



Designation: **D709—13 D709 – 16**

## Standard Specification for Laminated Thermosetting Materials<sup>1</sup>

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 reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

*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.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

[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[D621 Test Methods for Deformation of Plastics Under Load \(Withdrawn 1994\)<sup>3</sup>](#)

[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[D1180 Method of Test for Warpage of Sheet Plastics \(Withdrawn 1988\)<sup>3</sup>](#)

[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 \(Withdrawn 2012\)<sup>3</sup>](#)

#### 2.2 IEEE Standards:<sup>4</sup>

[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:<sup>5</sup>

[LI 1-1971 Industrial Laminated Thermosetting Products](#)

[LI 5-1969 Temperature Indices of Industrial Thermosetting Laminates](#)

<sup>1</sup> 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 Flexible and Rigid Insulating Materials.

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<sup>2</sup> 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.

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](#).

<sup>4</sup> 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](#).

<sup>5</sup> 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:*<sup>6</sup>

[MIL-P-997 Plastic Material, Laminated, Thermosetting, Electric Insulation, Sheets, Glass Cloth, Silicone Resin](#)

[MIL-P-15035 Plastic Sheet, Laminated, Thermosetting, Cotton-Fabric-Base, Phenolic-Resin](#)

[MIL-P-15037 Plastic Sheet, Laminated, Thermosetting, Glass-Cloth, Melamine-Resin](#)

[MIL-P-15047 Plastic Material, Laminated Thermosetting Sheets, Nylon Fabric Base, Phenolic-Resin](#)

[MIL-P-18177 Plastic Sheet, Laminated, Thermosetting, Glass Fibre Base, Epoxy-Resin](#)

[MIL-P-22324 Plastic Sheet, Thermosetting, Paper-Base, Epoxy-Resin](#)

2.5 *Federal Specifications:*

[L-P-513 Plastic Sheet and Insulation Sheet, Electrical \(Laminated, Thermosetting, Paper-Base, Phenolic-Resin\)](#)<sup>6</sup>

[L-P-509 Plastic Sheet, Rod and Tube, Laminated Thermosetting](#)<sup>6</sup>

2.6 *IEC Standard:*

[Publication 60893-3 Specification for Industrial Laminated Sheets Based on Thermosetting Resins for Electrical Purposes](#)<sup>7</sup>

### 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, etc., 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](#).

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

<sup>7</sup> 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-P and LP Grade Designation <sup>A</sup>	Description
Type I—Cellulose Paper-Base Phenolic Resin (Unless Noted)		
X	...	mechanical
XP	...	mechanical; hot-punching stock
XPC	...	mechanical; cold-punching and cold-shearing stock
XX	L-P-513, Type PBG	electrical and mechanical
XXP	...	electrical and mechanical; hot-punching stock
XXX	L-P-513, Type PBE	electrical and high humidity
XXXP	L-P-513, Type PBE-P	electrical and high humidity; hot-punching stock
XXXPC	L-P-513, Type PBE-P	punchable at lower temperature than Grade XXXP
FR-1	...	paper-base, flame-resistant, similar to Grade XP
FR-2	...	paper-base, flame-resistant, similar to Grade XXXP
FR-3	MIL-P-22324, 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	MIL-P-15035, Type FBM	mechanical
CE	MIL-P-15035, Type FBG	mechanical and electrical
L	MIL-P-15035, Type FBI	mechanical; fine machining
LE	MIL-P-15035, Type FBE	mechanical and electrical; fine machining
Type IV—Glass-Base		
G-3	...	continuous filament-type glass cloth; phenolic resin, general purpose
G-5	...	continuous filament-type glass cloth, melamine binder; general purpose; good arc and flame resistance
G-7	MIL-P-997, 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	MIL-P-15037, Type GME	continuous filament-glass cloth, melamine binder. Superior to Grade G-5 under wet conditions, good arc and flame resistance
G-10	MIL-P-18177, 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	MIL-P-18177, 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	MIL-P-18177, Type GEE	continuous filament-glass cloth with a flame-resistant epoxy resin binder; properties similar to G-10
FR-5	MIL-P-18177, Type GEB	continuous filament-glass cloth with a heat- and flame-resistant epoxy resin binder; properties similar to G11
GPO-1, GPO-2, and GPO-3		Glass mat with polyester resin binder, for general purpose, flame resistance and tracking resistance
GPO-1P, GPO-2P, and GPO-3P		Glass mat with polyester resin binder, for general purpose, flame resistance and tracking resistance
Type V—Nylon-Base		
N-1	MIL-P-15047, Type NPG	nylon cloth-base, phenolic resin binder; excellent electrical properties under high humidity; good impact
Type VI—Composite-Base Laminates		
CEM-1	...	cellulose paper core, glass surfaces, flame-resistant resin (see X1.28)
CEM-3	...	non-woven glass core, glass surfaces, flame-resistant resin (see X1.29)

<sup>A</sup> The MIL-P and LP-513 designations apply only to sheet materials. LP-509 applies to sheet and tube material. 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, etc.—and so forth. Reference shall accordingly be made to the latest edition of the specification.

