Designation: E 1004 – 99

An American National Standard

Standard Practice for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method[1]

This standard is issued under the fixed designation E 1004; 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 a procedure for determining the electrical conductivity of nonmagnetic metals using the electromagnetic (eddy-current) method. The procedure has been written primarily for use with commercially available direct reading electrical conductivity instruments. General purpose eddy-current instruments may also be used for electrical conductivity measurements but will not be addressed in this practice.

1.2 This practice is applicable to metals that have either a flat or slightly curved surface and includes metals with or without a thin nonconductive coating.

1.3 Eddy-current determinations of electrical conductivity may be used in the sorting of metals with respect to variables such as type of alloy, aging, cold deformation, heat treatment, effects associated with non-uniform heating or overheating, and effects of corrosion. The usefulness of the examinations of these properties is dependent on the amount of electrical conductivity change caused by a change in the specific variable.

1.4 Electrical conductivity, when evaluated with eddy-current instruments, is usually expressed as a percentage of the conductivity of the International Annealed Copper Standard (IACS). The conductivity of the Annealed Copper Standard is defined to be 0.58×10^8 S/m (100 % IACS) at 20°C.

1.5 The values stated in SI units are regarded as standard.

1.6 *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:*

B 193 Test Method for Resistivity of Electrical Conductor Materials[2]

E 105 Practice for Probability Sampling of Materials[3]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for Lot or Process[3]

E 543 Practice for Agencies Performing Nondestructive Testing[4]

E 1316 Terminology for Nondestructive Examinations[4]

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification In Nondestructive Testing[5]

ANSI/ASNT-CP-189 Standard for Qualification and Certification of NDT Personnel[5]

2.3 *AIA Standard:*

NAS 410 Certification and Qualification of Nondestructive Testing Personnel[6]

3. Terminology

3.1 *Definitions*—Definitions of terms relating to eddy-current examination are given in Terminology E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *temperature coefficient*—the fractional or percentage change in electrical conductivity per degree Celsius change in temperature.

4. Significance and Use

4.1 Absolute probe coil methods, when used in conjunction with reference standards of known value, provide a means for determining the electrical conductivity of nonmagnetic materials.

4.2 Electrical conductivity of a sample can be used as a means of determining: (*1*) type of metal or alloy, (*2*) type of heat treatment (for aluminum this evaluation should be used in conjunction with a hardness examination), (*3*) aging of the alloy, (*4*) effects of corrosion, and (*5*) heat damage.

5. Limitations

5.1 The ability to accomplish the examinations included in 4.2 is dependent on the conductivity change caused by the variable of interest. If the conductivity is a strong function of the variable of interest, these examinations can be very accurate. In some cases, however, changes in conductivity due

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[2] *Annual Book of ASTM Standards*, Vol 02.03.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from American Society for Nondestructive Testing 1711 Arlingate Plaza, PO Box 28518, Columbus, OH 43228–0518

[6] Available from Aerospace Industries Association of America, Inc., 1250 Eye St. NW, Washington, D.C. 20005. (Replacement standard for MIL-STD-410.)

to changes in the variable of interest may be too small to detect. The ability to isolate the variable of interest from other variables is also important. For example, if the alloy is not known, the heat treatment cannot be determined from conductivity alone.

5.2 The curve relating temper and conductivity of an aluminum alloy should be known before attempting to interpret conductivity measurements. For example, knowing alloy and heat treatment, the adequacy of the heat treatment can be estimated.

6. Basis of Application

6.1 *Personnel Qualification*:

6.1.1 Personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document. The practice of the standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.1.2 Qualification and certification for personnel may be reduced when the following conditions are met:

6.1.2.1 The test will be limited to operating equipment, which displays the results in percent IACS.

6.1.2.2 A specific procedure is used that is approved by a certified Level III in accordance with 6.1.1.

6.1.2.3 Documentation of training and examination is performed to ensure that personnel are qualified. Qualified personnel are those who have demonstrated, by passing written and practical proficiency tests, that they possess the skills and job knowledge necessary to ensure acceptable workmanship.

