MIL-STD-1884(AT)
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SUPERSEDING
(see 6.3)

MILITARY STANDARD

COATING, PLASMA SPRAY DEPOSITION

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DEPARTMENT OF DEFENSE
Washington, DC 20301

Coating, Plasma Spray Deposition

MIL-STD-1884(AT)

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FOREWORD

This Military standard is intended to ensure plasma spray coating operations on parts for military vehicles meet prescribed requirements. This is not an acquisition document.

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1. SCOPE

1.1 Purpose. The procedures covered by this standard are intended to be used to ensure that plasma spray coating operations, either manual or automated, meet prescribed requirements. This process can be used on parts requiring protection from wear, heat, corrosion (with sealer), abrasion and to restore dimensionally discrepant parts.

1.2 Scope. This standard covers the requirements for thermally coating ferrous and nonferrous materials by means of plasma spray deposition.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this standard to the extend specified herein.

SPECIFICATIONS
MILITARY

MIL-P-80109	- Plasma Spray Systems, Powder, Guns, and Accessories.

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the acquisitioning authority or as directed by the contracting officer.)

PUBLICATIONS
US DEPARTMENT OF LABOR

OSHA - Safety and Health Standards
(29 CFR 1910,) General Industry.

(Application for copies should be addressed to the Superintendent of Documents, Government Printing Office, Washington, DC 20402.)

2.2 Other publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

SOCIETY OF AUTOMOTIVE ENGINEERS, INC. (SAE)
SPECIFICATIONS

AMS 2750	- Pyrometry.
AMS 4026	- Aluminum Alloy, Sheet and Plate.
AMS 4117	- Aluminum Alloy, Bars and Rings.
AMS 4901	- Titanium Alloy, Sheet, Strip and Plate.
AMS 4928	- Titanium Alloy, Bars and Forgings.
AMS 6350	- Steel, Sheet, Strip and Plate.
AMS 6382	- Steel, Bars, Forgings, and Rings.
SAE J 877	- Properties of Low Carbon Steel Sheets and Strip and Their Relationship to Formability.

(Copies may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Avenue, Warrendale, PA 15096.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)
STANDARD

ASTM E3	- Standard Methods of Preparation of Metallographic Specimens.
ASTM E407	- Standard Methods for Microetching Metals and Alloys.
ASTM E643	- Conducting a Ball Punch Deformation Test for Metallic Sheet Material, Method for.

(Copies may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

AMERICAN WELDING SOCIETY (AWS)

AWS Welding Handbook, Volume 3 Seventh Edition, Chapter 12 "Thermal Spraying".

(Copies of the above publication may be obtained from the American Welding Society Inc., 550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.)

AMERICAN SOCIETY FOR METALS (ASM)

ASM Handbook, Volume 2 Eighth Edition, "Metal Spraying".

(Copies of the above publications may be obtained from the American Society for Metals, Metals Park, Ohio 44073.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

3. DEFINITIONS.

3.1 Rotating part. Rotating parts are defined as those turning on an axis such as bearing plates, discs, hubs, shafts, etc.

3.2 Non-rotating (stationary) part. Non-rotating parts are defined as nonmoving or fixed parts.

3.3 Plasma lot. A plasma lot shall consist of all the parts (with the same part number) plasma sprayed by the same operator per shift using the same process and equipment and the same powder lot.

3.4 Powder lot. A powder lot shall be all the powder of a specified type with the same batch lot number to be used for coating.

3.5 Simulated part. A simulated part is a test piece or section with a similar surface configuration to the part it represents. The simulated part shall be approved by the acquisitioning authority materials laboratory.

4. GENERAL REQUIREMENTS

4.1 Equipment.

4.1.1 Plasma spray gun. The plasma spray gun shall be a specially constructed torch that disassociates and ionizes a suitable plasma gas when a high voltage arc is struck between an anode and cathode. The gun shall provide for the injection of powder materials into a high velocity flame and high temperature arc wherein the powder materials can be heated to plasticity and propelled toward the workpiece to be coated (ref. MIL-P-80109).

