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Designation: D470 – 13

Standard Test Methods for
Crosslinked Insulations and Jackets for Wire and Cable[1]

This standard is issued under the fixed designation D470; 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 These test methods cover procedures for testing crosslinked insulations and jackets for wire and cable. To determine the test to be made on the particular insulation or jacket, refer to the product specification for that type. These test methods do not apply to the class of products known as flexible cords.

1.2 In many instances the insulation or jacket cannot be tested unless it has been formed around a conductor or cable. Therefore, tests are done on insulated or jacketed wire or cable in these test methods solely to determine the relevant property of the insulation or jacket and not to test the conductor or completed cable.

1.3 The procedures appear in the following sections:

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AC and DC Voltage Withstand Tests	22 to 29
Capacitance and Dissipation Factor Tests	38 to 44
Cold Bend	128
Cold Bend, Long-Time Voltage Test on Short Specimens	51 to 57
Double AC Voltage Test on Short Specimens	45 to 50
Electrical Tests of Insulation	17 to 64
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Insulation Resistance Tests on Completed Cable	30 to 37
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Physical Tests of Insulation and Jacket Compounds	5 to 16
Surface Resistivity Test	116 to 120
Track Resistance Test	129 to 132
U-Bend Discharge Test	121 to 125
Water Absorption Test	65 to 71
Water Absorption Test, Accelerated	72 to 86
Water Absorption Test on Fibrous Coverings	105 to 110

1.4 Whenever two sets of values are presented, in different units, the values in the first set are the standard, while those in the parentheses are for information only.

1.5 *This standard does not purport to address all of the safety problems, 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.* For specific hazards see Section 4.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
D150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation
D257 Test Methods for DC Resistance or Conductance of Insulating Materials
D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
D454 Test Method for Rubber Deterioration by Heat and Air Pressure
D572 Test Method for Rubber—Deterioration by Heat and Oxygen
D573 Test Method for Rubber—Deterioration in an Air Oven
D1193 Specification for Reagent Water
D1711 Terminology Relating to Electrical Insulation
D2132 Test Method for Dust-and-Fog Tracking and Erosion Resistance of Electrical Insulating Materials
D3755 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Under Direct-Voltage Stress
D5025 Specification for Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials
D5207 Practice for Confirmation of 20–mm (50–W) and 125–mm (500–W) Test Flames for Small-Scale Burning Tests on Plastic Materials
D5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

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[1] These test methods are under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee D09.07 on Electrical Insulating Materials.

Current edition approved Feb. 1, 2013. Published February 2013. Originally approved in 1937. Last previous edition approved in 2005 as D470 – 05. DOI: 10.1520/D0470-13.

[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.

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2.2 *ICEA Standard:*
T-24-380 Guide for Partial-Discharge Procedure[3]

3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, refer to Terminology D1711.

3.2 *Definitions of Terms Specific to This Standard:*
3.2.1 *aging (act of), n*—exposure of material to air or oil at a temperature and time as specified in the relevant material specification for that material.

3.3 *Symbols:*
3.3.1 *kcmil*—thousands of circular mils.

4. Hazards

4.1 *Mercury:*
4.1.1 *Mercury metal vapor poisoning has long been recognized as a hazard in industry. The exposure limits are set by governmental agencies and are usually based upon recommendations made by the American Conference of Governmental Industrial Hygienists.*[4]*The concentration of mercury vapor over spills from broken thermometers, barometers, and other instruments using mercury can easily exceed these exposure limits. Mercury, being a liquid with high surface tension and quite heavy, will disperse into small droplets and seep into cracks and crevices in the floor. This increased area of exposure adds significantly to the mercury vapor concentration in air. The use of a commercially available emergency spill kit is recommended whenever a spill occurs. Mercury vapor concentration is easily monitored using commercially available sniffers. Make spot checks periodically around operations where mercury is exposed to the atmosphere. Make thorough checks after spills.* See 8.3.2 and 8.3.3.

4.2 *High Voltage:*
4.2.1 Lethal voltages are a potential hazard during the performance of this test. It is essential that the test apparatus, and all associated equipment electrically connected to it, be properly designed and installed for safe operation.
4.2.2 Solidly ground all electrically conductive parts which it is possible for a person to contact during the test.
4.2.3 Provide means for use at the completion of any test to ground any parts which were at high voltage during the test or have the potential for acquiring an induced charge during the test or retaining a charge even after disconnection of the voltage source.
4.2.4 Thoroughly instruct all operators as to the correct procedures for performing tests safely.
4.2.5 When making high voltage tests, particularly in compressed gas or in oil, it is possible for the energy released at breakdown to be sufficient to result in fire, explosion, or rupture of the test chamber. Design test equipment, test chambers, and test specimens so as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury. If the potential for fire exists, have fire suppression equipment available. Design test equipment, test chambers, and test specimens so as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury. See Sections 20, 27, 33, 42, 48, 54, 62, 68, 76, 118, 123 and 130.

4.3 *Ozone:*
4.3.1 *Ozone is a physiologically hazardous gas at elevated concentrations. The exposure limits are set by governmental agencies and are usually based upon recommendations made by the American Conference of Governmental Industrial Hygienists.*[4] *Ozone is likely to be present whenever voltages exist which are sufficient to cause partial, or complete, discharges in air or other atmospheres that contain oxygen. Ozone has a distinctive odor which is initially discernible at low concentrations but sustained inhalation of ozone can cause temporary loss of sensitivity to the scent of ozone. Because of this it is important to measure the concentration of ozone in the atmosphere, using commercially available monitoring devices, whenever the odor of ozone is persistently present or when ozone generating conditions continue. Use appropriate means, such as exhaust vents, to reduce ozone concentrations to acceptable levels in working areas.* See Section 90.

