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NEMA STANDARDS PUBLICATION NO. LI 1

nema

Industrial Laminated Thermosetting Products

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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LI 1

INDUSTRIAL LAMINATED THERMOSETTING PRODUCTS

Published by:

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History of Laminated Standards

These standards and authorized engineering information provide practical information concerning the manufacture, testing, and performance of laminated thermosetting sheets, tubes, and rods used in the manufacture of electrical apparatus and supplies. They represent general practice in the industry, promote production economies, and assist users in the proper selection of laminated thermosetting products.

Standards on laminated thermosetting material were originally developed by the Associated Manufacturers of Electrical Supplies. That Association became the Supply Division of NEMA in 1926, at which time the NEMA *Handbook of Supply Standards* dated October 1927 was published containing four pages of standards on laminated thermosetting material. Those four pages covered thickness and tolerances of the following types of laminated phenolic plate:

1. Pieces cut and punched from sheet and blanks cut from sheet.
   Heavy-weave fabric (duck) base material.
2. Pieces cut or punched from sheet.
   a. Paper-based laminates.
   b. Asbestos-base laminates.
   c. Fine-weave fabric base laminates.

Also included were tolerances in the width and length of laminates phenolic plate and diameters of laminated phenolic round tubing.

In 1927 and 1928 additional standards were developed on tolerances on length and rectangular forms of tubing.

In November 1931, the NEMA Laminated Phenolic Products Standards, Publication No. 31-13, was published. This contained all the standards in the NEMA *Handbook of Supply Standards* and, in addition, physical and electrical properties of Grades, X, P, XX, and XXX (paper base) and Grades, C, CE L, and LE (fabric-base) laminated phenolic sheet.

In November 1939, Publication No. 38-57 was issued. In addition to expanding the properties of the previous grades, new grades covering XXP, XXXP, A, and AA in sheet form and rolled and molded tubing grades X, XX, C, CE, and LE were added. The next NEMA editions were Publication No. 46-118, LP 1-1951, LP 1-1955, LP 1-1959, LI 1-1965, LI 1-1971, LI 1-1983, and the current LI1-1989.

This Standards Publication has been developed by the Industrial Laminate Section and has been approved for publication by the National Electrical Manufacturers Association. In its preparation and revision consideration has been given to the work of other organizations, such as the American Society for Testing and Materials, striving toward the development of standards, and credit is hereby given to all of those whose standards may have been helpful in the preparation of this volume.

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Foreword

The standards in this publication have been developed over a period of years in close coordination with user needs. New and improved grades have been developed to satisfy military and industrial requirements particularly in the aerospace, electronic, and computer industries. In most cases, these standards are the same as military specifications.

NEMA standards for polyester-glass laminates were developed initially as a joint activity with the Society of the Plastics Industry, and a number of standards for laminates for printed circuits and multilayer circuits were developed jointly with the Institute for Interconnecting and Packaging Electronic Circuits (IPC). Both of these groups represent user interest in their memberships.

The NEMA Industrial Laminate Section's testing and research facilities at the University of Cincinnati, and prior to that, at the University of Delaware have been instrumental over a period of many years in developing new test methods and perfecting old test methods, and also in conducting round robins among both user and producer laboratories in proving out the reproductibility of test methods. Special programs have also been undertaken in behalf of users at the Industrial Laminate Section's research facilities to verify certain aspects of the performance of materials before the publication of user specification.

In addition to cooperative work with the users on mechanical and electrical properties, much work has been carried on for Underwriters Laboratories, Inc. with regard to safety aspects of laminates, particularly the effect of heat, flammability, and ignition from electrical sources.

User comments and recommendations are solicited on all aspects of these standards. They should be addressed to:

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Scope

The Scope of this Standards Publication includes information concerning the manufacture, testing, and performance of laminated thermosetting products in the form of sheets, rods, and tubes as described in 1.1 through 1.16.

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INDUSTRIAL LAMINATED THERMOSETTING PRODUCTS

Section 1
GENERAL

1.1 GENERAL DESCRIPTION

Laminated thermosetting products consist essentially of fibrous reinforcing materials, such as cellulose paper, cotton fabric, asbestos fabric, nylon fabric, glass fabric, etc. that are impregnated with a thermosetting resin binder and consolidated under high temperature and pressure into dense solid products capable of having high mechanical and electrical properties. Resins used in laminated thermosetting products include phenolics, melamines, silicones, polyesters, and epoxies. Most of these resins are dissolved in suitable solvents to form solutions capable of impregnating fibrous reinforcements.

1.1.1 Sheets

After impregnation and drying, the material is cut into sheets that are stacked together between metal pressing plates, and pressed under high temperatures and pressures to form laminated thermosetting sheets. During this stage, the resin is polymerized from a liquid to a solid state that is virtually infusible and insoluble. Temperatures in the range of approximately 132°C to 180°C (270°F to 350°F) are commonly employed. For the silicone resins, temperatures up to 260°C (500°F) may be required. After the material has been heated sufficiently to cause polymerization, it is cooled under pressure and the finished sheets removed. Molding pressures of approximately 1000 psi are common. With certain resins and certain types of fibrous reinforcing materials, it may be possible to produce satisfactorily laminated sheets at other pressures.

