Designation: F1941/F1941M – 15

Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric[1]

This standard is issued under the fixed designation F1941/F1941M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This specification covers the coating of steel unified inch and metric mechanical fasteners by electrodeposition. The properties of the coatings shall conform to the ASTM standards for the individual finishes. This standard shall be used in place of ASTM B633 for mechanical fasteners.

Coating thickness values are based on standard tolerances for inch and metric external threads. The coating must not cause the basic thread size to be transgressed by either the internal or external threads. The method of designating inch coated threads shall comply with ASME B1.1 and ISO 965-1, ISO 965-2, and ISO 965-3 for ISO metric coated threads.

With normal methods for depositing metallic coatings from aqueous solutions, there is a risk of delayed failure due to hydrogen embrittlement for case hardened fasteners and fasteners having a hardness above 39 HRC. Although this risk can be managed by selecting raw materials suitable for the application of electrodeposited coatings and by using modern methods of surface treatment and post heat-treatment (baking), the risk of hydrogen embrittlement cannot be completely eliminated. Therefore, the application of a metallic coating by electrodeposition is not recommended for such fasteners.

1. Scope*

1.1 This specification covers application, performance and dimensional requirements for electrodeposited coatings on threaded fasteners with unified inch and metric screw threads, but it may also be applied to other threaded parts and non-threaded parts such as washers and pins. It specifies coating thickness, supplementary hexavalent chromate or non-hexavalent conversion finishes, corrosion resistance, precautions for managing the risk of hydrogen embrittlement and hydrogen embrittlement relief for high-strength and surface-hardened fasteners. It also highlights the differences between barrel and rack plating and makes recommendations as to the applicability of each process.

1.2 The values stated in inch-pound units and SI metric units. The values stated in each system may not be exact equivalents; therefore each system shall be used independently of the other. Combining values from the two systems may result in non-conformance to the standard.

1.3 Terms used in this specification are defined in Terminology F1789.

1.4 The following precautionary statement pertains to the test method portion only, Section 9, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B117 Practice for Operating Salt Spray (Fog) Apparatus

B487 Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section

B499 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals

B504 Test Method for Measurement of Thickness of Metallic Coatings by the Coulometric Method

[1] This specification is under the jurisdiction of ASTM Committee F16 on Fasteners and is the direct responsibility of Subcommittee F16.03 on Coatings on Fasteners.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

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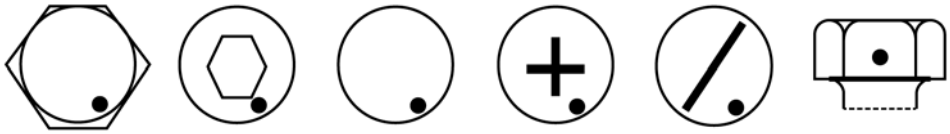


NOTE 1—Black dot (•) indicates test surface.

FIG. 1 Significant Surfaces on Externally Threaded Fasteners

B567 Test Method for Measurement of Coating Thickness by the Beta Backscatter Method
B568 Test Method for Measurement of Coating Thickness by X-Ray Spectrometry
B659 Guide for Measuring Thickness of Metallic and Inorganic Coatings
D6492 Practice for Detection of Hexavalent Chromium On Zinc and Zinc/Aluminum Alloy Coated Steel
E376 Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Testing Methods
F519 Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments
F606/F606M Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets
F788 Specification for Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series
F1470 Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection
F1624 Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique
F1789 Terminology for F16 Mechanical Fasteners
F1940 Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners
F2078 Terminology Relating to Hydrogen Embrittlement Testing

2.2 *ASME Standards:*[3]
B1.1 Unified Inch Screw Threads (UN and UNR Thread Form)
B1.2 Gages and Gaging for Unified Inch Screw Threads
B1.16M Gages and Gaging for Metric M Screw Threads
B18.6.3 Machine Screws, Tapping Screws, and Metallic Drive Screws (Inch Series)

2.3 *National Aerospace Standard (AIA):*[4]
NASM-1312-5 Fast Test Method – Method 5: Stress Durability

2.4 *IFI Standard:*[5]
IFI-142 Hydrogen Embrittlement Risk Management

2.5 *ISO Standards:*[6]
ISO 965-1 ISO General Purpose Metric Screw Threads – Tolerances – Part 1: Principles and Basic Data
ISO 965-2 ISO General Purpose Metric Screw Threads – Tolerances – Part 2: Limits of Sizes for General Purpose External and Internal Screw Threads
ISO 965-3 ISO General Purpose Metric Screw Threads – Tolerances – Part 3: Deviations for Construction Screw Threads
ISO 4042 Electroplated Coatings

3. Terminology

3.1 *Definitions:*

3.1.1 *reference area*—the area within which a specified number of single measurements are required to be made.