PHYSICAL TESTS OF INSULATIONS AND JACKETS

5. Significance and Use

5.1 Physical tests, properly interpreted, provide information with regard to the physical properties of the insulation or jacket. The physical test values give an approximation of how the insulation will physically perform in its service life. Physical tests provide useful data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

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6. Physical Tests

6.1 Physical tests shall include determination of the following:
6.1.1 Tensile strength,
6.1.2 Tensile stress,
6.1.3 Ultimate elongation,
6.1.4 Permanent set,
6.1.5 Accelerated aging,
6.1.6 Tear resistance,
6.1.7 Effects of oil immersion, and
6.1.8 Thickness of insulations and jackets.

7. Sampling

7.1 *Number of Samples*—Unless otherwise required by the detailed product specification, wire and cable shall be sampled for the physical tests, other than the tests for insulation and jacket thickness, as follows:
7.1.1 *Sizes Less than 250 kcmil (127 mm^2)* —One sample shall be selected for each quantity ordered between 2000 and 50 000 ft (600 and 15 000 m) of wire or cable and one additional sample for each additional 50 000 ft. No sample shall be selected from lots of less than 2000 ft.
7.1.2 *Sizes of 250 kcmil (127 mm^2) and Over*—One sample shall be selected for each quantity ordered between 1000 and

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[3] Available from the Insulated Cable Engineers Assoc., P.O. Box 440, South Yarmouth, MA 02664.

[4] American Conference of Governmental and Industrial Hygienists, 6500 Glenway Ave., Building D-7, Cincinnati, OH 45211.

25 000 ft (300 and 7600 m) of wire or cable and one additional sample for each additional 25 000 ft. No sample shall be selected from lots of less than 1000 ft.

7.2 *Size of Samples*—Samples shall be at least 6 ft (2 m) in length when the wire size is less than 250 kcmil (127 mm^2), and at least 3 ft (1 m) in length when the wire size is 250 kcmil or over.

8. Test Specimens

8.1 *Number of Specimens*—From each of the samples selected in accordance with Section 7, test specimens shall be prepared as follows:

	Number of Test Specimens
For Determination of Initial Properties (Unaged):	
Tensile strength, tensile stress, and ultimate elongation	3
Permanent set	3
For Aging Tests:	
Air pressure, heat, or oxygen pressure	3
Air oven	3
For Oil Immersion	3

One specimen of each three shall be tested and the other two specimens held in reserve, except that when only one sample is selected all three specimens shall be tested and the average of the results reported. For the tear test, six individual specimens as described in 8.5 shall be used.

8.2 *Size of Specimens*—In the case of wire and cable smaller than AWG 6 (13.3 mm^2) having an insulation thickness less than 0.090 in. (2.29 mm), the test specimen shall be the entire section of the insulation. When the full cross section is used, the specimens shall not be cut longitudinally. In the case of wire and cable of AWG 6 and larger, or in the case of wire and cable smaller than AWG 6 having an insulation thickness greater than 0.090 in., specimens approximately square in section with a cross section not greater than 0.025 in.^{2} (16 mm^2) shall be cut from the insulation. In extreme cases, use of a segmental specimen is permitted.

8.2.1 The test specimens shall be approximately 6 in. (150 mm) in length. Specimens for tests on jackets shall be taken from the completed wire or cable and cut parallel to the axis of the wire or cable. With the exception of the tear tests, the test specimen shall be either a segment or sector cut with a suitable sharp instrument or a shaped specimen cut out with a die and shall have a cross-sectional area not greater than 0.025 in.^{2} (16 mm^2) after irregularities, corrugations, and reinforcing cords or wires have been removed by buffing.

8.3 *Preparation of Specimens:*

8.3.1 The test specimen is to have no surface incisions and be as free as possible from other imperfections. Remove surface irregularities, such as corrugations due to stranding, etc., so that the test specimen will be smooth and of uniform thickness.

8.3.2 The removal of the insulation often is greatly accelerated by using mercury. In most cases a test specimen which is an entire section is obtained, free from surface incisions and imperfections. **Warning**—see 4.1. Introduce the mercury at one end of the specimen between the insulation and the tinned surface of the conductor, with the specimen inclined on a support with the end to which the mercury is applied at the top. The separation of the insulation results from the amalgamation of the tin of the conductor with the mercury. The amalgamation is assisted by first immersing and rubbing the tinning on the exposed end of the conductor in the mercury. It is also possible to facilitate the removal of the insulation by stretching the conductor to the breaking point in a tensile-strength machine.

8.3.3 **Warning**—Mercury is a hazardous material. See 4.1. Care should be exercised to keep mercury from the hands. The use of rubber gloves is recommended for handling specimens as in 8.3.2.

8.4 *Specimens of Thin-Jacketed Insulation*—In the case of wires or cables having a thin jacket crosslinked directly to the insulation, it is usually necessary to prepare die-cut specimens of the jacket and insulation. Make an effort to separate the jacket from the insulation by slitting the covering through to the conductor and pulling the jacket and insulation apart by pliers. (Immersing the sample in hot water for a few minutes just prior to pulling off the jacket often facilitates this procedure.) If the jacket cannot be removed, prepare specimens by buffing. Equip the buffing apparatus with a cylindrical table arranged so that it can be advanced very gradually. Remove the conductor from two short lengths of wire by slitting the covering. Stretch one length of covering into the clamps of the buffing apparatus so that it lies flat, with the jacket toward the wheel. The jacket is buffed off, with due care not to buff any further than necessary, or overheat the material. Repeat the process with the other length of covering, except that the insulation is buffed off. Die-cut specimens shall be prepared from the buffed pieces after they have been allowed to recover for at least 30 min. Jackets with a thickness of less than 0.030 in. (0.76 mm) shall not be tested.

