

ANSI/AWS C2.18-93
An American National Standard

**Guide for the
Protection of Steel with
Thermal Sprayed Coatings of
Aluminum and Zinc and their
Alloys and Composites**



American Welding Society

Keywords — Aluminum, Aluminum Metal Matrix Composite, Arc Spray, Flame Spray, Steel Protection, Thermal Spray Coating, Zinc, Zinc/Aluminum Alloy

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An American National Standard

Approved by
American National Standards Institute
April 22, 1993

Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites

Prepared by
AWS Committee on Thermal Spraying

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This guide presents an industrial process for the application of thermal spray coatings (TSC) on steel. It covers safety, job/contract description, background and requirements, selection of TSCs, TSC operator qualification, materials and equipment, application-process method with quality-control check points, Job Control Record, maintenance and repair of TSCs, records, debris containment and control, and warranty.



American Welding Society

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International Standard Book Number: 0-87171-407-8

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Foreword

(This Foreword is not a part of ANSI/AWS C2.18-93, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*, but is included for information purposes only.)

Thermal spray coatings (TSCs) are used extensively for the corrosion protection of steel and iron in a wide range of environments. The corrosion tests carried out by the American Welding Society¹ and the 34-year marine-atmosphere performance report of the LaQue Center for Corrosion Technology² confirm the effectiveness of flame sprayed aluminum and zinc coatings over long periods of time in a wide range of hostile environments. The British Standards Institution code of practice for the corrosion protection of steel³ specifies that only TSCs give protection greater than 20 years to first maintenance for the 19 industrial and marine environments considered and that only sealed, sprayed aluminum or zinc gives such protection in sea water immersion or splash zones.

The selection of a TSC depends on the desired service life, environmental envelope, operating duty and substrate-inspection cycle, and the maintenance and repair support provided during the life-cycle. This AWS guide summarizes the major elements to select, plan, and quality control (QC) the application of TSCs for the protection of steel. The information in this guide is formatted as an industrial process instruction (with fill-in blanks) to permit purchasers to analyze and specify their TSC requirements and process envelope and for Thermal Spray Coating Contractors (TSCCs) to add and subtract as necessary to match their production and quality capabilities and their customer requirements.

This document has been coordinated with the Zinc Metallizers Association.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Managing Director, Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

1. *Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report*, American Welding Society C2.14-74. AWS publications available from American Welding Society, P.O. Box 351040, Miami, FL 33135.
2. R.M. Kain and E.A. Baker, *Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Spray Coatings on Steel*, ASTM STP 947. ASTM publications available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.
3. *Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion*, British Standards Institution B.S. 5493: 1977. Available from American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

Table of Contents

	Page No.
<i>Personnel</i>	iii
<i>Foreword</i>	iv
<i>List of Tables</i>	vii
<i>List of QC Check Points</i>	vii
<i>List of Figures</i>	vii
<i>Acronyms and Conversion Factors Used in this Publication</i>	viii
1. General	1
1.1 Scope	1
1.2 Definitions	1
2. Safety	2
2.1 General	2
2.2 Thermal Spray Powder	2
3. Job and Contract Description	2
3.1 General	2
3.2 Thermal Spray Boundary (TSB)	2
3.3 Job Control Record (JCR)	3
3.4 Selection of TSC	3
3.5 TSC Inspector	3
3.6 TSC Operator Qualification	3
4. Background and Requirements	3
4.1 Background	3
4.2 Requirements	3
5. Materials	4
5.1 Thermal Spray Wire and Powder	4
5.2 Abrasive Blasting Media	6
5.3 Sealer and Intermediate Topcoat	7
5.4 Profile Tape for Anchor-Tooth Depth Measurement	8
5.5 Bend and Companion Coupons	8
5.6 Tensile-Bond Test Specimens	8
5.7 Gases	8
6. Equipment for Thermal Spraying	9
6.1 Thermal Spray Guns	9
6.2 Air Compressors	9
6.3 Air Dryers	9
7. Quality Control Equipment	9
7.1 Surface Preparation	9
7.2 TSC Application	9
8. Application-Process Method	9
8.1 Surface Preparation	9
8.2 New Steel Substrate	10
8.3 Contaminated Steel Substrate	10
8.4 Post-Blasting Substrate Condition and Thermal Spraying Period	12
8.5 Thermal Spraying	13

	Page No.
8.6 Sealing	15
8.7 Intermediate and Top Coats	15
9. Maintenance and Repair (M&R) of Thermal Spray Coatings	16
9.1 Solvent Clean	16
9.2 Scrape Off Loosely Adherent Paint/TSCs	17
9.3 Cleaning, Manual and Blast	17
9.4 Feather	17
9.5 Light Abrasion	17
9.6 Apply TSC	17
9.7 Seal and Topcoat	17
10. Records	17
11. Debris Containment and Control	17
12. Utility Services	17
13. Work Procedures and Safety	18
14. Warranty	18
14.1 Thermal Spray Coating Contractor's Warranty	18
14.2 Thermal Spray Coating Materials	18
Annex A — Sample Job Control Record (JCR) for Thermal Spray Coatings (TSC)	19
Annex B — Recommendations for the Selection of Thermal Spray Coatings of Aluminum and Zinc and Their Alloys and Composites for the Protection of Steel in Various Environments and Service	22
Annex C — Thermal Spray Operator Qualification and Certification	27
Annex D — Sample Thermal Spray Operator Qualification Form	30
Thermal Spray Specifications and Related Documents	(Inside Back Cover)

List of Tables

Table	Page No.
1 Inspection and Acceptance Tests — Shop and Field	4
2 TSC Inspection and Acceptance Tests — Laboratory	4
3A/B Nominal Feedstock Required	5
4A/B Nominal Wire Feedstock Spray Rates and Coverage	6
5 Nominal Powder Flame Feedstock Spray Rates and Coverage	6
6 Blasting Media and Mesh Size Recommended for TSCs on Steel Substrates	7
7 Sealer, Intermediate, and/or Topcoat Specification	8
8 Flame- and Arc-Spray Standoff Distances and Spray-Pass Widths (Nominal)	13
9 Maintenance and Repair (M&R) Actions for TSCs	16
B1 Estimated Service Life of Aluminum and 90/10 Aluminum MMC TSCs	23
B2 Estimated Service Life of Zinc and 85/15 Zn TSCs	24
C1 Tensile-Bond Qualification Requirements for Thermal Spray Operators	28
C2 Typical Tensile-Bond Values in Laboratory and Production Spraying	29

List of QC Check Points

1 Oil and Grease Contamination	10
2 Masking	11
3 Clean Dry Air	11
4 Clean Blasting Media	11
5 Near-White Metal Finish and Anchor-Tooth Profile	12
6 Thermal Spray Equipment Set-Up	13
7 TSC Application	15
8 Seal Coat Thickness	15
9 Intermediate and Top-Coat Thickness	16

List of Figures

Figure	
1 TSC Thickness for Greater Than The Specified Profile Depth	14
B1 Estimated Service Life of Al and Al MMC TSCs	25
B2 Estimated Service Life of Zn and 85/15 Zn/Al TSCs	25
C1 TSC Bend Test: Pass and Fail Examples	28

Acronyms and Conversion Factors Used in This Publication

AWWA	American Water Works Association
Al	aluminum
ANSI	American National Standards Institute
AW	arc wire
AWS	American Welding Society
DFT	dry film thickness
FP	flame powder
JCR	Job Control Record
m	meter = 39.4 inches
M&R	maintenance and repair
MMC	metal matrix composite
NACE	National Association of Corrosion Engineers
QC	quality control
SSPC	Steel Structures Painting Council
TSB	thermal spray boundary
TSC	thermal spray coating
TSCC	thermal spray coating contractor
WFT	wet film thickness
Zn	zinc
85/15	alloy of 85 weight% zinc and 15 weight% aluminum
90/10	metal matrix composite of 90 vol% Al and 10 vol% alumina
μm	micron or micrometer = 10^{-6} meter

Length

1 in.	= 25.4 mm
0.001 in.	= 25.4 microns (μm) $\approx 25 \mu\text{m}$
1/16 in.	= 0.0625 in. = 1.5875 mm ≈ 1.6 mm
3/32 in.	= 0.09375 in. = 2.38125 mm ≈ 2.4 mm
1/8 in.	= 0.125 in. = 3.175 mm ≈ 3.2 mm
3/16 in.	= 0.1875 in. = 4.7625 mm ≈ 4.7 mm
1 μm	= 10^{-6} meter = 0.0394×10^{-3} in.
1 mm	= 0.0394 in. = 39.4×10^{-3} in.

Thermal Spraying

Parameter	To Convert From	To	Multiply By
Spray Rate	lb/hr	kg/hr	0.454
	kg/hr	lb/hr	2.20
Area Coverage	$\text{ft}^2/\text{hr}/0.001 \text{ in.}$	$\text{m}^2/\text{hr}/100 \mu\text{m}$	0.236
	$\text{m}^2/\text{hr}/100 \mu\text{m}$	$\text{ft}^2/\text{hr}/0.001 \text{ in.}$	4.24

Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites

1. General

1.1 Scope. This guide covers the application of thermal spray coatings (TSC) for the protection of steel with aluminum, zinc and their alloys, mixtures, and composites. This scope of this guide includes the major elements of an industrial process instruction covering job description, safety, consumable materials, surface-preparation and thermal spray equipment, quality control (QC) equipment, TSC operator training and qualification, a step-by-step surface preparation and thermal spraying application method with quality control checkpoints, maintenance and repair of thermal spray coatings, and a job control record. Nominal TSC feedstock spray rates and coverage information for a common planning base are presented for purchasers and contractors. A TSC selection guide for various service environments and the operator qualification requirements are presented in appendices. This guide is modelled on the thermal spray method of MIL-STD-2138A(SH), *Metal Sprayed Coating Systems for Corrosion Protection Aboard Naval Ships*.¹

1.2 Definitions. The following define abrasive blast cleaning methods for various surface finishes.

Abrasive Blast Cleaning:

NACE No. 1: White-Metal Blast-Cleaned Surface Finish. Defined as a grey-white (uniform metallic) color, slightly roughened to form a suitable pattern for coatings. This surface is free of all oil, grease, dirt, mill scale,

rust, corrosion products, oxides, paint, and other foreign matter. (NACE No. 1 is comparable to SSPC-SP 5, *White Metal Blast Cleaning*.)²

SSPC-SP 5: White-Metal Blast Cleaning. These blast-cleaned surfaces must have a uniform, grey-white metallic color and must be free of all oil, grease, dirt, mill scale, rust, corrosion products, oxides, old paint, stains, streaks, or any other foreign matter.³

NACE No. 2: Near-White Blast Finish. This is defined as a surface from which all oil, grease, dirt, rust scale, and foreign matter have been completely removed except for slight shadows, streaks, or discolorations (of oxides bonded with metal). At least 95% of any given surface area has the appearance of NACE No. 1, and the remainder of the area is limited to slight discolorations. (NACE No. 2 is comparable to SSPC-SP 10 *Near-White-Metal Blast Cleaning*.)

SSPC-SP 10: Near-White-Metal Blast Cleaning. A near-white metal blast-cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter, except for staining as noted. Staining shall be limited to no more than 5% of each square inch of surface area and may consist of light

1. Military specifications are available from Standardization Order Desk, 700 Robbins Avenue, Building #4, Section D, Philadelphia, PA 19111-5094.

2. *Visual Standard for Surfaces of New Steel Centrifugally Blast Cleaned with Steel Grit and Shot*, TM0175-75. Available from National Association of Corrosion Engineers, 1440 South Creek Drive, P.O. Box 218340, Houston, TX 77084.

3. *Steel Structures Painting Manual*, Volume 2. Available from Steel Structures Painting Council (SSPC), 4400 Fifth Avenue, Pittsburgh, PA 15213-2683.

shadows, slight streaks, or minor discolorations caused by stains of mill scale or stains of previously applied paint.

2. Safety

2.1 General. The basic precautions for thermal spraying are essentially the same as for welding and cutting. Consult Chapter 11 (Safety), AWS *Thermal Spraying: Practice, Theory, and Application*⁴; ANSI/ASC Z49.1, *Safety in Welding and Cutting*⁴, and NFPA 58, *Standard for the Storage and Handling of Liquefied Petroleum Gases*.⁵ Read and follow safety precautions in the manufacturer's *Material Safety Data Sheet* for specific feed-stock materials used.

Airborne metal dusts, finely divided solids, or accumulations should be treated as explosives. Adequate ventilation in the thermal spray work area and collection of the overspray should be made to minimize the danger of dust explosions and fires. In shop environments, wet-bag, and filter-cartridge collectors may be used to collect the fine overspray particles, thus minimizing the explosion and fire hazard and release of controlled and hazardous materials. Bag- and filter-cartridge-collector units should be at least 15 m (50 ft) removed from the spraying area to preclude ignition from the flame or heat of thermal spray guns.

