Designation: D709 – 17

Standard Specification for Laminated Thermosetting Materials[1]

This standard is issued under the fixed designation D709; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This specification covers laminated thermosetting materials consisting of two or more plies or layers of reinforcing material bonded by a thermosetting synthetic resin. Examples of such reinforcement are cellulose paper, cotton fabric, glass fabric, and synthetic fiber fabrics. These materials are available in the form of sheets, rolled and molded tubes, and molded rods.

1.2 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1—This specification resembles IEC 60893-3 in title only. The content is significantly different.

1.3 The following safety hazards caveat pertains only to the test methods described in this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation

D257 Test Methods for DC Resistance or Conductance of Insulating Materials

D348 Test Methods for Rigid Tubes Used for Electrical Insulation

D349 Test Methods for Laminated Round Rods Used for Electrical Insulation

D495 Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation

D621 Test Methods for Deformation of Plastics Under Load (Withdrawn 1994)[3]

D668 Test Methods of Measuring Dimensions of Rigid Rods and Tubes Used for Electrical Insulation

D883 Terminology Relating to Plastics

D1180 Method of Test for Warpage of Sheet Plastics (Withdrawn 1988)[3]

D1711 Terminology Relating to Electrical Insulation

D2303 Test Methods for Liquid-Contaminant, Inclined-Plane Tracking and Erosion of Insulating Materials

D2304 Test Method for Thermal Endurance of Rigid Electrical Insulating Materials

D3636 Practice for Sampling and Judging Quality of Solid Electrical Insulating Materials

D6054 Practice for Conditioning Electrical Insulating Materials for Testing (Withdrawn 2012)[3]

2.2 *IEEE Standards:*[4]

1 General Principles for Temperature Limits in the Rating of Electric Equipment

98 Guide for the Preparation of Test Procedures for the Thermal Evaluation and Establishment of Temperature Indices of Solid Electrical Insulating Materials

99 Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment

101 Guide for the Statistical Analysis of Thermal Life Test Data

2.3 *NEMA Standards:*[5]

LI 1-1971 Industrial Laminated Thermosetting Products

LI 5-1969 Temperature Indices of Industrial Thermosetting Laminates

[1] This specification is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.07 on Electrical Insulating Materials.

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

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.

[5] Available from National Electrical Manufacturers Association (NEMA), 1300 N. 17th St., Suite 1752, Rosslyn, VA 22209, http://www.nema.org.

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

LI 3-1961 High-Temperature Properties of Industrial Thermosetting Laminates

2.4 *Military Specifications:*[6]

MIL-I-24768 Insulation, Plastics, Laminated, Thermosetting, General Specifications for

2.5 *IEC Standard:*

Publication 60893-3 Specification for Industrial Laminated Sheets Based on Thermosetting Resins for Electrical Purposes[7]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this specification, refer to Terminologies D883 or D1711.

4. Types and Grades

4.1 Laminated materials covered by this specification are classified in accordance with the types of reinforcement used in their manufacture, and the electrical, mechanical, and heat-resisting characteristics of the finished products (Note 2).

NOTE 2—Further descriptive information regarding these various types and grades of laminated thermosetting materials is given in Table 1 and Appendix X1 – Appendix X3. Appendix X3 also includes tables covering engineering information on other properties of the various grades of laminated thermosetting products that are not included in these specification requirements.

5. Forms

5.1 Laminated thermosetting materials are available in four forms: sheets, tubes (Note 3), rods (Note 4), and molded shapes (Note 5), as indicated in Table 2. This specification covers the material in three forms: sheets, tubes of two classes (rolled and molded), and molded rods. The classes of tubes desired shall be specified by the purchaser in the contract or order. In cases where the purchaser desires a particular class of molded rod the purchaser shall so specify.

NOTE 3—Tubes are made of laminations of fibrous sheet impregnated material, rolled upon mandrels under tension or between heated pressure rolls, or both. They are of two classes, rolled and molded. Rolled tubes are oven-baked after rolling on the mandrels. Molded tubes are cured in molds under heat and pressure.

NOTE 4—Molded rods are composed of laminations of impregnated sheet material molded in cylindrical molds under heat and pressure, and then ground to size. Molded rods are of two classes made by winding the impregnated sheet convolutely before molding or by forming strips in the molding operation.

Machined rods, manufactured from certain grades of sheet material, are not covered by this specification. In rods machined from sheets, the laminations are parallel chords of a circular cross-section. In general, the properties of these rods conform to those of the grade of sheet stock from which they are cut. This type of rod has the potential to be low in flexural strength when stress is applied perpendicular to the lamination.

NOTE 5—Molded shapes are composed of impregnated sheet materials cut into various sizes and shapes to fit the contours of a mold, and molded under heat and pressure. In special cases some macerated material is used in combination with impregnated sheet materials, depending upon the design of the piece. The requirements of this specification, particularly with regard to mechanical properties, cannot be considered as applying to molded shapes, except for rectangular and square tubes, since such properties will depend to a considerable extent upon the design of the piece.

6. General Requirements

6.1 *Materials and Workmanship*—Laminated material shall be uniform in quality. It shall be free of blisters, wrinkles, or cracks and shall be reasonably free of other small defects such as scratches, heat marks, and so forth, as defined in Terminology D883. Tubes of any grade having wall thickness greater than ½ in. (13 mm) and molded paper-base rods (Grades XX and XXX) having diameters greater than 1 in. (25 mm) have the potential to show checks or cracks between the laminations on machined or sawed edges.

6.2 *Finish and Color*—Requirements for finish (Note 6) and color (Note 7) shall be as specified by the purchaser in the contract or order.

NOTE 6—The various forms and grades of laminated thermosetting material are available in the finishes shown in Table 3.

NOTE 7—The various types and grades of laminated thermosetting material are available in the colors shown in Table 4. Where MIL-P specifications are involved, natural color only shall be supplied.

6.3 *Warp or Twist*—The warp or twist shall not exceed the values prescribed in Table 5.

6.4 *Punching Properties*—The grades of material differ in their suitability for punching, but thin pieces of any of the grades are permitted to be punched in simple shapes, provided good punching practice is used, including sharp, close-clearance dies, proper stripper plates, and proper heating conditions. When using good punching practice as outlined below, the various grades shall punch satisfactorily in thickness up to and including the maximum limits as prescribed in Table 6. Where punching properties better than those listed in Table 6 are required for particular parts, this shall be subject to agreement between the purchaser and the manufacturer. In good punching practice the edges of the piece shall be no closer to the edge of the strip than twice the thickness of the sheet, the holes shall be no smaller in diameter than the thickness of the sheet nor have square corners, and the distance between the holes or between the holes and the edge of the piece shall be no less than the thickness of the sheet. For thicker materials, depending upon the grade, heating the material to a temperature of 120 to 140°C (approximately 15 min for material ⅛ in. (3 mm) in thickness) is generally necessary for best punching results, although in Grade XP or XPC it is possible that this will make the material too soft. In this case, better results are likely to be obtained by heating at lower temperatures or for a shorter time. If more than 2 min elapse between the time the strip leaves the heating medium and the last piece is punched, results will be poor.

NOTE 8—The punching properties of the cotton fabric-base grades and of the paper-base grades classed as punching stock are somewhat better than those of the other glass or nylon fabric-base grades. All grades can be punched in thin thicknesses under suitable conditions.

6.5 *Machining Properties*—In general, most of the grades can be drilled, tapped, sawed, and machined. Grades X, XP, XPC, A, G-7, and N-1 are not recommended for drilling and

[6] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094 Attn: NPODS.

[7] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

TABLE 1 Types and Grades of Laminated Thermosetting Materials

D709 Grade Designation	MIL-I-24768 Specification Sheet Number and Grade Designation[A]	Description
Type I—Cellulose Paper-Base Phenolic Resin (Unless Noted)		
X	/12 Type PBM	mechanical
XP	/19 Type PBM-P	mechanical; hot-punching stock
XPC	/20 Type PBM-PC	mechanical; cold-punching and cold-shearing stock
XX	/11 Type PBG	electrical and mechanical
XXP	/21 Type PBG-P	electrical and mechanical; hot-punching stock
XXX	/10 Type PBE	electrical and high humidity
XXXP	/22 Type PBE-P	electrical and high humidity; hot-punching stock
XXXPC	/23 Type PBE-P	punchable at lower temperature than Grade XXXP
FR-1	/24 Type PBM-PF	paper-base, flame-resistant, similar to Grade XP
FR-2	/25 Type PBE-PCF	paper-base, flame-resistant, similar to Grade XXXP
FR-3	/26 Type PEE	flame-resistant, epoxy resin; electrical and mechanical
ES-1	...	mechanical; engraving stock usually melamine binder
ES-2	...	mechanical; engraving stock usually melamine binder
ES-3	...	mechanical; engraving stock usually melamine binder
Type II—Cellulose Fabric-Base Phenolic Resin		
C	/16 Type FBM	mechanical
CE	/14 Type FBG	mechanical and electrical
L	/15 Type FBI	mechanical; fine machining
LE	/13 Type FBE	mechanical and electrical; fine machining
Type IV—Glass-Base		
G-3	/18 Type GPG	continuous filament-type glass cloth; phenolic resin, general purpose
G-5	/8 Type GMG	continuous filament-type glass cloth, melamine binder; general purpose; good arc and flame resistance
G-7	/17 Type GSG	continuous filament-type glass cloth, silicone resin binder; good mechanical strength, heat and arc resistance; low dielectric losses and high insulation resistance under humid conditions
G-9	/1 Type GME	continuous filament-glass cloth, melamine binder. Superior to Grade G-5 under wet conditions, good arc and flame resistance
G-10	/2 Type GEE	continuous filament-type glass cloth, epoxy resin binder; high mechanical strength good insulation resistance, dielectric loss, and dielectric strength under dry and humid conditions
G-11	/3 Type GEB	continuous filament-type glass cloth, heat-resistant epoxy binder; properties similar to Grade G-10 but higher flexural strength retained at elevated temperatures
FR-4	/27 Type GEE-F	continuous filament-glass cloth with a flame-resistant epoxy resin binder; properties similar to G-10
FR-5	/28 Type GEB-F	continuous filament-glass cloth with a heat- and flame-resistant epoxy resin binder; properties similar to G11
GPO-1	/4 Type GPO-1P	Glass mat with polyester resin binder, for general purpose
GPO-2	/5 Type GPO-2P	Glass mat with polyester resin binder, for general purpose and flame resistance
GPO-3	/6 Type GPO-3P	Glass mat with polyester resin binder, for general purpose, flame resistance and tracking resistance
GPO-1P	/31 Type GPO-N-1P	Glass mat with polyester resin binder, for general purpose, has better punching performance than standard GPO
GPO-2P	/32 Type GPO-N-2P	Glass mat with polyester resin binder, for general purpose, and flame resistance, has better punching performance than standard GPO
GPO-3P	/33 Type GPO-N-3P	Glass mat with polyester resin binder, for general purpose, flame resistance and tracking resistance has better punching performance than standard GPO
Type V—Nylon-Base		
N-1	/9 Type NPG	nylon cloth-base, phenolic resin binder; excellent electrical properties under high humidity; good impact
Type VI—Composite-Base Laminates		
CEM-1	/29 Type CEM-1	cellulose paper core, glass surfaces, flame-resistant resin (see X1.28)
CEM-3	/30 Type CEM-3	non-woven glass core, glass surfaces, flame-resistant resin (see X1.29)

[A] Individual Specification Sheets are subsidiary documents of the main MIL-I-24768 standard, and are designated as MIL-I-24768/1, /2, and so forth. Revisions of this specification are designated by suffix letters added to the MIL-P or LP Specification number, *A* for the first revision, *B* for the second, and so forth. Reference shall accordingly be made to the latest edition of the specification.

tapping parallel with laminations. Grades XXX, CE, and LE are best suited to these operations.

7. Detail Requirements for Sheets

7.1 Sheet material shall conform to the requirements for physical and electrical properties prescribed in Tables 7-12.

7.2 *Rate of Burning*—Tests shall be conducted on laminates from 1/32 to 1/4 in. (0.8 to 6.4 mm) in thickness in accordance with Method I of Test Methods D229. The rate of burning shall be Class I for Grades FR-1, FR-2 and FR-3, and Class O for Grades FR-4, FR-5, CEM-1, G-5, G-7, G-9, and GPO-2.

TABLE 2 Available Forms of Laminated Thermosetting Materials

Type	Grade	Forms					
		Sheets	Round Tubes		Round Rods		Rectangular and Square Molded Tubes
			Rolled	Molded	Molded	Machined	
I	X	A	A	B	B	...	C
	XP, XPC	A	B	B	B	...	B
	XX	A	A	A	A	D	C
	XXP	A	B	B	B	...	B
	XXX	A	A	A	A	D	C
	XXXP	A	B	B	B	...	B
	XXXPC	A	B	B	B	...	B
	FR-1	A	B	B	B	...	B
	FR-2	A	C	C	C	C	B
	FR-3	A	C	C	C	...	C
	ES-1, ES-2, and ES-3	A	B	...	B	...	...
II	C	A	A	C	A	D	C
	CE	A	B	A	A	D	C
	L	A	C	A	A	D	C
	LE	A	A	A	A	D	...
IV	G-3	A	A	B	C	...	...
	G-5	A	A	B	A	D	
	G-7	A	C	C	C	D	B
	G-9	A	A	C	A	D	C
	G-10	A	A	B	A	D	B
	G-11	A	C	B	C	...	B
	G-11	A	C	C	C	C	C
	FR-4	A	C	C	C	C	C
	FR-5						
	GPO-1, GPO-2, and GPO-3	A	D	D	D	D	D
	GPO-1P, GPO-2P, and GPO-3P	A	D	D	D	D	D
V	N-1	A	C	C	C	D	C
VI	CEM-1	A	D	D	D	D	D
	CEM-3	A	D	D	D	D	D

[A] Materials covered by this specification.
[B] Not recommended in this form.
[C] Detailed requirements on these materials are not yet available.
[D] Materials not covered by this specification.

TABLE 3 Available Finishes of Laminated Thermosetting Materials

Form	Grade	Finish[A]
Sheets	XX, XXX, CE, LE	semigloss or polished
	X, C, L, G-3, G-5, G-7, G-9, G-10, G-11, N-1, FR-2, FR-4, FR-5, GPO-1, GPO-2, GPO-3, GPO-1P, GPO-2P, GPO-3P, CEM-1, CEM-3	semigloss
	XPC, XP, XXP, XXXP, XXXPC, FR-1, FR-3	semigloss or dull
	ES-1, ES-2, ES-3	dull or polished
Round tubing and rods	G-3, G-5, G-7, G-9, G-10, G-11, N-1	ground only
	all other grades	ground, buffed, or varnished
Molded square and rectangular forms	all grades	semigloss, ground, or varnished

[A] *Ground finish* is applied by a fine grinding wheel or belt, is free of any pronounced scratches and is suitable for a majority of applications.
Buffed finish is somewhat more glossy than the ground finish, and is obtained by buffing the tube or rod following grinding, using a touch of shellac or other polishing compound on the buffer.
Varnished finish is sometimes applied to tubes or rods for special decorative, special electrical, or chemical-resistant applications. It is obtained by coating the tube or rod one or more times with a varnish or lacquer and air-drying or baking. Because the varnish requires operations that could change greatly the physical and electrical properties, such finished tubes or rods are not covered by this specification.

7.3 *Flame Resistance*—Tests shall be conducted on laminates ½ in. (12.7 mm) in thickness in accordance with Method II of Test Methods D229. The requirements for average ignition time and burning time are shown in Table 13.

8. Detail Requirements for Tubes

8.1 Tubes shall conform to the requirements for physical and electrical properties prescribed in Table 14, Table 15, and Table 16 for round rolled tubes, and in Table 17, Table 18, and Table 19 for round molded tubes.

9. Detail Requirements for Molded Rods

9.1 Molded rods shall conform to the requirements for physical properties prescribed in Tables 20 and 21.

TABLE 4 Available Colors of Laminated Thermosetting Materials

Type	Grade	Standard Color[A]
Sheets	X, XX, XXP, XXX, C, CE, L, LE	natural or black
	XP, XPC	natural, black, or chocolate
	XXXP, XXXPC, FR-1, FR-3, G-3, G-5, G-7, G-9, G-10, G-11, N-1, FR-2, FR-4, FR-5, GPO-1, GPO-2, GPO-3, GPO-1P, GPO-2P, GPO-3P, CEM-1, CEM-3	natural
	ES-1	black or gray surface, white core
	ES-2	black or gray surface, white subcore, black core
	ES-3	white or gray surface, black core
Round tubing and rods and molded square and rectangular forms	X, XX, XXX, C, CE, L, LE	natural or black
	FR-1, G-3, G-5, G-7, G-9, G-10, G-11, N-1	natural

[A] *Natural* color is produced by the natural undyed paper or fabric and resin used. Woven glass-base grades contains streaks due to differential coloration of various warp or filler threads under heat-treating conditions. The natural color of the phenolic material will vary from a light tan to a light brown or reddish brown. The color of the glass-base melamine and silicone materials will vary from white to light gray to a brown color. That of the glass-base silicone material will be from white to cream.