8.5 *Specimen for the Tear Test*—Cut the specimen with a sharp knife or die. After irregularities, corrugations, and reinforcing cords or wires have been removed, the test specimen shall conform to the dimensions shown in Fig. 1. The thickness of the test specimen shall be not greater than 0.150 in. (3.81 mm) and not less than 0.040 in. (1.02 mm). Split the specimen longitudinally with a new razor blade to a point 0.150 in. from the wider end.

8.6 *Condition and Age*—In accordance with Section 7, take samples of the insulated wire and cable for physical and accelerated aging tests after crosslinking. Perform tests between 24 h and 60 days after crosslinking unless agreed to by the manufacturer. Do not heat, immerse in water, or subject the specimens to any mechanical or chemical treatment not specifically prescribed in these methods, unless agreed upon by the producer and the purchaser. Age specimens having cable tape applied prior to crosslinking with such tape removed.

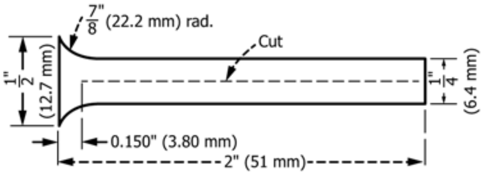

FIG. 1 Test Specimens for Tear Test

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9. Measurement of Thickness of Specimens

9.1 Make the measurement of thickness for cables with unbonded components with either a micrometer or microscope, but, for cables with bonded components, use only a microscope. The micrometer and microscope shall be capable of making measurements accurate to at least 0.001 in. (0.025 mm).

9.1.1 *Micrometer Measurements*—When a micrometer is used, take the average thickness of the insulation as one-half of the difference between the mean of the maximum and minimum diameters over the insulation at one point and the average diameter over the conductor or any separator measured at the same point. Take the minimum thickness of the insulation as the difference between a measurement made over the conductor or any separator plus the thinnest insulation wall, and the diameter over the conductor or any separator. Make the first measurement after slicing off the thicker side of the insulation. Do not include the thickness of any separator in the thickness of insulation.

9.1.1.1 If the wire or cable has a jacket, remove the jacket and determine the minimum and maximum thickness of the jacket directly with a micrometer. Take the average of these determinations as the average thickness of the jacket.

9.1.2 *Microscope Measurements*—When a microscope is used, determine the maximum and minimum thickness from a specimen cut perpendicular to the axis of the sample so as to expose the full cross-section. Take the average of these determinations as the average thickness.

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9.2 *Number of Thickness Measurements*—When the lot of wire to be inspected consists of two coils or reels, or less, at least one determination of the thickness is made on each coil or reel. When the lot consists of more than two coils or reels and less than 20 coils or reels, make at least one determination of the thickness on each of two coils or reels taken at random. If the lot consists of 20 or more coils or reels, select more than 10 % of the coils or reels at random and make at least one determination of the thickness on each coil or reel so selected.

10. Calculation of Area of Specimens

10.1 When the total cross section of the insulation is used, take the area as the difference between the area of the circle whose diameter is the average outside diameter of the insulation and the area of the conductor. Calculate the area of a stranded conductor from its maximum diameter.

10.2 When a slice cut from the insulation by a knife held tangent to the wire is used, and the slice so cut has the cross section of a segment of a circle, calculate the area as that of the segment of a circle whose diameter is that of the insulation. The height of the segment is the thickness of insulation on the side from which the slice is taken. (If necessary, obtain the values from a table giving the areas of segments of a unit circle for the ratio of the height of the segment to the diameter of the circle.)

10.3 When the cross section of the slice is not a segment of a circle, calculate the area from a direct measurement of the volume or from the specific gravity and the weight of a known length of the specimen having a uniform cross-section.

10.4 When the conductor is large and the insulation thin, and a portion of a sector of a circle is used, calculate the area as thickness times the width. This applies either to a straight test specimen or to one stamped out with a die, and assumes that corrugations have been removed.

10.5 When the conductor is large and the insulation thick, and a portion of a sector of a circle is used, calculate the area as the proportional part of the area of the total cross section.

10.6 Determine the dimensions of aged specimens before beginning the aging cycle.

11. Physical Test Procedures

11.1 Determine the physical properties in accordance with Test Methods D412, except as specified in the following:

11.2 Test the specimens at a temperature of 68 to 82°F (20 to 28°C).

11.3 For all physical tests, except the set test, mark the specimens with gage marks 1 in. (25 mm) apart and place in the jaws of the testing machine with a maximum distance between the jaws of 4 in. (100 mm). For the set test mark the specimens with gage marks 2 in. (50 mm) apart.

11.4 *Set Test*—Make a set test on a separate test specimen having a length of approximately 6 in. (150 mm) and mark with gage marks 2 in. (50 mm) apart. Place the specimen in the jaws of the testing machine with a maximum distance between jaws of 4 in. (100 mm) and stretch at the rate of 20 in. (500 mm)/min (jaw speed) until the gage marks are 6 in. (150 mm) apart. Release the test specimen within 5 s, and determine the distance between bench marks 1 min after the beginning of release. The set is the difference between this length and the original 2-in. (50-mm) gage length, expressed as a percentage.

11.5 *Tear Test*—Make a tear test on a minimum of six individual test specimens prepared as described in 8.5. Place the two halves of the split end of the test specimen in the jaws of the tension testing machine and separate the jaws at the rate of 20 in. (500 mm)/min. Determine the tear resistance by dividing the load in pounds (or kilograms) required to tear the section by the thickness of the test specimen in inches (or millimeters). Consider the average of the results obtained on all test specimens as the value of the tear resistance.

12. Aging Test Procedures

12.1 Age specimens in accordance with Test Method D454, D572, or D573, and Specification D5423 except as specified in 12.2 and 12.3.