3.1.2 *sealant*—chemical with or without integral lubricant applied on the substrate which forms a composite layer with a conversion coating in order to improve chemical resistance, corrosion protection, UV resistance, etc.

3.1.3 *significant surface*—Figs. 1 and 2 illustrate significant surfaces on standard externally and internally threaded fasteners and washers.

3.1.4 *top coat*—additional layer with or without integral lubricant applied on a substrate in order to achieve functional properties such as torque-tension control, color, chemical resistance, etc.

4. Classification

4.1 *Coating Material*—The coating material shall be selected and designated in accordance with Table 1.

4.2 *Coating Thickness*—The coating thickness shall be selected and designated in accordance with Table 2.

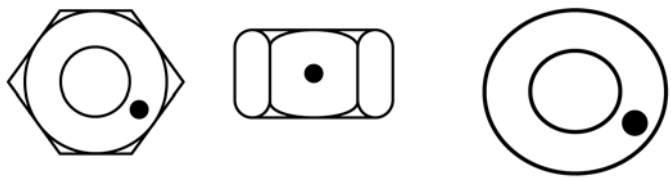
4.3 *Conversion Finish*—The conversion finish shall be selected and designated in accordance with Table 3. When not specified, hexavalent chromium, or hexavalent chromium free

[3] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098.

[5] Available from Industrial Fasteners Institute (IFI), 1717 East 9th Street, Suite 1105, Cleveland, OH 44114–2879.

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.



NOTE 1—Black dot (•) indicates test surface.

FIG. 2 Significant Surfaces on Internally Threaded Fasteners and Washers

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TABLE 1 Designation of Common Coating Materials

Coating Designation	Coating Type
Fe/Zn	Zinc
Fe/Cd	Cadmium
Fe/Zn-Co	Zinc Cobalt Alloy
Fe/Zn-Ni	Zinc Nickel Alloy
Fe/Zn-Fe	Zinc Iron Alloy

TABLE 2 Designation of Coating Thickness – Inch and Metric

NOTE 1—The conversion factor from inch to microns is 2.54×10^4 (for example, 0.0001 in. = 2.54 µm).

Thickness Designation	Minimum Thickness	
	in.	µm
3	0.0001	3
5	0.0002	5
8	0.0003	8
12	0.0005	12

TABLE 3 Designation of Conversion Finish

Type	Typical Appearance	Conversion Designation	
		Hexavalent Chromium	Hexavalent Chromium Free
Clear	Transparent colorless with slight iridescence	A	AN
Blue-bright	Transparent with a bluish tinge and slight iridescence	B	BN
Yellow	Yellow iridescent	C	CN
Opaque	Olive green, shading to brown or bronze	D	DN
Black	Black with slight iridescence	E	EN

passivation such as trivalent chromium passivation or other non-chromium passivation finish shall be used at the option of the manufacturer and its appearance shall be selected in accordance with the designation selected in Table 3.

4.4 *Supplemental Lubricant, Sealants or Top Coats*—Additional sealants or top coats (with or without integral lubricant) may be chosen to increase corrosion resistance and to achieve other specific properties such as torque-tension, UV resistance, etc. The selection of the nature of a sealant or top coat should be based on desired additional properties. When sealants or top coats are specified, the classification code in Table 3 shall be appended by adding the letter "S" (for example Fe/Zn 5ANS). When specifying a lubricant, the classification code in Table 3shall be appended with the letter "L" (for example Fe/Zn 5ANSL).

NOTE 1—When using a sealant or top coat, a separate conversion finish layer and/or lubricant layer may not be required to achieve the corrosion performance or provide lubricity.

4.5 Fig. 3 illustrates the basic electroplating coating systems.

4.5.1 Only coating material layer(s).

4.5.2 Coating material layer(s) plus conversion finish (for example Fe/Zn 5A).

4.5.3 Coating material layer(s) plus conversion finish plus additional lubricant (example Fe/Zn 5ANL).

4.5.4 Coating material layer(s) plus conversion finish plus sealant top coat (example Fe/Zn 5ANS).

4.5.5 Coating material layer(s) plus conversion finish plus sealant top coat plus additional lubricant (example Fe/Zn 5ANSL).

