UL 1063

STANDARD FOR SAFETY

Machine-Tool Wires and Cables

UL Standard for Safety for Machine-Tool Wires and Cables, UL 1063

Ninth Edition, Dated August 2, 2023

SUMMARY OF TOPICS:

This new Ninth Edition of ANSI/UL 1063 dated August 2, 2023 includes the addition of odd AWG sizes and other clarifications.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated March 31, 2023.

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AUGUST 2, 2023

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UL 1063

Standard for Machine-Tool Wires and Cables

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This ANSI/UL Standard for Safety consists of the Ninth Edition.

The most recent designation of ANSI/UL 1063 as an American National Standard (ANSI) occurred on August 2, 2023. 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 ULSE at any time. Proposals should be submitted via a Proposal Request in the Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Scope

1.1 These requirements cover all-thermoplastic Type MTW, 600-V, machine-tool wires and cables for use as specified in the National Electrical Code (NFPA 70), and in the National Fire Protection Association Electrical Standard for Industrial Machinery (NFPA 79). These wires and cables comply with a flame test and are for use at 90 °C (194 °F) and lower temperatures in dry locations and at 60 °C (140 °F) and lower temperatures where exposed to moisture, oil, or coolants such as cutting oils and the like.

1.2 The two single-conductor constructions covered are described in Table 1.1. Both are PVC-insulated and one includes a nylon jacket over the insulation. These single-conductor constructions may be optionally shielded and jacketed. The multiple-conductor constructions covered consist of assemblies of these single-conductor constructions (sizes and styles may be mixed) enclosed by a PVC jacket.

Table 1.1
Single-Conductor Constructions

Conductor[a] size AWG or kcmil	NEC Construction A (Nylon jacket not used)				NEC Construction B					
	Minimum average thickness of the insulation		Minimum thickness of any point of the insulation		Minimum average thickness of the insulation		Minimum thickness of any point of the insulation		Minimum thickness of any point of nylon jacket	
	Mils	(mm)	Mils	(mm)	Mils	(mm)	Mils	(mm)	Mils	(mm)
22, 7-strand only; 21 – 12	30	(0.76)	27	(0.69)	15	(0.38)	13	(0.33)	4	(0.10)
11 – 10	30	(0.76)	27	(0.69)	20	(0.51)	18	(0.46)	4	(0.10)
9, 8	45	(1.14)	40	(1.02)	30	(0.76)	27	(0.69)	5	(0.13)
7, 6	60	(1.52)	54	(1.37)	30	(0.76)	27	(0.69)	5	(0.13)
5 – 2	60	(1.52)	54	(1.37)	40	(1.02)	36	(0.91)	6	(0.15)
1 – 4/0	80	(2.03)	72	(1.83)	50	(1.27)	45	(1.14)	7	(0.18)
250 – 500	95	(2.41)	86	(2.18)	60	(1.52)	54	(1.37)	8	(0.20)
550 – 1000	110	(2.79)	99	(2.51)	70	(1.78)	63	(1.60)	9	(0.23)

[a] A conductor is appropriate for use with a cross-sectional area that does not correspond to one of the AWG or kcmil sizes in Table 6.2 when the finished wire or cable complies with the marking requirement in 30.2 and with each of the following:

a) The conductor shall have a DC resistance that is not larger than the resistance determined by interpolation (by cross-sectional area) between the resistances of the next larger and smaller sizes shown in the applicable Table 6.7 or Table 6.8.

b) The number of strands, the thicknesses of insulation, the thickness of any nylon jacket, and other particulars shall comply with the requirements applicable to the next smaller size shown in Table 6.2.

2 Units of Measurement

2.1 When a value for measurement is followed by a value in other units in parentheses, the second value may be only approximate. The first stated value is the requirement.

3 References

3.1 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.

4 Terms

4.1 Wherever the designation "UL 1581" is used in this wire standard, reference is to be made to the designated part(s) of the Reference Standard for Electrical Wires, Cables, and Flexible Cords (UL 1581). Wherever the designation "UL 2556" is used in this wire standard, reference is to be made to the designated part(s) of the Standard for Wire and Cable Test Methods, (UL 2556).

CONSTRUCTION

5 General

5.1 Materials

5.1.1 Each material used in a machine-tool wire or cable shall be compatible with all of the other materials used in the wire or cable.

5.2 PVC

5.2.1 Wherever "PVC" appears in these requirements the intention is to designate a synthesized compound whose characteristic constituent is polyvinyl chloride or a copolymer of vinyl chloride and vinyl acetate.

6 Conductors

6.1 Metal

6.1.1 Each conductor shall be only of stranded soft-annealed copper with or without continuous coating of tin applied before the conductor is stranded or insulated.

6.1.2 Each strand in a bare copper conductor shall comply with the requirements of ASTM B3.

6.1.3 Each strand in a tin-coated conductor shall comply with the requirements of ASTM B33.

6.2 Sizes

6.2.1 Conductors shall not be smaller than 22 AWG and shall not be larger than 1000 kcmil.

6.2.2 The size of each conductor shall be verified either by determination of the DC resistance or by determination of the cross-sectional area as described in 6.6.1. Determination of the conductor size by measurement of the direct-current resistance as described in 6.7.1 is the referee method in all cases.

6.3 Number and assembly of strands and conductor diameters

6.3.1 Conductors shall be stranded with at least the number of strands indicated in the applicable Table 6.3, Table 6.4, or Table 6.5. A 19-wire combination round-wire unilay-stranded soft-annealed copper 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. Otherwise, no particular assembly of the individual strands is required; however, untwisted strands shall not be used for the entire conductor or any part thereof. Class B or C 16 AWG – 1000 kcmil conductors shall be with or without compressed strands. Compressed stranding shall not be used in the Size 22 AWG, 7 strand construction, or in the Class K and

M constructions. Only single-bunch, bunch stranding and the concentric, rope-lay, and 19-wire combination unilay assemblies indicated in Table 6.3, Table 6.4, and Table 6.5 shall be used. Compact stranding shall not be used.

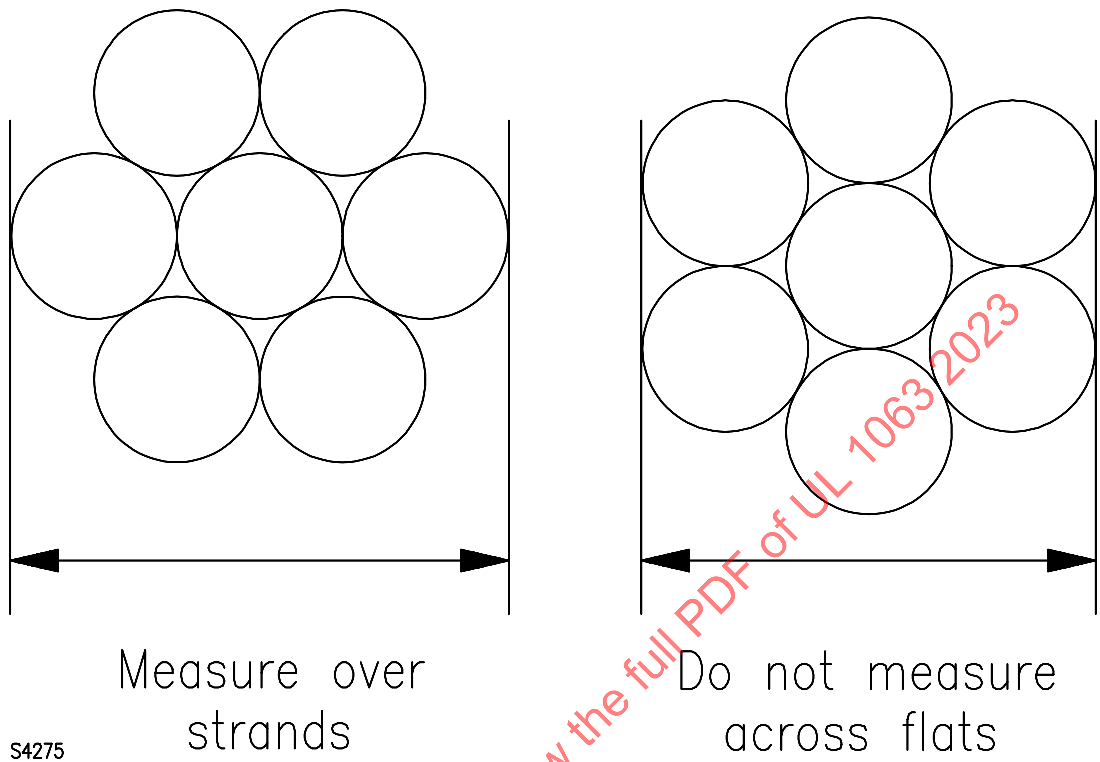
6.3.2 A compressed round concentric-lay-stranded conductor shall be a round conductor consisting of a central core wire surrounded by one or more layers of helically laid wires with, for the 6 AWG – 1000 kcmil sizes, the direction of lay reversed in successive layers or unilay or unidirectional lay. The direction of lay of the outer layer shall be left-hand in all cases. The strands of one or more layers shall be slightly compressed by rolling, drawing, or other means to slightly change the originally round strands to various shapes that fill some of the spaces originally present between the strands.

