SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS2448A

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Superseding AMS2448

Application of Tungsten Carbide Coatings on Ultra High Strength Steels High Velocity Oxygen / Fuel Process

RATIONALE

AMS2448A results from a Five Year Review and update of this specification.

1. SCOPE

1.1 Purpose

This specification covers engineering requirements for applying tungsten carbide thermal spray coatings to ultra high strength steels (220 ksi and above) utilizing high velocity oxygen fuel (HVOF) combustion driven processes and the properties for such coatings. The processes and procedures herein apply only to the properties of the as-deposited coating.

1.2 Application

This process has been used typically to provide coatings that possess lower porosity and higher adhesive and/or cohesive strength than generally attainable with plasma spray and for applications requiring wear, heat, and corrosion resistance or dimensional restoration that were traditionally chrome plated. However, usage is not limited to such applications.

1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
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2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS6454	Sheet Steel, Strip, and Plate, 1.8Ni - 0.80Cr - 0.25Mo (0.38 - 0.43C) (SAE 4340), Consumable Electrode Melted
AMS6484	Steel, Bars, Forging, and Tubing, 0.80Cr - 1.8Ni - 0.25Mo (0.38 - 0.43C) (SAE 4340), Normalized and Tempered
AMS7881	Tungsten Carbide-Cobalt Powder, Agglomerated and Sintered
AMS7882	Tungsten Carbide-Cobalt Chrome Powder, Agglomerated and Sintered
SAE J442	Test Strip, Holder, and Gage for Shot Peening

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM C 633	Adhesion or Cohesive Strength of Flame-Sprayed Coatings
ASTM E 384	Microhardness of Materials

3. TECHNICAL REQUIREMENTS

3.1 Equipment

3.1.1 Torch

A specially constructed gun that utilizes combustion products to generate a high velocity gas stream for heating of the coating material to a molten or plasticized state, and transfer of the coating material to the work piece shall be used. The torch shall be microprocessor-controlled and fitted with an automated device for regulating the gas(es) and fuel(s). The torch shall be mounted on an automated manipulating device during the deposition process to maintain a constant working distance and traverse rate or maintained in a fixed position with the component mounted on a manipulating device that will maintain a constant working distance.

3.1.2 Gauges

3.1.2.1 Pressure gauges shall have a minimum accuracy of ±1.5% of full scale.

3.1.2.2 Flow meters shall have a minimum accuracy of ±2% of full scale.

3.1.3 Powder Feeder

The powder feed system shall supply a metered flow of material.

3.2 Materials

3.2.1 Gases and fuels specifications used by the processor for procurement shall be acceptable to the cognizant engineering organization.

3.2.2 Coating material shall conform to AMS7881 or AMS7882 unless otherwise specified by the cognizant engineering organization. All powders shall be dry, free flowing and uniformly blended.

3.3 Preparation

3.3.1 Cleaning

Surfaces to be coated shall be thoroughly cleaned to remove oil, grease, dirt, paint and other foreign material. Final cleaning shall take place no more than four hours prior to coating. Cleaning procedures shall not embrittle, pit, or damage surfaces to be coated.

3.3.2 Masking

Parts shall be masked by any appropriate means to protect all surfaces that are not being coated.

3.3.3 Surface Conditioning

After cleaning, surfaces to be coated shall be grit-blasted with aluminum oxide blast media at 60 to 80 psi (414 to 552 KPa) and 6 to 8 inches (152 to 203 mm) standoff distance to clean and prepare the surface for HVOF deposition. Grit shall be free from moisture, oil, dirt and other contaminants. Grit size shall be of the finest possible size necessary to achieve a 120 to 150 Ra surface roughness, but shall never be coarser than 54 grit. A surface profilometer shall be used to verify the proper surface conditioning for each procedure used.

3.4 Application

3.4.1 Process

The parameters for gas flows and pressures, powder feed rates, and spray distance, as well as deposition rates and traverse speeds shall be determined by a statistical method designed to achieve the desired coating properties specified by this document and/or the cognizant engineering organization.

