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 B 499; 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 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.

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, or the reluctance of a magnetic-flux path passing through the coating and the basis 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 *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 *International Standard:*

ISO 2178 Non-Magnetic Coatings on Magnetic Substrate—Measurement of Coating Thickness—Magnetic Method[2]

3. Significance and Use

3.1 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. The test method requires that the magnetic properties of the substrate used during the calibration be the same as that of the test specimen.

4. Factors Affecting the Measuring Accuracy

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

4.1.1 *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 4.1.6 on surface roughness). For thicknesses greater than about 25μ m, this uncertainty is proportional to the coating thickness.

4.1.2 *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 calibrated using a calibration 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.)

4.1.3 *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 2) and the nature of the basis metal, its value should be determined experimentally if not supplied by the manufacturer.

NOTE 2—In this method "instrument probe" will also include the term "magnet."

4.1.4 *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 from the discontinuity, depending on the instrument.

4.1.5 *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

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[2] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

perpendicular to the axis of a cylindrical surface. A similar effect can occur with a single-pole probe if the tip is unevenly worn.

4.1.6 *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 the zero of the instrument at several positions on a portion of the uncoated, rough, basis metal.

4.1.7 *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.

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

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

4.1.10 *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.

4.1.11 *Conductivity of Coating*—Some magnetic instruments work at frequencies between 200 and 2000 Hz. At these frequencies, eddy currents produced in thick, highly conductive coatings may interfere with the reading.

4.1.12 *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.

4.1.13 *Probe Orientation*—Instruments using the principle of magnetic attraction 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 different calibration, or may be impossible.

5. Calibration of Instruments

5.1 Before use, each instrument shall be calibrated in accordance with the instructions of the manufacturer, employing suitable thickness standards.

5.2 During use, the calibration shall be checked at frequent intervals, at least once a day. Attention shall be given to the factors listed in Section 4 and to the procedures described in Section 5.

5.3 Calibration standards of known thickness are available either as shims or foils or as coated specimens.

5.3.1 *Calibration Foils*:

NOTE 3—In the following paragraphs, the use of the word "foil" will imply a nonmagnetic metallic or nonmetallic foil or shim.

5.3.1.1 Because of the difficulty of ensuring adequate contact, foils are generally not recommended for the calibration of instruments based on the principle of magnetic attraction but they are suitable in some circumstances provided the necessary precautions are taken. They can normally be used for the calibration of other types of instruments.

5.3.1.2 Foils are advantageous for calibration 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. Calibration foils are subject to wear and indentation and, therefore, should be replaced frequently. Worn foils shall not be used to calibrate the instrument.

5.3.2 *Coated Standards*—These calibration standards consist of coatings of known, uniform thickness permanently bonded to the substrate material.[3]

5.4 The basis metal of the calibration standards shall have magnetic properties similar to those of the basis metal of the coated test specimen. To confirm their suitability, a comparison of the readings obtained with the basis metal of the bare standard and that of the test specimen is recommended.

5.5 In some cases the calibration of the instrument should be checked by rotating the probe in increments of 90° (see 4.1.7 and 4.1.8).

5.6 The basis-metal thickness for the test and the calibration shall be the same if the critical thickness, defined in 4.1.3, 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.

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

6. Measuring Procedure

6.1 Operate each instrument in accordance with the instructions of the manufacturer giving appropriate attention to the factors listed in Section 4.

6.2 Check the calibration 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.

6.3 Observe the following precautions:

6.3.1 *Basis-Metal Thickness*—Check whether the basis-metal thickness exceeds the critical thickness. If not, either use the back-up method mentioned in 5.6 or make sure that the calibration has been made on a standard having the same thickness and magnetic properties as the test specimen.

[3] Coated standards suitable for many applications of the test method may be purchased from the office of Standard Reference Materials, National Institute of Standards and Technology, Gaithersburg, MD 20899.

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

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

6.3.4 *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.

6.3.4.1 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, whichever is the greater, then the measurement shall be discarded and repeated.

6.3.4.2 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).

6.3.4.3 Instruments of the attractive force type are sensitive to vibrations, and readings that are obviously erroneous should be rejected.

6.3.5 *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 calibration. If this is impossible, make four measurements in various orientations by rotating the probe in increments of 90°.

6.3.6 *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.

6.3.7 *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.

6.3.8 *Lead Coatings*—The magnet of an instrument of the attractive force type 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.

6.3.9 *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 calibrated 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.

6.3.10 *Positioning of Probe*—In general, place the instrument probe perpendicular to the specimen surface at the point of measurement. For some instruments of the attractive force type, 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 instrument is to be used in a horizontal or upside-down position, calibrate it for that position.

7. Report

7.1 The report should include the following information:

7.1.1 Type of instrument used,

7.1.2 Size and description of test specimen,

7.1.3 Whether special jigs were used,

7.1.4 Type of calibration standard and the method used,

7.1.5 Thickness of the coating as determined from the measurements,

7.1.6 Operator identification, and

7.1.7 Date.

8. Precision and Bias

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

8.2 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.

8.3 Instruments suitable for compliance with 6.1 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.

8.4 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 calibration standard used to calibrate the instrument.

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

9. Keywords

9.1 coating thickness; coatings; magnetic method; nonmagnetic coatings; 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 calibrated 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.