~~Designation:E1004–02~~

~~Standard Practice for~~ Designation: E 1004 – 09

Standard Test Method 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.

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

1. Scope*

1.1 This ~~practice~~ test method 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.~~ test method.

1.2 This ~~practice~~test method 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:*[2]

B 193 Test Method for Resistivity of Electrical Conductor Materials

E 105 Practice for Probability Sampling ~~of~~Of Materials

E 122 Practice for Calculating Sample Size to Estimate, ~~with a~~ With Specified ~~Tolerable Error,~~ Precision, the Average for a Characteristic of a Lot or Process

E 543 ~~Practice~~Specification for Agencies Performing Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

Recommended Practice SNT-TC-1A for Personnel Qualification and Certification In Nondestructive Testing[3]

ANSI/ASNT-CP-189 Standard for Qualification and Certification of NDT Personnel[3]

2.3 *AIA Document:*

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

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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* ~~, Vol 02.03.~~volume information, refer to the standard's Document Summary page on the ASTM website.

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

[3] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

***A Summary of Changes section appears at the end of this standard.**

NAS–410 Certification and Qualification of Nondestructive Testing Personnel[4]

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 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 If specified by the contractual agreement, personnel performing examinations to this ~~standard~~test method shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. 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 examination 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 Testing 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.

6.3 The following additional items are subject to contractual agreement between the parties using or referencing this ~~standard.~~ test method.

6.3.1 Timing of Examination

6.3.2 Extent of Examination

6.3.3 Reporting Criteria/Acceptance Criteria

6.3.4 Reexamination of Repaired/Reworked Items

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~~at ambient temperature prior to conductivity evaluation. When possible, examinations should be performed at room temperature (typically ~~70~~68 ± 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).

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

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

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.~~ — Tests should not be performed within two coil diameters of any discontinuity, such as an edge, hole, or notch unless coil manufacturer's instructions allow. Consult manufacturer's instructions to determine equipment limitations for inspection adjacent to any discontinuity. If no information regarding probe use restrictions or limitations adjacent to such discontinuities exist, examinations should not be performed within two coil diameters of any discontinuity.

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.

NOTE 1—Similar materials from various manufacturing methods (extrusion, forging, casting, rolling, machined vs. unmachined) may exhibit significant conductivity variation between processes.

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.~~test method. 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:

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

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

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

where:

σ = electrical conductivity of the sample in *S/m*,
ρ = ~~electrical conductivity in~~ *electrical resistivity in* Ω·*m, and*
f = examination frequency in Hz.

These formulas are for nonmagnetic materials when the relative permeability, μ_{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~~ The eddy-current density decrease with depth is also ~~a function of~~affected by the 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 mathematical design methods to choose appropriate combinations of characteristics. Many instruments use one probe coil. In instruments with several coils, the difference between coils is the coil geometry. For most conductivity instruments, the cable connecting the coil to the instrument is an integral part of the measuring circuit and the cable length should not be modified without consulting the instrument manufacturer or manual.

8.2.1 The probe coil should be designed to minimize the effect of heat transfer from hand to coil.

~~8.2.2Some probe coils are designed to permit measurements closer than two coil diameters from an edge or discontinuity.~~

8.3 Mechanical handling apparatus for feeding the samples or moving the probe coil, or both, may be used to automate a specific measurement.

9. Standardization and Calibration

9.1 *Standardization*— Turn the instrument on and allow it sufficient time to stabilize in accordance with the manufacturer's instructions. Adjust, balance, and standardize the conductivity meter against the instrument's operational standards, and