Field work may require partial or complete containment of the work site for surface preparation and thermal spraying and the collection and safe disposal of the used blasting media and thermal spray overspray. Follow the industrial safety and environmental compliance requirements cited in 3.1 and section 13. Consult local community (city, county, and state) and Federal air quality and hazardous materials control agencies for amplifying information as required.

The extremely hot conditions of thermal spray operations require additional precautions such as not pointing the thermal spray gun at any person or at any combustible or explosive material. Paper, wood, oily rags, cleaning solvents, sealers, and paints should be stored away from the thermal spraying area.

Good housekeeping in the shop and field work areas should always be maintained to avoid accumulation of metal dusts, with particular attention given to inspecting for dust on beams, rafters, tops of booths, and in floor cracks.

4. Available from American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, FL 33135.

5. Available from National Fire Protection Association (NFPA), Batterymarch Park, Quincy, MA 02269.

2.2 Thermal Spray Powder. The following are basic safety principles for handling aluminum and zinc powders:

(1) Read and follow the manufacturer's instructions on the Materials Safety Data Sheet.

(2) Avoid any condition that will suspend or float particles in the air creating a dust cloud.

(3) Avoid actions that generate static electricity, create sparks or otherwise result in reaching the ignition energy or temperature. This includes NO SMOKING.

(4) Take actions to minimize and dissipate the generation of static electricity, such as bonding and grounding, to avoid spark discharge.

(5) Take steps to limit the size of a fire or explosion and to hold any resulting damage to the very minimum, i.e., store aluminum and zinc powder containers separately and away from flammable materials and oxidizing agents such as sulphur and nitrates. Zinc dust forms an explosive mixture with dry and moist air.

(6) Do not use water to extinguish aluminum or zinc fires. Use dry sand or a Class D extinguisher.

SAFETY PRECAUTION: Uncontrolled aluminum and zinc powder are a combustion and explosion hazard (from suspended fine aluminum or zinc dust). Thermal spray aluminum and zinc powders, nominally 40–110 μm (0.0016–0.0044 in.) diameter, are not a combustion or explosive hazard when handled and used in accordance with powder manufacturer's instructions.

Note: Safety and Procedure Precautions are cited in double-lined boxes. QC Check Points are cited in single-lined boxes.

Recommendations for Storage and Handling of Aluminum Powder and Paste gives the Aluminum Association's recommendations for the storage and handling of aluminum powder.⁶

3. Job and Contract Description

3.1 General. Describe the overall job and cite all the major thermal spray job or contract requirements referencing the sections and paragraphs in the body of the job or contract as applicable. Cite job-site access, job permits, industrial safety and environmental compliance requirements as appropriate.

3.2 Thermal Spray Boundary (TSB). The perimeter of the area of the workpiece or structure to be thermal

6. *Recommendations for Storage and Handling of Aluminum Powder and Paste*, TR-2, SGE/5M/12-86/4A. Available from the Aluminum Association, Inc., 818 Connecticut Avenue NW, Washington, DC 20006.

sprayed should be defined as the *Thermal Spray Boundary (TSB)*. Particular attention must be placed on properly ending the TSC in the TSB and feathering it into the uncoated area. The TSB should end 5–8 cm (2–3 in.) beyond the toe of the proposed weld joint feathering to zero thickness in the next 3–5 cm (1 to 2 in.) and should be wrapped around contoured corners whenever possible.

3.3 Job Control Record (JCR). Annex A presents a JCR that covers the essential job information and the QC check points in six areas: the TSC Contractor (TSCC); the purchaser's invoice; TSC type and requirements; TSC operator qualification; blasting and thermal spray equipment; and the nine QC check points of the application-process method of this guide (see section 8). Page 1 of the JCR summarizes the purchaser's requirements and the planning information. Page 2 summarizes the production QC checkpoints.

3.4 Selection of TSC. TSCs are used for long-term, generally greater than 20 years, protection of steel in atmospheric and corrosive environments. Annex B presents the recommendations for selection of TSCs and TSC thickness for several environments and service life. This information is based on the coating specifications of the British Standards Institution⁷ and the Canadian Standards Association⁸ including the literature AWS 19-Year Report and the LaQue Center for Corrosion Technology 34-year marine-exposure inspection reports.

3.5 TSC Inspector. The TSC inspector is a person who is knowledgeable of the concepts and principles of, and skilled in observing and measuring conformance to, this guide. The TSC inspector, at a minimum, should meet the knowledge and skill requirements of Annex C, Thermal Spray Operator Qualification and Certification, or as otherwise specified by the purchaser or purchasing contract.

3.6 TSC Operator Qualification. The TSC operator qualification recommendations are presented in Annex C. They are based on ANSI/AWS C2.16-92, *Guide For Thermal Spray Operator Qualification*,⁴ with additions appropriate to the protection of steel with TSCs.

7. *Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion*, British Standards Institution B.S. 5493: 1977. Available from American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

8. Canadian Standards Association, CSA Standard G189-1966, *Sprayed Metal Coatings for Atmospheric Corrosion Protection*, Reaffirmed 1980. Available from Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario M9W1R3, Canada.

4. Background and Requirements

4.1 Background. The background for this thermal spray job should be briefly described.

4.2 Requirements. The following should be detailed:

- (1) TSC feedstock material.
- (2) TSC minimum inspection and end-item acceptance criteria for the following:
 - (a) Surface-preparation and thermal spray process qualification to include materials, equipment, and method.
 - (b) Production area and components to include specific inspection and measurement procedures, locations and frequency.

Table 1 summarizes the inspections and tests that can be made during shop and field application of TSCs. Table 2 lists the analytic tests that may be used to further examine and qualify the surface preparation, feedstock material, and thermal spray processes. The purchasing contract should specify the required test's *pass and fail* values.

Page 1 of the Job Control Record (Annex A) summarizes the job requirements, TSC operator qualifications, and the materials and equipment to be used. Page 2 of the JCR lists the nine QC Check Points for performing the job.

The TSCC's quality assurance program, JCR, and QC check points equivalent to this guide may be used if mutually agreed to by the purchaser and the TSCC.

(3) TSC work requirements including industrial process, what is to be sprayed (and not sprayed), spray material(s) and thickness, QC steps, end-item acceptance inspection, and the Job Control Record (JCR).

(4) TSC inspector qualification, designation, and authority on behalf of the purchaser.

(5) TSC operator qualification.

(6) Schedule (thermal spray job start, duration, key events, and completion).

(7) Concurrent work that may or will be on-going during the thermal spray work on the job site that may cause mutual interference. Cite the procedural and remedial actions to be taken should interference occur. File *Delay and Disruption* reports as required.

(8) Job site work permits; access permits; work regulations and procedures; safety requirements, equipment, and procedures; and JCR.

(9) Containment and disposal of waste and debris generated by the paint removal and surface preparation.⁹

(10) Applicable Federal, State, County, City, or union regulations.

9. The Steel Structures Painting Council maintains and publishes information on these issues. See *SSPC Guide 61(CON), Guide for Containing Debris Generated During Paint Removal Operations and SSPC Guide 71(DIS) Guide for the Disposal of Lead-Contaminated Surface Preparation Debris*, SSPC 92-07.

Table 1
Inspection and Acceptance Tests — Shop and Field

Test	Surface Preparation	TSC	Sealer/Topcoat
Visual	Finish per SSPC SP 10	Smooth & uniform. No blisters, cracks, loose particles, or exposed steel.	Smooth & uniform. No runs, sags, lifting, pinholes, or overspray.
Anchor-Tooth Depth	50–100 μm (0.002–0.004 in.)	Not applicable	Not applicable
Coating Thickness (average & $\pm$ value)	Not applicable	____ $\pm$ ____ μm (____ $\pm$ ____ in.)	____ $\pm$ ____ μm (____ $\pm$ ____ in.)
Coating Tensile-Bond (average & $\pm$ value)	Not applicable	____ $\pm$ ____ MPa (____ $\pm$ ____ psi) measured with portable adhesion tester.	Not applicable
Bend (mandrel diameter = ____ μm [____ in.])	Macro system test for • Surface preparation	• TSC application	Not applicable
Companion Coupon	Surface preparation	Metallograph & tensile bond	Thickness
Knife-Peel	Not applicable	No peeling or delamination	Not applicable
Other as specified by the Purchaser			

Table 2
TSC Inspection and Acceptance Tests — Laboratory

Property	Test
Tensile Bond (minimum values)	ASTM C 633: ____ Mpa (____ psi)
Porosity & TSC Morphology (maximum values)	Metallographic: ____ x magnification, ____ % porosity and ____ % unmelts
Substrate-TSC Interface Contamination	Metallographic: ____ x magnification & $\leq$ ____ % contamination

(11) Other information and requirements that are required for planning and completion of the thermal spray job or contract.

5. Materials

The TSCC should indicate the materials and procedures to be used for the job unless already specified by the purchaser or the purchasing contract.

5.1 Thermal Spray Wire and Powder. Aluminum, zinc, 85 zinc/15 aluminum (weight %), and 90 aluminum/10 alumina (volume %) metal matrix composite (MMC) are currently used for corrosion protection of steel. Aluminum, zinc and 85 zinc/15 aluminum are available in both powder and wire form. 90 aluminum/10 alumina MMC (90/10 MMC) is currently only available in wire form. Generic thermal spray wire and powder material classification and specifications may be found in MIL-W-6712C, *Wire; Metallizing*, and Table 5.9.4,

Nonferrous Materials, of AWS *Thermal Spraying: Practice, Theory, and Application*, 1985.

5.1.1 Thermal Spray Feedstock. The thermal spray wire and powder feedstock specification and nomenclature that uniquely identifies the feedstock material (e.g., AWS, ASTM, or federal and military specifications) and applicable certification requirements, that will be used on the job should be indicated.

- (1) Feedstock material: _____
- (2) Procurement source: _____
- (3) Certification requirements: _____

5.1.2 Nominal Feedstock Requirements, Area Coverage, and Spray Rates. Table 3A (Table 3B for U.S. Customary Units) gives nominal deposit efficiency and

the thermal spray feedstock material required per unit-area/thickness-unit for representative materials spraying on a flat plate. *Deposit efficiency* is the ratio of sprayed material adhering on a large, flat plate compared to the amount sprayed. Tables 4 and 5 present the nominal spray rates (weight/hr) and area coverage for flame and arc spraying on a flat plate. Additional feedstock will be required for spraying complex geometrical shapes. Specific values vary with such variables as the shop or field job site, thermal spray equipment, spray parameters, process used, and the geometrical shape of the components and structures being sprayed. The data in Tables 3, 4, and 5 are representative data from the spray tables of various equipment manufacturers and are presented for comparative purposes and relative ranking; they are not intended for cost estimating purposes.

Table 3A
Nominal Feedstock Required Per m²/μm (Metric)
(Deposit Efficiency on a Flat Plate)

Feedstock Material	Flame Spray		Arc Spray	
	Deposit Efficiency (%)	Material Required (kg/m ² /μm)	Deposit Efficiency (%)	Material Required (kg/m ² /μm)
Aluminum Wire	80–85	0.0027	70–75	0.0029
Aluminum Powder	85–90	0.0027	NA	NA
Zinc Wire	65–70	0.0098	60–65	0.011
Zinc Powder	85–90	0.0076	NA	NA
85/15 Wire	85–90	0.0070	70–75	0.0093
90/10 MMC Wire	80–85	0.0027	70–75	0.0029

Table 3B
Nominal Feedstock Required Per ft²/0.001-in. (U.S. Customary Units)
(Deposit Efficiency on a Flat Plate)

Feedstock Material	Flame Spray		Arc Spray	
	Deposit Efficiency (%)	Material Required (lbs/ft ² /0.001 in.)	Deposit Efficiency (%)	Material Required (lbs/ft ² /0.001 in.)
Aluminum Wire	80–85	0.0014	70–75	0.017
Aluminum Powder	85–90	0.0014	NA	NA
Zinc Wire	65–70	0.0050	60–65	0.054
Zinc Powder	85–90	0.0039	NA	NA
85/15 Wire	85–90	0.0036	70–75	0.0049
90/10 MMC Wire	80–85	0.0014	70–75	0.0017

Table 4A
Nominal Wire Feedstock Spray Rates and Coverage (Metric)

Feedstock Material	Flame Spray (by Wire Diameter)			Arc Spray
	2.4 mm	3.2 mm	4.8 mm	(per 100 amps)
	Spray Rate, kg/hr			Coverage, m ² /hr/100μm
Aluminum	2.5 (8.73)	5.4 (18.9)	7.3 (25.3)	2.7 (8.26)
Zinc	9.1 (9.44)	20 (21.2)	30 (30.7)	17 (10.2)
85/15 Zn/Al	8.2 (11.8)	18 (26.2)	26 (38.0)	16 (9.68)
90/10 Al MMC	2.5 (8.73)	5.4 (18.9)	7.3 (25.3)	2.7 (8.26)