**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 1/8 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.

**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
II	ES-1, ES-2, and ES-3	A	B	...	B	...	...
	C	A	A	C	A	D	C
	CE	A	B	A	A	D	C
	L	A	C	A	A	D	C
IV	LE	A	A	A	A	D	...
	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	A	D	D	D	D	D
V	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
VI	N-1	A	C	C	C	D	C
	CEM-1	A	D	D	D	D	D
	CEM-3	A	D	D	D	D	D

<sup>A</sup> Materials covered by this specification.

<sup>B</sup> Not recommended in this form.

<sup>C</sup> Detailed requirements on these materials are not yet available.

<sup>D</sup> Materials not covered by this specification.

**TABLE 3 Available Finishes of Laminated Thermosetting Materials**

Form	Grade	Finish <sup>A</sup>
Sheets	XX, XXX, CE, LE 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 XPC, XP, XXP, XXXP, XXXPC, FR-1, FR-3 ES-1, ES-2, ES-3	semigloss or polished semigloss
Round tubing and rods	G-3, G-5, G-7, G-9, G-10, G-11, N-1 all other grades	semigloss or dull dull or polished ground only ground, buffed, or varnished
Molded square and rectangular forms	all grades	semigloss, ground, or varnished

<sup>A</sup> *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.

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 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 4 Available Colors of Laminated Thermosetting Materials**

Type	Grade	Standard Color <sup>A</sup>
Sheets	X, XX, XXP, XXX, C, CE, L, LE	natural or black
	XP, XPC	natural, black, or chocolate
	XXXX, 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

<sup>A</sup> *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 <sup>A</sup> on Basis of 36-in. Dimension, %
Sheets <sup>B</sup>	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 <sup>C</sup>
	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

<sup>A</sup> 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.

<sup>B</sup> These requirements do not apply to cut pieces, but only to sheet sizes, tube lengths, and rod lengths as manufactured.

<sup>C</sup> In the case of Grade G-7 the maximum permissible warp or twist shall be 1.5 %.

**7.3 Flame Resistance**—Tests shall be conducted on laminates 1/2 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 **Table 20**, **Table 21**, and **Table 22**.

## 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 **Table 23**, **Table 24**, and **Table 25**.

**TABLE 6 Maximum Thickness in Inches (Millimetres) for Various Grades at Which Satisfactory Punching Results shall be Obtained<sup>A</sup>**

Grade	At Room Temperature (20 to 30°C) <sup>B</sup>	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 <sup>B</sup> (1.6)	
XXXX	...	3/32 (2.4)	
XXXXPC, 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)	

<sup>A</sup> 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.  
<sup>B</sup> Simple shapes, compound dies only.

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.

## 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 <sup>A</sup> in. (mm)	Increments of Sizes of Round Tubes, in. (mm) <sup>B</sup>
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 <sup>A</sup>	1/2 (13)



**TABLE 7 Flexural Strength Requirements for Sheets, Measured Flatwise (Condition A),<sup>A</sup> Min Average, psi**

Grade	Thickness <sup>B</sup>																	
	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 <sup>C</sup>	CW <sup>C</sup>	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	10 000	8 000	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 <sup>D</sup>	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	...	...	...	...	...	...	...	...	...	...	...	...

<sup>A</sup> See 14.2.

<sup>B</sup> For intermediate thicknesses, the values for the next smaller thickness shall apply.

<sup>C</sup> LW = tested in a lengthwise direction.

CW = tested in a crosswise direction.

<sup>D</sup> 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.

ASTM D709-16

<sup>A</sup> 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.

<sup>B</sup> 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 Table 36, Tables 36 and 37, Table 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 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 1/2 in. (1.6 to 13 mm) in thickness.