Black colored sheets have substantially uniform black surfaces and a black body. Sawed, sanded, and machined surfaces of sheets, and ground surfaces of tubes, show a light grayish black tinge. Sawed, sanded, machined, and ground surfaces and edges of some cotton fabric-base grades and of asbestos paper-base materials show a decided grayish black tinge.

Chocolate colored sheets have a uniform dark brown or chocolate color surface with natural core.

Experience has shown that colors other than those mentioned have ingredients which prevent laminated products from meeting the specified standard electrical or mechanical performance values. Even black and chocolate colors affect electrical characteristics. For instance, the standard color for grade XXXP is "natural" only because the presence of any dye or pigment would impair its electrical qualities.

TABLE 5 Permissible Warp or Twist

Form	Thickness or Outside Diameter	Maximum Permissible Warp or Twist[A] on Basis of 36-in. Dimension, %
Sheets[B]	1/32 to 1/16 (0.79 to 1.58), excl	5.0
	1/16 to 1/8 (1.58 to 3.17), excl	2.5
	1/8 to 1/4 (3.17 to 6.35), incl	1.0[C]
	Over 1/4 to 3/4 (6.35 to 19.05), incl	0.5
	Over 3/4 (19.05)	0.25
Tubes and molded rods	1/8 to 1/4 (3.17 to 6.35), incl	2.0
	Over 1/4 to 3/4 (6.35 to 19.05), incl	1.0
	Over 3/4 (19.05)	0.5

[A] In case of warp, this percentage is stated in terms of the lateral dimensions (length or width); in the case of twist, which applies only to sheet forms, the percentage is stated in terms of the dimensions from one corner to the diagonally opposite corner.

[B] These requirements do not apply to cut pieces, but only to sheet sizes, tube lengths, and rod lengths as manufactured.

[C] In the case of Grade G-7 the maximum permissible warp or twist shall be 1.5 %.

TABLE 6 Maximum Thickness in Inches (Millimetres) for Various Grades at Which Satisfactory Punching Results shall be Obtained[A]

Grade	At Room Temperature (20 to 30°C)	When Heated Before Punching	
		To 120 to 140°C	To approximately 60°C
X	1/32 (0.8)	3/32 (2.4)	
XP, FR-1	1/16 (1.6)	1/8 (3)	
XPC	1/8 (3)	1/4 (6)	
XX	1/32 (0.8)	3/32 (2.4)	
XXP	1/32 (0.8)	1/8 (3)	
XXX	...	1/16 [B] (1.6)	
XXXP	...	3/32 (2.4)	
XXXPC, FR-2, FR-3, CEM-1, CEM-3	1/16 (1.6)	...	1/8 (3)
C, L	1/16 (1.6)	3/16 (4.8)	
CE	...	3/32 (2.4)	
LE	1/32 (0.8)	3/32 (2.4	
G-3, G-5, G-7, G-9, G-10, G-11, FR-4, FR-5	1/8 (3)	1/8 (3)	
N-1	1/16 (1.6)	3/16 (4.8)	

[A] With simple forms and special precautions greater thicknesses than the above can sometimes be punched. With poor dies, poor punching practice, or intricate parts, good results cannot be expected in the thicknesses listed in this table.

[B] Simple shapes, compound dies only.

10. Sheet Sizes and Permissible Variations

10.1 *Length and Width*—The nominal length and width of the sheets shall be ±1 in. (±25 mm) from the manufacturer's standard.

10.2 Tolerances of material cut by sawing shall be as prescribed in Table 22 and those cut by shearing shall be as prescribed in Tables 23 and 24.

NOTE 9—Due to variations in sizes of press equipment, there is considerable variation in the lengths and widths of manufacturers' standard size sheets. For most of the grades, these standard sizes range between 36 and 50 in. (914 and 1270 mm) in width, and between 36 and 96 in. (914 and 2438 mm) in length. Certain grades are sometimes supplied in standard sizes ranging from 24 to 36 in. (610 to 914 mm) in width, and from 24 to 96 in. (610 to 2438 mm) in length. In order to avoid damage to the sheets during shearing, it is recommended that this operation not take place at temperatures lower than 20°C (68°F) and not higher than 40°C (104°F).

10.3 *Thickness*—The permissible variations from the standard thicknesses (Note 10) of the various grades of sheets shall be within the requirements prescribed in Table 25. At least 90 % of the area of the sheet shall be within the variations prescribed in Table 25, and at no point shall the thickness as measured vary from the nominal by a value greater than 125 % of the specified variation. Permissible ranges in thickness of component parts of engraving stock sheets are given in Table 26.

NOTE 10—Sheets are available in the thicknesses shown in Table 27.

TABLE 7 Flexural Strength Requirements for Sheets, Measured Flatwise (Condition A),[A] Min Average, psi

Grade	Thickness[B]																	
	1/32 (0.8)		1/16 (1.6)		3/32 (2.4)		1/8 (3)		3/16 (4.8)		1/4 (6)		1/2 (13)		3/4 (18)		(25) and over	
	LW[C]	CW[C]	LW	CW	LW	CW	LW	CW	LW	CW	LW	CW	LW	CW	LW	CW	LW	CW
X	22 000	20 000	25 000	22 000	25 000	22 000	25 000	22 000	25 000	22 000	25 000	22 000	24 000	21 000	24 000	21 000	22 000	19 000
XX	15 000	13 000	15 000	14 000	15 000	14 000	15 000	14 000	15 000	14 000	15 000	14 000	15 000	14 000	15 000	14 000	13 500	12 500
XXX	13 500	11 800	13 500	11 800	13 500	11 800	13 500	11 800	13 500	11 800	13 500	11 800	13 500	11 800	13 500	11 800	12 000	10 600
XPC	...	...	10 000	8 000	10 000	8 000	12 000	10 000	12 000	10 000	12 000	10 000	...	...	...	...	...	...
XP	12 000	10 000	13 000	11 000	13 000	11 000	14 000	12 000	14 000	12 000	14 000	12 000	...	...	...	...	...	...
XXP	14 000	12 000	14 000	12 000	14 000	12 000	14 000	12 000	14 000	12 000	14 000	12 000	...	...	...	...	...	...
XXXP, XXXPC	12 000	10 500	12 000	10 500	12 000	10 500	12 000	10 500	12 000	10 500	12 000	10 500	...	...	...	...	...	...
FR-1	12 000	10 000	13 000	11 000	13 000	11 000	14 000	12 000	14 000	12 000	14 000	12 000	...	...	...	...	...	...
FR-2	12 000	10 500	12 000	10 500	12 000	10 500	12 000	10 500	12 000	10 500	12 000	10 500	...	...	...	...	...	...
FR-3	20 000	16 000	20 000	16 000	20 000	16 000	20 000	16 000	20 000	16 000	20 000	16 000	...	...	...	...	...	...
ES-1	...	...	13 500	13 500	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ES-2	...	...	...	...	13 500	13 500	13 500	13 500	13 500	13 500	13 500	13 500	...	...	...	...	...	...
ES-3	...	...	13 500	13 500	13 500	13 500	13 500	13 500	13 500	13 500	13 500	13 500	...	...	...	...	...	...
C	17 000	16 000	17 000	16 000	17 000	16 000	17 000	16 000	17 000	16 000	17 000	16 000	16 000	15 000	16 000	15 000	15 000	14 000
CE	16 500	14 000	16 500	14 000	16 500	14 000	16 500	14 000	16 000	14 000	16 000	14 000	15 500	13 500	15 500	13 500	14 500	13 000
L	16 500	14 500	16 500	14 500	16 500	14 500	16 500	14 500	16 500	14 500	16 500	14 500	15 500	14 000	15 500	14 000	15 000	13 500
GPO-1, GPO-2, GPO-3	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	18 000	...	...	...	...
GPO-1P, GPO-2P, GPO-3P	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	...	...	...	...	...	...	...	...
LE	16 000	14 000	16 000	14 000	16 000	14 000	16 000	14 000	16 000	14 000	16 000	14 000	15 000	13 500	15 000	13 500	14 500	13 000
G-3	18 000	16 000	20 000	18 000	20 000	18 000	20 000	18 000	20 000	18 000	20 000	18 000	20 000	18 000	19 000	17 000	17 000	15 300
G-5	55 000	45 000	50 000	40 000	47 000	39 000	44 000	38 000	41 000	36 000	38 000	34 000	31 200	28 500	31 200	28 500	31 200	28 500
G-7	10 000	8 000	20 000	18 000	20 000	18 000	20 000	18 000	18 000	15 000	18 000	15 000	16 000	13 000	16 000	13 000	14 400	11 700
G-9	...	...	60 000	40 000	...	...	55 000	35 000	...	...	...	...	45 000	30 000	...	...	...	...
G-10, G-11[D]	60 000	50 000	60 000	50 000	60 000	50 000	55 000	45 000	55 000	45 000	55 000	45 000	45 000	35 000	40 000	30 000	40 000	30 000
FR-4	60 000	50 000	60 000	50 000	60 000	50 000	55 000	45 000	56 000	45 000	55 000	45 000	45 000	35 000	40 000	30 000	40 000	30 000
FR-5	60 000	50 000	60 000	50 000	60 000	50 000	60 000	45 000	55 000	45 000	55 000	45 000	45 000	35 000	40 000	30 000	40 000	30 000
N-1	10 000	9 500	10 000	9 500	10 000	9 500	10 000	9 500	9 500	9 000	9 000	8 500	9 000	8 500	9 000	8 500	8 000	7 500
CEM-1	50 000	40 000	35 000	28 000	30 000	25 000	...	...	...	...	...	...	...	...	...	...	...	...
CEM-3	50 000	40 000	40 000	32 000	33 000	27 000	...	...	...	...	...	...	...	...	...	...	...	...

[A] See 14.2.
[B] For intermediate thicknesses, the values for the next smaller thickness shall apply.
[C] LW = tested in a lengthwise direction.
CW = tested in a crosswise direction.
[D] The flexural strength of Grade G-11 for a lengthwise specimen 1/8 in. (3 mm) thick measured at 150 C, Condition E-1/501, shall be no less than 30 000 psi for thicknesses up to 1/4 in. (6.4 mm) inclusive.

11. Tube Sizes and Permissible Variations

11.1 *Length*—The length of rolled or molded tubes are permitted to vary within ±1 in. (±25 mm) from the manufacturer's standard length (Note 11), unless otherwise specified. When tubes cut to definite lengths are specified, the permissible variations shall be as shown in Tables 28 and 29.

NOTE 11—Tubes are available in manufacturers' lengths which vary from 18 to 24 in. (457 to 610 mm) in small outside diameters and from 30 to 48 in. (762 to 1219 mm) in large diameters. In a number of diameters of certain grades longer lengths are available.

11.2 *Diameter*—The nominal inside and outside diameter (Note 12) shall be specified by the purchaser. The permissible variations in inside and outside diameters of round rolled and molded tubes shall be within the requirements prescribed in Table 30. The permissible variations in inside and outside dimensions of square and rectangular molded tubes shall be within the requirements prescribed in Table 31.

11.3 *Thickness*—The permissible variations in wall thickness (Note 12) for round tubing with inside diameters up to 4 in. (102 mm) shall be as shown in Tables 32 and 33. The permissible variations in wall thickness of square and rectangular molded tubes shall be within the requirements prescribed in Table 34.

NOTE 12—The standard ranges of sizes of round tubes, including inside and outside diameters and wall thicknesses, are given in Table 35. Standard increments of sizes of round tubes are as follows, except as limited by Table 35.

Nominal Inside and Outside Diameters[A] in. (mm)	Increments of Sizes of Round Tubes, in. (mm)[B]
1/8 to 1 (3 to 25), incl	1/32 (0.8)
1 1/16 to 3 (27 to 76), incl	1/16 (1.6)
3 1/8 to 6 (79 to 152), incl	1/8 (3)
6 1/4 to 8 (158 to 203), incl	1/4 (6)
8 to 25 (203 to 635), incl[A]	1/2 (13)

[A] No standards have been developed for sizes above 25 in. (635 mm) up to 48 in. (1219 mm). No standards have been developed for Grade G-5 (melamine glass-rolled tubes) for sizes above 8 in. (203 mm) inside diameter.
[B] Steps in outside diameter apply only to molded tubes. Rolled tubes are ground to size order.

The standard sizes of square and rectangular molded tubes are as shown in Table 36.

12. Rod Sizes and Permissible Variations

12.1 *Length*—Unless otherwise specified, molded rods shall be furnished to manufacturer's standard lengths (Note 13). When molded rods cut to definite lengths are specified, the permissible variations shall be as shown in Tables 36 and 37.

NOTE 13—Molded rods are available in lengths that vary from 18 to 48 in. (457 to 1219 mm) for small diameters, and from 30 to 48 in. (762 to

TABLE 8 Impact and Bonding Strength Requirements for Sheets

Grade	Impact Strength (Izod, Edgewise), min avg, ft·lb/in. of notch		Bonding Strength, min avg, lb		Grade	Impact Strength (Izod, Edgewise), min avg, ft·lb/in. of notch		Bonding Strength, min avg, lb	
	Condition E-48/50 thicknesses: ⅛ in. (3 mm) up to maximum thickness for grade, but not over 2 in. (51 mm)		Thicknesses, ½ in. (13 mm) up to maximum for grade, but not over 2 in.[A] (51 mm)			Condition E-48/50 thicknesses: ⅛ in. (3 mm) up to maximum thickness for grade, but not over 2 in. (51 mm)		Thicknesses, ½ in. (13 mm) up to maximum for grade, but not over 2 in.[A] (51 mm)	
	LW[B]	CW[B]	Condition A[C]	Condition D-48/50[C]		LW[B]	CW[B]	Condition A[C]	Condition D-48/50[C]
X	0.55	0.50	700	400	G-3	6.50	5.50	850	700
XX	0.40	0.35	800	600	GPO-1, GPO-2, GPO-3[D]	8.0	8.0	850	800
XXX	0.40	0.35	950	700	G-5	[E]	[E]	1570	1400
					G-7	6.5	5.5	650	550
FR-1	...	...	...	...	G-9	...	...	1700	1500
FR-2	...	...	...	...					
FR-3	...	...	...	...					
ES-1	0.25	0.22	...	...	G-10	7.0	5.5	2000	1600
ES-2	0.25	0.22	...	...	G-11	7.0	5.5	1600	1500
ES-3	0.25	0.22	...	...	GPO-1P, GPO-2P, GPO-3P[A]	5.0	5.0	...	...
C	1.90	1.70	1800	1600		7.0	5.5	2000	1600
CE	1.60	1.40	1800	1600					
L	1.35	1.10	1600	1500	FR-4	7.0	5.5	1600	1500
LE	1.25	1.00	1600	1500	FR-5	1.8	1.2	...	...
					CEM-1	...	...	...	...
					CEM-3	3.0	2.0	1000	1000
					N-1				

[A] Specimens shall be nominal ½ in. (13 mm) in thickness or machined to 0.500± 0.005 in. (13 ± 0.13 mm) from thicker sheets. Unmachined specimens shall be within standard tolerance for ½-in. thickness for the guide being tested. For thicker sheets, the specimens shall be cut from the center of the cross-section, machining approximately equal amounts from each surface.
[B] LW = tested in a lengthwise direction.
CW = tested in a crosswise direction.
[C] See 14.2.
[D] For specimens ⅛ to ½ in. (3 to 13 mm) inclusive.
[E] Impact requirements for Grades G-5 and G-9 are as follows:

Thickness, in. (mm)	Minimum Average Impact Strength, ft-lb/1-in. (25 mm) notch	
	LW	CW
⅛ to ½ (3 to 13), excl	7.0	5.5
½ to 2 (13 to 51), excl	9.0	6.0[A]

[A] For specimens ⅛ to 3⁄16 in. inclusive.

1219 mm) for large diameters.

12.2 *Diameter*—The diameters of rods (Note 14) shall be as specified by the purchaser. The permissible variations in diameter of molded rods shall be as shown in Table 38.

NOTE 14—Molded rods are available in the ranges of diameters given in Table 39.

13. Sampling and Number of Tests

13.1 For purposes of sampling, a production lot shall consist of a given machine run, and of a particular thickness range as agreed upon between the purchaser and the manufacturer. A machine run shall consist of all of the material pressed from a coating operation in which the basic resin, filler, and treating conditions are the same.