Table 4B
Nominal Wire Feedstock Spray Rates and Coverage (U.S. Customary Units)

Feedstock Material	Flame Spray (by Wire Diameter)			Arc Spray
	3/32 in.	1/8 in.	3/16 in.	(per 100 amps)
	Spray Rate, lbs/hr			Coverage, ft ² /hr/0.001 in.
Aluminum	5.5 (370)	12 (800)	16 (1070)	6 (350)
Zinc	20 (400)	45 (900)	65 (1300)	23 (430)
85/15 Zn/Al	18 (500)	40 (1110)	58 (1610)	20 (410)
90/10 Al MMC	5.5 (370)	12 (800)	16 (1070)	6 (350)

Table 5
Nominal Powder Flame Feedstock Spray Rates and Coverage

Feedstock Material	Spray Rate kg/hr (lbs/hr)	Coverage m ² /hr/100μm (ft ² /hr/0.001 in.)
Aluminum	6.8 (15)	100 (1100)
Zinc	14 (30)	80 (830)

To estimate the area coverage for a specified TSC material and thickness, take the Table 4 or Table 5 coverage value and divide by the desired TSC thickness. For example, the coverage for spraying a 0.008 in. thick 85/15 Zn/Al TSC with a 400 amp arc spray machine would be (using Table 4B):

$$\text{Coverage} = [410 \text{ ft}^2/\text{hr}/0.001 \text{ in.}]/100 \text{ amps}] \\ \times [400 \text{ amps}] \div (0.008 \text{ in.}) 205 \text{ ft}^2/\text{hr}$$

TSCCs should develop their own shop and field deposit efficiency and production planning factors for their specific equipment and their mode of operation. Past production records should be consulted for *did-cost* information suitable for job cost estimating and cost control.

For planning and cost estimating a specific job, the following should be enumerated preferably using information from past TSC jobs for items 4–7 below:

- (1) Thermal spray process: _____
- (2) Material form (wire or powder): _____
- (3) Finish thickness, μm (0.001 in.): _____
- (4) Weight/unit area for the finish thickness, kg/m² (lbs/ft²): _____
- (5) Coverage, m²/hr/μm (ft²/hr/0.001 in.): _____
- (6) Spray efficiency (%): _____
- (7) Spray coverage for finish thickness m²/hr/μm (ft²/hr/____ in.): _____

5.2 Abrasive Blasting Media. Blasting equipment, media, and mesh size appropriate to meeting the surface finish and the anchor-tooth profile requirements of the purchaser or purchasing contract should be used.

Table 6 lists the blasting media which have been found suitable for the final anchor-tooth surface preparation for the various thermal spray materials and thermal spray processes.

Table 6
Blasting Media and Mesh Size Recommended for TSCs on Steel Substrates

Thermal Spray Material	Process	Blasting Media ^a	Size ^b
Al, Zn, 85/15, 90/10 MMC	1. Flame Wire	1. • Aluminum oxide • Angular steel grit	1. 10–30 Mesh • G-16 to G-24
Al, Zn, 85/15, 90/10 MMC	2. Arc Wire	2. Same as 1 above plus • Copper & nickel slag	• G016 to G-24
Al, Zn	3. Flame Powder	3. Same as 1 above	

Notes:

- a. All blasting media shall be dry and free of all oil/grease, fines, and materials not allowable in the blasting media material specification.
b. Select mesh size appropriate to the anchor-tooth depth requirement and the blasting equipment used.

To minimize the cost of surface preparation:

(1) Use less expensive blasting media such as garnet, flint, mineral sand, and mineral slag to initially clean and profile the steel to near the purchaser's surface preparation requirement. This initial blast cleaning, often called *rough* or *strip blasting*, is used to remove paint, scale, or rust from corroded and pitted steel to near-white finish and to near the specified anchor-tooth depth using a low-cost blasting or recycled blasting media. *Note: If the blasting media is being recycled, remove oil, grease, chemical, or salt contamination from the steel before blast cleaning.*

(2) Use Table 6 blasting media to remove strip blasting media and to complete the final anchor-tooth blasting to a minimum near-white metal finish and the specified anchor-tooth depth.

5.2.1 Rough or Strip Blasting. Specify the surface preparation method (e.g., pressure-pot or mechanical blasting machine) to be used and the blasting material and mesh size to be used.

(1) Blasting machine (pressure-pot or centrifugal): _____

(2) Blasting media and mesh size/range: _____

Note: The cost of surface preparation, especially for field work where it is difficult to collect and recycle the blasting media, may be reduced by strip blasting with less expensive media (e.g., garnet, flint, mineral sand, and mineral slag) followed by anchor-tooth blasting with the Table 6 media. These strip blasting media, however, must be free of oil, grease or other materials that could contaminate the substrate and must be free of fines to maintain good cleaning and cutting ability.¹⁰

10. For further information see the *Steel Structures Painting Manual*, Vol I and II, and the *Abrasive Blasting Handbook/Update '91* available from A. B. Williams Enterprises Inc., P.O. Box 1728, Woodstock, GA 30188-1728.

5.2.2 Anchor-Tooth Blasting. The recommended anchor-tooth blasting media for the various thermal spray processes and materials are given in Table 6. For the job specify the following:

(1) Blasting machine (pressure-pot or centrifugal): _____

(2) Blasting media and mesh size/range: _____

(3) The suitability of the anchor-tooth surface preparation method (equipment, media, procedure, and QC checkpoints) on new or aged steel comparable to that of the job should be qualified by bend test (C6.1) or the knife-peel test (C6.3) or both. Tensile bond and metallographic analysis may also be used for a more comprehensive analysis of the anchor-tooth surface preparation method or as otherwise specified by the purchaser or purchasing contract.

(4) One set of blasting equipment (mechanical blasting cabinet and media, pressure pot and hoses) should be dedicated to final anchor-tooth surface preparation to prevent substrate contamination.

5.3 Sealer and Intermediate Topcoat

5.3.1 Discussion. TSC sealers are low-viscosity, clear or colored (pigmented) paints, lacquers, and vinyls formulated to flow over and be absorbed into the natural pores of the TSC. The pigment particle size for colored sealers must be small enough to flow easily into the pores of the TSC, nominally a 5-fineness grind per ASTM D 1210, *Test Method for Fineness of Dispersion of Pigment-Vehicle Systems*.¹¹ The sealer improves the appearance and reduces the retention of dirt and the contamination of the TSC. Sealed TSCs have a longer service life, are easier to clean and maintain, and do not degrade

11. ASTM specifications are available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

cathodic protection. Sealers must be chemically compatible with the TSC material, the service environment, and the intermediate/topcoat paint. The sealers may need to be suitably thinned to effectively penetrate the TSC. Sealed TSCs are preferable to painted TSCs.

Intermediate/topcoat coatings may be applied as necessary to meet the paint-color function and aesthetic requirements. Appropriate intermediate/topcoat paints have a longer service life on TSCs than on bare steel, and rusting and pitting are materially reduced. Intermediate/topcoats do not provide longevity to the TSC protection of the steel. Excessively thick intermediate/topcoats will retain moisture and contaminants, thus shortening the service life of the TSC.

Sealer and intermediate/topcoat paints should be defined by the service environment and the maintenance cycle. They should be specified by the purchaser or purchasing contract.

Description and specification of sealer and intermediate/topcoat paints may be found in the Steel Structures Painting Council's *Steel Structures Painting Manual*, Volume 2, and Table 4C, Part 2, Product Section CP, Pretreatment and sealers for sprayed-metal coatings, of *BS 5493:1977, Code for practice for Protective Coating of Iron and Steel Structures Against Corrosion*.

Epoxy polyamide (suitably thinned), organic powder coatings for ambient-temperature sealers, and heat-resistant aluminum paint for high-temperature sealers have been specified and successfully used by the U.S. Navy for aluminum TSCs (MIL-STD-2138A(SH)). The evolving technology of polymer paint and powder, electrostatically or thermal spray applied, requires purchasers and TSCCs, at the time of contract writing, to evaluate those technologies and specify that sealer and topcoating system which best meets their service and life cycle cost requirements compliant with the evolving environmental regulations. Specific sealer and topcoat selections may be ranked and validated with accelerated mechanical and environmental exposure tests simulating the service environment and duty cycles.

5.3.2 Job Specification. In Table 7, the sealer, intermediate, and topcoat product specifications that should

be cited by the purchaser or purchasing contract should be listed. If not cited, or incorrectly cited in the purchasing contract, the TSCC should recommend to the purchaser to use a sealer, intermediate, and topcoat system suitable for the TSC and the intended service.

5.4 Profile Tape for Anchor-Tooth Depth Measurement. The following items can be used for Anchor-Tooth Depth Measurement:

- (1) Surface profile replica tape (0.0015–0.0045 in.) and a spring micrometer to measure the replica tape.
- (2) Needle depth micrometer to measure the *depth of the valleys* in the steel.

5.5 Bend and Companion Coupons. Bend and companion coupons of carbon steel should measure approximately 50mm x 100–200mm x 13mm (2 x 4 to 8 x 0.050 in.) carbon steel. These coupons may also be used for metallographic analysis.

5.6 Tensile-Bond Test Specimens

5.6.1 Laboratory ASTM C 633 Test Specimens. Tensile-bond test specimens should be carbon steel, 2.54 cm (1 in.) in diameter and 2.54 cm (1 in.) in length, threaded per ASTM C 633, *Adhesion or Cohesive Strength of Flame-Sprayed Coatings*.

5.6.2 Field Instrument Test Specimens. Tensile-bond test specimens shall be compatible with the portable tensile-bond testing instrument. *Note: Portable instruments should be calibrated against the ASTM C 633, Adhesion or Cohesive Strength of Flame-Sprayed Coatings, procedure.*¹¹ Portable instruments with large diameter test specimens, e.g., 50 mm vice 25 mm (2 in. vice 1 in.) diameter, produce better statistical results.

5.7 Gases

5.7.1 Oxygen. Oxygen equal or equivalent to *Federal Specification BB-O-925, Oxygen, Technical, Gas and Liquid*¹², should be used for thermal spraying.

12. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Table 7
Sealer, Intermediate, or Topcoat Specification (Specified by the Purchasing Contract)

Paint Type	Sealer	Intermediate	Topcoat
Manufacturer			
Stock #			
Tint or Color Match			
Dry Film Thickness (DFT)			

5.7.2 Acetylene. Acetylene equal or equivalent to *Federal Specification BB-A-106, Acetylene, Technical, Dissolved*, shall be used for thermal spraying. Other fuel gases as specified by the thermal spray gun manufacturer (e.g., methylacetylene-propadiene stabilized [MAPP] or propane may also be used).

6. Equipment for Thermal Spraying

6.1 Thermal Spray Guns. Any flame wire (FW), flame powder (FP), or arc wire (AW) equipment can be used, provided it can perform as follows:

- (1) Spray for 3 minutes without sputtering or shutdown
- (2) "Start and stop spraying" for eight "10-second spray, 5-second off" sequences without fusing or sputtering that could cause discontinuities or "globs" of improperly melted or sprayed metal on the working surface

Note: This proof of equipment quality should be demonstrated with the intended TSC feedstock material during the initial or preliminary trials of the equipment to be used by the TSCC. It is not intended to be used as a daily equipment check.

6.2 Air Compressors. An air compressor with sufficient volume and pressure is necessary to operate the abrasive-blasting equipment and thermal spray equipment.

6.3 Air Dryers. An air dryer is necessary to maintain clean, dry air (in accordance with ASTM D4285, *Method for Indicating Oil or Water in Compressed Air*) for the final anchor-tooth or brush blasting (light blasting to remove the surface oxide on a substrate already profiled to the specified depth) just prior to thermal spraying.

7. Quality Control Equipment

7.1 Surface Preparation. The QC equipment for surface preparation should include the following:

- (1) **Visual Inspection for Metal Finish:** 10x Magnifier or Loop.

- (2) **Blasting Media Contamination:**

(a) Small glass or plastic container (4 oz [100 cc]) with tops for qualitative *oil-contamination test* of the blasting media and the abrasive blasting system.

(b) Clean, white cloth squares (e.g., handkerchief) to collect and qualitatively detect moisture and contamination in the compressed air.

- (3) **For Anchor-Tooth Depth:**

(a) Profile replica tape, 40–110 m (0.0015–0.0045 in.) thickness range for anchor-tooth measurement. The profile tape is an emulsion film of microscopic bubbles on a uniform and incompressible 50 m (0.002 in.) thick

mylar film. The emulsion side of the tape is pressed and rubbed onto the blast-cleaned surface. The peaks of the profile break the bubbles and reach the mylar tape. The removed tape is a *replica* of the anchor-tooth profile.

