Designation: B49 – 17

Standard Specification for Copper Rod for Electrical Purposes[1]

This standard is issued under the fixed designation B49; 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 specification covers the requirements for rod in diameters from ¼ to 1⅜ in. (6.4 to 35 mm) produced from high conductivity coppers listed in Table 1, namely, electrolytic tough-pitch, oxygen-free, or fire-refined high conductivity coppers, and are suitable for further fabrication into electrical conductors.

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

1.3 The following safety hazards caveat pertains only to Section 13. *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.*

1.4 *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 The following documents in the current issue of the Book of Standards form a part of this specification to the extent referenced herein and define materials suitable for use in rod manufacture:

2.2 *ASTM Standards:*[2]

B5 Specification for High Conductivity Tough-Pitch Copper Refinery Shapes

B115 Specification for Electrolytic Copper Cathode

B170 Specification for Oxygen-Free Electrolytic Copper—Refinery Shapes

B193 Test Method for Resistivity of Electrical Conductor Materials

B224 Classification of Coppers

B577 Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper

B846 Terminology for Copper and Copper Alloys

E8/E8M Test Methods for Tension Testing of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E53 Test Method for Determination of Copper in Unalloyed Copper by Gravimetry

E478 Test Methods for Chemical Analysis of Copper Alloys

E1606 Practice for Electromagnetic (Eddy Current) Examination of Copper and Aluminum Redraw Rod for Electrical Purposes

E2575 Standard Test Method for Determination of Oxygen in Copper and Copper Alloys (Withdrawn 2017)[3]

2.3 *Other Document:*[4]

NBS Handbook 100 *Copper Wire Tables*

3. Terminology

3.1 For definitions of general terms relating to copper and copper alloys refer to Terminology B846.

4. Ordering Information

4.1 Orders for rod under this specification shall include the following information:

4.1.1 ASTM designation and year of issue,

4.1.2 Quantity of each size,

4.1.3 UNS designation and requirements of copper (Sections 5 – 10),

4.1.4 Finish (Sections 9 and 10),

[1] This specification is under the jurisdiction of ASTM Committee B05 on Copper and Copper Alloys and is the direct responsibility of Subcommittee B05.07 on Refined Copper.

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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 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 Technical Information Service (NTIS), 5301 Shawnee Rd., Alexandria, VA 22312, http://www.ntis.gov.

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

4.1.5 Package with or without joints (see 5.3),
4.1.6 Rod diameter (see 9.2),
4.1.7 Inspection (Section 15),
4.1.8 Package size (see 19.1), and
4.1.9 Special package marking as agreed upon between the manufacturer and the purchaser (Section 19).

4.2 The following requirements are optional and should be specified in the contract or purchase order when required.
4.2.1 Certification (Section 17) and
4.2.2 Test Report (Section 18).

5. Material and Manufacture

5.1 The rod shall be fabricated from copper of such quality and purity that the finished product shall have the properties and characteristics prescribed in this specification.

NOTE 1—The following specifications define materials suitable for use: Classification B224, or Specification B5, or Specification B115, or Specification B170.

5.2 Copper of special qualities, forms, or types, as agreed upon between the manufacturer and the purchaser and that will conform to the requirements prescribed in this specification may also be used.

5.3 The rod coils shall be furnished in continuous lengths with or without joints, as ordered.

6. Chemical Composition

6.1 Each rod type shall conform to the chemical composition requirements prescribed in Table 1 for the type of copper ordered (Section 5).

6.2 By agreement between the manufacturer and the purchaser, the addition of silver up to an average of 30 troy oz per short ton of copper (0.10 %) will be considered within the specification, copper including silver in the chemical analysis, with no individual silver analysis to exceed 35 troy oz per short ton (0.12 %). In the case of oxygen-free silver-bearing coppers, the designation OFS (oxygen-free, silver-bearing) will be used as shown in Classification B224 and will include the UNS Nos. C10400, C10500, and C10700 as defined by the agreed silver content.

6.3 Silver-bearing tough-pitch copper corresponds to the designation STP (silver-bearing tough-pitch) as shown in Classification B224 and to coppers having UNS Nos. C11300, C11400, C11500, and C11600.

6.4 *Oxygen Content*—Oxygen-free copper as described herein is defined as a copper containing not in excess of 0.0010 % (10 ppm) oxygen and produced without the use of metallic or other deoxidizers.