4.1.2 Automatic spray equipment. When the plasma spray process is done by automated equipment, the preheating and process temperature checks may be waived providing prior approval is obtained in writing from the acquisitioning authority materials laboratory.

4.1.3 Cup test machine. A cup test machine equipped with dies as specified in ASTM E643 to form a spherical cup shape shall be used for determining bond adhesion (see 6.2). This machine shall be utilized to conduct cup tests on coated panels prepared in accordance with 5.1.2.1. These panels shall meet requirements after testing as specified in 5.2.2.

4.2 Material.

4.2.1 Plasma gas. Unless otherwise specified, the plasma gas shall be any of the following:

a. Nitrogen (N_2).
b. Mixture of nitrogen and hydrogen ($N_2 + H_2$) (see 4.2.1.1).
c. Argon (Ar).
d. Mixture of argon and hydrogen ($Ar + H_2$).
e. Mixture of argon and helium (Ar + He).

Note: Nitrogen shall not be used for spraying titanium parts.

4.2.1.1 Restrictions. Plasma gas consisting of nitrogen or nitrogen mixtures shall only be used when approved by the acquisitioning authority materials laboratory.

4.2.2 Coating powder. The powder for coating shall be as specified on the engineering drawing. It shall be dry, free flowing, and thoroughly blended.

4.2.3 Bonding adhesive. The adhesive bonding material used for the bond strength test shall be capable of producing a tensile bond strength greater than the strength of the coating material to be tested.

4.3 Required procedures and operations.

4.3.1 Surface machining. When required, surfaces may be machined undersize or holes oversize to allow for finish thickness of the coating.

4.3.2 Heat treatment. When required, the heat treatment of parts shall be performed before coating.

4.3.3 Surface treatments. Unless otherwise specified, all surface treatments (e.g., black oxide, phosphate, anodize, etc.) as specified on the engineering drawing, shall be done after plasma spraying.

4.3.4 Surface preparation.

4.3.4.1 Cleaning. Part surfaces shall be clean and free from moisture, oil, grease, dirt, scale, paint or other foreign matter detrimental to plasma spraying. Parts shall be thoroughly cleaned by vapor degreasing or washing in petroleum solvents. Other solvents may be used providing the solvents leave no residue on the work surface. The chloride content for all liquids used for cleaning or rinsing titanium and titanium alloy parts shall not exceed 200 parts per million (ppm).

4.3.4.2 Handling and storage:

a. Handling. All surfaces requiring plasma spraying shall be handled with clean lint-free gloves, tongs, or other means that will preclude surface contamination.

b. Storage. If a delay in spraying occurs beyond 2 hours but less than 20 hours, special measures shall be employed to protect the surface to be coated from dust, dirt, moisture, etc. Protection shall be in the form of covering or inserting the parts in clean plastic bags. Alternative methods may be to store parts overnight in a moderate temperature oven maintained at 200 $\pm$ 5 degrees Fahrenheit (°F) or in a vacuum chamber under low pressure. Should the delay in spraying, after proper surface preparation, exceed 20 hours the parts shall be reprocessed in accordance with 4.3.4.1.

4.3.4.3 Overspray protection. Areas adjacent to the area to be plasma spray coated shall be suitably protected from overspray by masking or shielding.

4.3.4.3.1 Tolerances. Unless otherwise specified on the engineering drawing, a tolerance of -0 and + 1/8 inch shall be allowed on the boundaries of areas designated to be coated.

4.3.5 Abrasive blast. All surfaces designated for plasma coating shall be roughened by abrasive blasting with the coarsest nonmetallic abrasive practical for the specified base material.

4.3.6 Preheating. Unless otherwise specified (see 4.1.2), surfaces shall be preheated by a suitable and controllable source. The following shall apply:

a. Preheating is performed to remove moisture and minimize the thermal shock encountered during deposition.

b. Temperature of the part, during the preheating and coating application, shall be controlled to prevent discoloration, oxidation, distortion and other conditions determined by the coating or substrate.

c. Temperature of the part after preheat and prior to spraying shall be measured using the appropriate pyrometric devices in accordance with AMS 2750.