3.4.2 Preheating

Surfaces to be coated shall be heated to remove moisture, Surface temperature shall not exceed 350 °F (177 °C). Preheating may be accomplished with the torch or by other suitable means and shall be monitored as specified in 3.4.3.4.

3.4.3 Coating

The coating material shall be deposited on the designated surface in sufficient thickness to permit finishing to specified dimensions.

3.4.3.1 Areas on which coating is optional must be prepared and handled in the same manner as the area on which coating is required and adhesion requirements still apply.

3.4.3.2 A spray angle of 90° ± 5 should be maintained. For cylindrical components, angle is measured relative to the centerline axis of the cylinder. For any application that requires a spray angle at less than 85°, all test specimens shall be sprayed at the same angle as the component and all minimum mechanical property requirements will apply.

3.4.3.3 Spray deposition shall be continuous except for interruptions to measure coating thickness and/or for cooling cycles to maintain part below maximum allowable temperature.

3.4.3.4 Substrate Temperature

Unless otherwise specified, maximum temperature of the substrate during preheating and coating application shall be controlled to not exceed 350 °F (177 °C). Temperature measurements shall be made utilizing a laser-sighted infrared (IR) thermometer with adjustable emissivity (0.1 to 0.99) and response time of less than 1 second. Measurement location shall be taken on the parent metal adjacent to the edge of the coating as it traverses the area to be coated. If geometric or part size constraints do not allow this procedure to be followed, then the temperature shall be measured immediately adjacent to the coated area along the same path of travel as the gun plume. Emissivity shall be set to a standard value for high strength steel. Resolution of the IR thermometer shall be 1 C° or 1 F°, depending on the scale used and spot diameter should be less than 2.5 inch (64 mm) or equivalent to the actual diameter of the IR beam.

3.4.4 Test Specimens

Specimens required under 3.7 shall be coated, as far as practicable, using the process procedures identified on the Coating Process Control Sheet (see Figure 1) with the parts that they represent. Specimens representing components rotated under the spray shall be sprayed at the same rotational speed and incremental step rate as the component. If there are multiple application angles on the same component, each of the deposition angles shall be evaluated with specimens for compliance with minimum mechanical property limits. Specimens shall be evaluated prior to coating application on production components.

3.4.5 Specimen Material

Bond strength specimens shall be fabricated from AMS6484, heat treated to produce a hardness 40 HRC minimum and no higher than the hardness of the component substrate. Metallographic and bend test specimens shall be fabricated from AMS6454 and heat treated to produce a hardness of 40 HRC minimum. Alternatively, test specimens can be made from the same material, in the same condition as the component.

3.5 Surface Finishing

Procedures for finishing shall be in accordance with the cognizant engineering organization's specifications.

3.6 Properties

3.6.1 Adhesion

3.6.1.1 Bend Test

Specimens prepared and tested in accordance with 3.7.1 shall not show separation of the coating from the substrate, when examined visually without magnification. Cracking of the coating and minimal separation at the specimen edges shall be considered acceptable.

3.6.1.2 Bond Strength

Specimens, prepared and tested in accordance with 3.7.2, shall be 10 ksi (69 MPa) minimum.

3.6.2 Coating Hardness

The coating hardness, tested in accordance with 3.7.3, shall be HV_{300g} 950 minimum.

3.6.3 Microstructure

A detailed standard procedure for metallographic specimen preparation and examination shall be used to ensure consistent results as in 4.4.1. Examination of a suitably prepared cross-sectioned specimen shall show the coatings to be free from cracks and delaminations. Repolishing can only be performed on specimens that show flaws induced by the polishing method. Oxide content cannot be induced and is not grounds for repolishing. Microstructural properties shall be evaluated in accordance with the following:

3.6.3.1 Voids and oxides shall be uniformly distributed and not greater than 1% in any field of view (approximately 0.02 inch (0.5 mm) length) when examined at 400X magnification on the cross sectioned specimen. Any single void greater than 0.002 inch (0.05 mm) shall be cause for rejection.

