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Standard Specification for Modified Concentric-Lay-Stranded Copper Conductors for Use in Insulated Electrical Cables[1]

This standard is issued under the fixed designation B784; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Typos in Section 1 were corrected editorially in April 2017.

1. Scope

1.1 This specification covers bare modified concentric-lay-stranded conductors made from round copper wires, either uncoated or coated with tin, lead, or lead alloy for general use in insulated electrical cables. These conductors shall be constructed with a central core consisting of not more than seven wires, surrounded by one or more layers of helically laid wires.

1.2 For the purposes of this specification, conductors are classified as follows (Explanatory Note 1 and Note 2):

1.2.1 *Class B Modified*—Conductors to be insulated with various materials such as rubber, paper, and crosslink polyethylene.

1.2.2 *Class C Modified and Class D Modified*—Conductors where greater flexibility is required than is provided by Class B Modified conductors.

1.3 The values stated in inch-pound or SI units are to be regarded separately as standard. Each system shall be used independently of the other. Combining the values from the two systems may result in non- conformance with the specification. For conductor sizes designated by AWG or kcmil sizes, the requirements in SI units are numerically converted from the corresponding requirements in inch-pound units. For conductor sizes designated by AWG or kcmil, the requirements in SI units have been numerically converted from corresponding values stated or derived in inch-pound units. For conductor sizes designated by SI units only, the requirements are stated or derived in SI units.

1.3.1 For density, resistivity and temperature, the values stated in SI units are to be regarded as standard.

NOTE 1—The significant differences in this specification from Specification B8 are as follows: (*1*) The central core is permitted to contain up to seven wires drawn into the assembly with an infinite length of lay while Specification B8 permits only one, and (*2*) The construction is applicable only to stranded assemblies of 19 or more wires.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 The following documents of the issue in effect at the date of material purchase form a part of this specification to the extent referenced herein.

2.2 *ASTM Standards:*[2]

B3 Specification for Soft or Annealed Copper Wire

B8 Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft

B33 Specification for Tin-Coated Soft or Annealed Copper Wire for Electrical Purposes

B189 Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes

B263 Test Method for Determination of Cross-Sectional Area of Stranded Conductors

B354 Terminology Relating to Uninsulated Metallic Electrical Conductors

2.3 *Other Standard:*

NBS Handbook 100[3]

3. Ordering Information

3.1 Orders for material under this specification shall include the following information:

3.1.1 Quantity of each size and class,

3.1.2 Conductor size: circular-mil area or American Wire Gage (AWG) (Section 6),

3.1.3 Class (see 1.2 and Table 1),

3.1.4 Temper (see 10.2),

[1] This specification is under the jurisdiction of ASTM Committee B01 on Electrical Conductors and is the direct responsibility of Subcommittee B01.04 on Conductors of Copper and Copper Alloys.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Available from National Technical Information Service (NTIS), 5301 Shawnee Rd., Alexandria, VA 22312, http://www.ntis.gov.

TABLE 1 Construction Requirements of Modified Concentric-Lay-Stranded Copper Conductors

NOTE 1—See Explanatory Note 5.

