UL 1072

STANDARD FOR SAFETY

Medium-Voltage Power Cables

UL Standard for Safety for Medium-Voltage Power Cables, UL 1072

Fourth Edition, Dated June 30, 2006

SUMMARY OF TOPICS

This revision of ANSI/UL 1072 dated April 13, 2020 includes a correction to Table 18.1, Construction of metal component of insulation shielding.

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The requirements are substantially in accordance with Proposal(s) on this subject dated January 17, 2020.

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The most recent designation of ANSI/UL 1072 as an American National Standard (ANSI) occurred on March 12, 2020. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Scope

1.1 These requirements cover the shielded and nonshielded medium-voltage power cables that are described in Table 1.1 (single-conductor) and Table 1.2 (multiple-conductor). Multiple-conductor cables may include one or more individually jacketed non-conductive optical-fiber members. These electrical and hybrid electrical and optical-fiber cables are for use (optical and electrical functions associated in the case of a hybrid cable) in accordance with Article 328 and other applicable parts of the National Electrical Code (NEC), ANSI/NFPA 70.

1.2 These cables have one or more stranded copper or aluminum conductors that are insulated with a solid, extruded dielectric. Cables that have a metal sheath or interlocked armor incorporate an effective grounding path. A grounding conductor is optional in other cables. Cables for direct burial are so marked and have an overall covering (see 1.4 for direct-burial cables that are not covered). Cables that are for use in cable trays generally are so marked (see 62.1 and 62.2). Cables that are sunlight-resistant generally are so marked (see 64.1 – 64.3). Cables that are marked “MV-90” or “MV-90 dry” have a maximum operating temperature of 90°C (194°F). Cables that are marked “MV-105” have a maximum operating temperature of 105°C (221°F) for use where design conditions require a maximum conductor temperature above 90°C (194°F). Cables that are marked “dry” have insulation for use only in dry locations. All other cables have insulation that is for use in both wet and dry locations. Multiple-conductor cables that include one or more optical-fiber members are surface marked to so indicate. Cables that are marked “oil resistant II” are for exposure to mineral oil at temperatures not in excess of 75°C (167°F). Cables that are marked “oil resistant I” are for exposure to mineral oil at temperatures not in excess of 60°C (140°F).

1.3 A multiple-conductor Type MV cable that has a smooth (other than lead) or corrugated metal sheath or that has interlocked metal armor may be marked for use also as Type MC cable.

1.4 This standard does not include requirements for cables with concentric neutral conductors. However, it is possible to have a single-conductor cable with a concentric neutral conductor manufactured in accordance with the requirements of other standards, that meets the requirements for jacketed single-conductor shielded cable in this standard.

Table 1.1
Single-conductor Type MV cables

Voltage rating	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Overall covering
2400	8 AWG – 1000 kcmil	90°C (194°F) dry	XLPE or EPCV	–	Column A Table 15.3	nonshielded	None
		90°C (194°F) dry	XLPE, EPCV, DREP, or EP	–	Column B Table 15.3	nonshielded	Nonconductive jacket Column B Table 27.20
		90°C (194°F) wet or dry	XLPE, DREP, or EP	–	Column C Table 15.3	nonshielded	Nonconductive jacket Column C Table 27.20
5000	8 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100 or 133	Table 15.1 or Table 15.2	Shielded	a
8000	6 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1 or Table 15.2	Shielded	a
15000	2 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1 or Table 15.2	Shielded	a
25000	1 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1 or Table 15.2	Shielded	a
28000	1 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1 or Table 15.2	Shielded	a
35000	1/0 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1 or Table 15.2	Shielded	a

[a] The overall covering consists of one of the following (see Table 26.1 for complete descriptions):

1) Conductive nonmetallic insulation covering (Table 17.3) as part of shielding, with or without nonmagnetic metal sheath or armor over conductive nonmetallic insulation covering as part of shielding, with or without supplementary non-conductive jacket (Table 29.1) over metal sheath or armor.

2) Non-conductive jacket (Table 27.18) over shielding, with or without nonmagnetic metal sheath or armor over non-conductive jacket, with or without supplementary non-conductive jacket (Table 29.1) over metal sheath or armor.

3) Nonmagnetic metal sheath or armor as part of shielding, with or without supplementary non-conductive jacket (Table 29.1) over metal sheath or armor.

Table 1.2
Multiple-conductor Type MV cables

Voltage rating	Circuit conductors							Grounding conductor	Overall covering
	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Individual covering		
2400	8 AWG – 1000 kcmil	90°C (194°F) dry	XLPE or EPCV	–	Column A Table 15.3	nonshielded	None	Optional Covered 23.1	None – assembly of single-conductor cables
		90°C (194°F) dry	XLPE, EPCV, DREP, or EP	–	Column B Table 15.3	nonshielded	Non-conductive jacket Column B Table 27.20	Optional Covered 23.1	None – assembly of single-conductor cables
		90°C (194°F) wet or dry	XLPE, DREP, or EP	–	Column C Table 15.3	nonshielded	Non-conductive jacket Column C Table 27.20	Optional Covered Table 23.1	None – assembly of single-conductor cables
		90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP		Column C Table 15.3	nonshielded	None or Non-conductive jacket (Table 19.1)	Optional Bare 23.5	Non-conductive jacket (Table 27.18)
				–				Required Bare 23.1	Interlocked armor with or without Supplementary jacket
								May be required Bare 23.3 and 23.4	Metal sheath with or without Supplementary jacket
5000	8 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F)	XLPE, DREP, or EP	100	Table 15.1, Table 15.2	Shielded	Non-conductive jacket (Table 27.18) over shield	Optional Covered 23.1	None
							Conductive nonmetallic insulation covering (Table 17.3) as part of shield	Optional Covered Table 23.1	None

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Table 1.2 Continued

Voltage rating	Circuit conductors							Grounding conductor	Overall covering
	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Individual covering		
							Metal sheath as part of shield with or without Supplementary jacket	Optional Covered 23.1	None
8000	6 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1, Table 15.2	Shielded	None or Non-conductive jacket (Table 19.1)	Optional Bare 23.5	Non-conductive jacket (Table 27.18)
								Required Bare 23.1	Interlocked armor with or without Supplementary jacket
15000	2 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173				May be required to Bare 23.3 and 23.4	Metal sheath with or without Supplementary jacket
							Non-conductive jacket (Table 27.18) over shield	Optional Covered 23.1	None
25000	1 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173			Conductive nonmetallic insulation covering (Table 17.3) as part of shield	Optional Covered 23.1	None
							Metal sheath as part of shield with or without supplementary jacket	Optional Covered 23.1	None
28000	1 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1, Table 15.2		None or Non-conductive jacket (Table 19.1)	Optional Bare 23.5	Non-conductive jacket (Table 27.18)

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Table 1.2 Continued

Voltage rating	Circuit conductors							Grounding conductor	Overall covering
	Size	Use	Insulation material	Percent insulation level	Insulation thicknesses	Shield	Individual covering		
								Required Bare 23.2	Interlocked armor with or without Supplementary jacket
								May be required Bare 23.3 and 23.4	Metal sheath with or without Supplementary jacket
35000	1/0 AWG – 2000 kcmil	90°C (194°F) or 105°C (221°F) wet or dry	XLPE, DREP, or EP	100, 133, or 173	Table 15.1, Table 15.2	Shielded	Non-conductive jacket (Table 27.18) over shield	Optional Covered Table 23.1	None
							Conductive nonmetallic insulation covering (Table 17.3) as part of shield	Optional Covered 23.1	None
							Metal sheath as part of shield with or without Supplementary jacket	Optional Covered 23.1	None

2 Units of Measurement

2.1 In addition to being stated in the inch/pound units that are customary in the USA, each numerical requirement in this standard is also stated in units that make the requirement conveniently usable in countries employing the various metric systems (practical SI and customary). Equivalent – although not necessarily exactly identical – results are to be expected from applying a requirement in USA or metric terms. Equipment calibrated in metric units is to be used when a requirement is applied in metric terms.

3 References

3.1 Wherever the designation "UL 1581" is used in this cable standard, reference is to be made to the designated part(s) of the Reference Standard for Electrical Wires, Cables, and Flexible Cords (UL 1581).

3.2 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

CONSTRUCTION

4 Materials

4.1 Only materials that are acceptable for the particular use shall be used in a cable.

4.2 Each material used in a cable shall be compatible with all of the other materials used in the cable.

5 General

5.1 Medium-voltage cable shall be designated as Type MV and shall comply in all respects with the applicable requirements for construction details, test performance, and markings.

CONDUCTOR(S)

6 Materials

6.1 The conductor(s) in a cable shall be of soft-annealed copper or of semi-annealed (1/2 – 3/4 hard) or hard-drawn aluminum. Soft-annealed copper wires (strands) shall comply with ASTM B 3. A metal coating that is provided on soft-annealed copper in accordance with 9.1 or 9.2 shall be of tin complying with ASTM B 33. An aluminum conductor shall comply with the Requirements for Aluminum Conductors of an 8000 Series Alloy, Section 10 of UL 1581, or shall be of a 1/2 – 3/4 hard 1350 Series aluminum alloy having either the tensile strength required for a 1350-H19 (extra-hard) aluminum alloy in the American Society for Testing and Materials Standard Specification for Aluminum 1350-H19 Wire for Electrical Purposes, ASTM B 230, or the tensile strength required for a semi-annealed 8000 Series alloy.

6.2 An individual conductor shall not be smaller than 8 AWG (8.367 mm^2) and shall not be larger than 2000 kcmil or 113 mm^2. The nominal cross-sectional area of a conductor is indicated in Table 20.1 of UL 1581.

7 Resistance

7.1 The direct-current resistance of any length of conductor in ohms per thousand conductor feet or in ohms per conductor kilometer shall not be higher than the maximum (nominal x 1.02) resistance indicated in the applicable table in D-C Conductor Resistance, Section 30 of UL 1581, at 20°C (68°F) or at 25°C (77°F) when measured as described in D-C Conductor Resistance, Section 220 of UL 1581, except that the equipment selected shall be accurate to within 0.5 percent of the value read. If, as provided for in 11.2, metal-coated wires are used in only the outer layer of an uncoated copper conductor, the direct-current resistance of the resulting conductor shall not exceed the value tabulated for an uncoated conductor of the same size and construction. See 7.2 for cabling factors applicable to multiple-conductor cables.

7.2 In a finished multiple-conductor cable, the increased resistance of a conductor because of cabling shall not be higher than the applicable value multiplied by the following factor, with the result rounded off to the same number of decimal places as the tabulated value.

a) One layer of conductors: 1.02

b) More than one layer of conductors: 1.03

8 Conductor Diameter

8.1 The nominal, maximum (1.01 x nominal), and minimum (0.98 x nominal) diameters of solid and stranded conductors are shown in Tables 20.1, 20.2, 20.3, 20.3.1, 20.4, and 20.6 of UL 1581. Conductor diameter is to be measured using the method shown in Conductor Diameter, Section 200 of UL 1581.

8.2 Compressed unilay copper conductors that are smaller in diameter than the requirement (0.98 x nominal as indicated in Table 20.3 of UL 1581) for compressed concentric-lay conductors shall be marked the same as compact conductors in accordance with 70.1(n).

9 Stranding

9.1 Each conductor shall be solid: concentric-lay-stranded (in this standard, this term includes compressed-stranded and compact-stranded), with at least the number of strands indicated in Table 9.1, or shall be rope-lay-stranded. The outer layer shall be left-hand in all cases. Copper wires (strands) smaller than 36 AWG (0.005 inch or 0.127 mm in diameter) and aluminum wires (strands) smaller than 22 AWG (0.0253 inch or 0.642 mm in diameter) shall not be used.

Table 9.1
Conductor stranding

Conductor size	Number of strands in combination unilay	Minimum number of strands	
		Compact stranded	All others
8 AWG	19[a]	7	7
7	–	7	7
6 – 2	19	7	7
1 – 4/0	19	18	19
213 – 500 kcmil	–	35	37
501 – 1000	–	58	61
1001 – 1500	–	–	91
1501 – 2000	–	–	127

[a] Copper only

[b] Conductors with a lesser number of strands shall be permitted based on the results of an investigation which shall include testing for connectability and bending.

9.2 A compact-stranded conductor shall be a round conductor consisting of a central core wire (one or more strands) surrounded by one or more layers of helically laid (strands). A compact-stranded copper conductor shall consist of uncoated strands. Compact-stranded aluminum conductor and compact-stranded copper conductor shall have all layers with the same direction of lay (unidirectional) or shall have the direction of lay reversed in adjacent layers (concentric-lay-stranded). Each layer shall be rolled, drawn, or otherwise compressively formed to change the originally round strands to various close-fitting shapes that achieve almost complete filling of the spaces originally present between the strands. Each compacted layer – including the outermost layer – shall have a smooth, round outer surface. The length of lay of the strands in the outer layer of a 1 AWG – 1000 kcmil conductor shall be 8 – 16 times the overall diameter of that layer. The length of lay of the strands in the outer layer of an 8 – 2 AWG conductor shall be 8.0 – 17.5 times the overall diameter of that layer. A compact-stranded conductor shall not be segmented.

9.3 A compressed-stranded conductor shall be a round conductor consisting of a central core wire (one or more strands) surrounded by one or more layers of helically laid (strands) having the unilay construction, the unidirectional lay construction, or with the direction of lay reversed in successive layers. The strands of one or more layers shall be slightly compressed by rolling, drawing, or other means to change the originally round strands to various shapes that achieve filling of some of the spaces originally present between the strands.

9.4 A 19-wire combination round-wire unilay-stranded soft-annealed copper or an acceptable aluminum alloy conductor shall be round and shall consist of a straight central wire, an inner layer of six wires of the same diameter as the central wire with the six wires having identical lengths of lay, and an outer layer consisting of six wires of the same diameter as the central wire alternated with six smaller wires having a diameter of 0.732 times the diameter of the central wire and with all twelve wires of the outer layer having the same length of lay and direction of lay as the six wires of the inner layer.

9.5 Concentric-lay-stranded coated or uncoated annealed copper conductors (including compressed conductors) shall comply with the applicable parts of ASTM B 8. Compact round concentric-lay-stranded uncoated copper conductors shall comply with the applicable parts of ASTM B 496.

9.6 Concentric-lay-stranded aluminum conductors (including compressed conductors) shall comply with the applicable parts of ASTM B 231. Compact stranded aluminum shall comply with the applicable parts of ASTM B 400.

9.7 The length of lay in only the outer layer of a 1 AWG – 1000 kcmil round compact-stranded conductor shall neither be less than 8 nor more than 16 times the overall diameter of that layer. The length of lay of the strands in the outer layer of a 8 – 2 AWG compact-stranded conductor shall be 8.0 – 17.5 times the overall diameter of that layer. The direction of lay of the outer layer shall be left-hand.

9.8 Every stranded conductor other than a compact-stranded conductor shall comply with the following:

a) The direction of lay of the strands, members, or ropes in a 6 AWG – 2000 kcmil conductor other than a combination unilay, compressed unilay, or compressed unidirectional lay conductor shall be reversed in successive layers. Rope-bunched lay and rope-concentric lay conductors shall be either unidirectional or reversed.

b) For a bunch-stranded member of a rope-lay-stranded conductor in which the members are formed into rope-stranded components that are then cabled into the final conductor, the length of lay of the individual strands within each component shall not be more than 30 times the outside diameter of one of those members.

c) For a concentric-stranded member of a rope-lay-stranded conductor, the length of lay of the individual strands in a member shall be 8 – 16 times the outside diameter of the member. The direction of lay of the strands in each member shall be reversed in successive layers of the member.

d) The length of lay of the strands in both layers of a 19-wire combination round-wire unilay-stranded copper or aluminum conductor shall be 8 – 16 times the outside diameter of the completed conductor. Otherwise, the length of lay of the strands in every layer of a concentric-lay-stranded conductor consisting of fewer than 37 strands shall be 8 – 16 times the outside diameter of that layer.

e) The length of lay of the strands in the outer two layers of a concentric-lay-stranded conductor consisting of 37 or more strands shall be 8 – 16 times the outside diameter of the conductor.

f) The length of lay of the members or ropes in the outer layer of a rope-lay-stranded conductor shall be 8 – 16 times the outside diameter of that layer.

10 Strand Filler

10.1 A moisture-excluding filler material is acceptable in the interstices of the inner layers of the conductor strands for the purpose of keeping moisture from entering the cable. Such a material shall be investigated and found acceptable. The investigation shall consist of testing to determine that the material does not have a detrimental effect on either of the following:

a) The conductor stress relief layer – The test is described in the Insulated Cable Engineers Association Publication T-32-645, 1993 "Guide for Establishing Compatibility of Sealed Conductor Filler Compounds with Conducting Stress Control Materials".

b) The ability to properly terminate the cable as intended – The tests are described in the Standard for Wire Connectors, UL 486A-486B. These tests could include one or all of the following: secureness, heating, pullout, and cyclic heating.

11 Metal Coating

11.1 If the insulation or other material adjacent to a copper conductor corrodes unprotected copper in the test in 32.1, each of the individual strands of that conductor shall be separately covered with a metal coating that complies with 6.1.

11.2 In the case of a copper conductor on whose wires a coating is not needed for corrosion protection but is used, it is acceptable to coat only the wires of the outer layer (see 7.1) or to coat all of the wires. The metal coating used shall comply with 6.1.

12 Joints

12.1 A joint in one of the individual wires (strands) shall be made in a workmanlike manner, shall not change the diameter of the wire (strand) or of the overall conductor, and shall not lessen the mechanical strength or impair the flexibility of the overall conductor. A joint shall not be made in the stranded conductor as a whole but, for other than a rope-lay-stranded conductor (see 12.2) shall be made by separately joining each individual wire (strand) in a manner that does not increase the overall diameter of the entire stranded conductor. A joint in a compact-stranded or compressed-stranded conductor shall be made before compacting or compressing. A joint in any conductor shall be made before the conductor-stress-relief material, the insulation, and other coverings are applied.

12.2 In a rope-lay-stranded conductor consisting of a central core surrounded by one or more layers of stranded members (primary groups), each member may be considered to be equivalent to a solid wire and, as such, may be spliced as a unit. These joints are to be dispersed throughout the length of the conductor so that the diameter and configuration of the completed conductor are not substantially affected, and so that the flexibility of the completed conductor is not adversely affected thereby. In no case shall these joints be closer together than two lay lengths.

CONDUCTOR STRESS RELIEF (CONDUCTOR SHIELDING)

13 Details

13.1 Conductor stress relief shall be provided on each circuit conductor. It shall be readily removable from the conductor and shall be bonded to the insulation (the tension necessary to remove the stress relief from the insulation is not specified). The conductor stress relief used with XLPE or EPCV insulation shall be of conductive nonmetallic material. The conductor stress relief used with EP or DREP insulation shall be of either conductive or non-conductive nonmetallic material. The conductor stress relief shall comply with Table 13.1 (form), Table 13.2 (thicknesses), and Table 13.3 (material).

13.2 The thickness(es) of a conductive tape used alone, of a conductive or non-conductive extrusion used alone, or of a conductive or non-conductive extrusion plus a conductive tape are to be determined on a full cross section of the conductor shielding produced by cutting a specimen of the finished conductor through perpendicular to its longitudinal axis. All measurements are to be made over the tops of strands or at the impressions left by strands. In the case of a conductive tape used alone, the minimum thickness is to be measured directly by means of one of the following:

a) A dead-weight dial micrometer having a presser foot 0.250 ±0.010 inch or 6.4 ±0.2 mm in diameter and exerting a total of 3.0 ±0.1 ozf or 85 ±3 gf or 0.84 ±0.02 N on the specimen – the load being applied by means of a weight, or

b) An optical device that is accurate to at least 0.001 inch or 0.01 mm.

In all other cases, the minimum thicknesses are each to be measured directly by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm.

13.3 The volume resistivity of the finished conductive conductor shielding taken as a unit shall comply with 44.1. The relative permittivity and the dielectric withstand stress of specimens of the non-conductive conductor stress control shall comply with 45.1.

Table 13.1
Conductor shielding

Voltage ratings	Construction of conductor stress relief
2400, 5000, 8000, and 15000	A conductive or non-conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27 directly on the conductor or Overlapping[a] conductive tape covered by a conductive or non-conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27 or Overlapping[a] conductive tape alone
25000, 28000, and 35000	A conductive or non-conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27 directly on the conductor or Overlapping[a] conductive tape covered by a conductive or non-conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27

[a] The amount of overlap is not specified.

Table 13.2
Thicknesses of conductor stress relief

Material	Minimum thickness at any point[a]
Conductive tape of any convenient width applied with an unspecified overlap directly to the conductor	2.5 mils or 0.06 mm
A conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27 over the above-mentioned tape or directly on the conductor.	6 mils or 0.15 mm
The properties of the material used shall comply with 13.3 when specimens are prepared and tested as indicated in the method to which reference is made in 13.3.	

[a] Where both tape and extruded material are used, no reduction is acceptable in any of the specified thicknesses of the tape or extruded material.

Table 13.3
Properties of extruded conductor stress relief

Property	Value
I. Ultimate elongation (see Section 30 for method) using 1-inch or 25-mm bench marks on specimens that first are die-cut from a specially molded slab that is not more than 0.1 inch or 2.5 mm thick and then are aged as follows in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F) for 90°C (194°F) cable or at 136.0 ±1.0°C (276.8 ±1.8°F) for 105°C (221°F) cable.	100 percent (minimum)
II. Brittleness temperature by the Acceptance Impact Procedure B described in ASTM D 746 using five die-punched specimens that are 0.25 ±0.02 inch or 6.35 ±0.51 mm wide	−10°C (+14°F) (maximum)
III. Cold – see Section 38 for method	No damage shall result

INSULATION

14 Material, Application, and Centering

14.1 Each circuit conductor shall be insulated for its entire length with a thermoset insulation that complies with Table 14.1 (XLPE), Table 14.4 (EP), Table 14.7 (EPCV), or Table 14.10 [DREP (Discharge Resistant EP)] – see 14.4 for the long-term evaluation of a thermoset insulation material not named in Table 14.1 or 14.4 or not complying with the specified short-term tests. The insulation shall be applied directly to the outer surface of the conductor stress relief and shall be bonded thereto (see 13.1). The insulation shall not have any repairs or joints and shall not have defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification.

14.2 The insulation in 2400 V nonshielded single-conductor cables constructed as indicated in columns A and B of Table 15.3 is not required to be for use in wet locations. Insulation that is for use in wet locations shall be used in all other single-conductor cables and in all multiple-conductor cables other than those consisting of an assembly of the 2400 V nonshielded single-conductor cables constructed without any overall covering as indicated in column A or B of Table 15.3.

14.3 The insulation shall have a circular cross section and shall be applied concentrically about the conductor and the conductor stress relief.

14.4 Either of the following materials that the manufacturer wishes to use as insulation or a jacket shall be evaluated for the requested temperature rating as described in Long-Term Aging, Section 481 of UL 1581:

a) Material generically different from any insulation material that is named in 14.1 or any – jacket material that is referenced in 19.2, 27.1, or 29.1 (new material).

b) Material that is named in 14.1 or referenced in 19.2, 27.1, or 29.1 yet does not comply with the short-term tests specified for the material.

The temperature rating of materials (a) and (b) shall be as required for the particular construction of medium-voltage cable. The thicknesses of insulation and/or jacket using materials (a) and/or (b) shall be as required for the particular construction. Investigation of the electrical, mechanical, and physical characteristics of the cable using material (a) and/or (b) shall show the material(s) to be comparable in performance to the insulation or non-conductive jacket materials named or referenced in 14.1, 19.2, 27.1, or 29.1 for the required temperature rating. The investigation shall include tests such as crushing, impact, abrasion, deformation, heat shock, insulation resistance, and dielectric voltage-withstand.

