AEROSPACE MATERIAL SPECIFICATION

AMS2401™	REV. L
Issued 1963-07 Revised 2024-12 Superseding AMS2401K	

Plating, Cadmium
Low Hydrogen Embrittlement Process

RATIONALE

AMS2401L is the result of a Five-Year Review and update of this specification with changes to Ordering Information, Purpose (see 1.1), Stress-Relief Treatment (see 3.1.2.3), Fixture/Electrical Contact Points (see 3.1.5), Hydrogen Embrittlement Relief Treatment (see 3.3.1), Post-Treatment (see 3.3.2), Thickness (see 3.4.1.4.1), Adhesion (see 3.4.2), Quality (see 3.5), Periodic Tests (see 4.2.2.1), Sampling and Testing (see 4.3), Adhesion Testing (see 4.3.3.2), Corrosion Testing (see 4.3.3.3), control factors (see 4.4.3), and Notes (see 8.2, 8.3, and 8.8).

NOTICE

ORDERING INFORMATION: The following information shall be provided to the plating processor by the purchaser:

1. Purchase order shall specify not less than the following:

- AMS2401L
- Plating thickness desired (see 3.4.1)
- Basis metal to be plated
- Tensile strength or hardness of the basis metal
- If preplate stress relief is to be performed by plating processor and if different from 3.1.2, time and temperature are to be specified
- If steel parts were machined, ground, cold formed, or cold straightened after heat treat (see 3.1.2)
- If steel parts have been shot peened, specify if required stress relief has been completed (see 3.1.2.3)
- Special features, geometry, or processing present on parts that requires special attention by the plating processor
- Hydrogen embrittlement relief to be performed by plating processor (parameters or reference document) if different from 3.3.1
- Minimum thickness on internal surfaces, if required (see 3.4.1.4.1)

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

For more information on this standard, visit
https://www.sae.org/standards/content/AMS2401L/

- Optional: periodic testing frequency (see 4.2.2) and sample quantity (see 4.3.2)
- Quantity of pieces to be plated
- Optional: fixture/electrical contact locations, when not specified (see 3.1.5)

2. Parts manufacturing operations such as heat treating, forming, joining, and media finishing can affect the condition of the substrate for plating or, if performed after plating, could adversely affect the plated part. The sequencing of these types of operations should be specified by the cognizant engineering organization or purchaser and is not controlled by this specification.

3. Part manufacturing operations, such as heat treatment, forming, joining, and media finishing, can affect the condition of the substrate for plating or, if performed after plating, could adversely affect the plate. The sequencing of these types of operations should be specified by the cognizant engineering organization and is not controlled by this specification.

4. The parts manufacturer shall ensure that surfaces of metal parts supplied to the processor are free from blemishes, pits, tool marks, and other irregularities that will affect the quality of the finished parts (see 3.5).

1. SCOPE

1.1 Purpose

This specification covers the engineering requirements for cadmium deposited on ferrous and nonferrous metals using a low hydrogen embrittlement (LHE) electroplating process.

1.2 Application

This process has been used typically to provide corrosion resistance to steel parts heat treated to tensile strengths of 180 ksi (1241 MPa) and higher and used at temperatures not higher than 450 °F (232 °C), but 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 that 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.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2451 Plating, Brush, General Requirements

AMS2750 Pyrometry

AMS2759/9 Hydrogen Embrittlement Relief (Baking) of Steel Parts

ARP4992 Periodic Test for Processing Solutions

AS2390 Chemical Process Test Specimen Material

AS7766 Terms Used in Aerospace Metals Specifications

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 B117 Operating Salt Spray (Fog) Apparatus

ASTM B253 Preparation of Aluminum Alloys for Electroplating

ASTM B374 Terminology Relating to Electroplating

ASTM B487 Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section

ASTM B499 Measurement of Coating Thicknesses by the Magnetic Method; Nonmagnetic Coatings on Magnetic Basis Metals