13.2 *Sheets*—One sheet of a particular grade or thickness shall be selected at random from each lot or shipment, whichever is the smaller. One set of test specimens as prescribed in Section 15 shall be considered sufficient. The average result for the specimens tested shall conform to the requirements prescribed in this specification. Because of the expense in both material and time, it is recommended that complete conformance tests be confined, where possible, to sheets from 1⁄16 to ½ in. (1.6 to 13 mm) in thickness.

13.3 *Tubes*—Random samples of any grade and size of tubing shall be taken to determine conformance with the density requirements. A minimum of 2 tubes from each lot of 50 tubes or a fraction thereof (of any one size), or 3 % of a larger quantity of tubes of any grade and specific size, shall be tested. The average result for the specimens tested shall conform to the requirements prescribed in this specification.

13.4 *Rods*—Random samples of rods shall be selected from each lot or shipment of any grade or size. A minimum of 2 rods from a lot of 50 rods or a fraction thereof (of any one size), or 3 % from larger lots, shall be tested. The average result for the specimens tested shall conform to the requirements prescribed in this specification.

TABLE 9 Permittivity and Dissipation Factor Requirements for Sheets[A]

Grade[B]	Condition A[C]	Condition D-24/23[C]								Condition D-48/50[C]
Thickness, in. (mm)[D]	1/32 (0.8) and over	1/32 (0.8)	1/16 (1.6)	3/32 (2.4)	1/8 (3)	3/16 (4.8)	1/4 (6)	1/2 (13)	Over 1/2 (13)	1/8 (3) only
					Permittivity at 1 MHz, max avg					
XX	5.50	6.30	6.20	6.10	6.00	6.00	6.00	6.00	6.00	...
XXX	5.30	6.00	5.90	5.80	5.70	5.70	5.70	5.70	5.70	...
XXP	5.00	5.50	5.30	5.30	5.20	5.20	5.20	...	...	5.80
XXXP, XXXPC	4.60	4.80	4.80	4.80	4.80	4.80	4.80	...	...	5.30
FR-2	4.60	4.80	4.80	4.80	4.80	4.80	4.80	...	...	5.30
FR-3	4.60	4.80	4.80	4.80	4.80	4.80	4.80	...	...	5.00
FR-4, FR-5	[E]	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.70	5.80
CEM-1	[E]	5.20	5.00	4.80	...	...	...	...	...	...
CEM-3[E]	5.40	5.40	5.40	...	...	...	...	...	...	...
LE	5.80	[F]	[F]	[F]	6.00	6.00	6.00	6.00	6.00	...
G-5	[E]	[F]	[F]	[F]	8.00	8.70	8.70	8.90	9.20	...
G-7	4.20	4.50	4.40	4.30	4.20	4.20	4.20	4.20	4.20	...
G-9	[E]	...	7.40	7.40	7.40	7.40	7.40	8.00	8.00	7.50
G-10, G-11	[E]	5.40	...	...	...	...	...	5.40	5.70	5.80
N-1	[E]	4.20	4.00	4.00	3.90	4.30	4.30	4.40	4.50	4.00
					Dissipation Factor at 1 MHz, avg max					
XX	0.045	0.053	0.052	0.051	0.050	0.050	0.050	0.050	0.050	...
XXX	0.038	0.048	0.047	0.046	0.045	0.044	0.043	0.043	0.043	...
XXP	0.040	0.080	0.060	0.060	0.050	0.050	0.050	...	...	0.10
XXXP, XXXPC	0.038	0.040	0.040	0.040	0.040	0.040	0.040	...	...	0.05
FR-2	0.038	0.040	0.040	0.040	0.040	0.040	0.040	...	...	0.05
FR-3	0.035	0.040	...	...	...	...	0.040	...	...	0.045
FR-4, FR-5	0.025	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.045
CEM-1	0.035	0.040	0.040	0.040	...	...	...	...	...	...
LE	0.055	[F]	[A]	[F]	0.070	0.070	0.070	0.070	0.070	...
G-5	0.020[G]	[F]	[F]	[F]	0.080	0.080	0.080	0.080	0.080	...
GPO-1, GPO-2[H], GPO-3	...	...	0.05	0.05	0.05	0.05	0.05	0.05	0.05	...
G-7	0.003	0.070	0.050	0.035	0.022	0.022	0.022	0.022	0.022	...
G-9	0.018[I]	0.018	0.018	0.018	0.018	0.018	0.018	0.020	0.025	0.020
G-10, G-11	0.025	0.035	...	...	...	...	...	0.035	0.035	0.045
GPO-1P, GPO-2P, GPO-3P	...	...	...	...	...	...	...	...	...	...
N-1	0.038	0.045	0.041	0.040	0.039	0.039	0.039	0.039	0.039	0.045

[A] Dielectric loss factor is the product of dissipation factor and permittivity.
[B] No dielectric loss values for Grades X, XPC, XP, FR-1, ES-1, ES-2, ES-3, C, CE, L, and G-3 are included because these grades are not suited to applications where low dielectric loss under radio frequencies is required.
[C] See 14.2.
[D] For intermediate thicknesses, the value for the next smaller thickness shall apply.
[E] Permittivity values for Grades FR-4, FR-5, G-5, G-9, G-10, G-11, CEM-1, CEM-3, and N-1, Condition A, are as follows:

Grade	Permittivity at 1 MHz, max avg (Condition A)					
Thickness, in. (mm)	1/32 to 1/16 (0.8 to 1.6), incl	Over 1/16 to 1/8 (1.6 to 3), incl	Over 1/8 to 1/4 (3 to 6), incl	Over 1/4 to 1/2 (6 to 13), incl	Over 1/2 to 1 (13 to 25), incl	Over 1 (25)
G-5	7.80	7.80	8.00	8.50	8.70	9.00
G-9	7.20	7.20	7.20	7.50	7.50	...
G-10, G-11, FR-4, FR-5	5.20	5.20	5.20	5.20	5.50	...
CEM-1	5.00	4.60	...	...	...	...
CEM-3	5.2	5.2	...	...	...	...
N-1	3.90	3.90	4.20	4.30	4.40	...
GPO-1, GPO-2, GPO-3	...	...	...	...	...	...
GPO-1P, GPO-2P, GPO-3P	...	...	...	...	...	...

[F] Dissipation factor and permittivity for Grades LE and G-5 in thicknesses below 1/8 in. (3 mm) show too great a change from Condition A to be measured satisfactorily with usual laboratory equipment.
[G] For Grade G-5 in thicknesses over 1 in. (24 mm), the value shall be 0.025.
[H] For GPO-2 only measured at 60 Hz.
[I] For Grade G-9 in thicknesses over 1/2 in. (13 mm), the value shall be 0.020.

13.5 Alternatively, the procedure described in Practice D3636 is acceptable for use with the inspection levels as agreed upon by the purchaser.

14. Conditioning

14.1 *Nomenclature*—The following letters shall be used to indicate the respective general conditioning procedures for test specimens:

14.1.1 *Condition A*—As received; no special conditioning.
14.1.2 *Condition C*—Humidity conditioning.
14.1.3 *Condition D*—Immersion conditioning in distilled water.
14.1.4 *Condition E*—Temperature conditioning.

NOTE 15—Whenever a conditioning letter is followed by a subscript 1, as D_1, this indicates that a prior temperature conditioning has been carried out.

TABLE 10 Dielectric Breakdown Requirements for Sheets, Parallel to Laminations (Step-by-Step Test), Min Average kV

Grade[A]	Condition A[B]		Condition D-48/50[B]	
Thickness, in. (mm)	1/32 to 1 (0.8 to 25), incl	Over 1 to 2 (25 to 51), incl	1/32 to 1 (0.8 to 25), incl	Over 1 to 2 (25 to 51), incl
XX	40.0	25.0	5.0	3.0
XXX	50.0	40.0	6.0	4.0
XP	40.0	...	...	...
XXP	60.0	...	5.0	3.0
XXXP, XXXPC	60.0	...	15.0	...
FR-1	40.0	...	...	...
FR-2	60.0	...	15.0	...
FR-3	60.0	...	30.0	...
FR-4, FR-5	45.0	...	40.0	...
CEM-1	45.0	...	40.0	...
CEM-3	45.0	...	40.0	...
C	15.0	10.0	...	
CE	35.0	25.0	2.5	2.5
GPO-1, GPO-2, GPO-3[C]	40.0	...	15.0	...
L	15.0	10.0	...	...
LE	40.0	30.0	3.0	3.0
GPO-1P, GPO-2P, GPO-3P[D]	...	...	5.0	...
G-5	23.0	15.0	5.0	3.0
G-7	32.0	25.0	15.0	...
G-9	60.0[E]	...	45.0[F]	40.0[F]
G-10, G-11	45.0	...	40.0	...
N-1	60.0	50.0	40.0	30.0

[A] Grades X, XPC, ES-1, ES-2, ES-3, and G-3 are not primarily electrical grades; therefore, requirements for electrical properties of these grades are not included.
[B] See 14.2.
[C] For specimens 1/16 to 1/2 in. inclusive.
[D] For specimens 1/16 to 3/16 in. inclusive.
[E] This value applies to sheets having a maximum thickness of 1/2 in. (13 mm).
[F] Thicknesses of 1/32 in. to and including 1/4 in. (0.8 to 6.4 mm).....60
Over 1/4 in. but less than 1/2 in. (6.4 to 12.7 mm).....55
From 1/2 in. to 1 in. (12.7 to 25.4 mm), incl.....45
Over 1 in. to and including 3.5 in. (25.4 to 88.9 mm).....40

14.2 *Designation*—Conditioning procedures shall be designated as follows:

14.2.1 A capital letter indicating the general condition of the specimen, that is, A for as received, C for humidity, D for immersion, or E for temperature conditioning.

14.2.2 A number indicating in hours the duration of the conditioning.

14.2.3 A number indicating in degrees Celsius the conditioning temperature.

14.2.4 A number indicating relative humidity in percent, whenever relative humidity is controlled.

14.2.5 The numbers shall be separated from each other by a slant mark, and from the capital letter by a dash.

NOTE 16—*Examples:* Condition C-24/23/50—Humidity condition, 24 h at 23°C and 50 % relative humidity; Condition D-48/50—Immersion condition, 48 h in distilled water at 50°C.

14.3 *Time Tolerances*—Oven conditioning shall be followed by cooling to room temperature (23°C) in a desiccator. Immersion conditioning shall be followed by cooling to room temperature in distilled water, as specified in Table 40.

14.4 *Temperature Tolerances*—Tolerances on the conditioning temperature shall be as follows:

Nominal Temperature, °C	Tolerance, ±, °C
23	2
50	2
105	2

14.5 *Test Conditions*—Tests shall be conducted following the conditions specified in Table 41, Table 42, and Table 43 whether or not this conditioning conflicts with the referenced test method in the tables, except that in all matters of dispute Condition A specimens shall be conditioned in accordance with Procedure A of Practice D6054 and all tests regardless of conditioning shall be conducted in the Standard Laboratory Atmosphere (23 ± 2°C, 50 ± 2 % relative humidity) except tests conducted on specimens in a conditioning chamber at the specific condition.

15. Methods of Testing Sheets

15.1 Methods of testing sheets, tubes, and rods shall be those shown in Table 41, Table 42, and Table 43 respectively.

15.2 In all cases, the test values reported shall be the average of the values determined for the number of specimens required by each specific test procedure.

NOTE 17—*Direction of Test*—When conducting tests on sheets "lengthwise" (LW) shall be interpreted to mean the direction of the sheet known to be stronger in flexure. "Crosswise" (CW) shall be the sheet direction known to be weaker in flexure and shall be 90° to the lengthwise direction.

16. Recommended Control Tests

16.1 Where experience indicates that a particular grade of material is satisfactory for some particular application, the number of tests required to ascertain the uniformity of the product and whether or not it meets these requirements is permitted to be greatly reduced. The tests listed in Table 44 are suggested as suitable to determine continuity of quality.

17. Retest and Rejection

17.1 If the results of any test do not conform to the requirements prescribed in this specification, at the option of the manufacturer that test shall be repeated on two additional sets of specimens from the same batch or shipment, each of which shall conform to the requirements specified. If either of these two additional sets of specimens fails, the material is permitted to be rejected at the option of the purchaser. Notice of failure of material based on tests made in accordance with this specification shall be reported to the manufacturer within 3 weeks from the receipt of the material by the purchaser. Any portion of the accepted shipment of material that subsequently is found not to be in accordance with this specification is permitted to be rejected, provided the manufacturer is notified within 90 days from the date of receipt of the material by the purchaser.

18. Packaging and Marking

18.1 *Packaging*—The material shall be packaged in substantial crates, boxes, or cartons so constructed as to ensure acceptance by common or other carriers for safe transportation

TABLE 11 Water Absorption Requirements for Sheets

Grade	Water Absorption, max avg, % (Condition E-1/105 followed by Condition D-24/23[A]													
Thickness, in. (mm)[B]	0.010 (0.2)	1/64 (0.4)	0.025 (0.6)	1/32 (0.8)	3/64 (1.2)	1/16 (1.6)	0.084 (2.1)	3/32 (2.4)	1/8 (3)	3/16 (4.8)	1/4 (6)	1/2 (13)	3/4 (18)	1 (25) and over
X	14.0	12.0	...	8.00	...	6.00	...	4.20	3.30	2.30	1.80	1.10	0.85	0.75
XX	7.00	6.20	...	3.10	...	2.00	...	1.60	1.30	1.00	0.85	0.55	0.50	0.45
XXX	...	4.00	...	2.10	...	1.40	...	1.10	0.95	0.70	0.60	0.45	0.40	0.35
XPC	...	...	...	8.00	...	5.50	...	4.00	3.00	2.00	1.60	...	...	...
XP	9.60	8.40	...	5.60	...	3.60	...	2.80	2.20	1.70	1.30	...	...	...
XXP	...	4.80	...	2.80	...	1.80	...	1.40	1.10	0.85	0.65	...	...	...
XXXP	...	1.65	...	1.30	...	1.00	...	0.85	0.75	0.65	0.60	...	...	...
XXXPC	...	...	...	1.30	...	0.75	...	0.65	0.55	0.50	...	...	...	...
FR-1	9.60	8.40	...	5.60	...	3.60	...	2.80	2.20	1.70	1.30	...	...	...
FR-2	...	...	...	1.30	...	0.75	...	0.65	0.55	0.50	0.40	...	...	...
FR-3	...	...	...	1.00	...	0.65	...	0.60	0.50	0.40	0.25	...	...	...
FR-4, FR-5	...	...	...	0.80	...	0.35	...	0.25	0.20	0.20	0.13	0.10	0.10	0.10
CEM-1	...	...	...	0.50	...	0.30	...	0.25	...	...	...	...	...	...
CEM-3	...	...	...	0.50	...	0.25	...	0.20	...	...	...	...	...	...
ES-1	...	...	...	...	3.00	2.50	2.20	...	...	...	...	...	...	...
ES-2	...	...	...	...	...	...	2.20[C]	2.10	1.80	1.40	1.00	...	...	...
ES-3	...	...	...	...	3.00	2.50	2.20	2.10	1.80	1.40	1.00	...	...	...
C	...	...	...	8.00	...	4.40	...	3.20	2.50	1.90	1.60	1.20	1.10	1.00
CE	...	...	...	4.50	...	2.20	...	1.80	1.60	1.30	1.10	0.75	0.70	0.65
L	8.50	7.70	...	6.00	...	2.50	...	1.90	1.60	1.30	1.10	0.90	0.75	0.70
LE	...	5.80	...	4.00	...	1.95	...	1.55	1.30	1.00	0.95	0.70	0.60	0.55
G-3	6.80	6.00	...	4.20	...	2.70	...	2.30	2.00	1.90	1.80	1.50	1.25	1.00
G-5	6.80	6.00	...	4.20	...	2.70	...	2.30	2.00	1.90	1.80	1.50	1.25	1.00
G-7	0.76	0.74	...	0.68	...	0.55	...	0.45	0.35	0.30	0.25	0.20	...	...
G-9	4.00	3.00	...	2.10	...	0.80	...	0.75	0.70	0.65	0.50	0.40	0.35	0.30
G-10, G-11	1.50	1.00	0.90	0.80	0.65	0.35	...	0.25	0.20	0.15	0.13	0.10	0.10	0.10
N-1	2.50	1.50	...	0.90	...	0.60	...	0.50	0.40	0.40	0.38	0.35	...	...
GPO-1	...	...	...	...	...	1.00	...	...	0.70	...	...	0.35	...	...
GPO-2	...	...	...	...	...	0.80	...	...	0.60	...	...	0.25	...	...
GPO-3	...	...	...	...	...	0.60	...	...	0.50	...	...	0.25	...	...
GPO-1P	...	...	...	...	...	1.00	...	...	0.70	...	...	...	...	...
GPO-2P	...	...	...	...	...	0.80	...	...	0.60	...	...	...	...	...
GPO-3P	...	...	...	...	...	0.60	...	...	0.50	...	...	...	...	...