5. Ordering Information for Electroplating

5.1 When ordering threaded fasteners to be coated by electrodeposition in accordance with this specification, the following information shall be supplied to the electroplater:

5.1.1 The desired coating, coating thickness, the conversion finish, the color and appearance (if applicable), or the classification codes as specified in Tables 1-3 and additional sealants or top coats (for example, Fe/Zn 5C denotes yellow zinc plated with a minimum thickness of 0.0002 in. or 5 µm for metric on significant surfaces).

5.1.2 The identification of significant surfaces (optional).

5.1.3 The requirement, if any, for stress relief before electroplating, in which case the stress-relief conditions must be specified.

5.1.4 The requirements, if any, for hydrogen embrittlement relief by heat treatment (baking), other than as required by 6.4.1 must be specified. Requirements shall include baking time and temperature.

5.1.5 The requirements, if any, for embrittlement testing other than as required by 6.4.3 must be specified.

NOTE 2—Through hardened fasteners with a specified maximum hardness of 39 HRC and below have a low susceptibility to hydrogen embrittlement and do not require baking.

5.1.6 The requirements, if any, for the type of electroplating process (barrel-plating or rack-plating). See Section 10 and Appendix X1.

5.1.7 The designation of inch coated thread class shall comply with ASME B1.1 and metric threads shall comply with ISO 965-1, ISO 965-2 and ISO 965-3.

6. Requirements

6.1 *Coating Requirements*—The electrodeposited coating as ordered shall cover all surfaces and shall meet the following requirements:

6.1.1 The coating metal deposit shall be bright or semi-bright unless otherwise specified by the purchaser, smooth, fine grained, adherent and uniform in appearance.

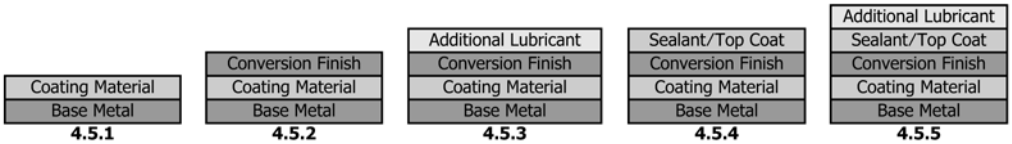

FIG. 3 Basic Electroplating Coating Systems

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6.1.2 The coated fastener shall be free of blisters, pits, nodules, roughness, unplated areas, and other defects that will affect the function of the coating.

6.1.3 The coating shall not be stained, discolored or exhibit any evidence of corrosion products.

6.1.3.1 Slight discoloration that results from baking, drying, or electrode contact during rack-plating, or all of these, as well as slight staining that results from rinsing shall not be cause for rejection.

6.2 *Corrosion Resistance*—Coated fasteners, when tested by continuous exposure to neutral salt spray in accordance with 9.3, shall show neither corrosion products of coatings nor basis metal corrosion products at the end of the test period. The appearance of corrosion products visible to the unaided eye at normal reading distance shall be cause for rejection, except when present at the edges of the tested fasteners. Refer to Annex A1 for neutral salt spray performance requirements for zinc, zinc alloy and cadmium coatings.

6.3 *Thickness*—The coating thickness shall comply with requirements of Table 2 when measured in accordance with 9.1.

6.3.1 *Restrictions on Coating Thickness*—This specification imposes minimum local thickness requirements at significant surfaces in accordance with Table 2. Thick or thin local thickness in a location other than a significant surface shall not be a cause for rejection. However the following restrictions apply:

6.3.1.1 Minimum coating thickness at low current density areas, such as the center of a bolt or recesses, must be sufficient to provide for adequate conversion finish adhesion.

6.3.1.2 *External Threads*—The after-coating dimensions of external threads must not exceed the thread's basic size. Coated external threads must conform to a basic GO gage. Coated inch external threads must accept a class 3A GO gage and coated metric threads must accept a class h (6h or 4h) GO gage (See ASME B1.2 and ASME B1.16M respectively). The NOTGO gage size is the same after coating as before coating. If a coated external thread does not freely enter the basic size GO gage, the thread discontinuity torque test in Specification F788 shall be used to determine thread acceptability.

6.3.1.3 *Internal Threads*—The after-coating dimensions of internal threads must not exceed the thread's basic size. Coated internal threads must conform to a basic GO gage. Coated inch internal threads must accept a class 2B or 3B GO gage and coated metric internal threads must accept a class H (6H, 5H or 4H) GO gage (See ASME B1.2 and ASME B1.16M respectively). The NOTGO gage size is the same after coating as before coating.