6.3.3 A finished compressed-stranded Class B or C conductor shall not be larger in average diameter than the maximum diameter indicated for the size under Y in Table 6.3 and shall not be smaller in average diameter than the minimum diameter indicated for the size under Z in Table 6.3 Class B or C 16 AWG – 1000 kcmil conductors with uncompressed strands shall not be larger or smaller in average diameter than the maximum and minimum diameters indicated for the size in Tables 20.4 (Class B) and 20.4.1 (Class C) of UL 1581. The average diameter of the conductor is to be determined and compared with the table in the manner described in 6.3.4 and 6.3.5. Class B 1 AWG – 1000 kcmil conductors with round unilay or unidirectional lay compressed strands shall not be larger or smaller in average diameter than the maximum and minimum diameters indicated for the size in Table 20.3.1 of UL 1581. A finished 19-wire combination unilay conductor shall not be larger in average diameter than the maximum diameter indicated for the size in Table 20.6 of UL 1581. The average diameter of a conductor is to be determined and compared with the tables in the manner described in 6.3.4 and 6.3.5.

6.3.4 For diameter measurements, the insulation is to be removed at a single place at the center of a straight length of the finished conductor. Measurements of the conductor diameter are to be made over the metal-coated or uncoated conductor strands by means of a machinist's micrometer caliper having flat surfaces both on the anvil and on the end of the spindle. The measurements for all constructions for which the diameter requirements apply are to be made over the strands rather than across flats; this is illustrated in Figure 6.1 only for a 7-strand construction. The measurements are to be made on a line extending through the center of the conductor and through the center of two wires (strands) in the outer layer that are 180° apart. The micrometer is to be calibrated to read directly to at least 0.001 inch or 0.01 mm, with each division of a width that facilitates estimation of each measurement to at least 0.0001 inch or 0.001 mm. The maximum and minimum diameters at that point are each to be recorded to the nearest 0.0001 inch or 0.001 mm, added together, and divided by 2 without any rounding of the sum or resulting average.

Figure 6.1

Conductor Diameter Measurement



6.3.5 Each minimum and maximum diameter indicated in Table 6.3 and in Tables 20.3.1, 20.4, 20.4.1, and 20.6 of UL 1581 is absolute. The unrounded average of the two diameter readings is therefore to be compared directly with both the minimum and the maximum in the table.

6.4 Lay

6.4.1 Concentric conductors

6.4.1.1 The length of lay of the strands in both layers of a 19-wire combination round-wire unilay-stranded copper 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. 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 that layer. The direction of lay of the outer layer shall be left-hand.

6.4.2 Single-bunch bunch-stranded conductors

6.4.2.1 The length of lay of the strands in a single-bunch bunch-stranded conductor shall not be greater than indicated in Table 6.1. The direction of lay shall be left-hand.

Table 6.1
Length of Lay of Strands in a Single-Bunch Bunch-Stranded Conductor

Size of conductor AWG or kcmil	Maximum length of lay	
	inches	(mm)
22 – 17	1	(25)
16, 15	1-1/4	(32)
14, 13	1-5/8	(41)
12, 11	2	(51)
10, 9	2-1/2	(64)
8, 7	2-3/4	(70)
6	3-3/8	(86)
5 – 1000	16 times the diameter of the conductor	

6.4.3 Rope-lay bunch-stranded conductors

6.4.3.1 The length of lay of the individual strands in a bunch-stranded member of a rope-lay-stranded conductor shall not be more than 30 times the overall diameter of the member, and the length of the lay of the members in the outer layer shall neither be less than 8 nor more than 16 times the overall conductor diameter. The direction of lay of the outer layer shall be left-hand.

6.5 Joints

6.5.1 A joint in one strand of a stranded conductor shall be made in a workmanlike manner, shall not change the diameter of the strand or of the overall conductor, and shall not lessen the mechanical strength of the overall conductor. A joint shall be made by separately joining each strand. A joint shall not impair the flexibility of the conductor. A joint in a compressed-stranded conductor shall be made before compressing.

6.6 Area

6.6.1 Where measured as the means of size verification (see 6.2.2) the cross-sectional area of a conductor shall not be smaller than the minimum indicated for the size in Table 6.2.

Table 6.2
Cross-Sectional Areas of Conductors

Conductor size, AWG or kcmil	Nominal		Minimum acceptable	
	cmil	(mm^2)	cmil	(mm^2)
22	640	(0.324)	627	(0.318)
21	812	(0.412)	796	(0.404)
20	1020	(0.519)	1000	(0.507)
19	1290	(0.653)	1264	(0.641)
18	1620	(0.823)	1571	(0.798)
17	2050	(1.04)	2009	(1.02)
16	2580	(1.31)	2528	(1.28)
15	3260	(1.65)	3195	(1.62)
14	4110	(2.08)	4028	(2.04)

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Table 6.2 Continued

Conductor size, AWG or kcmil	Nominal		Minimum acceptable	
	cmil	(mm^2)	cmil	(mm^2)
13	5180	(2.63)	5076	(2.58)
12	6530	(3.31)	6399	(3.24)
11	8230	(4.17)	8065	(4.09)
10	10380	(5.261)	10172	(5.16)
9	13090	(6.631)	12828	(6.50)
8	16510	(8.367)	16180	(8.20)
7	20820	(10.55)	20404	(10.34)
6	26240	(13.30)	25715	(13.03)
5	33090	(16.77)	32428	(16.43)
4	41740	(21.15)	40905	(20.73)
3	52620	(26.67)	51568	(26.14)
2	66360	(33.62)	65023	(32.95)
1	83690	(42.41)	82016	(41.56)
1/0	105600	(53.49)	103488	(52.42)
2/0	133100	(67.43)	130438	(66.08)
3/0	167800	(85.01)	164444	(83.31)
4/0	211600	(107.2)	207368	(105.1)
250	–	(127)	245	(124.5)
300	–	(152)	294	(149.0)
350	–	(177)	343	(173.5)
400	–	(203)	392	(198.9)
450	–	(228)	441	(223.4)
500	–	(253)	490	(247.9)
550	–	(279)	539	(273.4)
600	–	(304)	588	(297.9)
650	–	(329)	637	(322.4)
700	–	(355)	686	(347.9)
750	–	(380)	735	(372.4)
800	–	(405)	784	(396.9)
900	–	(456)	882	(446.9)
1000	–	(507)	980	(496.9)

Table 6.3
Stranding and Diameters of Compressed Round Concentric-Lay Conductors for Nonflexing Service

Conductor size AWG or kcmil	Minimum number of strands	ASTM class of stranding (not a requirement)	Z Minimum mils	Z Minimum (mm)	Y Maximum mils	Y Maximum (mm)
22	7 only	a, b	–	–	–	–
21	10	K[b]	–	–	–	–
20	10	K[b]	–	–	–	–
19	10	K[b]	–	–	–	–
18	16	K[b]	–	–	–	–
17	16	K[b]	–	–	–	–
16	19	C	55	(1.40)	57	(1.45)
15	19	C	63	(1.60)	65	(165)
14	19	C	70	(1.79)	72	(1.83)
13	19	C	78	(1.98)	81	(2.06)
12	19	C	87	(2.21)	90	(2.29)
11	19	C	98	(2.49)	101	(2.57)
10	19	C	111	(2.82)	114	(2.90)
9	19	C	123	(3.12)	127	(3.23)
8	19	C	139	(3.53)	143	(3.68)
7	19	C	156	(3.96)	161	(4.09)
6	19	C[c]	174	(4.42)	180	(4.57)
5	19	C[c]	196	(4.98)	202	(5.13)
4	19	C[c]	221	(5.61)	227	(5.77)
3	19	C[c]	247	(6.27)	255	(6.48)
2	19	C[c]	277	(7.04)	286	(7.26)
1	19	B[c]	316	(8.03)	325	(8.26)
1/0	19	B[c]	355	(9.02)	366	(9.30)
2/0	19	B[c]	397	(10.08)	409	(10.39)
3/0	19	B[c]	447	(11.35)	461	(11.71)
4/0	19	B[c]	502	(12.75)	517	(13.13)
250	37	B	547	(13.89)	564	(14.33)
300	37	B	599	(15.21)	617	(15.67)
350	37	B	648	(16.46)	668	(19.97)
400	37	B	692	(17.58)	713	(18.11)
450	37	B	734	(18.64)	756	(19.20)
500	37	B	773	(19.63)	797	(20.24)
550	61	B	812	(20.62)	837	(21.26)
600	61	B	849	(21.56)	875	(22.23)
650	61	B	883	(22.43)	910	(23.11)
700	61	B	916	(23.27)	944	(23.98)
750	61	B	949	(24.10)	978	(24.84)
800	61	B	980	(24.89)	1010	(25.65)

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Table 6.3 Continued

Conductor size AWG or kcmil	Minimum number of strands	ASTM class of stranding (not a requirement)	Z Minimum		Y Maximum	
			mils	(mm)	mils	(mm)
900	61	B	1039	(26.39)	1071	(27.20)
1000	61	B	1095	(27.81)	1128	(28.65)

[a] A class designation is not assigned to this conductor. The conductor is a concentric-lay-stranded construction and is designated as Size 22 AWG, 7 strand in ASTM B286. The conductor is composed of strands 10 mils or 0.254 mm in diameter (30 AWG).