1.1.2 Round Tubes

Tubes are produced by convolutely rolling impregnated reinforcing material upon mandrels between heated pressure rolls. The resins are then polymerized by either oven-baking for rolled tubes or by pressing in a heated mold for molded tubes. When the polymerization is completed, the tubes are virtually infusible and insoluble.

1.1.3 Rods

Molded rods are composed of plies of impregnated reinforcing material that have been molded in cylindrical molds under high temperature and pressure and then ground to size.

Rods machined from sheets are also made. In these rods, the laminations are parallel cords of a circular cross-section. In general, their properties conform to the grade of sheet stock from which they are cut. This type of rod is low in flexural strength when stress is applied perpendicular to the lamination.

1.1.4 Molded Shapes

Molded shapes are composed of impregnated reinforcing materials that have been cut into various sizes and shapes to fit the contours of a mold and molded under heat and pressure. In special cases, depending upon the design of the piece, some macerated material is used in combination with other impregnated reinforcing materials. The requirements of these standards, particularly with regard to mechanical properties, should not be considered as applying to molded shapes, except for rectangular and square tubes, since the properties of such shapes will depend to a considerable extent upon the design of the piece.

Authorized Engineering Information 11-16-1989.

1.2 THERMAL CLASSIFICATION

NEMA Publication No. LI 6 gives the NEMA temperature indices for all of the standard NEMA grades, based on electrical and mechanical tests conducted in accordance with IEEE Publication No. 1, dated June 1968, and related IEEE Publications No. 98, 99, and 101. (See 13.2 for the temperature indices.)

Authorized Engineering Information 11-16-1989.

1.3 GRADES AND STANDARDIZATION

While the properties of laminated thermosetting materials can be varied within quite a wide range by varying the reinforcing materials, the binders, or manufacturing processes, it has been found that a reasonable number of grades or classes will suffice for most applications.

A description of the chief characteristics of the grades of laminated thermosetting products and the various forms available is contained in the following standards.

Authorized Engineering Information 9-15-1982.

1.4 PAPER-BASE GRADES WITH PHENOLIC RESIN BINDER

GRADE X

Sheets – Primarily intended for mechanical applications where electrical properties are of secondary importance. Should be used with discretion when high-

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humidity conditions are encountered. Not equal to fabric-base grades in impact strength.

Rolled Tubes—Fair machining qualities and can be punched. Low dissipation factor and high electric strength under relatively dry conditions.

Rods and Molded Tubes—This grade is not recommended in these forms.

GRADE XP

Sheets—Primarily intended for hot punching. With good punching practice and depending on the complexity of the part design, sheets up to and including 0.062 inch may be punched at room temperature. In most cases it is suggested that the material be heated to 100°C (212°F) or higher to improve surface appearance of the edges. Temperatures between 120°C (248°F) and 140°C (284°F) are commonly used to punch sheets having a thickness up to and including 0.125 inch. More flexible and not as strong as Grade X. Intermediate between Grades X and XX in moisture resistance and electrical properties.

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

GRADE XPC

Sheets—Primarily intended for cold punching and shearing. More flexible and higher cold flow but lower in flexural strength than Grade XP. With good punching practice, sheets up to and including 0.125 inch in thickness can be punched at a room temperature of approximately 23°C (73°F). In general, at the same temperature and with a sharp shear sheets up to 0.094 inch in thickness can be sheared in 1.500 inch minimum width strips in both the lengthwise and crosswise directions without developing surface cracks.

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

GRADE XX

Sheets—Suitable for usual electrical applications. Not recommended for punching but may be machined using present state-of-the-art machine tools.

Rolled Tubes—Good machining and threading qualities and fair punching. Not as strong mechanically as Grade X rolled tubes but better in moisture resistance, with lower dielectric losses, particularly on exposure to high humidity.

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

Rods—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

GRADE XXP

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

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

GRADE XXX

Sheets—Good electrical properties in high-humidity applications. Has minimum cold flow characteristics.

Rolled Tubes—Best electrical properties for rolled paper-base tubes under humid conditions.

Molded Tubes and Rods—Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

GRADE XXXP

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

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

GRADE XXXPC

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 0.062 inch in thickness may be punched at a temperature not less than 23°C (73°F) and, in thicknesses over 0.062 inch up to and including 0.125 inch, 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.

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

GRADE ES-1

Sheets Only—Suitable for engraving as nameplates, etc. Made with black or various colored surfaces and white opaque core (usually melamine binder).

GRADE ES-2

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

GRADE ES-3

Sheets Only—Similar in application to Grade ES-1 but made with white or various colored surfaces and black core.

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1.5 FABRIC-BASE GRADES, WITH PHENOLIC RESIN BINDER

GRADE C

Sheets—Made from cotton fabric weighing over 4 ounces per square yard. The maximum thread count in any ply is 72 per inch in the fill direction, and the maximum total thread count in the warp and fill directions is 140 per inch. Being the strongest cotton fabric based material, it is suitable for gears and other applications requiring high impact strength and resiliency. Heavier fabrics provide higher impact strength but rougher machined edges. Consequently, there may be several subgrades adapted for various sizes of gears and types of mechanical service available under the Grade C designation. Its use for electrical applications is not recommended.

Rolled Tubes—Made from a cotton fabric with the same weight and thread count limits as sheets of this grade.

