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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.

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 as printed in 1982.

1.4 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 and health practices and determine the applicability of regulatory limitations prior to use.*

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 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.

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[1] This test method is under the jurisdiction of ASTM Committee B08 on Metallic and Inorganic Coatings and is the direct responsibility of Subcommittee B08.10 on Test Methods.

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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.

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 or 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 25μm (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 frequencies 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 well as ambient and surface temperatures, may require adjustments to be made to the instrument. Follow the manufacturer's instructions.

9.4 Observe the following precautions:

9.4.1 *Basis-Metal Thickness*—Check whether the basis-metal thickness exceeds the critical thickness. If not, either use the back-up method mentioned in 7.6 or make sure that the

calibration adjustment has been made on a reference standard having the same thickness and magnetic properties as the test specimen.

9.4.2 *Edge Effects*—Do not make readings close to an edge, hole, inside corner, and the like., of a specimen unless the validity of the calibration adjustment for such a measurement has been demonstrated.

9.4.3 *Curvature*—Do not make readings on a curved surface of a specimen unless the validity of the calibration adjustment for such a measurement has been demonstrated.

9.4.4 *Number of Readings*—Because of normal instrument variability and in order to minimize surface roughness effects, a measurement shall be the mean value of several readings.

9.4.4.1 For each measurement, make at least 3 readings, removing the probe after each reading, and average the readings. If any 2 of the readings differ from each other by more than 5 % of the average reading or 2 µm (0.08 mil), whichever is the greater, then the measurement shall be discarded and repeated.

9.4.4.2 The substrate or coating, or both may be too rough to meet this criterion. In such a case it may be possible to obtain a valid measurement by averaging a number of readings. To be valid under this test method, the validity of such a procedure must be demonstrated (see Appendix X1).

9.4.4.3 Magnetic pull-off instruments are sensitive to vibrations, and readings that are obviously erroneous should be rejected.

9.4.5 *Direction of Mechanical Working*— If the direction of mechanical working has a pronounced effect on the reading, make the measurement on the test specimen with the probe in the same orientation as that used during the calibration. If this is impossible, make four measurements in various orientations by rotating the probe in increments of 90°.

9.4.6 *Residual Magnetism*—When residual magnetism is present in the basis metal, when using two-pole instruments employing a stationary magnetic field make measurements in two orientations differing by 180°. With single-pole instruments employing a stationary magnetic field, it may be necessary to demagnetize the test specimen to get valid results, and this may also be advisable with two-pole instruments.

9.4.7 *Surface Cleanliness*—Before making measurements, clean any foreign matter such as dirt, grease, and corrosion products from the surface without removing any coating material. Avoid any areas having visible defects, such as welding or soldering flux, acid spots, dross, or oxide when making measurements.

9.4.8 *Lead Coatings*—The magnet of a pull-off instrument may stick to lead and lead alloy coatings. Apply a very thin film of oil to improve the reproducibility of readings and correct the measurement for the thickness of the oil film. Excess oil shall be wiped off so that the surface is virtually dry. The correction may be determined by measuring the coating thickness of a nonsticking coating of appropriate thickness with and without the oil film and taking the difference between the two measurements. Do not use this procedure with other coatings.

9.4.9 *Techniques*—The readings obtained may depend on the technique of the operator. For example, the pressure applied to a probe, or the rate of applying a balancing force to a magnet, will vary from one individual to another. Reduce or minimize such effects either by having the instrument adjusted by the same operator who will make the measurement or by using constant-pressure probes. In appropriate cases when a constant pressure probe is not being used, the use of a measuring stand is strongly recommended.

9.4.10 *Positioning of Probe*—In general, place the instrument probe perpendicular to the specimen surface at the point of measurement. For some magnetic pull-off instruments this is essential. With some instruments, however, it is desirable to tilt the probe slightly and select the angle of inclination giving the minimum reading. If, on a smooth surface, the readings obtained vary substantially with the angle of inclination, it is probable that the probe is worn and needs to be replaced. If a magnetic pull-off instrument is to be used in a position other than for what it was designed, such as upside-down, apply a correction factor for that position as per the manufacturers' instructions.

10. Report

10.1 The report should include the following information:

10.1.1 Type of instrument used including manufacturer, model number, principle of operation, and date of calibration,

10.1.2 Size and description of test specimen,

10.1.3 Whether special jigs were used,

10.1.4 Type of coating thickness standard and/or reference standard and the method used for accuracy verification and any calibration adjustment,

10.1.5 The number of measurements taken and the value of each measurement,

10.1.6 Operator identification, and

10.1.7 Date.

11. Precision and Bias

11.1 The equipment and its operation shall be such that the coating thickness can be determined with an uncertainty of less than 10 % at 95 % confidence level.

11.2 Although an uncertainty of less than 10 % may be achieved consistently for a great number of applications, the uncertainty may be greater when coating thickness is less than 25 µm (1 mil).

11.3 Instruments suitable for compliance with 9.1 are available commercially. For many coating systems, the instruments are capable of making measurements with an uncertainty of less than 5 % at 95 % confidence level.

11.4 The measurement bias is the discrepancy remaining between the measured thickness and the true thickness if all random errors are eliminated. It is, therefore, no greater than and attributable to (*1*) the calibration error of the instrument and (*2*) the quality of the reference standard used to adjust the instrument.

11.5 The precision is being determined by round-robin testing.

12. Keywords

12.1 coating thickness; coatings; magnetic method; nondestructive thickness; nonmagnetic coatings; plating thickness; thickness; thickness testing

APPENDIX

(Nonmandatory Information)

X1. MEASUREMENTS ON ROUGH SURFACES

X1.1 Measurements on rough surfaces are subject to random errors associated with the position of the instrument probe relative to the peaks and valleys of the rough surface. These random errors increase with surface roughness, but can be reduced by averaging 10 or more readings.

X1.2 Roughness can also introduce a bias (systematic error) because the probe seldom, if ever, rests at the bottom of a valley; and the magnetic field in the neighborhood of the probe differs from that at a smooth surface. In the case of a rough substrate, the valleys are filled with coating material but when the instrument is adjusted with a foil, the foil rests on the peaks of the substrate. A bias can be corrected for if the magnitude of the bias can be determined by microscopical or other measurements.