

Joint Standard

SSPC-CS 23.00/AWS C2.23M/NACE No. 12 Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

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SSPC: The Society for
Protective Coatings
40 24th Street, Sixth Floor
Pittsburgh, PA 15222-4656
(telephone +1 412/281-2331)

American Welding Society
550 NW LeJeune Road
Miami, FL 33126
(telephone +1 800-443-9353)

NACE International
1440 South Creek Drive
Houston, TX 77084-4906
(telephone +1 281/228-6200)

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Foreword

This "Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, Their Alloys, and Composites for the Corrosion Protection of Steel" is issued to meet a critical industry and government need.

Thermal spray coatings (TSCs) are used extensively for the corrosion protection of steel and iron in a wide range of environments. The corrosion tests carried out by the American Welding Society⁽¹⁾ and the marine-atmosphere performance reports of ASTM⁽²⁾ and the LaQue Center for Corrosion Technology⁽³⁾ confirm the effectiveness of flame-sprayed aluminum and zinc coatings over long periods of time in a wide range of hostile environments. The British Standards Institution "Code of Practice for the Corrosion Protection of Steel"⁽⁴⁾ specifies that only TSCs give protection for more than 20 years to first maintenance for the 19 industrial and marine environments considered and that only sealed, sprayed aluminum or zinc gives such protection in seawater immersion or splash zones.

This standard may be used by owners, and design, fabrication, and maintenance engineers to detail and contract for the application of TSCs for the preservation and maintenance of steel structures. This standard may also be used by TSC inspectors and TSC applicators to develop and maintain application procedures, equipment inventory, and an operator-training program.

This standard presents the basic need-to-know information for the application of quality TSCs. Appendixes present amplifying information. The Table of Contents gives an overview of this standard and may be used to find specific information.

This standard was prepared by the SSPC C.1.2.B Committee on Thermal Spraying, AWS C2B Subcommittee on Thermal Spray Coatings for Corrosion Protection, and NACE Task Group (TG) 146 on Thermal Spray Coatings. TG 146 is administered by Specific Technology Group (STG) 02 on Protective Coatings and Linings—Atmospheric, and is sponsored by STG 39 on Process Industry—Materials Applications.

⁽¹⁾ AWS C2.14-74, "Corrosion Tests of Flame-Sprayed Coated Steel, 19-Year Report" (Miami, FL: AWS). AWS standards can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5776, Telephone (800)-854-7179, Fax (303) 307-2740, Internet www.global.ihc.com

⁽²⁾ R.M. Kain, E.A. Baker, "Marine Atmospheric Corrosion Museum Report on the Performance of Thermal Spray Coatings on Steel," ASTM STP 947 (West Conshohocken, PA: ASTM, 1987). Available from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

⁽³⁾ S.J. Pikul, "Appearance of Thermal Sprayed Coatings After 44 Years Marine Atmospheric Exposure at Kure Beach, North Carolina," LaQue Center for Corrosion Technology, Inc, February 1996. Available from the LaQue Center for Corrosion Technology, Inc., 702 Causeway Drive, Wrightsville Beach, NC 28480.

⁽⁴⁾ BS 5493, "Code of Practice for Protective Coatings of Iron and Steel Structures Against Corrosion" (London, UK: British Standards Institution). Available from the American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036-8002, USA; and the British Standards Institution (BSI), British Standards House, 389 Chiswick High Rd., London W4 4AL, UK.

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Section 1: General

1.1 General

This standard is a procedure for the application of metallic thermal spray coating (TSCs) of aluminum, zinc, and their alloys and composites for the corrosion protection of steel. Required equipment, application procedures, and in-pro-

cess quality control (QC) checkpoints are specified. This standard may be used as a procurement document. Appendix A presents a fill-in-the-blanks model procurement specification. The flow diagram in Figure 1 provides an overview of the thermal spray coating process presented in this standard.