[b] Compressed stranding is only for the Class B and C constructions, not for the Size 22 AWG, 7 strand and Class K constructions (see 6.3.1). The nominal diameters are: Size 22 AWG, 7 30 mils or 0.76 mm, 20 AWG 38 mils or 0.97 mm, and 18 AWG 48 mils or 1.22 mm.

[c] An alternative construction for the ASTM class of stranding is the 19-wire combination round-wire unilay-stranded soft-annealed copper conductor described in the second sentence of 6.3.1 and for which nominal dimensions are shown in Table 6.6 and for which minimum and maximum diameters are indicated in Table 20.6 of UL 1581. Each strand shall be metal coated or uncoated.

Table 6.4
Stranding and Diameters of Conductors for Flexing Service

Conductor size AWG or kcmil	Minimum number of strands	ASTM class of stranding (not a requirement)	Nominal conductor diameter (not a requirement)	
			mils	(mm)
22	7 only	a, b	30	(0.76)
21	10	K[b]	34	(0.86)
20	10	K[b]	38	(0.97)
19	10	K[b]	42	(1.07)
18	16	K[b]	48	(1.22)
17	16	K[b]	54	(1.37)
16	26	K[b]	60	(1.52)
15	26	K[b]	69	(1.75)
14	41	K[b]	78	(1.98)
13	41	K[b]	90	(2.29)
12	65	K[b]	101	(2.57)
11	65	K[b]	114	(2.90)
10	104	K[b]	126	(3.20)
9	104	K[b]	140	(3.56)
8 – 1000	see note c	see note c	–	–

[a] See note a to Table 6.3.

[b] Compressed stranding is only for the Class B and C nonflexing constructions (Table 6.3), not for the Size 22–7 and Class K constructions. See 6.3.1.

[c] NFPA 79 accepts 8 AWG – 1000 kcmil conductors for flexing service of the same construction as the nonflexing conductors in these sizes shown in Table 6.3. See 31.1. Where a nonflexing construction is used, the diameter requirements in 6.3.2 – 6.3.5 apply.

Table 6.5
Stranding and Diameters of Conductors for Multiple-Conductor Cable Intended for Constant-Flexing Service

Conductor size AWG or kcmil	Minimum number of strands	ASTM class of stranding (not a requirement)	Nominal conductor diameter (not a requirement) mils	(mm)
22	7 only	a	–	–
21	–	–	–	–
20	–	–	–	–
19	41	M	42	(1.07)
18	41	M	48	(1.22)
17	65	M	54	(1.37)
16	65	M	60	(1.52)
15	65	M	69	(1.75)
14	41	K	78	(1.98)
13	41	K	90	(2.29)
12	65	K	101	(2.57)
11	65	K	114	(2.90)
10	104	K	126	(3.20)
9	104	K	140	(3.56)
8 – 1000	–	–	–	–

[a] See note a to Table 6.3.

Table 6.6
Nominal Strand and Conductor Dimensions for 19-wire Combination Round-Wire Unilay-Stranded Copper Conductors

AWG conductor size	Nominal strand dimensions								E = 3A + 2C	
	Large strand				Small strand				Nominal conductor diameter	
	A Diameter		B Cross-sectional area		C Diameter		D Cross-sectional area			
	inch	(mm)	cmil	(mm^2)	inch	(mm)	cmil	(mm^2)	inch	(mm)
14	0.0159	(0.40)	253	(0.128)	0.0117	(0.30)	137	(0.069)	0.071	(1.80)
13	0.0179	(0.45)	320	(0.162)	0.0131	(0.33)	171	(0.087)	0.080	(2.03)
12	0.0201	(0.51)	404	(0.223)	0.0147	(0.37)	217	(0.110)	0.090	(2.29)
11	0.0226	(0.57)	510	(0.258)	0.0165	(0.42)	272	(0.138)	0.100	(2.55)
10	0.0253	(0.64)	640	(0.324)	0.0185	(0.47)	342	(0.173)	0.113	(2.87)
9	0.0284	(0.72)	807	(0.408)	0.0208	(0.53)	433	(0.219)	0.127	(3.23)
8	0.0319	(0.81)	1018	(0.515)	0.0234	(0.59)	548	(0.277)	0.143	(3.63)
7	0.359	(0.91)	1289	(0.653)	0.262	(0.65)	686	(0.348)	0.160	(4.03)
6	0.0402	(1.02)	1616	(0.818)	0.0294	(0.75)	864	(0.437)	0.179	(4.55)
5	0.0452	(1.15)	2043	(1.034)	0.0331	(0.84)	1096	(0.555)	0.202	(5.13)
4	0.0507	(1.29)	2570	(1.301)	0.0371	(0.94)	1376	(0.696)	0.226	(5.74)
3	0.0570	(1.45)	3249	(1.644)	0.0417	(1.06)	1739	(0.880)	0.254	(6.45)

Table 6.6 Continued on Next Page

Table 6.6 Continued

AWG conductor size	Nominal strand dimensions								E = 3A + 2C Nominal conductor diameter	
	Large strand				Small strand					
	A Diameter		B Cross-sectional area		C Diameter		D Cross-sectional area			
	inch	(mm)	cmil	(mm^2)	inch	(mm)	cmil	(mm^2)	inch	(mm)
2	0.0640	(1.62)	4096	(2.073)	0.0468	(1.19)	2190	(1.108)	0.286	(7.26)
1	0.0718	(1.82)	5155	(2.609)	0.0526	(1.34)	2767	(1.400)	0.321	(8.15)
1/0	0.0807	(2.05)	6512	(3.296)	0.0591	(1.50)	3493	(1.768)	0.360	(9.14)
2/0	0.0906	(2.30)	8208	(4.154)	0.0663	(1.68)	4396	(2.225)	0.404	(10.26)
3/0	0.1017	(2.58)	10343	(5.234)	0.0745	(1.89)	5550	(2.809)	0.454	(11.53)
4/0	0.1142	(2.90)	13042	(6.600)	0.0836	(2.12)	6989	(3.537)	0.510	(12.95)

6.6.2 The cross-sectional area of a conductor having round strands is to be determined either:

a) As the sum of the areas of its component round strands (see 6.6.3), or

b) By the weight method in accordance with the test, Cross-sectional area by mass (weight) method in UL 2556.

6.6.3 The diameter of a round strand is to be measured over any tin or other metal coating by means of a machinist's micrometer caliper having flat surfaces on the anvil and on the end of the spindle. The caliper is to be calibrated to read directly to at least 0.001 inch or 0.01 mm with each division of a width that facilitates estimation of each measurement to 0.0001 inch or 0.001 mm.

6.7 Resistance

6.7.1 Where measured as the means of size verification (see 6.2.2) of a conductor stranded as indicated in Table 6.3, Table 6.4, or Table 6.5, the direct-current resistance of any length in ohms per thousand conductor feet or in ohms per conductor kilometer shall not be higher than indicated for the size in Table 6.7 at 25 °C (77 °F) or in Table 6.8 at 20 °C (68 °F) when measured by a Kelvin-bridge ohmmeter or its equivalent or, for a 19-wire combination unilay-stranded conductor, shall not be higher than indicated for the size in Table 6.10. See 6.7.2.

