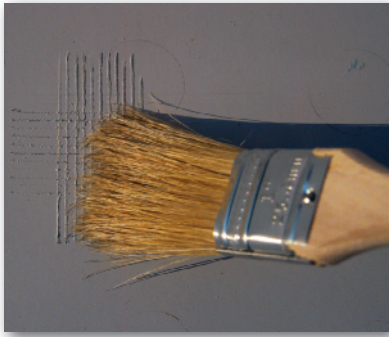
Cross-cut pattern (1mm spacing)



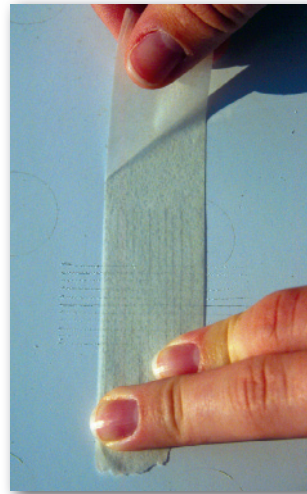
Cross-cut pattern (5mm spacing)

Turn the straightedge or guide 90° and make a second series of parallel knife cuts over top of the first set of cuts, but make them perpendicular to the first set to form a grid, cross-hatch or “Cross-Cut” pattern. If you used 11 cuts, you will have a 10 x 10 grid, or 100 squares.

If you used 6 cuts, you will have a 5 x 5 grid, or 25 squares.

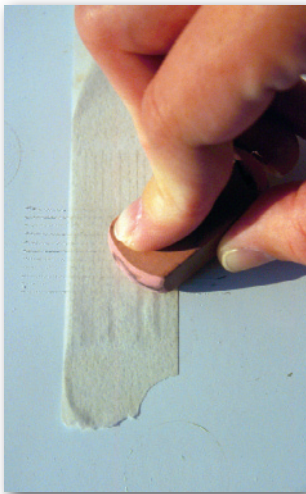


5-2 Remove any debris from the “Cross-cut” area using a soft brush (a new 1" paint brush works well).



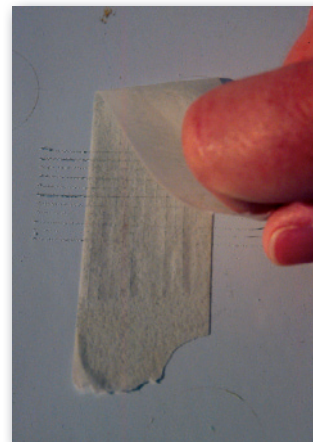
Apply tape to cross-cut area

5-3 Remove two complete wraps of adhesive tape and discard. Carefully remove a piece of the adhesive tape and apply it to the “Cross-cut” area.



Ensure tape is adherent

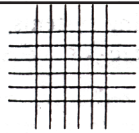
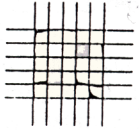
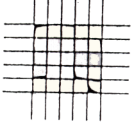
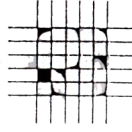
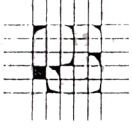
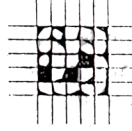
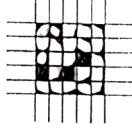
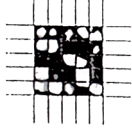
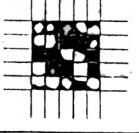
5-4 Using a soft pencil eraser, rub the tape over the cross-cut area. This step will help ensure good contact between the tape and the coating. Since you will generate some friction here, allow the tape to remain on the surface for a few seconds (to cool) before removing it in Step 5-5.



Remove tape 180° to the surface

5-5 Within 90 (+/- 30) seconds, grasp one end of the tape and remove it from the cross-cut area smoothly and rapidly, 180° back across the grid (i.e., peel back, do not pull upwards).

5-6 Examine the cross-cut area for coating delamination. Since there will be shavings of coating down in the grooves of the cuts, it is not a good idea to rate the adhesion based on what appears on the tape. The tape will almost always have coating debris on it. Instead, look at the cross-cut area on the coated surface and rate the condition according to the table on page 9-10. The ASTM D3359 standard provides a chart similar to the one shown below that illustrates the various percentages of delamination described in the table.

CLASSIFICATION OF ADHESION TEST RESULTS		
CLASSIFICATION	PERCENT AREA REMOVED	SURFACE OF CROSS-CUT AREA FROM WHICH FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGE BY PERCENT
5B	0% None	
4B	Less than 5%	
3B	5 - 15%	 
2B	15 - 35%	 
1B	35 - 65%	 
0B	Greater than 65%	

ASTM D3359 adhesion rating chart (Method B)

Rating	Percent Delamination	Description
5B	0% (none)	Edges of the cuts are completely smooth
4B	< 5%	Small flakes of coating are detached at the intersections
3B	5-15%	Small flakes of coating are detached along the edges and intersections
2B	15-35%	Coating has flaked along the edges and on parts of the square
1B	35-65%	Coating has flaked along the edges of the cuts in large ribbons and whole squares have detached
0B	>65%	Flaking and detaching worse than Rating 1B

5-7 Classify the location of the delamination as “adhesion” or “cohesion” according to the definitions provided in the table below. Usually this can only be done if the adhesion is rated 3B or lower.

Location of Delamination	Description
Adhesion	A distinct break between coating layers or a distinct break between the substrate and the first coating layer
Cohesion	A split within a coating layer

5-8 If possible, you should also record the identity of the coating layers where the delamination occurred (e.g., Adhesion: Primer/Topcoat). The table below illustrates an example of how to record the adhesion data. You can use an 8X or 10X magnifier or “loop” to view the cut area, if needed.

Example using Method B from ASTM D3359:

Location	Test No.	Adhesion Rating	Location of Delamination
Area 1	1	3B	Cohesion: Within the primer layer
Area 1	2	2B	Cohesion: Within the topcoat layer
Area 2	1	1B	Adhesion: Between the substrate and the primer
Area 2	2	2B	Adhesion: Between the primer and the topcoat
Area 3	1	5B	Not applicable
Area 3	2	4B	Cannot distinguish

Measuring Adhesion by the Knife Test (ASTM D6677)

The adhesion of a coating system to the underlying substrate and the adhesion of coating layers to one another can be evaluated using ASTM D6677, “Evaluating Adhesion by Knife.” This test method provides you with a quick and easy way to measure adhesion in the laboratory or in the field. While subjective, this type of adhesion testing has been conducted for many years, in fact long before it became an ASTM standard test method. It requires very little investment in equipment and can provide you with valuable information regarding the integrity of the coating system.



Knife, ruler, and test method

If the project specification or other document requires you to perform this type of adhesion testing, you will need the following testing equipment.

Item	Purpose
Steel Ruler or Guide	To generate straight cuts using a knife blade
Utility Knife With a New Razor Blade	To generate incisions (cuts) through the coating system to the underlying substrate
ASTM Test Method	To define the test procedure and rate the adhesion

Step 1: Select a Test Area

Selecting a test area is perhaps the most difficult part of testing adhesion, particularly if you are evaluating an older coating system that has been maintained by spot or area touch-up painting over many years. It is beyond the scope of this module to provide direction on where to test and how many tests to perform. However, you should test several areas and perform replicate tests in each area to ensure you are obtaining representative adhesion data. If you are testing the adhesion of a new coating system, you may want to minimize the number of locations that you test to reduce the amount of touch-up required. However, replicate testing in each area selected is always a good idea.

Step 2: Make Two Incisions

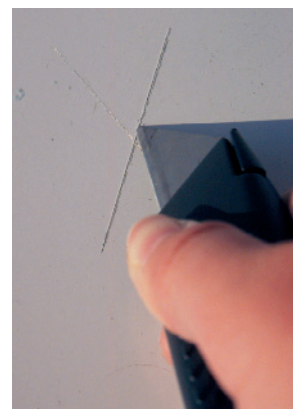
Mount a new razor blade in a utility knife holder and extend the blade outward. Using a straight edge make a 1.5" long cut through the coating system (down to the substrate). Now make a second 1.5" long cut across the first cut to form an “X”. The legs at the top and bottom of the “X” should be approximately 1" apart. The intersection of the “X” should be close to a 30-45° angle.



Cutting incision into coating film

Step 3: Measure the Adhesion

Starting at the intersection of the “X,” use the tip of the knife blade and attempt to lift the coating from the substrate or the underlying coating layer(s). Rate the adhesion according to the table in the ASTM standard, which is similar to the one below.



Measuring knife adhesion

Rating	Description
10	Coating is extremely difficult to remove. Fragments no larger than 1/32" x 1/32" removed with great difficulty.
8	Coating is difficult to remove. Coating chips from 1/16" x 1/16" to 1/8" x 1/8" removed with difficulty.
6	Coating is somewhat difficult to remove. Coating chips from 1/8" x 1/8" to 1/4" x 1/4" removed with slight difficulty.
4	Coating is somewhat difficult to remove. Coating chips in excess of 1/4" x 1/4" removed using light pressure with knife blade.
2	Coating is easy to remove. Once started with the knife blade, the coating can be grasped with fingers and easily peeled to a length of at least 1/4".
0	Coating is easy to remove. Once started with the knife blade, the coating can be grasped with fingers and easily peeled to a length greater than 1/4".

Step 4: Determine the Type and Location of Coating Delamination

If possible, classify the location of the delamination as “adhesion” or “cohesion” according to the definitions provided in the table below.

Location of Delamination	Description
Adhesion	A distinct break between coating layers or a distinct break between the substrate and the first coating layer
Cohesion	A split within a coating layer

You should also record the identity of the coating layers where the delamination occurred (e.g., Adhesion: Primer/Topcoat). The table below illustrates an example of how to record the adhesion data. You can use an 8X or 10X magnifier or “loop” to view the cut area, if needed.

Example using ASTM D6677 test method:

Location	Test No.	Adhesion Rating	Location of Delamination
Area 1	1	6	Cohesion: Within the primer layer
Area 1	2	4	Cohesion: Within the topcoat layer
Area 2	1	2	Adhesion: Between the substrate and the primer
Area 2	2	2	Adhesion: Between the primer and the topcoat
Area 3	1	10	Not applicable
Area 3	2	8	Cannot distinguish location of delamination

Measuring Pull-Off Adhesion (ASTM D4541; ASTM D7234)

If the project specification or other document requires you to perform a pull-off adhesion test according to ASTM D4541, “Pull-off Strength of Coatings Using Portable Adhesion Testers” or ASTM D7234, “Pull-off Strength of Coatings on Concrete Using Portable Adhesion Testers,” you will need to select and use an adhesion test device discussed in this Module. All of these devices are provided in kits that contain all of the necessary equipment to perform a series of adhesion tests. Because these devices require you to attach a pull-stub to the surface using an adhesive, the amount of time it takes to perform pull-off adhesion is greater than that required to perform a knife adhesion test. Depending on the type of adhesive you use and the air/surface temperature, you may have to attach the pull stubs on one day and pull them on the next.

This module primarily describes the use of pull-off adhesion testers for coatings on steel. For coatings on concrete, larger diameter pull stubs (e.g., 2” diameter) may be required. Also, custom made, concave and convex pull stubs for testing the adhesion of coatings/linings on the interior and exterior of pipe are available for some models. All of the adhesion testers described in this module are available with the larger diameter pull stubs. Special requirements for testing the pull off strength of coatings on concrete are listed at the end of this module.

Step 1: Select a Test Area

Selecting a test area is perhaps the most difficult part of testing adhesion, particularly if you are evaluating an older coating system that has been maintained by spot or area touch-up painting over many years. It is beyond the scope of this module to provide direction on where to test and how many tests to perform. However, you should test several areas and perform replicate tests (minimum

of triplicate) in each area to ensure you are obtaining representative adhesion data. If you are testing the adhesion of a new coating system, the number of locations that you test may not be as critical. In fact, the specifier may want to minimize the number of test areas to reduce the amount of touch-up required. However, triplicate testing in each area selected is always a good idea.

Step 2: Select a Test Device

Unless the project specification requires you to use a specific type of adhesion tester, you will need to select one. This module discusses four such devices, all of which conform to ASTM D4541 and ASTM D7234. However, these devices do not all work the same, and the device you select can influence the adhesion values that you generate. In general, the self-aligning test devices will usually produce higher (and more precise) adhesion values than the fixed alignment type.

ASTM D4541 Annex	Device	Pulling Mechanism	Type
A.2	Elcometer® Model 106	Mechanical (spring)	Fixed Alignment
A.3	HATE®	Hydraulic Pressure	Self-Aligning
A.4	PATTI® Quantum	Pneumatic Pressure	Self-Aligning
A.5	PosiTest® AT	Hydraulic Pressure	Self-Aligning

Once you select a test device, proceed to the section of Module 9 that describes the step-by-step use of that particular device. These sections are shown in the table below.

Model Section	Device
9.1	Elcometer® Model 106
9.2	HATE®
9.3	PATTI® Quantum
9.4	PosiTest® AT

SECTION 9-1 – MEASURING ADHESION USING THE ELCOMETER® MODEL 106

The Elcometer® Model 106 Adhesion Tester can be used to test the pull-off strength of a coating or coating system. It is a mechanical adhesion tester, which uses a calibrated compression spring to produce a perpendicular force on a pull stub. This force is automatically converted to pounds per square inch (psi) or MegaPascals (MPa) by reading one of the scales on the instrument.

There are several ranges of Elcometer® Model 106 adhesion testers to choose from. The models available and the range of each one are indicated in the table below. The 106/2 (0-1,000 psi) is the most common model.

Model No.	Range
106/1	0-500 psi
106/2 (shown)	0-1000 psi
106/3	0-2000 psi
106/4	0-3200 psi
106/4A	For use with 2" pull stubs
106/5	0-30 psi



Elcometer® Model 106/2 adhesion tester

The Elcometer® Model 106 Adhesion Testers are factory-calibrated. You cannot verify nor change the calibration. A device known as an Instron or a Tinius Olsen Universal Testing Machine is used to create a calibration curve. You should send the adhesion tester to a qualified laboratory once every six months if it is used frequently (annually is sufficient for infrequent use) and instruct them to create a calibration curve for you. The calibration curve that they create will enable you to convert the instrument reading to “actual pressure.”

Step 1: Prepare the Test Surface

Once you have selected a test area, you will need to prepare the surface. Ensure the area you selected is free of grease, oil, dirt or chalking, water, protrusions, or other conditions that will interfere with the attachment of a pull stub to the surface. The area you select must also be flat and rigid within a 4" diameter circle. Also, the ASTM standard recommends a minimum substrate thickness of ¼". If the test surface is very smooth or glossy, you may want to lightly roughen it using a fine grade of sandpaper. If you abrade the surface, be sure to wipe away any fine dust that was created.



Lightly roughen surface

Step 2: Prepare the Test Pull Stub

The Elcometer pull stub (also known as a “dolly”) is a round, two-sided aluminum fixture (1/2 square inch surface area). At first glance, both sides of the pull stub appear the same. However, one side of the pull stub is sloped on the top surface, while flat on the bottom surface. The bottom surface is the contact area. It is very important to attach the pull stub to the surface using the correct side of the pull stub. If you attach the pull stub “up-side-down,” the test device cannot be positioned properly and you will have to attach new pull stubs.



*Elcometer pull stub
(proper orientation)*



Roughen pull stub base



*Blast cleaned (L) versus non-blast
cleaned (R) pull stub*



Clean pull stub

Because the surface of the pull stub is polished aluminum, you will need to roughen it using a coarse sand paper. Alternatively, you can purchase pull stubs that have been pre-roughened by abrasive blast cleaning. In either case, wipe the pull stub to remove any dirt or debris using a soft cloth. You can also use some isopropyl alcohol (rubbing alcohol) to help remove oxides or other debris that may interfere with the attachment of a pull stub to the surface. The manufacturer does not recommend reusing pull stubs.

Step 3: Select an Adhesive

There are a variety of adhesives that can be used to attach the pull stub to the surface. The Elcometer adhesion tester kit comes with Araldite, a 100% solids epoxy adhesive. This adhesive requires at least 24 hours at room temperature to cure. While other “quick-set” adhesives are available and can be used, they may not be able to withstand the pulling forces of the test device, and may break before the coating does at a relatively low force. Also, cyanoacrylate adhesives (Super Glue) may soften or penetrate the coating film. Mix the adhesive you selected according to the manufacturer’s directions. If the adhesive is two-component, it will have a maximum working time. Do not mix up more than you can use during the working time.



Araldite 2011 epoxy adhesive

Step 4: Attach the Pull Stub to the Surface



Apply adhesive to pull stub

4-1 Using a wooden stick, apply an even layer of adhesive to the entire contact surface of the pull-stub (a 2-4 mil layer is adequate).



Attach pull stub

4-2 Attach the pull stub to the coated surface and gently push downward to displace any excess adhesive. Do not twist or slide the pull stub during attachment, because you may generate air bubbles in the adhesive.



Remove excess adhesive

4-3 Carefully remove the excess adhesive from the perimeter of the pull stub using a cotton swab or other device. Allow the adhesive to fully cure before performing the adhesion test.



Use tape to hold the pull stub in place

4-4 Push the pull stub inward against the surface, then apply tape across the head of the pull stub. Attach the tape to the test surface to hold the pull stub in place while the adhesive cures.