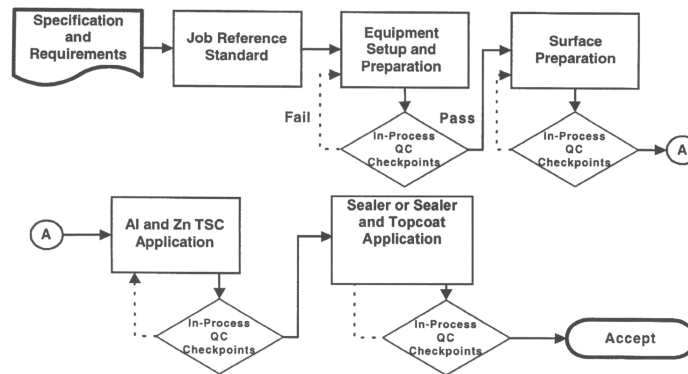


Figure 1: Thermal Spray Coating Process

Not included in this standard are requirements for design and fabrication, thermal spray equipment qualification, coating selection, and operator and inspector certification. For successful thermal spray application, the steel structure and components should be designed and fabricated according to NACE Standard RP0178.⁽⁵⁾ Additional consideration should be given to weldments whose oxyfuel cut edges may affect hardness which may preclude adequate profile depth.

1.2 Safety

The basic precautions for thermal spraying are essentially the same as for welding and cutting. Information on safety can be found in the Safety Chapter in *AWS Thermal Spraying: Practice, Theory, and Application*; ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*; and NFPA 58,⁽⁶⁾ *Standard for the Storage and Handling of Liquefied Petroleum Gases*. Safety precautions can also be found in the manufacturer's equipment technical instructions and manuals and the feedstock Material Safety Data Sheet. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Potential thermal spraying hazards include exposure to vapors, dust, fumes, gases, noise (from the spray gun), and arc ultraviolet (UV) radiation. Additionally, improperly used thermal spray equipment can create potential fire and explosion hazards from the fuel and carrier gases and a potential electrical shock hazard from the electrical and electronic equipment and charged wire spools. To minimize hazards, proper safety precautions shall be followed. Operators shall comply with the procedures in the safety references, the manufacturer's technical manuals, and the material safety data sheets.

Thermal spraying can be a completely safe process when performed by an operator who follows the recommended precautionary measures, has a proper understanding of thermal spraying practices, and has knowledge, skill, and exercises care in using thermal spray equipment.

1.3 Units of Measure

This specification makes use of both the International System (SI) and U.S. Customary units. The measurements are not exact equivalents; therefore each system must be used independently of the other without combining in any way.

⁽⁵⁾ NACE standards can be obtained from NACE International, 1440 South Creek Drive, Houston, TX 77084-4906.

⁽⁶⁾ Available from the National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

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The specification SSPC-CS 23.00 /ANSI/AWS C2.23M/NACE No. 12 uses SI units. U.S. Customary units are shown in appropriate columns in tables or within parentheses when used in the

text. Suitable conversions encompassing standard sizes of both can be made, however, if appropriate tolerances are applied in each case.

Section 2: Referenced Documents

The following standards contain provisions which, through reference in this text, constitute provisions of this SSPC/AWS/NACE standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this SSPC/AWS/NACE standard are encouraged to investigate the possibility of applying the most recent editions of the documents shown below. For undated references, the latest edition of the standard referred to applies

ASTM B 833, *Standard Specification for Zinc and Zinc Alloy Wire for Thermal Spraying (Metallizing)*⁽⁷⁾

ASTM C 633, *Standard Test Method for Adhesion or Cohesive Strength of Flame-Sprayed Coatings*

ASTM D 4285, *Method for Indicating Oil or Water in Compressed Air*

ASTM D 4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*

ASTM D 4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

ASTM D 4940, *Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives*.