CAUTION: Special care must be taken to avoid overheating the lower temperature melting nonferrous alloys such as aluminum and magnesium.

4.3.7 Coating deposition. The coating material shall be deposited on the designated surfaces to a sufficient thickness to provide, after subsequent operations, a finished coating thickness which will meet the engineering drawing dimensions.

4.3.7.1 Process control. Process control procedures shall be checked during plasma spraying to assure the specified operating parameters on the control sheet are maintained (see table I).

4.3.8 Substrate cooling. Because the plasma flame imparts a large amount of heat to the workpiece, rapid dissipation of heat at the point of flame to work contact is necessary to prevent overheating and oxidation of the deposits. Most substrate materials should not be permitted to exceed 400°F during spraying. Substrate cooling is usually achieved by internal circulation of cold water, or by an external blast of gas (air, nitrogen, carbon dioxide, or argon) impinging on the substrate on both sides of the torch flame.

4.3.9 Sealing (post treatment). When specified, coated parts shall be sealed to extend their service life or prevent corrosion of the substrate. The appropriate sealer may be applied to fill only subsurface pores in the deposit or both subsurface irregularities. The latter technique will provide a smooth coating to resist industrial atmospheres. There are various sealers designed for specific requirements; more specific information may be obtained from either the ASM Handbook Volume 2, Eighth Edition, or the AWS Handbook, Volume 3, Seventh Edition.

4.3.10 Identification. Each coated part shall be identified by applying the symbol (S) as a prefix to the serial number [eg., (S) S/N 1234] or as a prefix to the Federal manufacturer code on nonserialized parts. The prefix shall be applied in the same manner as specified on the engineering drawing for the part number.

4.4 Operator certification.

4.4.1 Plasma spray operator. The plasma spray operator shall demonstrate to the acquisitioning authority and supplier metallurgical engineer suitable proficiency in the operation of the plasma spray equipment and in the performance of other related items by successfully preparing and coating a set of test panels and specimens as described in 5.1.2 through 5.1.2.3. In the event an operator fails the test, the operator shall be

permitted to submit two more samples of the test panels or specimens which failed to pass the specified test. If any of the second set fail to conform to the specified acceptance requirements, the operator shall be disqualified. If re-examination is still desired after failing to pass the second set the operator shall be required to submit a complete series of qualification test panels and specimens as specified in 5.1.2 through 5.1.2.3. In addition, the operator shall be required to submit one additional set of the test panels or specimens which resulted in the initial disqualification. A plasma spray operator of semi-automatic or automatic equipment shall meet all the requirements of a manual spray operator.

4.4.1.1 Continuance of qualification. The qualification status of a plasma spray operator may be maintained by a continuous record of satisfactory proficiency or by annually successfully preparing and coating a set of test panels and specimens as described in 5.1.2.1 thru 5.1.2.3. Requalification of a plasma spray operator shall be required when there is evidence of a lack of proficiency as determined by a metallurigical engineer evaluating test panels and specimens.

5. DETAIL REQUIREMENTS

5.1 General.

5.1.1 Qualification. To ensure supplier capability to consistently deliver a satisfactory product, the supplier facilities and general procedures shall be qualified before parts for production are supplied unless such qualification is waived by the acquisitioning authority materials laboratory.

5.1.1.1 Qualification samples. The supplier shall submit test samples as specified in 5.1.2, together with the sample parts required for examination by the acquisitioning authority materials laboratory. The supplier shall plasma spray the coating and base metal combination as specified by the acquisitioning authority. Sample parts submitted shall be prepared in accordance with 5.1.3.2.

5.1.1.2 Requalification. In the event a supplier has not supplied plasma sprayed parts or test specimens for over 1 year, the supplier shall be required to requalify in a manner specified by the acquisitioning authority materials laboratory.