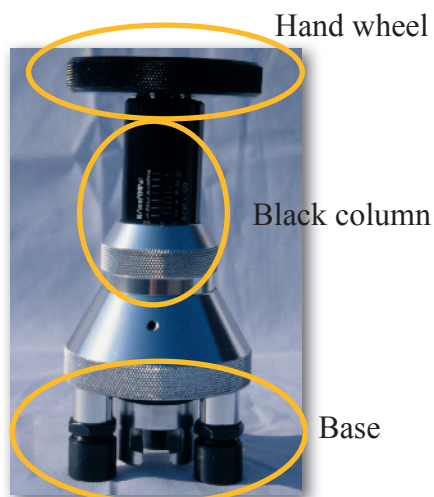
Step 5: Determine Whether Scoring is Required

ASTM standard test method D4541 does not recommend any type of scoring around the base of the pull stub prior to testing unless required by the specifier. Scoring may produce tiny fractures in the coating or may generate friction heat, which can change the properties of the coating and result in lower adhesion values. If the project specification requires you to score the coating around the perimeter of the pull stub, then you will need to use the hand-scoring device included in the Elcometer® Adhesion Test Kit. However, this must be done very carefully to avoid contact with the sides of the pull stub.

If you score around the perimeter, place the scoring device over the pull stub and rotate the cutter using a back and forth motion. Make sure you score down through all coating layers to the substrate. For thick coatings (e.g., 100 mils or more), you may need to use a 1" hole saw (with the lead drill bit removed) mounted in a portable drill to penetrate down to the underlying substrate. This requires considerable skill to avoid contacting the sides of the pull stub. You may want to score the coating prior to attaching the pull stub.



*Scoring the coating
(if specified)*



*Elcometer® 106/2
tester components*



*Elcometer® 106/3
or 106/4 tester (no
handwheel)*

Step 6: Perform the Adhesion Test

6-1 The Elcometer® adhesion tester consists of three basic components: A hand wheel (model 106/2) or hexagon-shaped nut at the top (models 106/3 and 106/4), a black column containing a dragging indicator pin and scale in the middle, and a base containing three legs and a pulling “jaw” (designed to fit the head of the pull stub) at the bottom.



Lower jaw



Position Tester



Verify levelness

6-2 Attach the adhesion tester to the pull stub by rotating the hand wheel (or hexagon-shaped nut) counterclockwise to lower the “jaw” of the device.

6-3 Slide the jaw completely under the head of the pull stub. Position the three legs of the instrument so that they are sitting flat on the coated surface.



Set drag pin

6-4 Slide the dragging indicator pin on the black column to “zero” by pushing it downward.



Rotate handwheel to increase load

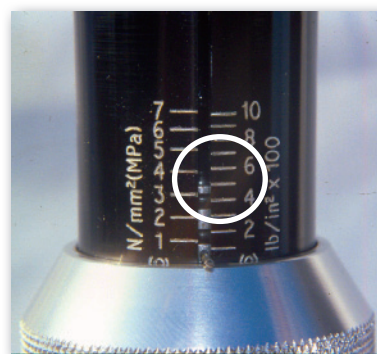


Rotate hexagon nut to increase load

6-5 Firmly hold the base of the instrument in one hand and rotate the hand wheel clockwise to raise the “jaw” of the device that is attached to the head of the pull stub. If the adhesion tester is equipped with a hexagon-shaped nut at the top, use the spanner wrench supplied with the tester. The tension on the spring will place a perpendicular, upward force on the pull stub. The dragging indicator pin will move upward on the black column as the force is increased, and will hold the reading for you. Increase the tension smoothly and evenly. Apply the tension using a moderate speed. The rate of force should not exceed 150 psi per second. Continue to increase the tension on the head of the pull stub (with minimal stopping) until one of the three “events” occurs (described below). You should complete the test in 100 seconds or less.

Step 7: Read the Scale and Record the Adhesion Value

The black column near the middle of the adhesion tester contains two scales and a dragging indicator pin located between the two scales. The right scale is pounds per square inch (psi) and the left scale is MegaPascals (MPa). As we discussed in Step 6, the dragging indicator pin will hold the reading for you until you push it back to “zero.” When you achieve the endpoint of the test (see the three possible events described below), read the scale across from the bottom of the dragging indicator pin. If you select the psi scale, multiply the scale value by 100. For example if the bottom of the dragging pin is between 3 and 4 on the psi scale, record the value as 350 psi (3.5 x 100).



Scales with dragging indicator pin

Three Possible Events

Event 1: The minimum psi required by the project specification is exceeded and the test is discontinued. When this occurs, relieve the tension by turning the hand wheel or spanner wrench counterclockwise until the “jaw” of the adhesion tester can be removed (slid) from beneath the head

of the pull stub. You can leave the pull stub on the surface, or you can easily remove it by tapping it on the side with a hammer. Record the adhesion as “Pass: > X psi.” Return the dragging indicator pin to “zero” on the scale before you conduct additional tests.

Event 2: The maximum psi of the adhesion tester has been achieved and the pull stub is still attached. When this occurs, relieve the tension by turning the hand wheel or spanner wrench counterclockwise until the “jaw” of the adhesion tester can be removed (slid) from beneath the head of the pull stub. You can leave the pull stub on the surface, or you can easily remove it by tapping it on the side with a hammer. Record the adhesion as “> X psi,” or select and use an adhesion tester with a higher capacity. You should not rerun the test on the same pull stub, since the coating system has already been stressed beneath the pull stub and a false low adhesion value may result. Return the dragging indicator pin to “zero” on the scale before you conduct additional tests.

Event 3: The force applied by the adhesion tester causes the pull stub to dislodge. When this occurs, read the scale across from the bottom of the dragging pin as described in Step 7. Return the dragging indicator pin to “zero” on the scale before you conduct additional tests.

You will need to record the type of break that occurred and the location of the break. The type of break can be described as “adhesion,” “cohesion,” or “glue.” You should also record the identity of the coating layers where the break occurred and the approximate percentage of each (e.g., 70% Adhesion: Primer/Topcoat; 30% Cohesion-Topcoat). Since the type and location of break are the same for all types of pull-off adhesion testers, they are described only once, at the end of this Module. An example “Table of Results” is also shown.

SECTION 9-2 – MEASURING ADHESION USING THE HATE® ADHESION TESTER

The HATE® Adhesion Tester can be used to test the pull-off strength of a coating or coating system. HATE stands for Hydraulic Adhesion Testing Equipment. The HATE® adhesion tester uses hydraulic oil pressure to produce a simultaneous, perpendicular push on the coated surface and pull on a pre-glued pull stub. This hydraulic pressure is automatically converted to pounds per square inch (psi) or “Bar” by reading one of the two scales (red or black) on the instrument dial. A digital version is also available. The range of the HATE® Adhesion Tester is 0-3,500 psi.



HATE® Adhesion Tester

The HATE® Adhesion Tester is factory-calibrated.

You cannot verify nor change the calibration. You should send the adhesion tester back to the manufacturer once every six months if it is used frequently (annually is sufficient for infrequent use) and instruct them to verify the accuracy of the tester. They may need to create a calibration curve for you. If so, the calibration curve that they create will enable you to convert the gage reading to “actual pressure.”

Step 1: Prepare the Test Surface

Once you have selected a test area, you will need to prepare the surface. Ensure the area you selected is free of grease, oil, dirt or chalking, water, protrusions, or other conditions that will interfere with the attachment of a pull stub to the surface. The area you select must also be flat and rigid within a 1” diameter circle. Also, the ASTM standard recommends a minimum substrate thickness of ¼”. If the test surface is very smooth or glossy, you may want to lightly roughen it using a fine grade of sandpaper. If you abrade the surface, be sure to wipe away any fine dust that was created.

Step 2: Prepare the Test Pull Stub

The HATE® pull stub is a round, two-sided stainless steel fixture with a hole through the center. The top of the pull stub has a larger diameter hole, while the bottom has a smaller diameter hole and a smooth, flat contact surface. This bottom side is the contact area.



HATE® pull stub



Top of HATE® pull stub



Bottom of HATE® pull stub

Because the surface of the pull stub is very smooth, you may want to roughen it using a coarse sand paper. Wipe the pull stub to remove any dirt or debris using a soft cloth. You can also use some isopropyl alcohol (rubbing alcohol) to help remove debris that may interfere with the attachment of a pull stub to the surface. The manufacturer allows the reuse of pull stubs.



Roughen pull stub contact surface

Step 3: Select an Adhesive

There are a variety of adhesives that can be used to attach the pull stub to the surface. The HATE® adhesion tester kit comes with Turbo Fuse, a single component instant bonding super glue. This adhesive and other “quick-set” adhesives are available and can be used. However, they may not be able to withstand the pulling forces of the test device and may break before the coating does at a relatively low force. Also, cyanoacrylate (Super Glue) adhesives may soften or penetrate the coating film. Adhesives like Araldite or Hysol 907 are two-component epoxy-type. These types of adhesives can usually withstand higher pulling forces. If the adhesive you selected is two-component, mix it according to the manufacturer’s directions. Also, a two-component adhesive will have a maximum working time. Do not mix up more than you can use during the working time.



Step 4: Attach the Pull Stub to the Surface

4-1 Insert a small diameter Teflon plug (supplied with the HATE® kit) through the top center hole of the stainless steel pull stub until the small tip of the plug protrudes from the contact (bottom) surface of the pull stub.



Insert teflon plug through top of HATE® pull stub



Small tip of teflon plug protrudes from bottom of HATE® pull stub



Apply adhesive to pull stub contact surface



Attach pull stub to coated surface



Remove the teflon plug

4-2 Using the adhesive dispenser bottle or a wooden stick, apply an even layer of adhesive to the entire contact surface of the pull stub (a 2-4 mil layer is adequate). Attach the pull stub to the coated surface and gently push downward to displace any excess adhesive. Do not twist or slide the pull stub during attachment, because you may generate air bubbles in the adhesive. Carefully remove the excess adhesive from the perimeter of the pull stub using a cotton swab or other device. Remove the Teflon plug from the pull stub and remove any adhesive that has accumulated on the end of the plug. Allow the adhesive to fully cure before performing the adhesion test.

4-3 Carefully hold the pull stub in place and apply tape across the head of the pull stub. Attach the tape to the test surface to hold the pull stub in place until the adhesive cures.



Use tape to hold pull stub in place

Step 5: Determine Whether Scoring is Required

ASTM standard test method D4541 does not recommend any type of scoring around the base of the pull stub prior to testing unless it is required by the specifier. Scoring may produce tiny fractures in the coating, which can change the properties of the coating and result in lower adhesion values. If the project specification requires you to score the coating around the perimeter of the pull stub, then you will need to use a razor knife, because there is no scoring device provided in the HATE® adhesion kit. This must be done very carefully to avoid contact with the sides of the pull stub.

Step 6: Perform the Adhesion Test

The HATE® adhesion tester consists of five basic components: A black, threaded hand lever, a pressure indicator dial containing a black needle and a red “sweep” needle, a flexible hydraulic hose, a stainless steel cylinder, and a “quick connect/disconnect” locking ring with a stainless steel pin protruding from the center.



Insert pin through center hole in pull stub

6-1 Attach the adhesion tester to the pull stub by rotating the black threaded hand lever counterclockwise to retract the stainless steel pin.



Attach quick connect locking ring to pull stub

6-2 Next, insert the center stainless steel pin through the center hole in the pull stub, then attach the quick-connect locking ring to the pull stub by pulling back on the snap-on ring and locking the ring onto the outside rim of the pull stub. Pull slightly upward on the adhesion tester to ensure it is locked onto the pull stub. If it does not lock onto the pull stub, there is a good chance the adhesive has seeped into the hole and has dried.



6-3 Rotate the red sweep needle on the gauge dial to “zero.”

The black hydraulic hose must remain straight during testing. Hold the pressure dial of the instrument in one hand and rotate the black, threaded hand lever clockwise. This will cause the center pin to push against the coated substrate and the snap-on locking ring to simultaneously pull upward on the pull stub. The black and the red indicator needles will rotate on the scale as the force is increased (Note: The black needle will return to “zero” when the pressure is released, but the red “sweep” needle will hold the reading for you). Increase the tension smoothly and evenly using a moderate speed (no faster than 150 psi per second). Continue to increase the tension on the head of the pull stub (with minimal stopping) until one of the three “events” occurs (described below). You should complete the test in 100 seconds or less.



Increase pressure by turning hand lever clockwise

Step 7: Read the Scale and Record the Adhesion Value

The analog pressure dial of the adhesion tester contains two scales. The red outer scale is pounds per square inch (psi) and the black inner scale is in “Bar.” As we discussed in Step 6, the red sweep needle will hold the reading for you until you return it to “zero.” When you achieve the endpoint of the test (see the three possible events described below), read and record the value from the scale, as indicated by the red sweep needle (1,400 psi is shown). If you have the digital version, the adhesion value is read from the display.



Read red sweep needle (1,400 psi shown)

Three Possible Events

Event 1: The minimum psi required by the project specification is exceeded and the test is discontinued. When this occurs, relieve the tension by turning the black threaded hand lever counterclockwise until the black needle points to “zero” on the pressure dial. Disconnect the adhesion tester from the pull stub by lifting upward on the snap-on ring. Remove the pull stub from the surface by tapping it on the side with a hammer. Record the adhesion as “Pass: > X psi.” Return the red sweep needle to “zero” on the dial before you conduct additional tests.

Event 2: The maximum psi of the adhesion tester has been achieved and the pull stub is still attached. When this occurs, relieve the tension by turning the black threaded hand lever counterclockwise until the black needle points to “zero” on the pressure dial. Disconnect



Digital display

the adhesion tester from the pull stub by lifting upward on the snap-on ring. Remove the pull stub from the surface by tapping it on the side with a hammer. Record the adhesion as “> X psi.” Return the red sweep needle to “zero” on the dial before you conduct additional tests.

Event 3: The force applied by adhesion tester causes the pull stub to dislodge. When this occurs, read the scale as described in Step 7. Return the red sweep needle to “zero” on the dial before you conduct additional tests.

You will need to record the type of break that occurred and the location of the break. The type of break can be described as “adhesion,” “cohesion,” or “glue.” You should also record the identity of the coating layers where the break occurred and the approximate percentage of each (e.g., 70% Adhesion: Primer/Topcoat; 30% Cohesion-Topcoat). Since the type and location of break are the same for all types of pull-off adhesion testers, they are described only once, at the end of this Module. An example “Table of Results” is also shown.

Step 8: Clean the Pull Stubs

The HATE® stainless steel pull stubs are reusable. A heat clamp is included in the HATE® adhesion tester kit. Plug the heat clamp into a 110 volt receptacle and allow the clamp to heat-up for a few minutes. Place the pull stub in the clamp. The pull stub will heat up and the adhesive/coating on the contact surface will begin to soften. Carefully scrape the contact surface with a knife blade or other scraping device until it is clean. **Use caution: The heat clamp and pull stub can reach temperatures of 520°C (968°F).**



Clean contact surface of HATE® pull stub using heat clamp and knife blade

SECTION 9-3 – MEASURING ADHESION USING THE PATTI® QUANTUM SERIES ANALOG ADHESION TESTER

The PATTI® Quantum Series Adhesion Tester (analog or digital) can be used to test the pull-off strength of a coating or coating system. PATTI stands for Pneumatic Adhesion Tensile Instrument. The PATTI® adhesion tester uses air pressure inside a piston to slowly and constantly increase the perpendicular force on a pull stub. This pressure is converted to pounds per square inch (psi) or KiloPascals (KPa) by using a special burst pressure conversion chart.



PATTI Quantum adhesion tester

The PATTI® Quantum Adhesion Tester is factory-calibrated. You cannot verify nor change the calibration. You should send the adhesion tester and piston(s) back to the manufacturer once a year and instruct them to verify the accuracy of the tester. If required, they will make any necessary adjustments to ensure your instrument is producing reliable test results. They will also give you a Certificate of Calibration.

Step 1: Prepare the Test Surface

Once you have selected a test area, you will need to prepare the surface. Ensure the area you select is free of grease, oil, dirt, chalk, water, protrusions, or other conditions that will interfere with the attachment of a pull stub to the surface. The area you select must also be flat and rigid within a 2" diameter circle. Also, ASTM D4541 recommends a minimum substrate thickness of 1/4". If the test surface is very smooth or glossy, you may want to lightly roughen it using a fine grade of sandpaper. If you abrade the surface, be sure to wipe away any fine dust that was created.

Step 2: Prepare the Test Pull Stub

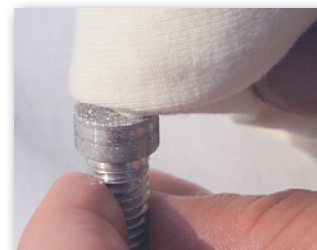
The PATTI® pull stub is a threaded, aluminum fixture. The top of the pull stub is threaded, while the bottom has a small, flat contact surface that is pre-roughened. This bottom side is the contact area.



PATTI® pull stub



Bottom of PATTI® pull stub



Clean pull stub prior to use

Wipe the pull stub to remove any dirt or debris using a soft cloth and some isopropyl alcohol

(rubbing alcohol) to help remove debris that may interfere with the attachment of the pull stub to the surface. The manufacturer does not recommend reusing pull stubs.

Step 3: Select an Adhesive

There are a variety of adhesives that can be used to attach the pull stub to the surface. The PATTI® adhesion tester kit comes with Miller-Stephenson (MS) Epoxy 907, a 100% solids epoxy adhesive. Araldite is another 100% solids epoxy adhesive that is compatible with the PATTI® adhesion tester. These adhesives require at least 24 hours at room temperature to cure. While other “quick-set” adhesives are available and can be used, they may not be able to withstand the pulling forces of the test device, and may break at a relatively low force without detaching the coating. Also, cyanoacrylate (Super Glue) adhesives may soften or penetrate the coating film. Mix the adhesive you selected according to the manufacturer’s directions. If the adhesive is two-component, it will have a maximum working time. Therefore, do not mix more than you can use during the working time.