Table 6.7
Maximum Acceptable DC Resistance of Conductors at 25 °C (77 °F)

Conductor size AWG or kcmil	Concentric-lay stranded conductor (22 AWG – 1000 kcmil) and round compressed-stranded conductor (16 AWG – 1000 kcmil)				Single-bunch bunch-stranded conductor			
	Uncoated		Coated		Uncoated		Coated	
	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)
22	17.2	(56.4)	18.5	(60.7)	17.2	(56.4)	18.5	(60.7)
21	13.5	(44.3)	14.0	(46.1)	5	(44.3)	14.0	(46.1)
20	10.8	(35.3)	11.4	(37.4)	10.9	(36.8)	11.7	(38.4)
19	8.53	(28.0)	8.84	(29.1)	8.53	(28.0)	8.87	(29.1)

Table 6.7 Continued on Next Page

Table 6.7 Continued

Conductor size AWG or kcmil	Concentric-lay stranded conductor (22 AWG – 1000 kcmil) and round compressed-stranded conductor (16 AWG – 1000 kcmil)				Single-bunch bunch-stranded conductor			
	Uncoated		Coated		Uncoated		Coated	
	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)
18	6.79	(22.2)	7.19	(23.6)	6.85	(22.5)	7.36	(24.6)
17	5.37	(17.6)	5.58	(18.3)	5.37	(17.6)	5.58	(18.3)
16	4.26	(14.0)	4.53	(14.9)	4.26	(14.0)	4.58	(15.0)
15	3.37	(11.1)	3.50	(11.5)	3.37	(11.1)	3.37	(11.5)
14	2.68	(8.78)	2.78	(9.14)	2.67	(8.76)	2.89	(9.48)
13	2.12	(6.97)	2.20	(7.25)	2.12	(6.97)	2.20	(7.25)
12	1.68	(5.53)	1.75	(5.75)	1.69	(5.55)	1.81	(5.94)
11	1.34	(4.39)	1.39	(4.53)	1.34	(4.39)	1.39	(4.53)
10	1.060	(3.476)	1.102	(3.615)	1.06	(3.38)	1.14	(3.74)
9	0.8407	(2.758)	0.8474	(2.868)	–	–	–	–
8	0.6663	(2.186)	0.6929	(2.274)	–	–	–	–
7	0.5284	(1.734)	0.5495	(1.803)	–	–	–	–
6	0.4192	(1.375)	0.4359	(1.430)	–	–	–	–
5	0.3325	(1.091)	0.3458	(1.134)	–	–	–	–
4	0.2636	(0.8649)	0.2742	(0.8993)	–	–	–	–
3	0.2091	(0.6860)	0.2175	(0.7133)	–	–	–	–
2	0.1659	(0.5440)	0.1724	(0.5657)	–	–	–	–
1	0.1315	(0.4313)	0.1367	(0.4485)	–	–	–	–
1/0	0.1042	(0.3419)	0.1084	(0.3556)	–	–	–	–
2/0	0.08267	(0.2712)	0.08598	(0.2820)	–	–	–	–
3/0	0.06558	(0.2151)	0.06820	(0.2238)	–	–	–	–
4/0	0.05200	(0.1705)	0.05352	(0.1755)	–	–	–	–
250	0.04401	(0.1444)	0.04577	(0.1501)	–	–	–	–
300	0.03667	(0.1204)	0.03814	(0.1252)	–	–	–	–
350	0.03144	(0.1031)	0.03269	(0.1072)	–	–	–	–
400	0.02751	(0.09024)	0.02831	(0.09288)	–	–	–	–
450	0.02445	(0.08213)	0.02516	(0.08256)	–	–	–	–
500	0.02200	(0.07220)	0.02264	(0.07431)	–	–	–	–
550	0.02000	(0.06563)	0.02080	(0.06825)	–	–	–	–
600	0.01834	(0.06016)	0.01907	(0.06257)	–	–	–	–
650	0.01692	(0.05553)	0.01742	(0.05715)	–	–	–	–
700	0.01572	(0.05157)	0.01618	(0.05307)	–	–	–	–
750	0.01467	(0.04812)	0.01510	(0.04953)	–	–	–	–
800	0.01375	(0.04512)	0.01416	(0.04644)	–	–	–	–
900	0.01222	(0.04011)	0.01259	(0.04128)	–	–	–	–
1000	0.01101	(0.03610)	0.01132	(0.03715)	–	–	–	–

Table 6.8
Maximum Acceptable DC Resistance of Conductors at 20 °C (68 °F)

Conductor size, AWG or kcmil	Concentric-lay stranded conductor (22 AWG – 1000 kcmil) and round compressed-stranded conductor (16 AWG – 1000 kcmil)				Single-bunch bunch-stranded conductor			
	Uncoated		Coated		Uncoated		Coated	
	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)
22	16.9	(55.4)	18.1	(59.4)	16.9	(55.5)	18.1	(59.4)
21	13.3	(43.6)	13.8	(45.3)	13.3	(43.6)	13.8	(45.3)
20	10.6	(34.6)	11.2	(36.7)	10.7	(35.1)	11.5	(37.7)
19	8.36	(27.4)	8.69	(28.5)	8.36	(27.4)	8.69	(28.5)
18	6.66	(21.8)	7.06	(23.2)	6.72	(22.1)	7.23	(23.7)
17	5.27	(17.3)	5.48	(18.0)	5.27	(17.3)	5.48	(18.0)
16	4.18	(13.7)	4.45	(14.6)	4.18	(13.7)	4.54	(14.9)
15	3.31	(10.9)	3.44	(11.3)	3.31	(10.9)	3.44	(11.3)
14	2.62	(8.62)	2.73	(8.96)	2.63	(8.64)	2.82	(9.25)
13	2.08	(6.82)	2.16	(7.09)	2.08	(6.82)	2.16	(7.09)
12	1.65	(5.43)	1.72	(5.64)	1.65	(5.42)	1.78	(5.84)
11	1.32	(4.30)	1.37	(4.47)	1.32	(4.30)	1.37	(4.47)
10	1.039	(3.409)	1.080	(3.546)	1.04	(3.42)	1.12	(3.68)
9	0.8245	(2.705)	0.8575	(2.813)	–	–	–	–
8	0.6535	(2.144)	0.6795	(2.230)	–	–	–	–
7	0.5182	(1.700)	0.5389	(1.768)	–	–	–	–
6	0.4112	(1.348)	0.4276	(1.403)	–	–	–	–
5	0.3261	(1.070)	0.3391	(1.082)	–	–	–	–
4	0.2585	(0.8481)	0.2689	(0.8820)	–	–	–	–
3	0.2050	(0.6727)	0.2132	(0.6996)	–	–	–	–
2	0.1626	(0.5335)	0.1691	(0.5548)	–	–	–	–
1	0.1289	(0.4230)	0.1340	(0.4398)	–	–	–	–
1/0	0.1022	(0.3354)	0.1063	(0.3487)	–	–	–	–
2/0	0.08108	(0.2660)	0.08432	(0.2766)	–	–	–	–
3/0	0.06431	(0.2110)	0.06688	(0.2194)	–	–	–	–
4/0	0.05099	(0.1673)	0.05248	(0.1722)	–	–	–	–
250	0.04316	(0.1416)	0.04488	(0.1473)	–	–	–	–
300	0.03597	(0.1180)	0.03740	(0.1227)	–	–	–	–
350	0.03082	(0.10114)	0.03206	(0.1052)	–	–	–	–
400	0.02698	(0.08851)	0.02776	(0.09109)	–	–	–	–
450	0.02398	(0.07867)	0.02467	(0.08097)	–	–	–	–
500	0.02158	(0.07080)	0.02222	(0.07287)	–	–	–	–
550	0.01961	(0.06436)	0.02040	(0.06693)	–	–	–	–
600	0.01798	(0.05900)	0.01871	(0.06135)	–	–	–	–
650	0.01660	(0.05447)	0.01709	(0.05606)	–	–	–	–

Table 6.8 Continued on Next Page

Table 6.8 Continued

Conductor size, AWG or kcmil	Concentric-lay stranded conductor (22 AWG – 1000 kcmil) and round compressed-stranded conductor (16 AWG – 1000 kcmil)				Single-bunch bunch-stranded conductor			
	Uncoated		Coated		Uncoated		Coated	
	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)	Ohms per 1000 feet	(Ohms per kilometer)
700	0.01541	(0.05057)	0.01586	(0.05205)	–	–	–	–
750	0.01438	(0.04721)	0.01481	(0.04858)	–	–	–	–
800	0.01348	(0.04425)	0.01388	(0.04554)	–	–	–	–
900	0.01199	(0.03933)	0.01234	(0.04048)	–	–	–	–
1000	0.01079	(0.03540)	0.01111	(0.03643)	–	–	–	–

6.7.2 The resistance of a conductor measured at a temperature other than 25 °C (77 °F) or 20 °C (68 °F) is to be changed to the resistance at 25 °C (77 °F) or 20 °C (68 °F) by means of the applicable multiplying factor from Table 6.9.