Table 14.1
Properties of XLPE[a] insulation from 90°C (194°F) and 105°C (221°F) cables

Property	Value
I. Physical properties – see Section 31 for method	See Table 14.2
II. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 62 for method	
Maximum elongation	Filled – 100 percent[b] Unfilled – 175 percent[b]
Maximum set	Filled – 5 percent[b] Unfilled – 10 percent[b]
III. Cold bend– see Section 38 for method	No damage shall result
IV. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 34 for method	
8 – 4/0 AWG conductors (round specimens)	25 percent
250 – 1000 kcmil conductors (flat, rectangular specimens)	15 percent
V. Insulation resistance at 60.0°F (15.6°C)	See Table 14.3
VI. Accelerated water absorption, electrical method – see Section 40 for method[c]	
Maximum relative permittivity after 24 h	3.5
Maximum increase in capacitance	1 – 14 d: 3.0 percent 7 – 14 d: 1.5 percent
Maximum stability factor after 14 d[d]	1.0 percent
Maximum stability factor difference[d]	1 – 14 d: 0.5 percent
VII. Relative permittivity – see Section 41 for method[e]	Maximum – 3.5
VIII. Power factor – see Section 41 method[e]	Maximum – 2.0 percent
XI. Dry electrical test[f]	See Section 42

[a] XLPE designates a cross-linked compound whose characteristic constituent is cross-linked polyethylene. For 2400 V cables only, the compound may be pigmented by the addition of carbon black.

[b] Greater elongation or set is acceptable if the loss of weight does not exceed 30 percent in a solvent extraction test made as described in ASTM D 2765.

[c] Not required for dry-locations cable (nonshielded 2400 V single-conductor cable insulated as indicated in column A or B of Table 15.3).

[d] Only one of these tests is required [see 40.1(d)].

[e] Not required for 2400 V or 5-kV cable.

[f] Required only for 105°C (221°F) cable.

Table 14.2
Physical properties of XLPE[a] insulation from 90°C (194°F) and 105°C (221°F) cables

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1800 lbf/in^2 or 12.4 MPa
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F) for 90°C cable or at 136.0 ±1.0°C (276.8 ±1.8°F) for 105°C cable.	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant insulation from nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column A of Table 15.3 and marked “oil resistant II” – see 70.1(h):		
Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant insulation from nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column A of Table 15.3 and marked “oil resistant I” – see 70.1(h):		
Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] XLPE designates a cross-linked compound whose characteristic constituent is cross-linked polyethylene. For 2400 V cables only, the compound may be pigmented by the addition of carbon black.

Table 14.3
Insulation resistance of XLPE[a] insulation from 90°C (194°F) and 105°C (221°F) cables

Property	Minimum value
V. Insulation resistance at 60.0°F (15.6°C)	
1) Insulation and individual non-conductive circuit-conductor jacket tested together – see Section 60 for method	
On jacketed nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column B of Table 15.3	Minimum K: 12,000 megohms based on 1000 conductor feet
On jacketed nonshielded wet-or-dry- locations 2400 V single-conductor cable insulated as indicated in column C of Table 15.3	
2) Insulation alone	
In nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column A of Table 15.3 – see Section 60 for method	Minimum K: 20,000 megohms based on 1000 conductor feet
In shielded single-conductor cable insulated as indicated in Table 15.1 or Table 15.2 – see Section 59 for method	or
In shielded multiple-conductor cable insulated as indicated in Table 15.1 or Table 15.2 – see Section 59 for method	Minimum K: 6100 megohms based on a conductor kilometer
In nonshielded multiple-conductor cable insulated as indicated in Table 15.1 or Table 15.2 without a non-conductive jacket on each circuit conductor – see Section 60 for method	

[a] XLPE designates a cross-linked compound whose characteristic constituent is cross-linked polyethylene. For 2400 V cables only, the compound may be pigmented by the addition of carbon black.

Table 14.4
Properties of EP[a] insulation from 90°C (194°F) and 105°C (221°F) cables

Property	Value
I. Physical properties – see Section 31 for method	See Table 14.5
II. Cold bend – see Section 38 for method	No damage shall result
III. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 65 for method	
Maximum elongation	50 percent
Maximum set	5 percent
IV. Insulation Resistance at 60.0°F (15.6°C)	See Table 14.6
V. Accelerated water absorption[b]	
Electrical method – see Section 40 for method	
Maximum relative permittivity after 24 h	4.0
Maximum increase in capacitance	1 – 14 d: 3.5 percent 7 – 14 d: 1.5 percent
Maximum stability factor after 14 d[c]	1.0 percent
Maximum stability factor difference[c]	1 – 14 d: 0.5 percent
VI. Relative permittivity – see Section 41 for method[d]	Maximum: 4.0
VII. Power factor – see Section 41 for method[d]	Maximum: 2.0 percent
VIII. Dry Electrical Test [e]	See Section 42

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

A copolymer (EPM) of ethylene and propylene.

A terpolymer (EPDM) of ethylene, propylene, and a small amount of nonconjugated diene.

A blend of EPM and EPDM.

[b] Not required for dry-locations cable (nonshielded 2400 V single-conductor cable insulated as indicated in column A or B of Table 15.3.

[c] Only one of these tests is required [see 40.1(d)].

[d] Not required for 2400 V or 5-kV cable.

[e] Required only for 105°C (221°F) cable.

Table 14.5
Physical properties of EP[a] insulation from 90°C (194°F) and 105°C (221°F) cables

Condition of specimens at time of measure	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	200 percent (2 inches or 50 mm)	700 lbf/in^2 or 4.83 MPa
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F) for 90°C cable or at 136.0 ±1.0°C (276.8 ±1.8°F) for 105°C cable	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of nonconjugated diene.

c) A blend of EPM and EPDM.

Table 14.6
Insulation resistance of EP[a] insulation from 90°C (194°F) and 105°C (221°F) cables

Property	Value
IV. Insulation resistance at 60°F (15.6°C)	
Insulation and individual non-conductive circuit-conductor jacket tested together – see Section 60 for method	
On jacketed nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column B of Table 15.3	Minimum K: 12,000 megohms based on 1000 conductor feet
On jacketed nonshielded wet-or-dry-locations 2400 V single-conductor cable insulated as indicated in column C of Table 15.3	
In nonshielded multiple-conductor cable insulated as indicated in Table 15.1 or Table 15.2 with a non-conductive jacket on each circuit conductor	
Insulation alone	
In nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column A or Table 15.3 – see Section 60 for method	Minimum K: 20,000 megohms based on 1000 conductor feet
In shielded single-conductor cable insulated as indicated in Table 15.1 or Table 15.2 – see Section 59 for method	or
In shielded multiple-conductor cable insulated as indicated in Table 15.1 or Table 15.2 – see Section 59 for method	Minimum K: 6100 megohms based on a conductor kilometer
In nonshielded multiple-conductor cable insulated as indicated in Table 15.1 or Table 15.2 without a non-conductive jacket on each circuit conductor – see Section 60 for method.	

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of nonconjugated diene.

c) A blend of EPM and EPDM.

Table 14.7
Properties of EPCV[a] insulation from 90°C (194°F) nonshielded 2400 V dry-locations cable

Property	Value
I. Physical properties – see Section 31 for method	See Table 14.8
II. Cold bend – see Section 38 for method	No damage shall result
III. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 65 for method	
Maximum elongation	50 percent
Maximum set	5 percent
IV. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 34 for method	
8 – 4/0 AWG conductors (round specimens)	25 percent
250 – 1000 kcmil conductors (flat, rectangular specimens)	15 percent
V. Insulation resistance at 60.0°F (15.6°C)	See Table 14.9

[a] EPCV designates a cross-linked compound whose characteristic constituent is a covulcanizate of ethylene propylene (EP) and polyethylene (PE).

Table 14.8
Physical properties of EPCV[a] insulation from 90°C (194°F) nonshielded 2400 V dry-locations cable

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	200 percent (2 inches or 50 mm)	1500 lbf/in^2 or 10.3 MPa
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

[a] EPCV designates a cross-linked compound whose characteristic constituent is a covulcanizate of ethylene propylene (EP) and polyethylene (PE).

Table 14.9
Insulation resistance of EPCV[a] insulation from 90°C (194°F) nonshielded 2400 V dry-locations cable

Property	Minimum value
V. Insulation resistance at 60°F (15.6°C)	
Insulation and individual non-conductive circuit-conductor jacket tested together – on jacketed nonshielded, dry-locations, 2400 V single-conductor cable insulated as indicated in column B of Table 15.3 – see Section 60 for method	Minimum K: 12,000 megohms based on 1000 conductor feet or Minimum K: 3650 megohms based on a conductor kilometer
Insulation in nonshielded dry-locations 2400 V single-conductor cable insulated as indicated in column A of Table 15.3 – see Section 60 for method	Minimum K: 20,000 megohms based on 1000 conductor feet or Minimum K: 6100 megohms based on a conductor kilometer

[a] EPCV designates a cross-linked compound whose characteristic constituent is a covulcanizate of ethylene propylene (EP) and polyethylene (PE).

Table 14.10
Properties of DREP (discharge-resistant EP[a]) insulation from 90°C (194°F) and 105°C (122°F) cables

Property	Value	
	5 – 25kv 90°C (194°F)	5 – 35 kv 105°C (221°F)
I. Physical properties – see Section 31 for method	See Table 14.5	
II. Cold bend – See Section 38 for method	No damage shall result	
III. Hot creep at 150.0 ±2.0°C (302.0 ±3.6°F) – see Section 65 for method		
Maximum elongation	30 percent	
Maximum set	5 percent	
IV. Insulation resistance at 60.0°F (15.6°C)	See Table 14.6	
V. Accelerated water absorption[b]		
Electrical method – see Section 40 for method		
Maximum relative permittivity after 24 h	4.0	

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Table 14.10 Continued

Property	Value	
Maximum increase in capacitance		
1 – 14 d	7.0 percent	3.5 percent
7 – 14 d	4.0 percent	1.5 percent
Maximum stability factor after 14 d[c]	1.0	
Maximum stability factor difference[c]	0.5	
VI. Relative permittivity – see Section 41 for method [d]	Maximum: 4.0	
VII. Power factor – see Section 41	Maximum: 2.0 percent	
VIII. Dry electrical test [e]	See Section 42	

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of non-conjugated diene.

c) A blend of EPM and EPDM.

[b] Not required for dry-locations cable (nonshielded 2400 V single conductor insulated as indicated in column B of Table 15.3.

[c] Only one of these tests is required [see 40.1(d)].

[d] Not required for 2400 V or 5 kV cable.

[e] Required only for 105°C (221°F) cable

Table 14.11
Physical properties of DREP (discharge-resistant EP[a]) insulation from 90°C (194°F) and 105°C (122°F) cables

Condition of specimens at time of measure	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	250 percent (2.5 inches or 60 mm)	550 lbf/in^2 or 3.79 MPa
Aged in full-draft circulating-air oven at: 121.0 ±1.0°C (249.8 ±1.8°F) for 90°C cable for 168 h	175 percent	75 percent of the result with unaged specimens
or 136.0 ±1.0°C (276.8 ±1.8°F) for 105°C cable for 168 h	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

[a] EP designates a cross-linked compound whose characteristic constituent is one of the following:

a) A copolymer (EPM) of ethylene and propylene.

b) A terpolymer (EPDM) of ethylene, propylene, and a small amount of non-conjugated diene.

c) A blend of EPM and EPDM.

15 Thicknesses

15.1 The maximum and minimum thicknesses at any point of the insulation shall comply with Table 15.1 or Table 15.2 (shielded single-conductor cable and shielded and nonshielded multiple-conductor cables) and the minimum average thickness and the minimum thickness at any point of the insulation shall comply with Table 15.3 (nonshielded single-conductor 2400 V cables) when determined as described in 15.2 (removal of bonded components damages the insulation) or 15.3 (insulation separable without being damaged).

15.2 In the case of a circuit conductor in which a bonded component (bonding to the insulation is required in 13.1 for conductor shielding and optional in 17.2 for extruded insulation shielding) cannot be removed without damage to the insulation, the thicknesses of the insulation are to be determined on a full cross section of the insulation produced by cutting a specimen of the finished conductor through perpendicular to its longitudinal axis. All measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The maximum and minimum thicknesses are to be measured directly and where an average thickness is needed (Table 15.3), the two are then to be averaged to determine the average thickness.

Table 15.1
Thicknesses, in mils, of XLPE, DREP, or EP insulation in 5 – 35 kV, shielded single- and multiple-conductor cable and of XLPE, EP, or DREP insulation in 2400 V, nonshielded multiple-conductor cable

Voltage rating of cable (phase-to-phase circuit voltage)	Conductor size (AWG or kcmil)	Insulation thickness (mils)					
		100 percent level[a]		133 percent level[a]		173 percent level[a]	
		Minimum at any point	Maximum at any point	Minimum at any point	Maximum at any point	Minimum at any point	Maximum at any point
2400	8 – 1000	85	120	–	–	–	–
	1001 – 2000	135	170	–	–	–	–
5000	8 – 1000	85	120	85	120	135	170
	1001 – 2000	135	170	135	170	135	170
5001 – 8000	6 – 1000	110	145	135	170	165	205
	1001 – 2000	165	205	165	205	210	250
8001 – 15000	2 – 1000	165	205	210	250	245	290
	1001 – 2000	210	250	210	250	245	290
15001 – 25000	1 – 2000	245	290	305	350	400	450
25001 – 28000	1 – 2000	265	310	330	375	425	475
28001 – 35000	1/0 – 2000	330	375	400	450	555	610

[a] The selection of the cable insulation level to be used is made on the basis of the fault current clearing times and other information as explained in the National Electrical Code (NEC) Table 310.64.

Table 15.2
Thicknesses, in mm, of XLPE, DREP, or EP insulation in 5 – 35 kV, shielded single- and multiple-conductor cable and of XLPE, EP, or DREP insulation in 2400 V, nonshielded multiple-conductor cable

Voltage rating of cable (phase-to-phase circuit voltage)	Conductor size (AWG or kcmil)	Insulation thickness (mm)					
		100 percent level[a]		133 percent level[a]		173 percent level[a]	
		Minimum at any point	Maximum at any point	Minimum at any point	Maximum at any point	Minimum at any point	Maximum at any point
2400	8 – 1000	2.16	3.05	–	–	–	–
	1001 – 2000	3.43	4.32	–	–	–	–
5000	8 – 1000	2.16	3.05	2.16	3.05	3.43	4.32
	1001 – 2000	3.43	4.32	3.43	4.32	3.43	4.32
5001 – 8000	6 – 1000	2.79	3.68	3.43	4.32	4.19	5.21
	1001 – 2000	4.19	5.21	4.19	5.21	5.33	6.35
8001 – 15000	2 – 1000	4.19	5.21	5.33	6.35	6.22	7.37
	1001 – 2000	5.33	6.35	5.33	6.35	6.22	7.37

Table 15.2 Continued on Next Page

Table 15.2 Continued

Voltage rating of cable (phase-to-phase circuit voltage)	Conductor size (AWG or kcmil)	Insulation thickness (mm)					
		100 percent level[a]		133 percent level[a]		173 percent level[a]	
		Minimum at any point	Maximum at any point	Minimum at any point	Maximum at any point	Minimum at any point	Maximum at any point
15001 – 25000	1 – 2000	6.22	7.37	7.75	8.89	10.2	11.4
25001 – 28000	1 – 2000	6.73	7.87	8.38	9.53	10.8	12.1
28001 – 35000	1/0 – 2000	8.38	9.53	10.2	11.4	14.1	15.5

[a] The selection of the cable insulation level to be used is made on the basis of the fault current clearing times and other information as explained in the National Electrical Code (NEC) Table 310.64.

15.3 The thicknesses of insulation from which all bonded and other components can be removed without damage to the insulation are to be determined as described in 15.2 (basic optical method) or by one of the following methods:

a) DIFFERENCE METHOD – Measurements are to be made by means of a machinist's micrometer caliper having a flat surface both on the anvil and on the end of the spindle and calibrated to read directly to at least 0.001 inch or 0.01 mm. All measurements are to be made on a length of the finished conductor from which all components over the insulation have been removed without damage to the insulation. The average thickness of the insulation is to be taken as 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 and the insulation shielding measured at the same point. The minimum thickness of the insulation is to be taken as the difference between a measurement (first measurement) made over the conductor and the conductor shielding plus the thinnest insulation wall, and the diameter over the conductor and the conductor shielding. The first measurement is to be made after slicing off the thicker side of the insulation. None of the thickness of the conductor shielding is to be included in the thickness of the insulation.

b) DIRECT MEASUREMENT – Measurements are to be made by means of the machinist's micrometer caliper described in (a) or by means of a dead-weight dial micrometer that exerts 10 ±2 gf or 0.10 ±0.02 N on a specimen through a flat, rectangular presser foot 0.078 inch by 0.375 inch or 1.98 mm by 9.52 mm. The anvil of the instrument is to be of the same dimensions as the presser foot. The instrument is to be calibrated as indicated in (a). The insulation is to be removed from a length of the finished conductor without damage to the insulation, and the maximum and minimum points are to be determined by direct measurement using the micrometer caliper or dial micrometer. The average of these determinations is to be taken as the average thickness of the insulation.

c) REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 15.2 or in (a) or (b) above are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 in or 0.001 mm is to be used. The insulation is to be removed from a length of the finished conductor without damage to the insulation and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The average of these determinations is to be taken as the average thickness of the insulation. The results of this optical procedure are to be taken as conclusive.

Table 15.3
Thicknesses of insulation in nonshielded single-conductor cables rated 2400 V

Size of conductor	Dry locations				Wet-or-dry-locations XLPE, DREP, or EP insulation with a non-conductive jacket over the insulation C	
	XLPE or EPCV insulation without any covering over the insulation A		XLPE, EPCV, DREP, or EP insulation with a non-conductive jacket over the insulation B			
	Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point
	mils					
8 – 4/0 AWG	110	99	90	81	125	113
213 – 500 kcmil	120	108	90	81	140	126
501 – 750	130	117	90	81	155	140
751 – 1000	130	117	90	81	155	140
	mm					
8 – 4/0 AWG	2.79	2.51	2.29	2.06	3.18	2.87
213 – 500 kcmil	3.05	2.74	2.29	2.06	3.56	3.20
501 – 750	3.30	2.97	2.29	2.06	3.94	3.56
751 – 1000	3.30	2.97	2.29	2.06	3.94	3.56

INSULATION SHIELDING

16 General

16.1 Insulation shielding, where required shall consist of both of the following elements:

a) A conductive nonmetallic covering (see 17.1 – 17.8) directly over and in intimate contact with the insulation, and

b) A nonmagnetic metal component (see 18.1) embedded in or directly over and in intimate contact with the conductive nonmetallic covering.

16.2 The insulation shielding on all of the individual conductors of a multiple-conductor cable shall be of the same physical makeup and construction.

17 Conductive Nonmetallic Covering

17.1 The conductive nonmetallic covering shall consist of a conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27 or, for 5-, 8-, or 15-kV cable, a conductive nonmetallic tape, or a conductive nonmetallic tape over a conductive nonmetallic coating. The covering shall be directly over and in intimate contact with the insulation. The covering shall enclose the insulation throughout the length of the circuit conductor. A supplementary conductive nonmetallic tape may be provided over a conductive extrusion. The covering shall be removable when the conductor is terminated or spliced (see marking requirement in 69.1).

17.2 An extruded covering that is not bonded to the insulation, a tape covering, and a coating-plus-tape covering shall be readily removable. An extruded covering may be bonded to the insulation (the means for removing a bonded covering from the insulation is not specified but typically is by means of a solvent, hot air, or a flame.) Extruded coverings with a stripping force of 3 – 24 lbf or 13.3 – 106.7 N or 1.36 – 10.9 kgf are not bonded. Bonded coverings have a stripping force greater than 24 lbf or 106.7 N or 10.9 kgf (see stripping-tension test in Section 33).

17.3 The volume resistivity of the finished extruded, tape, or coating-plus-tape covering taken as a unit shall comply with 46.1.

17.4 The properties of an extruded covering shall comply with Table 17.1 when specimens from the finished cable are prepared and tested as described in the paragraphs referenced in the table.

17.5 The thickness of an extruded covering shall not be less than indicated in Table 17.3 when measured as described in 17.6 (covering bonded to the insulation) or 17.7 (covering not bonded to the insulation).

17.6 The minimum thickness of an extruded covering that is bonded to the insulation is to be determined on a full cross section of the covering produced by cutting a specimen of the finished conductor through perpendicular to its longitudinal axis. All measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The minimum thickness is to be measured directly.

17.7 The minimum thickness of an extruded covering that is not bonded to the insulation is to be determined either optically as described in 17.6 or from measurements made on the covering removed from the finished conductor. In the latter case, direct measurements of the minimum thickness is to be made by means of a machinist's micrometer caliper having a flat surface both on the anvil and on the end of the spindle and calibrated to read directly to at least 0.001 inch or 0.01 mm.

17.8 Conductive tape may be of any convenient width, and shall be at least 2.5 mils or 0.06 mm in thickness at any point when removed from the finished conductor and measured using either of the following:

a) A dead-weight dial micrometer that exerts 10 ±2 gf or 0.10 ±0.02 N on a specimen through a flat, rectangular presser foot 0.078 inch by 0.375 inch or 1.98 mm by 9.52 mm and having a flat anvil of the same dimensions as the presser foot, or

b) A machinist's micrometer caliper having a flat surface both on the anvil and on the end of the spindle.

Each instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The tape shall be applied helically with an overlap of at least 10 percent of the tape width. The tape shall be applied either directly over the insulation or over a conductive nonmetallic coating on the insulation.

Table 17.1
Properties of extruded conductive covering

Property	Value(s)
I. Physical properties – see note [b] to Table 27.11 and Section 31 for method	See Table 17.2
II. Brittleness temperature by the Acceptance Impact Procedure B described in ASTM D 746 using five die-punched specimens that are 0.25 ±0.02 inch or 6.35 ±0.51 mm wide	Maximum –10°C (+14°F)
III. Cold bend – see Section 38 for method	No damage shall result

Table 17.2
Properties of extruded conductive covering

Condition of specimens at time of measurement	From cable in which the metal component of the insulation shielding is embedded in the extruded covering A		From cable in which the metal component of the insulation shielding is not embedded in the extruded covering B	
	Minimum ultimate elongation (1 inch or 25 mm bench marks)	Minimum tensile strength	Minimum ultimate elongation (1 inch or 25 mm bench marks)	Minimum tensile strength
Unaged	100 percent (1 inch or 25 mm)	1200 lbf/in^2 or 8.27 MPa	Not measured	Not measured
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F) for 90°C (194°F) cable, or at 136.0 ±1.0°C (276.8 ±1.8°F) for 105°C (221°F) cable	100 percent (1 inch or 25 mm)	85 percent of the result with unaged specimens	100 percent (1 inch or 25 mm)	Not measured
Specimens of 75°C (167°F) oil-resistant jacket from cable marked “oil resistant II” – see 70.1(h):	65 percent of the result with unaged specimens		Oil resistance is not applicable	
Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)				
Specimens of 60°C (140°F) oil-resistant jacket from cable marked “oil resistant I” – see 70.1(h)	65 percent of the result with unaged specimens		Oil resistance is not applicable	
Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)				

Table 17.3
Thicknesses of extruded conductive nonmetallic covering

Calculated minimum[c] diameter over insulation	On single-conductor cable in which the metal component of the insulation shielding is embedded in the extruded covering[a] A	In jacketed multiple-conductor cable in which the metal component of the insulation shielding is embedded in the extruded covering[b] B	In single- and multiple-conductor cable in which the metal component of the insulation shielding is not embedded in the extruded covering C
	Minimum thickness at any point	Minimum thickness at any point	Minimum thickness at any point
inches	mils		
0 – 0.700	60	24	24
Over 0.700 but not over 1.000	60	40	24
Over 1.000 but not over 1.500	64	40	24
Over 1.500 but not over 2.000	80	64	24
Over 2.000 but not over 2.500	90	64	24
mm	mm		
0 – 17.78	1.52	0.61	0.61
Over 17.78 but not over 25.40	1.52	1.02	0.61
Over 25.40 but not over 38.10	1.63	1.02	0.61
Over 38.10 but not over 50.80	2.03	1.63	0.61

Table 17.3 Continued on Next Page

Table 17.3 Continued

Calculated minimum[c] diameter over insulation	On single-conductor cable in which the metal component of the insulation shielding is embedded in the extruded covering[a]	In jacketed multiple-conductor cable in which the metal component of the insulation shielding is embedded in the extruded covering[b]	In single- and multiple-conductor cable in which the metal component of the insulation shielding is not embedded in the extruded covering
	A	B	C
	Minimum thickness at any point	Minimum thickness at any point	Minimum thickness at any point
Over 50.80 but not over 63.50	2.29	1.63	0.61

[a] Acceptable as the overall cable jacket.