12.2 The test period and temperature of aging is as prescribed in the product specification.

12.3 Between 16 and 96 h after the completion of the aging process, subject the aged specimens to tensile strength and ultimate elongation tests in accordance with Section 11. Perform physical tests on both aged and unaged specimens at the same time.

13. Oil Immersion Test

13.1 *Oil Immersion Test for Oil-Resistant Jackets*—Immerse buffed die-cut specimens in ASTM Oil No. 2, IRM 902, or equivalent at 121 ± 1°C for 18 h. At the end of the 18 h remove the specimens from the oil and allow to rest at room temperature for a period of 4 ± ½ h. Determine the tensile strength and elongation at the same time that the original properties are determined (see Section 11).

13.2 *Calculations for Tensile Strength and Measurement of Elongation*—The calculations for tensile strength are based on the cross sectional area of the specimen obtained before immersion in the oil. Likewise, the elongation is based on the original distance between the gage marks applied to the specimen before immersion in the oil.

14. Retests

14.1 If any specimen fails to conform to the values specified for any test, either before or after aging, repeat that test on two additional specimens from the same sample, except that when the value of tear resistance from the first set of six specimens fails to conform, test two additional sets. Failure of either of the retests indicates nonconformity of the sample to the requirement specified.

15. Report

15.1 Report the following information:

15.1.1 Manufacturer's name,

15.1.2 Manufacturer's lot number, if applicable,

15.1.3 Calculated values of thickness, tensile strength, tensile stress, ultimate elongation, set, and tear resistance,

15.1.4 All observed and recorded data on which the calculations are based,

15.1.5 Date of vulcanization of the rubber, if known,

15.1.6 Dates of all tests,

15.1.7 Ambient temperatures during the period of physical testing,

15.1.8 Type of testing machine used,

15.1.9 Method of aging, and

15.1.10 Time and temperature of aging.

16. Precision and Bias

16.1 This test method has been in use for many years, but no information has been presented to ASTM upon which to base a statement of precision. No activity has been planned to develop such information.

16.2 This test method has no bias because the values for this test is determined solely in terms of the test method itself.

ELECTRICAL TESTS OF INSULATION

17. Significance and Use

17.1 Electrical tests, properly interpreted, provide information with regard to the electrical properties of the insulation. The electrical test values give an indication as to how the insulation will perform under conditions similar to those observed in the tests. Electrical tests provide useful data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

18. Types of Voltage Tests

18.1 Perform voltage withstand tests using either alternating or direct current, or both, applied in accordance with Test Methods D149 and D3755, and as specified in the following sections. Perform the partial discharge test in accordance with ICEA T-24-380. The partial discharge, ac voltage, insulation resistance, and dc voltage tests are performed on entire lengths of completed cable.

19. Order of Testing

19.1 Perform the partial discharge, ac voltage, insulation resistance, and dc voltage tests in that order when any of these tests are required. The sequence of other testing is not specified.

20. Hazards

20.1 **Warning**—These tests involve the use of high voltages. See 4.2.

21. Sampling, Test Specimens, and Test Units

21.1 The specimen is defined in each test method.

AC and DC VOLTAGE WITHSTAND TESTS

22. Significance and Use

22.1 Voltage withstand tests are useful as an indication that the cable can electrically withstand the intended rated voltage with adequate margin. These tests are normally performed in the factory and are used for product acceptance to specification requirements.

23. Apparatus

23.1 *AC Apparatus*—For ac tests, use a voltage source and a means of measuring the voltage that is in conformance with the voltage source and voltage measurement sections of the apparatus section of Test Method D149. Use a power supply having a frequency of 49 to 61 Hz.

23.2 *DC Apparatus*—For dc tests, use any source of dc, but if using rectified alternating current, limit the dc ripple to 4 %. Measure the voltage with an electrostatic voltmeter or, in the case of the rectifying equipment, with suitable low-voltage indicators, provided the latter are so connected that their indications are independent of the test load. See Test Method D3755.

23.3 *Grounded Water Tank*—For tests requiring immersion in water, a metal water tank connected to ground or a tank of other material containing a grounded metal plate or bar is required.

24. Sampling, Test Specimens, and Test Units

24.1 The specimen consists of entire lengths of completed cable.

25. Rate of Voltage Application

25.1 Increase the applied voltage (from zero unless otherwise specified), at a uniform rate, from the initial value to the specified full test voltage within 60 s.

26. Application of Voltage to Cable

26.1 *Single-Conductor Cables without Shield, Sheath, or Armor:*

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26.1.1 Apply the specified voltage between the conductor and water while the cable is still immersed in the water and after it has been immersed for at least 6 h.

26.2 *Fibrous-Covered Cables without Metallic Sheath, Metallic Shield, or Metallic Armor:*

26.2.1 Test single-conductor cables of this type prior to the application and saturation of the fibrous covering. Apply the specified voltage between the conductor and the water while the cable is still immersed in water and after it has been immersed for at least 6 h.

26.2.2 Test multiple-conductor cables of this type after the application and saturation of the fibrous covering and after assembly. Without immersing the cable in water (dry test), apply the specified voltage between each conductor and all other conductors.

26.3 *Jacketed Cables and Integral Insulation and Jacket without Metallic Sheath, Metallic Shield, or Metallic Armor:*

26.3.1 When single-conductor cables of this type are twisted together into an assembly of two or more conductors without an overall jacket or covering, apply the specified voltage between each conductor and the water. Test such assemblies while they are still immersed in water and after they have been immersed for at least 1 h.

26.3.2 Test all other single-conductor cables of this type after immersion in water for at least 6 h and while still immersed.

26.3.3 Test each conductor of multiple-conductor cable with overall jacket against all other conductors connected to the grounded water tank.