(b) Spring dial anvil micrometer for measuring the profile tape.

(c) Dial surface profile gage (depth micrometer).

7.2 TSC Application. The quality-control (QC) equipment for thermal spraying should include the following:

(1) **Substrate Temperature:** Contact or infrared pyrometer to measure substrate temperatures.

(2) **Air Temperature, Dew Point, and Humidity:** Psychrometer or an equivalent digital humidity measurement instrument. A psychrometer is an instrument having two similar thermometers with the bulb of one being kept wet so that the cooling that results from evaporation makes it register at a lower temperature than the dry one, the difference being related to humidity.

(3) **TSC Thickness:** Magnetic pull-off or electronic thickness gage with secondary thickness standards.

NOTE: New U.S. paper money, e.g., a dollar bill, is about 100 μ m (0.004 in.) thick.

(4) **TSC Ductility:** 50 mm x 100–200 mm x 13 mm (2 in. x 4–8 in. x 0.050 in.) mild steel for bend coupons and a mandrel diameter suitable for the purchaser's TSC thickness (see C6, Initial TSC Operator Qualification and Certification).

(5) **Bend Coupon, Companion Coupon, and Sample Collection:** Sealable plastic bags to encase bend coupons and other QC samples collected during the job.

8. Application-Process Method

8.1 Surface Preparation. Proper surface preparation is a critical and necessary step for successful thermal spray operations.

8.1.1 Criteria. The steel substrate must be prepared as follows:

(1) Clean to at least a *near-white-metal finish* as defined by SSPC-SP 10. The SSPC-SP 10 cleaning standard is equivalent to the NACE 2 cleaning standard (see 1.2).

(2) Profile adequately with a sharp angular abrasive (not peened with other abrasive shapes), to a 50–100 μ m (0.002–0.004 in.) anchor-tooth profile so as to *mechanically anchor* the TSC. For TSCs greater than 300 μ m (0.012 in.) thick, use a profile depth approximately one-third the TSC thickness. Confirm the suitability of profile depth and TSC thickness with bend test (per C6.2) or tensile test (per ASTM 633), or both.

8.1.2 Procedure. Surface preparation should be accomplished in one abrasive blasting/cleaning operation

whenever possible. Steel substrates require approximately 0.6–0.7 Mpa (80–100 psi) air-blasting pressure. Air pressures and media size should be reduced and adjusted to preclude damage/distortion to thin-gage materials. The blasting time on the workpiece should be adjusted to just clean the surface and cut the required anchor-tooth with minimum loss of metal. Blast angle should be as close to perpendicular as possible but in no case greater than $\pm 45^\circ$ to the work surface. Do not overblast such as to force the peaks back into the valleys. Only angular and clean blasting media of suitable mesh size should be used to cut a 50–100 μm (0.002–0.004 in.) anchor-tooth profile. There must be no debris, no excessive fines, and no contamination such as sodium chloride and hazardous materials in the blasting media.

Angular blasting media (e.g., steel grit, mineral slag, and aluminum oxide) that will *cut an anchor-tooth* (not *peen*) and which leaves only a tightly adherent residue should be used. Clean blasting air and clean blasting media without excessive fines are required. Dedicated blasting equipment is highly recommended for continuous thermal spray production.

8.1.3 Rationale. A white-metal finish is the ideal surface finish for TSCs and is mandatory for many surface engineering applications. However, for corrosion-control applications, especially in the field, a near-white-metal finish should be sufficient considering the following:

(1) A near-white finish requires the same degree of cleanliness as a white-metal finish, but allows for up to 5% staining from the removed mill scale or previously applied paint.

(2) The aluminum and zinc TSCs recommended in this guide will be sealed and will provide anodic protection if damaged.

(3) Actually achieving a white-metal finish for a large and geometrically complex steel structure is impractical.

(4) Specifying a white-metal finish has a high-cost impact.

(5) TSCs applied with the arc-spray process provide higher tensile bond than the flame-powder or flame-wire process.

(6) Industry reports that applications of sealed, arc-sprayed aluminum and zinc TSCs on near-white steel are successful.

For these reasons, it is recommended that the near-white-metal finish be the **minimum** required finish with the white metal finish reserved for critical areas.

Note: Always validate the specific surface preparation and thermal spray equipment and processes on representative steel components or structures. Specific surface preparation and thermal spray processes can be developed and refined by repetitive test and evaluation leading

ing to an acceptable coating structure (thicknesses, density, and surface texture) and tensile bond strength for the intended service.

8.2 New Steel Substrate

8.2.1 Degreasing. The substrate should be degreased as required (e.g., steam cleaned, solvent washed, or detergent washed).

QC Check Point #1 — Oil and Grease Contamination

Inspect for the absence of oil and grease contamination by the following:

1. Visual inspection during removal of oil/grease contamination. Continue degreasing until all visual signs of contamination are removed.

2. Conducting either the qualitative *solvent evaporation test* or the *heat test*.

(a) The *solvent evaporation test* is made by applying several drops or a small splash of a residueless solvent such as trichloromethane, on the areas suspected of oil and grease retention (e.g., pitting and crevice corrosion areas, depressed areas especially those collecting contamination, etc). An *evaporation ring* will form if there is oil or grease contamination.

(b) The *heat test* is made by using a torch to heat the degreased metal to $\approx 110^\circ\text{C}$ (225°F). Residual oil/grease contamination is drawn to the metal surface and is visually apparent.

3. Continue inspection and degreasing (or high-pressure-water blasting or oven- or flame-charring for severe contamination) until the test is passed.

8.2.2 Masking. The following should be masked for protection:

(1) *All fit and function surfaces*

(2) *Overspray-control areas*

(3) *The non-TSC area beyond the TSB as required*

The *fit and function areas* are areas that must be protected from the blast cleaning, thermal spraying, and sealing and topcoating operations. *Overspray-control areas* are areas of complex geometry where you cannot eliminate overspray (see 8.5.2 on planning the thermal spray sequence). The TSB is defined in 3.2.

QC Check Point # 2 — Masking

Visually inspect the following:

1. All *fit and function surfaces* (and those other surfaces and areas specified by the purchaser or purchasing contract not to be thermal sprayed).
 - (a) These surfaces must be protected with covers or masking materials that will keep blasting media and TSCs from damaging or depositing on those surfaces.
 - (b) Ensure that the covers and masking are attached securely and will survive the blasting and thermal spraying operations.
2. For masking on complex geometries (e.g., pipe flanges, intersections of structural beams, and valve manifolds) to eliminate or minimize overspray. Overspray is that TSC applied outside the authorized parameters, primarily the gun-to-substrate standoff distance and spray angle (perpendicular $\pm 45^\circ$).
 - (a) Potential overspray surfaces should be protected with clean, metal masks or clean, removable masking materials to prevent the overspray from depositing on surfaces not already sprayed to the specified thickness.

8.2.3 Blast Equipment. The TSCC should use mechanical (centrifugal wheel) and pressure-pot blast cleaning equipment and procedures. Do not use suction blasting.

8.2.4 Blast Media. The TSCC should specify the abrasive-blasting materials actually used for the job, as allowed by 5.2, in the following table:

	Media	Mesh
Rough/Strip Blasting		
Anchor-Tooth Blasting		

QC Check Point # 3 — Clean, Dry Air

The air used for final anchor-tooth blasting and brush blasting prior to thermal spraying should be clean and dry without moisture and oil. The water and oil content of the compressed air should be qualitatively measured by the ASTM D 4285 *Standard Method for Indicating Oil and Water in Compressed Air*:

1. Slightly open a valve downstream of the filter or dryer. Allow the air to vent with a slight audible flow into an open, dry container for one minute. Any wetting or staining indicates contamination.
2. If moisture or contamination is detected, correct deficiency before going further.
3. Repeat 1 above, but place a clean, white cloth over the valve outlet. Any wetting or staining indicates contamination.

8.2.5 Surface Finish and Profile. A near-white-metal finish should be cleaned by abrasive blasting per SSPC-SP 10 (or NACE 2) definition and to a 50–100 μm (0.002–0.004 in.) profile.

Note: Substrate should be thick enough to preclude damage to the work piece or deformation from the abrasive blasting.

Check Point # 4 — Clean Blasting Media

Prior to the use of the abrasive-blasting media for final anchor-tooth blasting or brush blasting:

1. Visually inspect the blasting media for the absence of contamination and debris using 10x magnification.
2. Inspect for the absence of oil contamination using the following procedure:
 - (a) Fill a small, clean bottle (100–200 ml [4–6 oz]) half-full of abrasive particles.
 - (b) Fill the remainder of the bottle with distilled water.
 - (c) Cap and shake the bottle.
 - (d) Inspect water for oil sheen. If any oil sheen is observed, do not use the blasting media for final anchor-tooth blasting.
 - (e) Clean the blasting equipment, especially the pot and hoses, then replace the blasting media and retest.

QC Check Point # 5 — Near-White-Metal Finish and Anchor-Tooth Profile

1. Visually inspect for near-white-metal finish.*
2. Measure the anchor-tooth profile with *profile tape* or *depth gage micrometer*. Make one measurement every 10–20 m² (100 to 200 ft²) or as otherwise specified by the purchaser or the purchasing contract.
3. If the profile is < 50 μm (0.002 in.), continue blasting to obtain the 50–100 μm (0.002–0.004 in.) profile.
4. If the profile is > 100 μm (0.004 in.), measure and record the boundary of the > 100 μm (0.004 in.) area on the Job Control Record (JCR).
NOTE: The coating requires a minimum of 125–150 μm (0.005–0.006 in.) sprayed over the peaks of the profile.
5. Record information on sketches or drawings as required by the purchasing contract.

*Use one of the following inspection procedures suitable for the abrasive blasting media and method used: (1) SSPC-Vis 1-89, *Visual Standard for Abrasive Blast Cleaned Steel*, (2) NACE TM0170-70, *Visual Comparator for Surfaces of New Steel Air Blast Cleaned with Slag Abrasive*, or (3) NACE TM0175-75, *Visual Comparator for Surfaces of New Steel Centrifugally Cleaned with Steel Grit Abrasive*.

8.3 Contaminated Steel Substrates. Contaminated steel is designated as such by the surface condition (degree of corrosion scale and pitting) and by the type and amount of contaminants imbedded in the surface. It requires more intensive surface preparation than new steel. To produce the minimum required *near-white-metal finish with a 50–100 μm (0.002–0.004 in.) profile*, the surface preparation schedule should be tailored for the specific steel surfaces to be cleaned. High-pressure water cleaning, heat cleaning, chemical washing (followed by water flushing), steam cleaning, and abrasive-blast cleaning, singly and in combination, may be required to clean contaminated steel.

8.3.1 Degreasing. The surface should be degreased as required (e.g., hydroblast, steam clean, solvent wash, or detergent wash).

8.3.2 Masking and Blasting. Masking, blast equipment, blast media, and surface finish and profile are the same as for new steel as given in 8.2. However, after 8.2.5, one should wait 24 hours for rust bloom (i.e., the visual appearance of rust on the blast cleaned surface).

8.3.2.1 No or Light Rust Bloom. If there is no rust or light-rust bloom (light in color and greater than 10% of the surface area), the substrate area that will be thermal sprayed within the next 6 hours should be re-anchor-tooth blasted to SSPC SP-5 finish and a 50–100 μm (0.002–0.004 in.) angular profile.

8.3.2.2 Heavy Rust Bloom. If there is heavy rust bloom (dark brown or black color), other cleaning methods should be continued (e.g., wet-abrasive, high- and ultra-high-pressure water, or thermal charring singly or in combination) to remove the contamination.

8.3.2.3 Thermal Cleaning

SAFETY AND PROCEDURE PRECAUTION: Use this procedure only if there is no danger of an explosion or fire and no degradation of the metal temper. Do not exceed 300°C (575°F) on steel alloys.

(1) Bake-out or burn-off the contamination (the dark brown or black surface areas) in an oven or with a rosebud torch. Keep the substrate temperature between 250–300°C (480–570°F) for the time necessary to bake-out or burn-off the oil and grease contamination.

(2) Anchor-tooth blast the substrate area that will be thermal sprayed within the next 6 hours to a minimum near-white metal finish (SSPC-SP 10 or NACE 2 definition). If an anchor-tooth profile has already been established, brush blast to a minimum near-white metal finish.

(3) Repeat Steps (1) and (2) above as required until the thermal spray job is completed.

8.4 Post-Blasting Substrate Condition and Thermal Spraying Period

8.4.1 Steel Surface Temperature and Cleanliness. The steel surface temperature should be at least 5°C (10°F) above the dew point. The surface cleanliness should conform to SSPC-SP 10 (or NACE 2) finish as a minimum.