[b] Acceptable as an individual jacket (conductive insulation covering service as a jacket as well as part of the insulation shielding) on the insulated conductor (see 19.1 – 19.4).

[c] The minimum diameter over the insulation is to be the sum of the minimum conductor diameter; twice the minimum thickness at any point of the conductor stress relief; and twice the minimum thickness at any point of the insulation.

18 Nonmagnetic Metal Component

18.1 The metal component shall be nonmagnetic, shall be electrically continuous throughout the length of the insulated conductor, and shall consist of one or a combination of the constructions detailed in Table 18.1.

Table 18.1
Construction of metal component of insulation shielding

Form	Material and dimensions[a]	Application	
		Manner	Placement throughout the length of the insulated conductor
Tape or tapes	Copper of any convenient width and at least 2.5 mils or 0.06 mm thick or Other nonmagnetic metal of any convenient width and of a thickness that results in a conductance at least that of copper that is 2.5 mils or 0.06 mm thick	Helically applied or Corrugated and longitudinally applied with an unspecified overlap	Directly over and in intimate contact with the conductive nonmetallic covering
Straps	Copper having an effective cross-sectional area of at least 5000 circular mils (0.004 square inch) per inch of diameter over the insulation or of at least 0.1 square millimeter per millimeter of diameter over the insulation	Helically or longitudinally applied	Directly over and in intimate contact with the conductive nonmetallic covering
Wires		Helically or longitudinally applied	Directly over and in intimate contact with the conductive nonmetallic covering
	or	Helically applied	Directly over and in intimate contact with the conductive nonmetallic covering
	Other nonmagnetic metal having an effective cross-sectional area that results in a conductance at least that of the copper mentioned above	Corrugated and longitudinally applied	Embedded (0.005 inch or 0.13 mm minimum thickness at any point) in extruded insulation shielding (see 17.2, 17.4, and 17.5) with none of the metal exposed at either the

Table 18.1 Continued on Next Page

Table 18.1 Continued

Form	Material and dimensions[a]	Application: Manner	Application: Placement throughout the length of the insulated conductor
			inner or outer surface of the extruded insulation shielding before and after the cold-bend test in 38.1
Wire[b] braid		Applied around the underlying construction	Directly over and in intimate contact with the conductive nonmetallic covering
Sheath	Smooth aluminum or lead sheath complying with 28.2 and 28.4 – 28.6 or Welded and corrugated aluminum, bronze, or copper sheath complying with 28.2, 28.3, 28.7, and 28.8 or Extruded and corrugated aluminum sheath complying with 28.2, 28.3, 28.9, and 28.10 The sheath in any form shall have an effective cross-sectional area that results in a conductance at least that of the copper wires or straps mentioned above	Tightly formed around the underlying construction	Directly over and in intimate contact with the conductive nonmetallic covering

[a] Additional conductance in the metal component may be necessary to meet circuit needs. This additional conductance is to be provided by adding additional area, by using metal of a higher conductivity, or be using more than one of the constructions described.

[b] In a wire braid, the individual wires shall not be smaller in diameter than 6.3 mils or 0.160 mm (34 AWG).

JACKET ON INDIVIDUAL CIRCUIT CONDUCTORS FOR MULTIPLE-CONDUCTOR CABLE

19 Details

19.1 A jacket shall be provided on each shielded circuit conductor intended for use in a multiple-conductor cable that does not have any overall covering. A jacket is acceptable but is not required on each shielded or nonshielded circuit conductor intended for use in a multiple-conductor cable that has an overall covering. A jacket is required on each nonshielded single-conductor cable, other than the construction covered in column A of Table 15.3, intended for assembly into a multiple-conductor cable that does not have any overall covering.

19.2 A circuit-conductor jacket that is used, whether required or not, shall be of one of the non-conductive materials indicated in Table 27.1 (see 14.4 for the long-term evaluation of a non-conductive jacket material not named in Table 27.1 or not complying with the short-term tests specified in 27.2), or shall be one of the conductive materials covered in Section 17 where the functions of insulation shielding and circuit-conductor jacket are combined. A circuit-conductor jacket shall not have defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. A non-conductive circuit-conductor jacket that is used shall be applied directly over the insulation of a nonshielded circuit conductor and directly over the shielding of a shielded circuit conductor. The insulation or shield shall be completely covered and shall be well centered in the non-conductive jacket throughout the length of the circuit conductor. A non-conductive circuit-conductor jacket shall be removable without damage to any part(s) of the cable beneath the jacket.

19.2.1 For multiconductor cables with an overall non-metallic covering, a semiconducting covering consisting of a tape or extruded material, or both, may be used over the nonmagnetic metallic component of the shielding of individual conductors of multiconductor cables. The minimum thickness of the tape shall be 0.008 inches (0.2 mm). The surface of the semiconducting tape or layer shall be identified in accordance with 69.1. This covering is not intended to be considered a jacket.

19.3 Specimens prepared from samples of a circuit-conductor jacket taken from the finished cable shall exhibit properties that comply with Table 17.1 (conductive material), or the applicable table referenced in Table 27.1 (non-conductive jacket) when tested as described in Section 31.

19.4 The minimum thickness at any point of a non-conductive circuit-conductor jacket shall not be less than indicated in Table 19.1 (for a multiple-conductor cable having an overall covering) or in Table 27.18 (for a multiple-conductor cable not having any overall covering) when measured as described in 19.5 (basic optical method) or 19.6 (direct measurement) or, in case of doubt, by the referee method described in 19.7. For thicknesses of a conductive circuit-conductor jacket (functions of insulation shielding and circuit-conductor jacket combined), see 17.5, Table 17.3, and the notes to Table 17.3.

Table 19.1
Thicknesses of non-conductive jacket on each shielded or nonshielded circuit conductor in a multiple-conductor cable having an overall covering and insulated in the thicknesses indicated in Table 15.1 or Table 15.2

Calculated diameter under jacket		mils	mm
inches	mm	Minimum thickness at any point	Minimum thickness at any point
0 – 0.700	0 – 17.78	25	0.64
Over 0.700 but not over 1.500	Over 17.78 but not over 38.10	45	1.14
Over 1.500 but not over 2.500	Over 38.10 but not over 63.50	70	1.78
Over 2.500	Over 63.50	–	–

[a] The insulation thickness used in calculating the diameter under the jacket is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

19.5 BASIC OPTICAL METHOD – Measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The non-conductive circuit-conductor jacket is to be removed from a length of the finished conductor without damage to the jacket. The maximum and minimum points are to be measured directly.

19.6 DIRECT MEASUREMENT – Measurements are to be made by means of a dead-weight pin-gauge dial micrometer that exerts 25 ±2 gf or 0.25 ±0.02 N on a specimen through a flat, rectangular presser foot measuring 0.043 inch by 0.312 inch or 1.09 mm by 7.92 mm. The pin is to be 0.437 inch or 11.10 mm long and 0.020 inch or 0.51 mm in diameter. The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The non-conductive circuit-conductor jacket is to be removed from a short length of the finished conductor without damage to the jacket. A 3/8-inch or 10-mm slice is to be cut from the center of the resulting hollow length of the jacket with each cut perpendicular to the longitudinal axis of the hollow length. The maximum and minimum points are to be determined by direct measurement with the entire length of the pin contacting the inside surface of the jacket during each measurement.

19.7 REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 19.5 or 19.6 are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 inch or 0.001 mm is to be used. The non-conductive circuit-conductor jacket is to be removed from a length of the finished conductor without damage to the jacket and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The average of these determinations is to be taken as the average thickness of the jacket. The results of this optical procedure are to be taken as conclusive.

OPTICAL-FIBER MEMBER(S)

20 Construction

20.1 An overall jacket shall be part of and shall enclose each individual optical-fiber member. A member may include one or more glass fibers with their requisite individual coverings and may also include one or more strength elements. A member shall not include any metal or other conductive material but, otherwise, neither the jacket nor the underlying construction of the member is specified.

ASSEMBLY OF MULTIPLE-CONDUCTOR CABLE

21 Optical-Fiber Member(s)

21.1 One or more optical-fiber members(s) may be included in a multiple-conductor cable. Optical-fiber members may be grouped with or without electrical conductors. Optical-fiber members shall be cabled individually or as a group with the same direction and length of lay as the electrical conductors. In the performance of the cable, each optical-fiber member is to be considered as a filler. A group of optical-fiber members with or without any electrical conductor(s) in it shall not include any non-current-carrying metal parts such as a metal strength element or a metal vapor barrier, and shall not include any other conductive parts. A non-conductive strength element may be included; its construction is not specified.

22 Circuit Conductors

22.1 A multiple-conductor cable shall contain two or more circuit conductors, each of which shall be insulated and all of which shall be of the same size. All of the circuit conductors shall be insulated with the same material in one of the thicknesses indicated in Table 15.1 or Table 15.2, or 15.3. All shall have the same insulation level. All shall be shielded (see 16.2) or nonshielded and all shall be individually jacketed or not jacketed in accordance with 19.1. All shall have the same temperature, wet or dry, and voltage ratings. All of the circuit conductors in a given cable shall be of the same metal (see 23.7 for grounding-conductor metal).

22.2 The circuit conductors shall be cabled with a length of lay that is not greater than indicated in Table 22.1. The direction of lay may be changed at intervals throughout the length of the cable. The intervals need not be uniform. In a cable in which the direction of lay is reversed:

a) Each area in which the lay is right- or left-hand for several (typically 10) complete twists (full 360° cycles) shall have the insulated conductors cabled with a length of lay that is not greater than indicated in Table 22.1, and

b) The length of each lay-transition zone (oscillated section) between these areas of right- and left-hand lay shall not exceed 1.8 times the maximum length of lay indicated in Table 22.1.

If the direction of lay is not reversed in a cable containing layers of conductors, the outer layer of conductors shall have a left-hand lay and the direction of lay for the inner layers of conductors is not specified. If the direction of lay is not reversed in a single-layer cable, the conductors shall have a left-hand lay.

22.3 A left-hand lay is defined as a counterclockwise twist away from the observer.

Table 22.1
Length of lay of circuit conductors

Number of circuit conductors in cable	Maximum length of lay	
	With an overall covering on cable	Without an overall covering on cable
2	30 times conductor diameter[a]	60 times conductor diameter[a]
3	35 times conductor diameter[a]	
4	40 times conductor diameter[a]	
5 or more	15 times the calculated diameter over the assembly of circuit conductors but, in a multiple-layer cable, the length of lay of the circuit conductors in each of the inner layers in not specified (governed by the construction of the cabling machine)	

[a] "Conductor diameter" is the calculated diameter over one finished circuit conductor. The insulation thickness used in calculating the diameter is to be the specified average thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

23 Grounding Conductor

23.1 A grounding conductor is not required in a triplex or other multiple-conductor cable that does not have an overall non-conductive jacket or an overall metal covering and in which the circuit conductors comply with column A, B, or C of Table 15.3 (nonshielded single-conductor cable) or are individually shielded (see Table 1.2). Any grounding conductor that is used in a multiple-conductor cable shall be a single covered or bare conductor of the size indicated in column A (copper) or a single covered conductor of the size indicated in column B (aluminum) of Table 23.1 for MV-90 or Table 23.2 for MV-105, for the size of circuit conductors used in the cable shall be unsectioned (in one location). The covering on a grounding conductor is to be for corrosion or another protective purpose only and shall not be credited as insulation. The covering shall be colored as indicated in 68.4 and 68.5.

23.2 Single or multiple-conductor cable having interlocked aluminum armor or multiple-conductor cable with interlocked steel armor shall contain a grounding conductor that is not smaller in size or higher in resistance than indicated in Table 23.1 or Table 23.2 for the size of circuit conductors used in the cable. See 23.6.

23.3 Cable having a corrugated or smooth metal sheath with a resistance greater than indicated in one of the last four columns of Table 23.1 or Table 23.2 for the size of circuit conductors used in the cable shall contain a grounding conductor that is of a size such that the measured resistance (see 23.8) of the grounding conductor in parallel with the sheath is not higher than indicated in one of the last four columns of Table 23.1 or Table 23.2 for the size of the circuit conductors used in the cable. See 23.6.

23.4 Cable having a corrugated or smooth metal sheath with a resistance equal to or lower than indicated in one of the last four columns of Table 23.1 or Table 23.2 for the size of the circuit conductors used in the cable may contain a grounding conductor. See 23.6.

23.5 Cable having an overall non-conductive jacket but not having any metal sheath or interlocked armor may contain a grounding conductor. See 23.6.

23.6 Whether required or not, any grounding conductor provided in a multiple-conductor cable covered in 23.2, 23.3, 23.4, or 23.5 shall be bare and shall be cabled with the circuit conductors as a single conductor (one section) or divided into two or more equal parts with each such part or section cabled separately. The grounding conductor shall not be smaller in overall size than 14 AWG if of copper or 12 AWG if of aluminum. No part of a sectioned grounding conductor shall be smaller than 14 AWG if of copper or 12 AWG if of aluminum.

23.7 A grounding conductor shall not be laid straight and shall not be distributed helically (concentric) in a multiple-conductor cable. A grounding conductor of copper is appropriate in a multiple-conductor cable containing aluminum circuit conductors and not having an overall covering. In a multiple-conductor cable having an overall covering, a grounding conductor shall be of the same metal as the circuit conductors, except that a copper grounding conductor may be used with aluminum circuit conductors.

23.8 RESISTANCE – The resistance of the smooth or corrugated metal sheath, and any grounding conductor taken in parallel with the metal sheath, is to be determined by placing a sample of the finished cable in a wooden, V-shaped trough having stud-type wire connectors at the ends (spaced 10 ft or 3048 mm between centers) as shown in Figure 23.1. The sample of cable under test is not to be under any mechanical tension in the trough. The ends of the metal sheath and any grounding conductor are to be secured firmly in the wire connectors. The grounding conductor is to be folded around each end of the metal sheath and gripped against the sheath by the wire connectors. The wires of a stranded grounding conductor are to be spread out somewhat to result in maximum contact. Leads are to be brought out to a Kelvin double-bridge ohmmeter that has a range of 0.001 – 11 ohms and is accurate to within 2 percent of the value read. The resistance of the smooth or corrugated metal sheath and any grounding conductor is to be read directly in ohms.

Figure 23.1

Apparatus for measuring resistance of metal sheath and any grounding conductor

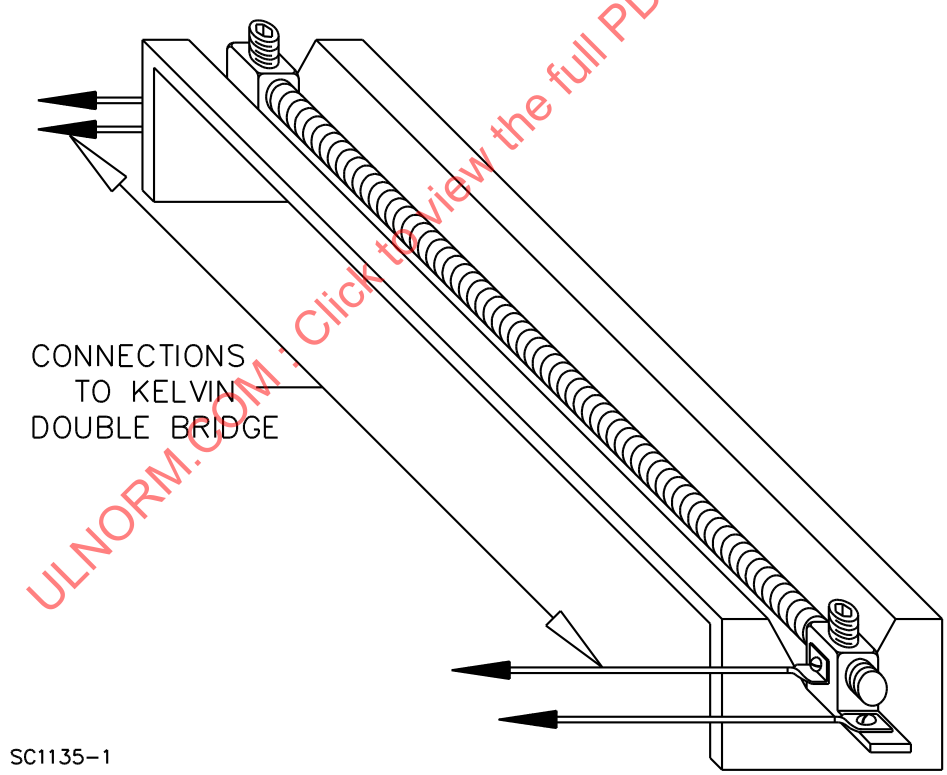


Table 23.1
Smallest acceptable grounding conductor in multiple-conductor Type MV-90 cable

Size of circuit conductors AWG or kcmil		Grounding conductor						Maximum direct-current resistance of corrugated or smooth sheath in cable without a grounding conductor, and of the parallel combination of grounding conductor and sheath in cable having a corrugated or smooth sheath of higher resistance than indicated in these 4 columns			
		Copper			Aluminum			20°C (68°F)		25°C (77°F)	
		Smallest AWG size of un-sectioned grounding conductor A	Smallest total cross-sectional area of sectioned grounding conductor[a]		Smallest AWG size of unsectioned grounding conductor B	Smallest total cross-sectional area of sectioned grounding conductor[a]					
Copper	Aluminum		cmil[b]	mm^2		cmil[c]	mm^2	Ohms based on 1000 feet of sheath	Ohms based on 1000 meters of sheath	Ohms based on 1000 feet of sheath	Ohms based on 1000 meters of sheath
8	8 – 6	8	16180	8.20	6	25715	13.03	0.6795	2.230	0.6929	2.274
6 – 2	4 – 1/0	6	25715	13.03	4	40905	20.73	0.4276	1.403	0.4359	1.430
1 – 2/0	2/0 – 250	4	40905	20.73	2	65033	32.95	0.2689	0.8820	0.2742	0.8993
3/0 – 250	300 – 400	3	51568	26.14	1	82016	41.56	0.2132	0.6996	0.2175	0.7133
300 – 400	450 – 600	2	65033	32.95	1/0	103488	52.42	0.1691	0.5548	0.1724	0.5657
450 – 600	750 – 900	1	82016	41.56	2/0	130438	66.08	0.1340	0.4398	0.1367	0.4485
750 – 1000	1000	1/0	103488	52.42	3/0	164444	83.31	0.1063	0.3487	0.1084	0.3556

[a] Resistance is the criterion of size but the area in this column is included for use if area is more convenient. A conductor having less than the tabulated area is acceptable if the resistance of the conductor complies with one of the last four columns.

[b] 0.98 times the nominal area in circular mils of the AWG conductor size in column A.

[c] 0.98 times the nominal area in circular mils of the AWG conductor size in column B.

Table 23.2
Smallest acceptable grounding conductor in multiple-conductor Type MV-105 cable

Size of circuit conductors AWG or kcmil		Grounding conductor						Maximum direct-current resistance of corrugated or smooth sheath in cable without a grounding conductor, and of the parallel combination of grounding conductor and sheath in cable having a corrugated or smooth sheath of higher resistance than indicated in these 4 columns			
		Copper			Aluminum			20°C (68°F)		25°C (77°F)	
		Smallest AWG size of un-sectioned grounding conductor A	Smallest total cross-sectional area of sectioned grounding conductor[a]		Smallest AWG size of unsec-tioned grounding conductor B	Smallest total cross-sectional area of sectioned grounding conductor[a]					
Copper	Aluminum		cmil[b]	mm^2		cmil[c]	mm^2	Ohms based on 1000 feet of sheath	Ohms based on 1000 meters of sheath	Ohms based on 1000 feet of sheath	Ohms based on 1000 meters of sheath
8	8 – 6	8	16180	8.20	6	25715	13.03	0.6795	2.230	0.6929	2.274
6 – 2	4 – 1/0	6	25715	13.03	4	40905	20.73	0.4276	1.403	0.4359	1.430
1 – 2/0	2/0 – 4/0	4	40905	20.73	2	65033	32.95	0.2689	0.8820	0.2742	0.8993
3/0 – 4/0	250 – 350	3	51568	26.14	1	82016	41.56	0.2132	0.6996	0.2175	0.7133
250 – 350	400 – 500	2	65033	32.95	1/0	103488	52.42	0.1691	0.5548	0.1724	0.5657
400 – 500	550 – 750	1	82016	41.56	2/0	130438	66.08	0.1340	0.4398	0.1367	0.4485
550 – 750	800 – 1000	1/0	103488	52.42	3/0	164444	83.31	0.1063	0.3487	0.1084	0.3556
800 – 1000	–	2/0	130438	66.08	4/0	207368	105.1	0.08432	0.2766	0.08598	0.2820

[a] Resistance is the criterion of size but the area in this column is included for use if area is more convenient. A conductor having less than the tabulated area is acceptable if the resistance of the conductor complies with one of the last four columns.

[b] 0.98 times the nominal area in circular mils of the AWG conductor size in column A.

[c] 0.98 times the nominal area in circular mils of the AWG conductor size in column B.

24 Fillers

24.1 Fillers shall be used where necessary to give a substantially circular cross section to a completed multiple-conductor cable that has an overall covering. Fillers may be separate or may be integral with any non-conductive jacket. Fillers shall be cabled with the conductors or, if applicable to the construction, may be in the center of the cable. Fillers shall be of non-conductive nonmetallic material but otherwise are not specified.

25 Assembly Covering

25.1 In a multiple-conductor cable on which there is a metal sheath (of any variety) or interlocked armor (with or without a supplementary jacket over the sheath or armor), the assembly of circuit conductors (with or without a jacket on each), any grounding conductor, and any fillers shall be enclosed either in a non-conductive jacket that complies with 25.3 – 25.5 or by a tape separator that complies with 25.6.

25.2 In a multiple-conductor cable on which there is an overall jacket but no metal sheath or interlocked armor, the assembly of circuit conductors, any grounding conductor, and any fillers may be enclosed in a nonmetallic separator or binder whose material and construction are not specified.

25.3 An assembly jacket shall be of one of the materials (non-conductive) indicated in Table 27.1. An assembly jacket shall not have any defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. An assembly jacket shall be applied directly over the underlying assembly. The underlying assembly shall be completely covered and shall be well centered in the assembly jacket.

25.4 Specimens prepared from samples of an assembly jacket taken from the finished cable shall exhibit properties that comply with the applicable one of the tables referenced in Table 26.1 when tested as described in Section 31.

25.5 The minimum thickness at any point of an assembly jacket shall not be less than indicated in Table 29.1 when measured as described in 25.7 (basic optical method) or 25.8 (direct measurement) or, in case of doubt, by the referee optical method described in 25.9.

25.6 A separator shall consist of a rubber-filled cloth tape or a treated-paper, polyester, polypropylene, or similar tape. The tape shall be applied to keep any grounding conductor from physical contact with the metal sheath or armor but, otherwise, the construction of the tape and the manner of its application are not specified. An open binder or skeleton arrangement is not acceptable for this purpose.

25.7 BASIC OPTICAL METHOD – Measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The non-conductive assembly jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be measured directly.

25.8 DIRECT MEASUREMENT – Measurements are to be made by means of a dead-weight pin-gauge dial micrometer that exerts 25 ±2 gf or 0.25 ±0.02 N on a specimen through a flat, rectangular presser foot measuring 0.043 inch by 0.312 inch or 1.09 mm by 7.92 mm. The pin is to be 0.437 inch or 11.10 mm long and 0.020 inch or 0.51 mm in diameter. The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The non-conductive assembly jacket is to be removed from a short length of the finished cable without damage to the jacket. A 3/8-inch or 10-mm slice is to be cut from the center of the resulting hollow length of the jacket with each cut perpendicular to the longitudinal axis of the hollow length. The maximum and minimum points are to be determined by direct measurement with the entire length of the pin contacting the inside surface of the jacket during each measurement.

25.9 REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 25.7 or 25.8 are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 inch or 0.001 mm is to be used. The non-conductive assembly jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. The results of this optical procedure are to be taken as conclusive.

OVERALL COVERING(S)

26 General

26.1 An overall covering(s) shall be provided on each single-conductor and multiple-conductor cable in accordance with Table 26.1. The finished cable shall in each case be round.