26.4 *Cables with Metallic Sheath, Metallic Shield, or Metallic Armor:*

26.4.1 Test all cables of this type with the sheaths, shields, or armors grounded, without immersion in water, at the specified test voltage. For cables having a metallic sheath, shield, or armor over the individual conductor(s), apply the specified test voltage between the conductor(s) and ground. For multiple-conductor cables with nonshielded individual conductors having a metallic sheath, shield, or armor over the cable assembly, apply the specified test voltage between each conductor and all other conductors and between each conductor and ground.

27. Procedure

27.1 **Warning**—These tests involve the use of high voltages. See 4.2.

27.2 Where the insulation on a single-conductor cable or on individual conductors of a multiple-conductor cable is covered with a crosslinked or thermoplastic jacket, either integral with, or separate from, the insulation, or where the thickness of the insulation is increased for mechanical reasons, determine the test voltage by the size of the conductor and the rated voltage of the cable and not by the apparent thickness of insulation.

27.3 *AC Tests:*

27.3.1 Test each insulated conductor for 5 min at the ac withstand voltage given in Table 1A, Table 1C, and Table 1D. This test is not necessary for non-shielded conductors rated up to 5000 V if the dc voltage test described in 27.4 is to be performed.

27.3.2 Do not apply a starting ac voltage (initial voltage) greater than the rated ac voltage of the cable under test.

27.4 *DC Tests:*

27.4.1 Upon completion of the insulation resistance test, test each insulated conductor rated for service at 5001 V and above for 15 min at the dc withstand voltage given in Table 1B, Table 1C, and Table 1D.

27.4.2 Upon completion of the insulation resistance test, test each non-shielded conductor rated up to 5000 V for 5 min at the dc withstand voltage given in Table 1B. Omit this test for non-shielded conductors rated up to 5000 V if the ac voltage test described in 27.3 was performed.

27.4.3 Do not apply a starting dc test voltage (initial voltage) greater than 3.0 times the rated ac voltage of the cable under test. The test voltage is permitted to be of either polarity.

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28. Report

28.1 Report the following information:

28.1.1 Manufacturer's name,

28.1.2 Manufacturer's lot number, if applicable,

28.1.3 Description of the cable construction,

28.1.4 Voltage and time of application,

28.1.5 Whether or not the cable was immersed in water, and

28.1.6 Whether or not the cable withstood the required voltage for the specified time.

29. Precision and Bias

29.1 No information is presented about the precision of this test method because the test result is non-quantitative.

29.2 No information is presented about the bias of this test method because the test result is non-quantitative.

TABLE 1 A Conductor Sizes, Insulation Thicknesses, and AC Test Voltages for Rubber Insulations

NOTE 1—These tables are intended for test voltage purposes only. The conductor sizes and insulation thicknesses given in each voltage class are not necessarily suitable for all types of cable or conditions of service where mechanical stresses govern.

NOTE 2—To limit the maximum voltage stress on the insulation at the conductor to a safe value, the minimum size of the conductor shall be in accordance with Table 1A. For cables or conditions of service where mechanical stresses govern, such as in submarine cables or long vertical risers, larger conductor sizes are recommended.

NOTE 3—Where the insulated conductor or conductors are covered by rubber or thermoplastic jackets, either integral with the insulation or separate therefrom, or where the thickness of the insulation is increased for nonsheathed submarine cables or for mechanical reasons, the test voltage shall be determined by the size of the conductor and rated voltage of the cable and not by the apparent thickness of the insulation.

NOTE 4—The actual operating voltage shall not exceed the rated circuit voltage by more than 5 % during continuous operation or 10 % during emergencies lasting not more than 15 min.

NOTE 5—The selection of the cable insulation level to be used in a particular installation shall be made on the basis of the applicable phase-to-phase voltage and the general system category as outlined in the following paragraphs:

100 % Level—Cables in this category are recommended where the system is provided with relay protection such that ground faults will be cleared as rapidly as possible, but in any case within 1 min. While these cables are applicable to the great majority of cable installations which are on grounded systems, they are also used also on other systems for which the application of cables is acceptable provided the above clearing requirements are met in completely de-energizing the faulted section.

In common with other electrical equipment, the use of cables is not recommended on systems where the ratio of the zero to positive phase reactance of the system at the point of cable application lies between −1 and −40 since excessively high voltages are likely to be encountered in the case of ground faults.

133 % Level—This insulation level corresponds to that formerly designated for ungrounded systems. Cables in this category are recommended in situations where the clearing time requirements of the 100 % level category cannot be met, and yet there is adequate assurance that the faulted section will be de-energized in a time not exceeding 1 h. Also they are used when additional insulation strength over the 100 % level category is desirable.

173 % Level—Cables in this category should be applied on systems where the time required to de-energize a grounded section is indefinite. Their use is recommended also for resonant grounded systems. Consult the manufacturer for insulation thicknesses.

NOTE 6—Do not use single-conductor cables in sizes AWG 9 and smaller for direct earth burial.

NOTE 7—Where additional insulation thickness is desired, it shall be the same as for the 133 % insulation level.

NOTE 8—These thicknesses are based on unipass construction. Where cable is provided with a protective covering, these insulation thicknesses shall be 90 mils (2.29 mm) for all conductor sizes listed.

NOTE 9—For 133 % insulation level (ungrounded neutral), the minimum conductor size is AWG 1.