**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: 1/8 in. (3 mm) up to maxi- mum thickness for grade, but not over 2 in. (51 mm)		Thicknesses, 1/2 in. (13 mm) up to maximum for grade, but not over 2 in. <sup>A</sup> (51 mm)			Condition E-48/50 thicknesses: 1/8 in. (3 mm) up to maxi- mum thickness for grade, but not over 2 in. (51 mm)		Thicknesses, 1/2 in. (13 mm) up to maximum for grade, but not over 2 in. <sup>A</sup> (51 mm)	
	LW <sup>B</sup>	CW <sup>B</sup>	Condi- tion A <sup>C</sup>	Condi- tion D- 48/50 <sup>C</sup>		LW <sup>B</sup>	CW <sup>B</sup>	Condi- tion A <sup>C</sup>	Condi- tion D- 48/50 <sup>C</sup>
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,	8.0	8.0	850	800
XXX	0.40	0.35	950	700	GPO-3 <sup>D</sup>				1400
					G-5	<i>E</i>	<i>E</i>	1570	550
					G-7	6.5	5.5	650	
					G-9	...	...	1700	1500
FR-1	...	...	...	...					
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 <sup>A</sup>	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				

<sup>A</sup> Specimens shall be nominal 1/2 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 1/2-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.

<sup>B</sup> LW = tested in a lengthwise direction.

CW = tested in a crosswise direction.

<sup>C</sup> See 14.2.

<sup>D</sup> For specimens 1/8 to 1/2 in. (3 to 13 mm) inclusive.

<sup>E</sup> 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
1/8 to 1/2 (3 to 13), excl	7.0	5.5
1/2 to 2 (13 to 51), excl	9.0	6.0 <sup>A</sup>

<sup>A</sup> For specimens 1/8 to 3/16 in. inclusive.

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.

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.



TABLE 9 Permittivity and Dissipation Factor Requirements for Sheets<sup>A</sup>

Grade <sup>B</sup>	Condition A <sup>C</sup>				Condition D-24/23 <sup>C</sup>					Condition D-48/50 <sup>C</sup>	
	Thickness, in. (mm) <sup>D</sup>	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		<sup>E</sup>	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.70	5.80
CEM-1		<sup>E</sup>	5.20	5.00	4.80	...	...	...	...	...	...
CEM-3 <sup>E</sup>		5.40	5.40	5.40	...	...	...	...	...	...	...
LE		5.80	<sup>F</sup>	<sup>F</sup>	<sup>F</sup>	6.00	6.00	6.00	6.00	6.00	...
G-5		<sup>E</sup>	<sup>F</sup>	<sup>F</sup>	<sup>F</sup>	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		<sup>E</sup>	...	7.40	7.40	7.40	7.40	7.40	8.00	8.00	7.50
G-10, G-11		<sup>E</sup>	5.40	...	...	...	...	...	5.40	5.70	5.80
N-1		<sup>E</sup>	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	<sup>F</sup>	<sup>A</sup>	<sup>F</sup>	0.070	0.070	0.070	0.070	0.070	...
G-5		0.020 <sup>G</sup>	<sup>F</sup>	<sup>F</sup>	<sup>F</sup>	0.080	0.080	0.080	0.080	0.080	...
GPO-1, GPO-2 <sup>H</sup> , 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 <sup>I</sup>	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

<sup>A</sup> Dielectric loss factor is the product of dissipation factor and permittivity.  
<sup>B</sup> 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.  
<sup>C</sup> See 14.2.  
<sup>D</sup> For intermediate thicknesses, the value for the next smaller thickness shall apply.  
<sup>E</sup> 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:  
<sup>F</sup> 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.  
<sup>G</sup> For Grade G-5 in thicknesses over 1 in. (24 mm), the value shall be 0.025.  
<sup>H</sup> For GPO-2 only measured at 60 Hz.  
<sup>I</sup> For Grade G-9 in thicknesses over 1/2 in. (13 mm), the value shall be 0.020.

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		...	...	...	...	...	...

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

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.

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

Grade <sup>A</sup>	Condition A <sup>B</sup>		Condition D-48/50 <sup>B</sup>		
	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 <sup>C</sup>		40.0	...	15.0	...
L		15.0	10.0	...	...
LE		40.0	30.0	3.0	3.0
GPO-1P, GPO-2P, GPO-3P <sup>D</sup>		...	...	5.0	...
G-5		23.0	15.0	5.0	3.0
G-7		32.0	25.0	15.0	...
G-9		60.0 <sup>E</sup>	...	45.0 <sup>F</sup>	40.0 <sup>F</sup>
G-10, G-11		45.0	...	40.0	...
N-1		60.0	50.0	40.0	30.0

<sup>A</sup> 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.

<sup>B</sup> See 14.2.

<sup>C</sup> For specimens 1/16 to 1/2 in. inclusive.

<sup>D</sup> For specimens 1/16 to 3/16 in. inclusive.

<sup>E</sup> This value applies to sheets having a maximum thickness of 1/2 in. (13 mm).

<sup>F</sup> 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

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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–23°C and 50 % relative humidity; Condition D-48/50—Immersion condition, 48 h in distilled water at 50°C–50°C.