Table 26.1
Overall coverings

Cable	Acceptable covering(s)			
	Type	**Material(s)**	**Properties**	**Thicknesses**
nonshielded single-conductor cables insulated in the thicknesses indicated in columns B and C of Table 15.3	Non-conductive jacket	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 27.20
Shielded single-conductor cables	Option 1: Conductive nonmetallic insulation covering that is part of shielding	Conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27	Column A of Table 17.2	Column A of Table 17.3
	Option 2: Non-conductive jacket over shielding	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 27.18
	Option 3: Nonmagnetic metal covering as part of shielding	a		
	Option 4: Supplementary non-conductive jacket	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 29.1
	over			
	Nonmagnetic metal covering that is part of shielding	a		
	Option 5: Nonmagnetic metal covering	a		
	over			
	Non-conductive jacket that is over shielding	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 27.18
	Option 6: Nonmagnetic metal covering that is part of shielding	a		
	over			

Table 26.1 Continued on Next Page

Table 26.1 Continued

Cable	Acceptable covering(s)			
	Type	**Material(s)**	**Properties**	**Thicknesses**
	Conductive nonmetallic insulation covering that is part of shielding	Conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27	Column A of Table 17.2	Column A of Table 17.3
	Option 7: Supplementary non-conductive jacket	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 29.1
	over			
	Nonmagnetic metal covering that is part of shielding	a		
	over			
	Conductive nonmetallic insulation covering that is part of shielding	Conductive extrusion of any insulation or jacketing material mentioned in Section 14 or 27	Column A of Table 17.2	Column A of Table 17.3
	Option 8: Supplementary non-conductive jacket	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 29.1
	over			
	Nonmagnetic metal covering	a		
	over			
	Non-conductive jacket that is over shielding	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 27.18
Multiple-conductor cable in which 2400 V nonshielded circuit conductors insulated in the thicknesses indicated in Table 15.1 or Table 15.2 are used with or without a non-conductive jacket of the thicknesses indicated in Table 19.1 on each circuit conductor	Option A: Non-conductive jacket	Any in Table 27.1	Table 27.2 – Table 27.14 as applicable	Table 27.18
Multiple-conductor cable in which shielded circuit conductors insulated in the thicknesses indicated in Table 15.1 or Table 15.2 are used that are not individually jacketed or have an individual non-conductive jacket of the thicknesses indicated in Table 19.1	Option B: Metal sheath or steel or aluminum armor	Section 28		
	over			
	Assembly covering consisting of non-conductive jacket	Any in Table 27.1	Table 27.2 – Table 27.20 as applicable	Table 29.1
	or			
	Tape separator	25.6		
	Option C: Supplementary non-conductive jacket over option B	Any in 27.1	Table 27.2 – Table 27.20 as applicable	Table 29.1
Multiple-conductor cable in which shielded circuit conductors insulated in the thicknesses indicated in Table 15.1 or Table 15.2 are used and have	None required but any used shall comply with option A, B, or C above			

Table 26.1 Continued on Next Page

Table 26.1 Continued

Cable	Acceptable covering(s)			
	Type	Material(s)	Properties	Thicknesses
either an individual jacket of the thicknesses indicated in column A of Table 17.3 or an individual non-conductive jacket of the thicknesses indicated in Table 27.18				
Multiple-conductor cable assembled of nonshielded single- conductor cables that are as indicated in column A, B, or C of Table 15.3	None acceptable			

[a] Smooth or corrugated metal sheath or interlocked aluminum armor complying with Section 28 (interlocked steel armor is not acceptable because it is magnetic).

27 Jacket

27.1 MATERIAL AND APPLICATION – An overall jacket shall be of one of the non-conductive materials indicated in Table 27.1 (see 14.4 for the long-term evaluation of a non-conductive jacket material not named in Table 27.1 or not complying with the short-term tests specified in 27.1), or shall be of one of the conductive materials covered in Section 17 where the functions of the insulation shielding and overall single-conductor cable jacket are combined. An overall jacket shall not have any defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. An overall jacket shall be applied directly over the underlying assembly or over the optional binder or separator mentioned in 25.2. The underlying assembly shall be completely covered and shall be well centered in the jacket. Impressions of the underlying assembly in the outer surface of the overall jacket shall not show depressions caused by unfilled spaces beneath the overall jacket.

Table 27.1
Non-conductive jacket

Jacket material[a]	Table of properties requirements
CP	Table 27.2
CPE	Table 27.4
NBR/PVC	Table 27.6
Neoprene	Table 27.8
PE[b]	Table 27.10
PVC	Table 27.12
TPE	Table 27.14

[a] An overall jacket of material that is generically different from any material covered in this table is acceptable if applicable for the use. A pull-out test is to be part of the evaluation. In the test, an outlet bushing is to be secured to the finished cable as intended using the tightening torque tabulated below. Then, 50 lbf or 22.7 kgf is to be exerted for 5 min along the longitudinal axis of the bushing to tend to pull the cable out of the bushing. To be acceptable, the cable is not to move more than 1/8 inch or 3 mm in the bushing.

[b] PE jacket is acceptable only for 90°C (194°F) cable.

Trade size of fitting in inches	Tightening torque		
	lbf-inch	N-m	kgf-m
3/8	200	22.6	2.30
1/2	300	33.9	3.46
3/4	500	56.5	5.76
1	700	79.1	8.06
1-1/4	1000	113	11.5
1-1/2	1200	136	13.8
2 and larger	1600	181	18.4

27.2 PROPERTIES – Specimens prepared from samples of an overall jacket taken from the finished cable shall exhibit properties that comply with Table 17.1 (conductive material), or with the applicable table referenced in Table 27.1 (non-conductive jacket) when tested as described in Section 31.

27.3 THICKNESSES – The minimum thickness at any point of a non-conductive jacket shall not be less than indicated in Table 27.18 (overall jacket on shielded single-conductor cable or on multiple-conductor cable) and the average thickness of the jacket and the minimum thickness at any point of the jacket shall not be less than indicated in Table 27.20 (overall jacket on nonshielded single-conductor 2400 V cables) when measured as described in 27.4 (basic optical method) or 27.5 (direct measurement) or, in case of doubt, by the referee optical method described in 27.6. For the thicknesses of a conductive overall jacket (functions of insulation shielding and the overall cable jacket combined), see 17.5, Table 17.3, and the notes to Table 17.3.

27.4 The thickness of a non-conductive extruded-to-fill jacket that fills the spaces between the wires on a wire-shielded single-conductor cable with individual wires 60 mils or greater (1.52 mm or greater) in diameter shall not be less than shown in Table 27.19. The jacket material shall be in contact with the insulation shielding and shall strip freely.

Table 27.2
Properties of non-conductive CP[a] jacket

Property	Value
I. Physical Properties – see Section 31 for method	See Table 27.3
II. Set using 1-inch or 25-mm bench marks – Maximum at room temperature using unaged specimens – see Section 36 for method	30 percent
III. Cold bend – see Section 38 for method	No damage shall result

[a] CP designates a cross-linked compound whose characteristic constituent is chlorosulfonated polyethylene.

Table 27.3
Physical properties of non-conductive CP[a] jacket

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1500 lbf/in^2 or 10.3 MPa
Specimens of jacket from 90°C (194°F) cable: Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of jacket from 105° (221°F) cable: Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked “oil resistant II” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked “oil resistant I” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] CP designates a cross-linked compound whose characteristic constituent is chlorosulfonated polyethylene.

Table 27.4
Properties of non-conductive CPE[a] jacket

Property	Value	
	Thermoplastic	Thermoset
I. Physical properties – see Section 31 for method	See Table 27.5	
II. Cold bend– see Section 38 for method	No damage shall result	
III. Heat distortion – Maximum reduction in thickness at 121 ±1.0°C (249.8 ±1.8°F) – see Section 35 for method	25 percent	Test not applicable
IV. Set using 1-inch or 25-mm bench marks – Maximum at room temperature using unaged specimens– see 36.1 for method	Test not applicable	30 percent

[a] CPE designates a thermoplastic or cross-linked compound whose characteristic constituent is chlorinated polyethylene.

Table 27.5
Physical properties of non-conductive CPE[a] jacket

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)		Minimum tensile strength	
	Thermoplastic	Thermoset	Thermoplastic	Thermoset
Unaged	150 percent (1-1/2 inches or 38 mm)	250 percent (2-1/2 inches or 62.5 mm)	1400 lbf/in^2 or 9.65 MPa	1500 lbf/in^2 or 10.3 MPa or
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	50 percent of the result with unaged specimens	60 percent of the result with unaged specimens	85 percent of the result with unaged specimens	
Specimens of 75°C (167°F) oil-resistant jacket from cable marked “oil resistant II” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens		65 percent of the result with unaged specimens	
Specimens of 60°C (140°F) oil-resistant jacket from cable marked “oil resistant I” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens		50 percent of the result with unaged specimens	

[a] CPE designates a thermoplastic or cross-linked compound whose characteristic constituent is chlorinated polyethylene.

Table 27.6
Properties of non-conductive NBR/PVC[a] jacket

Property	Value
I. Physical properties – see Section 31 for method	See Table 27.7
II. Set using 1-inch or 25-mm bench marks – Maximum at room temperature using unaged specimens – see 36.1 for method	30 percent
III. Cold bend – see Section 38 for method	No damage shall result

[a] NBR/PVC designates a cross-linked compound whose characteristic constituents are acrylonitrile butadiene rubber and polyvinyl chloride.

Table 27.7
Physical properties of non-conductive NBR/PVC[a] jacket

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1500 lbf/in^2 or 10.3 MPa
Specimens of jacket from 90°C (194°F) cable: Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of jacket from 105°C (221°F) cable: Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked “oil resistant II” – see 70.1(h):		

Table 27.7 Continued on Next Page

Table 27.7 Continued

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked “oil resistant I” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of result with unaged specimens
[a] NBR/PVC designates a cross-linked compound whose characteristic constituents are acrylonitrile butadiene rubber and polyvinyl chloride.		

Table 27.8
Properties of non-conductive neoprene[a] jacket

Property	Value
I. Physical properties – see Section 31 for method	See Table 27.9
II. Set using 1-inch or 25-mm bench mark – Maximum at room temperature using unaged specimens – see 36.1 for method	20 percent
III. Cold bend – see Section 38 for method	No damage shall result
[a] Neoprene designates a cross-linked compound whose characteristic constituent is polychloroprene.	

Table 27.9
Physical properties of non-conductive neoprene[a] jacket

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	250 percent (2-1/2 inches or 62.5 mm)	1500 lbf/in^2 or 10.3 MPa
Specimens of jacket from 90°C (194°F) cable: Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of jacket from 105°C (221°F) cable: Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked “oil-resistant II” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked “oil-resistant I” – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens
[a] Neoprene designates a cross-linked compound whose characteristic constituents is polychloroprene.		

Table 27.10
Properties of non-conductive PE[a] jacket

Property	Value
I. Physical properties – see note [b] to Table 27.11 and Section 30 for method	See Table 27.11
II. Heat distortion – Maximum reduction in thickness at 90.0 ±1.0°C (194.0 ±1.8°F) – see Section 35 for method	25 percent
III. Cold bend – see Section 38 for method	No damage shall result
IV. Environmental cracking – see Section 43 for method	No cracks shall result

[a] PE designates a compound whose characteristic constituent is thermoplastic polyethylene having a nominal density of 0.910 – 0.925 g/cm^3 and a high molecular weight. The compound may be filled or unfilled.

Table 27.11
Physical properties of non-conductive PE[a] jacket

Condition of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)[b]	Minimum tensile strength[b]
Unaged	350 percent (3-1/2 inches or 87.5 mm)	1400 lbf/in^2 or 9.65 MPa
Aged in a full-draft circulating-air oven for 48 h at 100.0 ±1.0°C (212.0 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked “oil-resistant II” – see 70.1(h):		
Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked “oil-resistant I” – see 70.1(h):		
Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] PE designates a compound whose characteristic constituent is thermoplastic polyethylene having a nominal density of 0.910 – 0.925 g/cm^3 and a high molecular weight. The compound may be filled or unfilled.

[b] PE is to be tested at a speed of 20 ±1 in/min or 500 ±25 mm/min.

Table 27.12
Properties of non-conductive PVC[a] jacket

Property	Acceptable value
I. Physical properties – see Section 31 for method	See Table 27.13
II. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 35 for method	50 percent
III. Heat shock – see 37.1 for method	No cracking shall result
IV. Cold bend – see Section 38 for method	No damage shall result

[a] PVC designates a thermoplastic compound whose characteristic constituent is polyvinyl chloride or a copolymer of vinyl chloride and vinyl acetate.

Table 27.13
Physical properties of non-conductive PVC [a] jacket

Conditions of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	100 percent (1 inch or 25 mm)	1500 lbf/in^2 or 10.3 MPa
Specimens of jacket from 90°C (194°F) cable: Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of jacket from 105°C (221°F) cable: Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	50 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens
[a] PVC designates a thermoplastic compound whose characteristic constituent is polyvinyl chloride or a copolymer of vinyl chloride and vinyl acetate.		

Table 27.14
Properties of non-conductive TPE[a] jacket

Property	Value
I. Physical properties – see Section 31 for method	See Table 27.15
II. Heat distortion – Maximum reduction in thickness at 150.0 ±1.0°C (327.6 ±1.8°F) – see Section 35 for method	50 percent
III. Heat shock – see 37.1 for method	No cracking shall result
IV. Cold bend – see Section 38 for method	No damage shall result
[a] TPE designates an extensible compound whose characteristic constituent is a thermoplastic elastomer.	

Table 27.15
Physical properties of non-conductive TPE[a] jacket

Conditions of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	200 percent (2 inch or 50 mm)	1200 lbf/in^2 or 8.27 MPa
Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

Table 27.15 Continued on Next Page

Table 27.15 Continued

Conditions of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 168 h at 60.0 ±1.0°C (140.0 ±1.8°F)	75 percent of the result with unaged specimens	75 percent of the result with unaged specimens

[a] TPE designates an extensible compound whose characteristic constituent is a thermoplastic elastomer.

Table 27.16
Properties of non-conductive XL[a] jacket

Property	Value
I. Physical properties – see Section 31 for method	See Table 27.13
II. Heat distortion – Maximum reduction in thickness at 121.0 ±1.0°C (249.8 ±1.8°F) – see Section 35 for method	50 percent

[a] XL designates a thermoset compound whose characteristic constituent is XLPE (cross-linked polyethylene), XLPVC (cross-linked polyvinyl chloride), XLEVA (cross-linked ethylene vinyl acetate), or blends thereof. It is appropriate to accomplish the cross-linking either chemically or by irradiation.

Table 27.17
Physical properties of non-conductive XL[a] jacket

Conditions of specimens at time of measurement	Minimum ultimate elongation (1-inch or 25-mm bench marks)	Minimum tensile strength
Unaged	100 percent (1 inch or 25 mm)	1500 lbf/in^2 or 10.3 MPa
Specimens of jacket from 90°C (194°F) cable: Aged in a full-draft circulating-air oven for 240 h at 100.0 ±1.0°C (212.0 ±1.8°F)	70 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of jacket from 105°C (221°F) cable: Aged in a full-draft circulating-air oven for 168 h at 121.0 ±1.0°C (249.8 ±1.8°F)	70 percent of the result with unaged specimens	70 percent of the result with unaged specimens
Specimens of 75°C (167°F) oil-resistant jacket from cable marked "oil resistant II" – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 60 d at 75.0 ±1.0°C (167.0 ±1.8°F)	65 percent of the result with unaged specimens	65 percent of the result with unaged specimens
Specimens of 60°C (140°F) oil-resistant jacket from cable marked "oil resistant I" – see 70.1(h): Aged in oil (see 480.5 of UL 1581) for 96 h at 100.0 ±1.0°C (212.0 ±1.8°F)	50 percent of the result with unaged specimens	50 percent of the result with unaged specimens

[a] XL designates a thermoset compound whose characteristic constituent is XLPE (cross-linked polyethylene), XLPVC (cross-linked polyvinyl chloride), XLEVA (cross-linked ethylene vinyl acetate), or blends thereof. It is appropriate to accomplish the cross-linking either chemically or by irradiation.

Table 27.18
Thicknesses of non-conductive jacket:
1) overall jacket on shielded single-conductor cable
2) circuit-conductor jacket on each shielded circuit conductor in a multiple-conductor cable not having any overall covering
3) overall jacket on multiple-conductor cable having an overall covering

Calculated diameter under jacket[a]		Minimum thickness at any point	Minimum thickness at any point
inches	mm	mils	mm
0 – 0.700	0 – 17.78	55	1.40
Over 0.700 but not over 1.500	Over 17.78 but not over 38.10	70	1.78
Over 1.500 but not over 2.500	Over 38.10 but not over 63.50	100	2.54
Over 2.500	Over 63.50	125	3.17

[a] The insulation thickness used in calculating the diameter under the jacket is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

Table 27.19
Thicknesses[a] of extruded-to-fill jacket

Calculated diameter under jacket		Minimum thickness at any point	Maximum thickness at any point	Minimum thickness at any point	Maximum thickness at any point
inches	mm	mils		mm	
1 – 1.500	0 – 38.10	45	80	1.14	2.05
Over 1.500	Over 38.10	70	120	1.78	3.05

[a] All thickness values are measured over the wires.

[b] The insulation thickness used in calculating the diameter under the jacket is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

Table 27.20
Thicknesses of non-conductive jacket on nonshielded single-conductor cables rated 2400 V

Size of conductor	Dry-locations cables with XLPE, EPCV, DREP, or EP insulation in the thicknesses indicated in column B of Table 15.3 B		Wet-or-dry-locations cable with XLPE, DREP, or EP insulation in the thicknesses indicated in column C of Table 15.3 C	
	Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point
	mils			
8 – 6 AWG	30	24	80	64
4 – 2/0	45	36	80	64
3/0 – 4/0	65	52	95	76
213 – 500 kcmil	65	52	110	88
501 – 750	65	52	125	100
751 – 1000	65	52	125	100
	mm			

Table 27.20 Continued on Next Page

Table 27.20 Continued

Size of conductor	Dry-locations cables with XLPE, EPCV, DREP, or EP insulation in the thicknesses indicated in column B of Table 15.3 B		Wet-or-dry-locations cable with XLPE, DREP, or EP insulation in the thicknesses indicated in column C of Table 15.3 C	
	Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point
8 – 6 AWG	0.76	0.61	2.03	1.63
4 – 2/0	1.14	0.91	2.03	1.63
3/0 – 4/0	1.65	1.32	2.41	1.93
213 – 500 kcmil	1.65	1.32	2.79	2.24
501 – 750	1.65	1.32	3.18	2.54
751 – 1000	1.65	1.32	3.18	2.54

27.5 BASIC OPTICAL METHOD – Measurements are to be made by means of an optical device that is accurate to at least 0.001 inch or 0.01 mm. The non-conductive overall or supplementary jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be measured directly and, where the average thickness is needed (Table 27.20), averaged to determine the average thickness.

27.6 DIRECT MEASUREMENT – Measurements are to be made by means of a dead-weight pin-gauge dial micrometer that exerts 25 ±2 gf or 0.25 ±0.02 N on a specimen through a flat, rectangular presser foot measuring 0.043 inch by 0.312 inch or 1.09 mm by 7.92 mm. The pin is to be 0.437 inch or 11.10 mm long and 0.043 inch or 1.09 mm in diameter. The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm. The non-conductive overall or supplementary jacket is to be removed from a short length of the finished cable without damage to the jacket. A 3/8-inch or 10-mm slice is to be cut from the center of the resulting hollow length of the jacket with each cut perpendicular to the longitudinal axis of the hollow length. The maximum and minimum points are to be determined by direct measurement with the entire length of the pin contacting the inside surface of the jacket during each measurement. Where an average thickness is needed (Table 27.20), the average of these determinations is to be taken as the average thickness of the jacket.

27.7 REFEREE OPTICAL METHOD – If the results obtained via the procedure described in 27.5 or 27.6 are in doubt, a micrometer microscope or other optical instrument calibrated (fine) to read directly to at least 0.0001 inch or 0.001 mm is to be used. The non-conductive overall or supplementary jacket is to be removed from a length of the finished cable without damage to the jacket and the maximum and minimum points are to be determined by direct measurement using the fine-calibration optical instrument. Where an average thickness is needed (Table 27.20), the average of these determinations is to be taken as the average thickness of the jacket. The results of this optical procedure are to be taken as conclusive.

28 Metal Covering

28.1 GENERAL – A metal covering shall consist of one of the following:

a) A smooth sheath complying with 28.4 – 28.6.

b) A welded and corrugated sheath complying with 28.7 and 28.8.

c) An extruded and corrugated sheath complying with 28.9 and 28.10.

d) Interlocked armor complying with 28.11 – 28.20.

28.2 The sheath, or the strip forming the armor, shall be continuous throughout the length of the cable. A sheath shall not have flaws that affect its integrity – that is, a sheath shall not have any weld openings, cracks, splits, foreign inclusions, or the like. The strip from which armor is formed may be spliced (see 28.13) but there shall not be any cut or broken ends. In a multiple-conductor cable, a metal covering shall be applied over the assembly covering (non-conductive assembly jacket or a tape separator) required in 25.1. In a shielded single-conductor cable, a continuous smooth or corrugated metal covering shall constitute the nonmagnetic metal component of the insulation shielding and shall comply with the conductance and application requirements in Table 18.1 (applied directly over the conductive nonmetallic covering portion of the insulation shielding). A metal covering shall not be used on a nonshielded single-conductor cable.

28.3 The number of corrugations per unit length of a welded or extruded corrugated metal sheath is not specified but is to be judged on the basis of the performance of the finished cable in the tests specified in this standard.

28.4 SMOOTH METAL SHEATH – A smooth metal sheath shall be of an aluminum-base alloy having a copper content of 0.40 percent or less, of commercially pure lead, or of an alloyed lead. The sheath shall be tightly formed around the underlying cable.

28.5 The average thickness and the minimum thickness at any point of the smooth sheath shall not be less than indicated in Table 28.1 (lead) or Table 28.2 (aluminum). The thicknesses of the smooth sheath are to be determined by means of a machinist's micrometer caliper that has a hemispherical surface on the anvil, has a flat surface on the end of the spindle, and is calibrated to read directly to at least 0.001 inch or 0.01 mm. The spindle shall be round.

28.6 A smooth sheath that does not comply with the requirements in this standard may be stripped from the entire length of the cable and the cable may be resheathed.

28.7 WELDED AND CORRUGATED METAL SHEATH – A welded and corrugated metal sheath shall be of an aluminum-base alloy having a copper content of 0.40 percent or less, of bronze, or of electrolytic copper. The sheath shall be tightly formed around the underlying cable and shall be welded and corrugated.

28.8 The minimum thickness at any point of the unformed metal tape from which the welded and corrugated sheath is made shall not be less than indicated in Table 28.3. The thickness of the unformed tape is to be determined by means of a machinist's micrometer caliper having an anvil and spindle that are round and are not larger than 0.200 inch or 5.1 mm in diameter, with flat surfaces on each.

28.9 EXTRUDED AND CORRUGATED METAL SHEATH – An extruded and corrugated metal sheath shall be of an aluminum-base alloy having a copper content of 0.40 percent or less. The sheath shall be tightly formed around the underlying cable.

28.10 The minimum thickness at any point of the unformed metal tube from which the extruded and corrugated sheath is made shall not be less than indicated in Table 28.3 when determined as indicated in the second sentence of 28.8.

28.11 INTERLOCKED ARMOR – Armor shall consist of interlocked steel or aluminum strip and shall comply with 28.2 and 28.11 – 28.19. Dimensions of the metal strip shall comply with 28.20.

28.12 The strip shall be made of steel or of an aluminum-base alloy with a copper content of 0.40 percent or less. Steel strip shall be protected against corrosion by a coating of zinc on all surfaces, including edges and splices. The coating on each surface shall be evenly distributed, shall adhere firmly at all points, and shall be smooth and free from blisters and all other defects that can diminish the protective value of the coating.

28.13 The steel or aluminum strip shall be uniform in width, thickness, and cross section and shall not have any burrs, sharp edges, pits, scars, cracks, or other flaws that can damage the underlying cable or any supplementary jacket. Splices shall not materially increase the width or thickness of the strip nor shall they lessen the mechanical strength of the strip or adversely affect the formed armor.

