

Specification for the Application of Thermal Spray Coatings to Machine Elements for OEM and Repair



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Specification for the Application of Thermal Spray Coatings to Machine Elements for OEM and Repair

2nd Edition

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Prepared by the
American Welding Society (AWS) C2 Committee on Thermal Spray

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This standard defines requirements for thermal spray coating systems for OEM and repair applications. Included are HVOF (High Velocity Oxyfuel) coatings that can be used as an alternative to hard chrome plating. The essential equipment, procedures for surface preparation, and the application of specific thermal spray coatings and sealers are detailed with in-process quality control checkpoints. This standard also presents management requirements and procedures for qualification, procedure approval, and documentation. Also covered are approved applications for thermal spray processes used for OEM and repair of machinery components along with minimum training requirements for thermal spray operators and inspectors. This specification has several annexes including annexes on safety, bend testing, and bond testing.



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Foreword

This foreword is not part of this standard but is included for informational purposes only.

The first edition of AWS C2.19/C2.19M:2013, *Specification for the Application of Thermal Spray Coatings to Machine Elements for OEM and Repair*, was developed pursuant to a request from the U.S. Naval Sea Systems Command to migrate MIL-STD-1687A(SH), *Thermal Spray Processes for Naval Ship Machinery Applications*, to an ANSI approved AWS Standard.

This is the second edition of the standard. A vertical line in the margin or underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2013 edition.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS C2 Committee on Thermal Spray, American Welding Society, 8669 NW 36 St, #130 Miami, FL 33166.

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Specification for the Application of Thermal Spray Coatings to Machine Elements for OEM and Repair

1. General Requirements

1.1 Scope. This specification covers thermal spray processes for original equipment manufacturers (OEMs) and the repair of machinery components. The scope includes (1) recommended applications, (2) management and engineering requirements, (3) equipment and facility requirements, (4) feedstock materials, and (5) application processes for thermal spray coatings.

The thermal spray processes covered by this standard are combustion, high velocity oxyfuel or airfuel, electric arc, and plasma processes. These processes use either powder and/or wire as feedstock.

Development of this standard was initiated at the request of the U.S. Navy to replace MIL-STD-1687A (SH), *Thermal Spray Processes for Naval Ship Machinery Applications*.

Others may use this standard and annexes to establish contract document requirements between equipment owners (purchaser) and thermal spray coating contractors where they may choose to invoke all or only a portion of this specification's requirements as fits the needs of their work.

1.2 Units of Measurement. This standard makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

U.S. Department of Labor Regulations:

- (1) CFR-29, Part 1910.107 *Spray Finishing using Flammable and Combustible Liquids*

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. A list of informative references is provided in Annex D.

AMS Standards:

AMS 2447, *Coating, Thermal Spray High Velocity Oxygen/Fuel Process*

ASTM Standards:

ASTM C633, *Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings*

ASTM D1655, *Standard Specification for Aviation Turbine Fuels*

ASTM D3699, *Standard Specification for Kerosine*

ASTM D4285, *Standard Test Method for Indicating Oil or Water in Compressed Air*

ASTM D4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*

ASTM D7393, *Standard Practice for Indicating Oil in Abrasives*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

ASTM E527, *Standard Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)*

AWS Standards:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes*

AWS C2.16/C2.16M, *Guide for Thermal Spray Operator Qualification Programs*

AWS C2.21M/C2.21, *Specification for Thermal Spray Equipment Performance Verification*

AWS C2.25/C2.25M, *Specification for Thermal Spray Feedstock—Solid and Composite Wires, and Ceramic Rods*

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

SSPC Standards:

SSPC-SP 1, *Solvent Cleaning*

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

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

U.S. DOD Specifications:

MIL-A-18455C NOT 1, *Argon, Technical*

MIL-E-51454A, *Ethyl Alcohol (Ethanol)*

MIL-PRF-32207, *Propellant, Methane*

U.S. Federal Specifications:

A-A-59315 Series, *Powder Materials for Flame and Plasma Sprayed Coatings*

BB-A-106, *Acetylene, Technical, Dissolved*

BB-A-1034B, *Compressed Air, Breathing*

BB-G-110, *Butane, Propane, and Butane-Propane Mixtures*

BB-H-866, *Gaseous Hydrogen Grades for Cutting and Welding and as a Lifting Medium for Balloons*

BB-H-1168, *Helium, Technical*

BB-N-411C, *Nitrogen, Technical*

BB-O-925A, *Oxygen, Technical, Gas and Liquid*

U.S. Department of Labor Regulations:

CFR-29, Part 1910.107, *Spray Finishing using Flammable and Combustible Liquids*

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included to accommodate usage specific to this document.

abrasive blasting. A method of surface cleaning or roughening by a forcibly projected stream of abrasive particles.

arc spraying. A thermal spraying process using an arc between two consumable electrodes of surfacing materials as a heat source and a compressed gas to atomize and propel the surfacing material to the substrate. See arc wire, electric arc spraying, and twin wire arc.

arc wire (AW). A nonstandard term for **arc spraying**. See electric arc spraying and twin wire arc.

blister. A raised coating area, often dome-shaped, resulting from a loss of adhesion between the coating and the substrate.

bond coat. A preliminary (or prime) thermal spray coating of material that improves the adherence of subsequent layers of thermal spray coating.

coating. A nonstandard term when used for **thermal spray deposit**. (see AWS A3.0M/A3.0)

coating system. One or more thermal spray coatings that are qualified for use singly or in combination. An example of a one-coating system is a stainless steel coating applied for restoration of dimensions. An example of a two-coating system is a nickel-base bond coat and ceramic finish coat for a steam seal.

composite powder. Powder particles that are formed by physically combining two or more materials in intimate contact, so that the end particles function as a unit.

cooling air, cooling jet. A gas jet, set of jets, or other nozzle shape, not affixed to the spray torch or gun, that delivers gas to the target surface for the purpose of accelerating the removal of process heat input to the coating and substrate for maintaining part thermal stability during the coating operation. Cooling jets may carry air, nitrogen, carbon dioxide, or other cooling gases. The placement of cooling jets and the type of cooling gas and flow rate are often considered critical process parameters, when they are used.

electric arc spraying. A nonstandard term for **arc spraying**. See arc wire and twin wire arc.

feedstock. Any consumable form of spray material used in application of a coating.

flame powder (FP). A thermal spraying process in which an oxyfuel gas flame is the source of heat for melting powdered surfacing material. Compressed gas may or may not be used for atomizing and propelling the surfacing material to the substrate.

flame wire (FW). A thermal spraying process in which an oxyfuel gas flame is the source of heat for melting wire surfacing material. Compressed gas may or may not be used for atomizing and propelling the surfacing material to the substrate.

frontal air, frontal jet. A directional gas jet, usually in pairs, affixed to the front of a thermal spray torch or gun, typically using air or another gas such as argon, nitrogen or carbon dioxide to provide supplemental cooling to the target surface, protection of coated surface from degradation such as oxidation and/or modify the shape of the spray plume. Frontal air jets differ from other cooling jets in that they are affixed to and move with the spray torch or gun.

fused thermal spray coating. A self-fluxing spray coating which is subsequently heated to melting so as to coalesce within itself and with the substrate.

graded thermal spray coating. A thermal sprayed coating composed of mixed materials in successive layers that progressively change in composition.

high velocity air fuel spraying (HVOF). A variant of the HVOF thermal spray process that uses compressed air as the oxidizing component of combustion instead of pure oxygen.

high velocity oxyfuel spraying (HVOF). A thermal spraying process using a high pressure oxyfuel mixture to heat and propel a powdered surfacing material to a substrate.

HP. A nonstandard term for **high velocity oxyfuel (HVOF)** and **high velocity air fuel (HVOF)**.

JCR. Job control record.

JRS. Job reference standard.

masking. The method of protecting areas adjacent to the surface to be thermally sprayed or blasted to prevent adherence of a coating or surface roughening.