Rods—Made from cotton fabric with the same weight and thread count limits as sheets of this grade. In general, characteristics are the same as those for sheets except as limited by inherent differences in construction and shape.

GRADE CE

Sheets—Made from cotton fabric with the same weight and thread count limits as Grade C. Suitable for applications requiring good moisture resistance, greater strength than Grade LE, and electrical properties nearly equivalent to Grade XX. This grade is not recommended for primary insulation* for electrical applications involving commercial power frequencies at voltages in excess of 600 volts.

Molded Tubes—Made from cotton fabric with the same weight and thread count limits as sheets of this grade. Except for electrical strength which may be low at molded seams, especially in units with thin walls, general characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

Rods—Made from cotton fabric having the same weight and thread count limits as sheets of this grade. In general, characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

GRADE L

Sheets—Made from fine-weave cotton fabric weighing 4 ounces or less per square yard. The minimum thread count in any ply is 72 per inch in the fill direction, and the minimum total thread count in the warp and fill directions is 140 per inch. Primarily suitable for machining and mechanical applications where finer edge detail and appearance than Grade C is required, particularly in thicknesses under 0.50 inches. Has high density and good moisture resistance; stronger than Grade LE but not as strong as Grade CE. Its use for electrical applications is not recommended.

Molded Tubes and Rods—Made from cotton fabric with the same weight and thread count limits as sheets of this grade. In general, characteristics are similar to those for sheets, except as limited by inherent differences in construction and shape.

GRADE LE

Sheets—Made from cotton fabric with the same weight and thread count limits as Grade L. Suitable for electrical applications requiring good moisture resistance and greater strength than Grade XX. Better than Grade CE in electrical properties, machining properties, and appearance, but not as strong mechanically. This grade is not recommended for primary insulation* for electrical applications involving commercial power frequencies at voltages in excess of 600 volts.

Rolled Tubes—Made from cotton fabric having the same weight and thread count limits as sheets of this grade. Suitable for use where the seams of molded tubes may be objectionable. In general, characteristics are similar to those for sheets except as limited by inherent differences in construction and shape.

Molded Tubes—Made from cotton fabric having the same weight and thread count limits as sheets of this grade. Except for electrical strength which may be low at molded seams, especially in units with thin walls, general characteristics are similar to those for sheets, except as limited by inherent differences in construction and shape.

Rods—Made from cotton fabric having the same weight and thread count limits as sheets of this grade. In general characteristics are similar to those for Sheets except as limited by inherent differences in construction and shape.

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*"Primary insulation" means insulation that is 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 separate insulation, etc., is not considered "primary insulation."

1.6 ASBESTOS-BASE GRADE

GRADE AA

Sheets—More resistant to heat than Grade C but not recommended for primary insulation* at any voltage. Small dimensional changes when exposed to moisture.

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

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1.7 GLASS-BASE GRADES†

†"Glass fabric" means continuous filament type woven glass cloth.

GRADE G-3 – Glass Fabric With Phenolic Resin Binder

Sheets – High impact and flexural strength. Used for thermal and mechanical applications. Good dimensional stability.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

GRADE G-5 – Glass Fabric With Melamine Resin Binder

Sheets – High mechanical strength and one of the hardest laminated grades, with good arc resistance. Meets UL 94 V-O when tested in accordance with UL 94. Excellent electrical properties under dry conditions. Good dimensional stability. Electrical applications should be limited to operating temperatures of 50°C (122°F) or less.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

GRADE G-7 – Glass Fabric With Silicone Resin Binder

Sheets – Extremely good dielectric loss properties under dry conditions and good electrical properties under humid conditions, although the percentage of range from dry to humid conditions is high. Excellent flame, heat, and arc resistance. Meets UL 94 V-O when tested in accordance with UL 94. Good impact and flexural strength.

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

GRADE G-9 – Glass Fabric With Moisture Resistant Melamine Resin Binder

Sheets – Similar to Grade G-5 but with better electric strength properties under wet conditions. Electrical applications should be limited to operating temperatures of 50°C (122°F) or less.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

GRADE G-10 – Glass Fabric With Epoxy Resin Binder

Sheets – Extremely high mechanical strength (flexural, impact and bonding) at room temperature. Good dielectric loss and electric strength properties under both dry and humid conditions.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

GRADE G-11 – Glass Fabric With Heat-Resistant Epoxy Resin Binder

Sheets – Properties similar to those of Grade G-10 at room temperature and, in addition, this grade has high retention of flexural strength at elevated temperatures.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

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1.8 NYLON-CLOTH GRADE WITH PHENOLIC RESIN BINDER

GRADE N-1

Sheets – Excellent electrical properties under high humidity conditions. Good impact strength, but subject to flow or creep under load, especially at temperatures higher than normal.

1.9 FLAME-RESISTANT GRADES

GRADE FR-1

Sheets – Paper-base laminates with a phenolic resin binder. Similar in all properties to Grade XP, but so formulated to have at least a UL 94 V-1 classification when tested according to UL 94.

GRADE FR-2

Sheets – Paper-base laminates with a phenolic resin binder. Similar in all properties to Grade XXXPC, but so formulated to have at least a UL 94 V-1 classification when tested according to UL 94.