28.14 Zinc-coated steel strip shall have a tensile strength of not less than 40,000 lbf/in^2 or 276 MPa and not more than 70,000 lbf/in^2 or 483 MPa. The tensile strength shall be determined on longitudinal specimens consisting of the full width of the strip when practical and otherwise on a straight specimen slit from the center of the strip. The test shall be made prior to application of the strip to the cable.

Table 28.1
Thicknesses of smooth lead sheath

Calculated diameter under lead[a]	Lead over which there is no supplementary jacket		Lead over which there is a supplementary jacket	
	Minimum thickness at any point	Maximum thickness at any point	Minimum thickness at any point	Maximum thickness at any point
inches	mils			
0 – 0.425	40	75	40	75
Over 0.425 but not over 0.700	60	95	50	85
Over 0.700 but not over 1.050	70	105	65	100
Over 1.050 but not over 1.500	85	135	75	110
Over 1.500 but not over 2.000	100	150	85	135
Over 2.000 but not over 3.000	115	170	100	150
Over 3.000	125	185	115	170
mm	mm			
0 – 10.80	1.02	1.91	1.02	1.91
Over 10.80 but not over 17.30	1.52	2.41	1.27	2.16
Over 17.30 but not over 26.70	1.78	2.67	1.65	2.54
Over 26.70 but not over 38.10	2.16	3.43	1.91	2.79
Over 38.10 but not over 50.80	2.54	3.81	2.16	3.43
Over 50.80 but not over 76.20	2.92	4.32	2.54	3.81
Over 76.20	3.18	4.70	2.92	4.32

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

Table 28.2
Thicknesses of smooth aluminum sheath with or without a supplementary jacket over the sheath

Calculated diameter under aluminum		Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point
inches	mm	mils		mm	
0 – 0.400	0 – 10.16	35	32	0.89	0.81
Over 0.400 but not over 0.740	Over 10.16 but not over 18.80	45	41	1.14	1.04
Over 0.740 but not over 1.050	Over 18.80 but not over 26.67	55	50	1.40	1.27
Over 1.050 but not over 1.300	Over 26.67 but not over 33.02	65	59	1.65	1.50
Over 1.300 but not over 1.550	Over 33.02 but not over 39.37	75	68	1.90	1.73
Over 1.550 but not over 1.800	Over 39.37 but not over 45.72	85	77	2.16	1.96

Table 28.2 Continued on Next Page

Table 28.2 Continued

Calculated diameter under aluminum		Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point
inches	mm	mils		mm	
Over 1.800 but not over 2.050	Over 45.72 but not over 52.07	95	86	2.41	2.18
Over 2.050 but not over 2.300	Over 52.07 but not over 58.42	105	95	2.67	2.41
Over 2.300 but not over 2.500	Over 58.42 but not over 64.77	115	104	2.92	2.64
Over 2.550 but not over 2.800	Over 64.77 but not over 71.12	125	113	3.18	2.87
Over 2.800 but not over 3.050	Over 71.12 but not over 77.47	135	122	3.43	3.10
Over 3.050 but not over 3.300	Over 77.47 but not over 83.82	145	131	3.68	3.33
Over 3.300 but not over 3.550	Over 83.82 but not over 90.17	155	140	3.94	3.56
Over 3.550 but not over 3.800	Over 90.17 but not over 96.52	165	149	4.19	3.78
Over 3.800 but not over 4.050	Over 96.52 but not over 102.9	175	158	4.45	4.01
Over 4.050	Over 102.9	–	–	–	–

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

Table 28.3
Minimum thickness at any point of unformed metal tape from which corrugated sheath is welded or extruded

Metal	Calculated diameter under sheath		Thickness of unformed metal tape	
	inches	mm	mils	mm
Aluminum	0 – 2.180	0 – 55	22	0.56
	Over 2.180 but not over 3.190	Over 55 but not over 81	29	0.74
	Over 3.190 but not over 4.200	Over 81 but not over 107	34	0.87
Bronze or electrolytic copper	0 – 2.365	0 – 60	17	0.43
	Over 2.365 but not over 3.545	Over 60 but not over 90	21	0.53
	Over 3.545 but not over 4.200	Over 90 but not over 107	25	0.64

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

28.15 Zinc-coated steel strip shall have an elongation of not less than 10 percent in 10 inches or not less than 10 percent in 254 millimeters. The elongation shall be determined as the permanent increase in length of a marked section of the strip (originally 10 inches or 254 mm in length) measured after the specimen has fractured. The test shall be made prior to application of the strip to the cable.

28.16 Unformed zinc-coated steel strip shall comply with the test for weight of zinc coating described in 51.1 – 51.7.

28.17 Finished zinc-coated steel strip, prior to being applied to the cable, shall have a zinc coating that remains adherent without flaking or spalling when the strip is subjected to a 180° bend over a mandrel that is 1/8 inch or 3.2 mm in diameter. The zinc coating is to be considered as complying with this requirement if, when the strip is bent around the specified mandrel, the coating does not flake and none of it can be removed from the strip by rubbing with the fingers.

28.18 Neither loosening or detachment during the adherence test nor superficial (small) particles of zinc formed by mechanical polishing of the surface of the zinc-coated steel strip is to constitute reason for rejection.

28.19 Unformed and formed zinc-coated steel strip shall comply with the copper sulphate test of the zinc coating described in Copper Sulphate Test of Zinc Coating on Steel Strip for and from Steel Armor, Section 50.

28.20 The width of unformed aluminum strip or of unformed zinc-coated steel strip shall not be greater than indicated in Table 28.4. The minimum thickness at any point of the formed metal strip removed from the finished cable shall not be less than indicated in Table 28.4 when measured by means of a machinist's micrometer caliper having an anvil and spindle that are round and are not larger than 0.020 inch or 5.1 mm in diameter, with flat surfaces on each.

Table 28.4
Dimensions of metal strip

Calculated diameter under armor[a]	Maximum width of unformed strip[b]	Minimum thickness at any point of the formed strip removed from the finished cable	
		Steel	Aluminum
inches	**mils**		
0 – 0.500	500	17	22
Over 0.500 but not over 1.000	750	17	22
Over 1.000 but not over 1.500	875	17	22
Over 1.500 but not over 2.000	875	22	27
Over 2.000	1000	22	27
mm	**mm**		
0 – 12.7	12.7	0.43	0.55
Over 12.7 but not over 25.4	19.0	0.43	0.56
Over 25.4 but not over 38.1	22.2	0.43	0.56
Over 38.1 but not over 50.8	22.2	0.56	0.69
Over 50.8	25.4	0.56	0.69

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

[b] The tolerances for the width of steel strip are plus 10 mils and minus 5 mils or plus 0.2 mm and minus 0.1 mm. The tolerances for the width of aluminum strip are plus and minus 10 mils or plus and minus 0.2 mm.

29 Supplementary Jacket over Metal Covering

29.1 A supplementary jacket is required over a metal sheath or armor on a cable that is marked [see 73.1 (a), (b), (c), and (d)] for direct burial. A supplementary jacket is not required over a metal sheath or armor on other cables. When used, a supplementary jacket shall consist of one of the materials indicated in Table 27.1 that has properties that comply with 27.2 (see 14.4 for the long-term evaluation of a non-conductive jacket material not named in Table 27.1 or not complying with the short-term tests specified in 27.2). A supplementary jacket shall not have defects (bubbles, open spots, rips, tears, cuts, or foreign material) that are visible with normal or corrected vision without magnification. A supplementary jacket shall be tight and shall be applied directly over the sheath or armor. The sheath or armor shall be completely covered and shall be well centered in the supplementary jacket. Impressions of the sheath corrugations or of the armor convolutions in the outer surface of a supplementary jacket shall not show depressions caused by unfilled spaces beneath the supplementary jacket.

29.2 The average thickness of a supplementary jacket and the minimum thickness at any point of a supplementary jacket shall not be less than indicated in Table 29.1 when measured as described in 27.4 (basic optical method) or 27.5 (direct measurement) or, in case of doubt, by means of the referee method described in 27.6.

Table 29.1
Thicknesses of supplementary jacket over a metal sheath or armor and thickness of non-conductive assembly jacket under metal covering on multiconductor cable

Calculated diameter under jacket[a]	Jacket over or under smooth metal sheath		Jacket over or under corrugated metal sheath or interlocked armor	
	Minimum average thickness	Minimum thickness at any point	Minimum average thickness	Minimum thickness at any point
inches	mils			
0 – 0.750	50	35	50	35
Over 0.750 but not over 1.500	65	46	50	35
Over 1.500 but not over 2.250	80	56	60	42
Over 2.250 but not over 3.000	95	67	75	52
Over 3.000	110	77	85	60
mm	mm			
0 – 19.05	1.27	0.89	1.27	0.89
Over 19.05 but not over 38.10	1.65	1.17	1.27	0.89
Over 38.10 but not over 57.15	2.03	1.42	1.52	1.07
Over 57.15 but not over 76.20	2.41	1.70	1.90	1.32
Over 76.20	2.79	1.96	2.16	1.52

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

PERFORMANCE

30 Test or Examination for Integrity and Continuity of Non-conductive Jacket Over Insulation Shielding or Over a Metal Sheath or Armor

30.1 A visual examination is specified in 30.2 for jackets for which a spark test is inappropriate. Otherwise, the integrity and continuity of non-conductive jacket over insulation shielding or over a metal sheath or over armor shall be demonstrated by the finished jacket withstanding, without electrical breakdown, the application of a 50, 60, 100, 400, 1000, 3000, or 4000 Hz essentially sinusoidal rms test potential of the magnitude indicated in Table 30.1. The a-c spark test is to be made as described in 30.3 – 30.11. One hundred percent of production shall be tested by the cable manufacturer at the cable factory.

30.2 The following finished jackets shall be examined for physical defects (bubbles, open spots, rips, tears, cuts, and foreign material) that are visible with normal or corrected vision without magnification:

a) A conductive jacket combining the functions of insulation shielding and overall single-conductor jacket.

b) An overall jacket of non-conductive neoprene of any dielectric strength.

c) An overall jacket of any non-conductive material having a dielectric strength too low to withstand the spark potential specified in Table 30.1.

d) An overall jacket (of any non-conductive material) applied over an assembly jacket of any material or over a polyester, polypropylene, or similar non-conductive binder tape having a dielectric strength greater than that of the overall jacket.

The visual examination that is required after the jacket is applied serves this purpose and need not be repeated.

30.3 A spark tester shall include a voltage source, an electrode, a voltmeter, a fault-signal device or system, and the necessary electrical connections. The ability of the equipment to comply with the requirements in 30.4 – 30.10 shall be certified at least annually by an accredited independent calibration service or its equivalent, such as checking the test potential with a voltmeter whose calibration is traceable. Calibration shall be traceable to a National Institute of Standards and Technology (USA) Standard or to other national physical measures recognized as equivalent by NIST.

30.4 The voltage source of a spark tester shall maintain the test voltage indicated in Table 30.1 under all normal conditions of leakage current. The voltage source shall not be connected to more than one electrode.

30.5 The electrode shall be of a link-chain or bead-chain or other acceptable type and shall make intimate contact throughout its entire length with the surface of the jacketed construction being tested.

30.6 The bottom of the metal electrode enclosure shall be U- or V-shaped, the chains shall have a length appreciably greater than the depth of the enclosure, and the width of the trough shall be approximately 1-1/2 inches or 40 mm greater than the diameter of the largest-diameter construction that is being tested.

30.7 For a bead-chain electrode, the longitudinal and transverse spacings of the chains and the diameter of each bead shall comply with Table 30.2.

Table 30.1
A-C spark-test potential in kilovolts for a non-conductive jacket over insulation shielding, a metal sheath, or armor

Specified average thickness of jacket		Jacket[a] of CP, thermoset CPE, or NBR/PVC	Jacket[b] of PE, thermoplastic CPE, or PVC
mils	mm		
25	0.64	1.0	2.0
30	0.76	1.5	2.5
45	1.14	2.0	4.0
50	1.27	2.0	4.5
60	1.52	2.5	5.5
65	1.65	2.5	6.0
75	1.90	3.0	6.5
80	2.03	3.0	7.0
85	2.16	3.5	7.5
95	2.41	4.0	8.5
110	2.79	4.5	10.0
140	3.56	5.5	12.5

[a] For a thermoset jacket of a thickness that is not shown, the test voltage is to be calculated on the basis of 40 kilovolts per inch of jacket thickness or 1.575 kilovolts per millimeter of jacket thickness, rounded to the nearest 0.5 kV.

[b] For a thermoplastic jacket of a thickness that is not shown, the test voltage is to be calculated on the basis of 90 kilovolts per inch of jacket thickness or 3.543 kilovolts per millimeter of jacket thickness, rounded to the nearest 0.5 kV.

Table 30.2
Maximum center-to-center spacings of bead chains

Diameter of a bead[a]		Longitudinal spacing[a]		Transverse spacing[a]			
				Chains staggered		Chains not staggered	
inch	mm	inch	mm	inch	mm	inch	mm
3/16	5.0	1/2	13	1/2	13	3/8	10
3/32	2.5	The chains shall be staggered and shall touch one another in the longitudinal and transverse directions.					

[a] A diameter and spacings other than indicated are acceptable if investigation shows that the chains contact an equal or greater area of the outer surface of the insulated conductor.

30.8 The electrode shall be provided with an earth-grounded metal screen or another guard that protects operating personnel against electric shock from the electrode and associated parts.

30.9 The voltmeter shall be connected to the circuit to indicate the actual test potential at all times.

30.10 The spark-test equipment shall include a light, counter, or other device or system that gives a visible signal in the event of a fault. When a fault is detected, the signal shall be maintained until the indicator is reset manually.

30.11 The length of the electrode is not specified, but the rate of speed at which the jacketed construction travels through the electrode shall result in every point on the jacketed construction being in contact with the electrode for not less than a total of 18 positive and negative crests of the supply voltage (the equivalent of 9 full cycles of the supply voltage). The maximum speed of the jacketed construction is to be determined by means of whichever of the following formulas is applicable:

feet per minute = 5/9 × frequency in hertz × electrode length in inches,

or

meters per minute = 1/150 × frequency in hertz × electrode length in millimeters.

For convenience, Table 30.3 shows the formulas for each of the frequencies mentioned in 29.1.

Table 30.3
Formula for maximum speed of jacketed construction in terms of electrode length L

Nominal supply frequency in hertz	Formula for feet per minute (L in inches)	Formula for millimeters per minute (L in millimeters)
50	$27.8L_{in}$	$0.333L_{mm}$
60	$33.3L_{in}$	$0.400L_{mm}$
100	$55.6L_{in}$	$0.667L_{mm}$
400	$222L_{in}$	$2.67L_{mm}$
1000	$556L_{in}$	$6.67L_{mm}$
3000	$1667L_{in}$	$20.0L_{mm}$
4000	$2222L_{in}$	$26.7L_{mm}$

30.12 The metal component of the insulation shielding or the metal sheath or armor of the jacketed construction and the conductor or conductors shall be earth-grounded during the spark test. An earth-ground connection shall be made at either or both the pay-off and take-up reels. In any case, a reel at which an earth-ground connection is made shall be bonded directly to the earth ground on the transformer or other voltage source in the spark tester.

31 Physical Properties Tests

31.1 The methods of preparation of samples, of selection and conditioning of specimens, and of making the measurements and calculations for tensile strength and elongation of extruded materials that are employed as conductor shielding, conductor insulation, insulation shielding, and jackets are to be as indicated (beginning with 400.1) under the heading PHYSICAL PROPERTIES TESTS OF INSULATION AND JACKET in UL 1581. All specimens shall be die-cut; tubular specimens shall not be used. Specific limits for individual materials are in Table 13.3 (conductor shielding), Table 14.1 – Table 14.4 (insulation), Table 17.1 and Table 17.2 (insulation shielding), and Table 27.2 – Table 27.15 (jackets).

32 Corrosion of Uncoated Copper Conductors

32.1 Uncoated copper conductors are to be removed from one unaged specimen of the finished cable and from one specimen aged at the elevated temperature for the length of time indicated in Table 13.3 for the ultimate-elongation test of the conductor-shielding material used in the cable. None of the two specimens of the uncoated copper shall show any evidence of corrosion in a close visual examination with normal or corrected vision without magnification. Normal oxidation or discoloration that is not caused by the conductor-shielding material is to be disregarded.

33 Adhesion (Stripping-Tension) Test of Extruded Insulation Shielding

33.1 The tension necessary to remove extruded insulation shielding from the insulation shown in Table 14.1 and Table 14.4 shall not be less than 3 lbf or 13.3 N or 1.36 kgf when samples from the finished cable are tested as described in 33.2 – 33.5. This requirement does not apply to insulation in Table 14.10. Removal of the shielding shall not damage the insulation and the insulation shall not retain any conductive material that cannot readily be removed.

33.2 This test is to be made on conductors from finished cable that contains insulation shielding whose conductive nonmetallic covering consists of an extrusion that is in contact with the insulation shown in Table 14.1 and Table 14.4. On each of three samples of the conductor (s) from such cable, the metal component of the insulation shielding and any jacket over it are to be removed.

33.3 Two parallel longitudinal cuts 1/2 inch or 13 mm apart and not less than 12 inches or 305 mm long are to be made through the extruded insulation shielding at one end of each sample starting at the end of the sample. Each sample is then to be rotated 180° and two additional, identical cuts are to be made starting from the same end. Starting tabs are to be made by peeling back both of the two resulting 1/2-inch or 13-mm strips from the starting end of each sample for a distance of 2 inches or 50 mm.

33.4 A sample is to be held securely at both of its ends. The free end of one of the starting tabs is to be gripped firmly so that the 1/2-inch or 13-mm strip can be pulled at an angle of 90° to the longitudinal axis of the conductor. The strip is to be peeled from the insulation at a rate of approximately 1/2 in/s or 13 mm/s for a distance of not less than 10 inches or 254 mm. The angle of pull is to be maintained as close as possible to 90° throughout the test. The tension necessary to remove the strip is to be monitored continuously and the minimum value is to be recorded.

33.5 The test is to be repeated with the second strip on the first sample. If neither of the following occur with either of the two strips on the first sample, the extruded insulation shielding is acceptable and the two remaining samples need not be tested:

a) The minimum peeling tension is less than 3 lbf or 13.3 N or 1.36 kgf.

b) The insulation is damaged by the peeling.

If (a) or (b) occurs, the test is to be repeated on each of the two remaining samples for a total of four additional strips tested. The extruded insulation shielding is not acceptable if any of the four additional strips experience (a) or (b).

34 Deformation Test of EPCV or XLPE Insulation

34.1 EPCV or XLPE insulation (the insulation plus the conductor shielding in the case of conductors that are too small to provide for flat, rectangular specimens) from finished cable shall not decrease more in thickness than the following percentage (this is indicated for the conductor size and round or flat specimen style in Table 14.7 (IV) (for EPCV) or in Table 14.1 (IV) (for XLPE) when specimens are subjected to the load indicated in Table 34.1 while being maintained at a temperature of 121.0 ±1.0°C (249.8 ±1.8°F):

Round specimens with conductor in place from 8 – 4/0 AWG conductors	25 percent maximum distortion
Flat, rectangular specimens from 250 – 1000 kcmil conductors	15 percent maximum distortion

Table 34.1
Specimen load

Size of conductor	Load[a] exerted on a specimen by the foot of the rod[a]	
	gf	N
8 AWG	500	4.90
7 – 1	750	7.35
1/0 – 4/0	1000	9.81
250 – 2000 kcmil	2000	19.61

[a] The specified load is not the weight to be added to each rod in the test apparatus but rather the total of the weight added and the weight of the rod. Because the weight of the rod varies from one apparatus to another, specifying the exact weight to be added to a rod to achieve the specified load on a specimen is impractical in all cases except for an individual apparatus.

34.2 Finished XLPE-insulated circuit conductors are to be removed from the finished cable, and any insulation shielding and other coverings over the insulation are to be removed without damage to the insulation.

34.3 The diameter D_1 over the XLPE insulation and the conductor shielding on each of five 1-inch or 25-mm specimens of 8 – 4/0 AWG circuit conductors is to be measured to the nearest 0.001 inch or 0.01 mm. In each case, the measurement is to be made at a marked position by means of a dead-weight dial micrometer whose presser foot puts a load of 85 ±3 gf or 0.84 ±0.02 N or 3.0 ±0.1 ozf on the specimen. The presser foot is to have a flat, round face whose diameter is 0.250 ±0.010 inch or 6.4 ±0.2 mm. The anvil of the instrument is to be round, is to be at least 1.5 inches or 38 mm in diameter, and is to be parallel to the face of the presser foot. In each case, the diameter d over the conductor is to be measured by means of the same dial micrometer. The original thickness T_1 of the insulation and conductor shielding is then to be calculated to the nearest 0.001 inch or 0.01 mm from the following formula.

$$T_1 = \frac{D_1 - d}{2}$$

34.4 For 250 – 2000 kcmil circuit conductors, five samples approximately 8 inches or 200 mm long are to be prepared with a thickness of 0.050 ±0.010 inch or 1.27 ±0.25 mm, with both surfaces smooth. From each of these samples, a flat, rectangular test specimen of the insulation 1 inch long and 9/16 inch wide or 25 mm by 14 mm is to be prepared. At a marked position, the original thickness T_1 of each of these specimens of insulation is to be measured to the nearest 0.001 inch or 0.01 mm by means of the dead-weight dial micrometer described in 34.3. The entire surface of the presser foot is to be in contact with the rectangular specimen during measurement.

34.5 The apparatus and test method are to be as described in 560.3 – 560.7 of UL 1581.

35 Deformation Test of Non-conductive Thermoplastic Jackets

35.1 Each circuit-conductor, assembly, overall, and supplementary jacket that is of a non-conductive thermoplastic material and is taken from the finished cable shall not decrease more in thickness than the following percentage (this and the test temperature are indicated for the particular material in the applicable properties table) when specimens are subjected to a load of 2000 gf or 19.61 N while being maintained at the following temperature:

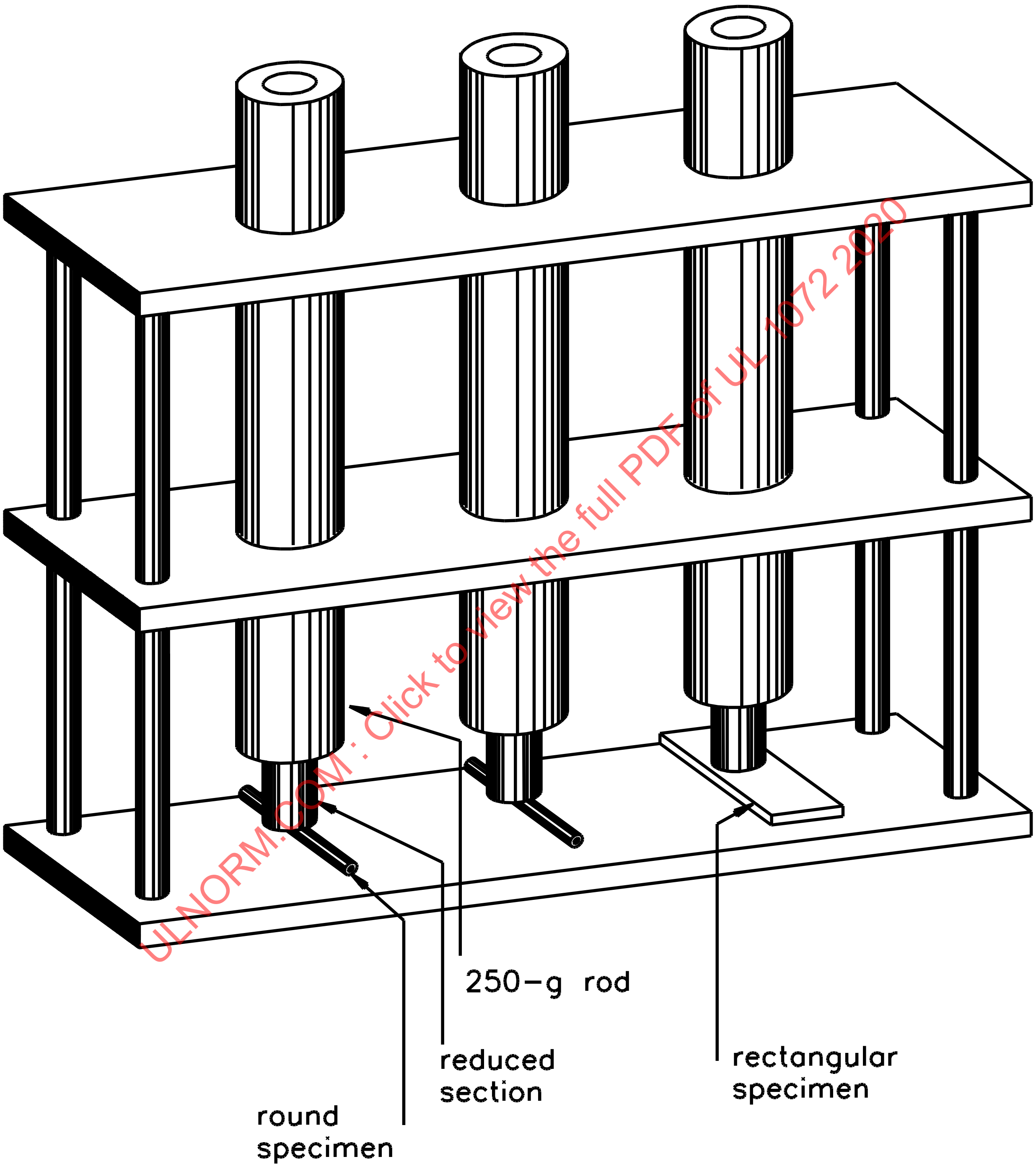
Non-conductive thermoplastic CPE	25 percent maximum distortion	121.0 ±1.0°C (249.8 ±1.8°F)	item III Table 27.4
Non-conductive PE	25 percent maximum distortion	90.0 ±1.0°C (194.0 ±1.8°F)	item II Table 27.10
Non-conductive PVC	50 percent maximum distortion	121.0 ±1.0°C (249.8 ±1.8°F)	item II Table 27.12
Non-conductive TPE	50 percent maximum distortion	150.0 ±1.0°C (327.6 ±1.8°F)	item II Table 27.14

35.2 Each circuit-conductor, assembly, overall, and supplementary jacket of non-conductive thermoplastic CPE, non-conductive PE, non-conductive PVC, and non-conductive TPE is to be removed from the finished cable without damage to the jacket. Five samples of each jacket approximately 8 inches or 200 mm long are to be prepared with a thickness of 0.050 ±0.010 inch or 1.27 ±0.25 mm, with both surfaces smooth. From each of these samples, a flat, rectangular test specimen 1 inch long and 9/16 inch wide or 25 mm by 14 mm is to be prepared.