Miller-Stephenson Epoxy 907 adhesive

Step 4: Attach the Pull Stub to the Surface



Apply adhesive to contact surface of pull stub

4-1 Using a wooden stick, apply an even layer of adhesive to the entire contact surface of the pull-stub (a 2-4 mil layer is adequate).



Attach pull stub to coated surface

4-2 Attach the pull stub to the coated surface and gently push downward to displace any excess adhesive. Do not twist or slide the pull stub during attachment, because you may generate air bubbles in the adhesive, reducing its strength.



*Slide plastic cut-off ring
over pull stub*

4-3 Carefully slide a plastic “cut-off” ring (tapered side down) over the pull stub down to the coated surface. This cut-off ring will displace the excess adhesive from the perimeter of the pull stub.



*Use tape to hold
pull stub in place*

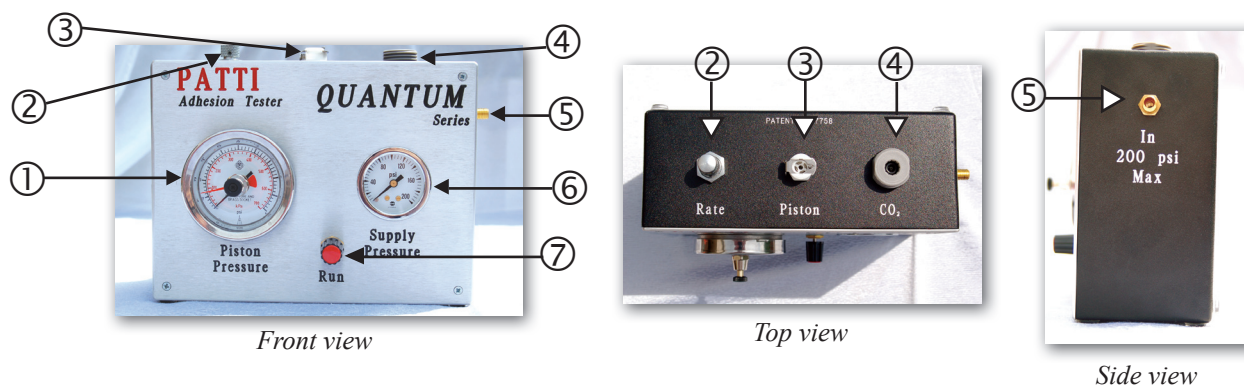
4-4 Apply tape across the top of the pull stub. Attach the tape to the test surface to hold the pull stub in place until the adhesive cures. Allow the adhesive to fully cure before removing the tape and cut-off ring, and performing the adhesion test.

Step 5: Determine Whether Scoring is Required

ASTM standard test method D4541 does not recommend any type of scoring around the base of the pull stub prior to testing unless it is required by the specifier. Scoring may produce tiny fractures in the coating, which can change the properties of the coating and result in lower adhesion values. If the project specification requires you to score the coating around the perimeter of the pull stub, then you will need to use a razor knife, because there is no scoring device provided in the PATTI® Quantum adhesion kit. This must be done very carefully to avoid contact with the sides of the pull stub.

Step 6: Set-up and Perform the Adhesion Test

6-1 General – The PATTI® Quantum adhesion tester consists of three basic components: An adhesion tester base component, an air hose and a piston. The adhesion testing base component contains several ports and dials. The function of each of these ports and dials is indicated on page 9-31.



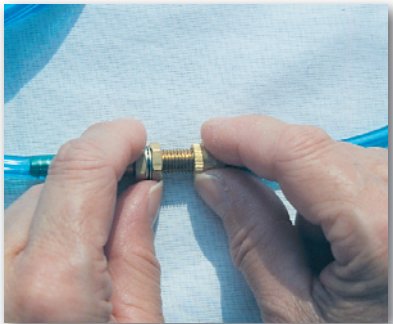
Position	Port/Dial Identification	Function
Front, Left (1)	Piston Burst Pressure Dial	Dial contains black needle and red sweep needle that measures piston burst pressure during testing.
Top, Left (2)	Rate Dial	Controls the rate of pull by regulating the amount of air entering the piston through the air hose.
Top, Middle (3)	“Piston” Port	Port for attaching blue air hose that traverses from the base component to the piston.
Top, Right (4)	CO ₂ (“Air In”) Port	Port for attaching CO ₂ cartridge to energize base component and piston.
Side (5)	Compressed Air Port	Inlet port for compressed air (200 psi max).
Front, Right (6)	Air Supply Dial	Pressure gage monitors internal air pressure available for conducting tests.
Front, Middle (7)	Run Button	Deploys compressed air from the base component through the blue air hose and into the piston.

The piston contains 3 parts: A round black base with a short “pigtail” hose and threaded female connector, a silicone rubber gasket (inside the base) and a round black threaded top plate. There are six pistons to choose from, as shown in the chart below. The two most commonly used pistons for industrial coatings on steel are the F-4 and the F-8.

Piston	Load Range (psi)
F-1	0-500
F-2	0-1000
F-4	0-2000
F-8	0-4000
F-16	0-8000
F-8/12	0-4000 / 0-10,000



Piston components



Connect piston hose to blue air hose



Connect blue air hose to piston port

6-2 Select a piston. Connect the “pigtail” hose from the piston to the long, blue hose with the threaded male end. Hand-tighten the brass connection.

6-3 Insert the opposite end of the blue air hose to the piston port (3, top middle) on the base component.



Insert CO₂ cartridge into holder



Thread CO₂ holder onto CO₂ port

6-4 Insert the CO₂ cartridge into the black holder. Thread the black holder containing the CO₂ cartridge onto the CO₂ port (4, top right) on the base component. You will here a hissing noise as the tip of the CO₂ cartridge is punctured and pressurized carbon dioxide enters the base component. Note that compressed air (regulated to 200 psi max) can be used instead of CO₂ cartridges. The “IN” port is located on the side of the base component (5, side).

6-5 Hand-tighten the black holder until it is snug. Do not over tighten. The “air supply” dial (6, front right) should read approximately 200 psi (this pressure will decrease as tests are performed). For compressed air, the “air supply” dial should match the pressure on the regulator that controls the pressure of the incoming air (200 psi max).



Remove plastic cut-off ring

6-6 Remove the plastic cut-off ring from the perimeter of the pull stub.



Position piston base over pull stub

6-7 Place the piston base over the threaded end of the pull stub until it sits flush on the coated surface. Make sure the silicone rubber gasket is seated inside the piston base.



Thread top plate onto pull stub

6-8 Carefully thread the black plate onto the pull stub until the top plate makes contact with the piston base.

Loosen the black plate $\frac{1}{4}$ turn so that a small gap is created between the piston base and the black top plate.

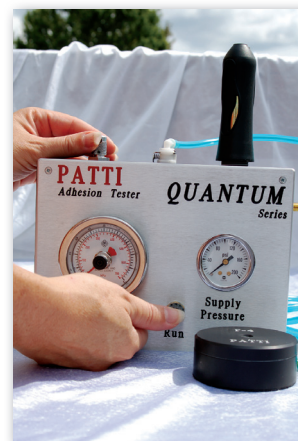


Set the pull rate

6-9 Close the Rate dial (2, top left). Do not overtighten this dial, as it may break. Return the red sweep needle on the “piston burst pressure dial” (1, front left) to zero. You are now ready to conduct an adhesion test.



Push and hold down run button



Open rate valve while pushing run button

6-10 Depress and HOLD in the “Run” button (7 front middle). This deploys air from the base component through the blue air hose and into the piston base.

6-11 While the “Run” button is depressed, slowly open the “Rate” valve (turn counter-clockwise) until the pressure increases at a rate of at least 2 psi/second. Do not exceed 6 psi/second.

As the rate dial is opened (turned counter-clockwise), the air pressure enters into the piston base through a small hole beneath the silicone rubber gasket inside the piston and causes it to rise up and press against the underside of the black top plate. Since the top plate is attached (threaded) onto the pull stub, a perpendicular force is generated. The black and the red indicator needles on the gage dial will continue to monitor the piston pressure. When the piston pressure overcomes the adhesion of the coating system or the adhesive, the pull stub will detach from the surface. Release the run button and open the rate valve further until the black needle returns to zero. Close the rate valve. The red “sweep” needle will hold the reading for you.

Step 7: Read the Scale and Record the Piston Burst Pressure

The pressure dial of the adhesion tester contains two scales. The black outer scale is pounds per square inch (psi) and the inner red scale is KiloPascals (KPa). Do not use the red scale. As discussed in Step 6, the red sweep needle will hold the reading for you until you return it to “zero.” When you achieve the endpoint of the test (see the three possible events described in Step 8), read and record the value from the scale, as indicated by the red sweep needle. You will need to convert this value to actual psi or KPa using a burst pressure conversion chart, since the pull stub surface contact area is only ½ inch diameter.



Read black, outer gage dial (psi)

Step 8: Convert the Piston Burst Pressure to Pull-off Strength

Locate the conversion charts included with the PATTI Quantum instruction manual. There are two charts for each piston range. One chart converts the burst pressure to pull-off strength in US Standard (psi) and the other chart converts the burst pressure to pull-off strength in metric (KPa). Make sure you use the chart that matches the piston you used to conduct the test (top left of each chart).

The left hand column on each chart contains bold numbers 10-100. The top row contains bold numbers 0-9. You can use these values on the chart to plot the burst pressure from Step 6 and convert it to pull-off strength.

Example: Let's say that you used an F-4 piston and wanted the pull-off strength in psi. Locate the Piston F-4 *US Standard Conversion Chart*. If the burst pressure was 46 psi, move down the left column and locate the bold value "40." Move across the top row and locate the bold value "6." Intersect the "40" and the "6" and record the psi value from the chart (937.3 psi).



US STANDARD CONVERSION CHART

Burst pressure (BP) conversion to pull-off strength (psi)
(using 0.5 inch O.D. Pull-stub)

PULL-OFF TENSILE STRENGTH

BP (psi)	0	1	2	3	4	5	6	7	8	9
10	202.6	223.0	243.4	263.8	284.2	304.6	325.0	345.4	365.8	386.2
20	406.7	427.1	447.5	467.9	488.3	508.7	529.1	549.5	569.9	590.3
30	610.7	631.1	651.6	672.0	692.4	712.8	733.2	753.6	774.0	794.4
40	814.8	835.2	855.6	876.0	896.5	916.9	937.3	957.7	978.1	998.5
50	1018.	1039.	1059.	1080.	1100.	1120.	1141.	1161.	1182.	1202.
60	1223.	1243.	1263.	1284.	1304.	1325.	1345.	1365.	1386.	1406.
70	1427.	1447.	1467.	1488.	1508.	1529.	1549.	1569.	1590.	1610.
80	1631.	1651.	1672.	1692.	1712.	1733.	1753.	1774.	1794.	1814.
90	1835.	1855.	1876.	1896.	1916.	1937.	1957.	1978.	1998.	2018.
100	2039.									

If you used an F-4 piston and wanted the pull-off strength in KPa, locate the F-4 piston metric chart. If the burst pressure was 46 psi, move down the left column and locate the bold value “40.” Move across the top row and locate the bold value “6.” Intersect the “40” and the “6” and record the KPa value from the chart (6,462 KPa).

PSI TO METRIC CONVERSION CHART

Piston F-4

Burst pressure (BP) conversion to pull-off strength (KPa)
(using 0.5 inch O.D. Pull-stub)

PULL-OFF TENSILE STRENGTH

BP (psig)	0	1	2	3	4	5	6	7	8	9
10	1397.	1537.	1678.	1819.	1959.	2100.	2241.	2382.	2522.	2663.
20	2804.	2944.	3085.	3226.	3367.	3507.	3648.	3789.	3929.	4070.
30	4211.	4352.	4492.	4633.	4774.	4914.	5055.	5196.	5337.	5477.
40	5618.	5759.	5899.	6040.	6181.	6322.	6462.	6603.	6744.	6884.
50	7025.	7166.	7307.	7447.	7588.	7729.	7869.	8010.	8151.	8292.
60	8432.	8573.	8714.	8854.	8995.	9136.	9277.	9417.	9558.	9699.
70	9839.9	9980.6	12121.	10262.	10402.	10543.	10684.	10824.	10965.	11106.
80	11247.	11387.	11528.	11669.	11809.	11950.	12091.	12232.	12372.	12513.
90	12654.	12794.	12935.	13076.	13217.	13357.	13498.	13639.	13779.	13920.
100	14061.									

Three Possible Events

Event 1: The minimum psi required by the project specification is exceeded and the test is discontinued. When this occurs, release the “RUN” button and relieve the tension by disconnecting the piston pigtail hose from the blue air hose. Carefully unthread the black top plate from the pull stub and lift the piston base from the surface. If you want to relieve the pressure from the base component, you will need to depress the small needle valve inside the male connector end of the blue hose. Make sure you return the red sweep needle to “zero” on the dial before you conduct additional tests. Remove the pull stub on the

surface by tapping it on the side with a hammer. Record the adhesion as “Pass, > X psi.”

Event 2: The maximum psi of the adhesion tester has been achieved and the pull stub is still attached. When this occurs, release the “RUN” button and relieve the tension by disconnecting the piston pigtail hose from the blue air hose. Carefully unthread the black top plate from the pull stub and lift the piston base from the surface. If you want to relieve the pressure from the base component, you will need to depress the small needle valve inside the male connector end of the blue hose. Make sure you return the red sweep needle to “zero” on the dial before you conduct additional tests. Remove the pull stub on the surface by tapping it on the side with a hammer. Record the adhesion as “> X psi.” If you want to use a higher range piston, you should test a different pull stub, as the coating beneath has already been stressed and a false low reading may occur if the same pull stub is retested.

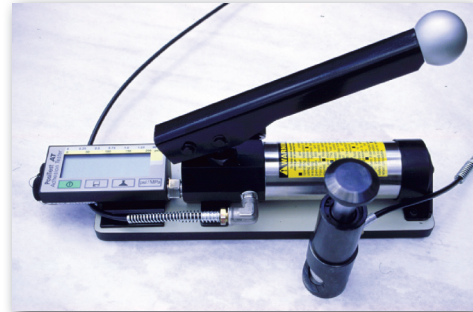
Event 3: The force applied by adhesion tester causes the pull stub to dislodge. When this occurs, read the scale as described in Steps 7 and 8. Make sure you return the red sweep needle to “zero” on the dial before you conduct additional tests.

You will need to record the type of break that occurred and the location of the break. The type of break can be described as “adhesion,” “cohesion,” or “glue.” You should also record the identity of the coating layers where the break occurred and the approximate percentage of each (e.g., 70% Adhesion: Primer/Topcoat; 30% Cohesion-Topcoat). Since the type and location of break are the same for all types of pull-off adhesion testers, they are described only once, at the end of this Module. An example “Table of Results” is also shown.

SECTION 9-4 – MEASURING ADHESION USING THE PosiTest® AT ADHESION TESTER

The PosiTest® AT Adhesion Tester can be used to test the pull-off strength of a coating or coating system. The PosiTest® AT uses hydraulic pressure to slowly and constantly increase the perpendicular force on a pull stub. This pull-off strength is read directly from the digital display in pounds per square inch (psi) or MegaPascals (MPa).

The PosiTest® AT adhesion test kit provides you with all of the necessary supplies to generate pull-off adhesion values for coatings on both concrete and steel. If you are testing the adhesion of thick coatings on concrete, you may need to use a special drilling template, which is not included in the basic kit, but can be purchased separately.



PosiTest® AT adhesion tester

The test kit includes:

- A hydraulic load cell equipped with a digital display
- An actuator assembly with 20mm and 50mm stand-offs
- 20 - 20mm and 12 - 50mm pull stubs
- Cutting tools for 20mm and 50mm test areas
- Adhesive with mixing pads and sticks
- Abrasive pads

The PosiTest® AT Adhesion Tester is factory-calibrated using a load cell. The tester is provided with a Certificate of Calibration stating its 1% accuracy and NIST traceability. You cannot verify nor change the calibration. If you feel the instrument requires calibration verification, you will need to return it to the manufacturer.

Step 1: Prepare the Test Surface

Once you have selected a test area, you will need to prepare the surface. Ensure the area you selected is free of grease, oil, dirt or chalking, water, protrusions, or other conditions that will interfere with the attachment of a pull stub to the surface. The area you select must also be flat and rigid within a 3" diameter circle. Also, the ASTM standard recommends a minimum substrate thickness of ¼". If the test surface is very smooth or glossy, you may want to lightly roughen it using the abrasive pad included with the kit. If you abrade the surface, be sure to wipe away any fine dust that was created using isopropyl alcohol (rubbing alcohol).

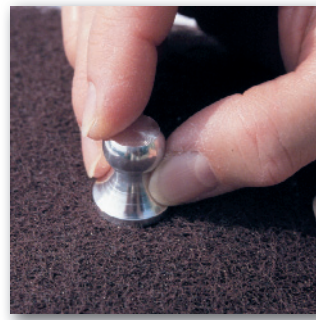


*Lightly roughen surface
with abrasive pad*

Step 2: Prepare the Test Pull Stub



PosiTest pull stub



*Roughen pull stub using
abrasive pad*

2-1 The PosiTest® AT pull stub is an aluminum fixture. The top of the pull stub is round, while the bottom is a flat. This bottom side is the contact surface.

2-2 Remove any oxidation or contaminants from the contact surface of the pull stub by rubbing it across the abrasive pad (included with the kit) 4-5 times. Wipe the pull stub to remove any dirt or debris using a soft cloth or paper towel. The manufacturer does not recommend reusing pull stubs.