ASTM E 3, *Standard Practice for Preparation of Metallographic Examination*

ANSI/AWS C2.18, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*

ANSI/AWS C2.25/C2.25M, *Specification for Solid and Composite Wires, and Ceramic Rods for Thermal Spraying*

ISO 8502-3, *Preparation of steel substrates before application of paints and related products—Tests for the assessment of surface cleanliness—Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)*⁽⁸⁾

NACE Standard RP0178, *Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion Service*

NACE Standard RP0287, *Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape*

SSPC-AB 1, *Mineral and Slag Abrasive*⁽⁹⁾

SSPC-AB 2, *Specification for Cleanliness of Recycled Ferrous Metallic Abrasives*

SSPC-AB 3, *Ferrous Metallic Abrasives*

SSPC-PA 1, *Shop, Field, and Maintenance Painting of Steel*

SSPC-PA 2, *Measurement of Dry Coating Thickness with Magnetic Gages*

SSPC-SP 1, *Solvent Cleaning*

SSPC-SP 5/NACE No.1, *White Metal Blast Cleaning*

SSPC-SP 10/NACE No. 2, *Near-White Metal Blast Cleaning*

SSPC-VIS 1, *Guide and Visual Reference Photographs for Steel Surfaces prepared by Dry Abrasive Blast Cleaning*

Section 3: Definitions

3.1 Aluminum MMC TSC: Aluminum metal matrix composite (MMC) TSC is a coating that contains a composite material in an aluminum matrix. It is produced by flame or arc spraying a solid or cored wire that contains the composite material.

3.2 Bend Test: The bend test (180° bend on a mandrel diameter based on the TSC thickness) is a qualitative test of

the ductility and tensile bond of the TSC. The bend test is a macro-system test of surface preparation, equipment setup, spray parameters, and application procedures.

3.3 Bond Test: A test to determine the tensile strength of a thermal spray coating.

⁽⁷⁾ ASTM standards can be obtained from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

⁽⁸⁾ ISO standards can be obtained from American National Standards Institute, 11 W. 42nd Street, New York, NY 10036-9002.

⁽⁹⁾ SSPC standards can be obtained from SSPC: The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656.

3.4 Companion Coupon: A small rectangular metal sample surface prepared and coated concurrently with the workpiece, used for inspection.

3.5 Contract Pre-Award Validation: The purchaser's contract pre-award evaluation of the thermal spray coating applicator includes (a) written procedures for and (b) demonstration of surface-preparation and thermal spray materials, equipment capabilities, and application process proposed for the contract work.

3.6 Cut Test: The TSC cut test shall consist of a single cut 40 mm (1.5 in.) long through the TSC to the substrate without severely cutting into the substrate. All cuts shall be made with sharp-edge tools. The chisel cut shall be made at a shallow angle. The cutting tool shall be specified in the contract.

3.7 Holding Period: Holding period is the time between the completion of the final anchor-tooth blasting, or final brush blasting, and the completion of the thermal spraying. The holding period, by definition, ends with the onset of rust bloom.

3.8 Job Control Record (JCR): The JCR is a record form that enumerates the essential job information and the in-process QC checkpoints required by this standard. The JCR includes information on safety precautions, and the equipment, parameters, and procedures for surface preparation, thermal spraying, and sealing or sealing and topcoating. Appendix B is a model JCR.

3.9 Job Reference Standard (JRS): The JRS is a job site pass/fail reference standard representative of the whole job or major sections of the job. See Paragraph 13.2 and Figure 2.

