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Standard Test Method for Resistivity of Electrical Conductor Materials[1]

This standard is issued under the fixed designation B193; 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 determination of the electrical resistivity of metallic electrical conductor material. It provides for an accuracy of ±0.30 % on test specimens having a resistance of 0.00001 Ω (10 μΩ) or more. Weight resistivity accuracy may be adversely affected by possible inaccuracies in the assumed density of the conductor.

1.2 *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]

A111 Specification for Zinc-Coated (Galvanized) "Iron" Telephone and Telegraph Line Wire

A326 Specification for Zinc-Coated (Galvanized) High Tensile Steel Telephone and Telegraph Line Wire (Withdrawn 1990)[3]

B9 Specification for Bronze Trolley Wire

B105 Specification for Hard-Drawn Copper Alloy Wires for Electric Conductors

B298 Specification for Silver-Coated Soft or Annealed Copper Wire

B355 Specification for Nickel-Coated Soft or Annealed Copper Wire

B415 Specification for Hard-Drawn Aluminum-Clad Steel Wire

B498/B498M Specification for Zinc-Coated (Galvanized) Steel Core Wire for Use in Overhead Electrical Conductors

B566 Specification for Copper-Clad Aluminum Wire

B606 Specification for High-Strength Zinc-Coated (Galvanized) Steel Core Wire for Aluminum and Aluminum-Alloy Conductors, Steel Reinforced

B800 Specification for 8000 Series Aluminum Alloy Wire for Electrical Purposes—Annealed and Intermediate Tempers

B802 Specification for Zinc-5% Aluminum-Mischmetal Alloy-Coated Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR)[Metric](Discontinued 1998-Replaced by B 802/B802M) B0802_B0802M

B803 Specification for High-Strength Zinc–5 % Aluminum-Mischmetal Alloy-Coated Steel Core Wire for Use in Overhead Electrical Conductors

B957 Specification for Extra-High-Strength and Ultra-High-Strength Zinc-Coated (Galvanized) Steel Core Wire for Overhead Electrical Conductors

B958 Specification for Extra-High-Strength and Ultra-High-Strength Class A Zinc–5% Aluminum-Mischmetal Alloy-Coated Steel Core Wire for Use in Overhead Electrical Conductors

2.2 *NIST Document:*

NBS Handbook 100 —Copper Wire Tables[4]

3. Resistivity

3.1 *Resistivity* (Explanatory Note 1) is the electrical resistance of a body of unit length, and unit cross-sectional area or unit weight.

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[1] This test method is under the jurisdiction of ASTM Committee B01 on Electrical Conductors and is the direct responsibility of Subcommittee B01.02 on Methods of Test and Sampling Procedure.

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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~~standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

3.2 *Volume Resistivity* is commonly expressed in ohms for a theoretical conductor of unit length and cross-sectional area; in inch-pound units in Ω·cmil/ft and in acceptable metric units in Ω· mm²/m. It may be calculated by the following equation:

$$\rho_v = (A/L)R$$

where:

ρ_v = volume resistivity, Ω·cmil/ft or Ω·mm²/m,
A = cross-sectional area, cmil or mm²,
L = gage length, used to determine R, ft or m, and
R = measured resistance, Ω.

3.3 *Weight Resistivity* is commonly expressed in ohms for a theoretical conductor of unit length and weight. The method for calculating weight resistivity, based on resistance, length, and weight measurements, of a test specimen is given in Explanatory Note 2.

4. Apparatus

4.1 Resistance shall be measured with a circuit configuration and instrumentation that has a resistance measurement capability of ±0.15 % accuracy.

5. Test Specimen

5.1 The test specimen may be in the form of a wire, strip, rod, bar, tube, or shape. It shall be of uniform cross section throughout its length within ±0.75 % of the cross-sectional area. Wherever possible it shall be the full cross section of the material it represents, if the full cross section is such that the uniformity of the cross-sectional area can be accurately determined.