ASTM B504 Measurement of Thickness of Metallic Coatings by the Coulometric Method

ASTM B567 Method for Measurement of Coating Thickness by the Beta Backscatter Method

ASTM B568 Measurement of Coating Thickness by X-Ray Spectrometry

ASTM B571 Qualitative Adhesion Testing of Metallic Coatings

ASTM B748 Measurement of Thickness of Metallic Coatings by Measurement of Cross Section with a Scanning Electron Microscope

ASTM B764 Test Method for Simultaneous Thickness and Electrode Potential Determination of Individual Layers in Multilayer Nickel Deposit (STEP Test)

ASTM F519 Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments

2.3 Definitions

Terms used in AMS are defined in AS7766.

3. TECHNICAL REQUIREMENTS

3.1 Preparation

3.1.1 Parts shall be within drawing dimension limits before plating, except as specified in 3.1.1.1.

3.1.1.1 In lieu of the requirement of 3.1.1 and unless otherwise specified on the drawing, all engine and propeller utility parts having part numbers with the prefix MS or AS and required to be plated in accordance with this specification shall be made to such dimensions that parts will be within drawing limits after plating. Undercutting before plating shall not be permitted unless specifically authorized by specifications referenced on the applicable drawing.

3.1.2 Stress-Relief Treatment

All steel parts having a hardness of 36 HRC and above and that are machined, ground, cold formed, or cold straightened after heat treatment shall be cleaned to remove surface contamination and then thermally stress relieved before plating. (Residual tensile stresses have been found to be damaging during electroplating.) Furnaces used for stress relief shall be controlled per AMS2750; the minimum requirements shall be Class 5 and Type D instrumentation. Temperatures to which parts are heated shall be such that maximum stress relief is obtained while still maintaining hardness of parts within drawing limits. Unless otherwise specified, the following treatment temperatures and times shall be used:

3.1.2.1 For parts, excluding nitrided parts, having a hardness of 55 HRC and above, including carburized and induction hardened parts, stress relieve at 275 °F ± 25 °F (135 °C ± 14 °C) for 5 to 10 hours.

3.1.2.2 For parts having a hardness less than 55 HRC and for nitrided parts, stress relieve at 375 °F ± 25 °F (191 °C ± 14 °C) for a minimum of 4 hours. Higher temperatures shall be used only when specified or approved by the cognizant engineering organization.

3.1.2.3 For peened parts, if stress-relief temperatures above 375 °F (191 °C) are specified, the stress relief shall be performed prior to peening.

3.1.3 Any specified residual compressive stress-inducing operations, such as shot peening, shall precede plating.

3.1.4 Cleaning

The plating shall be applied over a surface free from water breaks. The cleaning procedure shall not produce pitting or intergranular attack of the basis metal and shall preserve dimensional requirements (see 8.5).

3.1.5 Fixture/Electrical Contact Points

3.1.5.1 Except for barrel plating, for parts that are to be electroplated all over, and contact locations are not specified, contact locations shall be at the discretion of the processor.

3.1.5.2 For parts that are not to be electroplated all over and contact locations are not specified, contact locations may be in areas on which plate is not required or may be in the areas being plated provided the parts are moved to prevent contact marks/voids within the plating/coating.

3.1.5.3 Alternative methods for process completion of fixture contact points is permitted when approved by the cognizant engineering organization (see 8.8)

3.1.6 Aluminum alloys shall be zincate treated in accordance with ASTM B253 or other method acceptable to the cognizant engineering organization prior to plating.

3.2 Procedure

3.2.1 Parts shall be plated by electrodeposition of cadmium from a suitable cadmium plating solution without brighteners directly on the basis metal without a prior strike of other metal, such as copper or nickel, except in the case of parts fabricated from corrosion-resistant steel or similarly passive alloys on which a preliminary strike of nickel or other suitable metal is permissible.

3.2.2 Spotting-in and double plating are prohibited (see 8.9).

3.3 Post-Treatment

3.3.1 Hydrogen Embrittlement Relief Treatment (Baking)

Bake in accordance with AMS2759/9.