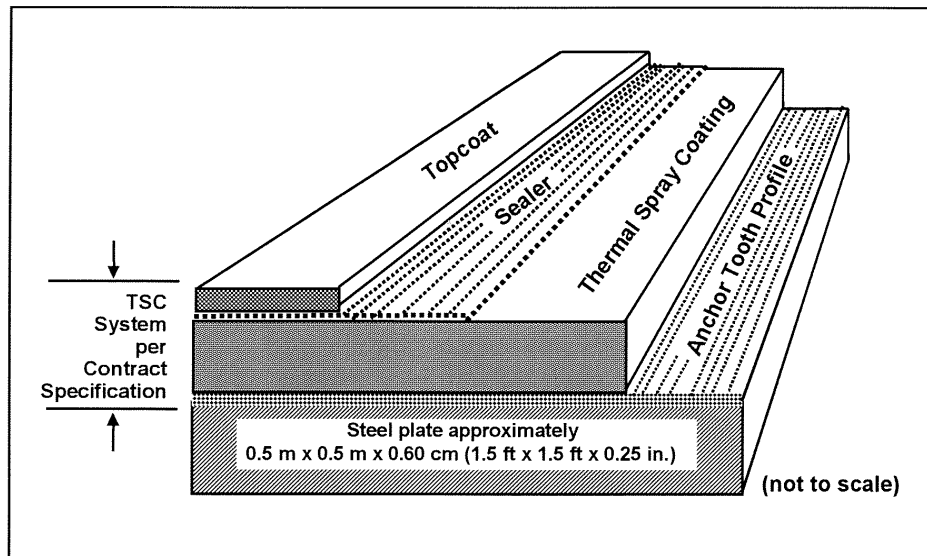


Figure 2: Job Reference Standard Illustration

3.10 Overspray: The portion of the thermal spray deposit that is not deposited on the desired area of the workpiece.

3.11 Rust Bloom: Discoloration indicating the beginning of rusting. For the purpose of this standard, rust bloom is rusting that occurs after specified surface preparation.

3.12 Sealer: The sealer is a thin paint coat about 38 μm (1.5 mils) thick that is absorbed into the pores of the TSC. Aluminum and zinc TSCs have porosities ranging up to 15%. Interconnected porosities may extend from the surface to the substrate. Sealing extends the service life. Sealing is accomplished (a) naturally by the oxidation of the sprayed aluminum or zinc filling the pores with a tightly ad-

herent oxide layer or (b) by applying thin paint sealer coatings that penetrate and are absorbed into the pores of the TSC.

3.13 Soluble-Salt Contaminants: These water-soluble salts are inorganic compounds (such as chlorides and sulfates) that contaminate a product. If soluble salts are present on a prepared steel surface, they may cause rust bloom and premature coating failure.

3.14 Topcoat: The topcoat is a paint coat over the seal coat. Note: Paint topcoats should never be applied over an unsealed TSC.

Section 4: Summary of Practice

4.1 The procedure for application of TSCs for the corrosion protection of steel includes (a) proper surface preparation of the substrate steel, (b) proper application of the TSC, and (c) proper application of the sealer or sealer and topcoat. The procedure includes the use of suitable abrasive blasting, thermal spraying, sealing/topcoating equipment, and in-

process QC checkpoints. Table 1 summarizes the TSC system requirements and the inspection and acceptance tests for shop and field applications. The TSC system material, thickness, adhesion strength, and sealer or sealer and topcoat should be related to the required service.

Section 5: Surface Finish Requirements

5.1 Surface Finish

5.1.1 The steel substrate shall be prepared to:

- (1) White metal finish, SSPC-SP 5/NACE No. 1, for marine and immersion service, or
- (2) The minimum of near-white metal finish, SSPC-SP 10/NACE No. 2, for other service applications.
- (3) The level of soluble-salt contamination on the surface shall conform to the contract specifications.

5.1.2 Surface finish and cleanliness shall be confirmed according to SSPC-VIS 1.

5.2 Angular Profile Depth

5.2.1 The steel substrate shall have, at a minimum, an angular profile depth $\geq 65 \mu\text{m}$ (2.5 mils) with a sharp angular shape.

5.3 Angular Profile Depth Measurement Schedule

5.3.1 The profile depth shall be measured according to NACE Standard RP0287 or ASTM D 4417, Method C

(replica tape, x-coarse, 38 to 113 μm [1.5 to 4.5 mils]), or Method B (profile depth gauge), or both.