3.6.3.2 Unmelted Particles

None in any field of view (approximately 0.04 inch (1.0 mm) length) when viewed at 200X magnification on the cross sectioned specimen.

3.6.3.3 Interface

Contamination of the coating at the substrate interface with surface preparation media shall not exceed 10% in any field of view (approximately 0.04 inch (1.0 mm) length) when viewed at 200X magnification on the cross-sectioned specimen. Any coating separation at the interface will not be acceptable. Separation is defined as gap between the coating and substrate greater than 0.002 inch (0.05 mm) in length following directly along the bond line. Any length less than this will be considered acceptable voids or porosity.

3.6.4 Carbide Distribution

In any 400X field of view, all carbides shall be uniformly distributed with no banding or clustering.

3.6.5 Residual Stress

Coatings shall be evaluated for residual stress by preparing and spraying a standard Almen Type “N” strip in identical fashion as the component being coated. Both the surface to be coated and uncoated surfaces of the Almen strip shall be grit-blasted to minimize curvature of the Almen strip to less than 0.002 inches (0.05 mm) arc height. The arc height of the Almen strip surface to be coated shall be measured after grit-blast surface preparation (first reading) and again after coating application (second reading). The first reading and subsequent coating application shall be with the convex surface of the Almen strip in the up position if the strip is not flat after grit blast and the second reading with the same surface, now coated, in the up position. The Almen strip shall be restrained flat, in the transverse direction by four screws located as indicated in SAE J442 during coating deposition. The measured change in deflection of the Almen strip resulting from the application of the coating shall be reported as the difference of the two readings, second reading minus first reading, and is indicative of the desired compressive coating stresses if the sign of the difference is positive. Acceptable values for Almen type “N” strip arc heights are positive 0.003 to 0.012 inches (0.075 to 0.30 mm) for a 0.005 inch (0.13 mm) thick coating.

3.6.6 The minimum finished coating thickness shall be 0.003 inch (0.076 mm). Areas on which the coating presence is optional shall be exempt from the minimum thickness requirement.

3.7 Test Methods

3.7.1 Bend Test

Test panels shall be approximately 0.05 x 1 x 3 inches (1.3 x 25 x 76 mm) and shall be coated on one side to a thickness of 0.001 to 0.003 inch (0.025 to 0.076 mm). Panels shall be tested by being bent around a 0.5 inch (13 mm) diameter bar, with the coated surface on the outside of the bend, at a rate of approximately ten degrees per second. Panels shall be bent to obtain a 90° permanent set.

3.7.2 Bond Strength

Test specimens shall be bar approximately 1 inch (25 mm) in diameter by 2 inches (51 mm) long and shall be coated to a thickness of 0.009 to 0.012 inch (0.2 to 0.3 mm). Specimens shall be prepared and tested in accordance with ASTM C 633. Adhesive only qualification tests shall be run under the same test conditions to verify integrity of the adhesive.

3.7.3 Microhardness

Test panels shall be approximately 0.05 x 1 x 3 inches (1.3 x 25 x 76 mm) and shall be coated on one side to a minimum thickness of 0.009 inch (0.20 mm). The hardness shall be the average of a minimum of ten evenly spaced indentations in accordance with ASTM E 384.

3.8 Quality

The coating, as received by purchaser, shall be adherent to the basis material and shall have a uniform, continuous surface free from spalling, chipping, flaking, and other imperfections detrimental to usage of the coating.

3.9 Tolerances

Unless otherwise specified by the cognizant engineering organization, a tolerance of -0 to +0.125 inch (3.2 mm) is allowed on the boundaries of the coated area.

3.10 Definition

3.10.1 Lot

A lot shall be all parts of a similar configuration, coated sequentially on the same machine setup using the same batch of coating material and process parameters, within a shift or eight hours of torch time, and presented for processor's inspection at one time.