NACE International. National Association of Corrosion Engineers.

oxide. For metallic sprayed coatings, evaluated microscopically, a measure of the field area percentage of a coating's cross section that can be characterized as formerly metallic material that has been chemically changed, usually by burning or oxidation. Oxides are visually distinct from unaffected adjacent coating material and are typically darker in color.

plasma powder (PP). A nonstandard term for **plasma spraying**.

plasma spraying. A thermal spray process wherein a non-transferred constricted electric arc-gas mixture (called a plasma) is utilized as the source of heat for melting and propelling the coating material to the workpiece.

porosity. Usually evaluated microscopically, a measure of the field area percentage of a coating's cross section that can be characterized as open space, usually as a result of less than complete density in coating compaction.

powder flame spraying. A method of flame spraying wherein the material to be sprayed is in powder form.

purchaser. The organization or company that is responsible for the engineering and contract specification(s). The term "owner" may be used in lieu of "**Purchaser**".

overlap. Distance between centerline of two adjacent spray patterns; also known as "stepover" or "raster".

owner. See **Purchaser**.

QA. Quality assurance.

QC. Quality control.

raster. A pattern of scanning lines traced by the spray stream of a torch.

seal coat. Material applied to infiltrate and close the pores of a spray coating.

spalling. The chipping, fragmentation or separation of a thermally sprayed surface.

SSPC. Society for Protective Coatings.

spit. Globular debris, often an accumulation of feedstock, coming from the interior or exterior of the torch or torch component that is entrained in the spray stream and may result in a defect in the coating. This defect may be seen as a small bump or embedded contaminate on the surface of the coating or porosity during the grinding operation.

stepover. See **overlap**.

thermal spray contractor. The facility or shop that carries out the thermal spray application.

thermal spray coating interface. The boundary between the thermal spray coating and the substrate.

thermal spray. A group of processes wherein finely divided metallic or nonmetallic feedstock is applied in a molten or semi-molten condition to form a surface coating. The feedstock may initially be in the form of powder, ceramic rod, or wire.

TSC. Thermal spray coating.

twin wire arc. A nonstandard term for **arc spraying**. See arc wire and electric arc spraying.

undercut. Removal of material, usually by machining, in preparation for replacement by thermal spray coating, or an area of the workpiece that has been prepared as such.

UV. Ultraviolet.

wire flame spraying. A method of flame spraying wherein the material to be sprayed is in wire form.

4. General Applications

Thermal spray coatings (TSCs) are applied to original equipment manufactured (OEM) components to provide surface-engineered coatings for improved resistance to surface mechanisms such as corrosion and wear, as well as many other types of surface enhancements. For machinery component repair, TSCs are also used to restore dimensions, buildup worn or mis-machined parts and to protect against wear, abrasion, corrosion and other surface mechanisms. TSCs are not intended to fill gouges or similar localized damage without building up the entire area. TSCs do not restore mechanical properties such as tensile strength or resistance to fatigue stresses. Additionally, high velocity oxyfuel or airfuel powder coatings are an effective alternative to hard chrome plating and are used to provide improved wear or abrasion resistance. Thermal spray coatings can be used to apply deposits that enhance surface properties in other ways for applications not addressed by this document, i.e. thermal resistance, electrical conductivity and clearance control.

(1) Information contained in this clause is presented for the purpose of assisting in the selection of a coating that would be appropriate for the intended application.

(2) Selection shall be made from the listings in Tables 1 and 2. Thermal spray applications and coatings not specified in Tables 1 and Table 2 shall receive Purchaser approval on a case-by-case basis before spraying.

(3) Table 3 gives the properties and minimum tensile bond requirements for the Table 1 applications.

4.1 Application Considerations. The suitability of the thermal spray process as a repair method is dependent on several factors. The following are examples of the factors that should be considered prior to attempting thermal spray repair or build-up:

(1) Parts must have sufficient strength to meet design requirements after the material removal required for preparing the surface for thermal spray.