(1) Manual Blasting. At a minimum, take one profile depth measurement every 1 to 2 m^2 (10 to 20 ft^2) of blasted surface.

(2) Automated Blasting. At a minimum, take one profile depth measurement every 100 to 200 m^2 (1,000 to 2,000 ft^2) of blasted surface.

(3) Angular Blast Media. Use clean dry angular blasting media. Mineral and slag abrasives shall be selected and evaluated per SSPC-AB 1, recycled ferrous metallic abrasives per SSPC-AB 2, and steel grit per SSPC-AB 3. The absence of oil contamination shall be confirmed using the test for oil in the appropriate abrasive specification (no oil film or slick). The soluble salt contamination shall be measured by ASTM D 4940. The suitability of the angular blast media, blasting equipment, and blasting procedures shall be validated according to Section 14, Contract Pre-Award Evaluation, Demonstration, and Validation. Table 2 indicates blasting media and mesh size found suitable for TSCs on steel substrates.

Section 6: TSC Requirements

6.1 Feedstock and TSC Thickness

6.1.1 The TSC feedstock material and thickness should be selected according to intended service environment and service life. (See ANSI/AWS C2.18)

6.1.2 The TSC feedstock material shall be specified according to ANSI/AWS C2.25/C2.25M or ASTM B 833.

6.1.3 The minimum and maximum TSC thickness shall be measured with an SSPC-PA 2, Type 2 fixed probe gauge or equivalent. The thickness scheduled is specified in Paragraph 6.3.

Table 1: TSC System Requirements and Acceptance Tests

TSC System Requirements			Acceptance Tests
Surface Preparation	TSC	Sealer or Sealer and Topcoat	
SSPC-SP 10/NACE No. 2 minimum ^(A)	Smooth and uniform. No blisters, cracks, loose particles, or exposed steel.	Smooth and uniform. No runs, sags, lifting, pinholes, or overspray.	Per the contract surface preparation standard.
Angular-profile depth $\geq 65 \mu\text{m}$ (2.5 mils)	---	---	Profile tape according to NACE Standard RP0287 or micrometer depth gauge according to ASTM D 4417
Specify blasting media	Specify feedstock	Specify paint(s)	Manufacturer's certificate ^(B) and MSDS
---	Coating Thickness ^(C) Minimum: $\text{---} \mu\text{m}$ (--- mils) Maximum: $\text{---} \mu\text{m}$ (--- mils)	Coating thickness Minimum: $\text{---} \mu\text{m}$ (--- mils) Maximum: $\text{---} \mu\text{m}$ (--- mils)	SSPC-PA 2 Type 2 Fixed Probe Gauge
---	Portable tensile bond ($\geq$ Table 3 values) Minimum: --- MPa (--- psi)	---	ASTM D 4541 ^(D)
Companion coupon bend/tensile-bond test ^(E) :	---	---	Bend/tensile-bond test
Condition of substrate surface preparation and TSC interface and morphology (structure) ^(F)	---	---	Metallographic examination of companion coupon
---	No peeling or delimitation	---	TSC Cut Test ^(G)
	Other as specified by the Contract		Other as specified by the Contract

^(A) For critical surfaces and marine and underwater service, clean to a white metal finish (SSPC-SP 5/NACE No. 1) with $\geq 65 \mu\text{m}$ (2.5 mils) angular profile. The owner should specify the minimum required blast quality and its validation according to Section 5, Job Reference Standard. The angularity of the blast profile can be determined by a metallographic analysis of a companion coupon according to ASTM E 3 using a specimen cut from a successful bend coupon prepared and thermal sprayed per the contract specifications and tested according to Paragraph 6.5.