[A] See 14.2
[B] For intermediate thicknesses, the value for the next smaller thickness shall apply.
[C] For 0.085-in. thickness of Grade ES-2.

TABLE 12 Arc Resistance and Tracking Resistance Requirements for Sheets

Grade[A]	Arc Resistance,[B] min avg, s	Tracking Resistance,[C] min avg, s
	Conditions A or D-48/50[D] Thickness 1/8 to 2 in. (3 to 51 mm), incl	Condition A
G-5	180	...
G-7	180	...
G-9	180	...
GPO-1	100	...
GPO-2	100	...
GPO-3	150	300
GPO-1P	100	...
GPO-2P	100	...
GPO-3P	150	300

[A] No requirements are contemplated for phenolic grades because of their extremely low arc resistance.
[B] Test Method D495 (stainless steel strip electrodes).
[C] Test Method D2303.
[D] See 14.2.

TABLE 13 Flame Resistance Requirements for Sheets

Grade	Average Time, s	
	Ignition, min	Burning, max
G-5	140	100
G-9	140	100
FR-4	50	100
FR-5	50	100
GPO-2	75	85
GPO-3	75	85
GPO-2P	75	85
GPO-3P	75	85

TABLE 14 Water Absorption Requirements for Round Rolled Tubes, Max Average % (Condition E-1/105 Followed by Condition D-24/23)

Grade	X		XX		XXX	C	LE	G-5	G-7	G-9	G-10
Wall Thickness, in. (mm)[A]	⅛ to ½ (3.2 to 12.7) ID, excl	½ to 8 (12.7 to 203.2) ID	⅛ to ½ (3.2 to 12.7) ID, excl	½ to 8 (12.7 to 203.2) ID	¼ to 8 (6.4 to 203.2) ID	⅜ to 8 (9.5 to 203.2) ID	3⁄16 to 8 (4.8 to 203.2) ID	⅛ to 8 (3.2 to 203.2) ID	⅜ to 6 (9.5 to 152.4) ID	⅛ to 8 (3.2 to 203.2) ID	⅛ to 8 (3.2 to 203.2) ID, excl
1 1⁄32 to 1⁄16 (0.8 to 1.6), excl	8.0	8.0	6.0	6.0	3.5[B]	...	7.5	5.0	1.0	4.2	1.0
1⁄16 to 3⁄32 (1.6 to 2.4), excl	7.0	5.0	3.6	3.0	1.5	5.0	5.0	3.9	1.0	3.0	0.8
3⁄32 to ⅛ (2.4 to 3.2), excl	6.0	4.3	2.5	2.5	1.3	3.6	3.0	3.7	0.8	2.5	0.7
⅛ to 3⁄16 (3.2 to 4.8), excl	5.2	4.0	2.0	2.0	1.0	3.0	2.5	3.5	0.8	2.0	0.6
3⁄16 to 1⁄16 (4.8 to 6.4), excl	...	3.5	1.4	1.4	0.8	2.3	1.9	3.0	0.8	1.8	0.5
¼ to ⅜ (6.4 to 9.5), excl	...	3.0	1.2	1.2	0.6	1.8	1.5	2.5	0.8	1.5	0.4
⅜ to ½ (9.5 to 12.7), excl	...	2.4	...	1.0	...	1.3	1.2	2.2	...	1.2	0.4
½ to 1 (12.7 to 25.4), excl	...	2.0	...	0.9	...	1.2	0.9	2.0	...	1.0	0.4
1 (25.4)	...	...	...	0.8	...	0.9	0.8	1.8	...	1.0	0.4

[A] For intermediate wall thicknesses, the value for the next smaller thickness shall apply.
[B] Applies only to ¼ to 2-in. (6.4 to 51 mm) inside diameter, inclusive.

TABLE 15 Density and Compressive Strength Requirements for Round Rolled Tubes

Grade	Inside Diameter, in. (mm)	Density, min, g/cm 3	Compressive Strength[A] (Axial), min avg, psi[B,C]	
			1⁄32-in. (0.8 mm) Wall	1⁄16-in. (1.6 mm) Wall and over
X	⅛ to ½, (3.2 to 12.7) excl	1.10	10 000	10 000
	½ to 8 (12.7 to 203.2)	1.12	10 000	12 000
XX	⅛ to ½ (3.2 to 12.7) excl	1.10	10 000	10 000
	½ to 8 (12.7 to 203.2)	1.12	...	13 000
XXX	¼ to ½ (6.4 to 12.7)	1.12	...	10 000
	½ to 8 (12.7 to 203.2)	1.12	...	13 000
C	⅜ to 8 (9.5 to 203.2)	1.12	...	12 000
LE	3⁄16 to ½ (4.8 to 12.7) excl	1.12	...	13 000
	½ to 8 (12.7 to 203.2)	1.14	...	13 000
G-5	⅛ to 8 (3.2 to 203.2)	1.70	...	13 000
G-7	⅜ to 1 (9.5 to 25.4) excl	1.55	...	6 000
	1 to 6 (25.4 to 152.4)	1.58	...	6 000
G-9	⅛ to 8 (3.2 to 203.2)	1.70	...	18 000
G-10	⅛ to ½ (3.2 to 12.7) excl	1.65	...	20 000
	½ to 8 (12.7 to 203.2)	1.70	...	20 000

[A] For wall thickness of 1⁄16 in. (1.6 mm) and over.
[B] The values given for compressive strength apply to wall thickness of 1⁄32 in. (0.5 mm) and over, to inside diameters of ¼ in. (6 mm) and over and to outside diameters of 2 in. (51 mm) and less.
[C] Conversion factor: 1 psi = 6.8948 kPa.

at the lowest rate to the point of delivery, unless otherwise specified in the contract or order.

18.2 *Marking*—Shipping containers shall be marked with the brand name of the material, type, grade, form, and quantity contained therein, as defined by the contract or order under which shipment is made, and the name of the manufacturer, and the number of the contract or order.

19. Keywords

19.1 industrial laminate; thermosetting molded shape laminate; thermosetting round rod laminate; thermosetting sheet laminate; thermosetting tube laminate

TABLE 16 Dielectric Strength Requirements for Round Rolled Tubes, Perpendicular to Laminations (Short-Time Test), Condition A,[A] Min Avg, V/Mil

Grade[B]	X[C]	XX		XXX	LE		G-5[D]	G-7	G-9		G-10
Wall Thickness, in. (mm)	⅛ to 8 (3.2 to 203.2) ID	⅛ to ½ (3.2 to 203.2) ID	½ to 8 (12.7 to 203.2) ID	¼ to 8 (6.4 to 203.2) ID	3⁄16 to ½ (4.8 to 12.7) ID, excl	½ to 8 (12.7 to 203.2) ID	⅛ to 8 (3.2 to 203.2) ID	⅜ to 6 (9.5 to 152.4) ID	⅛ to 8 (3.2 to 203.2) ID	D-48/50[E]	⅛ to 8 (3.2 to 203.2) ID, excl
1⁄32 to 3⁄64 (0.8 to 1.2), incl	400	310	400	...	...	70[F]	200	100	250	150	350
Over 3⁄64 to 1⁄16 (1.2 to 1.6), incl	400	310	400	225[G]	120[F]	120[F]	200	100	250	150	350
Over 1⁄16 to ⅛ (1.6 to 3.2), incl	325	290	290	250[H]	140	140	160	125	200	100	250
Over ⅛ to ¼ (3.2 to 6.4), incl	200	200	200	250[I]	120	120	110	115	160	80	200
Over ¼ to ½ (6.4 to 12.7), incl	145	...	145	...	85	85	80	100	120	60	150
Over ½ to ¾ (12.7 to 19.0), incl	120	...	120	...	70	70	65	...	80	40	...
Over ¾ to 1 (19.0 to 25.4), incl	...	...	105	...	60	60	55	...	80	40	...

[A] See 14.2.
[B] Dielectric strength values for Grade C are not contemplated.
[C] Dielectric strength of Grade X decreases markedly under humid conditions.
[D] The maximum wall thickness for Grade G-7 is ⅜ in. (9 mm).
[E] Condition D48/50 for Grade G-9 only.
[F] Low dielectric strength in the thin wall is due to the small number of laminations and the possibility of overlapping of resin-filled interstices.
[G] 1⁄16-in. (1.6-mm) wall only.
[H] ⅛-in. (3-mm) wall only.
[I] ¼-in. (6-mm) wall only.

TABLE 17 Density and Compressive Strength Requirements for Round Molded Tubes

Grade	Density,[A] min avg g/cm^3	Compressive Strength (Axial), min avg, psi[B,C]
XX	1.25	18 000
XXX	1.22	20 000
CE	1.25	19 000
L	1.25	18 000
LE	1.25	19 000

[A] Density values apply to all sizes of tubing.
[B] Compressive strength values apply to 1⁄16-in. (1.6-mm) wall thickness and over, and to ¼-in. (6-mm) inside diameter and over.
[C] Conversion factor: 1 psi = 6.8948 kPa.

TABLE 18 Water Absorption Requirements for Round Molded Tubes

Grade	Water Absorption, max, percent (Condition E-1/105 followed by Condition D-24/23)[A]							
Wall Thickness, in.[B]	1/32	1/16	3/32	1/8	3/16	1/4	1/2	1
XX	...	2.0	1.8	1.6	1.3	1.2	1.0	0.9
XXX	...	1.4	1.2	1.1	1.0	0.9	0.8	0.7
CE	...	3.0	2.2	2.0	1.8	1.6	1.2	1.1
L	6.5	3.5	2.2	1.8	1.6	1.6	1.5	1.4
LE	4.5	2.2	1.8	1.5	1.3	1.2	1.0	0.9

[A] For intermediate wall thicknesses, the value for the next smaller thickness shall apply.
[B] See 14.2.

TABLE 19 Dielectric Strength Requirements for Round Molded Tubes

Grade[A]	Minimum Average Dielectric Strength Perpendicular to Laminations (Short-Time Test), Condition A,[B,C] V/mil			
Wall Thickness in. (mm)	1/16 (1.6)	Over 1/16 to 1/8 (1.6 to 3), incl	Over 1/8 to 1/4 (3 to 6), incl	Over 1/4 to 1/2 (6 to 13), incl
XX	300	220	150	110
XXX	300	220	150	110
CE	[D]	175	125	90
LE	150[E]	175	125	90

[A] Dielectric strength values for Grade L are not included, since this grade is not manufactured primarily for electrical applications.
[B] See 14.2.
[C] No value is contemplated because of weakness at the mold seam.
[D] Mold seam has a more pronounced effect on 1/16-in. than on heavier wall thicknesses.
[E] Conversion factor: 1 mil = 0.0254 mm.

TABLE 20 Density, Flexural Strength, and Compressive Strength Requirements for Rods[A]

Grade	Diameter, in. (mm)	Density, min avg, g/cm^3	Flexural Strength,[B] min avg, psi[C]	Compressive Strength (Axial), min avg, psi[C]
XX	1/8 to 2 (3.2 to 51), incl	1.30	15 000	20 000
XXX	1/8 to 2 (3.2 to 51), incl	1.25	13 000	20 000
C	1/4 to 2 (6.4 to 51), incl	1.28	16 000	19 000
CE	1/4 to 2 (6.4 to 51), incl	1.26	13 000	20 000
L	3/16 to 2 (4.8 to 51), incl	1.28	16 000	19 000
LE	3/16 to 2 (4.8 to 51), incl	1.26	12 000	20 000
G-5	1/4 to 2 (6.4 to 51), incl	1.80	30 000	22 000
G-10	1/4 to 2 (6.4 to 51), incl	1.70	35 000	35 000

[A] Values given are for Condition A.
[B] These values cover diameters up to 1 in. (25 mm) maximum.
[C] Conversion factor: 1 psi = 6.8948 kPa.

TABLE 21 Water Absorption Requirements for Rods (Condition E-1/105, Followed by Condition D-24/23), max avg, %

Grade	Diameter, in. (mm)[A]				
	⅛ (3)	¼ (6)	½ (13)	1 (25)	Over 1 to 2 (25 to 51), incl
XX	2.5	1.5	1.0	1.0	1.3
XXX	1.5	1.0	0.75	0.75	0.75
C	...	2.5	2.0	2.0	1.5
CE	...	1.7	1.3	1.0	1.2
L	2.5[B]	2.0	1.5	1.2	1.2
LE	2.2[B]	1.4	1.1	1.0	1.1
G-5	...	4.5	3.0	3.0	3.5
G-10	...	0.75	0.50	0.50	0.50

[A] For intermediate diameters under 1 in. (25 mm), the value for the next smaller diameter shall apply.
[B] These values are for 3⁄16 in. (5 mm) diameter.

TABLE 22 Permissible Variations in Length and Width of Pieces Cut by Sawing From Standard Sheets, Plus or Minus, in.[A]

Nominal Thickness, in. (mm)	Length or Width, in. (mm)		
	6 (152) and under	Over 6 to 24 (152 to 610)	24 (610) and over
0.010 to ¼ (0.25 to 6.4), incl	0.010 (0.25)	0.015 (0.38)	1⁄32 (0.8)
17⁄64 to ½ (6.7 to 12.7), incl	0.012 (0.30)	0.017 (0.43)	1⁄32 (0.8)
33⁄64 to 1 (13.1 to 25.4), incl	0.015 (0.38)	0.020 (0.51)	1⁄32 (0.8)
1 1⁄64 to 1½ (25.8 to 38.1), incl	0.018 (0.46)	0.030 (0.76)	1⁄16 (1.6)
1 33⁄64 to 2 (38.5 to 50.8), incl	0.022 (0.56)	0.040 (1.02)	1⁄16 (1.6)

[A] For Grade N-1, the permissible variations shall be double the values given in the above table for each length or width, and thickness.

TABLE 23 Permissible Variations in Length and Width of Pieces Cut by Shearing From Sheets in Lengths Not Over 48 in., Plus or Minus, in.

Squaring Sheared				
Nominal Thickness, in.[A]	Length or Width, in.[A]			
	2 and under	Over 2 to 6	Over 6 to 24	Over 24
0.010 to 0.015, incl	0.015	...	...	...
Over 0.015 to 1/32, incl	0.007	...	...	...
Over 1/32 to 1/16, incl[B]	0.005	0.007	1/32	3/64
Over 1/16 to 3/32, incl[C]	0.010	1/32	3/64	3/64
Over 3/32 to 1/8, incl[D]	0.015	1/32	3/64	1/16

Rotary Sheared			
Nominal Thickness, in.[A]	Length or Width, in.[A]		
	5/64 to 3/4, incl	Over 3/4 to 3, incl	Over 3 to 6, incl
0.010 to 3/64, incl	0.005	0.005	0.010
Over 3/64 to 3/32, incl[E]	...	0.005	0.015
Over 3/32 to 5/32, incl[C]	...	0.020	1/32

[A] Conversion factor: 0.001 in. = 0.0254 mm.
[B] Except Grades X, XX, and XXX.
[C] Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, FR-1, FR-2, FR-3, and CEM-1.
[D] Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, XPC, FR-1, FR-2, FR-3, and CEM-1.
[E] Except Grades X, XX, and XXX.

TABLE 24 Permissible Variations in Length and Width of Pieces Cut from Sheets in Lengths not over 48 in. Plus or Minus, in. Grades GPO-1, GPO-2, GPO-3, GPO-1P, GPO-2P, and GPO-3P Only

Nominal Thickness, in.	Length or Width[A]		
	6 in. and under	6–18 in., incl	18–21 in., incl
1/32 to 1/4, incl	0.010	0.015	0.031
1/16 to 1/8, incl[B]	0.010	0.015	0.031
1/4 to 1/2, incl	0.012	0.017	0.031
1/2 to 1, incl	0.015	0.020	0.031
1 to 1.5, incl	0.018	0.030	0.062
1.5 to 2, incl	0.022	0.040	0.062

[A] Conversion factor: 0.001 in. = 0.0254 mm.
[B] Grades GPO-1P, GPO-2P, and GPO-3P only.