Circular Mils	Size American Wire Gage	Class B Modified			Class C Modified			Class D Modified		
		Number of Wires	Diameter (mils)	Diameter (mm)	Number of Wires	Diameter (mils)	Diameter (mm)	Number of Wires	Diameter (mils)	Diameter (mm)
5 000 000[A]		217	151.8	3.86	271	135.8	3.45	271	135.8	3.45
4 000 000		217	144.0	3.66	271	128.9	3.27	271	128.9	3.27
4 000 000		217	135.8	3.45	271	121.5	3.09	271	121.5	3.09
3 500 000		169	143.9	3.66	217	127.0	3.23	271	113.6	2.89
3 000 000[A]		169	133.2	3.38	217	117.6	2.99	271	105.2	2.67
2 500 000[A]		127	140.3	3.56	169	121.6	3.09	217	107.3	2.73
2 000 000[A]		127	125.5	3.19	169	108.8	2.76	217	96.0	2.44
1 900 000		127	122.3	3.11	169	106.0	2.69	217	93.6	2.38
1 800 000		127	119.1	3.03	169	103.2	2.62	217	91.1	2.31
1 750 000[A]		127	117.4	2.98	169	101.8	2.59	217	89.8	2.28
1 700 000		127	115.7	2.94	169	100.3	2.55	217	88.5	2.25
1 600 000		127	112.2	2.85	169	97.3	2.47	217	85.9	2.18
1 500 000[A]		91	128.4	3.26	127	108.7	2.76	169	94.2	2.39
1 400 000		91	124.0	3.15	127	105.0	2.67	169	91.0	2.31
1 300 000		91	119.5	3.04	127	101.2	2.57	169	87.7	2.23
1 250 000		91	117.2	2.98	127	99.2	2.52	169	86.0	2.18
1 200 000		91	114.8	2.92	127	97.2	2.47	169	84.3	2.14
1 100 000		91	109.9	2.79	127	93.1	2.36	169	80.7	2.05
1 000 000[A]		61	128.0	3.25	91	104.8	2.66	127	88.7	2.25
900 000		61	121.5	3.09	91	99.4	2.52	127	84.2	2.14
800 000[A]		61	114.5	2.91	91	93.8	2.38	127	79.4	2.02
750 000[A]		61	110.9	2.82	91	90.8	2.31	127	76.8	1.95
700 000[A]		61	107.1	2.72	91	87.7	2.23	127	74.2	1.88
650 000		61	103.2	2.62	91	84.5	2.15	127	71.5	1.82
600 000[A]		61	99.2	2.52	91	81.2	2.06	127	66.7	1.69
550 000		61	95.0	2.41	91	77.7	1.97	127	65.8	1.67
500 000[A]		37	116.2	2.95	61	90.5	2.30	91	74.1	1.88
450 000		37	110.3	2.80	61	85.9	2.18	91	70.3	1.79
400 000[A]		37	104.0	2.64	61	81.0	2.06	91	66.3	1.68
350 000[A]		37	97.3	2.47	61	75.7	1.92	91	62.0	1.57
300 000[A]		37	90.0	2.29	61	70.1	1.78	91	57.4	1.46
250 000[A]		37	82.2	2.09	61	64.0	1.63	91	52.4	1.33
211 000[A]	0000	19	105.5	2.68	37	75.6	1.92	61	58.9	1.50
167 000[A]	000	19	94.0	2.39	37	67.3	1.71	61	52.4	1.33
133 000[A]	00	19	83.7	2.13	37	60.0	1.52	61	46.7	1.19
105 000[A]	0	19	74.5	1.89	37	53.4	1.36	61	41.6	1.06
83 000[A]	1	19	66.4	1.69	37	47.6	1.21	61	37.0	0.94

[A] These sizes of conductors provide for one or more schedules of preferred series and commonly are used in the industry. The sizes not marked are given simply as a matter of reference and it is suggested that their use be discouraged.

3.1.5 Whether coated or uncoated; if coated, designate type of coating (see 10.1 and 10.2),

3.1.6 Details of special-purpose lays, if required (see 5.2),

3.1.7 Lagging, if required (see 14.2),

3.1.8 Special package marking, if required (Section 13),

3.1.9 Place of inspection (Section 12), and

4. Joints

4.1 Welds and brazes may be made in rods or in wires prior to final drawing. Welds and brazes may be made in the finished individual wires composing the conductor, but shall not be closer together than prescribed in Table 2.

TABLE 2 Minimum Distance Between Joints in the Completed Conductor

Number of Wires in Conductor	Soft All Classes
19	1 ft
20 and over	1 ft in a layer[A]

[A] Except as indicated, the limitations apply to closeness of joints throughout the completed conductor.

5. Lay

5.1 The lay of a layer of wires shall be not less than eight nor more than sixteen times the outside diameter of that layer, except that for conductors composed of 37 wires or more, this requirement shall apply only to the two outer layers. The lay of the layers other than the two outer layers shall be at the option of the manufacturer, unless otherwise agreed upon.

5.2 Other lays for special purposes shall be furnished by special agreement between the manufacturer and the purchaser (Explanatory Note 3).

5.3 The direction of lay of the outer layer shall be left-hand unless the direction of lay is specified otherwise by the purchaser.

5.4 The direction of lay shall be reversed in successive layers, unless otherwise specified by the purchaser.

6. Construction

6.1 The areas of cross section, numbers, and diameters of wires in the various classes of concentric-lay-stranded conductors shall conform to the requirements prescribed in Table 1.

6.2 The diameters of the wires listed in Table 1 are nominal. Where "combination strand" is required in order to insulate the conductor properly (strands in the outer layer having a larger diameter than those in the inner layers) the diameters shall be subject to a tolerance of ±5 %, provided that the area of cross section after stranding is in accordance with Section 11.