Figure 35.1

Deformation test apparatus with specimens in place

Added weights are not shown



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35.3 At a marked position, the thickness T_1 of each of these original specimens is to be measured by means of a dead-weight dial micrometer whose presser foot puts a load of 85 ±3 gf or 0.84 ±0.02 N or 3.0 ±0.1 ozf on the specimen. The presser foot is to have a flat, round face whose diameter is 0.250 ±0.010 inch or 6.4 ±0.2 mm. The anvil of the instrument is to be round, is to be at least 1.5 inches or 38 mm in diameter, and is to be parallel to the face of the presser foot. The entire surface of the presser foot is to be in contact with the rectangular specimen during measurement.

35.4 The apparatus and test method are to be as described in 560.3 – 560.7 of UL 1581.

36 Set of Non-conductive Thermoset Jackets

36.1 Each circuit-conductor, assembly, overall, and supplemental jacket that is of a non-conductive thermoset material and is taken from the finished cable shall not exhibit a set greater than the following (this is indicated for the particular material in the applicable properties table) when specimens are tested as described in 36.2 – 36.6:

No-nconductive CP, Non-conductive thermoset CPE, Non-conductive NBR/PVC	30 percent maximum set (0.30 inch or 7.5 mm)	item II Table 27.2 item IV Table 27.4 item II Table 27.6
Non-conductive neoprene	20 percent maximum set (0.20 inch or 5.0 mm)	item II Table 27.8

36.2 The set test is to be made at room temperature by means of the power-driven testing machine described in 420.1 of UL 1581. The machine shall be such that the movable grip can be stopped instantly.

36.3 The set test is to be made using four unaged specimens that have not been stretched or subjected previously to any test. The specimens are to be taken from the finished cable. The specimens are to be die-cut and marked with lines 1 inch or 25 mm apart (bench marks) as described for the physical-properties tests in 420.2, 420.4 – 420.6, 440.1 – 440.3, and 440.22 – 440.24 of UL 1581. One specimen is to be clamped in position with both of the bench marks visible between the grips. The grips are to be adjusted symmetrically to distribute the tension uniformly over the cross section of the specimen. The movable grip is to be adjusted to make the test piece taut but not under tension. The temperature of the ambient air is to be recorded.

36.4 The grips are to be separated at a rate of 20 ±1 in/min or 500 ±25 mm/min until the bench marks are 3 inches or 75 mm apart. The test specimen is to be held in the stretched position for 5 s, released immediately without snapping back, and rested for 1 min. The distance between the marks is then to be measured to the nearest 0.01 inch or 0.1 mm and is to be recorded. Just before releasing the specimen, the distance R between the marks is to be observed again and, if it has decreased below the 3 inches or 75 mm because of slipping of the specimen in the grips, the specimen that slipped is to be discarded and the test is to be repeated with a fresh specimen.

36.5 Set is the difference between the distance R measured between bench marks after release and rest and the original bench-mark separation of 1 inch or 25 mm, expressed as a percentage of the original separation:

$$Set = \frac{[R - (1\,in\ \ or\ \ 25\,mm)] \times 100}{(1\,in\ \ or\ \ 25\,mm)}$$

36.6 A non-conductive thermoset jacket is acceptable if, for the first specimen of that jacket, the calculated set does not exceed 30 percent (0.30 inch or 7.5 mm) for non-conductive CP, non-conductive thermoset CPE, or non-conductive NBR/PVC and 20 percent (0.20 inch or 5.0 mm) for non-conductive neoprene. If the set calculated for the first specimen exceeds this value, the test is to be repeated on each of the three remaining specimens of that jacket. That jacket is not acceptable if, for any of the three additional specimens, the calculated set exceeds 30 percent (0.30 inch or 7.5 mm) for non-conductive CP, non-conductive thermoset CPE, or non-conductive NBR/PVC and 20 percent (0.20 inch or 5.0 mm) for non-conductive neoprene.

37 Heat Shock Test of Non-conductive PVC and TPE Jackets

37.1 Each circuit-conductor, assembly, overall, and supplementary jacket that is of non-conductive PVC or TPE and is taken from the finished cable shall not show any cracks either on the surface or internally when samples are wound around the mandrel indicated in Table 37.1 and then are subjected to a temperature of 121.0 ±1.0°C (249.8 ±1.8°F) in a full-draft circulating-air oven for 1 h. This test is indicated in Table 27.12 (III) and Table 27.14 (III).

Table 37.1
Mandrel diameter and number of turns for heat-shock test

Calculated outside diameter of jacketed sample (cable, assembly, or circuit conductor)		Diameter of metal mandrel as a multiple of the calculated outside diameter of the jacketed sample (cable, assembly, or circuit conductor)	Number of turns
inches	mm		
0 – 0.750	0 – 19.05	3	6
Over 0.750 but not over 1.500	Over 19.05 but not over 38.10	8	180° bend
Over 1.500	Over 38.10	12	180° bend

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

37.2 This test is to be made using four sample lengths of the finished cable with an overall or supplementary jacket of PVC or TPE and each PVC- or TPE- jacketed assembly and circuit conductor from the finished cable. One sample is to be tightly wound for six complete turns, or for a 180° bend as indicated in Table 37.1, around a metal mandrel having a diameter that complies with Table 37.1. Where six turns are used, successive turns are to be in contact with one another. Both ends of the sample are to be securely held in place by friction tape or another means. After heating to a temperature of 121.0 ±1.0°C (249.8 ±1.8° F) for 1 h in a full-draft circulating-air oven, the sample is to be examined for surface and internal cracks. Internal cracks can be detected as circumferential depressions in the outer surface.

37.3 A PVC or TPE jacket is acceptable if, for the first sample of that jacket, there isn't any evidence of cracking. If the first sample having a particular jacket cracks, the test is to be repeated on each of the three remaining samples having that jacket. That jacket is not acceptable if there is evidence of cracking of any of the three additional samples having that jacket.

38 Cold Bend Test of Complete Cable

38.1 While at a temperature of −35.0±2.0°C (–31.0 ±3.6°F), finished cable shall be capable of being wound around a right-circular mandrel of the diameter indicated in Table 38.1 without damage to any of its parts.

38.2 Four essentially straight test lengths of the finished cable are to be cooled for 1 h in circulating air precooled and maintained at a temperature of –35.0 ±2.0°C (–31.0 ±3.6°F). At the end of the hour, one specimen is to be removed from the cold chamber and bent for 180° around a wooden mandrel of the diameter indicated in Table 38.1 without any more tension than is necessary to keep the surface of the cable in contact with the mandrel. The bend is to be made at a uniform rate in the direction opposite to any curvature in the specimen, and the time taken to remove the test length from the cold chamber and to complete the bend is not to exceed 30 s.

Table 38.1
Multiplying factor for determining mandrel diameter for cold bend test

Cable	Calculated outside diameter of the cable		Diameter of wooden mandrel as a multiple of the calculated outside diameter of the cable
	inch	mm	
Without a metal covering	0 – 0.800	0 – 20.32	x8
	Over 0.800	Over 20.32	x10
With armor or a smooth or corrugated metal sheath	–	–	x14

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

38.3 With a minimum of handling and flexing, the test length is then to be removed from the mandrel and placed on a horizontal surface where it is to remain undisturbed for at least 4 h before being examined for surface damage and then is to be disassembled and examined further for damage. The cable is acceptable if, for the first test length, there aren't any cracks, splits, tears, or other openings in any part of the cable. Adjacent convolutions of any interlocked armor may separate somewhat but none of the cable inside the armor is to be visible. Internal cracking of an extruded part can be detected as circumferential depressions in the outer surface of the part. If the first test length has any of these faults, the test is to be repeated on each of the three remaining test lengths. The cable is not acceptable if any of the three additional test lengths has one or more of these faults.

39 Cold-Impact Test

39.1 A cable is resistant to a temperature of -40°C (-40°F) if the finished cable shows no cracking of any of its components, including the conductor stress relief layer, insulation, insulation stress relief layer, and jacket, when a specimen of the finished cable is cooled for at least 4 h in air, maintained at a low temperature of -40.0 ±2.0°C (-40.0 ±3.6°F) for 4 h, and is then subjected to the energy of a free-falling, flat-faced, 3-lb or 1.36-kg weight, that is 1 inch or 25 mm in diameter and falls through a distance of 36 inches or 915 mm and impacts the specimen laid on a wooden anvil. The test is to be conducted as described in the Impact at Abnormally Low Temperature Test, of UL 1581. The marking “-40C” or “minus 40C” is required on the surface [see 70.1(o)] and on the tag, reel, or carton [see 72.1(k)].

40 Accelerated Water Absorption – Electrical Method – Tests of DREP, EP, and XLPE Insulations

40.1 Insulations on circuit conductors shall have the effect that specimens of the insulated conductor that are immersed continuously in tap water at the specified temperature for 14 d comply with all four of the following requirements when tested as described in 40.2 – 40.10. DREP, EP, and XLPE insulation from 90°C (194°F) cable shall be tested in water at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F). DREP, EP, and XLPE insulation from 105°C (221°F) cable shall be tested in water at a temperature of 90.0 ±1.0°C (194.0 ±1.8°F). These tests are not required for dry-locations cable – that is, they are not required for nonshielded 2400 V single-conductor cable insulated as indicated in column A or B of Table 15.3. All of these tests are to be made on the insulated conductor.

a) ϵ_r, the relative permittivity or dielectric constant of the insulation determined with 48 – 62 Hz current at an average stress of 80 volts per mil or 3150 volts per millimeter, after immersion of the specimens for 24 h, shall be 4.0 or less for EP insulation [14.4 (V)(A)(I)] and for DREP insulation [Table 14.10 (VI)] and 3.5 or less for XLPE insulation [14.1 (VII)].

b) The capacitance determined after immersion for 14 d shall, for EP insulation [Table 14.4 (V)] and DREP insulation [Table 14.10 (V)], not be more than 3.5 percent higher than the capacitance measured after the 24-h immersion; and shall, for XLPE insulation [Table 14.1 (VI)], not be more than 3.0 percent higher than the capacitance measured after the 24-h immersion.

c) The capacitance determined after immersion for 14 d shall, for XLPE insulation [Table 14.1(VI)], EP insulation [Table 14.4 (V)], and 105°C DREP insulation [Table 14.10 (V)], not be more than 1.5 percent higher than the capacitance measured after immersion for 7 d; and shall, for 90°C DREP insulation [Table 14.10 (V)], not be more than 4.0 percent higher than the capacitance measured after immersion for 7d.

d) EP [Table 14.4 (V)], XLPE [Table 14.1 (VI)], and DREP [Table 14.10 (V)] insulations shall comply with one of the following requirements:

1) The stability factor (the numerical difference between the percentage power factors measured with 48 – 62 Hz current at average stresses of 80 and 40 volts per mil or 3150 and 1575 volts per millimeter) determined after the fourteenth day of immersion shall be 1.0 percent or less, or

2) The stability factor determined after the first day subtracted from the stability factor determined after the fourteenth day shall be 0.5 percent or less.

40.2 Each of these tests is to be made on two specimens. If either of these specimens shows any unacceptable result, two additional specimens are to be tested. The insulation is not acceptable if one or both of the two additional specimens show any unacceptable result.

40.3 To determine whether or not the insulation complies with the requirements in 40.1 (each requirement is also stated in the item of the properties table for the material indicated in parentheses in 40.1), tests are to be made using a 15-ft or 5-m specimen of the insulated circuit conductor taken after cross-linking and before the application of any insulation shielding or other covering over the insulation. After not less than 48 h from the time of cross-linking, the specimen is to be dried for 24 h in air at 70.0 ±1.0°C (158.0 ±1.8°F) before being immersed in water.

40.4 The center 120-inch or 3048-mm portion of the specimen is to be immersed continuously in tap water at the specified temperature for 14 d. The 30-inch or 976-mm portion at each end of the specimen is to be kept dry above the water as leakage insulation. A tight-fitting cover for the tank is to be placed directly above the surface of the water, the level of which is to be kept constant.

40.5 The capacitance of the specimen is to be measured with 48 – 62 Hz current at an average stress of 80 volts rms per mil of measured insulation thickness or 3150 volts rms per millimeter of measured insulation thickness with bridge apparatus after 1 d, 7 d, and 14 d of immersion. The voltage applied during each measurement is to be between the conductor in the specimen and an electrode that is earth-grounded and is in contact with the water in which the specimen is immersed. Each result is to be expressed to the nearest picofarad. The increases in capacitance from 1 d to 14 d and from 7 d to 14 d are to be expressed as percentages of the 1-d and 7-d values, respectively.

40.6 The power factor of the specimen is to be measured as specified in of 40.1(d)(1) after 1 d and 14 d of immersion, and each result is to be expressed to the nearest 0.1 percent. The stability factor of the specimen is then to be computed and expressed to the nearest 0.1 percent.

40.7 The stability-factor difference is then to be computed for the specimen. This value is the numerical difference between the stability factors determined after 1 d and 14 d and is to be expressed to the nearest 0.1 percent.

40.8 For determination of the relative permittivity ϵ_r, the capacitance of the insulation is to be determined after immersion of the specimen for 24 h, 7 d, and 14 d.

40.9 For the relative permittivity ϵ_r determination, measurements of the capacitance of the insulation are to be made at a frequency of either 1000 or 60 Hz by means of a capacitance bridge. If measured at 1000 Hz, the rms potential impressed upon the insulation is not to exceed 10 V. If measured at 60 Hz, the potential impressed upon the insulation is to result in an average stress of the insulation at 80 volts rms per mil of measured insulation thickness or 3150 volts rms per millimeter of measured insulation thickness.

40.10 The test is to be made on a 15-ft or 5-m specimen of the insulated conductor from which any insulation shielding or other covering over the insulation has been removed, or the specimen of insulated conductor is to be selected from production after cross-linking and prior to the application of any insulation shielding or other covering. The center 120-inch or 3048-mm portion of the specimen is to be immersed in tap water for 14 d, with a 30-inch or 976-mm portion at each end kept dry above the water as leakage insulation. The water temperature and the depth of immersion of the specimen are to be the same whenever readings are taken. ϵ_r, the relative permittivity or dielectric constant of the insulation is to be determined after 1 d, 7 d, and 14 d by means of the formula

$$\epsilon_r = 0.0136 \times C \times \log_{10} \frac{DIA}{dia}$$

in which:

C is the capacitance in picofarads of the immersed 120 inches or 3048 mm of the specimen,

DIA is the measured diameter over the insulation in inches or millimeters, and

dia is the measured diameter over the conductor shielding in inches or millimeters.

41 Room-Temperature Relative Permittivity and Power Factor Tests at Rated Voltage for EP, DREP, and XLPE Insulations on 8 – 35-kV Circuit Conductors

41.1 EP, DREP, and XLPE insulations on circuit conductors rated over 5 kV shall have the effect that specimens of the insulated conductor immersed in tap water at a temperature of 24.0 ±8.0° C (75.2 ±14.4°F) comply with both of the following requirements when tested as described in 41.2 – 41.6. These tests are not required for 2400 V cable.

a) ϵ_r, the relative permittivity or dielectric constant determined with 48 – 62 Hz current at rated voltage to ground for the cable under test, after immersion of the specimens for at least 24 h, shall be 4.0 or less for EP insulation [Table 14.4 (VI)] and DREP insulation [Table 14.10 (VI)] and 3.5 or less for XLPE insulation [Table 14.1 (VII)(A)].

b) PF, the power factor measured with 48 – 62 Hz current at rated voltage to ground for the cable under test, after immersion of the specimens for at least 24 h, shall be 2.0 percent or less for EP insulation [Table 14.4 (VII)] and DREP insulation [Table 14.10 (VII)] and XLPE insulations [Table 14.1 (VIII)].

41.2 To determine whether or not the insulation complies with the requirements in 41.1 (each requirement is also stated in the item of the properties table for the material indicated in brackets in 41.1), tests are to be made using four 13-ft or 4.0-m specimens of 8- and 15-kV circuit conductors and 17-ft or 5.2-m specimens of 25-, 28-, and 35-kV circuit conductors. The specimens of insulated conductor are to be taken after cross-linking and before application of any insulation shielding or other covering over the insulation. After not less than 48 h from the time of cross-linking, two specimens are to be dried for 24 h in air at a temperature of 70.0 ±1.0°C (158.0 ±1.8°F) before being immersed in water.

41.3 The center 120-inch or 3048-mm portion of each specimen is to be immersed in tap water at a temperature of 24.0 ±8.0°C (75.2 ±14.4°F) for 24 h or longer. The remaining portions at the ends of each specimen are to be kept dry above the water as leakage insulation. A tight-fitting cover for the tank is to be placed directly above the surface of the water.

41.4 The capacitance and power factor of each specimen are to be measured with 48 – 62 Hz current after at least 24 h of immersion. During each measurement, the test voltage indicated in Table 41.1 is to be applied between the conductor in the specimen and an electrode that is earth-grounded and is in contact with the water in which the specimen is immersed. Each capacitance measurement is to be expressed to the nearest picofarad.

Table 41.1
Test voltage for room-temperature ε_r and PF test of insulation

Voltage rating of cable (phase-to-phase circuit voltage)	Test voltage[a]
8000	4620
15000	8660
25000	14435
28000	16165
35000	20210

[a] The test voltage is the rated voltage to ground for the cable under test, which is the phase-to-phase circuit voltage divided by the square root of 3 (1.732) and rounded off to the nearest 5 V.

41.5 ε_r, the relative permittivity or dielectric constant of the insulation is to be determined for each specimen after a 24 h or longer immersion by means of the formula

$$\epsilon_r = 0.0136 \times C \times \log_{10}\frac{DIA}{dia}$$

in which:

C is the capacitance in picofarads of the immersed 120 inches or 3048 mm of the specimen,

DIA is the measured diameter over the insulation in inches or millimeters, and

dia is the measured diameter over the conductor shielding in inches or millimeters.

41.6 The circuit-conductor insulation is acceptable if, for each of the first two specimens, the power factor (PF) after 24 h is not over 2.0 percent for DREP, EP, or XLPE and the relative permittivity (ϵ_r) after 24 h is not over 4.0 for DREP or EP or is not over 3.5 for XLPE. If any of these limits is exceeded for either specimen, the test is to be repeated on each of the two remaining specimens. The insulation is not acceptable if, for either of the two additional specimens, any of these limits is exceeded.

42 Dry Electrical Test

42.1 A sample of 1/0 AWG aluminum or copper 15-kV cable utilizing a 100 percent level of insulation along with conductor stress relief and an outer insulation shield with any acceptable metallic shield is to be used for the test. The sample shall be 30 ft or 9 m long and the test is to be performed with the cable in nonmetallic conduit of the 3-in trade size. The effective length between the terminals is to be at least 20 ft or 6 m. The sample is to be energized at rated phase-to-ground voltage and sufficient current to maintain a conductor temperature of 140°C (284°F) for 504 h (three weeks) continuously. At least three samples shall be tested. The current loading may be interrupted during the test, if necessary, provided that the total time is achieved.

42.2 The relative permittivity and power factor are to be measured before the current loading at ambient temperature, 105°C (221°F), and 140°C (284°F). After the current loading has been completed, the same properties are to be measured at the three temperatures.

42.3 The Partial Discharge Test, as described in Section 55, is to be performed before and after the current loading. This test is not conducted on DREP insulation.

42.4 After the test has been completed, either the power factor between the conductor and the insulation shields, shall not increase by more than 10 percent at each of the three test temperatures or, if after the 3-week period the increase in power factor is greater than 10 percent, the test shall be continued and, at 1-week intervals, the power factor shall be measured and recorded at each of the temperatures. If it is anticipated that testing will be continued beyond the 3-week period, readings shall be taken weekly. The cable has passed the test whenever the following equation is satisfied for all three temperatures during the same time period:

$$\frac{PF_n}{PF_{n-3}} \leq 1.1$$

in which:

PF_n is the last power factor measurement (average of the three samples) at the nth week when $n \geq$ 3 weeks. When the total duration of the test is 3 weeks, the initial power factor measurement is to be used for F_{n-3}.

The requirement may be satisfied at 3 weeks or at the end of any 1-week incremental period thereafter. The power factor shall not exceed the maximum limit specified at room temperature at any time during testing.

42.5 The results of the Partial Discharge Test shall comply with the requirements for partial discharge extinction level in 55.1 – 55.6 in the initial specimens and after the current loading has been completed. This test is not conducted on DREP insulation.

43 Environmental Cracking Test of Non-conductive PE Jacket

43.1 A non-conductive PE jacket shall not show any evidence of cracking when three specimens are prepared and tested as described in ASTM D 1693 with the modifications noted in 43.2, 43.3, and 43.4. This is indicated for non-conductive PE jackets in Table 27.10 (IV).

43.2 Six test specimens measuring approximately 1.5 inches by 0.5 inch by 0.125 inch or 38 mm by 13 mm by 3 mm are to be prepared from samples of the non-conductive PE jacket taken from the finished cable. The specimens are to be prepared by the compression and heat molding process that is described as Procedure C in ASTM D 1928 except that the temperature of each newly molded specimen may be lowered at any convenient rate. Note that, according to Table 1 of ASTM D 1248, uncolored and unfilled PE resin is typed by density (g/cm^3) as follows. Note also that only Type I PE is used in Type MV cable.