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Rated Circuit Voltage, Phase-to-Phase, V	Conductor Size, AWG or kcmil (mm^2)	Insulation Thickness				AC Test Voltage, kV			
		100 % Insulation Level (Grounded Neutral)		133 % Insulation Level (Ungrounded Neutral)		Other Than Ozone-Resisting Insulations		Ozone-Resisting Insulations	
		in.	mm	in.	mm	100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral	100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral)
0 to 600	18 to 16 (0.823 to 1.31)	0.030	0.76	0.030	0.76	1.0	1.0	1.0	1.0
	14 to 9 (2.08 to 6.63)	0.045	1.14	0.045	1.14	3.0	3.0	4.5	4.5
	8 to 2 (8.37 to 33.6)	0.060	1.52	0.060	1.52	3.5	3.5	6.0	6.0
	1 to 4/0 (42.4 to 107)	0.080	2.03	0.080	2.03	4.0	4.0	7.5	7.5
	225 to 500 (114 to 253)	0.095	2.41	0.095	2.41	5.0	5.0	8.5	8.5
	525 to 1000 (266 to 507)	0.110	2.79	0.110	2.79	6.0	6.0	10.0	10.0
	1000 (over 507)	0.125	3.18	0.125	3.18	7.0	7.0	11.5	11.5
601 to 1000	14 to 8 (2.08 to 8.37)	0.060	1.52	0.060	1.52	5.0	5.0	6.0	6.0
	7 to 2 (10.6 to 33.6)	0.080	2.03	0.080	2.03	6.0	6.0	7.5	7.5
	1 to 4/0 (42.4 to 107)	0.095	2.41	0.095	2.41	7.5	7.5	8.5	8.5
	225 to 500 (114 to 253)	0.110	2.79	0.110	2.79	9.0	9.0	10.0	10.0
	525 to 1000 (266 to 507)	0.125	3.18	0.125	3.18	10.0	10.0	11.5	11.5
	1000 (over 507)	0.140	3.56	0.140	3.56	11.5	11.5	11.5	11.5
1001 to 2000	14 to 8 (2.08 to 8.37)	0.080	2.03	0.080	2.03	6.0	6.0	7.5	7.5
	7 to 2 (10.6 to 33.6)	0.095	2.41	0.095	2.41	7.5	7.5	8.5	8.5
	1 to 4/0 (42.4 to 107)	0.110	2.79	0.110	2.79	9.0	9.0	10.0	10.0
	225 to 500 (114 to 253)	0.125	3.18	0.125	3.18	10.0	10.0	11.5	11.5
	500 (over 253)	0.140	3.56	0.140	3.56	11.5	11.5	11.5	11.5
2001 to 5000	8 to 4/0 (8.37 to 107)	0.155	3.94	0.155	3.94	...	...	13.0	13.0
	225 to 1000 (114 to 507)	0.170	4.32	0.170	4.32	...	...	13.0	13.0
	1000 (over 507)	0.190	4.83	0.190	4.83	...	...	13.0	13.0
5001 to 8000	6 (13.6 and over)	0.190	4.83	0.250	6.35	...	...	18	22
8001 to 15 000	2 (33.6 and over)	0.300	7.62	...	...	...	...	27.0	...
	1 (42.4 and over)	...	...	0.420	10.67	...	...	...	33

TABLE 1 *Continued*

Rated Circuit Voltage, Phase-to-Phase, V	Conductor Size, AWG or kcmil (mm^2)	Insulation Thickness				AC Test Voltage, kV			
		100 % Insulation Level (Grounded Neutral)		133 % Insulation Level (Ungrounded Neutral)		Other Than Ozone-Resisting Insulations		Ozone-Resisting Insulations	
		in.	mm	in.	mm	100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral	100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral)
15 001 to 25 000	1 (42.4 and over)	0.450	11.43	...	...	...	...	38.0	...
25 001 to 28 000	1 (42.4 and over)	0.500	12.70	...	...	...	...	42.0	...

TABLE 1 B Conductor Sizes, and DC Test Voltages for Rubber Insulations

Rated Circuit Voltage, Phase-to-Phase, V	Conductor Size, AWG or kcmil (mm^2)	DC Test Voltage, kV			
		Other than Ozone-Resisting Insulations		Ozone-Resisting Insulations	
		100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral)	100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral)
0 to 600	18 to 16 (0.823 to 1.31)	...	...	...	...
	14 to 9 (2.08 to 6.63)	9.0	9.0	13.5	13.5
	8 to 2 (8.37 to 33.6)	10.5	10.5	18.0	18.0
	1 to 4/0 (42.4 to 107)	12.0	12.0	22.5	22.5
	225 to 500 (114 to 253)	15.0	15.0	25.5	25.5
	525 to 1000 (266 to 507)	18.0	18.0	30.0	30.0
	over 1000 (over 507)	21.0	21.0	34.5	34.5
601 to 1000	14 to 8 (2.08 to 8.37)	15.0	15.0	18.0	18.0
	7 to 2 (10.6 to 33.6)	18.0	18.0	22.5	22.5
	1 to 4/0 (42.4 to 107)	22.5	22.5	25.5	25.5
	225 to 500 (114 to 253)	27.0	27.0	30.0	30.0
	525 to 1000 (266 to 507)	30.0	30.0	34.5	34.5
	over 1000 (over 507)	33.0	33.0	34.5	34.5
1001 to 2000	14 to 8 (2.08 to 8.37)	18.0	18.0	22.5	22.5
	7 to 2 (10.6 to 33.6)	22.5	22.5	25.5	25.5
	1 to 4/0 (42.4 to 107)	27.0	27.0	30.0	30.0
	225 to 500 (114 to 253)	30.0	30.0	34.5	34.5
	over 500 (over 253)	33.0	33.0	34.5	34.5
2001 to 5000	8 to 4/0 (8.37 to 107)	...	...	35.0	35.0
	225 to 1000 (114 to 507)	...	...	35.0	35.0
	over 1000 (over 507)	...	...	35.0	35.0
5001 to 8000	6 and over (13.6)	...	...	45.0	45.0
8001 to 15 000	2 and over (33.6)	...	...	70.0	...
	1 and over (42.4)	...	...	...	80.0
15 001 to 25 000	1 and over (42.4)	...	...	100.0	...
25 001 to 28 000	1 and over (42.4)	...	...	105.0	...