GRADE FR-3

Sheets – Paper-base laminates with epoxy resin binder. Has higher flexural strength than Grade XXXPC and is formulated to have a flame resistance of

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at least a UL 94 V-1 classification when tested in accordance with UL 94. Has low dielectric loss properties with good stability of electrical properties under conditions of high humidity. With good punching practice, sheets up to and including 0.062 inch in thickness may be punched at temperatures not less than 27°C (80°F) and, in thickness over 0.062 inch up to and including 0.125 inch, when warmed to a temperature not exceeding 66°C (150°F).

Tubes and Rods – No standards developed for this grade in these forms.

GRADE FR-4

Sheets – Continuous-filament glass cloth with an epoxy resin binder. Similar in all properties to Grade G-10, but so formulated to have at least a UL 94 V-1 classification when tested according to UL 94.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

GRADE FR-5

Sheets – Continuous-filament glass cloth with an epoxy resin binder. Similar in all properties to Grade G-11, but so formulated to have at least a UL 94 V-1 classification when tested according to UL 94.

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

Rods – Characteristics are similar to those for sheets except as limited by inherent differences in construction and shape. Molded seams are weak points mechanically and electrically.

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1.10 COPPER-CLAD LAMINATES

See Section 8.

1.11 COPPER-CLAD THIN LAMINATES FOR MULTILAYER

See Section 9.

1.12 EPOXY-RESIN-IMPREGNATED GLASS CLOTH (PREPREG) FOR MULTILAYER

See Section 10.

1.14 POLYESTER GLASS LAMINATES

See Section 11 for Grades GPO-1, GPO-2, GPO-3, GPO-1P, GPO-2P, and GPO-3P polyester glass-mat sheet laminates.

1.15 POST-FORMING GRADE CF

See Section 12.

1.16 COMPOSITE-BASE LAMINATES GRADE CEM-1

Laminates with continuous-filament glass cloth surfaces and a cellulose core, all with a flame-resistant epoxy resin binder. With good punching practice, sheets up to and including 0.094 inch in thickness may be punched at temperatures not less than 23°C (73°F) and in thickness over 0.094 inch up to and including 0.125 inch, when warmed to a temperature not exceeding 66°C (150°F). Meets UL 94 V-O when tested in accordance with UL 94.

GRADE CEM-3

Laminated with continuous-filament glass cloth surfaces and a nonwoven glass core, all with a flame-resistant epoxy resin binder. Property values approach those of FR-4. With good punching practice, sheets up to and including 0.062 inch in thickness may be punched at temperatures not less than 23°C (73°F) and in thickness over 0.062 inch, up to and including 0.125 inch when warmed to a temperature not exceeding 66°C (150°F). Meets UL 94 V-O when tested in accordance with UL 94.

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Section 2
APPLICATION

Considered on the basis of strength-weight ratio, laminated phenolic is one of the strongest materials known. With a density of cellulose-base grades of approximately 1.35 grams/cubic centimeter, only half that of aluminum, the mechanical grades find large application in the aircraft and other structural fields.

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 10-inch face gears in rolling mills.

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. In general, laminated phenolic is not suitable 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.

Paper-base epoxy laminates are used for those applications that require the stable electrical properties of epoxies under humid conditions. They combine a high degree of flame resistance with greater mechanical strength than is provided by grade XXXPC and can be punched.

Glass-base phenolic grades are used for motor insulation and in other applications where high strength and good electrical properties are required even at fairly high temperatures.

Glass-base melamine grades are used primarily for their high mechanical strength and resistance to arc and flame and are particularly suitable for power equipment in marine applications.

Glass-base silicone grades are resistant to high temperatures up to 200°C (392°F) and have especially low dielectric losses. These grades extend the upper temperature range of laminated material to a new high.

Glass-base epoxy laminates are used primarily in electronic applications at room temperature where their stable electrical properties are particularly desirable. They are often used in printed-circuit applications. Caution should be used in applications of Grades G-10 and FR-4 involving high mechanical stresses at elevated temperatures. However, Grades G-11 and FR-5 have excellent hot strength. These laminates have excellent dimensional stability over a wide temperature range.

Glass-base epoxy laminates having a high degree of flame resistance 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.

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

Composite-base laminates are suitable for those subtractive and additive printed circuit applications that require greater mechanical strength than electronic paper-base grades and where punching is the preferred method of fabrication.

Glass-mat-based polyester laminates are used as primary and secondary insulation in electrical apparatus where a high degree of electrical and mechanical properties are required under wet and dry conditions. Grades GPO-2 and GPO-3 exhibit superior arc and track resistance and meet UL 94 V-O flame requirements when tested in accordance with UL 94. Grades GPO-1P, GPO-2P, and GPO-3P can be punched at room temperature. Some grades retain dielectric and physical properties at elevated temperature up to 210°C (410°F).

In general, most of the grades can be drilled, tapped, sawed, and machined. Grades X, XP, XPC, 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.

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Section 3
FORMS, COLORS, AND FINISHES

3.1 QUALITY AND WORKMANSHIP

Sheets shall be free from blisters, wrinkles, or cracks and reasonably free from other small defects, such as scratches, dents, etc.

All tubes shall be free from blisters, pronounced mandrel scores, and loose layers and reasonably free from resin pockets and voids. Rolled tubes shall be free from wrinkles. Molded tubes shall be substantially free from seam cracks.