8.4.2 Holding Period

8.4.2.1 Time between the completion of the final anchor-tooth blasting (or final brush blasting) and the completion of the thermal spraying should be no greater than six hours for steel substrates. In high humidity and damp environments, shorter holding periods should be used. If rust bloom or a degraded coating appears at any time while spraying, 8.4.2.5 should be strictly observed.

8.4.2.2 In low-humidity environments or in enclosed spaces using industrial dehumidification equipment, it may be possible to retard the oxidation of the steel and *hold the near-white-metal finish* for more than six hours. The TSOC, with the concurrence of the purchaser, can

validate a holding period greater than six hours by determining the acceptable temperature-humidity envelope for the work enclosure by spraying and analyzing bend coupons or tensile bond coupons or both.

8.4.2.3 When specified by the purchasing contract, a flash-coat of TSC equal to or greater than 25 μm (0.001 in.) may be applied within six hours of completing surface preparation to extend the holding period for up to four hours beyond the complete application of the flash coat. The final TSC thickness, however, must be applied within four hours of the completion of the application of the flash coat.

8.4.2.4 For small and movable parts, if more than 15 minutes is expected to elapse between surface preparation and the start of thermal spraying, or if the part is moved to another location, the prepared surface shall be protected from moisture, contamination, and finger/hand marks. Wrapping with clean newsprint-free paper is normally adequate.

8.4.2.5 If rust bloom, blistering, or degraded coating appears at any time during the application of the TSC the following procedure applies:

- (1) Stop spraying.
- (2) Mark off the good sprayed area.
- (3) Call the TSC inspector to observe and evaluate the error, direct remedial action (i.e., remove degraded TSC and re-establish the minimum near-white-metal finish and anchor-tooth profile depth per 9.2.2 and 9.3.4). Record the actions taken to resume the job in the JCR.

8.5 Thermal Spraying

8.5.1 Thermal Spray Equipment Set-Up

8.5.1.1 Thermal spray equipment should be set up, calibrated, and operated per the manufacturer's instructions and technical manuals or the TSCC's spray parameters.

8.5.1.2 Spray parameters should be set for spraying the specified thermal spray material and, at a minimum

be validated with the bend test of Check Point # 6. C6.1 gives the criteria and procedures for the bend test.

8.5.1.3 A copy of the spray parameters used should be attached to the JCR.

QC Check Point # 6 — Thermal Spray Equipment Set-Up

1. Confirm that the equipment parameter settings are in accordance with the equipment manufacturer's technical manuals or the TSCC's revision thereto.
2. Observe the successful surface preparation, spraying the specified TSC thickness in crossing passes, and bend test of at least one bend coupon per C6.1 at the beginning of each work shift. This is a macro or overall systems check.
3. If the bend test fails, identify and fix problem(s) before continuing.
4. Record results, note identification, and retain the bend-test coupons for the JCR.

8.5.2 Plan The Thermal Spraying Sequence

8.5.2.1 Thermal spraying should be started as soon as possible after the final anchor-tooth or brush blasting and completed within six hours for steel substrates subject to the temperature to dew-point and holding-period variations in 8.4.

8.5.2.2 The surface geometry of the item or area to be sprayed should be inspected. Spraying pass or sequence should be planned according to the following:

- (1) Maintain the gun as close to perpendicular as possible and within $\pm 45^\circ$ to the substrate.
- (2) Use the manufacturer's recommended standoff distance for the air cap installed or the TSCC's revisions thereto. See Table 8 for nominal standoff and spray pass width values.

Table 8
Flame- and Arc-Spray Standoff Distances and Spray-Pass Widths (Nominal)

Thermal Spray	Perpendicular Standoff mm (in.)	Spray-Pass Width, mm (in.)	
		Air Cap	
		Regular	Fan
Flame Wire	130–180 (5–7)	20 (0.75)	Not Available
Flame Powder	200–250 (8–10)	50 (2)	75–100 (3–4)
Arc Wire	150–200 (6–8)	40 (1.5)	75–150 (3–6)

8.5.2.3 For complex geometries where overspray cannot be eliminated, an overspray-control area should be established. Clean, metal masks or clean, removable masking materials should be used to prevent the overspray from depositing on surfaces not already sprayed to the specified thickness. The TSB defined in 3.2 should be observed.

8.5.3 Execute Thermal Spraying Sequence

(1) For flame spraying, the initial 0.1–0.2 m² (1–2 ft²) starting-spray area should be preheated to approximately 120°C (250°F) to drive off residual moisture and to reduce the temperature differential between the sprayed metal and the substrate.

(2) Start-up and adjustment of the spray gun should be made off the workpiece (or surface to be thermal sprayed). In an enclosed space, spray onto a *scrap metal sheet*. Do not allow any nonvalidated spray coating on the prepared surface to be thermal sprayed.

(3) The specified coating thickness should be applied in several perpendicular overlapping passes. The coating tensile bond strength is greater when the spray passes are kept thin. Laying down an excessively thick spray pass will decrease the ultimate tensile-bond strength of the total thermal spray coating.

Note 1: For manual spraying, use crossing passes to minimize the thin spots in the coating.

Note 2: For robotic spraying, program overlapping and crossing passes to eliminate thin spots and stay within the coating thickness specification. Validate the automated spraying parameters and spraying program with tensile-bond or metallographic analysis, or both.

Note 3: Use spray gun extensions to reach into recessed spaces and areas.

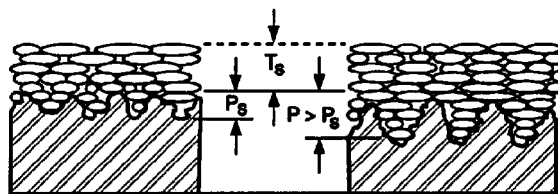
8.5.3.1 If rust bloom, blistering, or a degraded coating appears at any time during the application of the TSC, the following procedure applies:

- (1) Stop spraying.
- (2) Mark off the acceptable sprayed area.
- (3) Call the TSC inspector to observe and evaluate the error, direct remedial action, and record the actions taken to resume the job in the JCR.

8.5.3.2 The total coating thickness should be the thickness specified by the purchaser (T_s) applied over the purchaser's specified anchor-tooth profile (P_s). If the profile is greater than P_s , the TSC thickness over the deeper profiled area should approximately equal T_s over the peaks of the anchor-tooth profile; see Figure 1.

Note: Improved TSC thickness measurements can be made if the thickness gage is calibrated with a calibration wedge (wedge thickness is approximately T_s) over the deeper profiled areas before making applying the TSC.

8.5.3.3 Thermal spraying in low temperature environments must (1) meet the substrate surface temperature and cleanliness requirements of Section 8.4.1, (2) be qualified with a bend test (see Section 6), and (3) if specified by the purchaser, meet the tensile bond and metallographic requirements of Table 1. No moisture condensation on the surface is permissible during thermal spraying.



T_s = SPECIFIED TSC THICKNESS
 P_s = SPECIFIED PROFILE DEPTH
 P = ACTUAL PROFILE DEPTH

Figure 1 — TSC Thickness for Greater Than the Specified Profile Depth

QC Check Point # 7 — TSC Application

1. Measure/confirm substrate surface temperature with contract pyrometer to be $\geq 5^{\circ}\text{C}$ (10°F) above the dew point:
 - (a) Air temperature $\text{ }^{\circ}\text{C}$ ($\text{ }^{\circ}\text{F}$)
 - (b) Relative Humidity (RH) $\text{ }^{\circ}\%$
 - (c) Dew Point $\text{ }^{\circ}\text{C}$ ($\text{ }^{\circ}\text{F}$)
 - (d) Substrate surface temperature $\text{ }^{\circ}\text{C}$ ($\text{ }^{\circ}\text{F}$)
 - (e) {Surface temperature (d)} $\geq$ { 5°C dew point (c)}: (Yes/No) °
 - (f) If Yes $\rightarrow$ Continue.
 - (g) If No $\rightarrow$ **STOP**. Wait for proper conditions and/or adjust the work-area space temperature and humidity conditions so that the steel temperature is 5°C above the dew point.
2. Observe the spraying process as specified in 8.5.3:
 - (a) Preheat to 120°C (250°F) when flame spraying.
 - (b) Proper spray gun adjustment and spraying process (thickness/pass and crossing passes).
 - (c) No rust bloom on prepared steel during spraying.
 - (d) No degraded TSC.
 - (e) Specified TSC thickness. Ensure proper coating thickness in the contour transition areas (see Step 5 below).
4. Measure the total TSC thickness with a minimum of one measurement spot every 10–20 m^2 (100 to 200 ft^2) or as otherwise specified by the purchaser or the purchasing contract. Take the average value of 5 readings taken in one $\approx 10 \text{ cm}^2$ [1.6 in.^2] measurement spot.
5. Measure TSC thickness in *surface plane changes* and attachments (brackets, angles, plates, studs, etc.) welded or permanently attached to the substrate.
6. If too thin, continue spraying to the specified thickness range.
7. If within the contract specified thickness range, go to Step 9.
8. If too thick, perform the knife-peel test per C6.3.
 - (a) If PASS, go to Step 9.
 - (b) If FAIL, remove defective coating and reapply the specified TSC. Log discrepancies and remedial action in the JCR.
9. Record the locations and values of the TSC thickness measurements in the JCR.

8.6 Sealing

8.6.1 Seal coats should be applied as soon as possible after the TSC has been applied and before visible (10x magnification) oxidation of the TSC occurs, generally equal to or greater than 8 hrs for zinc and zinc alloy TSCs and equal to or greater than 24 hours for aluminum and aluminum MMCTSCs. Seal coat(s) shall only be applied to clean dry TSC surfaces in accordance with the specifications of the paint manufacturer or the purchaser or the purchasing contract. Seal coats for components whose operating temperatures are greater than 80°C (175°F) should be a heat-resistant aluminum paint or equivalent seal coat specified by the purchaser or purchasing contract. If moisture is present or suspected in the TSC pores, the steel should be heated to 120°C (250°F) to remove the moisture prior to the seal coat application. When possible, the steel from the reverse side of the TSC should be heated to minimize oxidation and contamination of the TSC prior to sealing.

8.6.2 Seal coat(s) should be applied as specified by the purchaser or purchasing contract:

Paint Type: _____

Mfg & Stock #: _____

No. Seal Coats: _____

Thickness/coat: $\text{ }^{\circ}\mu\text{m}$ (° x 0.001 in.)

Final Dry-Film Thickness: $\text{ }^{\circ}\mu\text{m}$ (° x 0.001 in.)

QC Check Point # 8 — Seal Coat Thickness

1. During application of the seal coat, visually validate complete coverage. Wet or dry film thickness measurements with conventional thickness gages cannot be made on the textured TSC.
2. If required by the contract, use a companion coupon for wet film thickness (WFT) or dry film thickness (DFT) measurements. After the seal coat has "dried to the touch", measure the DFT. Record the DFT readings in the JCR.

8.7 Intermediate and Top Coats. Intermediate and top coat(s) should be applied as specified by the contract:

Paint Type: _____

Mfg & Stock #: _____

No. Seal Coats: _____

Thickness/coat: $\text{ }^{\circ}\mu\text{m}$ (° x 0.001 in.)

Final Dry-Film Thickness: $\text{ }^{\circ}\mu\text{m}$ (° x 0.001 in.)

Note: Using different colors for each component of the paint system (seal, intermediate, and top coat) will help verify complete paint coverage during application and will allow monitoring of the wear or degradation of the paint coating system during service.

QC Check Point #9 — Intermediate and Top-Coat Thickness

1. During application of the intermediate and top coats, visually observe the intermediate and top-coat coverage. Apply more paint as required for complete coverage.
2. WFT and DFT cannot be measured on TSCs. Use a smooth companion coupon if WFT and DFT measurements are required by the purchaser or the purchasing contract.

9. Maintenance and Repair (M&R) of Thermal Spray Coatings

Inspection and maintenance of equipment and structures should be made on a scheduled basis responsive to the operating environments, duty cycle, severity of service, and estimated coating service life before maintenance repair and recoating. This section details the M&R procedures for the TSCs on steel substrates.

Table 9 lists the M&R procedures. These M&R procedures are based on the following:

- (1) The degree of damage and wear as related to exposure of the underlying coating or the substrate steel
- (2) The size of the damaged or worn area ($\leq 0.1 \text{ m}^2$ [1 ft^2] and $> 0.1 \text{ m}^2$ [1 ft^2])
- (3) The selection of specific M&R steps among 11 M&R steps

Note 1: Very simple, temporary coating repairs, such as spray-can degreasing and spray-can painting are occasionally required until the proper long-term repair can be made.