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TABLE 1 C Conductor Sizes, Insulation Thicknesses, and Test Voltages for Crosslinked Polyethylene Insulation

Rated Circuit Voltage, Phase-to-Phase, V	Conductor Size, AWG or kcmil (mm^2)	Insulation Thickness for 100 and 133 % Insulation Levels (Grounded and Ungrounded Neutral)				AC Test Voltage, kV for 100 and 133 % Insulation Levels (Grounded and Ungrounded Neutral)		DC Test Voltage, kV for 100 and 133 % Insulation Levels (Grounded and Ungrounded Neutral)	
		Column A		Column B		Column A	Column B	Column A	Column B
		in.	mm	in.	mm				
0 to 600	14 to 9 (2.08 to 6.63)	0.045	1.19	0.030	0.76	4.0	4.0	12.0	12.0
	8 to 2 (8.37 to 33.6)	0.060	1.57	0.045	1.14	5.5	5.5	16.5	16.5
	1 to 4/0 (42.4 to 107)	0.080	1.98	0.055	1.40	7.0	7.0	21.0	21.0
	225 to 500 (114 to 253)	0.095	2.39	0.065	1.65	8.0	8.0	24.0	24.0
	525 to 1000 (266 to 507)	0.110	2.77	0.080	2.03	10.0	10.0	30.0	30.0
601 to 2000	14 to 9 (2.08 to 6.63)	0.060	1.52	0.045	1.14	5.5	5.5	16.5	16.5
	8 to 2 (8.37 to 33.6)	0.070	1.78	0.055	1.40	7.0	7.0	21.0	21.0
	1 to 4/0 (42.4 to 107)	0.090	2.29	0.065	1.65	8.0	8.0	24.0	24.0
	225 to 500 (114 to 253)	0.105	2.67	0.075	1.90	9.5	9.5	28.5	28.5
	525 to 1000 (266 to 507)	0.120	3.05	0.090	2.29	11.5	11.5	34.5	34.5
		100 % Insulation Level (Grounded Neutral)		133 % Insulation Level (Ungrounded Neutral)		100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral)	100 % Insulation Level (Grounded Neutral)	133 % Insulation Level (Ungrounded Neutral)
Unshielded Unipass									
2001 to 5000	8 to 4/0 (8.37 to 107)	0.110	2.79	0.110	2.79	13	13	35	35
	225 to 500 (114 to 253)	0.120	3.05	0.120	3.05	13	13	35	35
	525 to 1000 (266 to 507)	0.130	3.30	0.130	3.30	13	13	35	35
Shielded									
2001 to 5000	8 to 1000 (8.37 to 507)	0.090	2.29	0.090	2.29	13	13	35	35
5001 to 8000	6 to 1000 (13.6 to 507)	0.115	2.92	0.140	3.56	18	22	45	45
8001 to 15 000	2 to 1000 (33.6 to 507)	0.175	4.45	0.215	5.46	27	33	70	80
15 001 to 25 000	1 to 1000 (42.4 to 507)	0.260	6.60	0.345	8.76	38	49	100	125
25 001 to 28 000	1 to 1000 (42.4 to 507)	0.280	7.11	...	...	42	...	105	...
28 001 to 35 000	1/0 to 1000 (53.5 to 507)	0.345	8.76	...	...	49	...	125	...

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TABLE 1 D Conductor Sizes, Insulation Thicknesses, Test Voltages, and Corona Extinction Levels for Ethylene Rubber Insulation

Rated Circuit Voltage, Phase-to-Phase, V	Conductor Size, AWG or kcmil (mm^2)	Insulation Thickness				AC Test Voltage		DC Test Voltage	
		100 % Insulation Level		133 % Insulation Level		100 % Insulation Level, kV	133 % Insulation Level, kV	100 % Insulation Level, kV	133 % Insulation Level, kV
		in.	mm	in.	mm				
0 to 600	14 to 9 (2.08 to 6.63)	0.030	0.76	0.030	0.76	4.0	4.0	12.0	12.0
	8 to 2 (8.37 to 33.6)	0.045	1.14	0.045	1.14	5.5	5.5	16.5	16.5
	1 to 4/0 (42.4 to 107)	0.055	1.40	0.055	1.40	7.0	7.0	21.0	21.0
	225 to 500 (114 to 253)	0.065	1.65	0.065	1.65	8.0	8.0	24.0	24.0
	525 to 1000 (266 to 507)	0.080	2.03	0.080	2.03	10.0	10.0	30.0	30.0
601 to 2000	14 to 9 (2.08 to 6.63)	0.045	1.14	0.045	1.14	5.5	5.5	16.5	16.5
	8 to 2 (8.37 to 33.6)	0.055	1.40	0.055	1.40	7.0	7.0	21.0	21.0
	1 to 4/0 (42.4 to 107)	0.065	1.65	0.065	1.65	8.0	8.0	24.0	24.0
	225 to 500 (114 to 253)	0.075	1.90	0.075	1.90	9.5	9.5	28.5	28.5
	525 to 1000 (266 to 507)	0.090	2.29	0.090	2.29	11.5	11.5	34.5	34.5
2001 to 5000	8 to 1000 (8.37 to 507)	0.090	2.29	0.090	2.29	13	13	35	35
5001 to 8000	6 to 1000 (13.6 to 507)	0.115	2.92	0.140	3.56	18	22	45	45
8001 to 15 000	2 to 1000 (33.6 to 507)	0.175	4.45	...	...	27	...	70	...
	1 to 1000 (42.4 to 507)	...	...	0.215	5.46	...	33	...	80
15 001 to 25 000	1 to 1000 (42.4 to 507)	0.260	6.60	0.345	8.76	38	49	100	125
25 001 to 28 000	1 to 1000 (42.4 to 507)	0.280	7.11	...	...	42	...	105	...
28 001 to 35 000	1/0 to 1000 (53.5 to 507)	0.345	8.76	...	...	49	...	125	...