^(B) Verification that the manufacturers or suppliers provide a certificate or affidavit that (1) the blasting media conforms to SSPC-AB 1 for mineral and slag abrasive, SSPC-AB 2 for recycled ferrous metallic abrasives, or SSPC-AB 3 for newly manufactured or remanufactured steel abrasive; (2) the TSC-feedstock chemical composition, obtained from a representative sample of each heat during the pouring or subsequent processing, conforms to ANSI/AWS C2.25; and (3) the sealer and topcoat paints are formulated for the contract-specified thermal spray coating. The Material Safety Data Sheets (MSDS) provide supporting physical and chemical information.

^(C) Measure the TSC thickness according to SSPC-PA 2. Calibrate the instrument using a calibration wedge near the contract-specified thickness placed over a representative sample of the contract-specified abrasive blasted steel, a prepared bend coupon, or both.

^(D) Specify the ASTM D 4541 self-adjusting portable tensile instrument to be used and its minimum acceptable value for the Job Reference Standard and the job work surfaces.

^(E) As an alternative to the portable tensile-bond test, which may be considered potentially destructive on a finished part, a companion coupon may be bend tested, or a companion tensile test specimen may be tested in accordance with ASTM C 633 to validate the coating adhesion strength. The bend test is a macro system test for proper surface preparation, equipment set-up, and spraying parameters.

^(F) Metallographic analysis of a companion coupon may be specified to establish the suitability of the surface preparation, TSC application, and/or porosity of the TSC.

^(G) TSC cut test should be made by a tool cutting through the TSC to the steel surface. The TSC is defective if any part of the coating lifts off the surface.

Table 2: Blasting Media and Mesh Size Found Suitable for TSCs on Steel Substrates

Thermal Spray Material	Process	Blasting Media	Size ^(A)
Al, Zn, 85/15 Zn/Al, 90/10 Al-Al ₂ O ₃ MMC	Flame wire and arc wire	Aluminum oxide	10-30 mesh
		Angular steel grit	G-16 to G-40
		Copper and nickel slag	G-16 to G-24
		Almandite garnet	G-16 to 30/40
		Chilled iron grit	G-16 to G-40
Al, Zn	Flame powder	Aluminum oxide	10-30 mesh
		Angular steel grit	G-16 to G-40
		Chilled iron grit	G-16 to G-40

^(A) Mesh size shall be selected as appropriate to the anchor-tooth depth requirement and the blasting equipment used.

6.2 TSC Thickness

6.2.1 Thickness Less Than Contract Specification

6.2.1.1 If upon later inspection, and prior to sealer application, the TSC thickness is less than the contract requirement, the applicator shall apply additional TSC to meet the thickness requirement.

6.2.2 Thickness Greater Than Contract Specification

6.2.2.1 If the TSC thickness is greater than the contract specification, information shall be recorded in the JCR and the inspector shall be notified immediately. The inspector should then notify the purchaser for resolution of this discrepancy. The TSC applicator and the purchaser should record all areas in excess of 150% of the acceptable coating thickness. If these areas are damaged during shipping, loading/unloading, or erection, they should be repaired in accordance with maintenance repair procedures as outlined in ANSI/AWS C2.18.

6.3 TSC Thickness Measurement Schedule

6.3.1 For flat surfaces a measurement line shall be used. The average value of five readings taken in line at 2.5-cm (1.0-in.) intervals shall be determined. The line measurement measures the peaks and valleys of the TSC.

6.3.2 For complex geometries and geometry transitions a measurement spot shall be used. The measurement spot should have an area of approximately 10 cm² (1.6 in.²). The spot measurement may not measure the peaks and valleys of the TSC.

6.3.3 Figure 3 illustrates the line and spot measurements.

6.3.4 Measurement Schedule: One line or spot measurement shall be taken every 10 to 20 m² (100 to 200 ft²) of applied TSC.