Note 2: Minimize the aesthetic difference between the new- and old-paint area by extending the repair area to be bordered by a weld bead, structural item, or defined geometrical area.

The description of the 11 M&R steps follow.

9.1 Solvent Clean: All oil or grease contamination should be removed by solvent cleaning. Solvents shall not cause detrimental effects on the substrate material and shall not leave any residue film on the substrate. The following cleaning solvents may be used:

Super Hi-Flash Naptha, Type I ASTM D 3734
n-Butyl Alcohol ASTM D 304

Cleaning may be done by wiping, brushing, or spraying. Precautions shall be taken to protect any parts which may be affected by the solvents.

**Table 9
Maintenance and Repair (M&R) Actions for TSCs**

M&R Step	Steel Substrate Not Exposed		Steel Substrate Exposed	
	Area $\leq 0.1 \text{ m}^2$	Area $\geq 0.1 \text{ m}^2$	Paint Repair	TSC Repair
9.1 Solvent Clean	9.1	9.1	9.1	9.1
9.2.1 Flexible-Blade Scrape	9.2.1	↓	↓	↓
9.2.2 Hard-Blade Scrape	↓	↓	9.2.2	9.2.2
9.3.1 Hand-Brush Clean	9.3.1	↓	↓	↓
9.3.2 Abrasive Brush Blast	↓	9.3.2	↓	↓
9.3.3 Power Tool Clean	↓	↓	9.3.3	↓
9.3.4 White-Metal Blast	↓	↓	↓	9.3.4
9.4 Feather 2–3 in. Border	9.4	9.4	9.4	9.4
9.5 Lightly Abrade	9.5	↓	↓	↓
9.6 Apply TSC	↓	↓	↓	9.6
9.7 Seal and Topcoat per 8.6 and 8.7	9.7	9.7	9.7	9.7

SAFETY PRECAUTION: When using solvents, consider and take the following precautions:

1. Vapors are flammable. Keep away from heat, sparks, and open flame!
2. Use only with adequate ventilation. Avoid prolonged breathing of vapor. Eye irritation and dizziness are signs of inadequate ventilation and dangerous concentration of vapors.
3. Avoid prolonged or repeated contact of the liquid with skin.
4. Follow the precautions of the solvent manufacturer's Material Safety Data Sheet and current OSHA Safety and Health Standards, 10 CFR 1910.

9.2 Scrape Off Loosely Adherent Paint/TSCs

9.2.1 Flexible-Blade Scrape To Bonded TSC: A 25 mm (1 in.) flexible-blade paint scraper should be used to remove loose paint and TSC around damaged or worn area until the tightly adherent paint and TSC is reached. Care should be taken not to gouge or further damage the TSC.

9.2.2 Hard-Blade Scrape to Bonded TSC: A hard-blade paint scraper should be used to push the blade underneath the loose TSC and push and scrape away all loosely adherent paint and TSC until reaching a well-bonded TSC area.

9.3 Cleaning, Manual, and Blast

9.3.1 Hand Brush Clean. A stiff hand-held stainless steel or bristle brush should be used to vigorously brush away loose debris. *Power tools should not be used as they will polish the TSC and may wear through the TSC to the substrate.*

9.3.2 Abrasive Brush Blast. Angular iron grit or aluminum oxide grit should be used to abrasive brush blast away loose paint. *Use low blasting pressures to minimize abrasion and removal of TSC but great enough pressure for reasonable paint and loose-TSC removal and the development of sufficient anchor-tooth pattern for sealers and topcoat paints.* Other blasting media may be used if qualified to meet the inspection and acceptance tests of Table 1.

9.3.3 Power-Tool Cleaning. For power-tool cleaning, a hand-held power cleaning tools, e.g., disc sander with 80-mesh abrasive paper and stainless steel rotary brushes should be used, using light pressure to clean and roughen the surface for painting. Do not polish the surface smooth.

9.3.4 Abrasive Blast to Near-White-Metal Finish and 50–100 μm (0.002–0.004 in.) Profile. The surface

should be abrasive (or mechanical) blasted to a near-white-metal finish with a 50–100 μm (0.002–0.004 in.) profile. Note the precautions and the detailed procedures in 8.1. Blasting nozzle should be kept perpendicular $\pm 10^\circ$ to the work surface; angle blasting into the TSC-steel bond-line may separate the bonded TSC from the substrate.

9.4 Feather. A 50–80 mm (2–3 in.) border should be feathered into the undamaged paint and TSC area. Feathering is the operation of tapering off the edge of a coating.

9.5 Light Abrasion. The prepared surface and the feathered area around the exposed TSC should be lightly abraded with sand paper to provide a mechanical bonding surface for the paint primer and sealer.

9.6 Apply TSC. The TSC should be applied as per 8.5. NOTE: Do not apply arc-spray TSC over flame-spray coatings because the greater energy (particle impact velocity and temperature) of arc spraying may delaminate marginal flame sprayed coatings.

9.7 Seal and Topcoat. Seal and topcoat should be applied as per 8.6 and 8.7.

10. Records

The TSCC should use a JCR to record the production and QC information required by the purchaser or the purchasing contract. Additionally, the TSCC should have its own Quality Assurance Program and a JCR to record all pertinent information. Annex A is a recommended JCR which contains entries for the major planning, production, and QC items of this guide.

The TSCC should keep records for a time period consistent with the TSCC's quality assurance and records program and as required for regulatory compliance and the purchasing contract.

11. Debris Containment and Control

The TSCC and the purchaser should coordinate the specific requirements, responsibilities, and actions for the containment, collection, and removal of the debris produced by the TSCC and its subcontractors.

12. Utility Services

The utility services and the time they are required for use by the TSCC should be listed. These may be provided by the purchaser.

13. Work Procedures and Safety

The purchaser shall provide its standard operating and safety procedures and compliance requirements to the TSCC. The TSCC should follow all appropriate procedures and meet all appropriate requirements.

14. Warranty

14.1 Thermal Spray Coating Contractor's Warranty. The TSCC shall warrant the quality of its workman-

ship as mutually agreed to by the purchaser and the TSCC.¹³

14.2 Thermal Spray Coating Materials. The TSCC shall provide the purchaser with a *Certificate of Materials Used*, attaching copies of the manufacturer's and supplier's material certification, attesting that the materials used conform to the purchasing contract.

13. For example, the purchaser providing timely access and support services and the TSCC conforming to the industrial process instruction including QC check points.

Annex A

Sample Job Control Record for Thermal Spray Coatings

(This annex is not a part of ANSI/AWS C2.18-93, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*, but is included for information purposes only.)

See sections 3 and 4 of C2.18-93 for a discussion of the Job Control Record (JCR).

Sample Job Control Record (JCR) for Thermal Spray Coatings (TSC)

1a) Thermal Spray Coating Contractor (TSCC) Name/Address/Phone and FAX numbers:

1b) Job Control or Identification #: _____ 1d) Date: _____
 1c) Point of Contact: _____ 1e) Date: _____

2a) Purchaser's Name/Address/Phone and Fax Numbers:

2b) Purchaser's Invoice #: _____ 2c) Completion Date: _____

2d) Contact Person: _____

2e) Job Description: _____

3a) TSC Type and Requirements:

3b) Thermal Spray Process (FP/FW/AW): _____

Thermal Spray Coating		Sealer		Topcoat	
Material	$\mu\text{m}/0.001 \text{ in.}$	Type	$\mu\text{m}/0.001 \text{ in.}$	Type	$\mu\text{m}/0.001 \text{ in.}$

3c) Safety Precautions: _____

3d) Surface Preparation Requirements: (near-white-metal finish with 50-100 μm (0.002-0.004 in.) angular profile): _____

3e) Substrate Material/Condition: _____

3f) Precautions for the Workpiece/Area: _____

3g) Quality Control (QC) Requirements (include TSC thickness measurement frequency/locations on workpieces): _____

3h) Other: _____

4a) Thermal Spray Operator Name/Employee Number: _____

4b) Date Qualified to AWS C2.18 TSC: _____ Spray Process _____ Feedstock: _____

4c) Qualification Tensile Bonds: Average Among 5 = _____ MPa; Minimum = _____ MPa

5a) Mfg/Model/Type Abrasive Blasting Equipment Used: _____

5b) Blast Cleaning Equipment and Media Used: _____

5c) Anchor-tooth Blasting Equipment and Media Used: _____

5d) Degreasing Method and Materials: _____

5e) Masking Materials Used: _____

5f) Thermal Spray Equipment Used: Type (flame or arc): _____; Manufacturer: _____; Model: _____

5g) TSC Material: _____

5h) TSC Material Certification: _____

Sample Job Control Record (JCR) for Thermal Spray Coatings (TSC) (continued)

6) Quality-Control (QC) Check Points Made During Production (See Section 8 of C2.18-93)

QC CP#	Action	Value Req'd	Value Measured	Pass/Fail	Time Made	Inspector Initials
1	Oil & Grease Contamination per solvent-evaporation or heat test. Circle test used.	None				
2	Masking on all a. Fit & function areas.	All				
3	b. Overspray-control areas. Clean Dry Air: a. Vent air into dry container for 1 minute. b. Vent air through clean white cloth for 1 minute.	All None None				
4	Clean Blasting Media: a. Visual inspect media for contamination. b. Oil contamination test with distilled water.	None None				
5	Near-White Metal Finish & Anchor-Tooth Profile: a. Visual inspect for near-white metal finish. b. Measure profile (per JCR 3d): • If < 50 μm , keep blasting. • If > 100 μm , record depth & mark area. c. Follow procedures specified for Contaminated Steel (see 8.3).	SSPC-SP 10 50-100 μm —				
6	Thermal spray Equipment Set-Up: a. Validate parameter settings; attach to JCR. b. Observe surface preparation & bend-coupon test at each shift or crew change. c. Retain coupon with JCR.	Only minor cracking				
7	TSC Application & Thickness (per JCR 3a): a. Masking proper & attached. b. [Metal surface temp.] — [dew point temp.] c. Observe the surface preparation, preheating, & spraying processes for proper procedures. d. Measure & record TSC thickness on drawings or sketches & attach to JCR.	— $\geq 5^{\circ}\text{C}$ — —		NA		
8	Seal Coat (per JCR 3a).			NA		
9	Topcoat (per JCR 3a).			NA		

REMARKS:

TSC Inspector Name (Stamp or Print): _____ Date _____

TSC Sprayer Name (Print): _____ Date _____

Annex B

Recommendations for the Selection of Thermal Spray Coatings of Aluminum and Zinc and Their Alloys and Composites for the Protection of Steel in Various Environments and Service

(This annex is not a part of ANSI/AWS C2.18-93, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*, but is included for information purposes only.)

B1. Service Life versus Environment

Thermal spray coatings (TSCs) are used for the protection of iron and steel in a wide range of corrosive environments. The long-term effectiveness, over 20 years, in rural, industrial, and marine environments is well documented. The corrosion tests carried out by the American Welding Society¹ and the 34-year marine-atmosphere performance report of the LaQue Center for Corrosion Technology² confirm the effectiveness of flame-sprayed aluminum and zinc coatings over a long period of time in a wide range of hostile environments. The British Standards Institution code of practice for the corrosion protection of steel specifies that only TSCs give protection greater than 20 years to first maintenance for the 19 industrial and marine environments considered and that only sealed, sprayed aluminum or zinc gives such pro-

tection in sea water immersion or splash zones.³ The Canadian Standards Association tabulates the life expectancy up to over 40 years for aluminum and zinc TSCs for various exposure environments.⁴

The selection of a TSC depends on the service environment, desired service life, operating duty cycle, and the maintenance and repair support provided during the life cycle. The aluminum TSC and zinc TSC service-life information in Tables B1 and B2 summarize the current information for aluminum and zinc TSCs for various service environments. Figures B1 and B2 shows the average TSC thickness of Tables B1 and B2 respectively. The service-life estimates of the 85/15 Zn/Al and the 90/10 aluminum metal matrix composites (MMC) TSCs introduced, in late 1970s and 1980s respectively, are based on accelerated laboratory tests and service applications through 1992. For the marine environment, pow-

1. *Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report*, American Welding Society C2.14-74. AWS publications available from American Welding Society, P.O. Box 351040, Miami, FL 33135.

2. *Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Sprayed Coatings on Steel*, ASTM STP 947, Kain, R. M. and Baker, E. A. ASTM publications available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

3. *Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion*, British Standards Institution B.S. 5493: 1977. Available from American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

4. *Sprayed Metal Coatings for Atmospheric Corrosion Protection*, Canadian Standards Association CSA Standard G189-1966. Available from Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario M9W1R3, Canada.

der TSC with higher aluminum content exhibits improved corrosion resistance. Where resistance from wear, abrasion, or both, are required in addition to corrosion protection, 90/10-MMC TSCs should be considered.

