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Endorsed by American Electroplaters' Society
Endorsed by National Association of Metal Finishers

Standard Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals[1]

This standard is issued under the fixed designation B499; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

ε[1] NOTE—Editorial corrections were made throughout in May 2021.

1. Scope

1.1 This test method covers the use of magnetic instruments for the nondestructive measurement of the thickness of nonmagnetic coatings over ferrous or other magnetic base metals. It is intended to supplement manufacturers' instructions for the operation of the instruments and is not intended to replace them.

NOTE 1—Autocatalytically deposited nickel-phosphorus alloys containing more than 8 % phosphorus are sufficiently nonmagnetic to be measured by this test method, as long as the measurement is made prior to any heat treatment.

1.2 These instruments measure either the magnetic attraction between a magnet and the basis metal, as influenced by the presence of the coating (categorized as "magnetic pull-off"), or the change in magnetic-flux density within the probe (categorized as "electronic"). These instruments cannot distinguish the thickness of individual layers. They can only measure the cumulative thickness of all layers beneath the probe down to the base metal.

1.3 Measurements made in accordance with this test method will be in compliance with the requirements of ISO International Standard 2178.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B530 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates

2.2 *International Standard:*

ISO 2178 Non-Magnetic Coatings on Magnetic Substrate—Measurement of Coating Thickness—Magnetic Method[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *accuracy, n*—the measure of the magnitude of error between the result of a measurement and the true thickness of the item being measured.

3.1.2 *adjustment, n*—the physical act of aligning a instrument's thickness readings to match those of a known thickness sample (removal of bias), in order to improve the accuracy of the instrument on a specific surface or within a specific portion of its measurement range. An adjustment will affect the outcome of subsequent readings.

3.1.3 *calibration, n*—the high-level, controlled and documented process of obtaining measurements on traceable calibration standards over the full operating range of the

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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.

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

instrument, then making the necessary instrument adjustments (as required) to correct any out-of-tolerance conditions.

3.1.3.1 *Discussion*—Calibration of coating thickness instruments is performed by the equipment manufacturer, an authorized agent, or by an authorized, trained calibration laboratory in a controlled environment using a documented process. The outcome of the calibration process is to restore/realign the instrument to meet/exceed the manufacturer's stated accuracy.

3.1.4 *reference standard, n*—a specimen of known thickness used to verify the accuracy of a coating thickness measuring instrument.

3.1.5 *verification of accuracy, n*—obtaining measurements on a reference standard prior to instrument use for the purpose of determining the ability of the coating thickness instrument to produce reliable values, compared to the combined instrument manufacturer's stated accuracy and the stated accuracy of the reference standard.

4. Summary of Test Method

4.1 Magnetic pull-off instruments employ an attraction principle and a stationary magnetic field. These mechanical instruments measure the force required to pull a permanent magnet from a coated magnetic metal substrate. The magnetic force of attraction to the substrate beneath the coating is opposed by a spring or coil. Tension is applied to the spring/coil until the magnetic attraction to the magnetic substrate is overcome. The instrument must be placed directly on the coated surface to obtain a measurement. The force holding the permanent magnet to the magnetic base is inversely proportional to the thickness of the coating layer(s) between the magnet and the magnetic base. For example, a thin coating applied to a ferrous substrate will require greater spring tension to pull the magnet off than will a thicker coating, since the magnet is closer to the ferrous substrate with the thinner coating. This inverse relationship is reflected on the nonlinear instrument scale.

4.2 Electronic instruments measure a change in magnetic flux density within the probe to produce a coating thickness measurement. The instrument probe must be placed directly (in a perpendicular position) on the coated surface to obtain a measurement. These instruments determine the effect on the magnetic field generated by the probe due to the proximity to the substrate.

5. Significance and Use

5.1 The thickness of a coating is often critical to its performance. For most nonferrous coatings on steel, the magnetic method is reliable for measuring coating thickness nondestructively and is suitable for specification acceptance testing and SPC/SQC applications.