6.3 Where compressed stranding is required in order to insulate the conductor properly, one or more layers of any stranded conductor consisting of 19 wires or more may be slightly compressed, thereby reducing the outside diameter of the conductor by not more than 3 %, provided that the area of cross section after stranding is in accordance with Section 11.

7. Physical and Electrical Tests of Stranded Conductors of Soft Wires

7.1 Tests for the electrical properties of wires composing conductors made from soft or annealed copper wire, bare or coated, shall be made before stranding.

7.2 Tests for the physical properties of soft or annealed copper wire, bare or coated, may be made upon the wires before stranding or upon wires removed from the complete stranded conductor, but need not be made upon both. Care shall be taken to avoid mechanical injury to wire removed from the conductor for the purpose of testing.

7.3 The physical properties of wires when tested before stranding shall conform to the applicable requirements of 10.2.

7.4 The physical properties of wires removed from the completed stranded conductor shall be permitted to vary from the applicable requirements of 10.2 by the following amounts (Explanatory Note 4):

7.4.1 *Average of Results Obtained on All Wires Tested*—The minimum elongation required shall be reduced in numerical value 5 (for example, from 30 to 25 %) from the numerical requirements for the wire before stranding.

7.4.2 *Results Obtained on Individual Wires*—The elongation of individual wires shall be reduced in numerical value 15 from the minimum requirements before stranding (that is, 10 in addition to the 5 allowed in 7.4.1), but in no case shall the elongation of any individual wire be less than 5 %.

7.5 In the event that the requirements prescribed in 7.4.2 are met but those prescribed in 7.4.1 are not met, a retest shall be permitted wherein all wires of the conductor shall be tested for the purpose of final determination of conformance to 7.4.

7.6 Elongation tests to determine compliance shall not be made on the conductor as a unit (Explanatory Note 6).

7.7 If a tinning, lead-coating, or lead-alloy-coating test is required, it shall be made on the wires prior to stranding.

8. Density

8.1 For the purpose of calculating mass per unit length, cross sections, etc., the density of the copper shall be taken as 0.32117 lb/in.^{3} or 8.89 g/cm^3 at 20°C (Note 2 and Explanatory Note 7).

NOTE 2—The term "mass" is being used in this specification as being more technically correct. It replaces the term "weight."

9. Mass and Resistance

9.1 The mass and electrical resistance of a unit length of stranded conductor are a function of the length of lay. The approximate mass and electrical resistance may be determined using the standard increments shown in Table 3. When greater accuracy is desired, the increment based on the specific lay of the conductor may be calculated (Explanatory Note 8).

10. Requirements for Wires

10.1 The purchaser shall designate the type of wire and the kind of coating, if any, to be used in the conductor.

10.2 Before stranding, the copper wire used shall meet all of the requirements of ASTM Specifications B3, B33, and B189 that are applicable to its type.

10.3 The central core shall be made of wire of the same type and temper as the concentric layers, unless otherwise specified.

11. Variation in Area

11.1 The area of cross section of the completed conductor shall be not less than 98 % of the area indicated in Column 1 of Table 1. Unless otherwise specified by the purchaser, the manufacturer may have the option of determining the cross-sectional area by either of the following methods; except that in case of a question regarding area compliance, the method of 11.1.2 shall be used.

11.1.1 The area of cross section of a conductor may be determined by calculations from diameter measurements, expressed to four decimal places, of its component wires at any point when measured perpendicularly to their axes.

11.1.2 The area of cross section of a conductor may be determined by Test Method B263. In applying that method, the increment in mass resulting from stranding may be the applicable value specified in 9.1 or may be calculated from the measured component dimensions of the sample under test. In case of a question regarding area compliance, the actual mass increment due to stranding shall be calculated.

12. Inspection

12.1 Unless otherwise specified in the contract or purchase order, the manufacturer shall be responsible for the performance of all inspection and test requirements specified.

12.2 All inspections and tests shall be made at the place of manufacture unless otherwise agreed upon by the manufacturer and the purchaser at the time of purchase.

12.3 The manufacturer shall afford the inspector representing the purchaser all reasonable manufacturer's facilities to satisfy that the material is being furnished in accordance with this specification.

TABLE 3 Standard Increments Due to Stranding

Type of Conductor	Increment of Resistance and Mass, %
Classes B Modified, C Modified, and D Modified, 2 000 000 cmil and under	2
Over 2 000 000 to 3 000 000 cmil	3
Over 3 000 000 to 4 000 000 cmil	4
Over 4 000 000 to 5 000 000 cmil	5

13. Product Marking

13.1 The net mass, length (or lengths and number of lengths, if more than one length is included in the package), size, kind of conductor, purchase order number, and any other marks required by the purchase order shall be marked on a tag attached to the end of the conductor inside of the package. The same information, together with the manufacturer's serial number (if any) and all shipping marks required by the purchaser, shall appear on the outside of each package.