Rods shall be free from blisters and substantially free from molded seam cracks.

NEMA Standard 9-15-1987.

3.2 FORMS OF LAMINATED THERMOSETTING PRODUCTS

The standard forms of laminated thermosetting products shall be sheets, tubes, rods, and molded shapes, as indicated in Table 3-1.

NEMA Standard 11-16-1989.

3.3 COLORS – SHEETS, TUBES, AND RODS

Form	Grade	Typically available colors
Sheets	X, XX, XXP, XXX, C, CE, L, LE, FR-1	natural or black
	XP, XPC	natural, black, or chocolate
	XXXP, XXXPC, AA, G-3, G-5, G-7, G-9, G-10, G-11, N-1, FR-2, FR-3, FR-4	natural
	FR-5, CEM-1, CEM-3	various colors
	ES-1	black or colored surface, white core
	ES-2	black or colored surface, white subcore, black core
	ES-3	white or colored surface, black core
Tubes and Rods	X, XX, XXX, C, CE, L, LE	natural or black
	AA, G-3, G-5, G-7, G-9, G-10, G-11, N-1, FR-4	natural

NEMA Standard 11-16-1989.

Table 3-1
FORMS OF LAMINATED THERMOSETTING PRODUCTS

Grade	Forms				
		Round Tubes			Rectangular and Square Molded Tubes
	Sheets	Rolled	Molded	Molded Rods	
X	X	X	–	–	–
XP, XPC	X	–	–	–	–
XX	X	X	–	X	–
XXP	X	–	–	–	–
XXX	X	X	–	X	–
XXXP	X	–	–	–	–
XXXPC	X	–	–	–	–
ES-1, ES-2, ES-3	X	–	–	–	–
C	X	X	–	X	–
CE	X	–	X	X	–
L	X	–	X	X	–
LE	X	X	X	X	–
AA	X	–	–	–	–
G-3	X	X	–	–	–
G-5	X	X	–	X	–
G-7	X	X	–	–	–
G-9	X	X	–	X	–
G-10	X	X	–	X	–
G-11	X	–	–	–	–
N-1	X	–	–	–	–
FR-1	X	–	–	–	–
FR-2	X	–	–	–	–
FR-3	X	–	–	–	–
FR-4, FR-5	X	–	–	–	–
CEM-1, CEM-3	X	–	–	–	–

"X" Covered by these standards.
"–" No standards contemplated for this form.

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Natural color is produced by the natural undyed paper or fabric and resin used. Woven glass-base grades contain streaks due to the differential coloration of various warp or filler threads under heat-treating conditions. The natural color of phenolic products will vary from a light tan to a light brown or reddish brown. The color of glass-base melamine and silicone products will vary from white to shades of gray and brown and that of cotton-fabric-base melamine products from white to cream. The color of glass-base epoxy-resin laminates will vary from yellowish green to brown. The color of paper-base epoxy-resin laminates will vary from ivory to tan. Black sheets have substantially uniform black surfaces and a black body. Sawed, sanded, and machined surfaces of sheets and ground surfaces of tubes show a slight grayish-black tinge. Sawed, sanded, machined, and ground surfaces and the edges of some cotton-fabric-base show a decided grayish-black tinge.

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

For several grades colors other than standard may be available. In some cases, colors other than natural may effect flame resistance or thermal endurance.

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Section 4A
DIMENSIONS AND TOLERANCES OF SHEETS, TUBES, AND RODS (CUSTOMARY UNITS)

For the purpose of these standards, unless otherwise stated, common fractions are expressed as decimal fractions to the nearest thousandth, e.g. 1/32 = 0.03125 exactly, NEMA standard = 0.031; 1/16 = 0.0625 exactly, NEMA standard = 0.062 (using Computer's rule round a terminal 5 to make the rounded value even).

4A.1 TOLERANCES FOR WARP OR TWIST (SHEETS)

Thickness Inches	Maximum Warp or Twist (Based on 36-inch Dimension), Percent*
0.031–0.062	5.0
0.063–0.125	2.5
0.126–0.250	1.0†
0.251–0.750	0.5
0.751–Max.	0.25

*In the case of warp, this percentage is stated in terms of the lateral dimensions (length or width); in the case of twist, the percentage is stated in terms of the dimensions from one corner to the diagonally opposite corner.

†The value for grade G-7 is 1.5 percent.

NEMA Standard 11-16-1989.

Note 1—These values do not apply to cut pieces but only to sheet sizes as manufactured.

Note 2—For method of measuring warp and twist, see ASTM D-709.

Authorized Engineering Information 11-16-1989.

4A.2 TOLERANCES IN LENGTH AND WIDTH (SHEETS)‡

The tolerance in length and width of manufacturers' standard size sheets shall be ±1 inch from the manufacturers' standard.**

NEMA Standard 9-15-1982.

‡For tolerances in the length and width of cut pieces, see 5A.01 and 5A.02. Thicknesses greater or lesser than these may be available; if so, case tolerances listed in 4A.5 apply.

**Because of variations in the size of press equipment, there is considerable variation in the length and width of manufacturers' standard size sheets. These standard sizes range between 18 and 60 inches in width and between 24 and 144 inches in length.