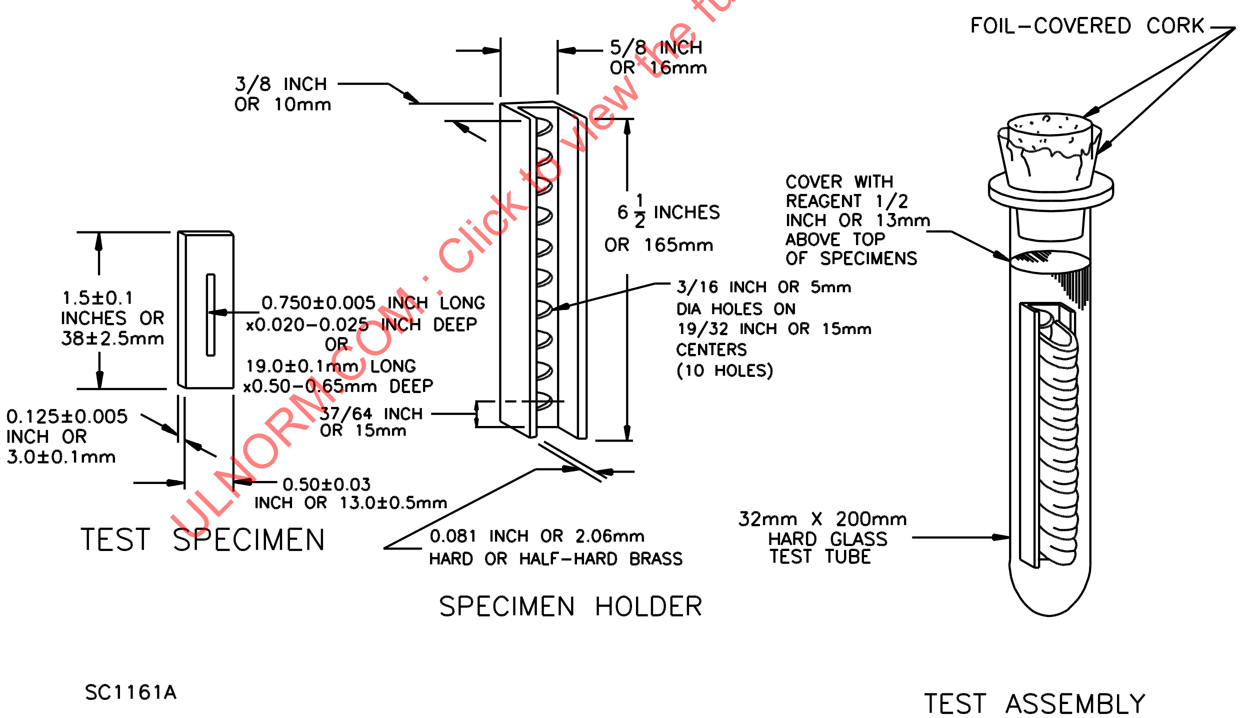
Type I:	0.910 – 0.925
Type II:	0.926 – 0.940
Type III:	0.941 – 0.959
Type IV:	over 0.959

43.3 The controlled imperfection on each of three specimens is to be made with a fresh razor or knife blade and is to consist of a rectangular groove or notch having dimensions within the limits indicated in the left-hand part of the illustration in Figure 43.1. The notch is to be centrally located on one of the surfaces of the specimen that measure 1.5 inches by 0.5 inch or 38 mm by 13 mm. The condition of the edges of the notch is to be as specified in ASTM D 1693.

43.4 Each of the three specimens is to be bent, with the notch to the outside of the bend, and is to be placed in the brass specimen holder as illustrated in Figure 43.1. The holder with the three specimens in it is to be placed in a hard-glass test tube that is 200 mm long and 32 mm in diameter. Cracking agent consisting of full-strength Igepal CO-630 (Antarox CO-630) made by the Dyestuff and Chemical Division of the GAF Corporation, 140 West 51 Street, New York, NY 10020 or its equivalent (CO-630 is the referee material) is to be added to the test tube to completely immerse the specimens. The test tube is to be closed by a nonreactive means such as a foil-covered cork and is then to be kept for 48 h in an oil or water bath or air oven operating at a temperature of 50.0 ±1.0°C (122.0 ±1.8°F). At the end of this time, the specimens are to be removed from the cracking agent, cooled to room temperature in still air, and are then to be examined for cracks as detailed in ASTM D 1693. The non-conductive PE jacket is acceptable if there are no cracks in any of the three specimens. If any of the first three specimens crack, the test is to be repeated on each of the three remaining specimens. The jacket is not acceptable if there are cracks on any of the three additional specimens.

Figure 43.1

Test assembly for environmental cracking of PE jacket



44 Volume Resistivity of Conductive Conductor Shielding

44.1 Finished extruded, tape, or extrusion-over-tape conductor shielding taken as a unit shall have a volume resistivity that does not exceed 100,000 ohm-centimeters at the rated temperature of the insulation when tested as described in ASTM D 257 with the modifications noted in 44.2 – 44.4. This is indicated in 13.3.

44.2 The insulation is to be removed from four 10-inch or 250-mm sample lengths of the finished circuit conductor(s) taken from the completed cable, or four 10-inch or 250-mm sample lengths are to be taken of the conductor shielding on the conductor before the insulation is applied. In either case, the conductor shielding is to be cut through to the conductor on opposite sides (180° apart) of the conductor and the conductor is to be removed to produce half-cylinder lengths of the conductor shielding alone. Two such lengths that are not damaged are to be prepared as specimens by applying conductive-paint electrodes to each as described in Section 6.1.3 of ASTM D 257. On each specimen, two potential electrodes at least 2 inches or 50 mm apart are to be applied and either a current electrode is to be applied at least 1 inch or 25 mm outside each of the potential electrodes, or the current electrodes may be eliminated if the measured volume resistivity is less than 90,000 ohm-centimeters for each of the two specimens.

44.3 The power in the test circuit is not to exceed 100 mW. The test is to be made at the rated temperature of the insulation with either alternating- or direct-current voltage. The volume resistivity is to be calculated from whichever of the following formulas applies:

$$\text{If the dimensions are in inches, } P = \frac{R(D^2 - d^2)}{L}$$

$$\text{If the dimensions are in millimeters, } P = \frac{0.039\,R(D^2 - d^2)}{L}$$

in which:

P is the volume resistivity in ohm-centimeters,

R is the measured resistance in ohms,

D is the diameter over the conductor shielding in inches or millimeters,

d is the diameter over the conductor in inches or millimeters, and

L is the distance between potential electrodes in inches or millimeters.

44.4 The conductor shielding is acceptable if, for either of the two specimens, the volume resistivity is not over 100,000 ohm-centimeters. If this limit is exceeded for either specimen, the test is to be repeated on each of the two remaining specimens. The conductor shielding is not acceptable if this limit is exceeded for either of the two additional specimens.

45 Relative Permittivity and Dielectric Withstand Stress of Extruded Nonconducting Conductor Stress Control

45.1 The extruded nonconducting stress control material shall have a relative permittivity ϵ_r, of not less than 8 at room temperature nor more than 200 at the rated temperature of the EP insulation, and shall have a dielectric withstand stress, in volts per mil or kV per millimeter at any temperature up to the rated temperature of the EP insulation, of not less than 1500 divided by the ϵ_r value for the test temperature used. The tests are to be made as described in 45.2 and 45.4.

45.2 Three specimens shall be prepared and each shall be an 18-inch or 45.7-mm length of conductor over which 0.015 – 0.030 inch or 0.038 – 0.076 mm or nonconducting stress control material has been extruded. The control 12-inch or 30.5 mm length of each specimen shall be shielded using a conductive-paint electrode applied to the surface of the stress control material. The measurements of capacitance for determining ϵ_r are to be made by means of a capacitance bridge and a 60 Hz potential after the sample has been held at the test temperature for at least 15 minutes.

45.3 ϵ_r, the relative permittivity of the nonconducting stress control material is to be determined for each test temperature by means of the formula

$$\epsilon_r = 0.0136 \times C \times \log_{10}\frac{DIA}{dia}$$

in which:

C is the capacitance in picofarads of the 12-inch shielded length of specimen

DIA is the measured diameter over the stress control layer in inches or millimeters, and

dia is the measured diameter over the conductor in inches or millimeters

45.4 Following the capacitance measurement of 45.2 and while the specimen is held at the test temperature, a 48 – 62 Hz potential shall be applied between the conductor and the grounded shield (conductive-paint electrode). The initially applied rms potential shall be anywhere in the range of near zero to 100 volts and shall be increased with a rate of rise not greater than 100 volts per second until dielectric failure occurs.

45.5 The dielectric stress, in volts per mil or kV per millimeter, at time of failure shall be calculated by means of the formula

$$S = 2V / (DIA - dia) \times 1000 \quad \text{volts per mil}$$

or

$$S = 2V / (DIA - dia) \times 0.039 \quad \text{kV per millimeter}$$

in which:

V is the rms potential at time of dielectric failure, in volts

DIA is the measured diameter over the stress control layer in inches or millimeters, and

dia is the measured diameter over the conductor in inches or millimeters

45.6 The nonconducting conductor stress control material is acceptable if the values of ϵ_r determined from 45.3 are in the range of 8 to 200, and the values of S determined from 45.5 exceed the value of 1500 divided by ϵ_r for the test temperature used.

46 Volume Resistivity of Insulation Shielding

46.1 The finished conductive nonmetallic covering portion of any insulation shielding (extruded, tape, or coating-plus-tape covering) taken as a unit shall have a volume resistivity that does not exceed 50,000 ohm-centimeters at the rated temperature of the insulation when tested as described in ASTM D 257 with the modifications noted in 46.2 – 46.4. This is indicated in 17.3.

46.2 Any covering over the insulation shielding is to be removed from four 10-inch or 250-mm sample lengths of the finished circuit conductor(s) taken from the finished cable, or four 10-inch or 250-mm sample lengths are to be taken of the conductive nonmetallic covering on the insulated conductor(s) before any covering is applied over the conductive nonmetallic covering. Two such lengths that are not damaged are to be prepared as specimens by applying conductive-paint electrodes to each as described in Section

6.1.3 of ASTM D 257. On each specimen, two potential electrodes at least 2 inches or 50 mm apart are to be applied and either:

a) A current electrode is to be applied at least 1 inch or 25 mm outside each of the potential electrodes, or

b) The current electrodes may be eliminated if the measured volume resistivity is less than 45,000 ohm-centimeters for each of the two specimens.

46.3 The power in the test circuit is not to exceed 100 mW. The test is to be made at the rated temperature of the insulation with either alternating- or direct-current voltage. The volume resistivity is to be calculated from whichever of the following formulas applies.

$$\text{If the dimensions are in inches, } P = \frac{2R(D^2 - d^2)}{L}$$

$$\text{If the dimensions are in millimeters, } P = \frac{0.079\,R(D^2 - d^2)}{L}$$

in which:

P is the volume resistivity in ohm-centimeters,

R is the measured resistance in ohms,

D is the diameter over the insulation shielding in inches or millimeters,

d is the diameter over the insulation in inches or millimeters, and

L is the distance between potential electrodes in inches or millimeters.

46.4 The conductive nonmetallic covering portion of the insulation shielding is acceptable if, for each of the two specimens, the volume resistivity is not over 50,000 ohm-centimeters. If this limit is exceeded for either specimen, the test is to be repeated on each of the two remaining specimens. The insulation shielding is not acceptable if this limit is exceeded for either of the two additional specimens.

47 Specific Surface Resistivity of Nonshielded Single-Conductor Cable

47.1 Finished nonshielded single-conductor cable shall have a specific surface resistivity of 200,000 megohms or more when three specimens are prepared and tested as described in ASTM D 257 with the modifications noted in 47.2 and 47.3.

47.2 Sample 24-inches or 610-mm or longer lengths of finished nonshielded single-conductor cable insulated as indicated in column A, B, or C of are to be immersed, except at their ends, in tap water at room temperature for 48 h. At the end of this time, the samples are to be removed from the water and the excess moisture is to be blotted off (not wiped). Each sample is to be cut into specimens that are 12 inches or 305 mm long without damaging the surface of the cable. Six specimens are to be prepared. Three of these undamaged specimens are then to be kept in still air at room temperature for 10 min. Two foil electrodes as described in Section 6.1.6 of ASTM D 257 or two conductive-paint electrodes as described in Section 6.1.3 of ASTM D 257 are to be applied to each of the three specimens. The electrodes are to be applied around the cable circumference with a distance of 6 inches or 152 mm between the electrodes. Each electrode is to be 1 inch or 25 mm wide. A direct-current potential of 250 – 500 V is to be applied between the two electrodes, and the resistance is to be measured as described in ASTM D 257. The specific surface resistivity is to be calculated from the resistance by means of whichever of the following formulas applies:

$$\text{If the dimensions are in inches, } P = 0.524 \times R \times D$$

$$\text{If the dimensions are in millimeters, } P = 0.0206 \times R \times D$$

in which:

P is the specific surface resistivity in megohms,

R is the measured surface resistance in megohms for a 6-inch or 152-mm spacing between electrodes, and

D is the measured diameter of the finished cable in inches or millimeters.

47.3 The cable is acceptable if, for each of the three specimens, the specific surface resistivity is at least 200,000 megohms. If this value is not reached for any of the three specimens, the test is to be repeated on each of the three remaining specimens. The cable is not acceptable if, for any of the three additional specimens, the specific surface resistivity is less than 200,000 megohms.

48 Alternative Tests for Resistance to Tracking of Nonshielded Dry-Locations 2400 V Single-Conductor Cable Insulated with EPCV or XLPE

48.1 The EPCV or XLPE insulation of nonshielded dry-locations 2400 V single-conductor cable that is insulated in the thicknesses indicated in column A of Table 15.3 shall not show evidence of tracking when specimens of the insulation from the finished cable are tested either by the dust-and-fog method described in ASTM D 2132 with the modifications noted in 48.2 – 48.4, or by the ammonium chloride dip method described in 48.5 – 48.8.

48.2 DUST-AND-FOG METHOD – For the ASTM dust-and-fog method, six specimens of the insulated conductor taken from the finished cable are to be prepared. Each specimen is to be 5-1/2 inches or 140 mm long and is to have seven electrodes applied to it with a distance of 3/4 inch or 19 mm between the electrodes. Each electrode is to consist of one or more turns of a solid round 12 AWG metal-coated copper wire wrapped around the insulated conductor. The metal-coated copper is to be firmly in contact with the insulation at all points around the circumference of the insulation. Each electrode is to be tight enough to remain in place on the insulation but is not to damage the insulation.

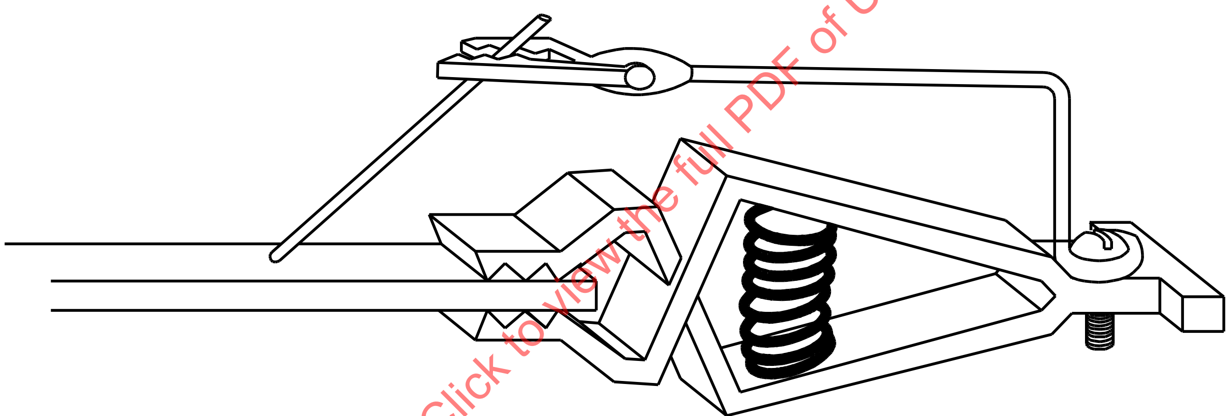
48.3 One specimen with the electrodes in place is to be placed in a horizontal position in the test chamber with the longitudinal axis of the specimen perpendicular to the axis of the spray. The end electrodes, each alternate electrode, and the conductor are to be earth-grounded. The top side of the specimen is to be dusted as specified for the full length of the specimen between the end electrodes, and then the dust is to be removed from bands approximately 1/32 inch or 0.8 mm wide on both sides of each of the three ungrounded electrodes.

48.4 After the break-in period, the 48 – 62 Hz rms potential applied to the three ungrounded electrodes of the specimen is to be raised to 1500 V with a current of 4 – 10 mA being maintained until the circuit breaker trips at the 2-A setting because of tracking (not because of erosion or excessive moisture or circuit malfunction). The insulation is acceptable if there is no visual evidence of tracking on the specimen. If there is evidence of tracking on the first specimen, the test is to be repeated on each of three additional specimens. If the three specimens are tested simultaneously, the specimens are to be placed in the test chamber so that they are equidistant from the nozzle. The insulation is not acceptable if there is visual evidence of tracking on any of the three additional specimens.

48.5 DIP METHOD – For the ammonium chloride dip method, ten or more specimens are to be tested. Each specimen is to be a strip that is of any convenient width, has a length of approximately 2 inches or 50 mm, and has a thickness of at least 0.060 inch or 1.5 mm. The strips are to be taken from the outside of the insulation and are to be tested with the natural curve of the insulation. The conductor and the conductor shielding are to be removed. The specimens are to be cleaned with an organic solvent, then washed with soap and water to remove traces of the solvent, rinsed with ethyl alcohol, and finally air dried. The surface of the specimens that was the outside of the insulation is not to be touched by the hands or anything else that can damage or contaminate the EPCV or XLPE. The holder for a specimen and electrode is to be made of a battery clip and an alligator clip arranged as shown in Figure 48.1. The electrode is to be a straight length of oxidation-resistant wire such as nickel/chromium resistance wire and is to be 0.04 inch or 1 mm in diameter. As shown in the illustration, the electrode is to contact the longitudinal center line of the specimen at a 45° angle on the surface of the specimen that was the outside surface of the insulation. There is to be at least 1-1/2 inches or 38 mm of specimen length between the contact point of the electrode and the free end of the specimen.

Figure 48.1

Holder for ammonium chloride dip method



48.6 A 48 – 62 Hz rms potential of 1000 V or less is to be applied between the electrode and an 0.1 percent solution of the American Chemical Society (ACS) reagent grade of ammonium chloride (NH_4Cl) in distilled water in an open-top beaker or other glass container with 0.02 percent of Triton X-100 or an equivalent nonionic wetting agent added. The solution is to be earth-grounded through a carbon rod immersed in the solution. The apparatus is to dip each specimen vertically into the solution with the free end of the specimen entering the solution first and the action reversed as the electrode becomes immersed about 1/16 inch or 1-1/2 mm below the surface of the solution and then reversed again as the specimen is withdrawn to 1 inch or 25 mm of its length measured from the electrode to the surface of the solution. This procedure of immersion to the electrode and withdrawal to 1 inch or 25 mm is to be continuous at the rate of 15 s for each cycle of immersion and withdrawal.

48.7 Tracking occurs when the current in the circuit does not return to zero as the specimen is withdrawn to 1 inch or 25 mm of its length. If this does not occur at the initial voltage, the potential is to be increased slowly or in steps (steps of 200 V are convenient) until, ultimately, 2000 V is applied to the specimen with or without the tracking current but without a visible arc. If a visible arc appears at any point in the procedure, the potential is to be decreased until there is no visible arc as the specimen is withdrawn. The potential is then to be raised again until 2000 V is reached with or without the tracking current but without a visible arc. The foregoing constitutes break-in of a specimen and is to be achieved in 10 or fewer cycles.

48.8 After break-in, the immersion and withdrawal procedure is to continue at 2000 V for a total of 50 cycles (including the 10 or fewer cycles of break-in), or fewer cycles if arcing is visible between the electrode and the solution across the full 1-inch or 25-mm length of the insulation. The insulation is not acceptable if, during the 50-cycle testing of each of any five consecutive specimens, visible arcing occurs through two or more successive cycles on any specimen at 2000 V or a lower potential. The insulation also is not acceptable if, during the 50-cycle testing of each of ten consecutive specimens, any two specimens have visible arcing for less than two successive cycles at 2000 V or a lower potential.

49 U-Bend Discharge Test of Nonshielded Single-Conductor Cable

49.1 Finished nonshielded single-conductor cable shall not break down electrically and shall not crack, erode, or track on its outside surface when two or four specimens are prepared and tested as described in 49.2 and 49.3.

49.2 Sample lengths of the finished nonshielded single-conductor cable, each at least 5 ft or 1525 mm long, are to be tested. Four sample lengths are to be prepared for a dry-locations cable, and eight sample lengths are to be prepared for a dry-or-wet-locations cable. For a cable that is insulated as indicated in column A or B of Table 15.3 (cable for dry locations), two of these lengths are to be tested unconditioned. For a cable that is insulated as indicated in column C of Table 15.3 (cable for dry or wet locations), two of these lengths are to be immersed for 14 d, except for their ends, in tap water that is maintained at a temperature of 75.0 ±1.0°C (167.0 ±1.8°F). At the end of this time, the two lengths are to be removed from the water and given 24 h to dry in still air that is at room temperature. These two immersion-conditioned lengths and two additional unconditioned lengths (two unconditioned lengths and no additional conditioned lengths in the case of a dry-locations cable) are then each to be bent at their midpoints for 180° around a mandrel of the diameter indicated in Table 49.1. The sides (legs) of each U are to be straight and parallel to one another.

Table 49.1
Multiplying factor for determining mandrel diameter for U-bend discharge test

Size of conductor	Diameter of mandrel as a multiple of the calculated outside diameter of the cable
8 – 2 AWG	6
1 – 3/0	8
4/0 AWG – 500 kcmil	10
550 – 1000	12

[a] The insulation thickness used in calculating the diameter is to be the specified average insulation thickness where an average is specified and is to be the specified minimum thickness at any point of the insulation where an average thickness is not specified.

49.3 Each of the U-bend specimens is to be supported separately with its bend down and the legs of the U extending upward in a vertical plane. The center of each bend is to rest on a flat, horizontal metal plate that is earth grounded. A 48 – 62 Hz essentially sinusoidal rms test potential of the magnitude indicated in Table 49.2 is to be applied between the conductor in each specimen and the metal plate. In each case, the voltage is to be applied for the number of hours indicated in Table 49.2. The cable is acceptable if, for either of the two dry-locations specimens or for any of the four dry-or-wet-locations specimens, there is no electrical breakdown and there is no visible cracking, erosion, or tracking of the outside surface. A change in color or glossiness or other appearance is not cause for rejection. If any of the first two or four specimens break down or show cracking, erosion, or tracking, the test is to be repeated on each of the two or four remaining specimens. The cable is not acceptable if any of the two or four additional specimens break down or show cracking, erosion, or tracking.

Table 49.2
Test voltage and time for U-bend discharge test

Cable	Test potential in kilovolts		Test period in hours
	Unconditioned specimens	Specimens conditioned in water	
Dry-locations 2400 V cable insulated as indicated in column A or B of Table 15.3	13	none	6
Wet-or-dry-locations 2400 V cable insulated as indicated in column C of Table 15.3	20	15	100

50 Copper Sulphate Test of Zinc Coating on Steel Strip for and from Steel Armor

50.1 The coating of zinc on steel strip for and from steel armor shall enable specimens of the strip to comply with all of the following requirements. This is indicated in 28.19.

a) A specimen of the zinc-coated steel strip tested before forming shall not show a bright, adherent deposit of copper on any surface, including edges, after two 60-s immersions in a solution of copper sulphate.

b) A specimen of the partially uncoiled steel armor from finished cable:

1) Shall not show a bright, adherent deposit of copper after one 60-s immersion in a solution of copper sulphate, and

2) Shall not show a bright, adherent deposit of copper on more than 25 percent of any surface, including edges, after two 60-s immersions in the copper sulphate solution.

50.2 The solution of copper sulphate is to be made from distilled water and the American Chemical Society (ACS) reagent grade of cupric sulphate ($CuSO_4$). In a copper container or in a glass, polyethylene, or other chemically nonreactive container in which a bright piece of copper is present, a quantity of the cupric sulphate is to be dissolved in hot distilled water to obtain a solution that has a specific gravity slightly higher than 1.186 after the solution is cooled to a temperature of 18.3°C (65.0°F). Any free acid that might be present is to be neutralized by the addition of approximately 1 gram of cupric oxide (CuO) or 1 gram of cupric hydroxide [$Cu(OH)_2$] per liter of solution. The solution is to be diluted with distilled water to obtain a specific gravity of exactly 1.186 at a temperature of 18.3°C (65.0°F). The solution is then to be filtered.