5.2 The test specimen shall have the following characteristics:

5.2.1 A resistance of at least 0.00001 Ω (10 μΩ) in the test length between potential contacts,

5.2.2 A test length of at least 1 ft or 300 mm,

5.2.3 A diameter, thickness, width, or other dimension suitable to the limitations of the resistance measuring instrument,

5.2.4 No surface cracks or defects visible to the unaided normal eye, and substantially free from surface oxide, dirt, and grease, and

5.2.5 No joints or splices.

6. Procedure

6.1 Make all determinations of the dimensions and weight of the test specimen using instruments accurate to ±0.05 %. In order to assure this accuracy in measuring the length between potential contacts, the surface in contact with the test specimen shall be a substantially sharp knife-edge when using a Kelvin-type bridge or a potentiometer.

6.2 The cross-sectional dimensions of the specimen may be determined by micrometer measurements, and a sufficient number of measurements shall be made to obtain the mean cross section to within ±0.10 %. In case any dimension of the specimen is less than 0.100 in. and cannot be measured to the required accuracy, determine the cross-section from the weight, density, and length of the specimen.

6.3 When the density is unknown, determine the density by weighing a specimen first in air and then in a liquid of known density at the test temperature, which shall be room temperature to avoid errors due to convection currents. Exercise care in removing all air bubbles from the specimen when weighing it in the liquid. Calculate the density from the following equation:

$$\delta = (W_a \times d)/(W_a - W_l)$$

where:

δ = density of the specimen, g/cm³;
W_a = weight of the specimen in air, g;
W_l = weight of the specimen in the liquid, g; and
d = density of the liquid at the test temperature, g/cm³.

6.4 When potential leads are used, make sure the distance between each potential contact and the corresponding current contact is at least equal to 1½ times the cross-sectional perimeter of the specimen. Make sure the yoke resistance (between reference standard and test specimen) is appreciably smaller than that of either the reference standard or the test specimen unless a suitable lead compensation method is used, or it is known that the coil and lead ratios are sufficiently balanced so that variation in yoke resistance will not decrease the bridge accuracy below stated requirements.

6.5 Make resistance measurements to an accuracy of ±0.15 %. To ensure a correct reading, allow the reference standard and the test specimen to come to the same temperature as the surrounding medium. (If the reference standard is made of manganin it is possible to obtain correct readings with the test specimen at reference temperatures other than room temperature). In all resistance measurements, the measuring current raises the temperature of the medium. Therefore, take care to keep the magnitude of the current low, and the time of its use short enough so that the change in resistance cannot be detected with the galvanometer.

To eliminate errors due to contact potential, take two readings, one direct and one with current reversed, in direct succession. Check tests are recommended whereby the specimen is turned end for end, and the test repeated. Surface cleaning of the specimen at current and potential contact points may be necessary to obtain good electrical contact.

7. Temperature Correction

7.1 When the measurement is made at any other than a reference temperature, the resistance may be corrected for moderate temperature differences to what it would be at the reference temperature, as follows:

$$R_T = \frac{R_t}{1+\alpha_T(t-T)}$$

where:

R_T = resistance at reference temperature T,
R_t = resistance as measured at temperature t,
α_T = known or given temperature coefficient of resistance of the specimen being measured at reference temperature T,
T = reference temperature, and
t = temperature at which measurement is made.

NOTE 1—The parameter α_T, in the above equation, varies with conductivity and temperature. For copper of 100 % conductivity and a reference temperature of 20°C, its value is 0.00393. Values at other conductivities and temperatures will be found in *NBS Handbook 100*.[4] Table 1 lists temperature coefficients for the common electrical conductor materials.

8. Report

8.1 For referee tests, report the following information:

8.1.1 Identification of test specimen,

8.1.2 Kind of material,

8.1.3 Test temperature,

8.1.4 Test length of specimen,

8.1.5 Method of obtaining cross-sectional area:

8.1.5.1 *If by micrometer,* the average values of micrometer readings, or

8.1.5.2 *If by weighing,* a record of length, weight, any density determinations that may be made, and calculated cross-sectional areas.