7. Physical Property Requirements

7.1 *Electrical Resistivity*—Resistivity of the copper in the annealed condition (See Note X1.1 and Table 2) shall not exceed the following values at 20 °C:

Type of Copper	Resistivity, max, at 20 °C Annealed, Ω · g/m^2
UNS C10100 only	0.15176 (101.00 % IACS min)
All others	0.15328 (100.00 % IACS min)

TABLE 1 Chemical Composition[A]

UNS Number Copper Type	C11000 ETP	C11040 ETP	C10100 OFE[B]	C10200 OF[C]
Copper, min	99.90 %[D] incl silver	99.90 %[E]	99.99 %[E]	99.95 %[D] incl silver
	ppm	ppm	ppm	ppm
Tellurium, max	. . .	2	2	. . .
Selenium, max	. . .	2	3	. . .
Bismuth, max	. . .	1.0	1.0	. . .
Group total, max	. . .	3	. . .	. . .
Antimony, max	. . .	4	4	. . .
Arsenic, max	. . .	5	5	. . .
Tin, max	. . .	5	2	. . .
Lead, max	. . .	5	5	. . .
Iron, max	. . .	10	10	. . .
Nickel, max	. . .	10	10	. . .
Sulfur, max	. . .	15	15	. . .
Silver, max	. . .	25	25	. . .
Oxygen	. . .	100–650	5 max	10 max
Maximum allowable total	. . .	65[F]	. . .	. . .
Cadmium, max	. . .	. . .	1	. . .
Phosphorus, max	. . .	. . .	3	. . .
Zinc, max	. . .	. . .	1	. . .
Manganese, max	. . .	. . .	0.5	. . .

Fire-Refined Coppers		
UNS Number Copper Type	C11020 FRHC	C11025 FRHC
Copper, min incl silver	99.90 %[D]	99.90 %[D]
Tellurium, max	. . .	10
Selenium, max	. . .	10
Bismuth, max	. . .	5
Group total, max	. . .	. . .
Antimony, max	. . .	50
Arsenic, max	. . .	10
Tin, max	. . .	150
Lead	. . .	150–450
Iron, max	. . .	20
Nickel, max	. . .	150
Sulfur, max	. . .	20
Silver, max	. . .	150
Oxygen	. . .	100–400
Maximum allowable total	. . .	750[F]
Cadmium, max	. . .	100
Phosphorus, max	. . .	. . .
Zinc, max	. . .	80
Manganese, max	. . .	. . .

[A] See 13.1.2.
[B] From Specification B170 Grade 1 copper or equivalent.
[C] From Specification B170 Grade 2 copper or equivalent.
[D] See 13.1.1.
[E] By difference. See 13.1.2 and 13.1.3.
[F] Not including oxygen.

TABLE 2 Equivalent Resistivity Values[A]

Conductivity at 68 °F (20 °C), % IACS	100.00	101.00
Ω · lb/mile^2	875.20	866.53
Ω · g/m^2	0.153 28	0.151 76
Ω · c mil/ft	10.371	10.268
Ω · mm^2/m	0.017 241 0	0.017 070
μΩ · in.	0.678 79	0.672 07
μΩ · cm	1.7241	1.7070

[A] The equivalent resistivity values for 100 % IACS (soft copper) were each computed from the fundamental IEC value (1/58 Ω · mm^2/m) using conversion factors each accurate to at least seven significant figures.

8. Mechanical Property Requirements

8.1 *Tensile Tests*—Rod finished by hot working or annealing shall have a minimum elongation of 30 % in 10 in. (250 mm). (Note X1.2 and Test Methods E8/E8M.)

8.2 *Torsion (Twist) Tests*—Torsion tests are not a requirement of this specification. However, a discussion will be found in Note X1.3.

8.3 *Embrittlement (Bend) Test:*

8.3.1 A test to reflect propensity towards hydrogen embrittlement shall be performed only on oxygen-free copper.

8.3.2 The specimen shall be tested in accordance with 13.6 and Specification B170.

8.3.3 The specimen, prepared and tested from the OFE (oxygen-free electronic) copper (UNS C10100) listed in Table 1, shall withstand without breaking into two pieces, a minimum of ten (10) reverse bends.

8.3.4 The specimen, prepared and tested from the OF (oxygen-free) copper (UNS C10200) listed in Table 1, shall withstand, without breaking into two pieces, a minimum of eight (8) reverse bends.

8.4 *Annealability*—Annealability is not a requirement of this specification. However, a discussion will be found in Note X1.4, Note X1.5, Note X1.6, and Note X1.7.

9. Other Requirements

9.1 *Surface Oxide*—The surface oxide film thickness shall be determined in accordance with 13.5.

9.1.1 Total thickness of the copper oxide film on cleaned copper rod or annealed shaved rod or cold-finished rod shall not exceed 750 Å (7.5×10^{-8} m).

9.1.2 The residual oxide film thickness on as-shaved rod does not need to be specified.

9.1.3 A surface oxide requirement is not necessary for rod ordered uncleaned.

9.2 *Diameter*—The diameter of the rod at any point shall not vary from that specified by more than the amounts prescribed in Table 3.

TABLE 3 Permissible Variations in Diameter

Nominal Diameter, in. (mm)	Permissible Variation, in. (mm)
¼ (6.4)	+0.020 (+0.51) −0.010 (−0.25)
Over ¼ (6.4) to ¾ in. (19 mm) incl.	±0.015 (±0.38)
Over ¾ (19) to 1.0 in. (25 mm) incl.	±0.020 (±0.51)
Over 1.0 (25) to 1⅜ in. (35 mm) incl.	±0.030 (±0.76)

9.3 *Electromagnetic (Eddy-current) Examination*—Electromagnetic examination of copper redraw rod is not a requirement of this specification. If it is performed for detecting surface discontinuities, however, a discussion will be found in Note X1.8.