TABLE 25 Permissible Variations in Thickness of Sheets, in.[A,B]

Nominal Thickness, in.[A,C,D]	Grades XPC, X, XP, XX, XXP, XXX, XXXP, XXXPC FR-1, FR-2, FR-3	Grade C	Grades ES-1, ES-2, ES-3, CE	Grade L	Grade LE	Grades FR-4, FR-5, G-3, G-5, G-7, G-9, G-10, G-11, CEM-1[E] CEM-3[E]	Grade N-1	Grades GPO-1, GPO-2, GPO-3, GPO-1P, GPO-2P, GPO-3P
	±	±	±	±	±	±	±	±
0.010	0.002	...	...	0.003	...	0.002	0.003	...
0.015	0.0025	...	...	0.0035	0.0035	0.003	0.0035	...
0.020	0.003	...	...	0.004	0.004	0.004	0.004	...
0.025	0.0035	...	0.005	0.0045	0.0045	0.005	0.0045	...
1/32	0.0035	0.0065	0.0065	0.005	0.005	0.0065	0.0065	0.0075
3/64	0.0045	0.0075	0.0075	0.0055	0.0055	0.0075	0.0075	...
1/16	0.005	0.0075	0.0075	0.006	0.006	0.0075	0.0075	0.0075
3/32	0.007	0.009	0.009	0.007	0.007	0.009	0.009	...
1/8	0.008	0.010	0.010	0.008	0.008	0.012	0.010	0.010
5/32	0.009	0.011	0.011	0.009	0.009	0.015	0.011	0.011
3/16	0.010	0.0125	0.0125	0.010	0.010	0.019	0.0125	0.0125
7/32	0.011	0.014	0.014	0.011	0.011	0.021	0.014	0.014
	±	+ Only	±	+ Only	±	±	±	±
1/4	0.012	0.030	0.015	0.024	0.012	0.022	0.015	0.015
5/16	0.0145	0.035	0.0175	0.029	0.0145	0.026	0.024	0.0175
3/8	0.017	0.040	0.020	0.034	0.017	0.030	0.032	0.020
7/16	0.019	0.044	0.022	0.038	0.019	0.033	0.040	0.022
1/2	0.021	0.048	0.024	0.042	0.021	0.036	0.048	0.024
5/8	0.024	0.053	0.027	0.048	0.024	0.040	0.054	0.027
3/4	0.027	0.058	0.029	0.054	0.027	0.043	0.058	0.029
7/8	0.030	0.062	0.031	0.060	0.030	0.046	0.062	0.031
1	0.033	0.065	0.033	0.065	0.033	0.049	0.066	0.033
1 1/8	0.035	0.069	0.035	0.069	0.035	0.053	...	0.035
1 1/4	0.037	0.073	0.037	0.073	0.037	0.055	...	0.037
1 3/8	0.039	0.077	0.039	0.077	0.039	0.058	...	0.039
1 1/2	0.041	0.081	0.041	0.081	0.041	0.061	...	0.041
1 5/8	0.043	0.085	0.043	0.085	0.043	0.064	...	0.043
1 3/4	0.045	0.089	0.045	0.089	0.045	0.067	...	0.045
1 7/8	0.047	0.093	0.047	0.093	0.047	0.070	...	0.047
2	0.049	0.097	0.049	0.097	0.049	0.073	...	0.049

Nominal Thickness, in.	Grade C	Grades G-5, G-9	Nominal Thickness, in.	Grade C
	+ Only	±		+ Only
2 1/4	0.105	0.079	6	0.230
2 1/2	0.113	0.085	6 1/2	0.240
2 3/4	0.121	0.090		
			7	0.260
3	0.130	0.097	7 1/2	0.280
3 1/2	0.146	0.110		
			8	0.290
4	0.163	...	8 1/2	0.310
4 1/2	0.179	...	9	0.320
			9 1/2	0.340
5	0.190	...		
5 1/2	0.210	...	10	0.360

[A] For a sheet of nominal thickness not listed in the table, the permissible variations shall be the same as the next greater thickness.
[B] Conversion factor: 0.001 in. = 0.0254 mm
[C] Minimum thickness for Grades XXP, XXX, and XXXP is 0.015 in.; for Grades XPC and CE it is 1/32 in.; for Grades ES-1 and ES-3 it is 3/64 in. (0.011 mm); for Grade G-6 it is 1/16 in.; and for Grade ES-2 it is 0.085 in.
[D] Maximum thickness for Grades XP, XPC, XXP, XXXP, XXXPC, FR-1, ES-2, and ES-3 is 1/4 in. (6.4 mm). Maximum thickness of Grade ES-1 is 0.084 in. (0.0021 mm).
[E] Maximum thickness for Grade CEM-1 and CEM-3 is 3/32 in. (2.4 mm).

TABLE 26 Permissible Ranges in Thickness of Component Parts of Engraving Stock Sheets, in.[A]

Grade	Surfaces		White Sub-Core	
	min	max	min	max
ES-1	0.0025	0.008	...	...
ES-2	0.0025	0.008	0.020	0.035
ES-3	0.006	0.015	...	...

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 27 Available Thicknesses of Laminated Thermosetting Sheets

Type	Grade	Thickness, in.[A]	
		min	max
I	X, XX	0.010	2
	XP	0.010	1/4
	XPC, FR-1	1/32	1/4
	XXP, XXXP	0.015	1/4
	XXXPC	1/32	3/16
	FR-2, FR-3	1/32	1/4
	XXX	0.015	2
	ES-1	3/64	1/4
	ES-3	0.085	1/4
	ES-3	3/64	1/4
II	C	1/32	10
	CE	1/32	2
	L	0.010	2
	LE	0.015	2
IV	G-3	0.010	2
	G-5, G-9	0.010	3½
	G-7	0.010	1
	G-10, G-11, N-1	0.010	1
	FR-4, FR-5	0.010	1
	GPO-1, GPO-2, GPO-3	1/16	3/16
	GPO-1P, GPO-2P, GPO-3P	1/16	3/16
V	N-1	0.010	1
VI	CEM-1, CEM-3	1/32	1/4

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 28 Permissible Variations in Cut Lengths of Round Tubes, Plus or Minus, in.[A]

Length, in.	3/16 to 2 in. OD, incl	Over 2 to 4 in. OD, incl	Over 4 in. OD	Over 4 to 8 in. OD, incl	Over 8 in. OD
3 and under	0.010	0.010	0.030	...	...
Over 3 to 6, incl	0.010	0.015	0.030	...	...
Over 6 to 12, incl	0.015	0.020	0.030	...	...
Over 12 to 48, incl	1/32	1/32	3/64	...	...
Over 48 to 72, incl	1/16	5/64	...	3/32	3/16
Over 72 to 96, incl	3/32	3/32	...	1/8	1/4

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 29 Permissible Variations in Cut Lengths of Square and Rectangular Molded Tubes, Plus or Minus, in.[A]

Length, in.	3/16 to 2 in. OD, incl	Over 2 to 4 in. OD, incl	Over 4 in. OD
3 and under	0.010	0.010	0.030
Over 3 to 6, incl	0.010	0.015	0.030
Over 6 to 12, incl	0.015	0.020	0.030
Over 12 to 48, incl	1/32	1/32	3/64

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 30 Permissible Variations in Diameter of Round Tubes, Plus or Minus, in.[A]

Nominal Inside and Outside Diameters, in.	Inside Diameter[B]		Outside Diameter
	Steel Mandrel	Built-up Mandrel	Ground, Buffed, or Varnished
1/8 to 23/32, incl	0.033	...	0.005
3/4 to 1 15/16, incl	0.004	...	0.005
2 to 4, incl	0.008	...	0.008
Rolled Only:			
4 1/8 to 12, incl	0.010	...	0.025
12 1/8 to 18, incl	0.030	0.060[C]	0.030[D]
18 1/8 to 24, incl	0.040	0.075[C]	0.035[D]
24 1/8 to 48, incl	0.060	0.090[C]	0.040[D]

[A] Conversion factor: 0.001 in. = 0.0254 mm.

[B] In the absence of a mandrel of the precise size required, phenolic tubes of that size can sometimes be made on a built-up mandrel. In such cases, this is accomplished by winding a phenolic laminated rolled tube on the next smaller size steel mandrel, curing, and grinding to the desired size.

[C] Grade G-5 tubes are made on steel mandrels only.

[D] Tubes from 12 1/8 to 48 in. outside diameter, incl, must be turned to the prescribed permissible variations in outside diameter.

TABLE 31 Permissible Variations in Inside and Outside Dimensions of Square and Rectangular Molded Tubes, Plus or Minus, in.[A,B]

Nominal Inside Dimensions, in.	Inside Dimensions[C]	Nominal Outside Dimension, in.	Outside Dimensions[D]	
	All Grades		Grades X, XX, XXX, L, LE	Grade CE
3/16 to 15/32, incl	0.005	9/32 to 15/32, incl	0.010	0.017
1/2 to 31/32, incl	0.006	1/2 to 31/32, incl	0.012	0.020
1 to 1 15/16, incl	0.007	1 to 1 15/16, incl	0.014	0.022
2 to 4, incl	0.010	2 to 5, incl	0.017	0.025

[A] These permissible variations apply to tubes of uniform nominal wall thickness in which the two axes perpendicular to the length are equal or have a ratio one to the other not exceeding 4 to 1.
[B] Conversion factor: 0.001 in. = 0.0254 mm.
[C] Use variations corresponding with appropriate inside or outside dimensions. For example, with a rectangular tube having nominal inside dimension 1 1/4 by 1 in., the variation on 1/4 in. will be ±0.005 in. and on 1 in. will be ±0.007 in.
[D] At the option of the manufacturer, it is acceptable to meet outside dimension by sanding or machining, if necessary.

TABLE 32 Permissible Variations in Wall Thickness[A] of Round Rolled Tubes up to 4 in. in Diameter

Nominal Wall Thickness, in.[B]	Permissible Variations from Average Wall Thickness of Individual Tube, ±, in.[B]				
	Grades X, XX	Grade LE		Grade C	Grades G-3, G-5, G-7, G-10
Average for Single Tube		3/16 to 1/2, in. ID, incl	Over 1/2 in. ID		
0.010 to 1/64, excl	0.003	...	...	...	...
1/64 to 1/32, excl	0.005	...	...	...	0.006
1/32 to 1/16, excl	0.006	0.010	0.08	0.015	0.008
1/16 to 1/8, excl	0.007	0.011	0.09	0.020	0.009
1/8 to 1/4, excl	0.009	0.013	0.011	0.020	0.011
1/4 to 1/2, incl	0.011	0.015	0.013		0.013

[A] Wall thickness measured at any point in any wall of any one tube of a given size shall fall within these permissible variations. This provides a means for measuring both the variation in wall thickness and deviation from concentricity.
[B] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 33 Permissible Variations in Wall Thickness[A] of Round Molded Tubes up to 3 7/8 in. in Inside Diameter

Nominal Wall Thickness, in.[B]	Permissible Variations from Average Wall Thickness of Individual Tube, ±, in.[B]				
	Grades XX, XXX, L, LE			Grade CE	
Average for Single Tube	1/8 to 1/4 in. ID, incl	Over 1/4 to 1/2 in. ID, incl	Over 1/2 in. ID	1/4 to 1/2 in. ID, incl	Over 1/2 in. ID
1/32 to 1/16, excl	0.008	0.008	0.008	0.015	0.015
1/16 to 1/8, incl	0.011	0.011	0.011	0.015	0.015
Over 1/8 to 1/4, incl	...	0.015	0.011	0.020	0.020
Over 1/4 to 1/2, incl	...	...	0.013	...	0.020

[A] Wall thickness measured at any point in any wall of any one tube of a given size shall fall within these permissible variations. This provides a means for measuring both the variation in wall thickness and deviation from concentricity.
[B] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 34 Permissible Variations in Wall Thickness[A] of Square and Rectangular Molded Tubes

Wall Thickness, in.[B]	Permissible Variations from Average Wall Thickness of Individual Tube,[C] ±, in.[B]			
Average for Single Tube	Grades X, XX, XXX, L, LE			Grade CE
Inside Dimension, in.[D]	3/16 to 1/4, excl	1/4 to 1/2, incl	Over 1/2	Over 3/8
3/64 to 1/16, excl	0.008	0.008	0.010	...
1/16 to 1/8, excl	0.011	0.010	0.013	0.015
1/8 to 1/4, excl	0.015	0.014	0.016	0.020
1/4 to 1/2, excl	...	0.018	0.020	0.025

[A] Wall thickness measured at any point in any wall of any one tube of a given size shall fall within these permissible variations. This provides a means for measuring both the variation in wall thickness and deviation from concentricity.
[B] Use variations corresponding with maximum inside dimension.
[C] At the option of the manufacturer, it is acceptable to meet outside dimension by sanding or machining, if necessary.
[D] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 35 Available Sizes of Round Tubes (see Note 13)[A]

Grade	Rolled Tubes							Molded Tubes						
	Inside Diameter, in.[B]		Outside Diameter, in.[B]		Wall Thickness, in.[B]		Maximum Ratio of Wall Thickness to Inside Diameter[C]	Inside Diameter, in.[B]		Outside Diameter, in.[B]		Wall Thickness, in.[D]		Maximum Ratio of Wall Thickness to Inside Diameter[D]
	min	max	min	max	min	max[D]		min	max	min	max	min	max[D]	
X	1/8	48	0.145	49 1/2	0.010	3/4	1/4		none	...	...	...	...	...
XX	1/8	48	0.145	50	0.010	1	1/2	1/8	3 7/8	1/4	4	1/16	1	1/2
XXX	1/4	8	5/16	10	1/32	1	1/2	1/8	3 7/8	1/4	4	1/16	1	1/2
C	3/8	48	1/2	50	1/16	2	1/2		none	...	...	...	...	...
CE		none	...	...	...	...	...	1/4	3 7/8	3/8	4	1/16	1	1/2
L		none	...	...	...	...	...	1/8	3 7/8	3/16	4	1/32	1	1/2
LE	3/16	48	1/4	50	1/32	1	1/2	1/8	3 7/8	3/16	4	1/32	1	1/2
G-3	1/4	48	9/32	50	1/64	1	1/2		none	...	...	...	...	...
G-5, G-10	1/8	48	5/32	50	1/64	1	1/2		none	...	...	...	...	...
G-7	3/8	6	7/16	6 3/4	1/32	3/8	1/8		none	...	...	...	...	...

[A] Detailed requirements are not yet available for Grades G-9, G-11, FR-4, and FR-5.
[B] Conversion factor: 0.001 in. = 0.0254 mm.
[C] By "maximum ratio of wall thickness to inside diameter" is meant that for any size of tube, the standard wall thickness shall not be greater than 1/4 ; or 1/2 of the inside diameter, whichever value applies. For example, maximum wall thickness of Grade X rolled tubes for 1/8-in. inside diameter is 1/32 in., for 1/4-in. inside diameter it is 1/16 in., for 1-in. inside diameter it is 1/4 in. and for 3-in. inside diameter and over it is 3/4 in.
[D] See 5.1.

TABLE 36 Available Sizes of Square and Rectangular Molded Tubes

Grade	Inside Dimension, in.[A]		Outside Dimension, in.[A]		Wall Thickness, in.[A]	
	Min	Max	Min	Max	Min	Max[B]
X	3/16	3 29/32	9/32	4	3/64	1/2
XX	3/16	3 29/32	9/32	4	3/64	1/2
XXX	3/16	3 29/32	9/32	4	3/64	1/2
CE	3/8	3 7/8	1/2	4	1/16	1/2
L	1/4	3 29/32	11/32	4	3/64	1/2
LE	1/4	3	11/32	4	3/64	1/2

[A] Tubes with a wall thickness greater than one half of the minimum inside dimension are not recommended for many applications.
[B] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 37 Permissible Variations in Cut Lengths of Molded Rods, Plus or Minus, in.[A]

Length, in.	1/8 to 1 15/16 in., incl, in Diameter	2 to 4 in., in Diameter
0 to 3, incl	0.010	0.010
Over 3 to 6, incl	0.010	0.015
Over 6 to 12, incl	0.015	0.020
Over 12	1/32	1/32

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 38 Permissible Variations in Diameter of Molded Rods

Nominal Diameter, in.[A]	Permissible Variations, ±, in.[A]
1/8 to 2, excl	0.005
2 to 4, incl	0.008

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE 39 Range of Diameters for Molded Rods

Grade	Range of Diameters, in. (mm)	
	min	max
XX,[A] XXX[A]	1/8 (3)	2 (51)
C, CE	1/4 (6)	4 (102)
L, LE	3/16 (5)	4 (102)
G-3, G-5, G-9, G-10	1/4 (6)	2 (51)

[A] Molded rods in these grades having diameters greater than 1 in. (25 mm) are permitted to show checks or cracks between the laminations on machined or sawed edges.