5.2 This test method should not be used to determine the thickness of electrodeposited nickel coatings on steel. Test Method B530 is suitable for that determination.

6. Apparatus

6.1 *Coating Thickness Instrument,* based on magnetic principles, commercially available, suitable to measure coating thickness accurately.

6.2 *Coating Thickness Standards,* with assigned values traceable to a National Metrology Institution. They may be coated or plated steel plates, or may be foils or shims of flat, non-metallic sheet (typically polyester).

7. Calibration and Standardization

7.1 Calibration of coating thickness instruments is performed by the equipment manufacturer, an authorized agent, or by an authorized, trained calibration laboratory in a controlled environment using a documented process. A Certificate of Calibration showing traceability to a National Metrology Institution can be issued. There is no standard time interval for re-calibration, nor is one absolutely required, but a calibration interval can be established based on experience and the work environment. A one-year calibration interval is a typical frequency suggested by many instrument manufacturers.

7.2 Before use, each instrument's calibration accuracy shall be verified in accordance with the instructions of the manufacturer, employing suitable thickness standards and, if necessary, any deficiencies found shall be corrected.

7.3 During use, calibration accuracy shall be verified at frequent intervals, at least once a day. Attention shall be given to the factors listed in Section 8 and to the procedures described in Section 9.

7.4 Coating thickness standards of known thickness are available either as shims, foils, or as coated specimens.

7.4.1 *Foils:*

NOTE 2—In the following paragraphs, the use of the word "foil'' will imply a nonmagnetic metallic or nonmetallic foil or shim.

7.4.1.1 Because of the difficulty of ensuring adequate contact, foils are generally not recommended for the calibration, verification of accuracy, and adjustment of magnetic pull-off instruments but they are suitable in some circumstances provided the necessary precautions are taken. They can normally be used with other types of instruments.

7.4.1.2 Foils are advantageous on curved surfaces and are more readily available than coated standards. To prevent measurement errors, it is necessary to ensure that intimate contact is established between foil and substrate. Resilient foils should be avoided to prevent indentation errors. Only nonferrous metal foils should be used for thicknesses less than 15 µm (0.6 mil). Foils are subject to wear and indentation and, therefore, should be replaced frequently. Worn foils shall not be used.

7.4.2 *Coated Standards*— These calibration standards consist of nonconductive coatings of known, uniform thickness permanently bonded to the substrate material.

7.4.3 The coating thickness of the standards used shall bracket the user's highest and lowest coating thickness measurement requirement. Standards suitable for many applications of the test method are commercially available and may be used provided the certified values are traceable to a National Metrology Institution.

7.5 In some cases the calibration of the instrument should be checked by rotating the probe in increments of 90° (see 8.1.8 and 8.1.9).

7.6 The basis-metal thickness for the test and the calibration adjustment shall be the same if the critical thickness, defined in 8.1.3, is not exceeded. It is often possible to back up the basis metal of the standard or of the test specimen with a sufficient thickness of similar material to make the readings independent of the basis-metal thickness.

7.7 If the curvature of the coating to be measured is such as to preclude calibration adjustment on a flat surface, the curvature of the coated standard, or of the substrate on which the foil is placed, shall be the same.

8. Factors Affecting the Measuring Accuracy

8.1 The following factors affect the accuracy of a coating thickness measurement:

8.1.1 *Coating Thickness*—Inherent to the test method is a measurement uncertainty that, for thin coatings, is constant and independent of the coating thickness. The magnitude of this measurement uncertainty is primarily a function of test piece surface finish (see 8.1.6 on surface roughness). For thicknesses greater than about 25 µm (1 mil), this uncertainty is proportional to the coating thickness.

8.1.2 *Magnetic Properties of the Basis Metal*—Magnetic thickness measurements are affected by variations in the magnetic properties of the basis metal. (For practical purposes, magnetic variations in low-carbon steel can often be considered to be insignificant. To avoid the influences of severe or localized heat treatments and cold working, the instrument should be adjusted using a reference standard having a basis metal with the same magnetic properties as that of the test specimen or, preferably and if available, with a sample of the part to be tested before application of the coating.)