5.1.2 Test samples. A minimum of two panels for cup test, one panel for microexamination and two bond strength specimens shall be plasma sprayed. The cup, and microscopic examination panels and bond specimens shall be fabricated from the materials specified in table II.

5.1.2.1 Cup test panels. Cup test panels shall be prepared as follows:

a. Size: 3.00 X 1.75 X 0.050 inches.
b. Material: Alloy specified in table II.
c. Coating: Suitable for service environment or as otherwise specified by acquisition authority.
d. Coating thickness: 4 to 6 mils or 2 to 4 mils when specified by the acquisitioning authority.

5.1.2.2 Microscopic test panel. The same material and requirements as the cup test panel shall apply to the microscopic test panel (5.1.2.1). Specimen configuration other than the shape specified shall require the approval of the acquisitioning authority materials laboratory.

5.1.2.2.1 Metallographic test sample. Metallographic test samples shall be prepared in accordance with 5.1.2.1 and plasma sprayed along with the first production lot of parts and each subsequent plasma lot (see 3.3) and submitted to the acquisitioning authority with the parts. When approved by the acquisitioning authority materials laboratory, the plasma spray supplier may submit microphotographs of the coating in lieu of the test samples.

5.1.2.3 Bond strength specimens. Bond strength specimens shall be prepared as follows:

a. Size. Two specimens to the dimensions as specified in figure 1. Other specimen configurations may be used providing written permission is obtained from the acquisitioning authority material laboratory.
b. Material. One specimen of the selected alloy as specified in 5.1.2 and one specimen of any suitable material for the uncoated end of the test specimen.
c. Coating. Only the specimen of the similar alloy as the parts being coated is to be coated using the coating material as specified by the acquisitioning authority.

Note: The uncoated specimen shall be suitably identified (e.g., slotted along the outside diameter).

d. Coating thickness. 9 to 12 mils.

5.1.3 Process approvals.

5.1.3.1 Processing data. Operation sheets covering the coating process shall be established for each part number by the plasma spray source. Table I shows a typical operation sheet, the format is optional provided all pertinent information is shown. Processing procedures shall not be dependent upon part function (rotating versus nonrotating) or the critical nature when in service. The engineering requirements as specified on the drawing shall prevail during any acceptance testing.

5.1.3.2 Sample part. A sample part, or a simulated part shall be processed in accordance with the procedure established in 5.1.3.1 and submitted to the acquisitioning authority for approval prior to production parts being plasma sprayed.

5.1.3.3 Rework. Rework of descrepant parts with damaged or imperfect coatings, shall be reworked by a qualified source approved by the acquisitioning authority. The number of reworks will also be an acquisitioning authority decision based on degree descreptant and method of repair.

5.1.3.3.1 Stripping. Reworking to completely remove the defective coating is permissable by mechanical methods. Nonmechanical (chemical) stripping shall be subject to approval of the acquisitioning authority.

5.1.4 Process certificaton. Unless otherwise specified, the supplier shall furnish three copies of a certificate stating the following information:

a. Purchase order number.
b. Part number and revision letter.
c. Serial number of parts coated (when applicable).
d. Plasma lot numbers.
e. Quantity and serial numbers of rejected parts stripped and recoated.
f. Test results per 5.2.1 through 5.2.4.
g. Statement of conformance to this standard, latest revision.

5.2 Test methods.

5.2.1 Visual. All parts and assemblies, (before and after machining), test panels, and test specimens, shall be visually inspected to verify that plasma coating is adherent to the substrate material and has a uniform continuous surface free from spalling, chipping, flaking, cracking, and other objectionable imperfections.