6.3.1.4 Surfaces such as threads, holes, deep recesses, bases of angles, and similar areas on which the specified thickness of deposit cannot readily be controlled, are exempted from minimum thickness requirements unless they are specially designated as not being exempted. When such areas are subject to minimum thickness requirements, the purchaser and the manufacturer shall recognize the necessity for either thicker deposits on other areas or special racking.

6.3.2 *Applicability to Unified Inch Screw and M Series Metric Threads:*

6.3.2.1 The applicability of the required coating to unified inch and M series metric screw threads is limited by the basic deviation of the threads, and hence limited by the pitch diameter, allowance and tolerance positions. Refer to Appendix X3 as a guideline for the tolerances of the various thread sizes and classes and the coating thickness they will accommodate.

6.3.2.2 Because of the inherent variability in coating thickness by the barrel-plating process, the application of a minimum coating thickness of 0.0005 in. or 12 µm for metric is not recommended for a standard screw thread by this method due to the fact that dimensional allowance of most threaded fasteners normally does not permit it. If the size of the fastener is large enough to economically use the rack-plating process, then the latter shall be used to obtain this thickness requirement. If heavier coatings are required, allowance for the deposit buildup must be made during the manufacture of fasteners by adjusting pre-plating thread size.

6.3.3 *Applicability to Wood Screws and Thread Forming Screws*—Any classification code in Tables 1-3 may be applied to screws that cut or form their own threads.

6.4 *Hydrogen Embrittlement Relief:*

6.4.1 *Requirement for Baking for Through Hardened Fasteners*—Unless otherwise specified by the purchaser, baking is not mandatory for fasteners with specified maximum hardness 39 HRC and below (see Note 3). Coated fasteners made from steel heat treated to a specified hardness above 39 HRC, and fasteners with captive washers made from hardened steel shall be baked to minimize the risk of hydrogen embrittlement.

NOTE 3—With proper care many steel fasteners can be plated without baking by correlating process conditions, and coating material to the susceptibility of the fastener material to hydrogen embrittlement, and by applying adequate process control procedures, such as those outlined in Appendix X4.2. Test Method F1940 is a recognized verification method for process control to minimize the risk of hydrogen embrittlement. Upon agreement between the supplier and the purchaser, this test method can be used as a basis for determining if baking should be mandated in a controlled process environment.

6.4.2 *Baking Conditions*—Unless otherwise specified, minimum baking times shall be in accordance with Table 4.

6.4.2.1 Bake temperatures shall always be kept below the tempering temperature of quenched and tempered steel parts to avoid alteration of mechanical properties by re-tempering.

6.4.2.2 Bake temperatures shall not exceed the values specified in Table 4 to avoid the risk of solid or liquid metal embrittlement.

NOTE 4—Bake times and temperatures are lowered to minimize the risk of solid or liquid metal embrittlement resulting from alloy compositions such as those containing lead or from lowering melting point of the coating material. For example, cadmium has a melting point of 610°F or 310°C in comparison to zinc which has a melting point of 786°F or 419°C.

6.4.2.3 Baking to relieve hydrogen embrittlement should be performed after electroplating, prior to the application of the conversion finish and prior to the application of sealant and/or top coat, if any where baking temperatures can damage the conversion film thereby negating its performance. After experimentation, coaters may find other sequences are suitable. The time between coating and baking should be as short as

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TABLE 4 Hydrogen Embrittlement Relief Requirements[B]

Specified Core Hardness (HRC)	Min Baking Time	Min – Max Baking Temperature[C,D]	ASTM Hydrogen Embrittlement Test Requirement[E]	Tapping Screw Hydrogen Embrittlement Test Requirement	ASTM Process Control Test Requirement[E]
Over 39 and up to 44[A]	Min 14 h	375 to 425°F or 190 to 220°C	F606/F606M or F1624	ASME B18.6.3 or F1624	F1940 or F519
Over 44[A]	Min 24 h	375 to 425°F or 190° to 220C	F606/F606M or F1624	ASME B18.6.3 or F1624	F1940 or F519