8.1.3 *Basis Metal Thickness*—For each instrument, there is a critical thickness of the basis metal above which the measurements will not be affected by an increase in the thickness of the basis metal. Since it depends on the instrument probe (Note 3) and the nature of the basis metal, its value should be determined experimentally if not supplied by the manufacturer.

NOTE 3—In this method "instrument probe" will also include the term "magnet."

8.1.4 *Edge Effects*—The method is sensitive to abrupt changes in the surface contour of the test specimen. Therefore, measurements made too near an edge or inside corner will not be valid unless the instrument is specifically calibrated for such a measurement. The effect may extend to about 20 mm (0.8 in.) from the discontinuity, depending on the instrument.

8.1.5 *Curvature*—The measurements are affected by the curvature of the test specimen. The influence of curvature varies considerably with the make and type of instrument but always becomes more pronounced as the radius of curvature decreases. Instruments with two-pole probes may also produce different readings if the poles are aligned in planes parallel or perpendicular to the axis of a cylindrical surface. A similar effect can occur with a single-pole probe if the tip is unevenly worn.

8.1.6 *Surface Roughness*—Measurements are influenced by the surface topography of the basis metal and coating. Surface roughness becomes significant when the degree of roughness is greater than 10 % of the coating thickness, causing increased scatter in measurements. Therefore, it is necessary, on a rough or scratched surface, to make a greater number of measurements at different positions to obtain an average value that is representative of the mean coating thickness. If the basis metal is rough, it may also be necessary to check, and adjust if necessary, the zero of the instrument at several positions on a portion of the uncoated, rough, basis metal.

8.1.7 *Direction of Mechanical Working of the Basis Metal*—Measurements made by an instrument having a two-pole probe or an unevenly worn single-pole probe may be influenced by the direction in which the magnetic basis metal has been subjected to mechanical working (such as rolling), the reading changing with the orientation of the probe on the surface.

8.1.8 *Residual Magnetism*—Residual magnetism in the basis metal affects the measurements made by instruments that employ a stationary magnetic field. Its influence on measurements made by instruments employing an alternating magnetic field is much smaller.

8.1.9 *Stray Magnetic Fields*—Strong stray magnetic fields, such as are produced by various types of electrical equipment, can seriously interfere with the operation of instruments based on magnetic principles.

8.1.10 *Foreign Particles*—Magnetic instruments of all types must make physical contact with the test surface and are, therefore, sensitive to foreign material that prevents intimate contact between probe and coating surface. Both the test surface and instrument probe should be kept free of foreign material.

8.1.11 *Conductivity of Coating*—Magnetic instruments employing an alternating magnetic field operating frequency above 200 Hz could produce eddy currents in thick, highly conductive coatings that may interfere with the reading.

8.1.12 *Pressure*—Instrument readings are sensitive to the pressure with which the probe is applied to the test specimen. Application of the probe should not be allowed to deform the coating.

8.1.13 *Probe Orientation*—Magnetic pull-off instruments may be sensitive to the orientation of the magnet in relation to the field of gravity of the earth. Thus, the operation of an instrument in a horizontal or upside-down position may require a correction factor or may be impossible.

9. Procedure

9.1 Operate each instrument in accordance with the instructions of the manufacturer giving appropriate attention to the factors listed in Section 8.

9.2 Verify the accuracy of the instrument at the test site each time the instrument is put into service and at frequent intervals during use to assure proper performance.

9.3 Many instruments can be adjusted in order to improve their accuracy on a specific surface or within a specific portion of its measurement range. In most instances it should only be necessary to check zero on the uncoated substrate and begin measuring. However, the effects of properties of the substrate (composition, magnetic properties, shape, roughness, edge effects) and coating (composition, mass, surface roughness), as