Step 3: Select an Adhesive

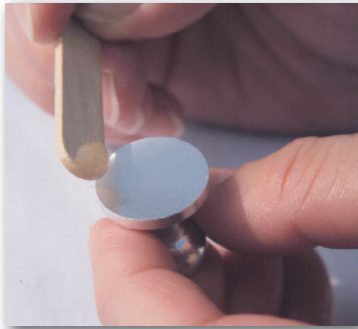
There are a variety of adhesives that can be used to attach the pull stub to the surface. The PosiTest® AT adhesion tester kit comes with Araldite, a 100% solids epoxy adhesive. This adhesive requires at least 24 hours at room temperature to cure.

While other “quick-set” adhesives are available and can be used, they may not be able to withstand the pulling forces of the test device, and may break

before the coating does at a relatively low force. Also, cyanoacrylate type adhesives (Super Glue) may soften or penetrate the coating film. Using the wooden stir stick and the cardboard palette included in the kit, mix the adhesive according to the manufacturer’s directions. Since the adhesive is two-component, it will have a maximum working time. Do not mix up more than you can use during the stated working time.



Step 4: Attach the Pull Stub to the Surface



Apply adhesive to pull stub

4-1 Using the wooden stir stick, apply a uniform layer of adhesive to the entire contact surface of the pull stub (a 2-4 mil layer is adequate).



Attach pull stub to coated surface

4-2 Attach the pull stub to the coated surface and gently push downward to displace any excess adhesive. Do not twist or slide the pull stub during attachment, because you may generate air bubbles in the adhesive.



Remove excess adhesive

4-3 Carefully remove the excess adhesive from the perimeter of the pull stub. Allow the adhesive to fully cure before performing the adhesion test.



Use tape to hold pull stub in place

4-4 Apply tape across the rounded head of the pull stub. Attach the tape to the test surface to hold the pull stub in place until the adhesive cures.

Step 5: Determine Whether Scoring is Required

ASTM standard test method D4541 does not recommend any type of scoring of the coating around the base of the pull stub prior to testing unless required by the specifier. Scoring may produce tiny fractures in the coating or may generate friction heat, which can change the properties of the coating and result in lower adhesion values. If the project specification requires you to score the coating around the perimeter of the pull stub, then you will need to use the hand-scoring device included in the PosiTest® AT adhesion test kit. However, this must be done very carefully to avoid contact with the sides of the pull stub.

If you score around the perimeter, place the scoring device included with the PosiTest® AT adhesion kit over the pull stub and rotate the cutter using a back and forth motion. Make sure you score down through all coating layers to the substrate. You may want to consider scoring the coating before you attach the pull stub.



Scoring coating around perimeter of pull stub (if specified)

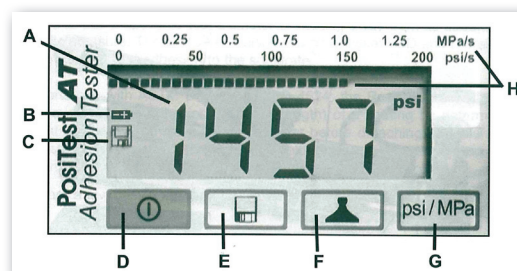
Step 6: Perform the Adhesion Test

There are two PosiTest Adhesion Tester models: A Manual Model (AT-M) and an Automatic Model (AT-A). The PosiTest® AT-M adhesion tester consists of two basic components: An adhesion tester base component and an actuator. The base component contains a hydraulic cylinder with a pressure release valve, a lever and a pressure gauge.



Open pressure release valve

6-1 Verify that the pressure relief valve on the cylinder is completely open. Push the black actuator handle completely down into the actuator assembly.



6-2 Turn the tester on by depressing the green “on/Zero” button (D). Make sure the LCD indicates “0.” Select the pull stub size (F) (20mm for coatings on steel; 50mm for coatings on concrete), then the desired units of measurement (G) (psi/MPa).



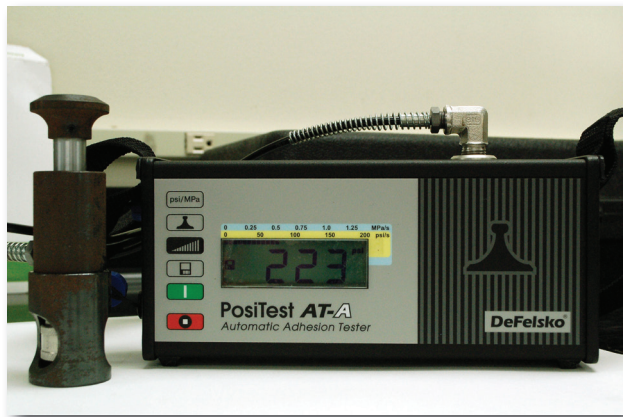
Position actuator onto pull stub

6-3 Place the actuator assembly over the round head of the pull stub and attach the quick connect coupling to the pull stub. Close the pressure release valve on the pump tightly.

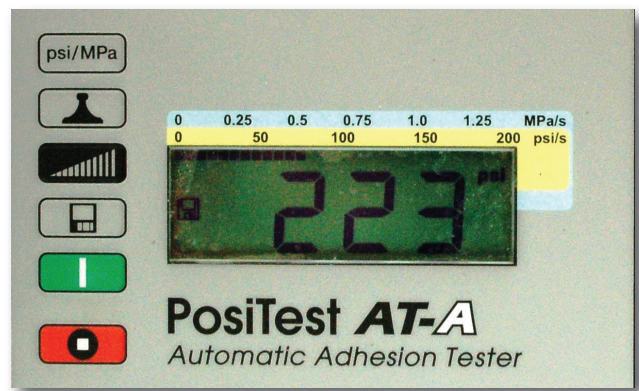


Pump lever to increase hydraulic pressure

6-4 Begin pumping the lever above the cylinder until the digital display indicates pressure is being applied. The pull rate indicator (H) illustrates the load rate as the test is being performed. Continue pumping at a uniform rate of no more than 150 psi (1 MPa) per second until the actuator detaches the pull stub. The display will hold the maximum pressure reading for you. You should complete the test in less than 100 seconds.



PosiTest Model AT-A



PosiTest Model AT-A Display

NOTE: If you are using the Model AT-A, follow these three steps:



Green "On/Start" Button (D)



Pull Stub Size Selection Button (F)



Unit of Measurement Selection Button (G)

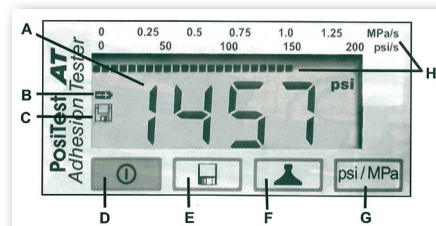
6-2A Turn the tester on by depressing the green "On/Start" button (D). Make sure the LCD indicates "0." Select the pull stub size (F) (20mm for coatings on steel; 50mm for coatings on concrete), then the desired units of measurement (G) (psi/MPa).

6-3A Place the actuator assembly over the round head of the pull stub and attach the quick connect coupling to the pull stub.

6-4A Push the "On/Start" button (D). The pull rate indicator (H) illustrates the load rate as the test is being performed. The load rate is controlled by the instrument and will continue to be applied at a constant rate until the actuator detaches the pull stub. The display will hold the maximum pressure reading for you.

Step 7: Read the Display and Record the Pressure

Read and record the maximum pressure from the display (in psi or MPa). The value shown (A) is 1,457 psi. To store the value, depress the “Memory” button (E). To zero the tester, depress the “Power On/Zero” button (D) on the Model AT-M or the “On/Start” button on the Model AT-A. You must zero the tester before you conduct another adhesion pull test.



Record pressure from display
(1,457 psi is shown)

Three Possible Events

Event 1: The minimum psi required by the project specification is exceeded and the test is discontinued. When this occurs, relieve the pressure by opening the pressure release valve on the hydraulic cylinder. Make sure you “zero” the display before you conduct additional tests. Remove the pull stub from the surface by tapping it on the side with a hammer. Record the adhesion as “Pass, > X psi.”

Event 2: The maximum psi of the adhesion tester has been achieved and the pull stub is still attached. When this occurs, relieve the pressure by opening the pressure release valve on the hydraulic cylinder. Make sure you “zero” the display before you conduct additional tests. Remove the pull stub from the surface by tapping it on the side with a hammer. Record the adhesion as “> X psi.”

Event 3: The pressure applied by adhesion tester causes the pull stub to dislodge. When this occurs, read the display as described in Step 7. Make sure you “zero” the display before you conduct additional tests.

You will need to record the type of break that occurred and the location of the break. The type of break can be described as “adhesion,” “cohesion,” or “glue.” You should also record the identity of the coating layers where the break occurred and the approximate percentage of each (e.g., 70% Adhesion: Primer/Topcoat; 30% Cohesion-Topcoat).

SECTION 9-5 – SPECIAL REQUIREMENTS FOR TENSILE ADHESION TESTING OF COATINGS ON CONCRETE

The procedures used to test the pull-off adhesion strength of coatings on steel (described in Sections 9-1 through 9-4) are very similar to the procedures used to test the pull-off adhesion strength of coatings on concrete. However, there is a different ASTM standard test method for testing coatings on concrete (ASTM D 7234), and there are a few minor differences in the equipment and the procedures. This section highlights the major differences between testing coatings on steel and coatings on concrete, but does not provide the exact procedures you need to use for each instrument. You should review the ASTM standard prior to conducting testing coatings on concrete surfaces.

1. Thick film coatings (those greater than 20 mils) may have lateral bond strength, which can produce misleading pull-off values. Therefore, you will likely need to score the coating (down to the concrete) prior to attaching the pull stub to the coated surface. Scoring a coating on concrete that is less than 20 mils in thickness may also be required. Scoring can be done by hand if the coating is thin enough. For very thick coatings, a mechanical method of scoring the coating may be required. Independent of the scoring method you select, you will need to score the coating prior to attaching the pull stub. Otherwise you may inadvertently shear-off the pull stub.
2. When attaching the pull stub to the surface, make sure that any excess glue does not flow into the score groove.
3. Unlike steel, concrete is a heterogeneous (non-uniform) substrate that contains cement paste and aggregate. While you may use any diameter pull stub, a 2" (50mm) diameter pull stub is recommended so that you are testing the adhesion strength of the coating over a more representative surface area. Square pull stubs are used with some test devices.

4. The load rate applied to the pull stub by the adhesion tester should be approximately 30 psi per second, so that the test pull is completed in 5 to 30 seconds.
5. Concrete has extremely high compressive strength (typically in excess of 4000 psi), but relatively low tensile strength (typically less than 400 psi). Therefore, it is quite possible that you will obtain a relatively low value when you test coatings on concrete, and the plane of fracture (the location of break) is typically within the concrete substrate (the coating tensile strength exceeds the concrete tensile strength). In this case, you can report the minimum coating adhesion pull-off strength, but the actual coating adhesion strength is unknown.

SECTION 9-6 – TENSILE ADHESION TESTING: RECORD THE TYPE AND LOCATION OF BREAK

Independent of which adhesion tester you select, if “Event 3” occurs and an actual value is recorded, then you will need to record the type of break that occurred and the location of the break. The type of break can be described as “adhesion,” “cohesion,” or “glue.”

Type of Break	Description
Adhesion	A distinct break between coating layers or a distinct break between the substrate and the first coating layer.
Cohesion	A split within a coating layer.
Glue	The adhesion/cohesion strength of the coating system exceeds the strength of the glue used to attach the pull stub. This may or may not require retesting, depending on the actual value.

You should also record the identity of the coating layers where the break occurred and the approximate percentage of each (e.g., 70% Adhesion: Primer/Topcoat; 30% Cohesion-Topcoat). The table below provides an example of how to record the adhesion data. The example is based on three test areas and triplicate pull stubs in each area.

Example Table of Adhesion Results:

Location	Pull Stub ID	Adhesion Value (psi)	Location of Break and Percentage of Each
Area 1	1-A	300	100% Cohesion – Primer
Area 1	1-B	250	100% Cohesion – Topcoat
Area 1	1-C	375	70% Adhesion: Primer/Topcoat; 30% Cohesion – Topcoat
Area 2	2-A	400	100% Adhesion: Substrate/Primer
Area 2	2-B	340	100% Adhesion: Primer/Topcoat
Area 2	2-C	425	70% Adhesion: Primer/Topcoat; 30% Cohesion – Topcoat
Area 3	3-A	500	50% Cohesion – Primer; 50% Glue
Area 3	3-B	400	50% Cohesion – Topcoat; 40% Cohesion – Primer
Area 3	3-C	450	50% Glue; 40% Adhesion: Primer/Topcoat

MEASURING COATING THICKNESS USING THE TOOKE GAGE

8

The inspection gages we discussed in Module 6 all measure the dry film thickness of a coating *non-destructively*. This is how you will measure coating thickness the majority of the time. However, these coating thickness gages have one rather significant limitation: they cannot distinguish the thickness of individual layers after all of the coats have been applied. They can only measure the “gap” between the gage probe and the metal substrate. This gap is represented by all of the layers applied to the substrate (e.g., primer, intermediate coat and topcoat). That is why it is so important to measure the thickness of each coat after it is applied, but before the next layer is applied. This way, you have some indication that each layer was applied to the correct thickness.

The Tooke Gage:

- ✓ Measures the thickness of individual layers
- ✓ Contains three precision cutting tips
- ✓ Makes an incision into the coating film
- ✓ Requires that the layers be alternating or different colors
- ✓ Does not require a metallic substrate

Occasionally, you may need to measure the thickness of the individual layers (e.g., primer, intermediate coat and topcoat) after they have all been applied. The non-destructive gages won’t work for you here. In this case, you’ll need to measure the thickness of the layers destructively using a device called a Tooke Gage. The Tooke Gage conforms to ASTM D4138.

What is a Tooke Gage?

The Tooke Gage was invented by Raymond Tooke of MicroMetrics Company. It consists of a gage body (plastic or aluminum) and battery compartment, a 50 power illuminated

microscope with a scale etched onto the lens, a focus adjustment for the microscope and three tungsten carbide precision cutting tips. It is perhaps the most accurate field method of measuring coating thickness. You do not have to calibrate the Tooke Gage, and it is unaffected by the type of substrate, the effect of the base metal, and surface profile. The Tooke Gage is destructive, in that it makes an incision or groove (about the width of a line drawn with a pencil) through the coating film down to the substrate. The Tooke Gage can be used to measure coating thickness up to 50 mils.



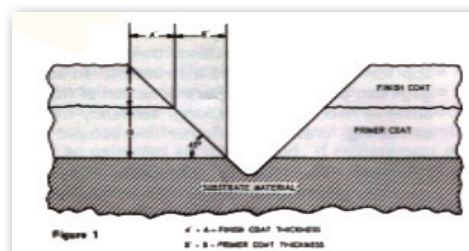
Tooke Gage Model OG204

There are several versions and models of destructive coating thickness gages like the Tooke Gage. You may hear them referred to as Paint Inspection Gages or PIGs. The Tooke Gage Model OG204 is described in this Module. Appendix 8-A describes the use of the Tooke Gage Model OG204-U, which uses a universal microscope ocular. If you have a Model OG204-U Tooke Gage, you will need to use a different division-to-layer thickness conversion. The conversion chart for this model is shown in Appendix 8-A.



Tooke Gage Model OG204-U

The Tooke Gage measures coating thickness using basic trigonometry. By cutting a precision “V” groove into the coating system using one of the tungsten carbide cutting tips, a right triangle is created. The angles of the right triangle are known. By measuring the length of one leg of the triangle, you can calculate the length of the other leg, which represents the coating thickness. If the coating layers are different or alternating in color, then each layer can be both seen and the thickness measured through the Tooke Gage lens. The good news is that you do not have to know trigonometry, nor do you actually have to calculate the third angle. The cutting tips and the scale etched on the microscope lens do the work for you. Let’s follow the steps below (in order) so that you can be sure to use the Tooke Gage properly.



Cross-section of groove. Right triangles are shown on left side.

Step	Operation
1	Determine the thickness <i>range</i> you will be measuring
2	Apply a benchmark on the top of the coating
3	Select a cutting tip
4	Position the cutting tip
5	Cut a groove into the coating film using the cutting tip you selected in Step 3
6	Locate the groove through the illuminated, 50X microscope lens
7	Line-up the scale divisions etched on the microscope lens so that they are parallel with the groove length
8	Count and record the number of layers on the surface
9	Count the number of divisions on the scale that overlay each layer
10	Convert the divisions to mils

We will look at each of these steps in greater detail.

Step 1: Determine the Thickness Range You Will Be Measuring

Before you select a cutting tip or blade to make an incision, you will need to have a general idea of how thick the coating is. If you do not know, then you will need to measure the total thickness non-destructively using one of the dry film thickness gages we discussed in Module 6. Once you know how thick the coating system is, then you will be able to select a cutting tip. This will become clearer once we move on to Step 3, “Select a Cutting Tip.”

Example: *Let’s assume that the total coating thickness was measured and is 12-15 mils.*

Step 2: Apply a Benchmark on the Top of the Coating

Using a marker, pen or pencil, make a benchmark across the top of the coating film. The benchmark should be 1/8"-1/4" wide and approximately 1" long. Wait a few seconds for the ink to dry before proceeding to Step 4.