10. Workmanship, Finish, and Appearance

10.1 The rod shall be free of defects, but blemishes of a nature that do not interfere with the intended application are acceptable.

11. Sampling

11.1 *Routine Sampling*—For the routine analysis of copper rod coils, the methods of sampling shall be at the discretion of the tester.

11.2 This procedure shall be used in case of rod dispute between the manufacturer and the purchaser.

11.2.1 A lot shall be considered as a single coil of finished rod. A minimum of two samples of sufficient length shall be taken from the suspected non-conforming rod coil for retesting. Samples may be taken from either end of the rod coil at the discretion of the tester. Specific numbers and locations shall be determined between the producer and user. If the test pieces from both test samples pass the appropriate test(s), then the coil shall be deemed to conform to the particular requirement(s) of the standard. If a test piece fails a test, the rod coil represented in the shipping lot shall be deemed not to conform to this standard.

11.2.2 A shipping lot shall be the quantity of rod in coil form that is present in a single container, such as a truck or railroad car.

11.3 When a cast refinery shape has been chemically analyzed and converted into rod without remelting, further chemical analysis shall not be required.

12. Number of Tests and Retests

12.1 *Tests:*

12.1.1 *Chemical Analysis*—Chemical composition shall be determined in accordance with the element mean of the results from at least two replicate analyses of the sample(s).

12.1.2 *Other Tests:*

12.1.2.1 *Electrical Resistivity, Tensile Elongation, Diameter, and Surface Oxide*—Results shall be reported as the average obtained from at least two test specimens, each taken from a separate test piece where possible.

12.1.2.2 *Hydrogen Embrittlement Test and Microscopical Examination*—All specimens tested must meet the requirements of the specification.

12.2 *Retests:*

12.2.1 When requested by the manufacturer or supplier, a retest shall be permitted when results of tests obtained by the purchaser fail to conform to the requirements of the product specification.

12.2.2 The retest shall be as directed in the product specification for the initial test except the number of test specimens shall be twice that normally required for the specified test.

12.2.3 All test specimens shall conform to the product specification requirement(s) in retest. Failure to conform shall be cause for rejection.

13. Test Methods

13.1 *Chemical Analysis:*

13.1.1 In case of dispute, copper content of the coppers other than UNS C10100 and UNS C11040 in Table 1 shall be determined in accordance with Test Method E53.

13.1.2 Analytical method for determining impurity levels of coppers listed in Table 1 shall be in accordance with Specification B115.

13.1.3 Copper content of UNS C10100 and UNS C11040 types shall be calculated by subtracting from 100 % the total impurity concentration determined. The impurity total for UNS C10100 is defined as the sum of sulfur, silver, lead, tin, bismuth, arsenic, antimony, iron, nickel, zinc, phosphorus,

selenium, tellurium, manganese, cadmium, and oxygen present in the sample. The impurity total for UNS C11040 is defined as the sum of sulfur, silver, lead, tin, bismuth, arsenic, antimony, iron, nickel, selenium, tellurium, and oxygen present in the sample.

13.1.4 The test methods annex of Specification B170 should be referenced for the oxygen-free coppers. Test Methods E478 should be referenced for the determination of silver-bearing alloys permitted under this specification.

13.1.5 Oxygen content shall be determined on cleaned copper samples using a suitable laboratory apparatus or a commercial instrument designed specifically for this purpose. Test Method E2575 shall be referenced to determine oxygen content in copper and copper alloys only for the range 5 to 400 ppm since standards have not been developed above this range.

13.2 *Tensile Elongation*—Elongation shall be determined as the permanent increase in length, caused by breaking of the rod in tension, measured between gage marks placed originally 10 in. (250 mm) apart upon the test specimen (Note X1.2). The fracture shall be between gage marks and not closer than 1 in. (25 mm) to either gage mark.

13.3 *Electrical Resistivity:*

13.3.1 At the option of the manufacturer, electrical resistivity shall be determined in accordance with 13.3.2 or 13.3.3. However, in case of dispute, 13.3.2 shall apply.

13.3.2 Resistance measurements (Note X1.1) shall be made on specimens of the rod after cleaning and processing down to a diameter of approximately 0.080 in. (2.0 mm) and annealing at approximately 932 °F (500 °C) for 30 min. Other equivalent annealing methods may be used. Test specimens processed to a diameter other than 0.080 in. may be used if agreed upon between the manufacturer and the purchaser.

13.3.3 Resistance measurements may be determined on specimens of the rod after cleaning, but without further processing and annealing. However, in the event of failure of a rod specimen to conform to the criteria of 7.1, a retest is permitted using the procedure of 13.3.2.

13.3.4 Electrical resistivity shall be determined in accordance with Test Method B193 except that when the option of 13.3.3 is elected, the plus and minus tolerance for the cross-sectional area as specified in Test Method B193 shall not apply.