B2. Attributes of TSCs

Aluminum and zinc and their alloys and composites provide broad atmospheric protection. Aluminum and zinc are anodic to steel and protect the ferrous substrate in electrolytic solutions. When applied in a non-through-porosity thickness, they provide both barrier and cathodic protection. When cut through, exposing the steel, or when applied in a through-porosity thickness, these TSCs provide cathodic protection to the steel. Aluminum corrodes less rapidly than zinc in highly acidic conditions while zinc performs better in alkaline conditions. Aluminum TSCs have greater wear and abrasion resistance than zinc TSCs.

Porosity is an inherent feature of TSCs. When applied at *non-through porosity thickness* (nominally about 175 μm [0.007 in.] for oxyacetylene sprayed aluminum and 90/10 MMC), these TSCs will protect the substrate

steel. When applied at *less than the non-through porosity thickness*, the TSC will retard substrate corrosion because of galvanic protection, eventually being consumed. The porosity of the TSC is a function of the feedstock material, the application method, and the spraying parameters. Oxyfuel flame spraying and small diameter wire (1.6 and 2.3 mm [0.06 and 0.09 in.]), low-current (100–200 amps) arc spraying produce the denser (lower porosity) TSCs.

When zinc is alloyed with aluminum, the zinc-rich spray material forms an effective corrosion-resistant coating, having the attributes of both elemental components. Zinc's greater electrochemical activity provides greater cathodic protection than aluminum. Aluminum, with its lower electrochemical activity and a loosely adherent aluminum-oxide film (as compared to the tightly adherent stainless-steel-oxide film) provides long-term protection at the non-through porosity thickness and improved wear and abrasion resistance as compared to zinc TSCs.

Zinc melts at 420°C (780°F), aluminum at 660°C (1220°F). Aluminum and aluminum MMC TSCs can be used in service up to about 550°C (1000°F), zinc and zinc alloy TSCs, 320°C (600°F). Aluminum and alumi-

Table B1
Estimated Service Life of Aluminum and 90/10 Aluminum MMC TSCs
(Identical values except for exposure to wear, abrasion, & impact)

Type of Exposure	Coating Thickness Required for Indicated Service Life			
	5–10 yrs	10–20 yrs	20–40 yrs	> 40 yrs
Rural Atmosphere	—	—	50–200 μm (0.006–0.008 in.)	—
Industrial Atmosphere	—	150–200 μm (0.006–0.008 in.)	250–300 μm (0.010–0.012 in.)	300–375 μm (0.012–0.015 in.)
Marine Atmosphere	150–200 μm (0.006–0.008 in.)	200–250 μm (0.008–0.010 in.)	250–300 μm (0.010–0.012 in.)	300–375 μm (0.012–0.015 in.)
Fresh Water Atmosphere	150–200 μm (0.006–0.008 in.)	200–250 μm (0.008–0.010 in.)	250–300 μm (0.010–0.012 in.)	—
Salt Water Immersion	200–250 μm (0.008–0.010 in.)	250–300 μm (0.010–0.012 in.)	300–350 μm (0.012–0.014 in.)	—
High Temperature >300°–600°C (600°–1100°F)	200–250 μm (0.008–0.010 in.)	250–300 μm (0.008–0.010 in.)	—	—
Wear, Abrasion, and Impact* (90/10 MMC recommended)	200–250 μm (0.008–0.010 in.)	250–300 μm (0.010–0.012 in.)	—	—

*Service life varies with severity of service.

Table B2
Estimated Service Life of Zn and 85/15 Zn/Al TSCs

Type of Exposure	Coating Thickness Required for Indicated Service Life			
	5–10 yrs	10–20 yrs	20–40 yrs	> 40 yrs
Rural Atmosphere	—	75–125 μm (0.003–0.005 in)	150–200 μm (0.006–0.008 in)	250–300 μm (0.010–0.012 in)
Industrial Atmosphere	—	150–200 μm (0.006–0.008 in)	300–375 μm (0.012–0.015 in)	350–400 μm (0.014–0.016 in)
Marine Atmosphere	—	250–300 μm (0.010–0.012 in)	300–375 μm (0.012–0.015 in)	350–400 μm (0.014–0.016 in)
Fresh Water Atmosphere	150–200 μm (0.006–0.008 in)	250–300 μm (0.010–0.012 in)	300–375 μm (0.012–0.015 in)	—
Potable Water*	—	190–250 μm	(0.075–0.010 in)	—
Salt Water Immersion	250–300 μm (0.010–0.012 in)	350–400 μm (0.014–0.016 in)	—	—

*Zinc only per ANSI/AWWA D102, *Painting Water Storage Tanks*.

num MMC on a 60Ni16CrFe base TSC, sealed with an asphalt based sealer (25% aluminum flake + 75% bituminous coal tar with suitable solvent), can provide service up to 1150°C (2100°F).

Aluminum composite TSCs are used when wear and abrasion resistance are required over that provided by aluminum and zinc TSCs.

SAFETY PRECAUTION: Thermite Sparking — Thermite sparking is caused by the reaction of rusted steel and aluminum (in the form of a finely divided smear) which combine to produce a combustible mix, subsequently ignited by some impacted energy. Aluminum smears may be generated on rusting steel by striking or dragging steel components and tools over bare aluminum surfaces or vice versa. Bare aluminum and bare aluminum TSCs should be avoided whenever there is a thermite sparking hazard. Avoid situations where bare aluminum or bare aluminum TSCs and rusted steel in a combustion or explosion source can occur on a regular basis. There appears to be little, if any, risk of thermite sparking as a result of the impact of rusty steel on to a sealed or painted aluminum, aluminum alloy, or aluminum composite TSC surfaces, unless the sealer or paint is heated to 150°C (300°F) or contains a cellulose nitrate base.

The application of TSCs emits no volatile organic compounds, needs no drying time, and can be applied in low- and high-temperature environments. The natural

surface texture of TSCs also provide an excellent base for sealers and powder coatings. TSCs should normally be sealed except for service intended to expose the metal as anodes for cathodic protection. The sealer fills the pores of the TSC, smooths the sprayed surface, and improves the appearance and service life of the TSC. Sealers also simplify maintenance (which is generally only the reapplication of the sealer). Sealers should be applied immediately after applying the TSC.

Sealed TSCs are preferable to painted TSCs. Paints usually have a longer life on sealed TSCs than on bare steel, and rusting and pitting of the steel is reduced or prevented. Sealed TSCs should be painted only when: (1) the environment is very acidic or very alkaline, i.e., when pH is outside the range of 5 to 12 for zinc and zinc alloy TSCs or 4 to 9 for aluminum and 90/10 MMC TSCs; (2) the metal is subject to direct attack by specific chemicals; (3) the required decorative finish can be obtained only with paint; and (4) when additional abrasion resistance is required.

B3. Examples

There is a history of corrosion protection by aluminum and zinc TSCs for structural steel work: buildings, bridges, towers, radio and TV antenna masts, steel gantry structures, high power search radar aerials, overhead walkways, railroad overhead line support columns, electrification masts, tower cranes, traffic island posts, and street and bridge railings. On a smaller scale, aluminum

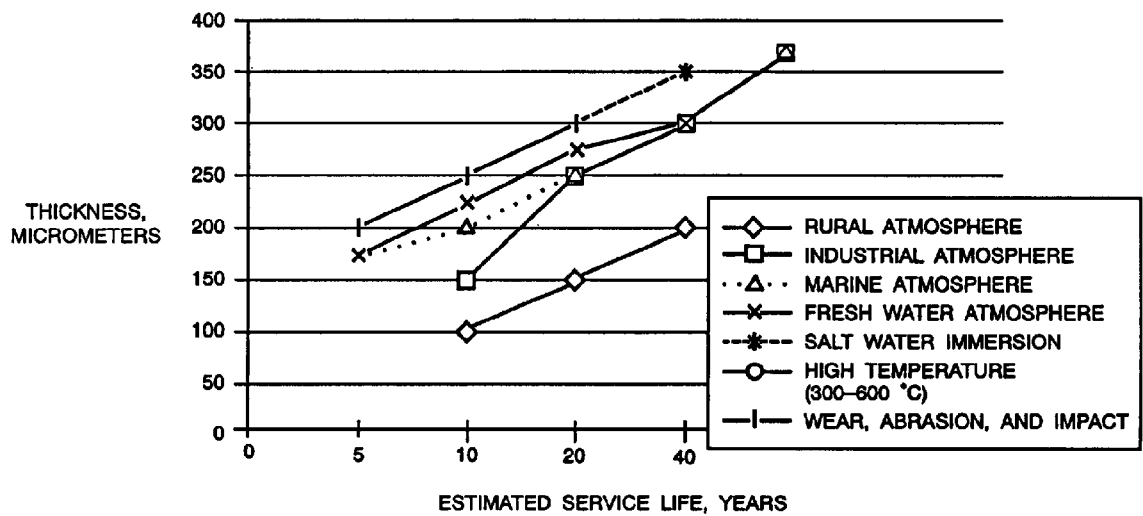


Figure B1—Estimated Service Life for Al and Al MCC TSCs

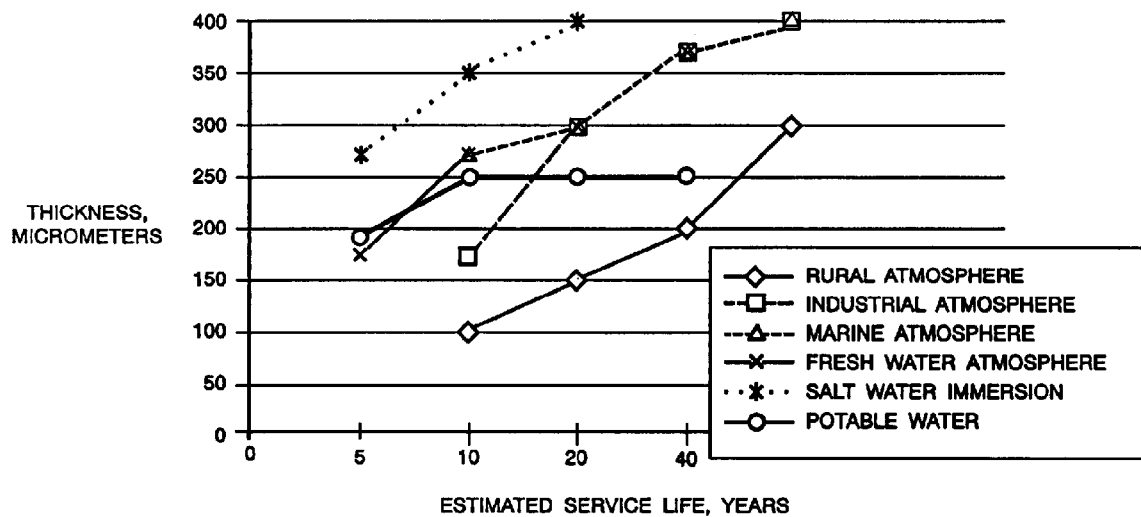


Figure B1—Estimated Service Life for Zn and 85/15 Zn/Al TSCs

and zinc TSCs have been successfully used to protect lawn furniture in corrosive sea coast environments.

Zinc TSCs complement hot-dip galvanizing and should be considered for coating when fabrications are excessively large or otherwise cannot be hot-dip galvanized. Zinc TSC should also be considered for repairing galvanized coating damaged during the fabrication process (e.g., welding, cutting and joining areas) and for maintenance recoating. Here, zinc spray is particularly advantageous because it ensures the uniformity and reproducibility of the galvanized coating thickness.

Wellhead valve assemblies, for offshore use, have been thermal-spray coated for salt atmosphere protection since the 1950s. Aluminum TSCs are used for high-temperature corrosion protection of flare stacks. Aluminum TSCs and zinc TSCs have been used for external protection of oil and propane gas storage tanks. TSCs have been used to protect pipelines against many environments. Pile couplings, valves, manhole covers, industrial gas bottles and other small industrial items are candidates for TSCs.

The interior of steel hopper rail cars for hauling coal have been sprayed with aluminum for sulfuric-acid corrosion protection and with aluminum composite for both corrosion and abrasion protection. Steel car exteriors have been sprayed with zinc for atmospheric-corrosion protection.

Zinc TSCs are used to protect potable water pipelines and storage tanks as specified in ANSI/AWWA D-102-78, *American Water Works Association Standard for Painting Water-Storage Tanks*⁵. Aluminum and zinc TSCs are used on sluice gates in irrigation systems and canal lock gates in shipping canals. These coated components have required virtually no maintenance for decades.