14. Packaging and Package Marking

14.1 Package sizes for conductors shall be agreed upon by the manufacturer and the purchaser in the placing of individual orders (Explanatory Note 9).

14.2 The conductors shall be protected against damage in ordinary handling and shipping. If heavy wood lagging is required, it shall be specified by the purchaser at the time of purchase.

15. Keywords

15.1 copper conductors for insulated wires; copper modified concentric-lay-stranded; electrical copper conductors

TABLE 4 Diameter, Area, and Mass of Modified Concentric-Lay-Stranded Copper Conductors

Size of Conductor cmil or AWG Number	Nominal Conductor Diameter Class B Modified[A]		Area		Mass, lb			DC Resistance At 20°C	
	(in.)	(mm)	$(in.)^2$	$(mm)^2$	per 1000 ft	per Mile	(kg/m)	Ω/1000 ft.	Ω/km
5 000 000 cmil[B]	2.581	65.56	3.927	2533.54	15890	83899	23.68	.00218	.00715
4 000 000 cmil	2.448	62.18	3.534	2280.00	14300	75504	21.31	.00242	.00794
4 000 000 cmil	2.309	58.65	3.142	2027.09	12590	66475	18.76	.00270	.00886
3 500 000 cmil	2.159	54.84	2.749	1773.54	11020	58186	16.42	.00308	.0101
3 000 000 cmil[B]	1.998	50.75	2.356	1520.00	9353	49384	13.94	.00356	.0117
2 500 000 cmil[B]	1.824	46.33	1.963	1266.45	7794	41152	11.61	.00428	.0140
2 000 000 cmil[B]	1.632	41.45	1.571	1013.55	6175	32604	9.20	.00529	.0174
1 900 000 cmil	1.590	40.39	1.492	962.58	5866	30972	8.74	.00557	.0183
1 800 000 cmil	1.548	39.32	1.414	912.26	5558	29346	8.28	.00588	.0193
1 750 000 cmil[B]	1.526	38.76	1.374	886.45	5403	28528	8.05	.00604	.0198
1 700 000 cmil	1.504	38.20	1.335	861.29	5249	27715	7.82	.00622	.0204
1 600 000 cmil	1.459	37.06	1.257	810.97	4940	26083	7.36	.00661	.0217
1 500 000 cmil[B]	1.412	35.86	1.178	760.00	4631	24452	6.90	.00705	.0231
1 400 000 cmil	1.364	34.65	1.100	709.68	4323	22825	6.44	.00756	.0248
1 300 000 cmil	1.315	33.40	1.021	658.71	4014	21194	5.98	.00814	.0267
1 250 000 cmil[B]	1.289	32.74	0.9817	633.35	3859	20376	5.75	.00847	.0278
1 200 000 cmil	1.263	32.08	0.9425	608.06	3705	19562	5.52	.00882	.0289
1 100 000 cmil	1.209	30.71	0.8639	557.35	3396	17931	5.06	.00962	.0316
1 000 000 cmil[B]	1.152	29.26	0.7854	506.71	3088	16305	4.60	.0106	.0348
900 000 cmil	1.094	27.79	0.7069	456.06	2779	14673	4.14	.0118	.0387
800 000 cmil[B]	1.031	26.19	0.6283	405.35	2470	13042	3.68	.0132	.0433
750 000 cmil[B]	0.998	25.35	0.5890	380.00	2316	12228	3.45	.0141	.0462
700 000 cmil[B]	0.964	24.49	0.5498	354.71	2161	11410	3.22	.0151	.0495
650 000 cmil	0.929	23.60	0.5105	329.35	2007	10597	2.99	.0163	.0535
600 000 cmil[B]	0.893	22.68	0.4712	304.00	1853	9784	2.76	.0177	.0581
550 000 cmil	0.855	21.72	0.4320	278.71	1698	8965	2.53	.0192	.0630
500 000 cmil[B]	0.813	20.65	0.3927	253.35	1544	8152	2.30	.0212	.0695
450 000 cmil	0.772	19.61	0.3534	228.00	1389	7334	2.07	.0235	.0771
400 000 cmil[B]	0.728	18.49	0.3142	202.71	1235	6521	1.84	.0264	.0866
350 000 cmil[B]	0.681	17.30	0.2749	177.35	1081	5708	1.61	.0302	.0991
300 000 cmil[B]	0.630	16.00	0.2356	152.00	926.3	4891	1.38	.0353	.116
250 000 cmil[B]	0.575	14.61	0.1963	126.64	771.9	4076	1.15	.0423	.139
No. 0000[B]	0.528	13.41	0.1662	107.23	653.3	3449	0.97	.0500	.164
No. 000[B]	0.470	11.94	0.1318	85.03	518.1	2736	0.77	.0630	.207
No. 00[B]	0.419	10.64	0.1045	67.42	410.9	2170	0.61	.0795	.261
No. 0[B]	0.373	9.47	0.08289	53.48	325.8	1720	0.49	.100	.328
No	0.332	8.43	0.06573	42.41	258.4	1364	0.39	.159	.522