4A.3 TOLERANCES IN THICKNESS OF COMPONENT PARTS OF ENGRAVING STOCK GRADES (SHEETS)

	Tolerances in Thickness, Inches			
	Surfaces		White Subcore	
Grade	Minimum	Maximum	Minimum	Maximum
ES-1	0.0025	0.008	...	...
ES-2	0.0025	0.008	0.020	0.035
ES-3	0.0060	0.015	...	...

NEMA Standard 11-16-1989.

4A.4 RANGE OF THICKNESS (SHEETS)

	Thickness Range, Inches	
Grade	Minimum	Maximum*
X	0.010	2.000
XP	0.010	0.250
XPC	0.031	0.250
XX	0.010	2.000
XXP	0.015	0.250
XXX	0.015	2.000
XXXP	0.015	0.250
XXXPC	0.031	0.250
ES-1	0.047	0.250
ES-2	0.085	0.250
ES-3	0.047	0.250
C	0.031	10.000
CE	0.031	2.000
L	0.010	10.000
LE	0.015	2.000
AA	0.062	2.000
G-3, G-7	0.010	2.000
G-5, G-9	0.010	3.500
G-10, G-11	0.010	4.000
N-1	0.010	1.000
FR-1, FR-2, FR-3	0.031	0.250
FR-4, FR-5	0.002	4.000
CEM-1, CEM-3	0.031	0.094

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*Thicknesses greater than these may be available; if so, class tolerances listed in 4A.5 apply.

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4A.5 TOLERANCES IN THICKNESS (SHEETS)

At least 90 percent of the area of the sheet shall be within the tolerances given in Table 4A-1. At no point shall the thickness vary from the nominal by a value greater than 125 percent of this specified tolerance.

Table 4A-1
TOLERANCES IN THICKNESS, INCHES

Nominal Thickness, Inches	Grades X, XP, XPC, XX, XXP, XXX, XXXP, XXXPC, FR-1, FR-2, FR-3	Grades ES-1, ES-2, ES-3, CE	Grade C	Grade L	Grade LE	Grade AA	Grades G-3, G-5, G-7, G-9, G-10, G-11, FR-4, FR-5, CEM-1, CEM-3	Grade N-1
	Plus or Minus	Plus or Minus	Plus	Plus	Plus	Plus or Minus	Plus or Minus	Plus or Minus
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
0.031	0.0035	0.0065	0.0065	0.005	0.005	—	0.0065	0.0065
0.047	0.0045	0.0075	0.0075	0.0055	0.0055	—	0.0075	0.0075
0.062	0.005	0.0075	0.0075	0.006	0.006	0.018	0.0075	0.0075
0.094	0.007	0.009	0.009	0.007	0.007	0.018	0.009	0.009
0.125	0.008	0.010	0.010	0.008	0.008	0.020	0.012	0.010
0.156	0.009	0.012	0.011	0.009	0.009	—	0.015	0.011
0.188	0.010	0.0125	0.0125	0.010	0.010	0.024	0.019	0.0125
0.219	0.011	0.014	0.014	0.011	0.011	—	0.021	0.014
0.250	0.012	0.015	0.030	0.024	0.012	0.028	0.022	0.015
0.312	0.014	0.017	0.035	0.029	0.0145	0.034	0.026	0.024
0.375	0.017	0.020	0.040	0.034	0.017	0.038	0.038	0.032
0.438	0.019	0.022	0.044	0.038	0.019	0.044	0.033	0.040
0.500	0.021	0.024	0.048	0.042	0.021	0.048	0.036	0.048
0.625	0.024	0.027	0.053	0.048	0.024	0.058	0.040	0.054
0.750	0.027	0.029	0.058	0.054	0.027	0.068	0.043	0.058
0.875	0.030	0.031	0.062	0.060	0.030	0.076	0.046	0.062
1.000	0.033	0.033	0.065	0.065	0.033	0.086	0.049	0.066
1.125	0.035	0.035	0.069	0.069	0.035	—	0.053	—
1.250	0.037	0.037	0.073	0.073	0.037	0.106	0.055	—
1.375	0.039	0.039	0.077	0.077	0.039	—	0.058	—
1.500	0.041	0.041	0.081	0.081	0.041	0.124	0.061	—
1.625	0.043	0.043	0.085	0.085	0.043	—	0.064	—
1.750	0.045	0.045	0.089	0.089	0.045	0.144	0.062	—
1.875	0.047	0.047	0.093	0.093	0.047	—	0.070	—
2.000	0.049	0.049	0.097	0.097	0.049	0.160	0.073	—
2.125	0.052	—	0.105	0.105	—	—	0.079	—
2.500	0.056	—	0.113	0.113	—	—	0.085	—
2.750	0.061	—	0.121	0.121	—	—	0.091	—
3.000	0.065	—	0.130	0.130	—	—	0.097	—
3.500	0.073	—	0.146	0.146	—	—	0.110	—
4.000	0.082	—	0.163	0.163	—	—	0.122	—
4.500	0.090	—	0.179	0.179	—	—	0.134	—
5.000	0.095	—	0.190	0.190	—	—	0.156	—
5.500	0.105	—	0.210	0.210	—	—	0.156	—
6.000	0.115	—	0.230	0.230	—	—	0.172	—
6.500	0.120	—	0.240	0.240	—	—	0.180	—
7.000	0.130	—	0.260	0.260	—	—	0.195	—
7.500	0.140	—	0.280	0.280	—	—	0.210	—
8.000	0.145	—	0.290	0.290	—	—	0.216	—
8.500	0.155	—	0.310	0.310	—	—	0.232	—
9.000	0.160	—	0.320	0.320	—	—	0.240	—
9.500	0.170	—	0.340	0.340	—	—	0.255	—
10.000	0.180	—	0.360	0.360	—	—	0.270	—

NOTE 1—For a sheet having a nominal thickness not listed in the table, the tolerances shall be the same as for the next larger nominal thickness.
NOTE 2—The minimum and maximum thickness for each grade shall be in accordance with 4A.4.