TABLE 40 Conditioning Time Tolerances

Conditioning		Cooling		Remarks
Condition	Time Tolerance	Time	Time Tolerance	
E-48/50	–0 h +2 h	16 h or more	–0 h	Cool in desiccator. Start test within ½ h after removing specimen from desiccator.
D-48/50 D-24/23	–0 h +½ h	1 h	–0 h +2 h	Cool by immersion in a sufficient quantity of distilled water to reduce the temperature to 23°C within 1 h. Remove individually as needed, and wipe surface water off with a cloth. Start test within 1 min after removing specimen from water.
E-1/105	–0 min +6 min	2 h or more	–0 h	See water absorption test.
E-1/150	–0 min +6 min			The test for flexural strength shall be made in the oven immediately after the conditioning period.
D_1-24/23	–0 h +½ h			See water absorption test.
C-96/35/90	–0 h +2 h			Test after humidity conditioning shall be made on specimens in the humidity chamber.

TABLE 41 Test Method, Number, and Size of Specimens Required for Tests on Sheets

Property	Test Method	Number of Test Specimens	Condition	Size
Rate of burning (1/32 in. through ¼ in. thickness)	D229, Method I	20	A, E-168/70	5½ by ½ in. (127 by 13 mm) by thickness
Flame resistance (½ in. thickness)	D229, Method II	4	A	½ in. (13 mm) (± standard permissible variation for grade) by ½ ± 0.01 in. by 10 ± 1/16 in. (13 ± 0.25 mm by 254± 1.6 mm)
Flexural strength (tested flatwise)	D229	4 LW,[A] 4 CWay,[A]	A	See Test Methods D229
Impact strength (tested edgewise)	D229	4 LW, 4 CWay	E-48/50	2½ by ½ in. (63.5 by 13 mm) by thickness, notched. Built up to ½-in. thickness (± standard permissible variation for grade), or machined down to a thickness of 0.500 ± 0.005 in. (127 ± 0.127 mm) from thicker sheets
Bonding strength	D229	4 4	A D-48/50	1 by 1 by ½ in. (25 by 25 by 13 mm) (± standard permissible variation for grade), or machined to a thickness of 0.500 ± 0.005 in. (12.7 ± 0.127 mm) from thicker sheets
Water absorption	D229	3	E-1/105 followed by D-24/23	3 by 1 in. (76 by 25 mm) by thickness
Dielectric breakdown or proof parallel to laminations, tapered-pin, step-by-step	D229	1 4	A and D-48/50	3 by 2 in. (76 by 51 mm) by thickness
Dissipation factor and permittivity at 1 MHz	D229	2 2	A D-24/23 or D-48/50	See Test Methods D229
Arc resistance[B]	D495	3	A	3 by 2 in. (76 by 51 mm) by thickness
Tracking resistance	D2303	5	A	2 × 5 × ¼ in. (50 × 130 × 6 mm)
Dimensions (length, width and thickness)	D229	1	A	Full-size sheet or cut plate
Warp and twist	D229	4	A	Full-size sheet

[A] LW = cut lengthwise.
CW = cut crosswise.
[B] Grades G-5, G-9, and G-7 only.

TABLE 42 Test Method, Number, and Size of Specimens Required for Tests on Tubes

Property	Test Method	Number of Specimens	Condition	Size
Density	D348	1 (right) 1 (left)	A	1 in. (25 mm) long up to 3 in. (76 mm) ID ½ by 2 in. (13 by 51 mm) cut from wall over 3 in. (76 mm) ID
Water absorption	D348	3	E-1/105 and D-24/23	1 in. (25 mm) long up to 3 in. (76 mm) ID 1 by 3 in. (25 by 76 mm) cut from wall over 3 in. (76 mm) ID
Compressive strength, axial	D348	4	A	1 in. (25 mm) long
Dielectric strength perpendicular to laminations	D348	3	A	12 in. (305 mm) long
Dissipation factor and permittivity	D348	2	A	4 in. (102 mm) long
Arc resistance[A]	D495	3	A	2 in. (51 mm) long
Dimensions, warp or twist	D668		A	Any length or diameter

[A] Grades G-5 and G-7 only.

TABLE 43 Test Method, Number, and Size of Specimens Required for Tests on Rods

Property	Test Method	Number of Specimens	Condition	Size
Flexural strength	D349	4	A	5 in. (127 mm) long
Compressive strength, axial	D349	4	A	½ in. (13 mm) long for ⅛ to ½ in. (3 to 13 mm) diameter, inclusive, 1 in. (25 mm) long over ½ in. (13 mm) diameter
Density	D349	1 (right) 1 (left)	A ...	1 in. (25 mm) long up to 1 in. (25 mm) diameter, inclusive, ½ in. (13 mm) long over 1 in. (25 mm) diameter
Water absorption	D349	3	E-1/105 and D-24/23	1 in. (25 mm) long for diameters up to and including 1 in. (25 mm); ½ in. (13 mm) long for larger diameters.
Arc resistance[A]	D495	3	A	2 in. (51 mm) long
Dimensions, warp or twist	D668		A	Any length or diameter

[A] Grades G-5 and G-7 only.

TABLE 44 Recommended Control Tests for Sheet Material

Grade	Flexural Strength	Impact Strength	Bonding Strength[A]	Water Absorption	Dielectric Strength Parallel to Laminations (Condition A)[B]	Dissipation Factor and Permittivity (Condition D-24/23)[B]	Arc Resistance	Rate of Burning
X	x	...	x	x	...	...	...	...
XX	x	...	...	x	...	...	...	...
XXX	x	...	...	x	...	x	...	...
XP	x	...	...	x	...	...	...	...
FR-1, GPO-2, GPO-2P	x	...	...	x	...	...	...	x
XPC, GPO-1, GPO-1P	x	...	...	x	...	...	...	...
XXP	x	...	...	x	...	x	...	...
XXXP, XXXPC	x	...	...	x	...	x	...	...
FR-2, FR-3	x	...	...	x	...	x	...	...
ES-1	x	...	...	x	...	...	...	...
ES-2	x	...	...	x	...	...	...	...
ES-3	x	...	...	x	...	...	...	...
C	x	x	x	x	...	...	...	...
CE	x	x	...	x	x	...	...	...
L	x	x	x	x	...	...	...	...
LE	x	...	...	x	...	x	...	...
G-3	x	x	x	x	...	...	...	...
G-5, G-9	x	...	x	x	x	...	x	x
G-7, GPO-3, GPO-3P	x	...	x	...	...	x	x	x
G-10, G-11[C]	x	...	...	x	...	x[D]	...	x
FR-4, FR-5, CEM-1, CEM-3	x	...	...	x	...	x	...	x
N-1	x	...	x	...	...	x	...	...

[A] ½ in. (13 mm) and over in thickness.
[B] See 14.2
[C] Include high-temperature flexural strength described in Footnote *D* following Table 7.
[D] Conditioned at D-48/50.

APPENDIXES

(Nonmandatory Information)

X1. DETAILED DESCRIPTIONS OF THE VARIOUS GRADES OF LAMINATED MATERIALS

TYPE I—CELLULOSE PAPER-BASE PHENOLIC RESIN, LAMINATED MATERIAL (UNLESS NOTED)

X1.1 Grade X

X1.1.1 *Sheets*—Primarily intended for mechanical applications where electrical properties are of secondary importance. Should be used with discretion when high humidity conditions are encountered. Not equal to fabric-base grades in impact strength.

X1.1.2 *Tubes, Rolled*— Good punching and fair machining qualities. Low power factor and high dielectric strength under relatively dry conditions.

X1.1.3 *Tubes, Molded, and Rods*—This grade is not recommended in these forms.

X1.2 Grade XP

X1.2.1 *Sheets*—Primarily intended for punching hot. More flexible and not as strong as Grade X. Moisture resistance and electrical properties intermediate between Grades X and XX. With good punching practice (see 6.4) this grade may be punched cold up to and including 1⁄16 in. (1.6 mm) in thickness and when heated to 120 to 140°C, up to and including 1⁄8 in. (3 mm) in thickness.

X1.2.2 *Tubes and Rods*— This grade is not recommended in these forms.

X1.3 Grade XPC

X1.3.1 *Sheets*—Primarily intended for cold punching and shearing. More flexible, lower in flexural strength than Grade XP, higher cold flow. With good punching practice (see 6.4), this grade can be punched up to and including 1⁄8-in. (3-mm) thickness at a room temperature of approximately 23°C. In general, this grade can be sheared up to and including 3⁄32 in. (2.4 mm) in thickness, at the same temperature, with a sharp power squaring shear in both lengthwise and crosswise directions, in 1½-in. (38-mm) wide strips without developing surface racks.

X1.3.2 *Tubes and Rods*—This grade is not recommended in these forms.

X1.4 Grade XX

X1.4.1 *Sheets*—Suitable for usual electrical applications. Good machinability.

X1.4.2 *Tubes, Rolled*—Good machining, punching, and threading qualities. Not as strong mechanically as Grade X rolled, but having better moisture resistance. Better grade for low dielectric losses, particularly on exposure to high humidity.

X1.4.3 *Tubes, Molded*—Better in moisture resistance than Grade XX rolled. Good machining and good electrical properties, except in thin walls where the dielectric strength may be low at the molded seams.

X1.4.4 *Rods*—Similar characteristics to sheet except as limited by the inherent differences in construction and shape.

X1.5 Grade XXP

X1.5.1 *Sheets*—Better than Grade XX in electrical and moisture-resisting properties and more suitable for hot punching. Intermediate between Grades XP and XX in punching and cold flow characteristics.

X1.5.2 *Tubes and Rods*—This grade is not recommended in these forms.

X1.6 Grade XXX

X1.6.1 *Sheets*—Suitable for radio frequency work, for high-humidity applications and with minimum cold-flow characteristics.

X1.6.2 *Tubes, Molded*—Similar characteristics to sheet except as limited by the inherent differences in construction and shape.

X1.6.3 *Tubes, Rolled*—No property standards developed for this grade in this form.

X1.6.4 *Rods*—Similar characteristics to sheet except as limited by the inherent differences in construction and shape.

X1.7 Grade XXXP

X1.7.1 *Sheets*—Better in electrical properties than Grade XXX and more suitable for hot punching. Intermediate between Grades XXP and XX in punching characteristics. This grade is recommended for applications requiring high insulation resistance and low dielectric losses under severe humidity conditions.

X1.7.2 *Tubes and Rods*—This grade is not recommended in these forms.

X1.8 Grade XXXPC

X1.8.1 *Sheets*—Similar in electrical properties to Grade XXXP and suitable for punching at lower temperatures than Grade XXXP. With good punching practice, sheets up to and including 1⁄16 in. (1.6 mm) in thickness may be punched at a temperature not less than 23°C (73.4°F) and in thicknesses over 1⁄16 in. up to and including 1⁄8 in. (3 mm) when warmed to temperatures up to 60°C (140°F). This grade is recommended for applications requiring high insulation resistance and low dielectric losses under severe humidity conditions.

X1.8.2 *Tubes and Rods*—This grade is not recommended in these forms.

X1.9 Grade FR-1

X1.9.1 *Sheets*—Paper-base laminate with a phenolic resin so modified to have a reduced rate of burning after the source of ignition is removed. Similar in all other properties to Grade XP.

X1.9.2 *Tubes and Rods*—This grade is not recommended in these forms.

X1.10 Grade FR-2

X1.10.1 *Sheets*—Paper-base laminate with a phenolic resin so modified as to have a reduced rate of burning after the source of ignition is removed. Similar in all other properties to Grade XXXPC.

X1.10.2 *Tubes and Rods*—This grade is not recommended in these forms.

X1.11 Grade FR-3

X1.11.1 *Sheets*—Paper-base laminate with epoxy resin binder having higher flexural strength than Grade XXXPC and so modified as to have a reduced rate of burning after the source of ignition is removed.

X1.11.2 *Tubes and Rods*—No standards have been developed for this grade in these forms.

X1.12 Grades ES-1

X1.12.1 *Sheets*—Suitable for engraving as nameplates, and so forth. Black or gray surfaces and white opaque core (usually melamine binder).

X1.13 Grades ES-2

X1.13.1 *Sheets*—Similar in application to Grade ES-1, but made with white subcore (usually melamine) and black core (usually phenolic binder) to obtain toughness when made in thick sheets.

X1.14 Grade ES-3

X1.14.1 *Sheets*—Similar in application to Grade ES-1, but with white or gray surfaces and black core.

TYPE II—CELLULOSE FABRIC-BASE PHENOLIC RESIN LAMINATED MATERIAL

X1.15 Grade C

X1.15.1 *Sheets*—Made throughout from cotton fabric weighing over 4 oz/yd^2 and having a count as determined from inspection of the laminated sheet of not more than 72 threads/in. in the filler direction nor more than 140 threads/in. total in both warp and filler directions. A strong, tough material suitable for gears and other applications requiring high impact. The heavier the fabric base used, the higher will be the impact strength, but the rougher the machined edge; consequently, there may be several subgrades in this class adapted for various sizes of gears and types of mechanical service. This grade does

not have controlled electrical properties and its use for electrical applications is not recommended.

X1.15.2 *Tubes, Rolled*—Made from a cotton fabric with the same weight and thread-count limits as for sheets of this grade.

X1.15.3 *Tubes, Molded*—No standards have been developed for this grade in this form.

X1.15.4 *Rods*—Made from a cotton fabric with the same weight and thread-count limits as for sheets of this grade. Characteristics in general are same as for sheet except as limited by the inherent differences in construction and shape.

X1.16 Grade CE

X1.16.1 *Sheets*—Made of same fabric weight and thread-count limits as Grade C. For electrical applications requiring greater toughness than Grade XX or mechanical applications requiring greater resistance to moisture than Grade C. This grade is not recommended for primary insulation[5] for electrical applications involving commercial power frequencies at voltages in excess of 600 V.

X1.16.2 *Tubes, Rolled*—No standards have been developed for this grade in this form.

X1.16.3 *Tubes, Molded*—Made of fabric of the same weight and thread-count limits as Grade C sheet. For use where a tough, dense, fabric-base material is required having good mechanical properties and good resistance to moisture.

X1.16.4 This grade is not recommended for primary insulation[8] for electrical applications involving power frequencies at voltages in excess of 600 V.

X1.16.4.1 Dielectric strength may be low at molded seams, especially in thin walls.

X1.16.5 *Rods*—Characteristics same as for molded tubes except as limited by the inherent differences in construction and shape.

X1.17 Grade L

X1.17.1 *Sheets*—Made throughout from cotton fabric weighing 4 oz or less/yd.^{2} The minimum thread count per inch in any ply is 72 in the filler direction and 140 total in both warp and filler directions. For purposes of identification, the surface sheets have a minimum thread count of 75 threads/in. in either the warp or filler directions and the sum of the warp and filler is 152. This grade is suitable for small gears and other fine machining applications, particularly in thicknesses under ½ in. (13 mm). Not quite so tough as Grade C. This grade does not have controlled electrical properties and its use for electrical applications is not recommended.

X1.17.2 *Tubes, Rolled*—No standards have been developed for this grade in this form.

X1.17.3 *Tubes, Molded*—Made from fine-weave cotton fabric weighing 4 oz or less/yd.^{2} As determined by inspection of the molded tube, the minimum thread count per inch is 72 in the filler direction and 140 total in both warp and filler directions. Has high density and good moisture resistance. For mechanical applications *primarily* where finer machined appearance than with Grade CE molded is desired or where tougher material than Grade LE molded is required. This grade does not have controlled electrical properties and its use for electrical applications is not recommended.

X1.17.4 *Rods*—Similar in count and weight of fabric to Grade L molded tube; also in general characteristics except as limited by the inherent differences in construction and shape.

X1.18 Grade LE

X1.18.1 *Sheets*—Made of fabric of same weight and thread-count limits as Grade L sheet. For electrical applications requiring greater toughness than Grade XX. Better machining properties and finer appearance than Grade CE, also available in thinner sizes. Good in moisture resistance. This grade is not recommended for primary insulation[8] for electrical applications involving commercial power frequencies at voltages in excess of 600 V.

X1.18.2 *Tubes, Rolled*—Made from fabric of same weight and thread-count limits as Grade L molded tubes. For use where the seams from a molded tube may be objectionable and where the application requires good machining qualities, together with fair electrical and good mechanical properties. This grade is not recommended for primary insulation[8] for electrical applications involving commercial power frequencies at voltages in excess of 600 V.

X1.18.3 *Tubes, Molded*—Made from a fine-weave cotton fabric of the same weight and thread-count limits as Grade L molded. Has excellent machining and moisture-resisting characteristics. For use in restricted electrical applications where a tougher material than Grade XX tube is required at some sacrifice of electrical properties; dielectric strength may be low at molded seams, especially in thin walls. Better electrically than Grade CE molded, but not quite as tough. This grade is not recommended for primary insulation[8] for electrical applications involving commercial power frequencies at voltages in excess of 600 V.