3.3.2 Following hydrogen embrittlement relief baking, plating may be reactivated (see 8.4), and parts shall be immersed in a 3 to 6% solution of chromic acid, followed by rinsing and drying.

3.4 Properties

3.4.1 Thickness

The finished thickness shall be as specified, determined on representative parts or on test specimens in accordance with ASTM B487, ASTM B499, ASTM B504, ASTM B567, ASTM B568, ASTM B748, ASTM B764, direct dimensional inspection provided the resolution of the measuring instrument is ten times more precise than the attribute being measured, or other method permitted by the cognizant engineering organization.

3.4.1.1 Plate thickness may be specified by AMS2401 and a suffix number normally designating the minimum thickness in ten-thousandths of an inch (µm); except as indicated in Table 1, the maximum plate thickness shall be 0.0002 inch (5 µm) greater than the minimum. Thus, AMS2401-2 designates a thickness of 0.0002 to 0.0004 inch (5 to 10 µm) and AMS2401-6 designates a thickness of 0.0006 to 0.0008 inch (15 to 20 µm).

3.4.1.1.1 Plate thickness, when specified by AMS2401 and a suffix number, shall be as stated in Table 1 for the specified suffix number and type of part or surface.

3.4.1.2 Where “flash” is specified, flash plate thickness shall be approximately 0.0001 inch (2.5 µm).

3.4.1.3 The plate shall be substantially uniform in thickness on significant surfaces except that slight buildup on exterior corners or edges will be permitted provided finished drawing dimensions are met.

3.4.1.4 See Table 1 for thickness requirements on listed surfaces. All other surfaces of the part that cannot be touched by a sphere 0.75 inch (19 mm) in diameter, such as holes, recesses, threads, and other areas where a controlled deposit cannot be obtained under normal plating conditions, may be under the specified limit provided they show visual plating coverage. Such surfaces shall not be masked to prevent plating.

3.4.1.4.1 If specified, internal surfaces, as defined in 3.4.1.4, are to be plated to the specified thickness.

Table 1A - Plate thickness and salt spray corrosion resistance requirements, inch/pound units

AMS2401 Thickness Designation Specified[1]	External Threads Thickness Inches	External Threads Salt Spray Resistance Hours, Min	Nuts, Washers, and Unthreaded Surfaces of Bolts, Screws, Studs, and Other Parts Externally Threaded Thickness Inches	Nuts, Washers, and Unthreaded Surfaces of Bolts, Screws, Studs, and Other Parts Externally Threaded Salt Spray Resistance Hours, Min	Parts Not Externally Threaded Except Nuts and Washers Thickness Inches	Parts Not Externally Threaded Except Nuts and Washers Salt Spray Resistance Hours, Min
2401	0.0001 to 0.0004	100	0.0002 to 0.0005	150	0.0003 to 0.0005	200
2401-1	0.0001 to 0.0003	100	0.0002 to 0.0004	150	0.0001 to 0.0003	100
2401-2	0.0001 to 0.0004	100	0.0002 to 0.0004	150	0.0002 to 0.0004	150
2401-3	0.0002 to 0.0005	150	0.0003 to 0.0005	200	0.0003 to 0.0005	200
2401-4	0.0003 to 0.0006	200	0.0004 to 0.0006	225	0.0004 to 0.0006	225
2401-5	0.0004 to 0.0007	225	0.0005 to 0.0007	250	0.0005 to 0.0007	250

[1] For thickness designations AMS2401-X, where X is greater than 5, plate thickness in ten-thousandths of an inch shall be X to X+2 except on external threads, where the plate thickness shall be X-1 to X+2; such parts shall withstand salt spray for not less than 240 hours.