6.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

7. Variables Influencing Accuracy

7.1 Consider the influence of the following variables to ensure an accurate evaluation of electrical conductivity.

7.1.1 *Temperature*—The instrument, probe, reference standards, and parts being examined shall be stabilized as ambient temperature prior to conductivity evaluation. When possible, examinations should be performed at room temperature (typically 70 ± 15°F).

7.1.2 *Probe Coil to Metal Coupling*—Variations in the separation between the probe coil and the surface of the sample (lift-off) can cause large changes in the instrument output signal. Instruments vary widely in sensitivity due to lift-off, and some have adjustments for minimizing it. Standardize the instrument with values at least as large as the known lift-off. Surface curvature may also affect the coupling. (Consult the manufacturer's manual for limitations on lift-off and surface curvature).

7.1.3 *Edge Effect*—Examinations should not be performed within two coil diameters of any discontinuity, such as an edge, hole, or notch. Use a shielded probe if examinations closer to the geometric features are required.

7.1.4 *Uniformity of Sample*—Variations in material properties are common and can be quite large. Discontinuities or inhomogeneities in the metal near the position of the probe coil will change the value of the measured conductivity.

7.1.5 *Surface Conditions*—Surface treatments and roughness can affect the measured conductivity value of a material. Cladding also has a pronounced effect on conductivity readings as compared to the base metal values. Procedures for determining the electrical conductivity of clad materials are not addressed in this practice. The sample surface should be clean and free of grease.

7.1.6 *Instrument Stability*—Instrument drift, noise, and nonlinearities can cause inaccuracies in the measurement.

7.1.7 *Nonunique Conductivity Values*—It should be noted that two different alloys can have the same conductivity. Thus, in some cases, a measurement of conductivity may not uniquely characterize an alloy. Overheated parts and some heat-treated aluminum alloys are examples of materials that may have identical conductivity values for different heat treatments or tempers.

7.1.8 *Sample Thickness*—Eddy-current density decreases exponentially with depth (that is, distance from the metal surface). The depth at which the density is approximately 37 % (1/e) of its value at the surface is called the standard depth of penetration δ. Calculate the standard depth of penetration for nonmagnetic materials using one of the following formulas:

$$\delta = \frac{503.3}{\sqrt{f\sigma}}\,(m),\ \sigma = 1/\rho \tag{1}$$

$$\delta = \frac{K}{\sqrt{(1/\rho)\,f\mu_r}}\,(cm),\ K \simeq 50,\ \mu_r = 1 \tag{2}$$

$$\delta = \frac{1}{\sqrt{\pi\mu\sigma f}}\,(m),\ \mu = \mu_o\mu_r,\ \mu_o = 4\pi\times10^{-7},\ \mu_r = 1 \tag{3}$$

where:

σ = electrical conductivity of the sample in *S/m*,
ρ = electrical conductivity in $\Omega\cdot m$, and
f = test frequency in Hz.

These formulas are for nonmagnetic materials when the relative permeability, $\mu_{rel} = 1$. If the thickness of the sample and the reference standards is at least 2.6δ, the effect of thickness is negligible. Smaller depths of penetration (higher frequencies) may be desirable for measuring surface effects. Depth of penetration is also a function of coil diameter. The change due to coil diameter variation is not considered in the above equation. Consult the instrument manufacturer if penetration depth appears to be a source of error in the measurement.

8. Apparatus

8.1 *Electronic Apparatus*—The electronic apparatus shall be capable of energizing the probe coil with alternating currents of suitable frequencies and power levels and shall be capable of sensing changes in the measured impedance of the coil. Equipment may include any suitable signal-processing device (phase discriminator, filter circuits, and so forth). The output may be displayed in either analog or digital readouts. Readout is normally in percent IACS although it may be scaled for readings in other units. Additional apparatus, such as computers, plotters, or printers, or combination thereof, may be used in the recording of data.

8.2 *Probe*—Probe coil designs combine empirical and