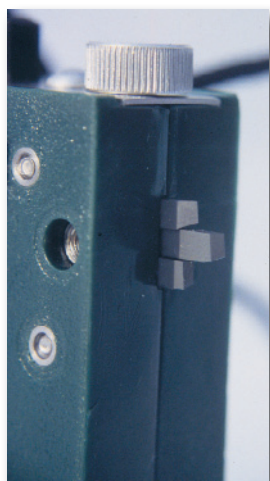


Apply a benchmark

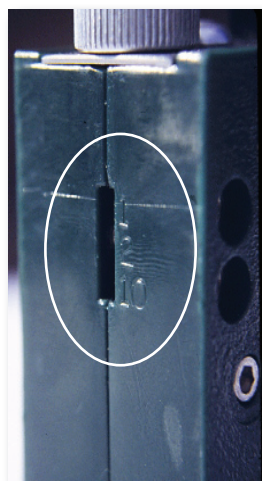
Step 3: Select a Cutting Tip

The Tooke Gage is supplied with three cutting tips. They are labeled, “1X, 2X and 10X.” The 10X tip can be used to make an incision into a coating film that is 3 mils or less in total thickness. The 2X tip can be used to make an incision into a coating film that is 3–20 mils in total thickness, and the 1X tip can be used to make an incision into a coating film that is 20–50 mils in total thickness. This is why it is important for you to have a general idea of the coating thickness range prior to selecting a cutting tip, as we discussed in Step 1. All three cutting tips are mounted on the side of the Tooke Mark IV (green plastic body). The designation (1, 2 or 10) is stamped next to each tip.

Example: Based on a total coating thickness of 12-15 mils, select the “2X” cutting tip



Three cutting tips



Tip designations

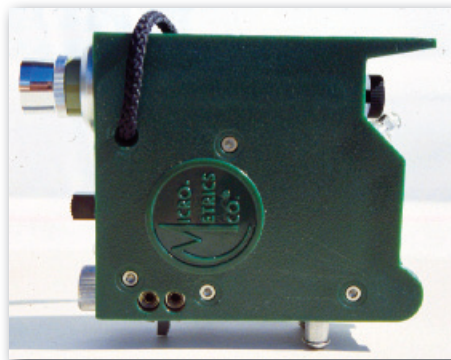
Cutting Tips and Thickness Ranges

Cutting Tip	Coating Thickness Range
1X	20-50 mils
2X	3-20 mils
10X	up to 3 mils

Step 4: Position the Cutting Tip



Position the tip selected in Step 3



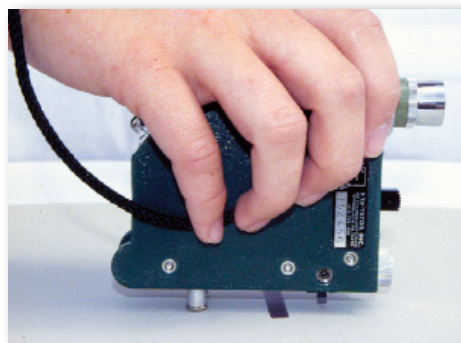
Tip and guide legs should be level

4-1 Since all three cutting tips are mounted in the Tooke Gage, you will need to make sure the tip you selected in Step 3 is mounted properly in the side of the gage. Using the allen wrench supplied with the gage, loosen the set screws and slide the tip you selected out of the gage body until it extends approximately 5/16". The remaining two cutting tips should be pushed inward. Tighten all of the set screws.

4-2 Position the Tooke Gage on its side, so that the extended cutting tip and two guide legs are sitting on a flat surface. Make sure the cutting tip and guide legs form a level tripod. The gage is now ready to make an incision through the coating film.

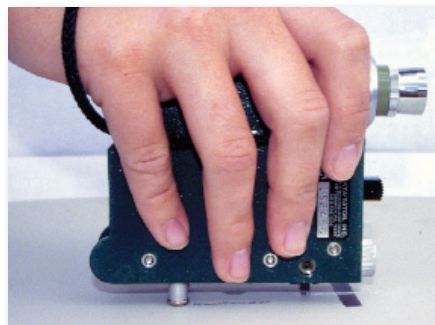
Step 5: Cut a Groove into the Coating Film using the Cutting Tip You Selected in Step 3

5-1 Position the Tooke Gage on its side, so that the extended cutting tip and two guide legs are sitting on the coated surface. Make sure that the cutting tip is resting above the horizontal benchmark created on the coated surface (Step 2). Using moderate pressure, pull the Tooke Gage toward you, carefully dragging the cutting tip perpendicularly across the benchmark. Use a smooth, steady motion.



Position cutting tip above benchmark

5-2 The guide legs and cutting tip must remain in contact with the coated surface at all times. Do not tilt or rock the gage, otherwise you will change the angle of the cutting tip. The total length of the cut should be approximately 1". Make sure the incision penetrates down to (and even into) the substrate. If it did not, do not attempt to retrace the cut. Make a new cut, but increase the downward pressure on the gage. You can now view the incision through the 50 power illuminated microscope.



Pull cutting tip across benchmark

Step 6: Locate the Groove Through the Illuminated, 50X Microscope Lens



Light switch



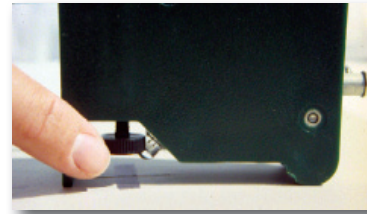
*Light on scribe/
benchmark intersection*

6-1 Turn the light on using the black on/off slide switch located on the top of the Tooke Gage.

6-2 Position the gage so that the light is reflecting onto the incision where it intersects the benchmark.



View cut through microscope



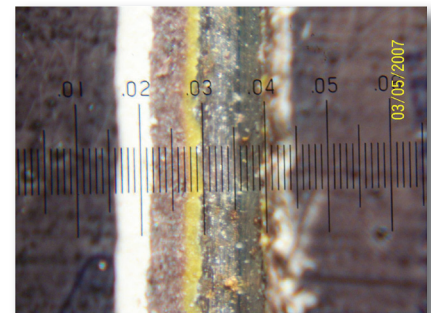
Focus adjustment

6-3 Look through the microscope lens. You may need to move the gage slightly to position the incision in the center of the lens. Remember that the microscope reverses the image, so if you reposition the Tooke Gage left, the image you see through the lens will move right, and vice-versa.

6-4 To focus the image, turn the black thumb wheel located at the bottom the gage next to the light bulb.

Step 7: Line-up the Scale Divisions Parallel with the Incision

Align the scale etched on the lens by rotating the eyepiece of the microscope. The divisions on the scale should be parallel with the incision you made with the cutting tip.



View of incision through lens

Step 8: Count and Record the Number of Layers on the Surface

Look at the left side (the tapered side) of the cut through the microscope lens. The right side of the cut was made by the backside of the cutting tip, which is not the precision cutting angle, so it can be ignored.

Locate the interface between the substrate and the first layer on the left side of the cut. Count the number of paint layers. Start with the layer next to the substrate (first coat or primer) and continue moving left until you come to the benchmark. Since the benchmark was made on the top surface, you can tell that there are no more layers. Record the number of layers and the color of each.

Example: Four (4) Layers (Based on Image in Step 7)

Layer No.	Color
1	Silver
2	Yellow
3	Brown
4	White

Step 9: Count the Number of Divisions on the Scale that Overlay Each Layer

The scale etched onto the microscope lens contains 100 black lines or divisions. Some of the divisions have a number above them. These numbers do not correspond to any unit of measurement. However, it is helpful to know that there are 10 divisions between each of the numbered lines. Count the number of lines that overlay each layer recorded in Step 8.

Example, continued: Four (4) Layers

Layer No.	Color	Divisions
1	Silver	5
2	Yellow	3
3	Brown	5
4	White	6

Step 10: Convert the Divisions to Mils (Model OG204; Standard Ocular)

To convert the divisions to mils, divide the number of lines for each layer by the number of the tip you selected to make the incision. If you selected the 10X tip, divide the divisions in Step 9 by “10.” If you selected the 2X tip, divide the divisions in Step 9 by “2.” If you selected the 1X tip, then divide the divisions in Step 9 by “1.”

Example, continued: Four (4) Layers. Incision was made using the 2X Cutting Tip

Layer No.	Color	Divisions	Divisions ÷ Cutting Tip	Mils
1	Silver	5	$5 \div 2$	2.5
2	Yellow	2	$3 \div 2$	1.5
3	Brown	5	$5 \div 2$	2.5
4	White	6	$6 \div 2$	3

Appendix 8-A: Tooke Gage Model OG204-U



*Tooke Gage Model OG204-U
with Universal Ocular*

Model OG204-U Division-to-Thickness Conversion (Universal Ocular)

Unit	1X Cutting Tip	2X Cutting Tip	10X Cutting Tip
Mils	2	1	0.2
Micrometers	40	25	5
Millimeters (mm)	0.05	0.025	0.005

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MEASURING DRY FILM THICKNESS NONDESTRUCTIVELY ON FERROUS AND NON-FERROUS METAL SURFACES



The thickness of a single layer of coating, or the thickness of each layer in a multiple coat system, is critical for coating system performance. If a coating is too thin, it will not adequately protect the

underlying layers or the substrate. If a coating is too thick, the solvents may not be able to evaporate from the film before the surface of the coating dries, causing entrapped solvents. Also, the coating may crack or may not fully cure if it is applied too thickly. Therefore, most coating specifications for industrial projects and most coating manufacturer's product data sheets indicate the minimum and the maximum dry film thickness (or DFT) for each layer. This range represents the thickness of the coating film *above* the peaks of the surface profile. In order to verify that the coating has been applied correctly, you will need to measure the dry film thickness after the application of each layer.

Dry Film Thickness Gages:

- ✓ Can be magnetic pull-off or electronic type
- ✓ Must be verified for accuracy before and after each use
- ✓ Are verified for accuracy using coating thickness standards or plastic shims
- ✓ Can store data, perform statistical analysis and download to a printer or upload to a computer

You can measure the dry film thickness nondestructively using two basic types of coating thickness gages: magnetic pull-off and electronic. There are advantages and limitations to each type of coating thickness gage. The magnetic pull-off gages are typically less expensive and a little more rugged than the electronic gages. However, the magnetic pull-off gages can only be used to measure coating thickness on ferrous (magnetic) surfaces like steel. The electronic gages are less susceptible to vibrations, are more accurate, and can

take measurements faster than the magnetic pull-off type gages. The electronic gages are also more versatile, since they can be used on both ferrous (magnetic) and non-ferrous (non-magnetic) metal surfaces like aluminum, brass, copper, and stainless steel.

Independent of whether you choose a magnetic pull-off or electronic type of DFT gage, you will need to verify that the one you have selected is accurate before and after each period of use (see adjustment directions below). This is called *verifying gage accuracy*.

The terms Calibration and Adjustment are often used interchangeably. This is not completely correct. Calibration is, “*the controlled and documented process of measuring traceable calibration standards and verifying the results are within the tolerance of the gage.*” Adjustment is “*the process of aligning and optimizing the gage’s readings to match a known thickness within a specific thickness range.*” This process improves the reliability of the gage readings on a specific surface, within a specific measurement range. We will be discussing both Calibration and Adjustment as part of this module.

Some of the gages described in this Module can actually be adjusted in the field, while some cannot. However, without *verifying* the accuracy of the gage, you will not know whether the measurements you take are representative of the true coating thickness. This module includes a description of the proper procedures for both verifying the accuracy of the gage you select, and for taking measurements of coating thickness.

There are two industry-recognized standards for measurement of dry film thickness, including ASTM D7091, “Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals” and SSPC-PA2, “Procedure for Determining Conformance to Dry Coating Thickness Requirements.” It is beyond the scope of this publication to provide detail on these industry standards. However, if the specification you are working to invokes one of these standards, you will need to read and comprehend the standard before you begin taking dry film thickness measurements.

Step 1: Selecting a Dry Film Thickness Gage

Before you measure the dry film thickness, you will need to choose a gage. Because there are several different gages available, it is important to ask yourself a few questions in order to make a more informed decision.

- Question 1: What type of substrate do I want to measure on?
Question 2: How thick is the coating that I want to measure?
Question 3: If the answer to Question 1 is steel, do I want a magnetic pull-off or an electronic gage?
Question 4: If the answer to Question 4 is “a magnetic pull-off gage,” do I want a manual or automated type?
Question 5: If the answer to Question 4 is “an electronic gage,” do I want one that will measure coatings on ferrous metal surfaces, non-ferrous metal surfaces, or both?
Question 6: If the answer to Question 4 is “an electronic gage,” do I want one that will store the measurements in memory, print-out the measurements or upload them into a computer software program, or run a statistical analysis of the measurements?

Example:

Question No.	Answer
1	Steel
2	15 mils – 20 mils
3	Electronic Gage
4	NA
5	Ferrous metal surfaces only
6	No

Step 2: Selecting a Gage Manufacturer and Model

Now that you have the answers to the six questions above, you will need to select a gage manufacturer and a model. There are many gage manufacturers to choose from. And each manufacturer has several models to choose from, depending on the thickness of the coating you want to measure. This module provides you with the basic instructions for use of four models of magnetic pull-off gages and three models of electronic gages. There are a variety of makes and models of dry film thickness gages on the market. This module represents only a cross-section of the more common thickness gages for measurement of industrial maintenance coatings. The coating thickness range for each gage discussed in this Module is listed in the table below.



Magnetic pull-off and electronic coating thickness gages

Magnetic Pull-Off	Range	Electronic	Range
DeFelsko PosiTest® FM	0-80 mils	DeFelsko Positector® 6000 FN	0-60 mils
Elcometer® 211	0-40 mils	Elcometer® 456 FNF	0-60 mils
ElektroPhysik® Mikrotest III	0-40 mils	Fischer DualScope® MPOR	0-80 mils
ElektroPhysik® Mikrotest IV	0-40 mils		

After you select a gage, you will need to verify its accuracy by comparing gage readings with standards of known thickness. The procedure that you will use to verify the accuracy of a coating thickness gage varies, depending on whether it is a magnetic pull-off or an electronic type gage. We will discuss magnetic pull-off type gages first.

SECTION 6-1 – USING MAGNETIC PULL-OFF GAGES

Section 6-1 discusses the use of magnetic pull-off gages, including three manual versions and one automatic version.



Magnetic pull-off gages

Step 1: Verifying the Accuracy of the Magnetic Pull-Off Gage

If you select a magnetic pull-off gage, you will only be able to verify gage accuracy. You should not adjust magnetic pull-off gages in the field. These gages should only be adjusted by the manufacturer.

There are two methods to choose from to verify the accuracy of magnetic pull-off gages. Method A requires using steel coating thickness standards containing known film thicknesses; while Method B requires using plastic, color-coded shims that are placed onto the prepared steel surface. Each of these methods is described below.

Note: SSPC-PA2 does not allow the use of plastic, color-coded shims (Method B) when verifying the accuracy of magnetic pull-off gages. Therefore, if the specification invokes SSPC-PA2 as the coating thickness measurement standard and you want to use a magnetic pull-off gage, then you can only use the coating thickness standards to verify gage accuracy (Method A). If the specification invokes ASTM D7091 as the coating thickness measurement standard, or if no reference to a coating thickness measurement standard appears in the specification, then you may use either Method A or Method B to verify gage accuracy.

Verification of Accuracy Using Method A: Coating Thickness Standards

There are two types of coating thickness standards that can be used to verify the accuracy of magnetic pull-off gages. One type is manufactured by The National Institute of Standards and Technology (NIST). These standards consist of steel blocks containing known thicknesses of chrome. Since chrome is non-magnetic, it is read as coating thickness by a DFT gage.



NIST coating thickness standards

A second type of standard (proprietary standards; e.g., KTA coating thickness standards) can also be used. Instead of a chrome layer, these standards contain plastic films (of various thicknesses) that are permanently attached to small steel coupons. There are 5 different plates in a set of KTA standards, and 4 or 5 plates in the NIST standards.



KTA coating thickness standards

Accuracy Verification Method A - Step 1:

Select a coating thickness standard that is close to the thickness of the coating that you anticipate measuring. Then choose one lower and one higher than the anticipated coating thickness. This will provide you with a thickness range to verify the gage accuracy.

Accuracy Verification Method A - Step 2:

If you are verifying the accuracy of a *manual* magnetic pull-off gage (PosiTest FM, Elcometer 211 or Mikrotest III), place the end of the instrument containing the magnet on one of the thickness standards and rotate the dial forward until the magnet makes contact with the standard. Slowly retract the dial until the magnet breaks contact with the standard. Repeat this step on the other two standards selected. If the readings from the dial scale are within the combined tolerance of the gage and the standard (as described below), then you can proceed to Step 2.



Verifying accuracy of manual magnetic pull-off gage

If the gage reading is outside of the combined accuracy of the coating thickness standard (test block) and the manufacturer's stated gage accuracy, you should return the instrument to the manufacturer or authorized agency for calibration. You should never adjust Type 1 coating thickness gages.

For example, if the gage accuracy is $\pm 5\%$ and the accuracy of the standard is $\pm 3\%$ then the combined accuracy of the gage and the standard is 6%, calculated by taking the square root of the sum of the squares values:

$$\sqrt{5^2 + 3^2} = 5.83 \text{ or approximately } 6\%$$

For the gage to be in agreement with the standard, the average thickness measured by the gage must be within $\pm 6\%$ of the standard's thickness. If the average thickness measured on a 10 mil reference standard is between 9.4 mils and 10.6 mils, the gage is considered accurate, even though the reading does not exactly match the reference standard. The minimum value of 9.4 mils is calculated as 10 mils minus 6% of 10 mils; the maximum of 10.6 mils is calculated as 10 plus 6% of 10 mils.



Verifying accuracy of automatic magnetic pull-off gage

If you are verifying the accuracy of a Mikrotest IV automatic magnetic pull-off gage, place the end of the instrument containing the magnet on one of the thickness standards and rotate the dial forward until the magnet makes contact with the standard. Push in the counterweight button on the underside of the handle. The dial will automatically retract until the magnet breaks contact with the standard. Once this happens, the gage will automatically stop. Repeat this step on the other two standards selected, then verify that the gage readings are within the combined tolerance of the gage and reference standard.