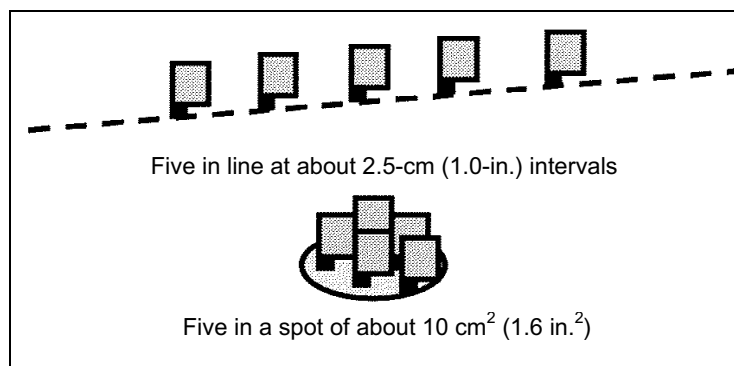


Figure 3: Line and Spot Measurements

6.4 TSC Tensile Bond and Measurement Schedule

6.4.1 The TSC tensile bond shall be measured according to ASTM D 4541 using a self-aligning adhesion tester or approved equivalent.

6.4.1.1 The minimum TSC tensile bond value shall be specified according to Table 3. Higher values may be specified.

Table 3: Minimum Tensile Bond Requirements
(According to ASTM D 4541 using self-aligning adhesion tester)

Feedstock	MPa (psi)
Zn	3.45 (500)
Al	6.89 (1,000)
85/15 Zn/Al	4.83 (700)
90/10 Al ₂ O ₃ MMC	6.89 (1,000)

6.4.1.2 One portable tensile-bond measurement shall be made every 50 m² (500 ft²). If the tensile bond is less than the contract specification, the degraded TSC shall be removed and reapplied.

6.4.1.3 For nondestructive measurement: Tensile force shall be measured to the *contract-specified tensile*. The tensile force shall then be reduced and the tensile fixture removed without damaging the TSC.

6.4.2 Note: The tensile-bond measurement of the portable test instrument may be calibrated according to the ASTM C 633 test method as described in Appendix C.

6.5 Bend Test

6.5.1 The bend test (180° bend on a mandrel) is used as a qualitative test for proper surface preparation, equipment setup, and spray parameters. The bend test puts the TSC in tension. The mandrel diameter for the threshold of cracking depends on substrate thickness and coating thickness.

6.5.2 Table 4 summarizes a very limited bend-test cracking threshold for arc-sprayed zinc TSC thickness on steel coupons 1.3 mm (0.05 in.) thick versus mandrel diameter.

Table 4: Bend-Test Cracking Threshold: Mandrel Diameter vs. TSC Thickness
For steel coupons 1.3 mm (0.05 in.) thick

TSC Thickness, μm (mils)	≥ 250 (10)	≥ 380 (15)	≥ 640 (25)
Mandrel Diameter, mm (in.)	13 (0.50)	16 (0.63)	< 25 (1.0) ^(A)

^(A) Confirm diameter with JRS.

6.5.3 Bend-Test Procedure for TSC Thickness Range 175 to 300 μm (7 to 12 mils)

(1) Five corrosion-control bend coupons shall be sprayed and shall pass the following bend test:

- Carbon steel coupons of approximate dimensions 50 x 100 to 200 x 1.3 mm (2 x 4 to 8 x 0.050 in.) shall be used.
- Surface shall be prepared according to contract specification.
- The TSC shall be sprayed 175 to 300 μm (7 to 12 mils) thick. The TSC should be sprayed in crossing passes laying down approximately 75 to 100 μm (3 to 4 mils) in each pass.

(d) Coupons shall be bent 180° around a 13-mm (0.50-in.) diameter mandrel.

(2) *Bend test passes* if, on the bend radius (see Figure 4), there is

- no cracking or spalling, or
- only minor cracking that cannot be lifted from the substrate with a knife blade.

(3) *Bend test fails* if the coating cracks with lifting from the substrate.