13.4 *Diameter*—Diameter of the rod shall be measured with a suitable measuring device, micrometer, caliper or other, reading at least to the nearest 0.001 in. (0.02 mm).

13.5 *Surface Oxide:*

13.5.1 The thickness and type of unreduced oxide films remaining on the surface of rod after cleaning shall be determined by an electrolytic reduction method. This test shall be performed by reducing the surface oxide(s) to copper in an electrolytic cell.[5] As shown by the schematic diagram in Fig. 1, the test sample is made cathodic with respect to an anode, which shall be made from a platinum wire or an equivalent inert electrode. Current shall be supplied from a dc power supply or a coulometer. A discussion on means to help improve accuracy and repeatability of this test method will be found in Note X1.9.

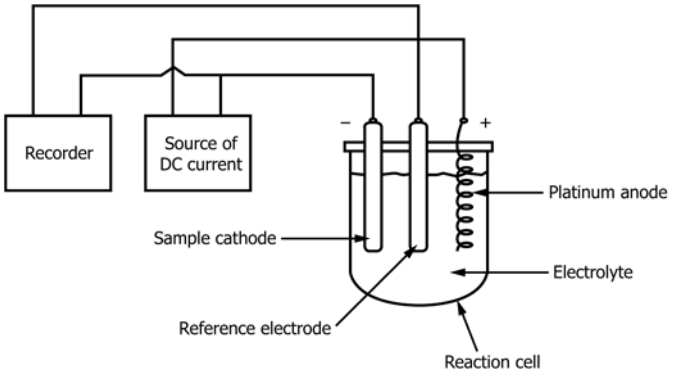

FIG. 1 Schematic Illustration Showing Electrolytic Reduction Test Method

13.5.2 Each of the oxides found on copper, namely cuprous and cupric, are reduced sequentially to copper at different reduction potentials, and the voltages are to be recorded against time during the entire test. When the individual reactions between the oxides and hydrogen ions are complete, gaseous hydrogen is evolved and may be seen visually at the surface of the copper rod sample.

13.5.3 A typical curve of voltage versus time is presented in Fig. 2. Cuprous oxide is reduced initially. When this reaction is complete, reduction of the cupric oxide occurs at a higher voltage.

13.5.4 Thickness of each oxide present shall be calculated as follows:

$$T = \frac{I\,t\,M}{Sd\,Fn} \tag{1}$$

[5] For a description of a similar, yet alternative standard procedure to determine tarnish films on coupons exposed to environmental tests, see "Monitoring Environmental Tests by Coulometric Reduction of Metallic Control Samples," *Journal of Testing and Evaluation*, 1989, pp. 357-367, ASTM. Also refer to "The Role of Surface Oxide and Its Measurement in the Copper Wire Industry," *Wire Journal*, March 1977, pp. 50-57, and "Analysis and Automation of Copper Surface Oxide Measurement," *Wire Journal*, February 1999, pp. 90-97, and "New Developments in Rod Surface Measurement and Analysis," *Wire Journal*, December, 2009, pp. 72-78.

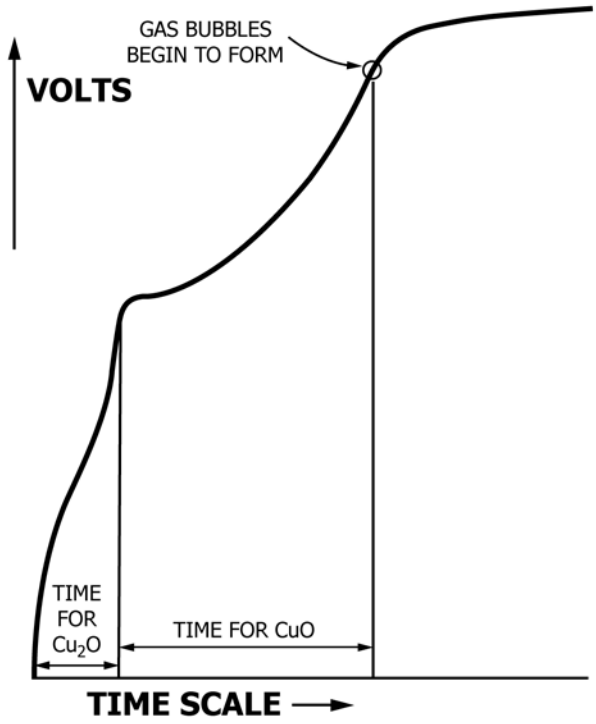

FIG. 2 Typical Voltage-Time Curve for the Reduction of Copper Oxide Films

where:

T = oxide thickness, cm;
I = current, A;
t = time of reaction, s;
M = molecular weight of the oxide, g;
S = surface area of immersed sample, cm^2;
d = oxide density (6.0 g/cm^3 for Cu_2O and 6.4 g/cm^3 for CuO);
F = Faraday constant, 96 500 C; and
n = hydrogen equivalent (2).