3.11 Mechanical Coating Removal

Coatings may be removed subject to section 4.6 requirements by mechanical methods such as grinding, or any method approved by the cognizant engineering organization provided original substrate conditions remain unchanged.

3.12 Chemical Coating Removal

Coatings may be removed subject to section 4.6 requirements.

3.12.1 Equipment

3.12.1.1 Tank

A container of adequate volume for the stripping solution and the parts being stripped. The tank must be manufactured from materials such that the structure will not be degraded by the stripping solution.

3.12.1.2 Heaters

Heating devices approved for use with the required solution(s) and capable of reliably maintaining the specified solution temperature.

3.12.1.3 Rectifier

Approved electrical device for delivery of controlled DC current to the electrolytic stripping solution.

3.12.1.4 Controls

Indicating devices used to determine and maintain process temperature and current flow shall have minimum accuracy as follows:

Temperature Gages: ±2% of full scale
Current and Voltage Gages: ±5% of full scale

3.12.1.5 Agitation

Agitation or circulation of the solution shall be accomplished by either pumping low pressure, clean, dry air through the solution, or by mechanical agitation using impeller or propeller driven flow.

3.13 Materials

Approved stripping solutions and their methods of use are shown in Table 1.

TABLE 1 - STRIPPING SOLUTIONS

Solution #	Solution Name	Immersion Use	Electrolytic Use
1	Rochelle Salt		X
2	Nickel Plating Strip Solution (See Note 8.2)	X	

3.14 Preparation

3.14.1 Composition and control of solution is shown in Table 2.

TABLE 2 - SOLUTION 1 - ROCHELLE SALT

Variable	Control Limits
Anhydrous Sodium Carbonate	20-30 oz./gal. (150 to 225 g/L) water (distilled or deionized is preferred)
Sodium Tartrate (Rochelle Salt)	8-12 oz./gal. (60 to 90 g/L) water (distilled or deionized is preferred)
pH	11.0 - 12.0
Temperature	140 to 150 °F (40 to 65 °C) is optimum
Voltage	4 to 6 volts DC
Current Density	4 to 8 A/in^2 (68 to 133 A/dM^2)
Solution Agitation	Use oil-free, compressed air

3.14.2 Solution Processing Requirements

The processing solutions and equipment shall be kept clean at all times. Operations shall be suspended and corrected when the following has occurred:

a. A nonremovable smut is formed or foreign material is deposited on the component surface.
b. The solution temperature or composition is outside the control limits.
c. The solution surface has developed a surface film.
d. The parts have been etched.
e. The coating removal rate has diminished to less than 0.001 inch/hour (25 µm/hour).

3.14.3 Masking

The specified solutions may have an effect on other plated, painted or surface treated areas. Masking of those areas by impermeable means is required.

3.15 Stripping Procedures

3.15.1 Electrolytic Method

Step 1 - A stainless steel cathode is required for this method. The coated part to be stripped is connected to the positive terminal conductor to act as the anode. Connection shall be made such that arcing is prevented.
Step 2 - Immerse the part into Solution #1 operated in accordance with Table 2.
Step 3 - Check progress at least every 45 minutes to remove any accumulated smut. Use Scotch Brite™ or equivalent nonwoven, nonmetallic abrasive mats to remove smut. Removal rate should be approximately 0.002 to 0.006 inch (0.05 to 0.15 mm) of coating per hour.
Step 4 - When coating is adequately stripped, remove the part from the tank and rinse thoroughly with water at room temperature. All remaining coating can be removed by grit blasting prior to reapplication.
Step 5 - Dry part with compressed, dry, oil free air and apply any necessary in-process corrosion preventative compound to prevent corrosion damage while part is in transit.

3.15.2 Non-electrolytic Immersion Method

Step 1 - Immerse part into Solution #2.
Step 2 - Check progress every 45 minutes and remove any accumulated surface smut. Use Scotch Brite™ or equivalent nonwoven, nonmetallic abrasive mats to remove smut. Removal rate should be approximately 0.001 inch (0.03 mm) of coating per hour.
Step 3 - When coating is adequately stripped, remove component from the tank and rinse thoroughly with water at room temperature.
Step 4 - Dry part with compressed air and apply any necessary in-process corrosion preventative compound to prevent corrosion damage while part is in transit.