(2) Parts that are highly stressed (approximately 90% of its yield point) in service such that static strain is significant would not normally be a good candidate for these applications.

(3) Applications where the coated surface would experience point loading, such as in a needle bearing journal, or repetitive impact point loading would not normally be good candidates for these applications.

(4) Applications where the applied coating thickness required for repair or buildup that exceeds the maximum values stated in Table 3 would not normally be good candidates for these applications.

Table 1
Recommended Thermal Spray Applications

Substrate	Application	Spray Process ^{a,b}	Spray Material Code ^c	Spray Category ^d
Carbon <u>steel</u> , low alloy, and Stainless steel; Cast Iron	Dimensional Restoration	PP	P1/P1a	4.1
		FP	P1	4.1
		AW/FW	W1/W2/W1a	2.1
		HP	P12/P13/P14/P15	15/16/17/18
	Wear, seal, erosion	PP	P1/P2a,P2b,P2c,P2d	4.1/8.1
			P2e,P2f,P2g	4.1/8.1
		FP	P2	10
		HP	P1/P2 P7/P8/P9/P10/P11	
Nickel base alloys	Dimensional Restoration	PP	P3/P1/P1a	6.1
		FP FW	P3	6.1
		HP	W3/W1/W1a	6.2
			P12/P13/P14/P15	15/16/17/18
	Wear, seal, erosion	PP	P3/P2a, P2b, P2c, P2d	6.1/8.1
		FP	P2e, P2f, P2g	6.1/8.1
		HP	P3/P2	10/11/12
			P7/P8/P9/P10/P11	13/14
Bronze	Dimensional Restoration	PP	P4	5.1
		FP	P4	5.1
		AW/FW	W1, W1a/W4	5.2
		HP	P15	18
	Wear, seal, erosion	PP	P4/P2a, P2b, P2c, P2d	5.1/8.1
		FP	P2e, P2f, P2g	5.1/8.1
		HP	P4/P2	10/11/12
			P7/P8/P9/P10/P11	13/14
All above	Chrome Plating Replacement	HP	P7/P8/P9/P10/P11	10/11/12
All above	Bond Coat ^e	FP	P1/P1a	13/14
		PP	P1/P1a/P1b/P1c/P1d	4.1/4.2
		AW	W1a/W1b	4.1/4.2/4.3/4.4/4.5
		FW	W1	2.3/2.4
		HP	P1a	2.2
				4.2

(a) Spray process are arc wire (AW), flame wire (FW), flame powder (FP), plasma powder (PP), and high velocity combustion processes (HP) powders for such processes as high velocity oxyfuel (HVOF) and high velocity air fuel (HVOF) used to obtain a single coating layer or multiple coating layers of a coating system.

(b) These processes are recommended for the listed applications and substrates. Thermal spray operators must be qualified per 5.4. Other processes may be used if the procedures and operators are qualified in accordance with this specification.

(c) See Table 2 for powder and wire chemical compositions and spray material codes.

(d) Spray categories and associated bond strength, porosity, oxide and thickness requirements are given in Table 3.

(e) Bond coats of NiCr, NiCrAl, NiAlMo, and similar alloys are preferred for high temperature applications, while NiAl bond coats are not recommended for corrosion environments.

Table 2
Nominal Chemical Composition of Thermal Spray Feedstock^(b)