13.6 *Hydrogen Embrittlement Susceptibility:*

13.6.1 The specimen of oxygen-free copper rod shall be drawn into 0.080-in. (2.03-mm) diameter wire, annealed in an atmosphere containing not less than 10 % of hydrogen for 30 min at 1560 ± 45 °F (850 ± 25 °C) and cooled quickly in the same atmosphere, or without undue exposure to air, quenched into water. Each specimen shall undergo the bend test in accordance with 13.6.2.

13.6.2 The specimen (13.6.1) shall be lightly clamped between jaws with edges having a radius of 0.200 in. (5.1 mm), bent by hand over one edge of the jaws through an angle of 90°, and returned to its original position. This constitutes a second bend. Each successive bend shall be made in the opposite direction from the previous bend (see Test Methods B577).

14. Significance of Numerical Limits

14.1 Calculated values shall be rounded to the nearest unit in the last right hand significant digit used in expressing the limiting value in accordance with the rounding-off method in Practice E29.

15. Inspection

15.1 All inspections and tests shall be made at the place of manufacture unless otherwise agreed upon between the manufacturer and the purchaser at the time of purchase. The manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy him that the material being furnished is in accordance with this specification.

16. Rejection and Rehearing

16.1 *Rejection:*

16.1.1 Product that fails to conform to the requirements of the product specification may be rejected.

16.1.2 Rejection shall be reported to the manufacturer, or supplier, promptly and in writing.

16.1.3 In case of disagreement or dissatisfaction with the results of the test upon which rejection was based, the manufacturer or supplier may make claim for a rehearing.

16.2 *Rehearing*—As a result of product rejection, the manufacturer or supplier may make claim for retest to be conducted by the manufacturer or supplier and the purchaser. Samples of the rejected product shall be taken in accordance with the product specification and tested by both parties as directed in the product specification, or alternatively upon agreement by both parties, an independent laboratory may be selected for the tests using the test methods prescribed in the product specification.

17. Certification

17.1 When specified in the contract or purchase order, the purchaser shall be furnished certification representative of the shipping lot indicating that requirements have been met as directed by this specification.

18. Test Report

18.1 When specified in the contract or purchase order, a report of test results shall be furnished.

19. Packaging and Package Marking

19.1 Package size shall be agreed upon between the manufacturer and the purchaser and shall be stated in the order.

19.2 The rod shall be packaged and protected against damage from normal handling and shipping as is consistent with good commercial practice.

19.3 Individual coils without joints and with a net mass greater than 3000 lb (1400 kg) shall be marked or otherwise identified with the following:

19.3.1 Coil production number,

19.3.2 Net weight,

19.3.3 Manufacturer's name, brand, or trademark, and

19.3.4 UNS Number and Copper Type.

19.4 Marking for coils other than described in 19.3 shall be agreed upon between the manufacturer and the purchaser.

20. Scrap Management

20.1 Scrap management is not a requirement of this specification. However, a discussion of good practices in scrap management for producers and users of the different copper types referenced in Table 1 will be found in Note X1.10.

21. Keywords

21.1 cathode; copper rod; electrical conductors; electrolytic tough-pitch copper; fire-refined high conductivity copper; oxygen-free copper; rapid elongation tensile test; scrap; shaving; subsurface oxides; uniform surface oxides

APPENDIX

(Nonmandatory Information)

X1. EXPLANATORY INFORMATION

NOTE X1.1—Relationships that may be useful in connection with the values of electrical resistivity prescribed in this specification are shown in Table 2. Resistivity units are based on the International Annealed Copper Standards (IACS) adopted by IEC in 1913, which is 1/58 Ω · mm^2/m at 20 °C for 100 % conductivity. The value of 0.017 241 Ω · mm^2/m and the value of 0.153 28 Ω · g m^2 at 20 °C are, respectively, the international equivalent of volume and weight resistivity of annealed copper equal (to five significant figures) to 100 % conductivity. The latter term means that a copper wire 1 m in length and weighing 1 g would have a resistance of 0.153 28 Ω. This is equivalent to a resistivity value of 875.20 Ω · lb/$mile^2$, which signifies the resistance of a copper wire 1 mile in length weighing 1 lb. It is also equivalent, for example, to 1.7241 μΩ/cm of length of a copper bar 1 cm^2 in cross section. A complete discussion of this subject is contained in *NBS Handbook 100.* The use of five significant figures in expressing resistivity does not imply the need for greater accuracy of measurement than that specified in Test Method B193. The use of five significant figures is required for reasonably accurate reversible conversion from one set of resistivity units to another. The equivalent resistivity values in Table 2 were derived from the fundamental IEC value (1/58 Ω · mm^2/m) computed to seven significant figures and then rounded to five significant figures.

NOTE X1.2—In general, tested values of elongation are reduced with increased speed of the moving head of the testing machine in the tension testing of copper wire and rod. In the case of tests on soft or annealed copper rod, however, the effects of speed of testing are not pronounced. In tests of soft rod made at speeds not greater than 12 in./min (300 mm/min), the values obtained for elongation are not affected to any practical extent (see Test Methods E8/E8M).

NOTE X1.3—Torsion tests are widely used by producers and users. Because of the uncertain correlation with performance, and the subjective aspect of interpretation, these tests should only be used as an indicator of in-house process control. Therefore, no standardized test is recommended.