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4A.6 TOLERANCES FOR WARP (ROUND TUBES)

Outside Diameter, Inches	Maximum Warp (Based on 36-inch Dimension), Percent*
0.125 to 0.250	2
0.251 to 0.750	1‡
0.751 to MAX	0.5

*This percentage is stated in terms of the tube length.

‡The value for Grade G-7 is 1.5 percent.

NOTE—For method of measuring warp, see ASTM D 709. This note approved as Authorized Engineering Information.

NEMA Standard 11-16-1989.

4A.7 RANGE OF SIZES (ROUND TUBES)

Grade	Inside Diameter, Inches		Outside Diameter, Inches		Wall Thickness, Inches		Maximum Ratio of Wall Thickness to Inside Diameter†
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum*	
				Rolled Tubes			
X	0.125	48	0.145	49.500	0.010	0.750	0.250
XX	0.125	48	0.145	50.000	0.010	1	0.500
XXX	0.250	8	0.312	10.000	0.031	1	0.500
C	0.375	48	0.500	50.000	0.062	2	0.500
LE	0.188	48	0.250	50.000	0.031	1	0.500
G-3	0.250	48	0.281	50.000	0.016	1	0.500
G-5, G-9, G-10	0.125	48	0.156	50.000	0.016	1	0.500
G-7	0.375	6	0.438	6.750	0.031	0.375	0.125
FR-4	0.125	48	0.156	50.000	0.016	1	0.500

*Tubes having a wall thickness greater than 0.500 inch can show checks and/or cracks between the laminations on machined or sawed edges.

†"Maximum ratio of wall thickness to inside diameter" means that for any size of tube the standard wall thickness shall be not greater than 0.125, 0.250, or 0.500 of the inside diameter, whichever value applies. For example, the maximum wall thickness of a Grade X rolled tube with a 0.125-inch inside diameter is 0.031 inch, with a 0.250-inch inside diameter it is 0.062 inch, with a 1-inch inside diameter it is 0.250 inch, and with a 3-inch inside diameter and above it is 0.750 inch.

NEMA Standard 11-16-1989.

4A.8 TOLERANCES IN LENGTH (ROUND TUBES)

The length of rolled or molded tubes shall be plus or minus 1 inch from the manufacturers' standard.*

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*Manufacturers' standard lengths vary from 18 to 48 inches depending on outside diameters. In a number of grades, longer lengths are available.

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4A.9 TOLERANCES IN INSIDE AND OUTSIDE DIAMETERS (ROUND TUBES)

Nominal Diameter, Inches	Plus or Minus Tolerance, Inches		
	Inside Diameter*		Outside Diameter Grounded, Buffed or Varnished Finish
	Steel Mandrel	Built-up Mandrel	
0.125–0.749	0.003	...	0.005
0.750–1.999	0.004	...	0.005
2.000–4.000	0.008	...	0.008
Rolled Only			Turned
4.001–12.000 incl.	0.010	...	0.025
12.001–18.000 incl.	0.030	0.060	0.030
18.001–24.000 incl.	0.040	0.075	0.035
24.001–48.000 incl.	0.060	0.090	0.040

NEMA Standard 9-15-1982.

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

Authorized Engineering Information 9-15-1982.

4A.10 TOLERANCES IN WALL THICKNESS (ROUND TUBES)

4A.10.1 Rolled Tubes—Inside Diameters Up To 4 Inches

Wall Thickness, Inches	Plus or Minus Tolerance* from Average Wall Thickness of Individual Tube, Inches				
	Grades X, XX, XXX	Grade LE Inside Diameter*		Grade C	Grades G-3, G-5, G-7, G-9, G-10, FR-4
		0.188 to 0.500	0.501 to MAX.		
0.010–0.016	0.003	...	...	...	...
0.017–0.031	0.005	...	...	...	0.006
0.032–0.062	0.006	0.010	0.008	...	0.008
0.063–0.125	0.007	0.011	0.009	0.015	0.009
0.126–0.250	0.009	0.013	0.011	0.020	0.011
0.251–0.500	0.011	0.015	0.013	0.020	0.013
0.031–0.062	0.000	0.008	0.008	0.015	0.015
0.063–0.125	0.011	0.011	0.011	0.015	0.015
0.126–0.250	...	0.015	0.011	0.020	0.020
0.251–0.500	...	...	0.013	...	0.020

*Wall thickness, measured at any point in the wall of any one tube of a given size, must fall within the tolerances given. This provides a means for measuring both the tolerance in the wall thickness and the deviation from concentricity.