5.2.2 Cup test. A test panel (see 5.1.2.1) shall be cup tested to verify conformance to the applicable coating material specification requirements as follow:

a. Draw the panel on a testing machine equipped with dies (see 4.1.3) to form a cup shape as specified in ASTM E643. The test panel shall be drawn at a prescribed rate with the coated side of the panel being opposite the punch.
b. Draw the panel to the depth specified in the applicable coating material specification.
c. Examine coated surface of panel for indications of coating failure. Cracking shall be acceptable provided there is no evidence of flaking or spalling. Flaking or spalling of the coating shall be rejected.

Note: Other devices may be used for cup testing provided equivalent results are obtained and it is approved by the acquisitioning authority materials laboratory.

5.2.3 Bond strength test. Two bond strength test specimens (see 5.1.2.3) shall be bonded together to form a single test specimen and the test specimen shall be bond strength tested to verify conformance to the applicable coating material requirements as follow:

a. Remove masking materials.
b. Verify that bonding end of the uncoated section of the test specimen has been cleaned, dried, and abrasive-blasted.
c. Apply an adhesive (see 4.2.3) to the bonding ends of the coated and uncoated sections of the test specimen.
d. Accurately align and join the ends of the two specimens.

Note: A fixture may be used to facilitate bonding of the test specimen.

e. Cure the adhesive in a hot air circulating oven at the temperature recommended by the manufacturer.
f. After bonding, dress the edge of the coating flush with the outside diameter of the test specimen.

Note: An abrasive disc or wheel may be used for this purpose but care shall be taken that the disc or wheel moves parallel to the centerline of the test specimen. Care shall be taken during dressing to ensure the temperature does not increase to affect the bond adhesion.

g. Test the bond specimen with a standard laboratory tensile tester equipped with universal joint grippers for each end of the joined specimens. Set the no-load cross-head speed at approximately 0.050 inch (1.27 mm) per minute.

5.2.4 Micro examination. A microscopic examination of a specimen cut normal to the coating surface shall not reveal any cracks, excessive or massive oxides or porosity when examined at an appropriate magnification in the etched and unetched condition in accordance with the procedures outlined in ASTM E3 and ASTM E407.

5.2.4.1 Oxides and porosity. Excessive or massive oxides or porosity shall be defined as not greater than 3% and 1% respectively, when viewed at 100X after etching. A minimum of 16 square inches (4" x 4") of field shall be viewed at 100 X for this purpose.

Note: The metallurgical specimen initially approved for a particular plasma spray application shall be the minimum acceptance standard for that plasma spray applicaton.

6. NOTES

6.1 Safety. Use of plasma spray equipment involves exposure to certain safety hazards specified in "OSHA Safety and Health Standards (29 CFR 1910), General Industry".

6.2 Cup test machine. The base machine to be used for this test shall be the industry accepted model available from Detroit Testing Machine Co., Detroit, Michigan or an approved equivalent (see 4.1.3).

6.3 Supersession data. This standard supersedes AVCO Lycoming Division, Stratford, Connecticut, specification No. P6405D entitled "Coating, Plasma Spray Deposition", dated 27 January 1983.

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(Project No. MFFP-A256)

TABLE I. Typical plasma spray control sheet.
Sheet ____ of ____.

VENDOR _____ VENDOR PROCESS # _____
PURCHASE ORDER NUMBER _____
PART NUMBER _____ S/N _____
AREA TO BE COATED _____
PART MATERIAL _____
GUN TYPE _____ GUN MODEL _____ NOZZLE _____

PART PREPARATION

METHOD OF CLEANING _____
MASKING INFORMATION _____
GRIT TYPE AND SIZE _____
GRIT BLAST PRESSURE (PSI) _____ ± Suction _____ Pressure _____
NOZZLE TO WORK DISTANCE _____

ARC GAS

GAS (1) PRIMARY _____
GAS (2) SECONDARY _____

Regulator (1)	PSI _____	±
Regulator (2)	PSI _____	±
Console (1)	PSI _____	±
Console (2)	PSI _____	±
Console Flow (1)	C.F.H. _____	±
Console Flow (2)	C.F.H. _____	±