Table 6.9
Factors for Adjusting DC Resistance of Conductors

Temperature of conductor		Multiplying factor for adjustment to resistance at		Temperature of conductor		Multiplying factor for adjustment to resistance at	
°C	(°F)	25 °C (77 °F)	20 °C (68 °F)	°C	(°F)	25 °C (77 °F)	20 °C (68 °F)
0	(32.0)	1.107	1.085	45	(113.0)	0.928	0.911
1	(33.8)	1.102	1.081	46	(114.8)	0.925	0.908
2	(35.6)	1.098	1.076	47	(116.6)	0.922	0.905
3	(37.4)	1.093	1.072	48	(118.4)	0.918	0.901
4	(39.2)	1.089	1.067	49	(120.2)	0.915	0.898
5	(41.0)	1.084	1.063	50	(122.0)	0.912	0.895
6	(42.8)	1.079	1.059	51	(123.8)	0.909	0.892
7	(44.6)	1.075	1.054	52	(125.6)	0.906	0.889
8	(46.4)	1.070	1.050	53	(127.4)	0.902	0.885
9	(48.2)	1.066	1.045	54	(129.2)	0.899	0.882
10	(50.0)	1.061	1.041	55	(131.0)	0.896	0.879
11	(51.8)	1.057	1.037	56	(132.8)	0.893	0.876
12	(53.6)	1.053	1.033	57	(134.6)	0.890	0.873
13	(55.4)	1.048	1.028	58	(136.4)	0.887	0.870
14	(57.2)	1.044	1.024	59	(138.2)	0.884	0.867
15	(59.0)	1.040	1.020	60	(140.0)	0.881	0.864
16	(60.8)	1.036	1.016	61	(141.8)	0.878	0.861
17	(62.6)	1.032	1.012	62	(143.6)	0.875	0.858
18	(64.4)	1.028	1.008	63	(145.4)	0.872	0.856
19	(66.2)	1.024	1.004	64	(147.2)	0.869	0.853
20	(68.0)	1.020	1.000	65	(149.0)	0.866	0.850

Table 6.9 Continued on Next Page

Table 6.9 Continued

Temperature of conductor °C	(°F)	Multiplying factor for adjustment to resistance at 25 °C (77 °F)	20 °C (68 °F)	Temperature of conductor °C	(°F)	Multiplying factor for adjustment to resistance at 25 °C (77 °F)	20 °C (68 °F)
21	(69.8)	1.016	0.996	66	(150.8)	0.863	0.847
22	(71.6)	1.012	0.992	67	(152.6)	0.860	0.844
23	(73.4)	1.008	0.989	68	(154.4)	0.858	0.842
24	(75.2)	1.004	0.985	69	(156.2)	0.855	0.839
25	(77.0)	1.000	0.981	70	(158.0)	0.852	0.836
26	(78.8)	0.996	0.977	71	(159.8)	0.849	0.833
27	(80.6)	0.992	0.973	72	(161.6)	0.846	0.830
28	(82.4)	0.989	0.970	73	(163.4)	0.844	0.828
29	(84.2)	0.985	0.966	74	(165.2)	0.841	0.825
30	(86.0)	0.981	0.962	75	(167.0)	0.838	0.822
31	(87.8)	0.977	0.958	76	(168.8)	0.835	0.819
32	(89.6)	0.974	0.955	77	(170.6)	0.833	0.817
33	(91.4)	0.970	0.951	78	(172.4)	0.830	0.814
34	(93.2)	0.967	0.948	79	(174.2)	0.828	0.812
35	(95.0)	0.963	0.944	80	(176.0)	0.825	0.809
36	(96.8)	0.959	0.941	81	(177.8)	0.822	0.807
37	(98.6)	0.956	0.937	82	(179.6)	0.820	0.804
38	(100.4)	0.952	0.934	83	(181.4)	0.817	0.802
39	(102.2)	0.949	0.930	84	(183.2)	0.815	0.799
40	(104.0)	0.945	0.927	85	(185.0)	0.812	0.797
41	(105.8)	0.942	0.924	86	(186.8)	0.810	0.794
42	(107.6)	0.938	0.921	87	(188.6)	0.807	0.792
43	(109.4)	0.935	0.917	88	(190.4)	0.805	0.789
44	(111.2)	0.931	0.914	89	(192.2)	0.802	0.787
				90	(194.0)	0.800	0.784

Table 6.10
Maximum Acceptable Direct-Current Resistance of 19-Wire Combination Round-Wire Unilay-Stranded Copper Conductors

Metal coating of strands	AWG size of conductor	20 °C		25 °C	
		Ohms based on 1000 feet of conductor	(Ohms based on 1 kilometer of conductor)	Ohms based on 1000 feet of conductor	(Ohms based on 1 kilometer of conductor)
Each coated	14	2.78	(9.15)	2.85	(9.32)
	13	2.21	(7.26)	2.25	(7.41)
	12	1.75	(5.75)	1.78	(5.88)
	11	1.37	(4.48)	1.39	(4.56)
	10	1.08	(3.55)	1.10	(3.62)
	9	0.857	(2.82)	0.874	(2.87)

Table 6.10 Continued on Next Page

Table 6.10 Continued

Metal coating of strands	AWG size of conductor	20 °C		25 °C	
		Ohms based on 1000 feet of conductor	(Ohms based on 1 kilometer of conductor)	Ohms based on 1000 feet of conductor	(Ohms based on 1 kilometer of conductor)
	8	0.679	(2.23)	0.692	(2.27)
	7	0.539	(1.76)	0.550	(1.81)
	6	0.427	(1.41)	0.436	(1.43)
	5	0.339	(1.11)	0.346	(1.13)
	4	0.269	(0.882)	0.274	(0.900)
	3	0.213	(0.700)	0.217	(0.713)
	2	0.169	(0.555)	0.172	(0.566)
	1	0.1340	(0.4398)	0.1367	(0.4485)
	1/0	0.1063	(0.3487)	0.1084	(0.3556)
	2/0	0.08432	(0.2766)	0.08598	(0.2820)
	3/0	0.06688	(0.2194)	0.06820	(0.2238)
	4/0	0.05248	(0.1722)	0.5352	(0.1755)
Each uncoated	14	2.62	(8.62)	2.68	(8.78)
	13	2.08	(6.82)	2.12	(6.97)
	12	1.65	(5.43)	1.68	(5.53)
	11	1.32	(4.30)	1.34	(4.39)
	10	1.039	(3.409)	1.060	(3.476)
	9	0.8245	(2.705)	0.8407	(2.758)
	8	0.6535	(2.144)	0.6663	(2.186)
	7	0.5182	(1.700)	0.5284	(1.734)
	6	0.4122	(1.348)	0.4192	(1.375)
	5	0.3261	(1.070)	0.3225	(1.091)
	4	0.2585	(0.8481)	0.2636	(0.8649)
	3	0.2050	(0.6727)	0.2091	(0.6860)
	2	0.1626	(0.5335)	0.1659	(0.5440)
	1	0.1289	(0.4230)	0.1315	(0.4313)
	1/0	0.1022	(0.3354)	0.1042	(0.3419)
	2/0	0.08108	(0.2660)	0.08267	(0.2712)
	3/0	0.06431	(0.2110)	0.06558	(0.2151)
	4/0	0.05099	(0.1673)	0.05200	(0.1705)

6.7.3 The DC resistance when measured on a single conductor within a completed twisted conductor assembly or multiple-conductor cable shall not exceed the value tabulated in Table 6.7, Table 6.8, or Table 6.10 as applicable, for a single conductor multiplied by whichever of the following factors is applicable:

a) Cabled in one layer: 1.02;

b) Cabled in more than one layer: 1.03; or

c) Cabled as an assembly of other pre-cabled units: 1.04

The DC resistance on a straightened single conductor taken from a complete assembly shall not exceed the value tabulated in Table 6.7, Table 6.8, or Table 6.10 as applicable.

6.7.4 Compliance shall be determined in accordance with the test DC Resistance in UL 2556.

7 Separator

7.1 General

7.1.1 A separator is not required but may be provided between the conductor and the insulation. A separator shall be insulating but shall not be considered as part of the required insulation.

7.1.2 A separator used between a conductor and insulation shall be colored or shall be opaque to make the separator clearly distinguishable from the conductor once the insulation is removed. The color shall be other than green or green and yellow and may be solid, striped, or in some other pattern.

8 Insulation and Nylon

8.1 General

8.1.1 APPLICATION – Every wire intended for use as a single conductor or in a cable shall be insulated for its entire length with properly compounded homogeneous PVC material. The insulation shall be applied directly to the surface of the conductor or any separator and shall fit snugly to and be concentric with that surface. The insulation shall not adhere to the metal conductor.

8.1.2 DEFECTS – The applied insulation shall be free from defects visible to the examiner whose vision is to be unaided except for the examiner's normal corrective lenses, if any.

8.1.3 REPAIRS – At each repair or joint in the insulation, the PVC shall comply with the thickness requirements in 8.2.1 – 8.3.8. Each length of insulated conductor having repairs or joints in the PVC shall comply with the test requirements in 8.4.1 – 8.4.2 and 14.1 – 24.3.2.

8.2 Average thickness of insulation

8.2.1 The average thickness of the insulation shall not be less than indicated in Table 1.1 when determined as described in 8.2.2 – 8.2.8.