NOTE X1.4—*Annealability (General)*—There are differences in annealing recrystallization temperatures between ETP, OFE, and FRHC coppers when following in-line resistance annealing and other methods of annealing copper rod for electrical wire applications. Although five different types of test methods have been reported in the literature for measuring the annealability of wirebar or rod, numerous variations exist. For a more thorough description of these tests, refer to the *Journal of Testing and Evaluation.*[6] Inasmuch as hardness and torsional measurements and rapid tensile elongation tests are frequently used, detailed procedures are contained in Note X1.5, Note X1.6, and Note X1.7 of this specification. Softening values for low temperature annealing copper and for other types of copper rods, if requested, shall be decided upon between the producer and the user.

NOTE X1.5—*Annealability by Hardness Tests*—A rod sample of suitable length shall be cut from each end of a coil lot. The as-received sample shall be cold rolled to a flat section, so that the thickness is equal to 30 % of the original rod diameter. No edge rolling is required. The flattened copper shall be heated at 527 ± 2 °F (275 ± 1 °C) for 15 min in a constant temperature bath and quenched immediately into water at ambient temperature. Other temperatures and times may be used by special agreement between the manufacturer and purchaser. Hardness shall be measured along the center line of the annealed specimen using the Rockwell F scale, in accordance with Test Methods E18.

NOTE X1.6—*Annealability by Torsion (Spiral Elongation)*—The spiral elongation test described herewith is used only for testing high conductivity copper that is sampled at the rod stage and does not address the quality of copper wire selected at later stages of commercial processing. Copper wire is initially given a low temperature anneal under tightly controlled conditions, subsequently wound into a spiral (helical configuration) under tensile load, and then stretched axially by a weight of specified mass. The change in length measured after the weight is removed, and the spiral has relaxed, is considered as a measure of softness.

Rod Treatment—A rod sample of suitable length shall be cut from the end of a coil lot, and if necessary, reduced to a diameter of either 0.25 in., +0.020 −0.010 (6.35 mm +0.50 −0.25) or 0.315 ± 0.015 in. (8.00 ± 0.40 mm) by cold drawing. This sample shall either be annealed or not annealed according to the following circumstances:

(*a*) No annealing treatment will be performed if the copper is processed according to a specific manufacturing schedule.

(*b*) The sample shall be subjected to an annealing treatment if it is desired to compare samples produced via different manufacturing routes. Under these circumstances, the rod sample shall be annealed under normal atmosphere for 1 h at 700 °C ± 20 (1256 to 1328 °F) and then quenched into water or a dilute (10 % v/v) sulfuric acid solution at ambient temperature. Copper oxide scale shall be removed in a 10 % v/v volume per volume, sulfuric acid bath and thoroughly washed to remove loose scale or adhering copper dust.

Preparation of Wire for Spiral Elongation Test—The rod sample shall be drawn into a 2.00-mm (0.080 in. ± 0.01) diameter wire in a series of passes, each of which shall reduce the cross-sectional area of the conductor by 20 to 25 %.

Particular care should be taken to avoid excessive heating of the copper during drawing. For example, the wire shall either be allowed to cool for 5 min between passes or quenched to ambient temperature after each pass. In addition, drawing speed should not exceed 60 m/min (200 ft/min), and the drawn wire shall be wound into a coil having a minimum diameter of 200 mm.

After drawing, a coil of the wire shall be formed by winding the conductor around a mandrel having a minimum diameter of 200 mm (7.87 in.). The copper coil shall then be removed from the mandrel, heated for 2 h at 392 ± 1 °F (200 ± 0.5 °C), in a constant temperature bath, and cooled immediately to ambient temperature.

Temperature of the copper wire must be kept uniform and measured quite accurately. Since good temperature control is extremely important, thermocouples should be placed at strategic locations throughout the annealing device. It is recommended that an 8-mm-diameter dummy rod sample be formed into a 200-mm-diameter ring and placed in the constant temperature bath at the same position normally occupied by the test wire. Using a thermocouple embedded in the rod to a depth equal to the radius, temperature should reach the annealing temperature within a 5-min period.

[6] Joint B-1 and B-2 Task Group, "The Annealability Testing of Copper," *Journal of Testing and Evaluation*, Vol 1, No. 1, ASTM, 1973.

Test Procedures—A 1400-mm-long test sample is cut from the annealed coil of wire. Using an indelible marking tool, a 1000-mm gage length is marked over the midlength of the copper wire. One end of the test sample is firmly secured to the end of a polished mandrel whose axis is horizontal and which has a diameter of 20 ± 0.01 mm. A 2.240-kg load is suspended from the free end of the wire, thereby inducing a stress of 7 MPa (1000 psi). The wire shall be wound into a spiral by rotating the mandrel at a speed of approximately 50 r/min, taking special care that each turn of the spiral touches the preceding one, that the turns are not pressed into place, that handling is kept to a minimum, and that the wire is wound in the same direction that it was previously coiled.