X1.18.4 *Rods*—Similar in count and weight of fabric to Grade LE molded tube, also in general characteristics except as limited by inherent differences in construction and shape. This grade is not recommended for primary insulation[8] for electrical applications involving commercial power frequencies at voltages in excess of 600 V.

TYPE IV—GLASS-BASE LAMINATED MATERIAL

X1.19 Grade G-3

X1.19.1 *Sheets*—Continuous filament-type glass cloth. General-purpose grade. High impact and flexural strength; bonding strength poorest of the glass-base grades. Good electrical properties under dry conditions. Dielectric strength perpendicular to laminations good. Good dimensional stability.

X1.19.2 *Tubes, Rolled*—Similar in characteristics to sheet except as limited by the inherent differences in construction and shape.

[8] By "primary insulation" is meant insulation in direct contact with terminals, conductors, or other current-carrying members. Laminated insulation used for its mechanical or thermal properties, such as armature slot wedges, spacers, structural members, switchboard panels where terminals have separated insulation, and so forth, is not considered as "primary insulation."

X1.19.3 *Tubes, Molded*—This grade is not recommended in this form.

X1.19.4 *Rods*—Similar in characteristics to sheet except as limited by the inherent differences in construction and shape. Mold seams are weak points mechanically and electrically.

X1.20 Grade G-5

X1.20.1 *Sheets*—Glass fabric, continuous filament-base, melamine resin binder. High mechanical strength and hardest laminated grade. Reduced rate of burning; second only to silicone laminates in heat and arc resistance. Excellent electrical properties under dry conditions. Low insulation resistance under high humidities. Good dimensional stability.

X1.20.2 *Tubes, Rolled*—Similar in characteristics to sheet except as limited by the inherent differences in construction and shape. Especially high internal bursting strength.

X1.20.3 *Tubes, Molded*—This grade is not recommended in this form.

X1.20.4 *Rods*—Similar in characteristics to sheet except as limited by the inherent differences in construction and shape. Mold seams are weak points mechanically and electrically.

X1.21 Grade G-9

X1.21.1 Continuous filament-type glass cloth with heat-resistant melamine resin binder.

X1.21.2 *Sheets*—Highest mechanical strength and one of the hardest laminated grades. Reduced rate of burning. Second only to silicone laminates in heat and arc resistance. Excellent electric strength properties under wet conditions. Good dimensional stability.

X1.21.3 *Rolled Tubes*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Especially high internal bursting strength.

X1.21.4 *Molded Tubes*—This grade is not recommended in this form.

X1.21.5 *Rods*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Mold seams are weak points mechanically and electrically.

X1.22 Grade G-7

X1.22.1 *Sheets*—Continuous filament-type glass cloth, silicone resin binder. Extremely good dielectric loss and insulation resistance properties under dry conditions, and good electrical resistance properties under dry conditions, and good electrical properties under humid conditions, although the percentage change from dry to humid conditions is high. Excellent heat and arc resistance. Second only to Grade G-5 in rate of burning. Good impact and flexural strength. Dielectric strength perpendicular to laminations, best of the silicone grades. Meets AIEE Class H insulation requirements with tentative maximum hot spot temperature of 180°C.

X1.22.2 *Tubes and Rods*—No standards have been developed for this grade in this form.

X1.23 Grade G10

X1.23.1 *Sheets*—Continuous filament-type glass cloth with epoxy binder. Extremely high mechanical strength (flexural, impact, and bonding) at room temperature. Good dielectric loss and dielectric strength properties under dry and humid conditions. Insulation resistance under high humidity is better than Grade G-7.

X1.23.2 *Rolled Tubes*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

X1.23.3 *Molded Tubes*—This grade is not recommended in this form.

X1.23.4 *Rods*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Mold seams are weak points mechanically and electrically.

X1.24 Grade G-11

X1.24.1 *Sheets*—Continuous filament-type glass cloth with heat-resistant epoxy binder. Properties similar to those of Grade G-10 at room temperature and, in addition, the material shall exhibit a minimum flexural strength of 30 000 psi (207 MPa) when measured at 150°C after 1 h at 150°C. Insulation resistance is similar to Grade G-10.

X1.24.2 *Rolled Tubes*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

X1.24.3 *Molded Tube*—This grade is not recommended in this form.

X1.24.4 *Rods*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Mold seams are weak points mechanically and electrically.

X1.25 Grade FR-4

X1.25.1 *Sheets*—Continuous-filament glass cloth with an epoxy resin binder similar to Grade G-10 but so modified to have a reduced rate of burning after the source of ignition is removed. Similar in all other properties to Grade G-10.

X1.25.2 *Rolled Tubes*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

X1.25.3 *Molded Tubes*—This grade is not recommended in this form.

X1.26 Grade FR-5

X1.26.1 *Sheets*—Continuous-filament glass cloth with an epoxy resin binder similar to Grade G-11 but so modified to have a reduced rate of burning after the source of ignition is removed. Similar in all other properties to Grade G-11.

X1.26.2 *Rolled Tubes*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

X1.26.3 *Molded Tubes*—This grade is not recommended in this form.

X1.26.4 *Rods*—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Mold seams are weak points mechanically and electrically.

TYPE V—NYLON-BASE LAMINATED MATERIAL

X1.27 Grade N-1

X1.27.1 *Sheets*—Nylon cloth-base, phenolic resin binder. Excellent electrical properties under high humidity conditions. Good impact strength, but subject to flow or creep, especially at temperatures higher than normal.

X1.27.2 *Tubes and Rods*—No standards have been developed for this grade in these forms.

TYPE VI—COMPOSITE-BASE LAMINATES

X1.28 Grade CEM-1

X1.28.1 *Sheets*—Laminate with continuous-filament glass cloth surfaces and a cellulose paper core, all with a flame-resistant epoxy resin binder. With good punching practice, sheets up to and including 3⁄32 in. (2.4 mm) in thickness may be punched at temperatures not less than 23°C (73.4°F) and in thicknesses over 3⁄32 in. up to and including 1⁄8 in. (3.2 mm), when warmed to a temperature not exceeding 65.5°C (150°F).

X1.28.2 *Tubes and Rods*—No standards have been developed for this grade in these forms.

X1.29 Grade CEM-3

X1.29.1 *Sheets*—Laminate with continuous-filament glass-cloth surfaces and a nonwoven glass core, all with a flame-resistant epoxy resin binder. With good punching practice, sheets up to and including 1⁄16 in. (1.6 mm) in thickness may be punched at temperatures not less than 23°C (73°F) and in thicknesses over 1⁄16 in up to and including 1⁄8 in. (3.2 mm), when warmed to a temperature not exceeding 66°C (105°F). This grade has a flame resistance of Class 0 when tested in accordance with Test Methods D229. Property values approach those of Grade FT-4.

X1.30 Grade GPO

X1.30.1 *Sheets*—Laminates prepared from random-laid glass fibers (mat) saturated with polyester resin and cured under heat and pressure. These are available in the following classes:

X1.30.1.1 *GPO-1*—Suitable for general purpose applications.

X1.30.1.2 *GPO-2*—For applications where flame resistance is required.

X1.30.1.3 *GPO-3*—For applications where resistance to electrical tracking and flame resistance are required.

X1.30.2 GPO-P, GPO-2P, and GPO-3P are the corresponding classes that have good punching characteristics at some expense to the electrical and mechanical properties.

X2. APPLICATIONS OF VARIOUS GRADES OF LAMINATED THERMOSETTING MATERIALS[8]

X2.1 The following[9] is a very brief summary of the field of application of the various grades of laminated thermosetting materials:

X2.1.1 Laminated phenolic is one of the strongest materials considered on basis of strength-weight ratio. With a density for cellulose base-grades of approximately 1.35, only half that of aluminum, the mechanical grades find large application in the aircraft and other structural fields.

X2.1.2 Because of their high strength, resilience, good wearing, and quiet running qualities, gears cut from either laminated phenolic plate or molded blanks are used in thousands of industrial applications ranging from the tiny gears in electric clocks to 8 to 10-in. (203 to 254 mm) face gears in rolling mills.

X2.1.3 The high strength, excellent resistance to moisture and heat, and good electrical properties of laminated phenolic, combined with the fact that it is readily machined, account for its large-volume use in all branches of the electrical industry.

X2.1.4 The resistance of laminated phenolic to corrosion makes it suitable for many applications in the various chemical industries, particularly where organic solvents, organic acids in any concentration, or dilute inorganic acids are encountered. Laminated phenolic is not suitable in general for use in alkaline media, although certain grades are more resistant to alkalies than others and are used for special applications in dilute alkaline solutions.

X2.1.5 The ES grades, paper-base with both melamine and phenolic binders, are primarily used for engraving applications such as nameplates, where white letters on a black background or black letters on a white or gray background are desired.

X2.1.6 Paper-base epoxy laminates are used for those applications which require greater mechanical strength than provided by Grade XXXPC. They combine the stable electrical properties of epoxy under humid conditions with reduced rate of burning after the source of ignition is removed.

X2.1.7 The glass-base phenolics are used for motor insulation and other applications demanding high strength and good electrical properties even at fairly high temperatures. The glass-base melamine materials are used primarily for high mechanical strength and resistance to arc and burning, particularly for power equipment in marine applications.

X2.1.8 The glass-base silicone materials are resistant to high temperatures up to 200°C, and have especially low dielectric losses. These grades extend the upper temperature range of laminates to a new high.

X2.1.9 Glass-base epoxy laminates are used primarily in electronic applications where their stable electrical properties

[9] From National Electrical Manufacturers Association (NEMA) standards for laminated thermosetting products.

are particularly desirable. They are often used in printed circuit applications. Caution should be used in applications of Grade G-10 involving high mechanical stresses at elevated temperatures. However, Grade G-11 has excellent hot strength. These laminates have excellent dimensional stability over a wide temperature range.

X2.1.10 Glass-base epoxy laminates having a reduced rate of burning can be produced. Such materials are used in electronic data-processing equipment, missiles, space vehicles, and other electronic equipment where resistance to burning is required.

X2.1.11 Nylon-base laminates find application in the electronic and high-frequency fields and for superior insulation resistance under high humidities. Their high flow or creep, particularly under hot conditions, requires special handling and design considerations.

X2.1.12 Composite-base laminates are suitable for those subtractive and additive printed circuit applications which require greater mechanical strength than electronic paper-base grades, where punching is a satisfactory method of fabrication.

X3. ENGINEERING INFORMATION

X3.1 Engineering information supplied by the National Electrical Manufacturers Association is given in Tables X3.1-X3.8 and Fig. X3.1. Typical property values are supplied which may be considered representative values for that particular grade. These values must not be used as specification requirements.

X3.2 The temperature indices of the laminated products listed in Table A1 are based on electrical and mechanical tests conducted in accordance with Test Method D2304 and IEEE Publication 1 and the related IEEE Publications No. 98, 99, and 101. These publications and NEMA Publications LI 1-1971, LI-5-1969, and LI 3-1961 should be consulted for more complete information. Design temperatures may need to be lower than the temperature indices shown in .

TABLE X3.1 Typical Values for Properties[A,B]

ASTM and NEMA Grade Designations	X	XX	XXX	XP	XPC	XXP	XXXP	XXXPC
Equivalent MIL-I-24768 Spec	/12	/11	/10	/19	/20	/21	/22	/23
Equivalent MIL-I-24768 Spec Type	PBM	PBG	PBE	PMB-P	PBM-PC	PGB-P	PBE-P	PBE-PC
Tensile strength, psi:								
LW	20 000	16 000	15 000	12 400	10 500	11 000	12 000	12 400
CW	16 000	13 000	12 000	9 000	8 500	8 500	9 500	9 500
Modulus of elasticity in tension, psi:[C]								
LW	1 900 000	1 500 000	1 300 000	1 200 000	1 000 000	900 000	1 000 000	1 000 000
CW	1 400 000	1 200 000	1 000 000	900 000	800 000	700 000	800 000	800 000
Modulus of elasticity in flexure, psi:[C]								
LW	1 800 000	1 400 000	1 300 000	1 200 000	1 000 000	900 000	1 000 000	1 000 000
CW	1 300 000	1 100 000	1 000 000	900 000	800 000	700 000	700 000	700 000
Compressive strength, psi:								
Flatwise	36 000	34 000	32 000	25 000	22 000	25 000.	25 000	25 000
Edgewise	19 000	23 000	25 500	. . .	. . .	. . .	. . .	. . .
Rockwell hardness (M scale)	M-110	M-105	M-110	M-95	M-75	M-100	M-105	M-95
Deformation of shrinkage-cold flow at 4000 psi. percent change[D]	. . .	0.90	0.80	. . .	. . .	. . .	0.80	. . .
Dielectric strength perpendicular to laminations,[E] V/mil:								
Short-time test:								
1/32 in.	950	950	900	900	850	950	900	900
1/16 in.	700	700	650	650	600	700	650	650
1/8 in.	500	500	470	470	425	500	470	470
Step-by-step test:								
1/32 in.	700	700	650	650	625	700	650	650
1/16 in.	500	500	450	450	425	500	450	450
1/8 in.	360	360	320	320	290	360	320	320
Insulation resistance[F] (Condition C-96/35/90), MΩ	. . .	60	1 000	. . .	. . .	500	20 000	50 000
Specific gravity	1.36	1.34	1.32	1.33	1.34	1.32	1.30	1.30
Specific volume, $in.^3/lb$	20.4	20.6	21.0	20.8	20.6	21.0	21.3	21.3
Thermal expansion, cm/cm·°C		← 0.000020 →					← 0.000020	
Thermal conductivity, $cal·cm/s·cm^2·°C$		← 0.00070 →					←	
Specific heat cal/g·°C		← 0.35 to 0.40 →					←	
Temperature index, °C (see X3.2):								
1/32 to 1/16 in.:								
Electrical	130	130	130	130	130	130	125	125
Mechanical	130	130	130	130	130	130	125	125
1/16 in. and over:								
Electrical	130	140	140	130	130	140	125	125
Mechanical	130	140	140	130	130	140	125	125
Effects of acids, alkalis, and solvents	See comments under last part of table.							

TABLE X3.1 *Continued*

ASTM and NEMA Grade Designations	**FR-1**	**FR-2**	**FR-3**	**FR-4**	**FR-5**	**C**	**CE**
Equivalent MIL-I-24768 Spec	/24	/25	/26	/27	/28	/16	/14
Equivalent MIL-I-24768 Spec Type	PBM-PF	PBE-PCF	PEE	GEE-F	GEB-F	FBM	FBG
Tensile strength, psi:							
LW	12 000	12 500	14 000	40 000	40 000	10 000	12 000
CW	9 000	9 500	12 000	35 000	35 000	8 000	9 000
Modulus of elasticity in tension, psi:[C]							
LW	1 200 000	1 000 000	1 200 000	2 500 000	2 500 000	1 000 000	900 000
CW	900 000	800 000	1 000 000	2 000 000	2 000 000	900 000	800 000
Modulus of elasticity in flexure, psi:[C]							
LW	1 200 000	1 000 000	1 300 000	2 700 000	2 800 000	1 000 000	900 000
CW	900 000	900 000	1 000 000	2 200 000	2 300 000	900 000	800 000
Compressive strength, psi:							
Flatwise	25 000	25 000	29 000	60 000	60 000	37 000	39 000
Edgewise	. . .	. . .	. . .	35 000	35 000	23 500	24 500
Rockwell hardness (M scale)	M-95	M-97	M-100	M-111	M-114	M-103	M-105
Deformation of shrinkage-cold flow at 4000 psi. percent change[D]	. . .	0.85	0.50	0.25	0.20	. . .	. . .
Dielectric strength perpendicular to laminations,[E] V/mil:							
Short-time test:							
1/32 in.	900	800	650	750	750	. . .	. . .
1/16 in.	650	650	600	700	700	. . .	500
1/8 in.	470	470	475	550	550	. . .	360
Step-by-step test:							
1/32 in.	650	550	500	500	500	. . .	. . .
1/16 in.	450	450	450	450	450	. . .	300
1/8 in.	320	320	325	350	350	. . .	220
Insulation resistance[F] (Condition C-96/35/90), MΩ	. . .	20 000	100 000	2000 000	200 000	. . .	. . .
Specific gravity	1.33	1.33	1.42	1.85	1.85	1.36	1.33
Specific volume, $in.^3/lb$	20.8	21.0	19.5	14.9	14.9	20.4	20.8
Thermal expansion, cm/cm·°C		→		0.000010	0.000009	← 0.000020 →	
Thermal conductivity, cal·cm/s·cm^2·°C				0.00070 →			
Specific heat cal/g·°C				0.35 to 0.40 →			
Temperature index, °C (see X3.2):							
1/32 to 1/16 in.:							
Electrical	130	75	90	130	140	85	85
Mechanical	130	75	90	140	160	85	85
1/16 in. and over:							
Electrical	130	105	110	130	170	115	115
Mechanical	130	105	110	140	180	125	125
Effects of acids, alkalis, and solvents	See comments under last part of table.						