8.2.2 Measurements from which the average thickness of insulation is to be determined are to be made by means of one of the following instruments:

a) A machinist's micrometer caliper may be used. The caliper is to have flat surfaces on the anvil and on the end of the spindle and is to be calibrated to read directly to at least 0.001 inch or 0.01 mm with each division of a width that facilitates estimation of each measurement to 0.0001 inch or 0.002 mm.

b) A dead-weight dial micrometer may be used. The micrometer is to exert a force of 10 ±2 gf or 0.10 ±0.02 N on a sample through a flat, rectangular presser foot 0.078 by 0.375 inch or 1.98 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) of this paragraph.

8.2.3 During the measurements, the sample, the measuring instrument, and the surrounding air are to be in thermal equilibrium with one another at a temperature of 24.0 ±8.0 °C (75.2 ±14.4 °F).

8.2.4 Measurements are to be made on a sample length of finished wire (single conductor or insulated conductor removed from a cable) from which the nylon jacket (if any) has been removed without damaging or stressing the insulation. For the size 22 AWG, 7 strand and the 21 – 10 AWG sizes, the sample is to be about 60 inches or 1500 mm long and, figuring from one end of the sample, measurement is to be made of the maximum and minimum diameters over the insulation at each of five points 10, 20, 30, 40, and 50 inches or 254, 508, 762, 1016, and 1270 mm from that end. For the 8 AWG – 1000 kcmil sizes, the sample is to be 24 inches or 610 mm long and, figuring from one end of the sample, measurement is to be made of the maximum and minimum diameters over the insulation at each of five points 4, 8, 12, 16, and 20 inches or 102, 203, 305, 406, and 508 mm from that end. Each of the ten measurements (two at each point) is to be estimated to the nearest 0.0001 inch (0.1 mil) or 0.002 mm and recorded. The insulation is to be removed for a short distance at one end of the sample without damage to the conductor or any separator, and the maximum and minimum diameters are then to be measured over the conductor or any separator and recorded as estimates to the nearest 0.0001 inch or 0.002 mm.

8.2.5 The average of the two recorded measurements over the conductor or any separator is to be subtracted from the average of the ten recorded measurements over the insulation. The result is to be divided by two and then rounded off to the nearest 0.001 inch as indicated in 8.2.6 or to the nearest 0.01 mm as indicated in 8.2.7. The rounded result is to be taken as the average thickness of insulation for comparison with the minimum acceptable average thickness specified for the applicable construction in Table 1.1. The wire or cable is not acceptable if the average thickness determined from the measurements is less than the figure in the table.

8.2.6 ROUNDING OFF TO THE NEAREST 0.001 inch – A figure in the third decimal place is to remain unchanged:

a) If the figure in the fourth decimal place is 0 – 4 and the figure in the third decimal place is odd or even, or

b) If the figure in the fourth decimal place is 5 and the figure in the third decimal place is even (0, 2, 4, and so forth).

A figure in the third decimal place is to be increased by 1:

c) If the figure in the fourth decimal place is 6 – 9 and the figure in the third decimal place is odd or even, or

d) If the figure in the fourth decimal place is 5 and the figure in the third decimal place is odd (1, 3, 5 and so forth).

8.2.7 ROUNDING OFF TO THE NEAREST 0.01 mm– A figure in the second decimal place is to remain unchanged

a) If the figure in the third decimal place is 0 – 4 and the figure in the second decimal place is odd or even, or

b) If the figure in the third decimal place is 5 and the figure in the second decimal place is even (0, 2, 4, and so forth).

A figure in the second decimal place is to be increased by 1:

c) If the figure in the third decimal place is 6 – 9 and the figure in the second decimal place is odd or even, or

d) If the figure in the third decimal place is 5 and the figure in the second decimal place is odd (1, 3, 5, and so forth).

8.2.8 If the results obtained via the procedures described in 8.2.2 – 8.2.5 are in doubt, a micrometer microscope or other optical instrument calibrated to read directly to at least 0.0001 inch or 0.001 mm is to be used to measure the maximum and minimum thicknesses of insulation directly at each of the five points mentioned in 8.2.4. To accomplish this, five sections 4 inches or 100 mm long are to be cut from the sample from 8.2.4 with one of the five points at the center of each section. Without damaging or stressing the insulation, the conductor and any separator are to be removed and the five tubes of insulation are to be cut in two at their centers. Each cut is to be clean and perpendicular to the longitudinal axis of the tube. This yields ten specimens for measurement, but measurements are to be made on only five specimens – on one specimen from each tube. The clean-cut end of each of the five specimens is to be viewed through the instrument and the maximum and minimum thicknesses of each are to be found and recorded to the nearest 0.0001 inch or 0.001 mm. The average of the ten measurements is to be calculated and then rounded off to the nearest 0.001 inch as indicated in 8.2.6 or to the nearest 0.01 mm as indicated in 8.2.7 and compared with the applicable average thickness in Table 1.1. When measured by means of an optical device, the average thickness of the insulation may be 3 mils or 0.08 mm less than specified in Table 1.1. The results of this procedure with the optical instrument are to be taken as conclusive.

8.3 Minimum thickness at any point of insulation and of nylon

8.3.1 The minimum thickness at any point of the insulation in Constructions A and B and of the nylon jacket in Construction B shall not be less than indicated in Table 1.1 when determined as described in 8.3.1 – 8.3.8.

8.3.2 The point of minimum diameter over the insulation is to be determined with the instrument used for the measurements specified in 8.2.4. The sample of insulation from 8.2.4 is to be used unless it has been cut as indicated in 8.2.8 in which case a second sample of the same length and with any nylon jacket removed is to be used.

8.3.3 With the point of minimum diameter at its center, a section 4 inches or 100 mm long is to be cut from the sample of insulation. Without damaging or stressing the insulation, the conductor and any separator are to be removed and the tube of insulation is to be cut in two at the point of minimum diameter to yield two specimens for measurement. The cut is to be clean and perpendicular to the longitudinal axis of the tube. In the case of a nylon jacket, two specimens, each 2 inches or 50 mm long are to be used. The conductor and insulation and any separator are to be removed from each and the ends of the nylon tubes are to be cut clean and perpendicular to the longitudinal axis of each tube.

8.3.4 For any nylon jacket and for the insulation, measurements of the minimum thickness of a specimen 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 0.043 by 0.312 inch or 1.09 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 (a pin 0.043 inch or 1.09 mm in diameter is acceptable for 14 AWG – 1000 kcmil wires and cables). The instrument is to be calibrated to read directly to at least 0.001 inch or 0.01 mm with each division of a width that facilitates estimation of each measurement to 0.0001 inch or 0.002 mm. See 8.2.3.

8.3.5 While the presser foot of the dial micrometer is raised from the pin, one of the specimens from 8.3.3 is to be placed on the pin (clean-cut end first) so that the entire length of the pin contacts the interior of the insulation or nylon. The presser foot is to be lowered gently onto the specimen and a reading estimated to the nearest 0.0001 inch or 0.002 mm is to be taken immediately and recorded. The presser foot is then to be raised, the specimen is to be rotated on the pin, and a second reading is to be taken and recorded. This procedure is to be repeated until the thinnest point of the insulation or nylon is found and recorded. The specimen is not to be rotated while in contact with the presser foot.

8.3.6 The procedures in 8.3.5 are to be repeated with the second specimen.

8.3.7 The smallest of all the readings recorded for both specimens is to be rounded off to the nearest 0.001 inch as indicated in 8.2.6 or to the nearest 0.01 mm as indicated in 8.2.7. The rounded result is to be taken as the minimum thickness at any point of the insulation or nylon for comparison with the minimum acceptable thickness at any point specified for the applicable insulation or for the nylon in Table 1.1. The wire or cable is not acceptable if the minimum thickness at any point determined from the measurements is less than the figure in the table for the insulation or the nylon.

8.3.8 If the results obtained via the procedures described in 8.3.2 – 8.3.7 are in doubt, a micrometer microscope or other optical instrument calibrated to read directly to at least 0.0001 inch or 0.001 mm is to be used to view the clean-cut end of one of the two specimens of the insulation or the nylon. The point of minimum thickness is to be located and the thickness reading recorded. The recorded value is to be rounded off to the nearest 0.001 inch as indicated in 8.2.6 or to the nearest 0.01 mm as indicated in 8.2.7 and compared with the applicable minimum thickness at any point of the insulation in Table 1.1 or with the minimum thickness at any point of the nylon in Table 1.1. When measured by means of an optical device, the minimum thickness at any point of the insulation (but not the nylon) may be 3 mils or 0.08 mm less than specified in Table 1.1. The results of this procedure with the optical instrument are to be taken as conclusive.

8.4 Physical properties

8.4.1 The average tensile strength and ultimate elongation of aged and unaged specimens of insulation from PVC jacket finished single-conductor and multiple-conductor wires and cables shall not be less than indicated in Table 8.1.