Accuracy Verification Method A - Step 3:

Because the gage was verified for accuracy on smooth steel, you will need to determine the effect that a roughened (i.e., abrasive blast cleaned) surface has on the coating thickness gage. This is known as the base metal reading or BMR. The BMR is a correction factor that is subtracted from the coating thickness measurements to determine the true coating thickness above the peaks of the surface profile.



Obtain a base metal reading (BMR)

IMPORTANT: You are not measuring surface profile here, but rather the effect of the surface roughness on a coating thickness gage. There is no correlation between the two. Surface profile is the “total peak-to-valley depth,” while the BMR is the effect of this surface profile on a coating thickness gage.

Take a minimum of ten readings on the prepared substrate, then average the readings. The mathematical average is the BMR. The BMR is considered constant and you only need to measure it at the beginning of a project. The BMR will not change significantly as long as the same or similar blast cleaning equipment and abrasive size and type are used, and the substrate itself is the same.

Example Base Metal Readings (mils)

0.8	0.6	0.2	1.0	0.6	0.7	1.0	0.3	0.4	1.2	Average 0.7 mil
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----------------

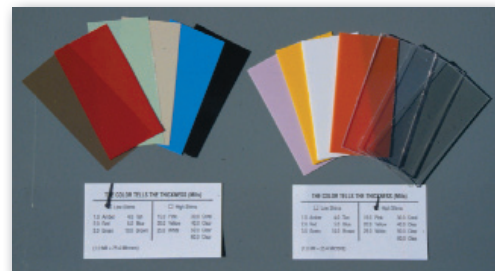
The use of the BMR when measuring the DFT is explained later in Step 2.

Accuracy Verification Method B: Using Plastic Shims

If accuracy verification is conducted according to ASTM D7091, then plastic shims may be used. There are two different sets of KTA plastic shims, a low set and a high set. When a plastic shim is selected and placed on the steel, it creates a known “gap” between the gage magnet and the steel. The thickness of each shim and the corresponding color of each shim are indicated below.

Low Set of Shims	
Color	Thickness
Amber	1 mil
Red	2 mils
Green	3 mils
Tan	4 mils
Blue	5 mils
Brown	10 mils

High Set of Shims	
Color	Thickness
Pink	15 mils
Yellow	20 mils
White	25 mils
Coral	30 mils
Clear	40 mils
Clear	50 mils
Clear	60 mils



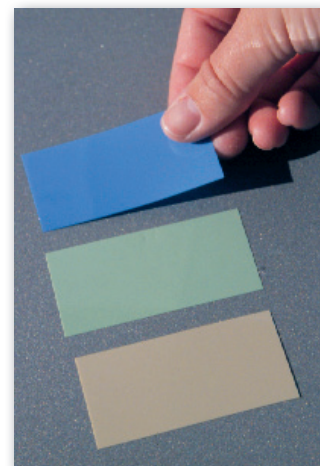
Low and high range plastic shims

Accuracy Verification Method B - Step 1:

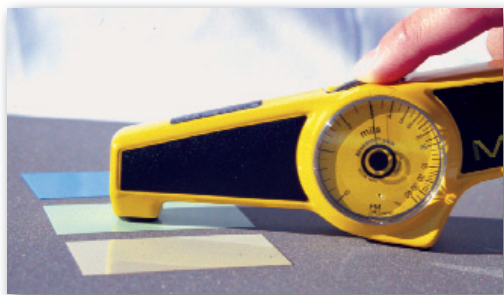
Select a plastic shim that is close to the thickness of the coating that you anticipate measuring. Then choose one lower and one higher than the anticipated coating thickness. This will provide you with a thickness range to verify gage accuracy. If you need a shim thickness that is not provided in either the high or the low sets, then stack two or more shims together to create the thickness you need. For example, if you want to verify accuracy at 7 mils, stack a 5 mil (blue) and a 2 mil (red) together. You must place the shim(s) on top of a smooth steel surface.

Accuracy Verification Method B - Step 2:

If you are verifying the accuracy of a *manual* magnetic pull-off gage (PosiTest FM, Elcometer 211 or Mikrotest III), place the end of the instrument containing the magnet on one of the shims (laying on the smooth steel) and rotate the dial forward until the magnet makes contact with the shim. Slowly retract the dial until the magnet breaks contact with the shim. Repeat this step on the other two shims selected.



Place shims on surface



Verify gage accuracy using plastic calibration shims

If the gage reading is outside of the combined accuracy of the plastic shim and the manufacturer's stated gage accuracy, you should return the instrument to the manufacturer or authorized agency for calibration. You should never adjust Type 1 coating thickness gages.

For example, if the gage accuracy is $\pm 5\%$ and the accuracy of the plastic shim is $\pm 5\%$, then the combined accuracy of the gage and the standard will be $\pm 7\%$ as calculated by taking the square root of the sum of the squared values:

$$\sqrt{5^2 + 5^2} = 7.071 \text{ or approximately } 7\%$$

For the gage to be in agreement with the shim, the average thickness measured by the gage must be within $\pm 7\%$ of the shim's thickness. If the average thickness measured on a 10 mil shim is between 9.3 mils and 10.7 mils, the gage is considered accurate, even though the reading does not exactly match the shim. The minimum value of 9.3 mils is calculated as 10 mils minus 7% of 10 mils; the maximum of 10.7 mils is calculated as 10 mils plus 7% of 10 mils.

If you are verifying the accuracy of a Mikrotest IV *automatic* magnetic pull-off gage, place the end of the instrument containing the magnet on one of the shims and rotate the dial forward until the magnet makes contact with the shim. Push in the counterweight button on the underside of the handle. The dial will automatically retract until the magnet breaks contact with the shim. Once this happens, the gage will automatically stop. Repeat this step on the other two shims selected.

Accuracy Verification Method B - Step 3:

Because the gage was verified for accuracy on smooth steel, you will need to determine the effect that a roughened (i.e., abrasive blast cleaned) surface has on the coating thickness gage. This is known as the base metal reading or BMR. The BMR is a correction factor that is subtracted from the coating thickness measurements to determine the true coating thickness above the peaks of the surface profile.

Step 2: Measuring the DFT using the Magnetic Pull-Off Gage



Examine magnet

2-1 Examine the magnet to make sure there is no coating residue, magnetic filings, or other contaminants on it. Place the gage on the coated surface to be measured.



Rotate scale wheel forward first (↺)

2-2 If you are using a *manual* magnetic pull-off gage (PosiTest FM, Elcometer 211 or Mikrotest III), use your finger or thumb to rotate the scale wheel forward (counterclockwise) until the magnet makes contact with the surface.



Retract scale wheel until magnet releases (↻)

2-3 Slowly and steadily turn the scale wheel backwards (clockwise) until the magnet breaks contact with the surface. Stop turning the scale wheel immediately after the magnet breaks contact. Read the coating thickness as the number on the scale that lines up with the vertical hairline on the plastic scale cover.



Rotate scale wheel forward, then push in counter weight button (↻)

2-4 If you are using a Mikrotest IV *automatic* magnetic pull-off gage, place the end of the instrument containing the magnet on the coated surface and rotate the dial forward until the magnet makes contact with the surface. Push in and release the counterweight button on the underside of the handle. The dial will automatically retract until the magnet breaks contact with the surface. Once this happens, the gage will automatically stop. Read the coating thickness as the number on the scale that lines up with the vertical hairline on the plastic scale cover.

Record the coating thickness from the gage and the Base Metal Reading (BMR).

Here are two examples of adjusting coating thickness for the BMR. Example 1 assumes the BMR was 0.7 mil. Example 2 assumes the BMR was 0.3 mil.

Item	Example 1	Example 2
Gage Dial Reading of Coating Thickness	6.5 mils	7.5 mils
BMR Correction	-0.7 mil	-0.3 mil
Actual Coating Thickness (above the peaks of the surface profile)	$6.5 - 0.7 = 5.8$ mils	$7.5 - 0.3 = 7.2$ mils

Watch Out!

Here are some things that can affect your measurements when using a magnetic pull-off gage:

1. Exposed magnets naturally attract iron filings, steel grit, etc. Assure that the magnet on your gage is free of contamination, including paint.
2. Vibrations may prematurely lift the magnet from the surface, giving erroneous readings. Make sure that the surface you are measuring is not vibrating.
3. Tacky or soft surfaces may prevent the magnet from lifting properly, and can contaminate your magnet. If you want to take coating thickness measurements on a soft film, you can take readings through a shim of known thickness that is placed on the surface. Subtract the shim thickness from the gage reading to assess the actual coating thickness.
4. Magnetic pull-off gages that require you to manually turn the scale wheel backwards (clockwise) until the magnet breaks contact with the surface are susceptible to human error by continuing to turn the dial beyond the point the magnet lifts from the surface. Make sure you stop turning the scale wheel immediately, or use an automatic version (Mikrotest IV).

SECTION 6-2 – ADJUSTING AND USING THE PosiTector® 6000

Section 6-2 discusses the use of the PosiTector® Model 6000 FN non-destructive electronic coating thickness gage. You can use this gage to measure coating thickness over both ferrous and non-ferrous metal surfaces. You do not have to set-up the gage for ferrous (F) or non-ferrous (N) surfaces. The gage automatically senses whether it should operate using a magnetic principle (the gage display will indicate “F”) or using an eddy current principle (the gage display will indicate “N”).

The PosiTector® Model 6000 gage is also available in “F” only and “N” only models, with integral or remote probes, and with memory, data print-out or downloading, statistical analysis and other features. We will only be discussing the basic operation of the PosiTector® Model 6000 FN gage with an integral probe. If you want to learn more about some of the advanced features of the gage, you’ll need to read the instruction booklet supplied with the gage.



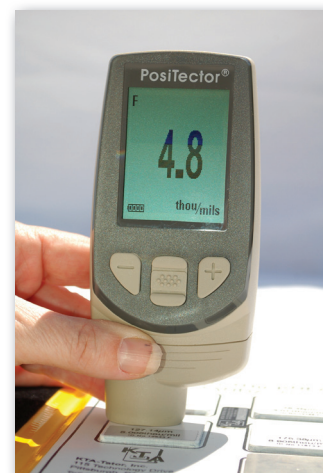
PosiTector® 6000

Step 1: Verifying Gage Accuracy

If you select a PosiTector® 6000 FN electronic coating thickness gage, you will be able to both verify gage accuracy and adjust the gage, if necessary.

The PosiTector® 6000 FN can be verified for accuracy using plastic shims. NIST traceable plates or other coating thickness standards can be used if you are going to measure coating thickness over steel. However, this is not usually necessary unless the project specification requires the use of traceable standards. If you choose to use the coating thickness standards, then follow the step-by-step instructions below, but substitute the standards for the plastic shims. If you use coating thickness standards, you will need to measure and subtract the Base Metal Reading (BMR) from the coating thickness measurements. The procedure for obtaining a BMR is described in Section 6-1, “Accuracy Verification Method A, Step 3” on page 6-7.

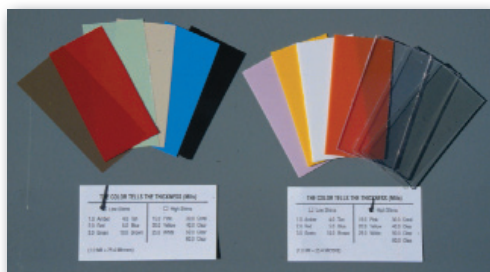
It is more common and more practical to verify the accuracy of the PosiTector® 6000 FN using plastic, color-coded shims that are placed onto the prepared surface. This method can be used for both ferrous (magnetic) and non-ferrous metal surfaces.



*Verifying accuracy using
coating thickness standards
(need to measure and subtract
BMR)*

Verification of Accuracy Using Plastic, Color-Coded Shims

There are two different sets of KTA plastic shims, a low set and a high set. When a plastic shim is selected and placed onto the metal surface, it creates a known “gap” between the gage probe and the metal. The thickness of each shim and the corresponding color of each shim are indicated below.



Low and high range plastic shims

Low Set of Shims	
Color	Thickness
Amber	1 mil
Red	2 mils
Green	3 mils
Tan	4 mils
Blue	5 mils
Brown	10 mils

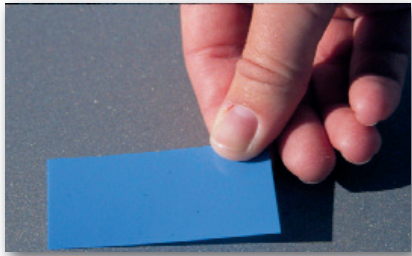
High Set of Shims	
Color	Thickness
Pink	15 mils
Yellow	20 mils
White	25 mils
Coral	30 mils
Clear	40 mils
Clear	50 mils
Clear	60 mils

The PosiTector® 6000 FN is calibrated at the factory and actually performs an automatic self-check each time it takes a measurement. If you are measuring coating thickness on a smooth, flat surface, the only verification you normally need to do is a check to make sure the gage is reading “zero” on the uncoated surface. However, if the surface is rough (e.g., abrasive blast cleaned), it is best to verify accuracy using plastic shims laid on the prepared surface. Gage readings are influenced by the shape and composition of the substrate, as well as the roughness of the surface. That is why gage adjustments are made possible.

The PosiTector® 6000 FN can be adjusted using either a one-point or a two-point procedure. If a procedure is not specified, use the one-point method first. If you find that the gage is not reading the shim thickness accurately after performing a one-point adjustment, then you’ll need to use the two-point method.

The step-by-step procedures for conducting both a one-point and a two-point adjustment are described below. The one-point method involves four steps, while the two-point method involves ten steps. Both of these procedures will prepare the gage to accurately measure the thickness of the coating *above* the peaks of the surface profile, if the surface has been abrasive blast cleaned.

Procedure for Conducting a One-Point Adjustment



Place shim on surface

Step 1: One-Point Adjustment

Select a plastic shim that represents the anticipated coating thickness. If you need a shim thickness that is not provided in either the high or the low sets, then stack two or more shims together to create the thickness you need. For example, if you want to verify accuracy at 7 mils, stack a 5 mil (blue) and a 2 mil (red) together. You must place the shim(s) on top of the prepared metal surface.



Examine gage probe



Power-up gage

Step 2: One-Point Adjustment

Examine the gage probe to assure cleanliness. Turn the PosiTector® 6000 FN to the “On” position by depressing the center of the middle button on the front of the gage. Access the main menu by pressing the same button again.

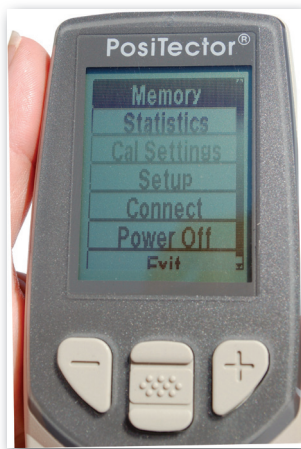


Figure 1: Main Menu

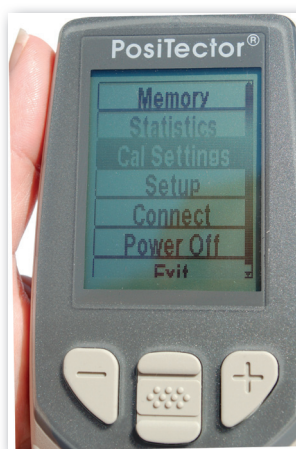


Figure 2: Cal Settings

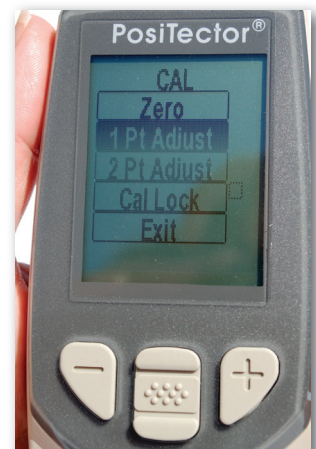


Figure 3: 1 Pt Adjust

Step 3: One-Point Adjustment

While you are in the menu, navigate through the options using the top and bottom portions of the center button until “Cal Settings” (Figure 2) is darkened on the display, then depress the center button to select this option. Navigate through the next four options using the the top and bottom portions of the center button until “1 Pt Adjust” is darkened on the display (Figure 3), then depress the middle of the center button to select this option.

Step 4: One-Point Adjustment

The gage will now ask you how many “1st point” readings you want to take (Figure 4). Enter the number of readings you want to obtain by repeatedly depressing the “+” button. The display will show you the number of readings you have requested. For example, let’s say you depressed the “+” button twice. The display will reveal “ $\bar{X} = 3$,” indicating that you want to collect 3 readings.

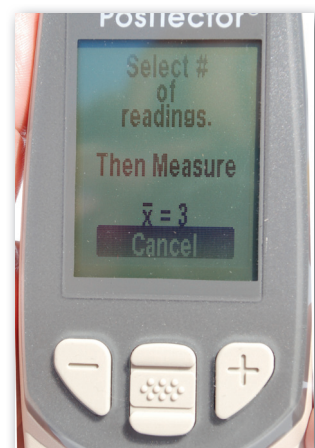


Figure 4: Enter number of readings desired



Figure 5

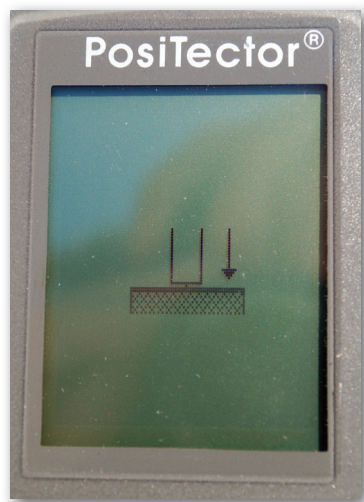


Figure 6

Step 5: One-Point Adjustment

Once you enter the desired number of “1st point” readings you want to take, place the instrument probe on the shim you selected (make sure the shim is laying flat on the prepared metal) and hold the gage steady. The probe position illustration on the display will show you when to pick the probe up off the shim (Figure 5) and when to set it back down on the same shim (Figure 6). Lift the gage at least 2" above the surface between measurements. The gage will beep twice and the green LED will blink when a measurement is taken. Note that the value will not be displayed until you have collected all of the “1st point” readings.



