INTERNATIONAL

Designation: E2338 − 22

Standard Practice for Characterization of Coatings Using Conformable Eddy Current Sensors without Coating Reference Standards[1]

This standard is issued under the fixed designation E2338; 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.

1. Scope*

1.1 This practice covers the use of conformable eddy current sensors for nondestructive characterization of coatings without standardization on coated reference parts. It includes the following: *(1)* thickness measurement of a conductive coating on a conductive substrate, *(2)* detection and characterization of local regions of increased porosity of a conductive coating, and *(3)* measurement of thickness for nonconductive coatings on a conductive substrate or on a conductive coating. This practice includes only nonmagnetic coatings on either magnetic ($\mu \neq \mu_0$) or nonmagnetic ($\mu = \mu_0$) substrates. In addition to discrete coatings on substrates, this practice can also be used to measure the effective thickness of a process-affected zone (for example, shot peened layer for aluminum alloys, alpha case for titanium alloys) and to assess the condition of other layered media such as joints (for example, lap joints and skin panels over structural supports). For specific types of coated parts, the user may need a more specific procedure tailored to a specific application.

1.2 Specific uses of conventional eddy current sensors are covered by Practices D7091 and E376 and the following test methods issued by ASTM: B244 and E1004. Guidance for the use of conformable eddy current sensor arrays is provided in Guide E2884.

1.3 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

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

1.5 *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]

B244 Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments

D7091 Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

E376 Practice for Measuring Coating Thickness by Magnetic-Field or Eddy Current (Electromagnetic) Testing Methods

E543 Specification for Agencies Performing Nondestructive Testing

E1004 Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy Current) Method

E1316 Terminology for Nondestructive Examinations

E2884 Guide for Eddy Current Testing of Electrically Conducting Materials Using Conformable Sensor Arrays

NOTE 1—See Appendix X1.

3. Terminology

3.1 *Definitions*—For definitions of terms relating to this practice, refer to Terminology E1316, including Section C on Electromagnetic Testing, and also Guide E2884.

3.1.1 *air standardization, n*—an adjustment of the instrument response to air or another insulating material to match a model for the sensor response in air.

3.1.1.1 *Discussion*—It is generally sufficient for the sensor to be placed at least one spatial wavelength away from any conductive or magnetic object to provide the equivalent of

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic Method.

Current edition approved June 1, 2022. Published June 2022. Originally approved in 2004. Last previous edition approved in 2017 as E2338 – 17. DOI: 10.1520/E2338-22.

[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**

response in air alone. Measurements on conductive materials after air standardization should provide absolute electrical properties and lift-off values. The performance can be verified on certified reference standards over the frequency range of interest.

3.1.2 *performance verification, coated part, n*—a measurement of coating electrical conductivity or thickness, or both, on a coated reference part with known properties to confirm that the coating electrical conductivity or thickness, or both, are within specified tolerances for the application.

3.1.2.1 *Discussion*—Performance verification is a quality control procedure that does not represent standardization and should be documented in the report (see Section 9).

3.1.3 *performance verification, uncoated part, n*—a measurement of electrical conductivity performed on a reference part with known properties to confirm that the electrical conductivity variation with frequency is within specified tolerances for the application.

3.1.3.1 *Discussion*—When a reference standardization is performed, reference parts used for standardization should not be used for performance verification. These variations should be documented in the report (see Section 9). Performance verification is a quality control procedure recommended prior to or during measurements after standardization.

3.1.4 *process-affected zone, n*—a region near the surface with depth less than a spatial half wavelength that can be represented by a conductivity that is different than the conductivity of the base material.

3.1.4.1 *Discussion*—In some cases, the process affected zone near the surface of a material can be modeled as a coating on a substrate.

3.1.5 *reference substrate standardization, n*—an adjustment of the instrument response to an appropriate reference substrate standard.

3.1.5.1 *Discussion*—The adjustment is to remove offsets between the model for the sensor response and at least two reference substrate measurements (for example, two measurements with different lift-offs at the same position on the standard). These standards should have a known electrical conductivity that is essentially uniform with depth and should have essentially the same electrical conductivity and magnetic permeability as the substrate in the components being characterized.

3.1.6 *sensor footprint, n*—area of the sensor face placed against the material under examination.

4. Significance and Use

4.1 *Conformable Eddy Current Sensors*—Conformable, eddy current sensors can be used on both flat and curved surfaces, including fillets, cylindrical surfaces, etc. When used with models for predicting the sensor response and appropriate algorithms, these sensors can measure variations in physical properties, such as electrical conductivity or magnetic permeability, or both, as well as thickness of conductive coatings on any substrate and nonconductive coatings on conductive substrates or on a conducting coating. These property variations can be used to detect and characterize heterogeneous regions within the conductive coatings, for example, regions of locally higher porosity.

4.2 *Sensors and Sensor Arrays*—Depending on the application, either a single-sensing element sensor or a sensor array can be used for coating characterization. A sensor array provides a better capability to map spatial variations in coating thickness or conductivity, or both (reflecting, for example, porosity variations), and provides better throughput for scanning large areas. The size of the sensor footprint and the size and number of sensing elements within an array depend on the application requirements and constraints, and the nonconductive (for example, ceramic) coating thickness.

4.3 *Coating Thickness Range*—The conductive coating thickness range over which a sensor performs best depends on the difference between the electrical conductivity of the substrate and conductive coating and available frequency range. For example, a specific sensor geometry with a specific frequency range for impedance measurements may provide acceptable performance for an MCrAlY coating over a nickel-alloy substrate for a relatively wide range of conductive coating thickness, for example, from 75 to 400 µm (0.003 to 0.016 in.). Yet, for another conductive coating-substrate combination, this range may be 10 to 100 µm (0.0004 to 0.004 in.). The coating characterization performance may also depend on the thickness of a nonconductive topcoat. For any coating system, performance verification on representative coated specimens is critical to establishing the range of optimum performance. For nonconductive coatings, such as ceramic coatings, the thickness measurement range increases with an increase of the spatial wavelength of the sensor (for example, thicker coatings can be measured with larger sensor winding spatial wavelength). For nonconductive coatings, when roughness of the coating may have a significant effect on the thickness measurement, independent measurements of the nonconductive coating roughness, for example, by profilometry, may provide a correction for the roughness effects.

4.4 *Process-Affected Zone*—For some processes, for example, shot peening, the process-affected zone can be represented by an effective layer thickness and conductivity. These values can in turn be used to assess process quality. A strong correlation must be demonstrated between these "effective coating" properties and process quality.

4.5 *Three-Unknown Algorithm*—Use of multiple-frequency impedance measurements and a three-unknown algorithm permits independent determination of three unknowns: *(1)* thickness of conductive nonmagnetic coatings, *(2)* conductivity of conductive nonmagnetic coatings, and *(3)* lift-off that provides a measure of the nonconductive coating thickness.

4.6 *Accuracy*—Depending on the material properties and frequency range, there is an optimal measurement performance range for each coating system. The instrument, its air standardization or reference substrate standardization, or both, and its operation permit the coating thickness to be determined within ±15 % of its true thickness for coating thickness within the optimal range and within ±30 % outside the optimal range. Better performance may be required for some applications.