Table 8.1
Minimum Acceptable Average Physical Properties of PVC Insulation and PVC Jacket

Condition of specimens at time of measurement	Minimum acceptable ultimate elongation (1-inch or 25-mm bench marks) – See 8.4.2	Minimum acceptable tensile strength – See 8.4.2
Unaged	100 % (1 inch or 25 mm)	1500 lbf/in^2 or 10.3 MPa
Aged in a forced air-circulating oven for 168 hours at 121.0 ±1.0 °C with nylon jacket of Construction B removed	Die-cut specimens: 45 % of the result with unaged specimens Other specimens: 65 % of the result with unaged specimens	70 % of the result with unaged specimens
Aged in IRM 902 oil for 96 hours at 100.0 ±1.0 °C	50 % of the result with unaged specimens	50 % of the result with unaged specimens
PVC is to be tested at a speed of 20 ±1 in/min or 500 ±25 mm/min.		

8.4.2 The methods of preparation of samples, selection and conditioning of specimens, and of making the measurements and calculations for ultimate elongation and tensile strength shall be determined in accordance with the test, Physical properties (ultimate elongation and tensile strength), in UL 2556 and 8.4.3 and 8.4.4. If the specimens are to be surface printed using a laser, samples for the physical properties test shall include the laser printed area.

8.4.3 Specimens of insulated conductors from a single conductor construction (Construction A) and of both insulation and jacket (Construction B) shall be immersed. Samples of Construction B shall be immersed without removal of the nylon jacket. After immersion for the specified length of time, each specimen shall be cut in half at the center of the U bend to provide two specimens for physical tests from each length immersed. The nylon covering shall be removed prior to the physical tests.

8.4.4 Specimens of PVC jacket from both single-conductor constructions and multiple-conductor constructions shall be immersed. Jackets from cables larger than 0.200 inches (5.08 mm) in core diameter shall be immersed die-cut. Jackets from cables less than 0.200 inches (5.08 mm) in core diameter may be immersed die-cut or tubular. One side of tubular jacket specimens shall be carefully slit longitudinally, and the specimens shall be entirely immersed in the oil so that both surfaces (inside and out) are exposed to the oil.

9 Nylon Jacket Over Insulation

9.1 General

9.1.1 Construction B shall have a nylon jacket applied directly over the insulation. The jacket shall be snug on the insulation and shall be at least as thick as indicated in Table 1.1. A nylon jacket shall not be considered as insulation.

9.1.2 The nylon jacket in Construction B shall not crack when wrapped around a mandrel as described in 9.1.3.

9.1.3 A specimen of finished single-conductor wire of Construction B is to be wrapped for four turns around a smooth metal mandrel of a diameter six times that of the specimen. When a mandrel specified above is not available, it shall be permitted to use a mandrel with a smaller diameter. However, in the event of non-compliant results, the sample shall be re-tested using the required mandrel size. The ends of the specimen are to be secured to the mandrel to result in four complete turns of the specimen being exposed to the air between the securing means. The specimen and mandrel are to be suspended for 24 hours in a forced air-circulating oven operating at a temperature of 95.0 ±1.0 °C (203.0 ±1.8 °F), after which the specimen and mandrel are to be removed from the oven and cooled for 1 hour in a silica-gel desiccator or its equivalent maintained at 24.0 ±3.0 °C (75.2 ±5.4 °F). After cooling, the specimen is to be straightened immediately upon removal from the desiccator and is then to be inspected for surface cracks.

10 Shielding

10.1 General

10.1.1 An insulated conductor or an insulated conductor within a multi-conductor cable, or an assembly of conductors may be enclosed in a conductive shield.

10.1.2 Where shielding is used around conductors in single or multi-conductor cables, a foil shield shall be permitted for non-flexing applications. A continuous drain wire shall be provided and shall be in contact with the foil shield.

10.1.3 Where shielding is used around conductors in single or multi-conductor cables, only a braid shield shall be permitted for flexing applications.

11 Cable Assembly

11.1 Flat and round cables

11.1.1 In 2-conductor cable in which the conductors are of the same size, the conductors may be laid parallel to one another to form a flat cable or they may be cabled to form a round cable. In 2-conductor cable in which the conductors are not both of the same size and in cable with three or more conductors of the same or different sizes, the conductors shall be cabled to form a round cable.

11.2 Conductor lay

11.2.1 The lay of cabled conductors shall not be longer than 15 times the calculated diameter of the assembly of conductors.

11.3 Fillers

11.3.1 Fillers shall be provided in a cable if they are needed to make the cable firm at all points and round or flat as applicable. Fillers may be integral with or separate from the overall jacket. If fillers are integral with the overall jacket, they and the jacket shall be readily separable from the underlying cable assembly. Fibrous filler materials that are not inherently resistant to moisture shall be rendered so, treatment with paraffin being acceptable if the paraffin does not adversely affect the ability of the finished cable to comply with the flame-test requirements in 18.1.

12 Binder

12.1 General

12.1.1 In cables without fillers or in which the fillers are separate from the overall jacket, a binder tape, thread, or other means is acceptable if a means is necessary to hold the assembly together while the overall jacket is being applied.

13 Overall Jacket

13.1 General

13.1.1 An overall PVC jacket is required to cover shielded, single conductor and multiple-conductors cables. An overall PVC jacket is permitted over non-shielded, single conductor or non-shielded multiple-conductor cables. The jacket shall conform closely to and be readily separable from the surface of the underlying assembly. The average thickness of the jacket and the minimum thickness at any point of the jacket shall not be less than indicated in Table 13.1. The average tensile strength and ultimate elongation of aged and unaged specimens of the jacket from finished cable shall not be less than indicated in Table 8.1.

Table 13.1
Minimum Acceptable Thickness of Overall Jacket

Calculated diameter or length of major axis of assembly under the jacket		Minimum acceptable average thickness[a]		Minimum acceptable thickness at any point[a]	
Mils	(mm)	Mils	(mm)	Mils	(mm)
425 or less	(10.8 or less)	45	(1.14)	36	(0.91)
over 425 but not over 700	(over 10.8 not over 17.8)	60	(1.52)	48	(1.22)
over 700 but not over 1500	(over 17.8 but not over 38.1)	80	(2.03)	64	(1.63)
over 1500 but not over 2500	(over 38.1 but not over 63.5)	110	(2.79)	88	(2.24)
over 2500	(over 63.5)	140	(3.56)	112	(2.84)

[a] Measurements are to be made by means of a dead-weight pin-gauge dial micrometer. The pin is to be 0.437 inch or 11.10 mm long and 0.043 inch or 1.09 mm in diameter. The rectangular end of the presser foot that touches a specimen is to be 0.043 inch or 1.09 mm wide and 0.312 inch or 7.92 mm long. The foot is to exert a total of 25 ±2 gf or 0.25 ±0.02 N on the specimen.

PERFORMANCE

14 Flexibility at Room Temperature After Aging

14.1 The insulation and nylon jacket (if present) on finished single-conductor wire of Construction A and similar wire taken from finished, multi-conductor cable shall not show any cracks, either on the surface or internally, when wound around a mandrel at room temperature, in accordance with the test, Flexibility at room temperature after aging in UL 2556 after aging in an air oven as specified in Table 8.1. The diameter of the mandrel is to be twice the diameter of the specimen for the 22 AWG, 7 strand and the 21 – 15 AWG sizes, and is to be as indicated in in Table 14.1, Column B for sizes 14 AWG – 1000 kcmil.

Table 14.1
Mandrel Diameters

Size of conductor	A (Heat shock)		B (Room temperature and cold bend)	
AWG	mm	(inches)	mm	(inches)
14, 13	3	(0.133)	8	(0.313)
12, 11	4	(0.148)	9	(0.375)
10, 9	4	(0.168)	14	(0.563)
8, 7	6	(0.228)	17	(0.688)
6, 5	16	(0.646)	32	(1.250)
4	19	(0.744)	35	(1.375)
3	20	(0.802)	37	(1.458)
2	22	(0.866)	40	(1.563)
1	26	(1.016)	68	(2.688)
1/0	28	(1.098)	73	(2.875)
2/0	30	(1.190)	76	(3.000)
3/0	33	(1.294)	83	(3.250)
4/0	36	(1.410)	89	(3.500)
250 kcmil	100	(3.940)	160	(6.304)
300	107	(4.215)	171	(6.744)
350	114	(4.475)	182	(7.160)
400	120	(4.710)	191	(7.536)
450	125	(4.935)	201	(7.904)
500	131	(5.145)	209	(8.232)
550	140	(5.515)	280	(11.030)
600	145	(5.715)	290	(11.430)
650	150	(5.895)	299	(11.790)
700	154	(6.070)	308	(12.140)
750	159	(6.245)	317	(12.490)
800	163	(6.410)	326	(12.820)
900	171	(6.725)	342	(13.450)
1000	178	(7.020)	357	(14.040)

Note – When the mandrel specified is not available, a mandrel with a smaller diameter may be used. However, in the case of noncompliant result, the wire or cable shall be retested using the specified mandrel.