Figure 7



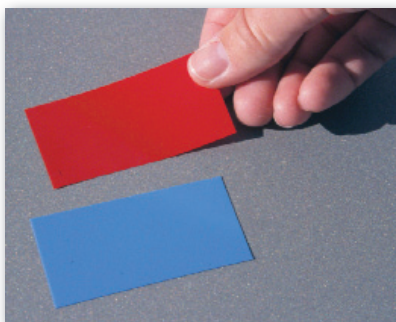
Adjust value to match shim thickness

Step 6: One-Point Adjustment

After you have collected all of the “1st point” readings, the average value will be displayed (Figure 7). If the value is acceptable, depress the center of the middle button to enter the value. If you want to adjust this value to match the thickness of the shim, lift the gage from the surface, then depress the “+” or “—” buttons located on the front of the gage. If you need to *increase* the reading, press and hold down the “+” button until the desired reading is displayed. If you need to *decrease* the reading, press and hold down the “—” button until the desired reading is displayed. If you increase or decrease the reading too far, just use the opposite button to create the value you desire on the display. Once the correct value is displayed, depress the center of the middle button to enter the value.

Procedure for Conducting a Two-Point Adjustment

Step1: Two-Point Adjustment



Place shims on surface

Select two plastic shims: one that is lower and one that is higher than the anticipated coating thickness. This will enable you to perform a two-point adjustment. If you need a shim thickness that is not provided in either the high or the low sets, then stack two or more shims together to create the thickness you need. For example, if you want to verify accuracy at 7 mils, stack a 5 mil (blue) and a 2 mil (red) together. You must place the shim on top of the prepared metal surface.



Figure 8: Power-up Gage

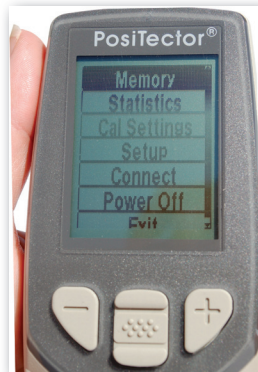


Figure 9: Main Menu



Figure 10: Cal Settings

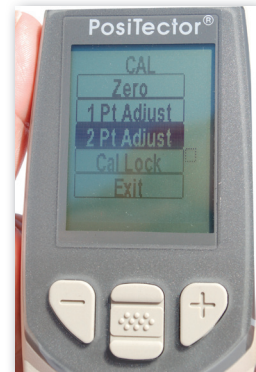


Figure 11: 2 Pt Adjust

Step 2: Two-Point Adjustment

Turn the gage to the “On” position by depressing the center of the middle button on the front of the gage (Figure 8). Next, depress the center button again. This will provide you with a menu of options (Main Menu; Figure 9). When you are in the menu mode, the top and bottom of the center button allows you to *navigate* through the options, and the middle of the center button allows you to *select* an option.

Step 3: Two-Point Adjustment

While you are in the menu, navigate through the options until “Cal Settings” (Figure 10) is darkened on the display, then depress the center button to select this option. Navigate through the next four options using the top or bottom of the center button until “2 Pt Adjust” is darkened on the display (Figure 11), then depress the middle of the center button to select this option.

Step 4: Two-Point Adjustment

The gage will now ask you how many “1st point” readings you want to take (Figure 12). Enter the number of readings you want to obtain by repeatedly depressing the “+” button. The display will show you the number of readings you have requested. For example, let’s say you depressed the “+” button twice. The display will reveal “ $\bar{X} = 3$,” indicating that you want to collect 3 “1st point” readings.

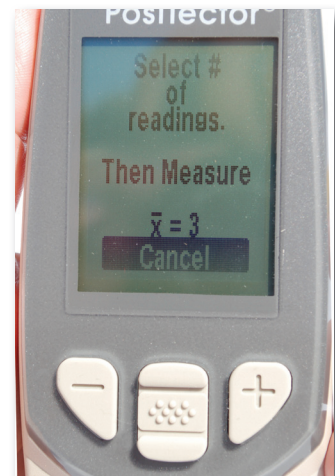


Figure 12: Enter number of readings desired



Figure 13

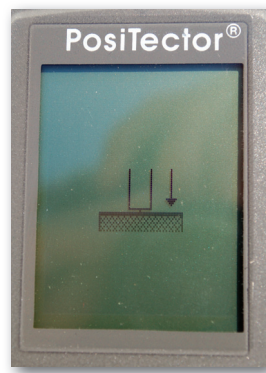


Figure 14



Figure 15



Adjust value to match shim thickness

Step 5: Two-Point Adjustment

Once you enter the desired number of “1st point” readings you want to take, place the instrument probe on the lower of the two shim thicknesses you selected (make sure the shim is laying flat on the prepared metal) and hold the gage steady. The probe position illustration on the display will show you when to pick the probe up off the shim (Figure 13) and when to set it back down on the same shim (Figure 14). Lift the gage at least 2" above the surface between measurements. The gage will beep twice and the green LED will blink when a measurement is taken. Note that the value will not be displayed until you have collected all of the readings.

Step 6: Two-Point Adjustment

After you have collected all of the “1st point” readings, the average value will be displayed (Figure 15). If the value is acceptable, depress the center of the middle button to enter the value. If you want to adjust this value to match the thickness of the shim, lift the gage from the surface, then depress the “+” or “—” button located on the front of the gage. If you need to *increase* the reading, press and hold down the “+” button until the desired reading is displayed. If you need to *decrease* the reading, press and hold down the “—” button until the desired reading is displayed. If you increase or decrease the reading too far, just use the opposite button to create the value you desire on the display. Once the correct value is displayed, depress the center of the middle button to enter the value.

Step 7: Two-Point Adjustment

The gage will now ask you how many “2nd point” readings you want to take. Enter the number of readings you want to obtain by repeatedly depressing the “+” button. The display will show you the number of readings you have requested. For example, let’s say you depressed the “+” button twice. The display will reveal “ $\bar{X} = 3$,” indicating that you want to collect 3 “2nd point” readings.

Step 8: Two-Point Adjustment

Once you enter the desired number of “2nd point” readings you want to take, place the instrument probe on the higher of the two shim thicknesses selected (laying on the prepared metal) and hold the gage steady. The display will show you when to pick the probe up off the shim and when to set it back down on the same shim using a probe position illustration. Lift the gage at least 2" above the surface between measurements. The gage will beep twice and the green LED will blink when a measurement is taken. Note that the value will not be displayed until you have collected all of the “2nd point” readings.



Place gage probe on high shim



Figure 16: Adjust value to match shim thickness

Step 9: Two-Point Adjustment

After you have collected all of the “2nd point” readings, the average value will be displayed (Figure 16). If the value is acceptable, depress the center of the middle button to enter the value. If you want to adjust this value to match the shim thickness, depress the “+” or “—” button located on the front of the gage (just as you did in Step 6). If you need to *increase* the reading, press and hold down the “+” button until the desired reading is displayed. If you need to *decrease* the reading, press and hold down the “—” button until the desired reading is displayed. If you increase or decrease the reading too far, just use the opposite button to create the value you desire on the display. Once the correct value is displayed, depress the center of the middle button to enter the value.

Step 10: Two-Point Adjustment

Now that you have performed the two-point adjustment, verify that the gage is accurately measuring the plastic shim thickness by placing the gage down onto the lower and the higher shims. Take several readings on each shim. The gage may not indicate the *EXACT* shim thickness, especially if the metal surface beneath the shim is roughened (e.g., by abrasive blast cleaning). As long as the displayed value is within 0.3 mil of the target thickness, the gage is considered adjusted. You are now ready to measure the thickness of the coating.

Do I need to “Zero” the gage?

The menu on the PosiTector 6000 FN gage provides an option to “Zero” the gage on the uncoated metal. This is actually the preferred adjustment method *if* you are measuring coating thickness on large, flat, smooth surfaces. But on roughened steel surfaces, it can be difficult to “Zero” the gage and maintain a zero reading. Therefore, verifying gage accuracy in the range of intended use (using plastic shims laid on the prepared surface) is simpler and will provide coating thickness values that are more consistent with readings taken with other coating thickness gages. So for roughened surfaces, the gage is not zeroed on the bare metal.

Do I need to measure and subtract the effect of the base metal?

When gage accuracy is verified using plastic shims on the prepared steel, you do not need to measure nor subtract any base metal reading (BMR). By placing the shims directly onto the prepared surface, and adjusting the gage to match the shim thickness, you essentially remove the effect of the surface roughness, since the gage will recognize and display only what is laying on top of the peaks of the surface profile. This is an acceptable practice, since you are only interested in the thickness of the coating above the peaks of the surface profile anyway. However, if you choose to verify gage accuracy using smooth coating thickness standards, the BMR applies.

Step 2: Measuring the DFT using the PosiTector® 6000 FN

Examine the gage probe to make sure there is no coating residue or other contaminants on it. Place the gage probe onto the coated surface to be measured. The gage will beep twice and the green LED will blink when a measurement is taken. The value is displayed. Lift the gage at least 2" above the surface between measurements. If you set the gage down onto the surface too slowly, the gage will sense the base metal and display an erroneously high value. Disregard this value. You may need to adjust your measuring technique (i.e., set the gage probe down onto the surface quicker) if this occurs. Power down the gage by selecting "Power Off" from the main menu, then press the center of the middle button.



Examine gage probe



Measure the coating thickness



Power down gage

SECTION 6-3 – ADJUSTING AND USING THE ELCOMETER® 456 WITH PINIP™ PROBE

Section 6-3 discusses the proper use of the Elcometer® Model 456 non-destructive electronic coating thickness gage equipped with a PINIP™ probe.

The Elcometer® Model 456 gage is available in ferrous (F) only, non-ferrous metal (N) only and ferrous/non-ferrous metal (FNF) models, with integral, separate and PINIP™ probes, and with memory, data print-out or downloading, statistical analysis and many other features. We will only be discussing the basic operation of the Elcometer® Model 456 F basic gage with a PINIP™ F (ferrous) probe. If you want to learn more about some of the advanced features of the gage, you'll need to read the instruction booklet supplied with the gage.



Elcometer® 456 with PINIP™ probe

Step 1: Verifying Gage Accuracy

If you select an Elcometer® Model 456 electronic coating thickness gage, you will be able to both verify gage accuracy and adjust the gage, if necessary.

The Elcometer® Model 456 can be verified for accuracy using plastic shims. Coating thickness standards can be used if you are going to measure coating thickness over steel. However, this is not usually necessary unless the project specification requires the use of traceable standards. If you choose to use the coating thickness standards, then follow the step-by-step instructions below, but substitute the standards for the plastic shims. If you use smooth standards, you will need to measure and subtract the Base Metal Reading (BMR) from the coating thickness measurements. The procedure for obtaining a BMR is described in Section 6-1, “Accuracy Verification Method A, Step 3” on page 6-7.



Verification of accuracy using coating thickness standards (need to measure and subtract BMR)

It is more common and more practical to verify the accuracy of the Elcometer® Model 456 using plastic, color-coded shims that are placed onto the prepared surface. This method can be used for both ferrous (magnetic) and non-ferrous metal surfaces.

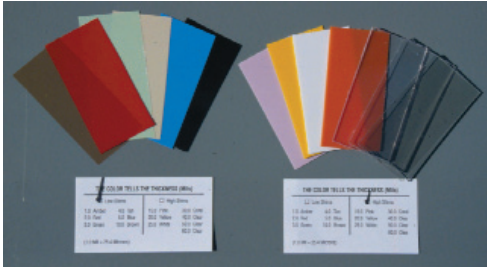
Accuracy Verification using Plastic, Color-Coded Shims

There are two different sets of KTA plastic shims, a low set and a high set. When a plastic shim is selected and placed onto the metal surface, it creates a known “gap” between the gage probe and the metal. The thickness of each shim and the corresponding color of each shim are indicated below.

The manufacturer of the Elcometer® Model 456 recommends a two-point adjustment for coatings applied to a roughened surface.

Low Set of Shims	
Color	Thickness
Amber	1 mil
Red	2 mils
Green	3 mils
Tan	4 mils
Blue	5 mils
Brown	10 mils

High Set of Shims	
Color	Thickness
Pink	15 mils
Yellow	20 mils
White	25 mils
Coral	30 mils
Clear	40 mils
Clear	50 mils
Clear	60 mils



Low and high range plastic shims

Procedure for Conducting a Two-Point Adjustment (rough surfaces) Step 1: Two-Point Adjustment

Turn the gage to the “On” position by depressing the on/off button on the front of the gage. There are 4 “soft keys” beneath the display. The reason these are called soft keys is because they will perform different functions depending on the gage mode that you are in. When you “power-up” the gage, the four soft keys can be used to activate the following four functions (starting with the far left soft key and moving right):



Turn the gage on

“CAL”	“BATCH”	“STATS”	“MENU”
Soft Key 1	Soft Key 2	Soft Key 3	Soft Key 4



Soft keys 1 - 4 (L-R)

In order to proceed with adjusting the gage, depress Soft Key 1: “CAL” A second bar of soft key identifiers will appear:

“BACK”	“↑”	“↓”	“Select”
Soft Key 1	Soft Key 2	Soft Key 3	Soft Key 4



Place gage probe on high thickness shim

Depress Soft Key 2 or 3: “↑” or “↓” until “Calibrate Method” is highlighted, then depress Soft Key 4, “Select.”

The “Cal Method” menu will appear on the display.

Depress the ↑ ↓ soft key until “Rough/2 Point” menu item is highlighted, then depress the “Select” soft key (Soft Key 4).

The display may ask you if you want to “Recalibrate now?” Depress the “Yes” key (Soft Key 4) to continue.

The display will prompt you to set the gage probe onto the “Thick Foil” (high thickness shim) that has been placed on the prepared, uncoated metal surface. The thickness of the shim you select should be slightly higher than the thickness of the coating you plan to measure. Lift the probe from the surface after a reading is displayed and adjust the reading as necessary using the ↑ ↓ soft keys until the desired reading is displayed, then press the “Set” key (Soft Key 4).



Place gage probe on low thickness shim

The display will prompt you to set the gage probe onto a “Thin Foil” (low thickness shim) that has been placed on the prepared, uncoated metal surface. The thickness of the shim you select should be slightly lower than the thickness of the coating you plan to measure. Lift the probe from the surface after a reading is displayed and adjust the reading as necessary using the ↑ ↓ soft keys until the desired reading is displayed, then press the “Set” key (Soft Key 4).

The gage display will then inquire, “Do you wish to test the readings?” Press the “Yes” key (Soft Key 4). Place the probe on the high thickness shim—if the displayed reading is acceptable, press “OK” (Soft Key 4). If the displayed reading is not acceptable, press the “Cal” key (Soft Key 1) and repeat the Cal process until the displayed readings are acceptable.

Once the accuracy of the gage has been verified, press the “Back” key (Soft Key 1) until you return to the opening display. You are now ready to take coating thickness measurements.

Do I need to “Zero” the gage?

The calibration menu on the Elcometer® Model 456 gage provides an option to zero adjust the gage on uncoated metal (“Smooth”). This is actually the preferred adjustment method *if* you are measuring coating thickness on large, flat, smooth surfaces. But on roughened steel surfaces, it can be difficult to “Zero” the gage and maintain a zero reading. Therefore, verifying gage accuracy in the range of intended use (using plastic shims laid on the prepared surface) is simpler and will provide coating thickness values that are more consistent with readings taken with other coating thickness gages. So for roughened surfaces, the gage is not zeroed on the bare metal.

Do I need to measure and subtract the effect of the base metal?

When gage accuracy is verified using plastic shims on the prepared steel, you do not need to measure nor subtract any base metal reading (BMR). By placing the shims directly onto the prepared surface, and adjusting the gage to match the shim thickness, you essentially remove the effect of the surface roughness, since the gage will recognize and display only what is laying on top of the peaks of the surface profile. This is an acceptable practice, since you are only interested in the thickness of the coating above the peaks of the surface profile anyway. However, if you verify gage accuracy using smooth coating thickness standards, the BMR applies.

Step 2: Measuring the DFT using the Elcometer® 456

Examine the gage probe to make sure there is no coating residue or other contaminants on it. Place the gage probe onto the coated surface to be measured. The gage will beep once and the green LED on the front (top right) of the gage will blink when a measurement is taken.

The instrument will automatically “power down” if it remains inactive for 60 seconds. You can turn the gage “off” by depressing and holding the on/off button on the front of the gage through a series of 4 “beeps.”



Examine gage probe



Measure the coating thickness

SECTION 6-4 – ADJUSTING AND USING THE FISCHER DUALSCOPE® MPOR

Section 6-4 describes the basic operation of the Fischer Dualscope® MPOR non-destructive electronic coating thickness gage. You can use this gage to measure coating thickness over both ferrous and non-ferrous metal surfaces. You do not have to set-up the gage for ferrous (F) or non-ferrous (N) surfaces. It will automatically display the type of surface you are measuring when the reading is displayed. The gage offers the convenience of two displays (one on the top of the gage and one on the side of the gage).