Spray Material Code ^(a)	Description	Specification	Al	Mo	Ni	Cr	Fe	Cu	C	Other Elements	
										Element	Amount
P1	Composite	N/A	7.0	5.5	Bal	9.0	5.0	—	—	—	—
P1a	Composite	N/A	5.0	—	95	—	—	—	—	—	—
P1b	Mech. Clad		6	—	Bal	18.5	—	—	—	—	—
P1c	Chem. Clad	67A60753	20	—	80	—	—	—	—	—	—
P1d	Water Atomized	A-A59315/20 Type I, Class I		—	80	20	—	—	—	—	—
P2a	High purity alumina	N/A	—	—	—	—	—	—	—	Al ₂ O ₃	Bal
P2b	Grey Alumina	N/A	—	—	—	—	—	—	—	Al ₂ O ₃ Other	Bal <0.5
P2c	Alumina Titania	N/A	—	—	—	—	—	—	—	Al ₂ O ₃ TiO ₂	87 13
P2d	Alumina Titania	N/A	—	—	—	—	—	—	—	Al ₂ O ₃ TiO ₂	60 40
P2e	Titania	N/A	—	—	—	—	—	—	—	TiO ₂	99 min
P2f	Chrome Oxide	N/A	—	—	—	—	—	—	—	Cr ₂ O ₃	99.7 min
P2g	Chrome Oxide Silica	N/A	—	—	—	—	—	—	—	Cr ₂ O ₃ TiO ₂ SiO ₂	Bal 3 5
P3	Monel	N/A	—	—	70	—	—	30	—	—	—
P4	Al-Bronze	A-A-59315/26 ^(c)	10	—	—	—	—	Bal	—	—	—
P5	420 stainless	N/A	—	—	—	13	Bal	—	0.22	—	—
P6	CuNi	N/A	—	—	38	—	—	Bal	—	—	—
P7 ^(d)	WC/17Co	AMS 2447 2447-7	—	—	—	—	—	—	5.1	Co W	17 Bal
P8 ^(d)	WC/10Co/4Cr	AMS 7882	—	—	—	4	—	—	3.8	Co W	10 Bal
P9 ^(d)	Intermetallic Alloy T-400	AMS 2447 2447-2	—	29	—	8	—	—	—	Co Si	Bal 3
P10 ^(d)	WC/Cr ₃ C ₂ /NiCr	N/A	—	—	6	20	—	—	5	W	Bal

(Continued)

Table 2 (Continued)

Spray Material Code ^(a)	Description	Specification	Al	Mo	Ni	Cr	Fe	Cu	C	Other Elements	
										Element	Amount
P11 ^(d)	Cr ₃ C ₂ /NiCr	AMS 2447 2447-3	—	—	20	Bal	—	—	11	—	—
P12 ^(d)	Alloy 718	UNS N07718 ⁸	1	3	Bal	19	18	—	—	Nb+Ta Co	3.5 1
P13 ^(d)	Alloy 625	UNS N06625	0.2	9	Bal	21	4	—	—	Nb+Ta	3.5
P14 ^(d)	316 SS	UNS S31600	—	2.5	13	17	Bal	—	0.1	Si	1
P15 ^(d)	Ni/Cr/Mo	N/A	—	18	Bal	23	<1	—	—	—	—
W1	Ni-Al	AWS C2.25 W-NiAl-2	20	—	80	—	—	—	—	—	—
W1a	Ni-Al	N/A	5.0	—	95	—	—	—	—	—	—
W2	Austenitic Stainless	AWS C2.25	—	—	5.0	18.0	Bal	—	0.15	Mn	8.75
W3	Ni-Cu (Monel)	AWS C2.25 W-NiCu-1	0.5	—	66.5	—	2.5	Bal	0.3	Mn	2.0
W4	Al-Bronze	AWS C2.25	9.5	—	—	—	1.0	88 min	—	—	—
W5	420 Stainless	AWS C2.25 W-FeCrNi-9	—	—	0.6	13	Bal	—	0.35	—	—
W6	CuNi	AWS A5.7 ERCuNi	—	—	30.5	—	0.55	Bal	—	Ti	0.35
W7	Carbon steel	AWS C2.25 W-FeC-3	—	—	—	—	Bal	—	0.25	Mn	0.45
W8	Babbitt (tin)	AWS C2.25 W-SnSbCu-1	—	—	—	—	0.08	4	—	Sb Pb Sn	7.5 0.35 Bal

(a) **P** for powder material; **W** for wire material.

(b) Single values are maximum weight percentages unless a minimum is specified.

(c) A-A-59315 Series, Powder Materials for Flame and Plasma Sprayed Coatings.

(d) Nominal Chemical Composition

⁸ ASTM E527 Standard Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)