14.2 For the Flexibility at room-temperature test, the forced air-circulating oven aging is to be as indicated in Table 8.1 and the diameter of the mandrel is to be twice the diameter of the specimen for the size 22 – 7 and the 20 – 16 AWG sizes and is to be as indicated in UL 83 for the 14 AWG – 1000 kcmil sizes. For the heat-shock test, the mandrel diameter is to be 0.094 inch or 2.39 mm for the size 22 – 7 and the 20 – 16 AWG sizes and is to be as indicated in UL 83 for the 14 AWG – 1000 kcmil sizes. For the cold-bend test, the mandrel diameter is to be 0.250 inch or 6.35 mm for the size 22 – 7 and the 20 – 16 AWG sizes and is to be as indicated in UL 83 for the 14 AWG – 1000 kcmil sizes.

15 Heat Shock Test

15.1 Neither the insulation nor the nylon jacket (if present) shall show any cracks, on the surface or internally, after a specimen of finished wire or cable is wound around a mandrel after conditioning in an air-circulating oven for 1 hour to a temperature of 121 ±1 °C. The mandrel diameter shall be 0.094 inch or 2.39 mm for the 22 AWG, 7 strands and the 20 – 15 AWG sizes, and as specified in Column A of Table 14.1 for 14 AWG and larger. Compliance shall be determined in accordance with the test, Heat Shock in UL 2556.

15.2 For 42.4 mm^2 (1 AWG) and smaller, the specimen shall be tightly wound for four adjacent turns around the mandrel, and both ends of the specimen shall be securely held in place. For 53.5 mm^2 (1/0 AWG) and larger, a U-bend shall be made between the specimen in contact with the mandrel for not less than 180 degrees.

16 Cold Bend Test

16.1 After conditioning at a temperature of −25 ±1 °C for 4 hours, the insulation and nylon covering (if present) shall not show any cracks when tested in accordance with the test, Cold bend, in UL 2556, modified as indicated in 16.2. The mandrel diameter shall be 0.250 inch or 6.35 mm for the size 22 AWG, 7 strands and the 20 – 16 AWG sizes and as specified in Column B of Table 14.1 for 14 AWG and larger Conditioning at a temperature of −40 ±1 °C shall be optional.

16.2 In the case of 85.0 mm^2 (3/0 AWG) or smaller conductors, the specimen shall be tightly wound for four adjacent turns around the mandrel, and the winding shall be done at a uniform rate of approximately 4 s per turn. For sizes 107 mm^2 (4/0 AWG) and larger, a 180° U-bend shall be performed.

16.3 When the wire or cable is marked with the optional "−40C" marking in accordance with 31.2, conditioning shall be carried out at a temperature of −40 ±1 °C.

17 Deformation Test

17.1 The insulation on:

a) Finished single-conductor wire of Constructions A or B, or

b) An insulated conductor from within a multi-conductor cable;

Shall not be more than 30 % when tested in accordance with the test, Deformation, in UL 2556 at 121.0 ±1.0 °C. The rod is to exert 400 gf or 3.92 N on the 22 AWG, 7 strand and the 21 – 15 AWG wires and is to exert the load indicated in Table 17.1 for the 14 AWG – 1000 kcmil sizes. The nylon shall be left in place on Construction B and measurements shall be made over the nylon.

Table 17.1
Deformation Load Requirements

Size of conductor		Load[a] exerted on a specimen by the foot of the rod	
mm^2	(AWG or kcmil)	N	(gf)
2.08 – 8.37	(14 – 8)	4.90	(500)
13.3 – 42.4	(6 – 1)	7.35	(750)
53.5 – 107	(1/0 – 4/0)	9.81	(1000)

Table 17.1 Continued on Next Page

Table 17.1 Continued

Size of conductor		Load[a] exerted on a specimen by the foot of the rod	
mm^2	(AWG or kcmil)	N	(gf)
127 – 1010	(250 – 2000)	19.61	(2000)

[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 in all cases is impractical except for an individual apparatus.

18 Flame Tests

18.1 Vertical flame

18.1.1 When tested in accordance with the test, FV-1/Vertical Flame, in UL 2556, a specimen of a wire or cable shall not flame longer than 60 seconds following five 15 second applications of the test flame, the period between applications being 15 second. If any specimen shows more than 25 % of the indicator flag burned away or charred (soot that can be removed with a cloth or the fingers and brown scorching area shall be ignored) after any of the five applications of flame, the wire or cable shall be judged capable of conveying flame along its length. If any specimen emits flaming or glowing particles or flaming drops at any time that ignite the cotton on the burner, wedge, or floor of the enclosure (flameless charring of the cotton shall be ignored), the wire or cable shall be judged capable of conveying flame to combustible materials in its vicinity.

18.2 VW-1 flame (optional)

18.2.1 Finished single-conductor and multiple-conductor wires and cables from which separate specimens comply with both the test FV1/VW-1 and with the test FT2/FH/Horizontal Flame Test, in UL 2556, are eligible to be durably marked "VW-1" on the surface of the wire or cable. Such marking is not required.

19 Tests for Relative Permittivity and Changes in Capacitance

19.1 The insulation on finished single-conductor wire of constructions A and B and similar wire taken from finished cable shall comply with the requirements in Table 19.1 when tested in accordance with the test, Capacitance and relative permittivity in UL 2556. The water temperature is to be 30.0 ±1.0 °C (86.0 ±1.8 °F).

Table 19.1
Maximum Acceptable Relative Permittivity (ϵ_r) and Changes in Capacitance

Construction	Maximum acceptable ϵ_r after immersion for 24 hours	Maximum acceptable change in capacitance 1 – 14 days	Maximum acceptable change in capacitance 7 – 14 days
A	8.00	10.0 %	5.0 %
B (tested with nylon removed)	10.0	10.0 %	5.0 %

20 Dielectric Voltage-Withstand and Breakdown Tests

20.1 General

20.1.1 The insulation on finished single-conductor or multiple-conductor wires and cables of Constructions A and B and similar wire taken from finished cable shall withstand application of the test potential indicated in Table 20.1 when tested in accordance with 20.2.1 – 20.3.1.

Table 20.1
Dielectric Test Potential

Conductor size AWG or kcmil	RMS test potential V
22 – 10	2000 V
9 – 2	2500
1 – 4/0	3000
250 – 500	3500
550 – 1000	4000

20.2 In air at room temperature

20.2.1 This test is to be made on two or more specimens of unaged wire at least 24 inches or 610 mm long and on similar specimens of wire that have been aged in a forced air-circulating oven for 168 hours at 121.0 ±1.0 °C (249.8 ±1.8 °F). Specimens are to be tested within 16 – 48 hours after removal from the oven. A section at least 6 inches or 152 mm long at the center of each specimen is to be wrapped with metal foil, and the wrapped section is to be wound around a metal mandrel with adjacent turns not quite touching (immersion of the specimen on the mandrel in powdered graphite or in water is acceptable in place of the use of foil). The diameter of the mandrel is to be 0.188 inch or 4.78 mm for the size 22 AWG, 7 strand and the 21 – 15 AWG sizes and is to be twice the value in Table 14.1, column A for the 14 AWG – 1000 kcmil sizes. The two ends of the wire are to be twisted together to keep the coiled section from unwinding, and the test voltage is then to be applied between the conductor and the mandrel.

20.2.2 Each specimen is to be stressed by means of a supply circuit that complies with the following. The test potential is to be obtained from a 48 – 62 Hz supply whose potential is continuously variable from near zero to at least the rms test potential indicated in Table 20.1 at a rate not exceeding 500 V/s. With a specimen in the circuit, the supply potential is to have a crest factor (peak voltage divided by rms voltage) equal to 95 – 105 % of the crest factor of a pure sine wave over the upper half of the output range. The output voltage is to be monitored continuously by a voltmeter that:

a) If of the analog rather than digital type, shall have a response time that does not introduce a lagging error greater than 1 % of full scale at the specified rate of increase in voltage, and that

b) Has an overall accuracy that does not introduce an error exceeding 5 %. The maximum current output of which the supply is capable shall enable routine testing of full reels of the finished wire or cable without tripping of the circuit breaker by the charging current.

20.2.3 The applied potential is to be increased from zero at an essentially uniform rate that:

a) Is not less than 100 % of the voltage rating for the product in 60 seconds and

b) Is not more than 100 % in 10 seconds (the rate of increase is not to exceed 500 V/s in any case). The increase is to continue in this manner until the voltage reaches the level indicated for the conductor size in Table 20.1. If this level is reached without breakdown, the potential is to be held