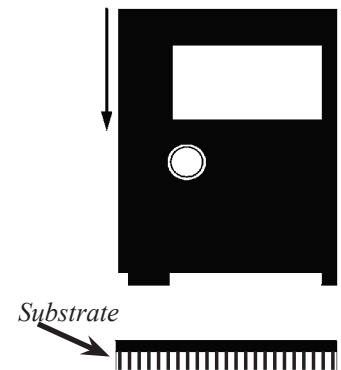


The Fischer Dualscope® MPOR can be optimized using plastic shims. Traceable coating thickness standards can be used if you are going to measure coating thickness over steel. However, this is not usually necessary unless the project specification requires the use of traceable standards. If you choose to use the coating thickness standards, then follow the step-by-step instructions below, but substitute the standards for the plastic shims. If you use coating thickness standards, you will need to measure and subtract the Base Metal Reading (BMR) from the coating thickness measurements. The procedure for obtaining a BMR is described in Section 6-1, “Accuracy Verification Method A, Step 3” on page 6-7.

It is more common and more practical to optimize the Fischer Dualscope® MPOR using plastic, color-coded shims that are placed onto the prepared surface. This method can be used for both ferrous (magnetic) and non-ferrous metals.

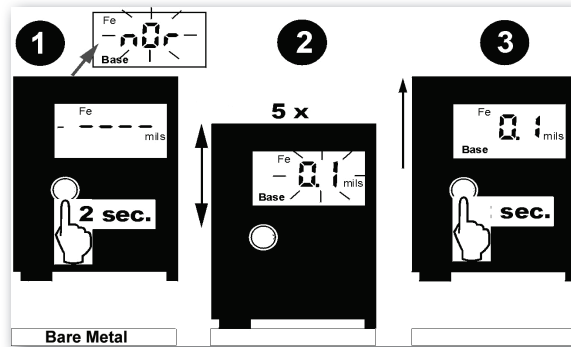
Step 1: Power-up the Gage

Remove the protective orange probe cover, then power-up the gage. The MPOR does not have an on/off button. The instrument will automatically power-up when it is placed on either a ferrous or a non-ferrous metal surface. Never power-up the gage by pressing your finger on the probe, as it may cause measurement errors. If the gage is not placed on a ferrous or non-ferrous metal surface, the display will indicate an error code (“Er6”), followed by four horizontal bars in the display, rather than a measurement.



Step 2: Normalize and Optimize the Gage

After you have powered-up the gage, you will need to normalize it to the substrate and optimize the gage to a known thickness. You need to do this prior to measuring coating thickness, otherwise the measurements you obtain will be questionable.



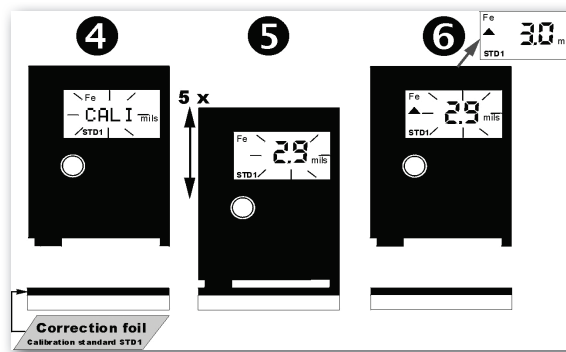
Step 2-1: Normalize the Gage

To normalize the gage, you will need access to bare metal. The metal should be the same type, shape and roughness as the metal being coated. You will notice that the gage is supplied with an uncoated, base material. You should not use this material to normalize the gage, since it is unlikely that it is representative of the metal surface on which you intend to use the gage.

- 2-1.1 Without the gage probe in contact with the surface, press the orange button for at least 2 seconds. ① The flashing message “**n0r**” (for “normalization”) and the display message “**Base**” will appear on the front display.
- 2-1.2 Place the gage onto the bare metal and obtain 5 measurements ②( = bare metal). After each measurement, the current reading will appear *flashing* on the display (*display reading “0.1” is an example only*).
- 2-1.3 After you obtain 5 measurements, lift the gage from the surface and press the orange button within two seconds. ③ “**CAL I**” and “**STD 1**” will appear on the display. ④ The gage is now normalized to the base metal and is ready to be optimized to a known thickness.

Step 2-2: Optimize the Gage

- 2-2.1 In order to optimize the gage, you will need access to an uncoated portion of the surface and a set of plastic color-coded shims. Select a color-coded plastic shim that represents the middle of the thickness range of the coating you intend to measure and place it onto the uncoated surface. A 3 mil shim is shown as an example. Obtain a minimum of 5 measurements on the shim. ⑤ The last reading will flash on the display.



- 2-2.2 Wait a few seconds after the last reading is taken until the symbol “▲” appears on the display. Using the orange button, set the display number to the thickness value of the shim. Press the button as often as you need to. If you have pressed the button too often, or the last reading of Step 2-2.1 was actually higher than the shim value, you will need to wait until the symbol “▼” is displayed. This will occur automatically after you wait a few seconds. Once the “▼” symbol is displayed, press the orange button as needed to adjust the display to match the shim value. ⑥
- 2-2.3 When you have finished adjusting the display, wait a few seconds and the display will indicate “0.0 mils.” The gage is now optimized and is ready for use. If you intend to use the gage to measure a coating that is substantially thinner or thicker than the shim you selected in 2-2.1, then you will need to re-optimize the gage using a shim that is representative of the anticipated coating thickness.

Step 3: Measure the Coating Thickness

If the gage has not powered-down (shut off), you can set it directly on the coated surface. The thickness of the coating in that spot will be shown on both the side and top displays of the gage. The displays will hold the reading until another one is taken, or the gage powers down (shuts off) because of non-use.



If the gage has powered down, simply place the gage probe on the coated surface and wait for the audible signal. After the signal, the coating thickness will be revealed by the displays. If you do not wait for the audible signal before lifting the gage from the surface, the display will indicate an error code (“Er6”), followed by four horizontal bars rather than a measurement. If this happens, simply place the gage probe on the surface again, and wait for the audible signal before lifting the gage.

5

CALCULATING AND MEASURING WET FILM THICKNESS

Most coating specifications indicate the *dry* film thickness or DFT required for each layer of coating to be applied. But unless there is no solvent in the coating material (100% solids), the applicator must know how thick to apply the *wet* coating so that when the solvent evaporates from the coating film into the air (known as film shrinkage), the correct dry film thickness is achieved. In most cases though,

you cannot get the wet film thickness or WFT from the specification, so you go to the coating manufacturer's application instructions or product data sheets to find it there.

To calculate wet film thickness you need 3 values:

- Target DFT
- % solids by volume (vol.)
- Amount of thinner added

Two formulas to remember:

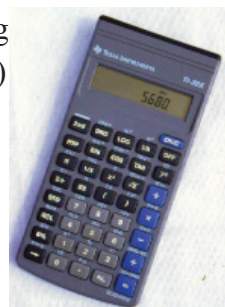
$$\text{WFT} = \frac{\text{DFT}}{\% \text{ solids by vol.}}$$

$$\text{WFT} = \left(\frac{\text{DFT}}{\frac{\% \text{ solids by vol.}}{100\% + \% \text{ thinner}}} \right)$$

Unfortunately, the coating manufacturers do not always publish a wet film thickness value on their application instructions, because it can vary depending on how much thinner is added to the coating and the actual dry film thickness that is specified. Therefore, it is important that you know how to calculate a target wet film thickness for both unthinned and thinned coatings, as well as know how to measure the wet film thickness during application of a coating. This module on measurement of wet film thickness will help you with both of these learning objectives.

Calculating the Target Wet Film Thickness

Before you measure the wet film thickness, you will need to calculate the target wet film thickness for the applicator to shoot for by obtaining three values. Without these values, the target wet film thickness (WFT) remains unknown. Also, attempts to determine the WFT without the help of a calculator can result in mathematical errors, so use your calculator.



Calculator makes calculating easier

Value No. 1: The target dry film thickness (DFT)

Value No. 2: The solids by volume content of the coating material

Value No. 3: The amount of thinner that will be added to the coating

Let's look at each of these a little closer to determine where the three values come from.

Step 1: Determine Value No. 1 – The Target Dry Film Thickness

The target dry film thickness (DFT) is indicated in the project specification. It is typically expressed in mils (0.001”) or microns (μm). There are 25.4 μm in 1 mil. If the project specification does not provide the target DFT, then you will need to locate the recommended DFT on the coating manufacturer's application instructions. In either case, write down the target DFT. If the project specification or the manufacturer's instructions provide a range for the DFT rather than a target, then write down the range.

Example: *“The primer coat shall be applied to a dry film thickness (DFT) of 2-4 mils.”*

Write down: 2-4 mils DFT

Step 2: Determine Value No. 2 – The Solids by Volume Content of the Coating Material

When the solids by volume content is indicated on the coating manufacturer's product data sheet, it is typically expressed as a percent (%). This value represents the non-volatile or non-evaporative content of a coating (e.g., the resin, pigment and additives). Often there is a solids by weight value on the product data sheet as well. Do not use this value.

Example: *Solids by Volume: 47%*

If the solids by volume content is not listed on the coating manufacturer's product data sheet, then you can use the value for the "theoretical coverage rate at 1 mil" on the product data sheet to estimate the solids by volume content of the coating. This can be a little more challenging, so you'll need to follow these next few steps carefully and you'll need to use your calculator.

1. **Start with the standard rule of coating coverage:** One US gallon of coating that is 100% solids by volume will cover 1,604 square feet if it is applied exactly 1 mil thick.
2. **Determine coverage rate at 1 mil.** Locate the theoretical coverage rate and the dry film thickness that the coverage rate is based on using the coating manufacturer's product data sheet. Multiply the two numbers together to determine the coverage rate at 1 mil.

Example: *The theoretical coverage rate is 401 square feet per gallon at 3 mils. $401 \times 3 = 1203$ square feet per gallon at 1 mil dry film thickness.*

3. **Calculate the solids by volume content.** Divide the theoretical coverage rate at 1 mil by 1,604.

Example: *The theoretical coverage rate is 1,203 square feet per gallon at 1 mil.*
 $1203 \div 1604 = 0.75$

4. **Convert the solids content to a percentage.** Multiply the volume solids value by 100.

Example: *$0.75 \times 100 = 75\%$ solids by volume*

Step 3: Determine Value No. 3 – The Amount of Thinner that will be added to the Coating

If the project specification and the coating manufacturer permit thinner to be added to the coating, the amount of thinner that will be added must be taken into consideration when calculating a target wet film thickness. This is because the thinner is part of the wet film that is applied to the surface, but is not part of the dry film that remains on the surface (the thinner will evaporate into the air).

Coating manufacturers typically communicate the amount of thinner to add based on a percentage of the total volume of coating mixed for application (e.g., 15%), or based on a certain volume (1 pint per gallon). Ultimately, you will need a "percent thinner" value for your calculation. If the coating manufacturer provides the percentage of thinner to add, then no further work is required. If the coating manufacturer indicates thinner addition by volume, then you will need to calculate the percentage using some very basic units of measurement.

- a) There are 4 quarts in 1 US gallon. A quart is 25% (1/4) of 1 US Gallon
- b) There are 8 pints in 1 US gallon. A pint is 12.5% (1/8) of 1 US Gallon

Example: *The coating was thinned 1 pint per gallon, or 12.5%*

Now that we have all three values (target DFT, percent solids by volume and percent thinner), we can calculate the target WFT.

Step 4: Select a Formula

There are two formulas. Select only one of the two formulas when calculating a wet film thickness. The formula you should select is based on whether or not the coating was thinned prior to use. Here are the two formulas. Formula A is one step, while Formula B requires two steps.

Formula A (NO thinner addition)

$\text{DFT} \div \% \text{ solids by volume} = \text{WFT}$

Formula B (WITH thinner addition)

Step 1: $\% \text{ solids by volume} \div (100\% + \% \text{ thinner added}) = \text{adjusted volume solids content}$

Step 2: $\text{DFT} \div \text{adjusted volume solids content} = \text{WFT}$

Step 5: Enter the Values into the Formula Selected in Step 4

Once you select a formula, enter the values into the formula to arrive at the wet film thickness range. Remember, ALL percentage values must be converted to decimal format, simply by moving the decimal point two places to the left. For example, 75% is 0.75

Example 1 – DFT range of 2-4 mils with no thinner added. The solids by volume is 75%. Use Formula A:

2 mils DFT $\div$ 0.75 solids by volume = 2.7 mils WFT

4 mils DFT $\div$ 0.75 solids by volume = 5.3 mils WFT

Therefore, the applicator should strive to apply the coating within a range of 2.5 – 5.5 mils WFT.

Example 2 – DFT range of 2-4 mils with 12.5% thinner added. Use Formula B:

(0.75 solids by volume $\div$ 1.125) = 0.67 adjusted volume solids content

2 mils DFT $\div$ 0.67 solids by volume = 3.0 mils WFT

4 mils DFT $\div$ 0.67 solids by volume = 6.0 mils WFT

Therefore, the applicator should strive to apply the coating within a range of 3-6 mils WFT. Even with the addition of 12.5% thinner, the coating should “shrink” to 2-4 mils DFT.

Measuring the Wet Film Thickness

Now that you have calculated the target wet film thickness, you can measure the thickness of the wet coating film as it is applied using a wet film thickness gage. While there are a couple different types, we will be discussing the standard stainless steel and the aluminum notch-type wet film thickness gages.



Stainless steel and aluminum notch-type WFT gages



*Low range WFT gage
(½ to 20 mils)*



*Mid-range WFT gage
(4 to 60 mils)*



*High range WFT gage
(10 to 500 mils)*

Step 1: Select a Measuring Face

The standard aluminum and stainless steel wet film thickness gages have four (4) measuring faces. Each face contains a different wet film thickness range. The chart below provides the measuring ranges for each of the four faces, for both the aluminum and stainless steel type gages.

WFT	WFT Range on Each Face			
	Face 1	Face 2	Face 3	Face 4
Stainless Steel (low)	½ – 2 mils	2½ – 4 mils	5 – 8 mils	10 – 20 mils
Stainless Steel (mid-range)	4 – 10 mils	12 – 24 mils	28 – 40 mils	45 – 60 mils
Stainless Steel (high)	10 – 40 mils	50 – 80 mils	100 – 160 mils	200 – 500 mils
Aluminum	1 – 6 mils	7 – 12 mils	14 – 30 mils	35 – 80 mils

Each face is a series of teeth, with notches between the teeth. Each tooth is numbered. The number corresponds to the wet film thickness in mils.

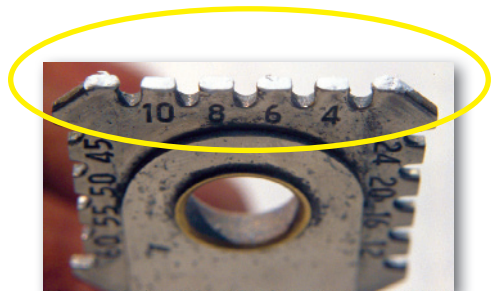
Step 2: Take a Wet Film Thickness Measurement

Immediately after the wet coating film is applied, insert the measuring face selected in Step 1 into the wet coating, perpendicular to the surface. The longer you wait between application and measurement, the less accurate are the results, because solvents are escaping from the film, increasing the solids by volume value used in the formula. The two “end teeth” on the face you select must penetrate down to the previous layer, or the substrate if you are measuring the thickness of the first coat.

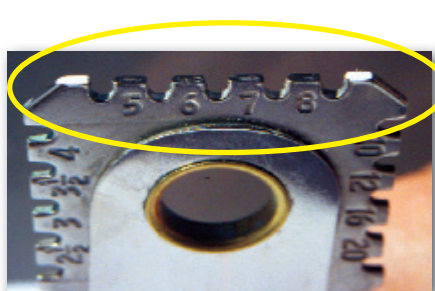
Withdraw the gage from the wet film. The two end teeth that penetrated down to the previous layer will be coated with paint. Observe the numbered teeth between the two end teeth. The highest numbered tooth containing wet paint is the wet film thickness.



Close-up of one face



Gage face with ends and all 4 teeth coated white. Need to use a higher range.

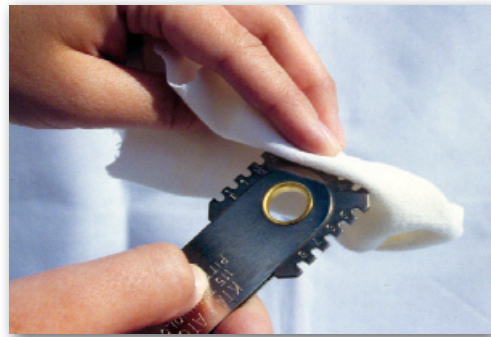


Gage face with only 2 ends coated white. Need to use a lower range.



Wet film thickness of 5 mils

If all of the numbered teeth are coated, then you will need to choose a face on the gage that represents a higher wet film thickness range. However, if none of the numbered teeth are coated, then you will need to choose a face on the gage that represents a lower wet film thickness range. Clean the gage using a clean soft rag, then repeat this step in several other areas. If the measured wet film thickness falls within the targeted range, then no further measurements are necessary. If the wet film thickness is outside of the target, then the application technique must be altered or adjustments must be made to the equipment until the target WFT is achieved.



Wipe teeth clean with rag

Step 3: Documenting the Wet Film Thickness

If the project specification requires a certain wet film thickness to be applied (e.g., coatings on wood or concrete), then the actual wet film thickness data must be recorded. However, if the project specification only indicates the dry film thickness requirements, then the wet film thickness may not have to be recorded, as it is simply a means to an end.

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