8.1.6 Weight, if used,

8.1.7 Method of measuring resistance,

8.1.8 Value of resistance,

8.1.9 Reference temperature,

8.1.10 Calculated value of resistivity at the reference temperature, and

8.1.11 Previous mechanical and thermal treatments. (Since the resistivity of a material usually depends upon them, these shall be stated whenever the information is available.)

8.2 For routine tests, only such of the items in 8.1 as apply to the particular case, or are significant, shall be reported.

TABLE 3 ~~Equivalent Resistivity Values for Copper~~[A]

~~Conductivity at 20°C (68°F) percent IACS~~	~~100.0~~
~~Volume Resistivity~~	
~~Ω·cmil/ft~~	~~10.371~~
~~Ω·mm²/m~~	~~0.017241~~
~~μΩ·in.~~	~~0.67879~~
~~μΩ·cm~~	~~1.7241~~
~~Weight Resistivity~~	
~~Ω·lb/mile²~~	~~875.20~~
~~Ω·g/m²~~	~~0.15328~~

TABLE 1 Resistivity and Conductivity Conversion

NOTE 1—These factors are applicable only to resistivity and conductivity values corrected to 20°C (68°F). They are applicable for any temperature when used to convert between volume units only or between weight units only. Values of density, δ, for the common electrical conductor materials, are listed in Table 2.

Given N→ Perform indicated operation to obtain ↓	Volume Resistivity at 20°C				Weight Resistivity at 20°C		Conductivity at 20°C	
	Ω·cmil/ft	Ω·mm²/m	μΩ·in.	μΩ·cm	Ω·lb/mile²	Ω·g/m²	% IACS (Volume Basis)	% IACS (Weight Basis)
Volume Resistivity at 20°C								
Ω·cmil/ft	. . .	N × 601.52	N × 15.279	N × 6.0153	N × 0.10535 × (1/δ)	N × 601.53 × (1/δ)	(1/N) × 1037.1	(1/N) × 9220.0 × (1/δ)
Ω·mm²/m	N × 0.0016624	. . .	N × 0.025400	N × 0.010000	N × 0.00017513 × (1/δ)	N × (1/δ)	(1/N) × 1.7241	(1/N) × 15.328 × (1/δ)
μΩ·in.	N × 0.065450	N × 39.370	. . .	N × 0.39370	N × 0.0068950 × (1/δ)	N × 39.370 × (1/δ)	(1/N) × 67.879	(1/N) × 603.45 × (1/δ)
μΩ·cm	N × 0.16624	N × 100.00	N × 2.5400	. . .	N × 0.017513 × (1/δ)	N × 100.00 × (1/δ)	(1/N) × 172.41	(1/N) × 1532.8 × (1/δ)
Weight Resistivity at 20°C								
Ω·lb/mile²	N × 9.4924 × δ	N × 5710.0 × δ	N × 145.03 × δ	N × 57.100 × δ	. . .	N × 5710.0	(1/N) × 9844.8 × δ	(1/N) × 87520
Ω·g/m²	N × 0.0016624 × δ	N × δ	N × 0.025400 × δ	N × 0.010000 × δ	N × 0.00017513	. . .	(1/N) × 1.7241 × δ	(1/N) × 15.328
Conductivity at 20°C								
% IACS (volume basis)	(1/N) × 1037.1	(1/N) × 1.7241	(1/N) × 67.879	(1/N) × 172.41	(1/N) × 9844.8 × δ	(1/N) × 1.7241 × δ	. . .	N × 0.11249 × δ
% IACS (weight basis)	(1/N) × 9220.0 × (1/δ)	(1/N) × 15.328 × (1/δ)	(1/N) × 603.45 × (1/δ)	(1/N) × 1532.8 × (1/δ)	(1/N) × 87520	(1/N) × 15.328	N 8.89 × (1/δ)	. . .

[A] ~~The equivalent resistivity values for 100 % IACS (soft copper) were each computed from the fundamental IEC value (1/58 Ω·mm²/m) using conversion factors each accurate to at least seven significant figures. Corresponding values for other conductivities (aluminum, etc.) may be derived from these by multiplying by the reciprocal of the conductivity ratios and where applicable also by the density ratios, both accurate to at least seven significant figures.~~