3.16 Post Strip Processing

3.16.1 The processes outlined above do not involve evolution of atomic hydrogen at the coating surface, or base metal interface. Therefore, there is no susceptibility to hydrogen embrittlement of the component and post processing hydrogen relief bake is not required.

4. QUALITY ASSURANCE

4.1 Responsibility for Inspection

Processor shall supply all test specimens for processor's tests and shall be responsible for the performance of all required tests. When parts are to be tested, the purchaser shall supply such parts. The cognizant engineering organization reserves the right to sample and to perform any conformity testing deemed necessary to ensure that the coating conforms to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

Bend test (3.6.1.1), coating hardness (3.6.2), microstructure (3.6.3), residual stress (3.6.4), thickness, (3.6.5), and tolerances (3.9) are acceptance tests, and shall be performed on each lot. For fatigue sensitive applications, residual stress (3.6.4) should be evaluated periodically as deemed appropriate by the processor and/or anytime process variables are changed.

4.2.2 Periodic Tests

Coating material composition verification (3.2.2) and bond strength (3.6.1.2) are periodic tests and shall be performed at a frequency selected by the processor unless frequency of testing is specified by the cognizant engineering organization.

4.2.3 Preproduction Tests

All technical requirements of this specification are preproduction tests and shall be performed prior to, or on the initial shipment of coated parts to a purchaser. In addition, these tests shall be performed when a significant change in material, and/or processing requires approval as in 4.4.3, and when the cognizant engineering organization requires conformity testing.

4.3 Sampling and Testing

4.3.1 Acceptance Tests

One or more sets of test specimens to represent each lot of parts. See 4.6.

4.3.2 Periodic Tests

Sample quantity shall be selected at the discretion of the processor unless otherwise specified by the cognizant engineering organization.

4.4 Approval

4.4.1 The processor shall establish a written process description of preparation, application, and inspection for each part number. The description shall include control factors and parameters that provide coated parts meeting specified requirements. Control factors considered proprietary by the processor shall be assigned codes within the process description. The processor shall maintain a complete record of proprietary factors and codes. These factors shall include sufficient information to reproduce the process. An example is shown in Figure 1.

4.4.2 The process description and control factors, or first article, whichever is specified, shall be approved by the cognizant engineering organization before production coated parts are supplied.

4.4.3 The processor of coated parts shall make no significant change to the process description, or to the materials, processes, or controls referenced in the process control sheet (see Figure 1) unless the change is approved by the cognizant engineering organization. A significant change is one which could affect the properties or performance of the coating or substrate.

4.5 Reports

Processor shall furnish with each lot a report stating that the parts have been processed and tested in accordance with specified requirements and that they conform to the acceptance test requirements. The report shall include the purchase order number, lot number, AMS2448A, part number, quantity and numerical test results.

4.6 Resampling and Retesting

If any lot acceptance test fails to meet specified requirements, disposition of parts may be based upon the results of a retest on three additional specimens for each nonconforming specimen if coated within the same lot. Except as specified in 4.6.1, 4.6.2, and 4.6.3, failure of any retest to meet specified requirements shall be cause for rejection of parts represented. Results of all tests shall be recorded.

4.6.1 If any lot acceptance test or retest fails to meet specified requirements, the parts in that lot may be stripped, recoated, and retested. Alternatively, all parts in the lot may be inspected for the nonconforming attribute, and nonconforming parts may be stripped, recoated, and retested. After stripping and recoating, parts shall meet the dimensions on the drawing.

4.6.1.1 When stripping is performed, the method shall be acceptable to the cognizant engineering organization and shall not roughen, pit, or embrittle the basis metal or adversely affect part dimensions. When parts have been stripped and replated, the purchaser shall be informed. See 8.6.