TABLE X3.1 *Continued*

ASTM and NEMA Grade Designations	L	LE	G-3	G-5	G-7	G-9	G-10	G-11
Equivalent MIL-I-24768 Spec	/15	/13	/18	/8	/17	/1	/2	/3
Equivalent MIL-I-24768 Spec Type	FBI	FBE	GPG	GMG	GSG	GME	GEE	GEB
Tensile strength, psi:								
LW	13 000	12 000	23 000	37 000	23 000	37 000	40 000	40 000
CW	9 000	8 500	20 000	30 000	18 500	30 000	35 000	35 000
Modulus of elasticity in tension, psi:[C]								
LW	1 200 000	1 000 000	2 000 000	2 300 000	1 800 000	2 300 000	2 500 000	2 500 000
CW	900 000	850 000	1 700 000	2 000 000	1 800 000	2 000 000	2 000 000	2 000 000
Modulus of elasticity in flexure, psi:[C]								
LW	1 100 000	1 000 000	1 500 000	1 700 000	1 400 000	2 500 000	2 700 000	2 800 000
CW	850 000	850 000	1 200 000	1 500 000	1 200 000	2 000 000	2 200 000	2 300 000
Compressive strength, psi:								
Flatwise	35 000	37 000	50 000	70 000	45 000	70 000	60 000	60 000
Edgewise	23 500	25 000	17 500	25 000	14 000	25 000	35 000	35 000
Rockwell hardness (M scale)	M-105	M-105	M-100	M-120	M-100	M-120	M-111	M-112
Deformation of shrinkage-cold flow at 4000 psi. percent change[D]	. . .	. . .	0.30	0.30	0.30	0.25	0.25	0.20
Dielectric strength perpendicular to laminations,[E] V/mil:								
Short-time test:								
1/32 in.	. . .	700	750	. . .	450	450	750	750
1/16 in.	. . .	500	700	350	400	400	700	800
1/8 in.	. . .	360	600	260	350	350	550	550
Step-by-step test:								
1/32 in.	. . .	450	550	...	400	400	500	500
1/16 in.	. . .	300	500	220	350	350	450	450
1/8 in.	. . .	220	450	160	250	275	350	350
Insulation resistance[F] (Condition C-96/35/90), MΩ	30	. . .	. . .	100	2 500	10 000	200 000	200 000
Specific gravity	1.35	1.33	1.65	1.90	1.68	1.90	1.80	1.80
Specific volume, $in.^3/lb$	20.5	20.8	16.8	14.6	16.5	14.6	15.3	15.3
Thermal expansion, cm/cm·°C	← 0.000020 →	→	0.000018	← 0.000010 →			← 0.000009 →	
Thermal conductivity, cal·cm/s·cm^2·°C	← 0.00070			0.00120		← 0.00070 →		
Specific heat cal/g·°C	← 0.35 to 0.40 →	→		0.26	0.25			
Temperature index, °C (see X3.2):								
1/32 to 1/16 in.:								
Electrical	85	85	140	[H]	170	[H]	130	140
Mechanical	85	85	170	140	220	140	140	160
1/16 in. and over:								
Electrical	115	115	140	[H]	170	[H]	130	170
Mechanical	125	125	170	140	220	140	140	180
Effects of acids, alkalis, and solvents	See comments under last part of table.							

TABLE X3.1 *Continued*

ASTM and NEMA Grade Designations	N-1	ES-1	ES-2	ES-3
Equivalent MIL-I-24768 Spec	/9	. . .	. . .	. . .
Equivalent MIL-I-24768 Spec Type	NPG	. . .	. . .	. . .
Tensile strength, psi:				
LW	8 500	12 000	13 000	15 000
CW	8 000	8 500	9 000	12 000
Modulus of elasticity in tension, psi:[C]				
LW	400 000	. . .	. . .	. . .
CW	400 000	. . .	. . .	. . .
Modulus of elasticity in flexure, psi:[C]				
LW	600 000	. . .	. . .	. . .
CW	500 000	. . .	. . .	. . .
Compressive strength, psi:				
Flatwise	[G]	. . .	. . .	. . .
Edgewise	[G]	. . .	. . .	. . .
Rockwell hardness (M scale)	M-105	M-118	M-118	M-120
Deformation of shrinkage-cold flow at 4000 psi. percent change[D]	. . .	. . .	. . .	. . .
Dielectric strength perpendicular to laminations,[E] V/mil:				
Short-time test:				
1/32 in.	850	. . .	. . .	. . .
1/16 in.	600	750	. . .	. . .
1/8 in.	450	. . .	550	. . .
Step-by-step test:				
1/32 in.	650	. . .	. . .	. . .
1/16 in.	450	550	. . .	. . .
1/8 in.	300	. . .	400	. . .
Insulation resistance[F] (Condition C-96/35/90), MΩ	50 000	. . .	. . .	. . .
Specific gravity	1.15	1.45	1.40	1.38
Specific volume, $in.^3/lb$	24.1	19.1	19.8	20.1
Thermal expansion, cm/cm·°C		. . .	← 0.000020 →	
Thermal conductivity, $cal·cm/s·cm^2·°C$			← 0.00070 →	
Specific heat cal/g·°C		← 0.35 to 0.40 →		
Temperature index, °C (see X3.2):				
1/32 to 1/16 in.:				
Electrical	. . .	. . .	. . .	. . .
Mechanical	. . .	. . .	. . .	. . .
1/16 in. and over:				
Electrical	. . .	. . .	. . .	. . .
Mechanical	. . .	. . .	. . .	. . .
Effect of acids:	All grades except Grade G-5 and G-9 are resistant to dilute solutions of most acids.			
Effect of alkalis:	Not recommended for use in alkaline solutions except melamine Grades G-5 and G-9 which are resistant to dilute alkaline solutions.			
Effect of solvents:	Not recommended for use in alkaline solutions except melamine Grades G-5 and G-9 which are resistant to dilute Unaffected by most organic solvents except acetone which may soften the punching stock grades. Aromatic hydrocarbons and chlorinated aliphatics may affect silicone Grade G7			

[A] All values are based on tests of material in Condition A, using ASTM test methods except as otherwise noted.
[B] Conversion factors: 1 psi = 6.8948 kPa; 1 mil = 0.0254 mm; 1 in. = 25.4 mm.
[C] Modulus of elasticity values are determined by measuring the slope of the stress-strain curve at the origin. These values are not too highly significant for materials of as plastic a nature as thermosetting laminates. They become less significant for the softer and more plastic grades, like Grade N-1, nylon base, and the punching Grades XP, SPC, XXP, and XXXP.
[D] Cold flow is determined by Method A of Test Methods D621 using 1/8-in. thick test specimens preconditioned for 68 h at 35°C and 90 % relative humidity, and then tested at 50°C.
[E] For typical dielectric strength values over the full range of sheet thickness for a particular grade, see the curves shown in Fig. X3.1.
[F] Insulation resistance is determined by Test Methods D257 using test specimens 2 by 3 in. by the thickness of the material, with 3/16 -in. taper-reamed holes spaced on 1-in. centers, and using tapered-pin electrodes such as Pratt & Whitney No. 3 stainless steel, or equivalents.
[G] Because of high cold flow of Grade N-1 material, its compressive strength cannot be measured accurately. Compressive yield strength flatwise is approximately 20,000 psi.

[H] Not recommended for electrical applications at elevated temperatures.

TABLE X3.2 Typical Values for Properties of Round Molded Tubes[A]

Grade	Tensile Strength,[B] psi[C]	Dissipation Factor at MHz cycles	Permittivity at MHz cycles	Specific Heat[D]	Thermal Conductivity[E]
XX	11 000	0.040	5.5	0.35 to 0.40	0.0007
XXX	9 000	0.040	5.3	0.35 to 0.40	0.0007
CE	8 500	...	...	0.35 to 0.40	0.0007
L	9 000	...	...	0.35 to 0.40	0.0007
LE	8 500	...	...	0.35 to 0.40	0.0007

[A] Values given are for Condition A.
[B] Tensile strength is determined by Test Methods D348.
[C] Conversion factor: 1 psi = 6.8948 kPa.
[D] Cal/g·°C.
[E] Cal·cm/s·cm^2.°C.

TABLE X3.3 Typical Values for Properties of Round Rolled Tubes[A]

Grade	Tensile Strength, psi[B]	Dissipation Factor, MHz	Permittivity, MHz
X	8 500	[C]	[C]
XX	8 000	0.040	5.0
C	6 000	[C]	[C]
LE	7 000	[C]	[C]
G-5	25 000	0.012	7.0
G-7		0.003	4.0

[A] Values given are for Condition A.
[B] No value recommended.
[C] Conversion factor: 1 psi = 6.8948 kPa.

TABLE X3.4 Typical Values for Properties of Molded Rods[A]

Grade	Tensile Strength,[B] psi[C]	Specific Heat[D]	Thermal Conductivity, cal·cm/s·cm^2·°C
XX	10 000	0.35 to 0.40	0.0007
XXX	9 000	0.35 to 0.40	0.0007
C	9 000	0.35 to 0.40	0.0007
CE	8 000	0.35 to 0.40	0.0007
L	11 000	0.35 to 0.40	0.0007
LE	10 000	0.35 to 0.40	0.0007
G-5	30 000	0.26	0.0012

[A] Values given are for Condition A.
[B] Tensile strength is determined by Test Methods D349.
[C] Conversion factor: 1 psi = 6.8948 kPa.
[D] Cal/g·°C.

TABLE X3.5 Typical Values for Bursting Strength of Rolled Tubes[A]

Grade	Inside Dimension, in.[B]	Wall Thickness, in.[B]	Bursting Strength, range, lb[B]
X	1	1/16	1200 to 2400
	1	1/8	3000 to 5000
XX	1	1/16	1000 to 2000
	1	1/8	2000 to 3000
C	1	1/16	1000 to 1400
	1	1/8	2200 to 3000
LE	1	1/16	1000 to 1400
	1	1/8	2200 to 3000

[A] Tested in accordance with Test Method D1180.
[B] Conversion factor: 1 lb = 454 g; 1 in. = 25.4 mm.

TABLE X3.6 Tolerances for Drilled Holes

Diameter of Hole, in.[A]	Tolerances, in.,[A] for Thicknesses of					
	Up to 1/4 in., incl		Over 1/4 to 1/2 in., incl		Over 1/2 to 1 in., incl	
	+	−	+	−	+	−
Paper-Base and Cotton Fabric-Base Grades (Types I and II)						
0.030 to 1/16, incl	0.001	0.003	...	...	...	...
Over 1/16 to 1/4, incl	0.002	0.004	0.002	0.006	...	...
Over 1/4 to 1/2, incl	0.002	0.004	0.002	0.006	0.003	0.007
Over 1/2 to 1, incl	0.002	0.006	0.003	0.007	0.003	0.007
Glass-Base and Composite-Base Grades (Types IV, and VI)						
The tolerances recommended are double those given for paper-base and cotton fabric-base grades.						
Nylon-Base Grades (Type V)						
Because of dimension changes due to heating caused by drilling, no standard tolerances have been developed for Grade N-1.						

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE X3.7 Typical Variations in Punched Holes and Contours

NOTE 1—The following variations in hole diameters and piece dimensions of punched thermosetting laminates are obtainable when good punching techniques are practiced. These variations are not intended as tolerance standards but serve only as a general guide in design.

NOTE 2—Holes should not be smaller than the thickness of the stock.

NOTE 3—Hole edges should not be closer to each other or to the edge of the piece than the thickness of the stock and, in no case, less than 1/16 in.

NOTE 4—Pierced holes tend to be tapered, particularly in the thicker stock.

Diameter of Hole, in.[A]	Paper-Base Grades (Type I)[A]				Cotton Fabric-Base Grades (Type II)[A]	
	Cold Punching Laminates		Hot Punching Laminates		1/16 in.	1/8 in.
	1/16 in.	1/8 in.	1/16 in.	1/8 in.		
	Variation in Punched Holes, plus or minus, in.					
Under 1/4	0.0025	0.003	0.003	0.004	0.003	0.004
1/4 to 1/2, excl	0.003	0.004	0.004	0.005	0.0035	0.004
1/2 to 1, incl	0.003	0.004	0.005	0.006	0.0035	0.005
Outside Diameter, in.	Variation in Punched Contours, plus or minus, in.					
Under 1	0.003	0.004	0.0035	0.005	0.0035	0.004
1 to 2, excl	0.004	0.005	0.0045	0.006	0.004	0.005
2 to 3, incl	0.005	0.006	0.005	0.006	0.005	0.006

[A] Conversion factor: 0.001 in. = 0.0254 mm.

TABLE X3.8 Typical Tolerances for Screw Machine Parts, All Grades Except N-1

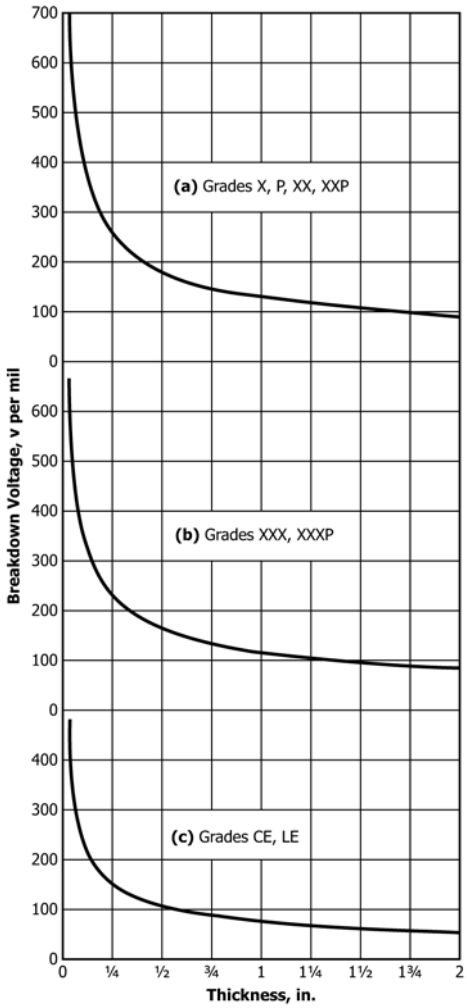
NOTE 1—As a guide for design purposes, the normal tolerances for screw machine parts made from laminated thermosetting material are as shown in this table.

NOTE 2—Concentricity of holes relative to an outer diameter should be specified if important. In fully machined parts having a maximum diameter of 2 in., a total indicator reading of 0.005 in. may be produced.

NOTE 3—Threading and tapping with National Form threads should not be closer than a Class-2 fit.

When Specified	Diameters[A]		Lengths[A]	
	Diameter, in.	Tolerance, plus or minus, in.	Diameter, in.	Tolerance, plus or minus, in.
As a decimal	Under 0.500	0.003	Under 1.000	0.005
	0.500 to 1.000, excl	0.004	1.000 to 3.000, excl	0.007
	1.000 to 2.000, incl	0.005		
In fractions	Under ½	0.005	Under 1	0.007
	½ to 1, excl	0.006	1 to 3, excl	0.010
	1 to 2, incl	0.008		

[A] Conversion factor: 0.001 in. = 0.024 mm.



NOTE 1—Step-by-step test (Condition A) perpendicular to laminations. Maximum thickness for Grades XP, XXP, and XXXP is ¼ in. (6 mm); minimum thickness for Grade CE is 1/16 in. (1.6 mm).

FIG. X3.1 Typical Dielectric Strength Values

SUMMARY OF CHANGES

Committee D09 has identified the location of selected changes to this standard since the last issue (D709 – 16) that may impact the use of this standard. (Approved April 1, 2017.)

(1) Removed MIL-P-997, -15035, -15037, -15047, -18177, and -22324 from Referenced Documents 2.4.
(2) Added MIL-I-24768 to Referenced Documents 2.4.
(3) Removed previous 2.5 and renumbered subsequent sections accordingly.
(4) Revised Table 1.
(5) Removed previous X1.26 and X27.
(6) Added new X1.25 – X1.26.4 and renumbered subsequent sections accordingly.
(7) Revised and reformatted Table X3.1.

Committee D09 has identified the location of selected changes to this standard since the last issue (D709 – 13) that may impact the use of this standard. (Approved March 1, 2016.)

(1) Corrected Grade C and L tolerances in Table 25.