[A] If Test Method F1940 process control testing is not performed, baking and product testing are mandatory in accordance with Table 4. If Test Method F1940 process control testing is performed and is shown to consistently pass at a minimum of a monthly basis, then product testing and baking are not mandatory. If Test Method F1940 process control testing is performed and does not pass, then baking and product testing are mandatory.
[B] Variables such as coating type, coating thickness, baking temperatures and plating process (barrel or rack plating) can effect baking requirements. ASTM F1940 process control testing can be used to isolate the effect of baking, and shall be the basis to increase or decrease baking times or to eliminate baking altogether. In the absence of Test Method F1940 process control testing, baking and testing requirements specified in Table 4 shall be used as the default for all conditions.
[C] Cadmium baking temperatures should be between 375 to 400°F or 190 to 205°C.
[D] Part temperature.
[E] When agreed upon between supplier and purchaser, alternative hydrogen embrittlement test methods such as NASM 1312-5 and alternative process control test methods may be used.

possible. The requirement, if any, for a specific maximum allowable time (in hours) between electroplating and baking shall be explicitly specified by the purchaser at the time of order. A reasonable tolerance of +2h resulting from normal operational constraints shall be assumed. (See Appendix X4.3 for additional information.)

6.4.3 *Hydrogen Embrittlement Testing*—Unless otherwise specified by the purchaser, hydrogen embrittlement testing in accordance with Table 4 is mandatory for through hardened fasteners with a specified core hardness above 39 HRC unless the electroplating process has been qualified in accordance with a test method in Table 4 (that is, the process has been shown not to cause embrittlement for a given product or class of product).

6.4.4 *Baking and Testing Requirements for Case Hardened Screws*—Surface hardening of case hardened screws introduces variables additional to the hardness of the core, notably case hardness and case depth. Case hardened screws that are electroplated shall adhere to the following baking requirements.

6.4.4.1 All lots of case hardened screws shall be baked for a minimum of 4 h at 375 to 400°F or 190 to 205°C part temperature.

6.4.4.2 All case hardened screws shall be tested for hydrogen embrittlement in accordance with ASME B18.6.3 for all self-tapping screws. For case hardened machine screws, the ASME B18.6.3 method shall be applied except use a hardened threaded test plate having a minimum thickness of one nominal diameter. The tapped holes shall be 2B for inch fasteners or 6H for metric fasteners.

6.4.5 Any lot that fails hydrogen embrittlement testing shall be baked for 24 h at 375 to 400°F or 190 to 205°C part temperature and retest shall be made using twice the original sample size.

6.5 *Stress Relieving Requirements for Work Hardened Fasteners Without Thermal Hardening*—Some cold formed fasteners that are not thermally hardened can fracture due to buildup of high residual stresses at stress concentration points. The types of fastener shapes that make this a particular concern are carriage bolts, thin head parts where the minimum thickness of the head is less than 50% of the nominal diameter of the screw, shoulder type fasteners where the thread major diameter is more than 20% smaller than the shoulder diameter, or where a larger diameter, thin washer or collar is formed on a double ended stud. An indication that high residual stresses may be present in a portion of the fastener is when localized hardness below the surface exceeds 30 HRC.

6.5.1 Fasteners with configurations or conditions described above shall be stress relieved at a minimum temperature of 875°F or 470°C prior to electroplating to avoid brittle fractures. Increased hardness resulting from thread rolling before, after or without thermal hardening are due to the creation of non-detrimental compressive stresses and do not require stress relief before electroplating.

NOTE 5—Stress relieving is not intended in cases where residual stresses are intentionally introduced, such as screws which are thread rolled after heat treatment.

6.6 *Non-Hexavalent Conversion Finishes*—When the use of hexavalent chromium is prohibited, coated fasteners shall be free of hexavalent chromium when tested in accordance with the test method defined in 9.4.

7. Dimensional Requirements

7.1 Threaded components, except those with spaced and forming threads, supplied for electrodeposited coating inch threads shall comply with ASME B1.1 and metric threads shall comply with ISO 965-1, ISO 965-2, and ISO 965-3 (see 6.3.1.2 and 6.3.1.3). Screw threads that are specifically manufactured to allow the application of 0.0005 in. or 12 µm for metric threads or greater coating thickness by the barrel-plating process, must adhere to a special allowance specified by the manufacturer or in ASME B1.1 or ISO 965-1, ISO 965-2, and ISO 965-3. The other dimensional characteristics shall be as specified in the applicable standard or drawing. It should be noted that modifications to the threads of a fastener could affect its properties or performance, or both. Refer to Appendix X3 for further information on effects of coating on pitch diameter, allowances and tolerances for external and internal threads.

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