Although the length between gage marks on the spiral is approximately 28 mm, this distance shall be measured to the nearest 1 mm, and recorded as the initial value "l_0."

The spiral of wire shall then be removed from the mandrel, carefully fastened at one end, and loaded axially at the other (lower) end with the same 2.240-kg weight as that used in the aforementioned coil winding operation.

The weight shall be supported initially with a platform and loaded onto the spiral uniformly and smoothly by either of two methods, namely: (*a*) lowering the platform supporting the weight or (*b*) raising the upper end of the spiral at a rate such that the stretching of the spiral does not exceed 20 cm/s.

After 1 min of free suspension, the weight is manually removed in a very careful manner and the elongated spiral is allowed to relax by placing it on a table for an additional period of 1 min. Note that the load is not to be removed by either raising the platform or lowering the upper end of the spiral. The extended length of the spiral between gage marks shall be measured to the nearest 1 mm and called "l_f." The spiral elongation value, in millimetres, is calculated as the difference $l_f - l_0$.

This same procedure shall be repeated on two additional spirals of wire from the same coil, and the average value obtained from three separate spirals shall be referred to as the "Spiral Elongation Number."

NOTE X1.7—*Annealability by the Rapid Elongation Tensile Test*—This test is typically used to evaluate annealability of high-conductivity copper rod that has a diameter of 8 mm (0.3125 in.). A rod sample of suitable length is cut from the end of a coil lot and drawn about 40 % reduction in area to a diameter of 6.3 mm. The as-drawn wire is then annealed in a constant temperature silicon oil or salt bath at a temperature of 260 ± 1 °C (500 ± 2 °F) for 8 min and quenched immediately into water. Tensile elongation is measured at ambient temperature using a gage length of 250 mm (~10 in.). Average to good annealing susceptibility is achieved if the tensile elongation value is at least 20 to 30 %.

NOTE X1.8—*Electromagnetic (Eddy-Current) Examination*—Nondestructive methods for locating surface discontinuities or imperfections in copper redraw rod are widely used by both producers and users. A detailed description of the procedures that could be followed is found in Practice E1606. This practice covers electromagnetic (eddy-current) examination of redraw rod that is made from tough-pitch or oxygen-free coppers in diameters from ¼ to 1 ⅜ in. (6.4 to 35 mm) and that are suitable for further fabrication into electrical conductors. Examination is achieved by passing the rod lengthwise through a stationary encircling annular test coil that is energized with alternating current at a fixed frequency. As the rod is passed through the coil, electrical impedance changes are caused by such variables as rod vibrations, electrical conductivity differences, dimensional changes, and mechanical discontinuities on the rod surface. Deep seated defects are not detected by this test method.

Test coils induce eddy currents in the moving rod and also sense changes in electrical characteristics of the rod. Their diameters should allow the largest practical fill factor, which is oftentimes greater than 60 %. The electrical apparatus energizes these test coils with alternating currents having frequencies usually in the range from 1 kHz to 1 MHz. Artificial discontinuity standards can be used for adjusting the sensitivity setting of the apparatus. They should be processed from mechanically shaved or machined copper rods that are similar to typical production lots. Artificial discontinuities should be small holes drilled radially, transverse notches, or other contours. They are not meant to be indicative of natural discontinuities, but only used for establishing levels of sensitivity. It should be noted that sensitivity control settings are arbitrary and may vary from instrument to instrument of the same design and manufacturer. A suggested instrument that can be used for passing the artificial discontinuity standards through a stationary test coil with a reciprocating motion is shown in Practice E1606. It should be constructed to minimize vibrations and to allow the standard to pass through the center of the coil in a straight line.

NOTE X1.9—*Surface Oxide Testing*—The Surface Oxide test measures multiple factors and combines them into one number. The two most influential of these factors are the uniform surface oxide (USO) thickness and the degree to which detrimental subsurface oxides (SSOs) are present in the sample. The latter can be considered a production defect since poor drawability, excessive fines generation, and wire breaks may occur if subsurface oxides (SSOs) are present in the hot-rolled rod. SSOs may occur if the high pressure descaler does not adequately remove the oxide scale in the roughing mill and some of this oxide becomes embedded in the rod by rolls downstream from the descaler. They can also occur if hot cracks occur in the cast bar or if there are fold overs of bar corners. To improve quality and reduce costs, it may be extremely important to determine if high surface oxide test results are caused by either high uniform surface oxides (USOs) or by the presence of SSOs, and methods for doing so will be listed in the latter.

Many different process and operating variables can impair the accuracy and repeatability of the test that is used to measure the uniform surface oxide (USO) film thickness on copper rod or wire. The most significant test parameters are as follows:

(1) Current Density—This property is calculated by taking the constant test current and dividing it by the surface area of the sample exposed to the electrolyte. Current density is a very important factor when SSOs are present or if the electrolyte is bad. However, under ideal conditions it is a negligible factor. The test takes more time to complete as the current density is decreased, but at the same time accuracy and repeatability are improved. As a compromise between attaining practical (short) laboratory test times while not losing extreme accuracy, a current density in the range between 0.15 and 0.55 milliamperes per square centimeter is typically used in the rod industry. In general, equipment is usually operated in the range of 1 to 20 milliamperes.