50.3 At one end of a sample length of finished cable that has armor formed of zinc-coated steel strip, the armor is to be unwound from the outside to expose the edges and the inner surface of the formed strip, and also to facilitate working cheesecloth between the turns onto the inner surface to dry that surface during the test. To reduce the damage to the zinc coating, the strip is not to be straightened as it is unwound but is to remain in the helical form with a diameter that is not larger than about three times the cable diameter. Three 6-inch or 150-mm (axial measurement) specimens are to be cut from the partially uncoiled armor. Additionally, three straight 6-inch or 150-mm specimens are to be cut from a sample length of the zinc-coated steel strip before forming.

50.4 With prudent attention to the risks to health and to the risk of fire, the six specimens are to be cleaned with an organic solvent. Each specimen is to be examined for evidence of damage to the zinc coating, and only specimens that are not damaged are to be selected for use in the test. One specimen of the unformed strip and one specimen of the armor are to be tested.

50.5 The two selected specimens are to be rinsed in water, and all of their surfaces are to be dried with clean cheesecloth. As much of the water as possible is to be removed in the drying operation because water slows the reaction between the zinc and the solution, thereby adversely affecting the test results.

The surface of the zinc is to be dry and clean before a specimen is immersed in the solution of copper sulphate. The specimens are not to be touched by the hands or anything else that can contaminate or damage the surfaces.

50.6 A glass, polyethylene, or other chemically nonreactive beaker having a diameter approximately equal to twice the diameter measured over the specimen of partially uncoiled armor is to be filled with the solution of copper sulphate to a depth of not less than 3 inches or 76 mm. The temperature of the solution is to be maintained at 18.3 ±1.1°C (65.0 ±2.0°F).

50.7 One of the selected specimens is to be immersed in the solution and is to be supported on end in the center of the beaker with at least half of its axial length immersed. The specimen is to remain in the solution for 60 s, during which time it is not to be moved nor is the solution to be stirred.

50.8 At the end of the 60 s period, the specimen is to be removed from the beaker, rinsed immediately in running tap water, rubbed with clean cheesecloth (a clean soft-bristle test-tube or bottle brush in good condition and of applicable size may be used to rub the interior surfaces of the specimen of partially uncoiled armor, but cheesecloth is to be used on the other surfaces of this specimen and on the unformed strip) until any loosely adhering deposits of copper are removed, and is then to be dried with clean cheesecloth. The turns of the specimen of partially uncoiled armor are not to be separated farther during this process. Again, the hands and other damaging and contaminating objects and substances are not to touch the surfaces that were immersed. The part of the specimen that was immersed is to be examined, considering each edge and broad surface separately and disregarding the portion of the specimen within 1/2 inch or 13 mm of its immersed end.

50.9 If the part of the specimen that was immersed has any deposit of bright, firmly adhering copper outside the 1/2-inch or 13-mm end portion, an estimate is to be made and recorded of the percentage of each edge and broad surface that is covered with copper.

50.10 Regardless of whether the first dip results in a bright, adherent deposit of copper, the immersion, washing, rubbing, drying, examining, estimating, and recording operations are to be repeated once using the same specimen and beaker of solution. After the second dip, the solution in the beaker is to be discarded.

50.11 The remaining specimen is to be subjected to the 2-dip procedure described in 50.7 – 50.10.

50.12 Neither the armor nor the unformed strip is acceptable if there is any bright, adherent copper showing outside the 1/2-inch or 13-mm end portion of the immersed part of the specimen of unformed strip after the first or second dip. Even if the unformed strip is acceptable, the armor is not acceptable if the specimen of partially uncoiled armor shows any bright, adherent copper after the first dip or more than 25 percent coverage after the second dip. If, after any dip there is adherent copper that is dull or dark rather than being bright and shiny, contamination is to be considered to be present. In each such instance, the results are to be disregarded and the test is to be repeated on a new specimen.

51 Weight of Zinc Coating on Steel Strip for Steel Armor

51.1 The amount of zinc per unit area, including edges, that coats steel strip intended for use in steel armor shall be 0.35 oz/ft^2 or more or shall be 0.11 kg/m^2 or more when one specimen of the unformed, zinc-coated steel strip is tested as described in 51.2 – 51.8. This is indicated in 28.16.

51.2 Three 3-inch or 75-mm straight lengths of the unformed zinc-coated steel strip are to be prepared. Each specimen is to be undamaged and is to be cleaned with an organic solvent, rinsed in ethyl alcohol, and dried by exposure to still air at room temperature. One specimen is to be selected for use in the test.

51.3 The stripping solution for this test is to be prepared by mixing 500 mL of the American Chemical Society (ACS) reagent grade of HCl having a specific gravity of 1.19 with 500 mL of distilled water and giving the resulting solution time to cool to room temperature.

51.4 A clean, zinc-coated specimen whose weight is 125 g or less is to be weighed W_1 to the nearest 0.01 g. A clean, zinc-coated specimen whose weight is over 125 g is to be weighed W_1 to the nearest 0.1 g. After being weighed for W_1, the specimen is to be immersed alone in the stripping solution to a depth that covers the specimen and is to remain immersed until the violent evolution of hydrogen ceases (see caveat in 51.5) and only a few bubbles are being evolved (approximately 15 – 30 s). The same stripping solution may be used for successive specimens until the time required for stripping the zinc from the steel becomes inconveniently long. The temperature of the stripping solution is not at any time to exceed 100°F (38°C). After being stripped, the specimen is to be scrubbed under running water, dipped in hot water, and wiped or blown dry. The dry, clean, stripped specimen then is to be weighed W_2 to the same accuracy as in the weighing for W_1.

51.5 DANGER – Hydrogen is an extremely flammable gas that is lighter than air and forms explosive mixtures with air.

Use forced ventilation.

Keep heat, sparks, open flame, and non-explosion-proof electrical equipment away.

Do not smoke.

Do not inhale the gas.

51.6 The total surface area A of the specimen, including edges, that was coated with zinc is to be determined to the nearest 0.01 inch^2 or to the nearest 5 mm^2. Alternatively, the average thickness G of the stripped specimen is to be determined to the nearest 0.001 in or 0.025 mm.

51.7 If the surface area is known, the weight of zinc coating is to be calculated for the specimen using whichever of the following formulas applies:

$$\text{If A is in square inches, } C = \frac{(W_1 - W_2) \times 5.08}{A}$$

$$\text{If A is in square millimeters, } C = \frac{(W_1 - W_2) \times 2.280}{A}$$

in which:

C is the weight of zinc coating in ounces per square foot of coated surface or in grams per square meter of coated surface;

W_1 is the weight of the clean, coated specimen in grams;

W_2 is the weight of the dry, clean, stripped specimen in grams; and

A is the coated surface area of the specimen in square inches or in square millimeters.

51.8 If only the thickness is known, the weight of the zinc coating may be calculated using whichever of the following formulas applies:

$$\text{If G is in inches, } C = \frac{(W_1 - W_2) \times G \times 328}{W_1}$$

$$\text{If G is in millimeters, } C = \frac{(W_1 - W_2) \times G \times 0.0129}{W_1}$$

in which:

C is the weight of zinc coating in ounces per square foot of coated surface or in grams per square meter of coated surface;

W_1 is weight of the clean, coated specimen in grams;

W_2 is the weight of the dry, clean, stripped specimen in grams; and

G is the thickness of the stripped specimen in inches or millimeters.

51.9 The zinc-coated steel strip is not acceptable if the calculation for the single specimen shows that there is less zinc on the steel than 0.35 oz/ft^2 or 0.11 kg/m^2.

52 Tension Test of Interlocked Armor

52.1 Interlocked armor shall be capable of withstanding for 5 min, without opening up at any point, an axial tension imparted by a weight that exerts 150 lbf or 667 N or 68 kgf.

52.2 The apparatus is to consist of a pair of clamps or other means (such as basket grips) that do not damage the cable, a weight that exerts 150 lbf or 667 N or 68 kgf, and a secure means for suspending the weight from a support. See Figure 52.1.

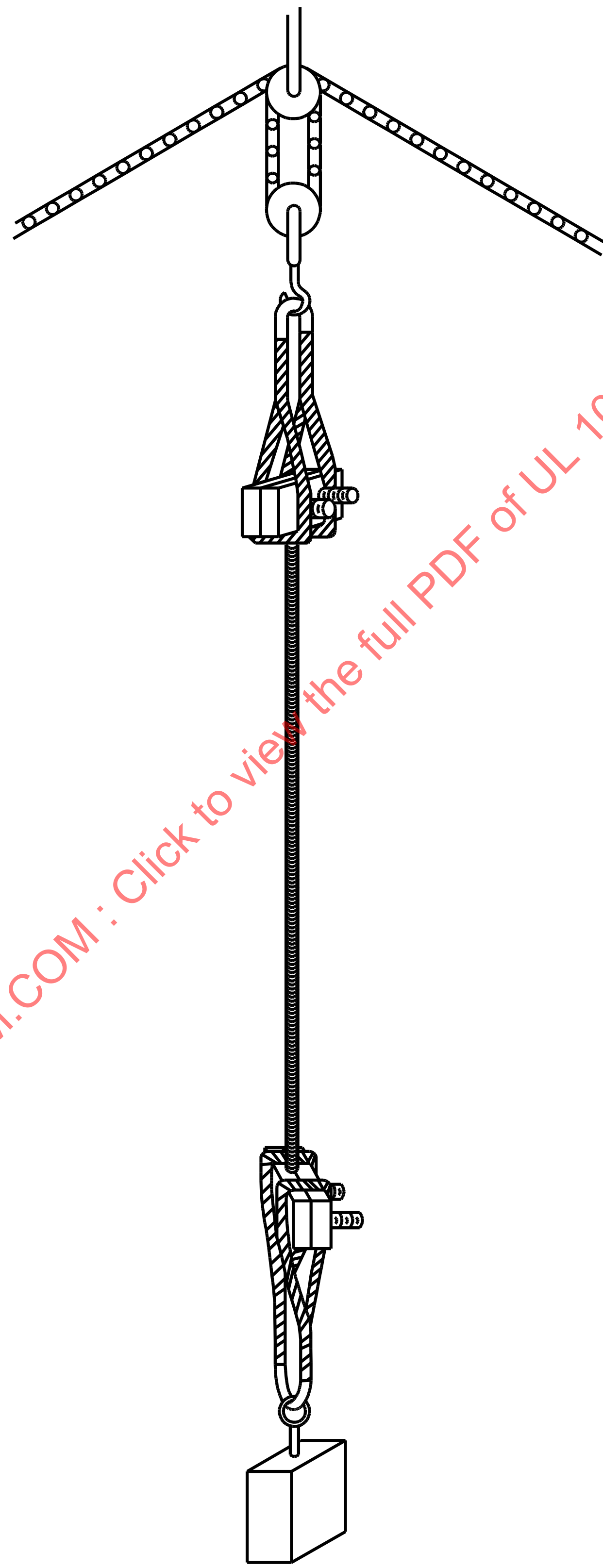
52.3 The clamps are to be made of hardwood, and the two pieces comprising each clamp are to be fastened together by two bolts by means of which the armor is to be clamped tightly between the jaws without being crushed. Two clamps constructed as shown in Figure 52.2 are to be provided. The weight is to be equipped with a secure means for attachment to one of the clamps. A block and tackle or a differential pulley is to be used to lift the sample, clamps, and weight.

52.4 Three samples are to be tested. In each case, one end of a sample length of the finished cable from which any jacket over the armor (see 29.1) has been removed is to be fastened in the clamps so that its ends project 2 inches or 50 mm beyond the edges of each clamp, thereby providing a sample 36 inches or 914 mm long between the clamps, which are then to be tightened to keep the sample from slipping.

52.5 The sample is to be suspended by the upper clamp with a loop of rope passing over the hook of a block and tackle or a differential pulley hung from a secure support, and the weight is to be attached to the lower clamp. The sample is to hang vertically for its full length and at right angles to the faces of the clamps. The sample, clamps, and weight are then to be raised gently so that it takes at least 45 s to apply the tension to the sample (a rate of not more than 200 lbf/min or 890 N/min or 91 kgf/min) until the weight just clears the floor and hangs free in the air. The weight is to be kept from rotating by hand. The weight is to be supported by the sample for 5 min, is then to be let down to the floor, and the weight and clamps are to be removed. Observation is then to be made to determine whether or not the edges of adjacent convolutions of the armor have separated to expose the interior of the cable. The cable is not acceptable if, for any of the three samples, there is exposure of the cable interior.

Figure 52.1

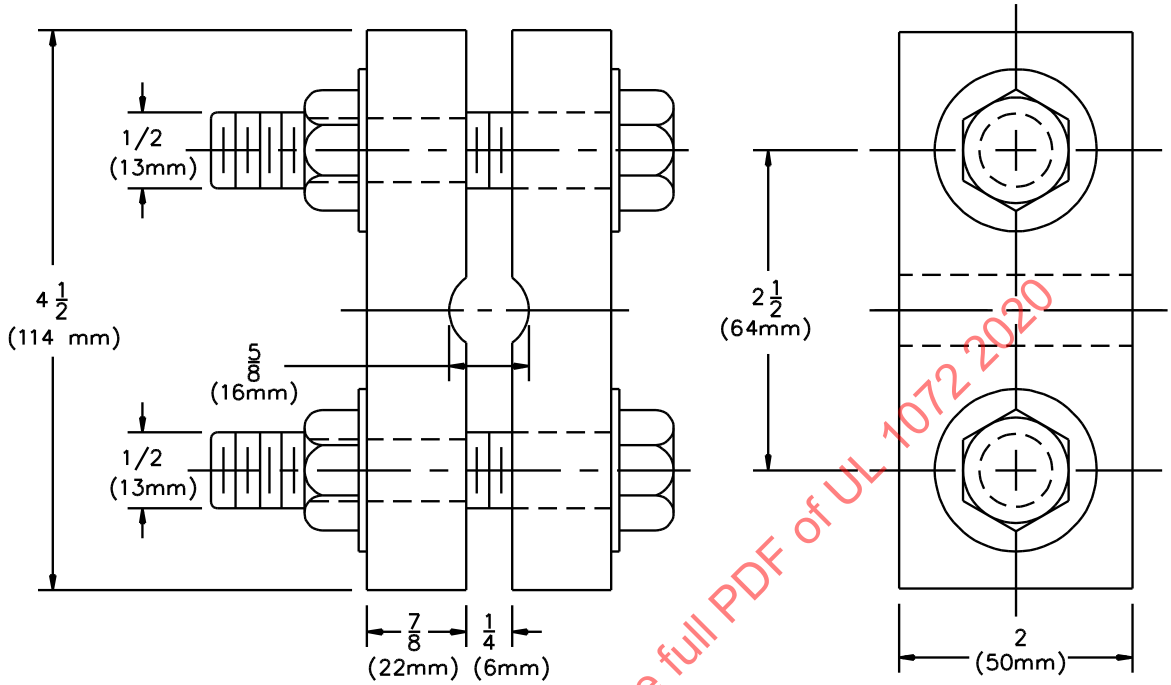
Apparatus for tension test



SC0685

Figure 52.2

Clamp for tension test



SB1078

53 Flexibility Test for Cable Having Interlocked Armor or a Smooth or Corrugated Metal Sheath

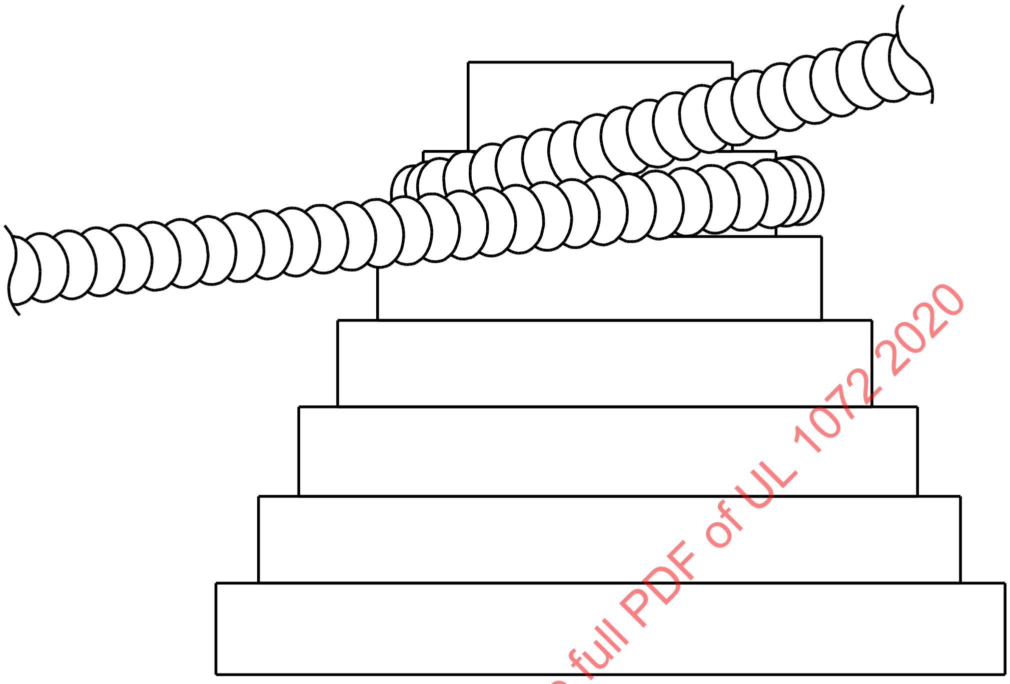
53.1 Finished cable in which there is interlocked armor or a smooth or corrugated metal sheath shall be capable of being wound around a circular mandrel having a diameter equal to 14 times the diameter measured over the metal armor or sheath without damage to the armor or sheath, to the jacket or separator (see 25.1) under the armor or sheath, or to the conductor or conductor assembly.

53.2 The apparatus is to consist either of a stepped cone as shown in Figure 53.1 (each step is to be a right-circular cylinder about 2 inches or 50 mm high) or of rods or cylinders of applicable diameter.

53.3 Any jacket over the armor or sheath (see 29.1) is to be removed from two test lengths of finished cable having armor or a smooth metal sheath and from six test lengths of finished cable having a welded and corrugated metal sheath. One test length of a cable having armor or a smooth metal sheath and three test lengths of a cable having a welded and corrugated metal sheath are then to be wound around the mandrel for 180° without any more tension than is necessary to keep the armor or sheath in contact with the mandrel throughout the turn. Each length is to be tested separately. In the case of a welded and corrugated metal sheath, one sample is to be bent with the weld line located at the inner edge of the bend, a second sample is to be bent with the weld line at the outer edge of the bend, and a third sample is to be bent with the weld line midway between the inner and outer edges of the bend. While a sample is in position on the mandrel, observation is to be made to determine whether or not the jacket or separator under the armor or sheath and the conductor or conductor assembly are damaged, and the armor or sheath is to be examined for damage. Cable having a smooth or corrugated sheath is acceptable if there are no weld openings, cracks, splits, tears, or other openings in a smooth or corrugated metal sheath. Adjacent convolutions of interlocked armor may separate somewhat but cable having interlocked armor is acceptable if no part of the cable inside the armor or metal sheath is visible. If any of these faults occur on the initial specimen or specimens, the test is to be repeated on the remaining one or three specimens. The cable is not acceptable if any of these faults occur on any of the additional specimens.

Figure 53.1

Stepped cone for flexibility test



SB1134

54 Tightness of Armor or Metal Sheath

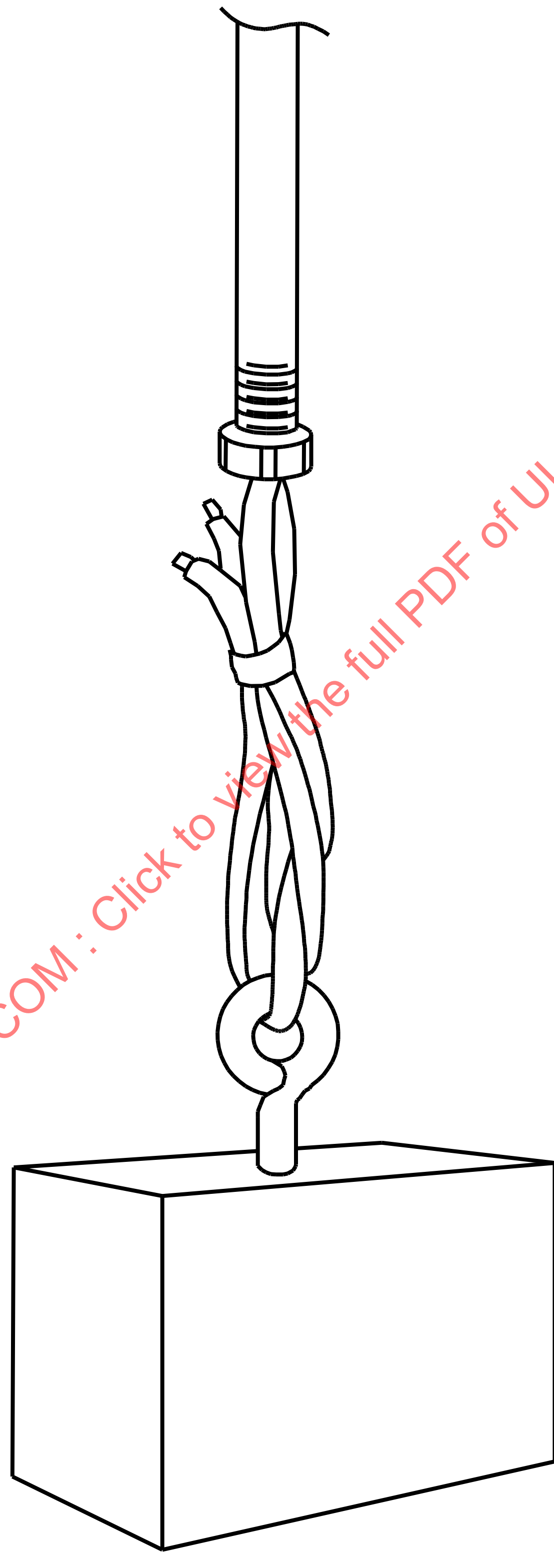
54.1 Any interlocked armor or smooth or corrugated metal sheath in a cable shall grip the underlying construction to keep it from being withdrawn from a 10-ft or 3-m sample of the finished cable by the application of a weight that exerts a pull of 30 lbf or 133 N or 13.6 kgf.

54.2 The apparatus is to consist of a 10 ft or 3 m length of pipe with an inside diameter that enables the cable sample to be pulled through the pipe, pipe caps with holes slightly larger in diameter than the inside diameter of the armor or metal sheath to be tested, and a weight that exerts a pull of 30 lbf or 133 N or 13.6 kgf. The pipe is to be used to keep a test sample approximately straight, and is to be supported in a vertical position with the pipe cap attached to the lower end. The pipe cap is to be used to provide a shoulder against which the armor or metal sheath of the sample can rest. The edges of the hole are to be rounded.

54.3 Two samples of the finished cable are to be cut to a length of 10-1/2 ft or 3150 mm and the armor or metal sheath is to be removed for 6 inches or 150 mm at one end of each sample. The ends of the armor or metal sheath are to be cut square and all burrs of metal are to be removed. One sample is then to be drawn into the pipe with the exposed 6 inch or 150 mm section of the conductor(s) projecting through the hole in the cap at the lower end of the pipe. The weight is to be attached to the conductor or assembly of conductors projecting through the hole, with the conductor or assembly not rubbing on the sides of the hole in the cap. The pipe in its vertical position is to be raised gently so that the weight just clears the floor and then hangs free for 60 s (see Figure 54.1). The cable is acceptable if the end(s) of the conductor(s) do not recede into the armor or metal sheath at the upper end a distance greater than 1/2 inch or 13 mm. If the conductor(s) of the first sample recede more than 1/2 inch or 13 mm, the test is to be repeated with the remaining sample. The cable is not acceptable if the conductor(s) of the additional sample recede more than 1/2 inch or 13 mm.

Figure 54.1

Test for tightness of armor or metal sheath



SB1133