14.3 Time Tolerances—Oven conditioning shall be followed by cooling to room temperature (23°C)–(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, 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.

**TABLE 11 Water Absorption Requirements for Sheets**

Grade	Water Absorption, max avg, % (Condition E-1/105 followed by Condition D-24/23 <sup>A</sup> )														
	Thickness, in. (mm) <sup>B</sup>	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	0.50	0.45
XX	7.00	6.20	...	3.10	...	2.00	...	1.60	1.30	1.00	0.85	0.55	0.50	0.50	0.45
XXX	...	4.00	...	2.10	...	1.40	...	1.10	0.95	0.70	0.60	0.45	0.40	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	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 <sup>C</sup>	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	1.00
CE	...	...	...	4.50	...	2.20	...	1.80	1.60	1.30	1.10	0.75	0.70	0.65	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	0.70
LE	...	5.80	...	4.00	...	1.95	...	1.55	1.30	1.00	0.95	0.70	0.60	0.55	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	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	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	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	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	...	...	...	...	...	...

<sup>A</sup> See 14.2

<sup>B</sup> For intermediate thicknesses, the value for the next smaller thickness shall apply.

<sup>C</sup> For 0.085-in. thickness of Grade ES-2.

**TABLE 12 Arc Resistance and Tracking Resistance Requirements for Sheets**

Grade <sup>A</sup>	Arc Resistance, <sup>B</sup> min avg, s		Tracking Resistance, <sup>C</sup> min avg, s	
	Conditions A or D-48/50 <sup>D</sup> 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	...

<sup>A</sup> No requirements are contemplated for phenolic grades because of their extremely low arc resistance.

<sup>B</sup> Test Method D495 (stainless steel strip electrodes).

<sup>C</sup> Test Method D2303.

<sup>D</sup> 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
	1/8 to 1/2 (3.2 to 12.7) ID, excl	1/2 to 8 (12.7 to 203.2) ID	1/8 to 1/2 (3.2 to 12.7) ID, excl	1/2 to 8 (12.7 to 203.2) ID	1/4 to 8 (6.4 to 203.2) ID	3/8 to 8 (9.5 to 203.2) ID	3/16 to 8 (4.8 to 203.2) ID	1/8 to 8 (3.2 to 203.2) ID	3/8 to 6 (9.5 to 152.4) ID	1/8 to 8 (3.2 to 203.2) ID	1/8 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 <sup>B</sup>	...	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 1/8 (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
1/8 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
1/4 to 3/8 (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
3/8 to 1/2 (9.5 to 12.7), excl	...	2.4	...	1.0	...	1.3	1.2	2.2	...	1.2	0.4
1/2 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

<sup>A</sup> For intermediate wall thicknesses, the value for the next smaller thickness shall apply.

<sup>B</sup> Applies only to 1/4 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 <sup>3</sup>	Compressive Strength <sup>A</sup> (Axial), min avg, psi <sup>B,C</sup>	
			1/32-in. (0.8 mm) Wall	1/16-in. (1.6 mm) Wall and over
X	1/8 to 1/2, (3.2 to 12.7) excl	1.10	10 000	10 000
	1/2 to 8 (12.7 to 203.2)	1.12	10 000	12 000
XX	1/8 to 1/2 (3.2 to 12.7) excl	1.10	10 000	10 000
	1/2 to 8 (12.7 to 203.2)	1.12	...	13 000
XXX	1/4 to 1/2 (6.4 to 12.7)	1.12	...	10 000
	1/2 to 8 (12.7 to 203.2)	1.12	...	13 000
C	3/8 to 8 (9.5 to 203.2)	1.12	...	12 000
LE	3/16 to 1/2 (4.8 to 12.7) excl	1.12	...	13 000
	1/2 to 8 (12.7 to 203.2)	1.14	...	13 000
G-5	1/8 to 8 (3.2 to 203.2)	1.70	...	13 000
G-7	3/8 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	1/8 to 8 (3.2 to 203.2)	1.70	...	18 000
G-10	1/8 to 1/2 (3.2 to 12.7) excl	1.65	...	20 000
	1/2 to 8 (12.7 to 203.2)	1.70	...	20 000

<sup>A</sup> For wall thickness of 1/16 in. (1.6 mm) and over.

<sup>B</sup> The values given for compressive strength apply to wall thickness of 1/32 in. (0.5 mm) and over, to inside diameters of 1/4 in. (6 mm) and over and to outside diameters of 2 in. (51 mm) and less.

<sup>C</sup> Conversion factor: 1 psi = 6.8948 kPa.

**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.