Table 1B - Plate thickness and salt spray corrosion resistance requirements, SI units

AMS2401 Thickness Designation Specified[1]	External Threads Thickness Millimeters	External Threads Salt Spray Resistance Hours, Min	Nuts, Washers, and Unthreaded Surfaces of Bolts, Screws, Studs, and Other Parts Externally Threaded Thickness Millimeters	Nuts, Washers, and Unthreaded Surfaces of Bolts, Screws, Studs, and Other Parts Externally Threaded Salt Spray Resistance Hours, Min	Parts Not Externally Threaded Except Nuts and Washers Thickness Millimeters	Parts Not Externally Threaded Except Nuts and Washers Salt Spray Resistance Hours, Min
2401	0.002 to 0.010	100	0.005 to 0.012	150	0.008 to 0.012	200
2401-1	0.002 to 0.008	100	0.005 to 0.010	150	0.002 to 0.008	100
2401-2	0.002 to 0.010	100	0.005 to 0.010	150	0.005 to 0.010	150
2401-3	0.005 to 0.012	150	0.008 to 0.012	200	0.008 to 0.012	200
2401-4	0.008 to 0.015	200	0.010 to 0.015	225	0.010 to 0.015	225
2401-5	0.010 to 0.018	225	0.012 to 0.018	250	0.012 to 0.018	250

[1] For thickness designations AMS2401-X, where X is greater than 5, plate thickness in millimeters shall be 0.0025X to 0.0025 (X+2) except on external threads, where the plate thickness shall be 0.0025 (X-1) to 0.0025 (X+2); such parts shall withstand salt spray for not less than 250 hours.

3.4.2 Adhesion

Adhesion shall be tested for in accordance with ASTM B571 using the bend test method except without using a mandrel. After bending, use a sharp knife to try and pry the coating and examine the surface at approximately 5X magnification for evidence of flaking or separation.

3.4.3 Corrosion Resistance

Except as specified in 3.4.3.1, carbon and alloy steel parts or representative test panels plated to a thickness of 0.0003 to 0.0005 inch (0.008 to 0.013 mm) shall show no visual evidence of corrosion of the basis metal after being subjected for a time not less than 200 hours to the continuous salt fog corrosion test conducted in accordance with ASTM B117.

3.4.3.1 Salt spray corrosion tests shall not apply to plated parts made of austenitic corrosion-resistant steels, to parts made of any corrosion-resistant steel or alloy when not plated all over, and to parts made of any steel when thickness is specified as “flash.”

3.4.4 Hydrogen Embrittlement

The plating process after baking shall not cause hydrogen embrittlement in steel parts HRC 36 and over when tested in accordance with 4.3.3.3.

3.5 Quality

Plated cadmium, as received by the purchaser, shall be continuous, adherent to basis metal, uniform in appearance, and essentially free from pin holes, porosity, blisters, nodules, pits, and other imperfections detrimental to usage of the plating. Slight staining or discoloration is permissible.

3.5.1 Imperfections in appearance that arise from surface conditions of the substrate, such as weld areas, variations in surface finish roughness, porosity, scratches, or inclusions, that persist in the finished plating/coating despite observance of industry-accepted plating practices shall not be considered as cause for rejection (see 8.3).

3.5.2 If the plating is specified to be subsequently ground or machined, the above requirements are not required to be inspected for.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The processor shall supply all samples for the processor's tests and shall be responsible for the performance of all required tests. When parts are to be tested, such parts shall be supplied by the purchaser. The purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that processing conforms to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

Thickness (see 3.4.1) and quality (see 3.5) are acceptance tests and shall be performed on parts, or samples representing parts when permitted, from each lot.

4.2.2 Periodic Tests

Corrosion resistance (see 3.4.3) is a periodic test and shall be performed at least quarterly unless frequency of testing is specified by the cognizant engineering organization. Adhesion (see 3.4.2) is a periodic test that shall be performed no less than daily for each generic class of alloy as defined by AS2390 processed during that day. Tests of cleaning and processing solutions are periodic tests and shall be performed at a frequency established by the processor unless frequency of testing is specified by the cognizant engineering organization (see 4.4.3 and 8.6). Hydrogen embrittlement (see 3.4.4) is a periodic test and shall be performed in accordance with ASTM F519 at least once in each month that steel parts 36 HRC and over are plated unless frequency of testing is specified by the cognizant engineering organization.