(2) Reference Electrode—Either saturated calomel or a silver/silver-chloride configuration are often used to determine voltage. However, if the current density is maintained fairly low, there is no accuracy-based reason to use a reference electrode.

(3) Electrolyte Solution—A 0.1 molar solution of sodium carbonate has generally been adopted, although potassium chloride solutions are also acceptable.

(4) Dissolved Oxygen in the Electrolyte—When a constant current is run between the anode and cathode, the anode creates oxygen. This is just one way in which dissolved oxygen enters the electrolyte. Overall test efficiency is diminished and leads to artificially high surface oxide values when dissolved oxygen in the electrolyte is reduced by the hydrogen at the cathode. Best results are obtained when oxygen is removed by bubbling nitrogen or argon gas through the electrolyte after each test run and electrolyte change. Since oxygen is also introduced into the electrolyte at the end of the test when hydrogen gas is generated by electrolysis, the test sample should be removed as soon as possible after bubbles are first observed at the cathode. Some commercial surface oxide testers automatically reduce the current to just a sensing level when the test has stopped.

(5) Sample Cleanliness—Any residual mill or quench solution on the sample should be thoroughly cleaned to prevent contamination of the electrolyte. This procedure is particularly important if the rod is acid pickled, since the test is very sensitive to pH.

(6) Physical Calibration—Studies using copper foil, which acts as a secondary standard and changes negligibly over time when properly stored, can be performed in the laboratory to determine the number of tests that can be run before readings change, which is a factor that depends upon the cell volume, the cleaning practice for test samples, and the surface area under test. Foil testing can also be used to check proper operation of the tester, compare two different testers, and gage R&R testing for quality control.

(7) Electrolyte Renewal—Electrolyte quality has a significant effect on the test results, inasmuch as contamination or depleted electrolyte tends to reduce the reduction efficiency.

The following methods can be used to determine when subsurface oxides are present:

(1) Twist Testing Combined with Surface Oxide Testing—Torsional twist testing of rod introduces stresses on the surface that may produce cracks and open-up fissures near the brittle SSOs. Exposure of these oxides to the electrolyte will increase the value of the cupric oxide (CuO) constituent compared with the untwisted rod, while at the same time the cuprous oxide (Cu_2O) value remains nearly constant. The optimum degree of twisting exposes SSOs without causing excessive exfoliation of oxides on the rod surface. Prior research on 8 mm rod has shown that a 5 by 5 twist test is the optimum level to be performed prior to surface oxide testing.

(2) High Variability of Test Results—Inasmuch as SSOs are usually periodic in nature, overall surface oxide results often display high variability. Furthermore, at the temperature where SSOs are stable, the resulting phase is mostly cupric oxide. Whereas the cuprous oxide values from sample to sample are usually quite consistent and have a low standard deviation, high variability of test data tends to occur in the cupric oxide measurements.

(3) Metallographic Examination of Samples—Although the presence of SSOs in rod can be detected clearly by metallographic analysis, it is oftentimes very time consuming. Twisting of the rod may be beneficial because cracks usually form where SSOs are present. Examination of fines, the cast bar, wire, and a "fishpole" of the hot rolled rod can also prove useful.

(4) Use of Variable Current Densities—Testing rod that contains SSOs is highly influenced by current density, especially at high dissolved oxygen levels in the electrolyte. Copper foil, most wires, some hot-rolled rods, and shaved rod samples show nearly constant surface oxide measurements with increasing values of current density. In contrast, however, these measurements increase significantly (as much as nine times or higher) with increasing current density when SSOs are present. In large part this occurs because at high current densities the reduction rate of uniform surface oxides is faster than the rate of partially buried scale. The influence of SSOs will usually be different for different rod sources since the exact geometric characteristics of these contaminants are usually never the same.

NOTE X1.10—The copper types (ETP, Silver-bearing, FRHC, OF) contain differing levels of alloying or impurity elements that can affect their subsequent use as scrap feed. To preserve the properties of the copper type, scrap generated from the different copper types should be packaged separately. Scrap packages should be identified with a label showing UNS Number and copper type. In the event that scrap cannot be segregated by UNS number, each scrap package should be identified as mixed scrap and the label should indicate all UNS numbers that are potentially present in the package.

SUMMARY OF CHANGES

Committee B05 has identified the location of selected changes to this standard since the last issue (B49 – 16) that may impact the use of this standard. (Approved April 1, 2017.)

(1) Revised Note X1.4.

Committee B05 has identified the location of selected changes to this standard since the last issue (B49 – 15a) that may impact the use of this standard. (Approved April 1, 2016.)

(1) Revised Note 1, 8.4, and Note X1.4.
(2) Added Section 20 Scrap Management and Note X1.10.
(3) Added Note X1.7 for Annealability by the Rapid Elongation Tensile Test.
(4) Added keywords "rapid elongation tensile test," and "scrap."