[A] To calculate the nominal diameters of Class C or Class D modified conductors or of any concentric-lay-stranded conductors made from round wires of uniform diameters, multiply the diameter of an individual wire (as given in Table 2) by that one of the following factors which applies:

Number of Wires in Conductor	Factor to Calculate Conductor Diameter
19	5
37	7
61	9
91	11
127	13
169	15
217	17
271	19

[B] These sizes of conductors provide for one or more schedules of preferred series, and commonly are used in the industry. The sizes not marked are given simply as a matter of reference, and it is suggested that their use be discouraged.

EXPLANATORY NOTES

NOTE 1—In this specification only modified concentric-lay-stranded conductor constructions are specifically designated. Conductor constructions not included in this specification should be specifically agreed upon by the manufacturer and the purchaser when placing the order.

NOTE 2—For definitions of terms relating to conductors, refer to Terminology B354.

NOTE 3—Certain types of insulated conductors may require a shorter lay than other conductors. It is expected that special requirements regarding length of lay will be specified by the purchaser in such instances.

NOTE 4—Wires unlaid from conductors manifestly will have different physical and electrical properties from those of the wire when prepared for cabling, on account of the deformation brought about by laying and again straightening for test.

NOTE 5—For the convenience of the users of this specification, Table 4 has been prepared giving the approximate diameters, areas, and mass per 1000 ft, per mile, and kg/m of the various constructions referred to in Table 1.

NOTE 6—To test stranded conductors for tensile strength successfully as a unit requires an adequate means of gripping the ends of the test specimen. Various means are available, such as a long tube or socket into which the conductor may be soldered, or in which, after insertion, the conductor may be swaged or pressed without serious distortion. Ordinary jaws or clamping devices usually are not suitable. The conductor testing facilities of many commercial laboratories are limited to a breaking strength of 30 000 lb (13 600 kg) or less. Consequently, it may be feasible to test very large-size conductors as a unit. Where such is imperative, special arrangements for the testing shall be agreed upon between the manufacturer and the purchaser.

NOTE 7—The value of density of copper is in accordance with the International Annealed Copper Standard. The corresponding value at 0°C is 0.32150 lb/in.^{2} or 8.90 g/cm^3. As pointed out in the discussion of this subject in *NBS Handbook 100*, there is no appreciable difference in values of density of hard-drawn and annealed copper wire. In calculations involving density note that the apparent density of coated wire is not constant but a variable function of wire diameter. The smaller the diameter, the greater the percentage of coating present, therefore the greater departure from the density of copper.

NOTE 8—The increment of mass or electrical resistance of a complete concentric- lay-stranded conductor, k, in percent is as follows:

$$k = 100(m - 1)$$

where m is the stranding factor, and is also the ratio of the mass or electrical resistance of a unit length of stranded conductor to that of a solid conductor of the same cross- sectional area or of a stranded conductor with infinite length of lay, that is, all wires parallel to the conductor axis. The stranding factor m for the completed stranded conductor is the numerical average of the stranding factors for each of the individual wires in the conductor, including the straight core wire or wires, if any (for which the stranding factor is unity). The stranding factor, m_{ind}, for any given wire in a concentric-lay-stranded conductor is as follows:

$$m_{ind} = \sqrt{1 + (9.8696 / n^2)}$$

where:

n = length of lay/diameter of helical path of the wire.

The derivation of the equation is given in *NBS Handbook 100*.

NOTE 9—To cooperate with the manufacturer in avoiding the accumulation of excessive amounts of scrap wire, it is suggested that package sizes permit ordinary variations of ±10 % in package lengths, and that occasional short lengths be permitted, such packages to be distinctly marked.