4.2.2.1 Periodic testing may be suspended in any test period when parts are not processed but shall be performed before or at time such processing is resumed. Preproduction testing may be required by the cognizant quality organization upon resumption of processing.

4.2.3 Preproduction Tests

All property verification tests (see 3.4) are preproduction tests and shall be performed prior to production and when the cognizant engineering organization requires confirmatory testing.

4.3 Sampling and Testing

Shall be not less than the following: A lot is a group of parts, all of the same part number, processed through the same chemical solutions in the same tanks under the same conditions, that have completed the chemical processing within a period of 24 hours of each other and are presented to inspection at the same time.

4.3.1 Acceptance Tests

Test samples shall be randomly selected from all parts in the lot. Unless the cognizant engineering organization provides a sampling plan, the minimum number of samples shall be as shown in Table 2.

Table 2 - Sampling for acceptance tests

Number of Parts in Lot	Quality	Thickness
Up to 7	All	All or 3[1]
8 to 15	7	4
16 to 40	10	4
41 to 110	15	5
111 to 300	25	6
301 to 500	35	7
501 to 700	50	8
Over 700	75	10

[1] Whichever is less.

4.3.2 Periodic Tests

Sample size shall be four for corrosion resistance and as specified in ASTM F519 for hydrogen embrittlement unless otherwise specified by the cognizant engineering organization. For adhesion tests, four test specimens of each generic class of alloy, as defined by AS2390, that have been processed through the same cleaning and plating operations as the parts that they represent. These adhesion test specimens shall be processed prior to the first production lot of parts or with the first production lot of parts.

4.3.3 Sample Configuration

4.3.3.1 Separate test specimens may be used under any one of the following circumstances:

4.3.3.1.1 The plated parts are of such configuration or size as to be not readily adaptable to specified tests.

4.3.3.1.2 Nondestructive testing is not practical on actual parts.

4.3.3.1.3 It is not economically acceptable to perform destructive tests on actual parts. Except as specified below, acceptance test specimens shall be made of the same generic class of alloy as the parts, established in accordance with AS2390, distributed within the lot, cleaned, plated, and post-treated with the parts.

4.3.3.2 Adhesion Testing

Test specimens for adhesion testing (see 3.4.2) shall be made of the same generic class of alloy as defined by AS2390 as the parts processed. The test specimens shall be 0.025 inch (0.64 mm) minimum thickness and not less than 1 x 4 inches (25 x 102 mm).

4.3.3.3 Corrosion Testing

Test specimens for corrosion testing (see 3.4.3) shall be 0.025 inch (0.64 mm) minimum thickness and not less than 4 x 6 inches (102 x 152 mm).

4.3.3.4 Hydrogen Embrittlement Test

Test shall be in accordance with the requirements of ASTM F519 Type 1a.1 using round notched specimens, unless a different specimen is specified by the cognizant engineering organization, stressed in tension under sustained load. For test purposes, the plating thickness shall be 0.0005 to 0.0007 inch (13 to 18 µm) measured on the smooth unnotched section of the specimen but with visual plating at the root of the notch. Testing beyond the 200-hour test period is not required.

4.4 Approval

4.4.1 The process and control factors, and/or a preproduction part, whichever is specified, shall be approved by the cognizant engineering organization before production parts are supplied.

4.4.2 If the processor makes a significant change to any material, process, or control factor from that which was used for process approval, all preproduction tests shall be performed and the results submitted to the cognizant engineering organization for process reapproval unless the change is approved by the cognizant engineering organization. A significant change is one which, in the judgment of the cognizant engineering organization, could affect the properties or performance of the parts. Production parts plated by the revised procedure shall not be shipped prior to receipt of reapproval.