Sealed aluminum and zinc TSCs improve the resistance to corrosion of steel bridgework and railings from marine corrosion and de-icing salts. Reinforcing steel in concrete can be zinc sprayed to retard corrosion. Reinforced concrete bridges and highways, especially in those in marine and freezing environments where de-icing salts are used, commonly suffer from chloride intrusion into the concrete followed by reinforcing steel corrosion and concrete spalling. Zinc TSCs are used for reinforcing steel protection prior to pouring the concrete. Zinc TSCs are sprayed directly on bridge concrete substructures to provide a cathodic protection coating or to be a secondary anode when electrically connected to an impressed current cathodic protection system.

In marine applications, ship structural areas and components are preserved with aluminum and zinc TSCs. The U.S. Navy routinely uses aluminum TSCs in new

ship construction and in the overhaul, repair, and maintenance of ship structures and for a wide range of shipboard components, especially those in topside and wet spaces. The British, Australian, and New Zealand navies use a duplex zinc (base) and aluminum (top) TSC system. Commercial shipping and barges have used TSCs to preserve ship superstructures and a range of topside and interior components.

Sealed TSCs have a longer service life, are easier to clean and maintain, and provide cathodic protection when the substrate is exposed. Sealer paints and powder coatings must be chemically compatible with the TSC material, the service environment and the intermediate/topcoat paint. Sealers must be suitably thinned and have a fine pigment grind to effectively penetrate the TSC. Description and specification of sealer and intermediate/topcoat paints may be found in the *Steel Structures Painting Manual* and British Standard Code for *Practice for Protective Coating of Iron and Steel Structures Against Corrosion*.

The evolving technology of polymer paint and powder, electrostatically or thermal spray applied, requires purchasers and TSCCs at the time of their coating system design and specification, to evaluate these technologies and specify that sealer/topcoat-polymer or polymer-powder system that best meets their service and LCC requirements compliant with the evolving environmental regulations. Specific polymer or organic-powder systems can be ranked and validated with accelerated exposure tests simulating the service environment and duty cycle. The penetrability of the sealer and polymer powder coatings into the TSC can be validated by metallographic analysis.

TSC systems are supplementing and replacing paint coating systems due to the increased awareness of owners, coating engineers, and specifiers of the attributes of TSCs, i.e., the predictable service life, the increased effectiveness over polymer coating systems, and the lower life cycle costs (LCC). The LCC includes the initial installation cost plus the repair and maintenance costs during the service life of the coating system. The installation cost of TSC systems may range up to 1½ times that of high-performance paint systems but the LCCs will be less than ¾ the paint system LCC concomitant with increased system availability. Comparative TSC and painting system LCC may be estimated by using:

(1) Steel Structures Painting Council (SSPC) economic model and data base presented in Chapter 8, *Comparative Painting Costs*, Volume 1, *Steel Structures Painting Manual*, or

(2) British Standard Code for *Practice for Protective Coating of Iron and Steel Structures Against Corrosion*, Appendix E, Choosing the most economical defense against corrosion.

5. Available from American Water Works Association, 6666 W. Quincy Avenue, Denver CO 80235.

Annex C

Thermal Spray Operator Qualification and Certification

(This Annex is not a part of ANSI/AWS C2.18-93, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*, but is included for information purposes only.)

C1. General

The ability to apply quality TSC proficiently depends on a knowledgeable TSC operator using proper thermal spray equipment and materials following an engineered process instruction (surface preparation, masking, thermal spraying, sealing and top coating, and quality control) in a safe manner. The TSC operator should demonstrate the ability to setup, operate, and secure thermal spray equipment to prepare and spray the intended TSC using the intended thermal spray equipment in accordance with the purchaser's process instruction and meeting the purchaser's technical requirements. The TSC operator should also be tested for an ability to inspect and *to accept or reject* proper masking and surface preparation, especially when another subcontractor or crew is doing the surface preparation. TSC operators must be able to recognize unsatisfactory surface preparation and call for corrective action or stop the job.

This Annex summarizes the recommended TSC operator qualification requirements from ANSI/AWS C2.16-92, *Guide for Thermal-Spray Operator Qualification*, with additions regarding application of thermal sprayed aluminum and zinc and their alloys and composites for the protection of steel.

The TSC inspector should certify the operator's qualification ability to meet the knowledge and performance standards of this guide after evaluating and observing C2 through C6. Annex D is the sample thermal spray operator qualification form from ANSI/AWS C2.16 that may be used.

C2. Written Test

The operator should satisfactorily complete a written test covering all the following aspects of the appropriate coating process and application method:

- (1) Surface preparation and masking
- (2) Fixturing and gun movement control
- (3) Setting and maintaining thermal spray parameters
- (4) Sealing
- (5) Quality control, inspection of surface preparation, and TSC acceptance inspection
- (6) Safety

C3. Surface Preparation and Masking

The TSC operator should be tested for knowledge of and application skills of the procedures for surface preparation and masking. The TSC operator should successfully accomplish surface preparation, masking, and thermal spraying the test specimens.

C4. Equipment Setup and Operation

The TSC operator should demonstrate the ability to setup and operate the thermal spray equipment to be used on the job in accordance with this guide and the purchaser's process instructions and meeting the purchaser's technical requirements. This knowledge should not be

limited to normal operation but should sufficiently test skills to recognize when the equipment malfunctions and when and how to take corrective action safely. The Job Control Record (JCR) of Annex A is the recommended form to record the information that may be required by the purchaser.

C5. Application of the TSC

The TSC operator should be qualified for the thermal spray processes and equipment specified in the purchasing contract. Separate qualification is required for flame-powder, flame-wire, and arc-wire spraying processes.

C6. Initial TSC Operator Qualification and Certification

The initial qualification and certification of a TSC operator should include the bend, knife-peel, and tensile-bond tests. The bend test is the ductility test of the TSC and depends on the quality of the surface preparation, application method, applied TSC thickness, and mandrel diameter.

For equal diameter mandrels, thin TSCs pass the bend test better than thick TSCs. Mandrels of 13 mm (0.5 in.) diameter should be used for TSC thicknesses in the range of 170–375 μm (0.007–0.012 in.). Larger and smaller diameter mandrels should be used for thicker and thinner TSCs, respectively. The TSCC should develop specific TSC thickness and mandrel diameter combinations if the 13 mm (0.5 in.) diameter mandrel is not suitable and if the purchaser agrees.

C6.1 Bend Test for TSC Thickness Range 175–350 μm (0.007–0.012 in.). Spray five corrosion-control bend coupons and pass the following bend test:

(1) Use a carbon steel coupons of approximate dimensions 50 mm x 100 mm to 200 mm x 1.25 mm (2 x 4 to 8 x 0.050 in.).

(2) Spray 200–250 μm (0.008–0.010 in.) thick TSC. The TSC should be sprayed in crossing passes laying down approximately 75–100 μm (0.003–0.004 in.) per pass.

(3) Bend coupons 180° around a 13 mm (0.5 in.) diameter mandrel.

Bend test passes if there is no cracking or only minor cracking visually observed on the bend-radius (see Figure C1).

Bend test fails if the coating cracks and can be “picked off” with a knife blade.

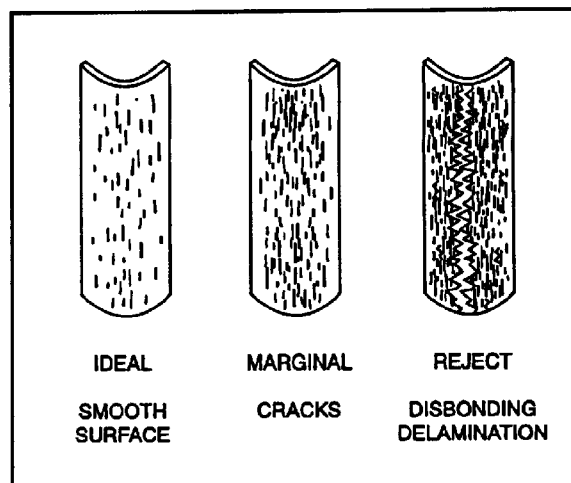


Figure C1 — TSC Bend Test: Pass and Fail Examples

Note: Failure may be caused by improper surface preparation; improper equipment and spraying parameter set-up (e.g., inadequate preheat, gas-flow rates/pressures, wire-feed setting, amperage and voltage settings); improper operator spraying standoff, spray angles, and linear surface speed over the substrate.

C6.2 Tensile-Bond Test. Five tensile-bond test specimens should be sprayed and tested in accordance with ASTM C633. They should pass the tensile bond requirements of Table C1.

NOTE: The ASTM C633 tensile test requires a 375–500 μm (0.015–0.020 in.) coating thickness to prevent the adhesive penetrating to the substrate.

Typical tensile-bond values for laboratory and production spraying operations are given in Table C2.

**Table C1
Tensile-Bond Qualification Requirements
for Thermal Spray Operators**

Spray Material	Average Tensile of Five MPa (psi)	Minimum Tensile MPa (psi)
Aluminum	13.8 (2000)	10.3 (1500)
Zinc	6.90 (1000)	5.52 (800)
85/15	13.8 (2000)	10.3 (1500)
90/10 MMC	13.8 (2000)	10.3 (1500)

Table C2
Typical Tensile-Bond Values in Laboratory
and Production Spraying

Spray Material	Tensile Bond, MPa (psi)	
	Flame Spray	Arc Spray*
Aluminum	19.3 (2800)	34.5 (5000)
Zinc	6.90 (1000)	17.2 (2500)
85/15	24.1 (3500)	34.5 (5000)
90/10 MMC	24.1 (3500)	34.5 (5000)

*Arc spray coatings have a higher tensile-bond strength from the increased deposition energy.

C6.3 Knife-Peel Test. The knife-peel test shall consist of a single knife cut 40 mm (1.5 in.) long through the TSC to the substrate. The bond shall be considered unsatisfactory if any part of the TSC along the cut line can be lifted from the substrate steel when using the knife blade to vigorously pry up the TSC along the cut line.

C7. Retesting of TSC Operator

In the event of the operator's failure to meet the minimum qualification requirements, the operator should be given additional training to meet the knowledge and skill requirements. After suitable training, a retest should be scheduled by the TSC inspector or the purchaser, or both.

C8. Duration of Qualification

TSC operators successfully completing the requirements of C2 through C6 should be qualified for a period of six months and continuously thereafter if they successfully perform production spraying in each thermal spray process (flame or arc) and feedstock type (powder or wire) for which qualified at least once every six months or as specified by the purchaser. Production spraying is defined as performing thermal spray operations at least eight hours in a consecutive 30-day period. A TSC operator whose qualification status has lapsed may be recertified by completing the written test (C2), bend test (C6.1), and the knife-peel test (C6.3).

Annex D

Sample Thermal Spray Operator Qualification Form

(This Annex is not a part of ANSI/AWS C2.18-93, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*, but is included for information purposes only.)

Pg ____ of ____

Name _____ Identification/Employee No. _____

Social Security No. _____

Company _____ Date _____

Co. Address _____ Co. Phone # _____

EXPERIENCE	NOTE
Process/Material Form*	1
Equipment Mfg./Model	
Application Method	2
Application Environment*	3
Material Classification	4
Safety Practices	5
Training School	6
Plant Production	7
Aircraft Production	7
Present Employer	7
Last Certified	8

Note 1. FP — Flame Powder DP — Detonation Powder HP — High-velocity Oxygen Fuel Powder
 FW — Flame Wire AW — Arc Wire
 FR — Flame Rod PP — Plasma Powder

2. M — Manual SA — Semi-Automatic A — Automatic R — Robotic
 CC — Computer Controlled

3. Atm — Atmospheric IG — Inert Gas V — Vacuum O — Other (specify)

4. Per AWS *Thermal Spraying: Practice, Theory, and Application*, Section 5.9:
 1 — Oxide Ceramics 4 — Nonferrous Materials 7 — Self-fluxing Alloys
 2 — Iron Base Alloys 5 — Other Carbides 8 — Tungsten Carbides
 3 — Nickel- and Cobalt-base Alloys 6 — Refractory Materials and Alloys 9 — Abradable Coatings

5. Safety Practices in Exam (Yes or No) 6. Last Written Examination Score (%) and Date

7. Cumulative Years and Inclusive Years, e.g., 6(77-83)

8. Month/Year of Most Recent Certification. ATTACH TSC LAB ANALYSIS (Annex C)

*Single Entry Only

Remarks _____

Signatures: Applicant/TSC Operator _____ Date: _____

TSC Inspector: _____ Date: _____

Thermal Spray Document List

AWS Designation	Title
TS	Thermal Spraying: Practice, Theory, and Application
C2.2	Recommended Practices for Metalizing with Aluminum and Zinc for Protection of Iron
C2.14	Corrosion Tests of Flame Sprayed Coated Steel, 19-Year Report
C2.16	Guide for Thermal-Spray Operator Qualification
C2.18	Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites

For ordering information, contact the Order Department, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida. Phone (1-800-334-9353).