INSULATION RESISTANCE TESTS ON COMPLETED CABLE

30. Significance and Use

30.1 The insulation resistance of a cable is primarily a measurement of the volume resistance of the insulating material, although surface resistance across the ends can be significant for short specimens or when atmospheric humidity is high. It is usually desirable for a cable to have a high value of insulation resistance. This test is used for product acceptance to specification requirements, but can also be useful for quality control purposes in indicating consistency of manufacture. See Test Methods D257 for a more complete discussion of the significance of insulation resistance tests.

31. Apparatus

31.1 *Megohm Bridge*—Use a megohm bridge or other equipment described in Test Methods D257. Make the measurement at a voltage of 100 to 500 Vdc.

32. Sampling, Test Specimens, and Test Units

32.1 The specimen consists of entire lengths of completed cable.

33. Procedure

33.1 **Warning—**This test involves the use of high voltages. See 4.2.

33.2 Unless otherwise specified in the product specification:

33.2.1 Perform this test only after performing the completed cable ac voltage tests as specified in 27.3,

33.2.2 Perform this test only before performing the completed cable dc voltage tests as specified in 27.4, and

33.2.3 Perform this test in accordance with Test Methods D257, and as follows:

33.2.4 Where the voltage tests are made on wire or cable immersed in water, measure the insulation resistance while the cable is still immersed.

33.3 *Single-Conductor Cables:*

33.3.1 For single-conductor cables test between the conductor and its metallic sheath or between the conductor and surrounding water.

33.3.2 *Multiple-Conductor Cables:*

33.3.2.1 For cables having unshielded conductors, test between each conductor and all other conductors, and between each conductor and the overall sheath or surrounding water.

33.3.2.2 For cables having shielded conductors, test between each conductor and its shield.

33.3.3 Connect the conductor of the specimen under test to the negative terminal of the test equipment, and take readings after an electrification time of 1 min. On short sections of wire or cable, a guard circuit is permitted to prevent end leakage. Maintain the temperature of the water from 10 to 30°C (50 to 85°F).

34. Calculation

34.1 Calculate the minimum insulation resistance in megohms-1000 ft (305 m) at a temperature of 60°F (15.6°C) for each coil, reel, or length of wire or cable as follows:

$$R = K \log D/d \tag{1}$$

where:

R = minimum insulation resistance in megohms-1000 ft,
K = constant for the grade of insulation (see 34.1.1),
D = diameter over the insulation, and
d = diameter under the insulation.

34.1.1 Obtain the constant K for the grade of insulation in the cable under test by reference to the product specification for that type.

34.1.2 Where a nonconducting separator is applied between the conductor and the insulation, or where an insulated conductor is covered with a non-metallic jacket, the insulation resistance shall be at least 60 % of that required for the primary insulation based on the thickness of that insulation.

34.1.3 When the length of the cable tested differs from 1000 ft (305 m), correct the measured value of insulation resistance to megohms-1000 ft by multiplying by the ratio $L/1000$ ($L/305$) where L is the length in feet (metres).

34.2 The insulation resistance of wire and cable varies widely with temperature. If the temperature at the time measurement was made differs from 60°F (15.6°C), adjust the resistance to that at 60°F by multiplying the measured value by the proper correction factor from Table 2. Use the coefficient furnished by the manufacturer for the particular insulation or determine it in accordance with Section 35.

35. Determining Temperature Coefficients for Insulation Resistance

35.1 Select three specimens, preferably of AWG 14 solid wire with a 0.045 in. (1.14 mm) wall of insulation, as representative of the insulation under consideration. Use sufficient length to yield insulation resistance values under 25 000 MΩ at the lowest water-bath temperature.

35.2 Immerse the three specimens in a water bath equipped with heating, cooling, and circulating facilities, with the ends of the specimens extended 2 ft (0.6 m) above the surface of the water and properly prepared for minimum leakage. Leave the specimens in the water at room temperature for 16 h before adjusting the bath temperature to 10°C, or transfer the specimens to a 10°C test temperature bath.

35.3 Measure the resistance of the conductor at suitable intervals of time until it remains unchanged for at least 5 min. The insulation is then at the temperature of the bath as read on the bath thermometer. Take insulation resistance readings in accordance with Sections 32 to 34.

35.4 Expose the three specimens to successive water-bath temperatures of 10, 16, 22, 28, and 35°C, returning to 28, 22, 16, and 10°C. Take insulation resistance readings at each temperature after equilibrium is established. Average all the readings taken at each temperature.

35.5 Using semi-log paper (log R versus T), plot the average readings obtained in 35.4.

35.6 *Calculations:*

35.6.1 Using the semi-log plot from 35.5, determine the insulation resistance at 60°F (15.6°C) and at 61°F (16.1°C). Obtain the 1°F coefficient per degree by dividing the insulation resistance at 60°F by the insulation resistance at 61°F.

35.6.2 If a more precise value is desired for the 1°F coefficient per degree, subject the numerical values used in 35.5 to regression analysis in order to determine the parameters of the best fitting curve. The slope parameter is related to the 1°F coefficient per degree.

36. Report

36.1 Report the following information:

36.1.1 Manufacturer's name,

36.1.2 Manufacturer's lot number, if applicable,

36.1.3 Description of the cable construction,

36.1.4 Specimen length,

36.1.5 Whether or not a guard circuit was used,

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