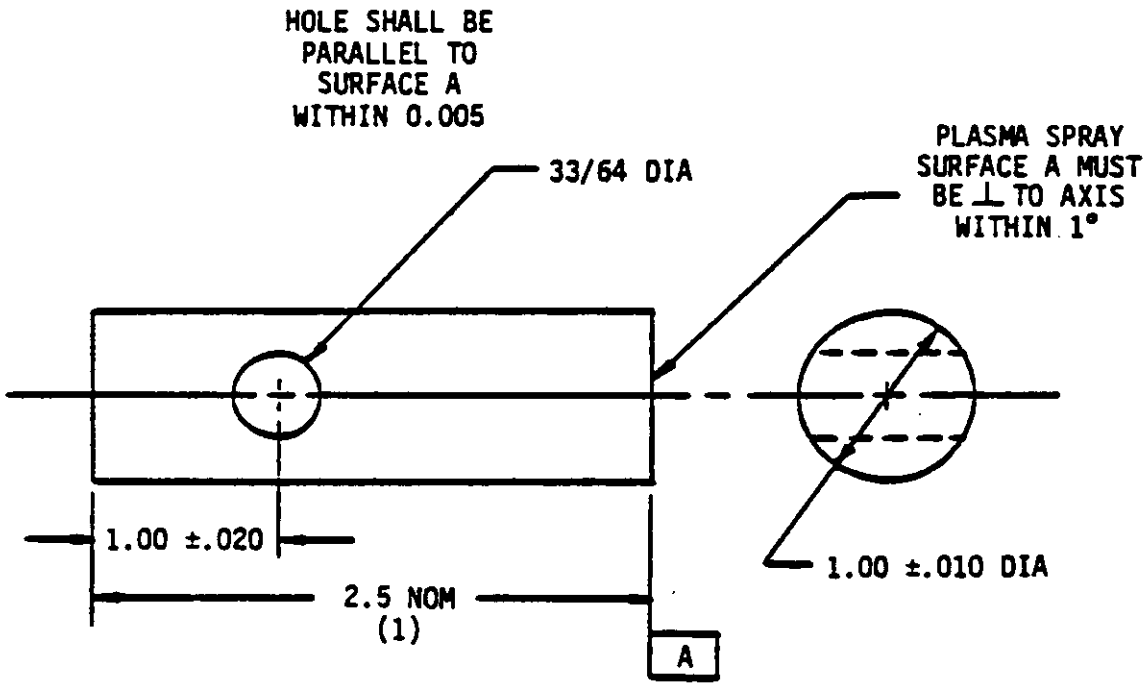
POWER
Voltage DC Operating _____ ±
Amperes DC Operating _____ ±

COATING MATERIAL
Material Specification _____ Other _____
Material Lot # _____

COATING DATA
Elapsed Time Between Surface Prep and Spraying _____
Powder Feed Rate (LB/HR) _____
Powder Port _____ Meter Wheel _____
Gun to Work Distance _____ Carrier Gas Flow _____
Minimum Gun to Work Angle _____
Part RPM _____ ± _____ Surface Feed/Min _____ ±
Coating Thickness as Sprayed _____
Preheat Temp _____ ± Method of Preheat _____
Max Part Temp During Spraying _____
Number of Passes Per Cycle _____
Cool Timer Per Cycle _____ ±
Method of Cooling Air _____ Gas ___ Static _____
Total Number of Cycles (Cool & Spray) _____ ±
CERTIFICATION # _____
APPROVAL _____

TABLE II. Materials for test specimens.

Part base material	Bond specimens	Cup and micro specimens
Steel, nickel, cobalt	AMS 6382	AMS 6350
Titanium or titanium alloys	AMS 4928	AMS 4901
Aluminum or aluminum alloys	AMS 4117	AMS 4026
Magnesium or magnesium alloys	As specified by acquisitioning authority.	



NOTE:

(1) Actual specimen length may be varied to suit test facilities.
(2) All dimensions are given in inches.

FIGURE 1. Bond strength test specimen.

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c. Reason/Rationale for Recommendation:

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