NOTE—See 4A.7 for the maximum wall thickness for any given inside diameter.

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4A.10.2 Molded Tubes—Inside Diameters Up to 3.875 Inches

Wall Thickness, Inches	Plus or Minus Tolerance* from Average Wall Thickness of Individual Tube, Inches				
	Grades, XX, XXX, L, LE, Inside Diameter			Grades CE, AA, Inside Diameter	
	0.125–0.250	0.251–0.500	0.501–MAX.	0.250–0.500, Incl.	0.501—MAX.
0.031–0.062	0.008	0.008	0.008	0.015	0.015
0.063–0.125	0.011	0.011	0.011	0.015	0.015
0.126–0.250	...	0.015	0.011	0.020	0.020
0.251–0.500	...	...	0.013	...	0.020

*Wall thickness, measured at any point in the wall of any one tube of a given size, must fall within the tolerances given. This provides a means for measuring both the tolerance in the wall thickness and the deviation from concentricity.

NOTE—See 4A.7 for the maximum wall thickness for any given inside diameter.

NEMA Standard 11-16-1989.

4A.11 TOLERANCES FOR WARP (SQUARE AND RECTANGULAR MOLDED TUBES)

Outside Dimension, Inches	Maximum Warp (Based on 36-Inch Dimension), Percent*
0.125–0.250	2
0.251–0.750	1†
0.751–MAX	0.5

*This percentage is stated in terms of the tube length.

†The value for Grade G-7 is 1.5 percent.

NOTE—For method of measuring warp, see ASTM D 709.

NEMA Standard 11-16-1989.

4A.12 RANGES OF SIZES* (SQUARE AND RECTANGULAR MOLDED TUBES)

Grade	Inside Dimension, Inches		Outside Dimension, Inches		Wall Thickness	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum*
X, XX, XXX	0.188	3.906	0.281	4.000	0.047	0.500
CE	0.375	3.875	0.500	4.000	0.062	0.500
L	0.250	3.906	0.344	4.000	0.047	0.500
LE	0.250	3.000	0.344	4.000	0.047	0.500
AA	0.500	3.750	0.750	4.000	0.125	0.500

*Tubes having a wall thickness greater than one half of the minimum (inside) dimensions are not recommended for many appliances.

NEMA Standard 11-16-1989.

4A.13 TOLERANCES IN LENGTH (SQUARE AND RECTANGULAR MOLDED TUBES)

The length of molded tubes shall be plus or minus 1 inch from the manufacturers' standard.†

NEMA Standard 11-16-1989.

†Manufacturers' standard lengths vary from 18 to 48 inches depending on outside dimension. In a number of grades, longer lengths are available.

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4A.14 TOLERANCES IN INSIDE AND OUTSIDE DIMENSIONS* (SQUARE AND RECTANGULAR MOLDED TUBES)

Dimension, Inch	Plus or Minus Tolerance†, Inches, Inside Dimensions	Nominal Outside Dimension, Inches	Plus or Minus Tolerance, Inches, Outside Dimension	
	All Grades		Grades X, XX, XXX, L, LE	Grades CE, AA
0.188–0.469 incl.	0.005	0.281–0.469 incl.	0.010	0.017
0.500–0.969 incl.	0.006	0.500–0.969 incl.	0.012	0.020
1.000–1.938 incl.	0.007	1.000–1.938 incl.	0.014	0.022
2.000–4.000 incl.	0.010	2.000–5.000 incl.	0.017	0.025

*These tolerances apply to tubes having a 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.

†The tolerances shall correspond to the appropriate inside or outside dimensions. For example, for a rectangular tube having a nominal inside dimension of 0.250 inch × 1.0 inch, the tolerance will be plus or minus 0.005 for the 0.250 inch dimension and plus or minus 0.007 inch for the 1.0 inch dimension.

NEMA Standard 11-16-1989.

4A.15 TOLERANCES IN WALL THICKNESS* (SQUARE AND RECTANGULAR MOLDED TUBES)

Average Wall Thickness for Single Tube, Inches	Plus or Minus Tolerance* from Average Wall Thickness of Individual Tube, Inches				
	Inside Dimension†				
	Grades X, XX, XXX, A, L, LE			Grade CE	Grade AA
	0.188–0.250	0.251–0.500	0.501–MAX.	0.376–MAX.	0.501–MAX.
0.047–0.062	0.008	0.008	0.010	...	...
0.063–0.125	0.011	0.010	0.013	0.015	0.025
0.126–0.250	0.015	0.014	0.016	0.020	0.030
0.251–0.500	...	0.018	0.020	0.025	0.030

*Wall thicknesses, measured at any point in any wall of any one tube of a given size, must fall within the tolerances given. This provides a means for measuring both the tolerance in wall thickness and the deviation from parallelism.

†For rectangular tubes, the tolerances shall apply to the maximum inside dimension.

NEMA Standard 11-16-1989.

NOTE– Tubes having a wall thickness greater than one-half of the minimum inside dimension generally do not meet the above tolerances.

Authorized Engineering Information 11-16-1989.

4A.16 TOLERANCES FOR WARP (MOLDED RODS)

Outside Diameter, Inches	Maximum Warp (Based on 36-Inch Dimension), Percent*
0.125–0.250	2.0
0.251–0.750	1.0†
0.751–MAX.	0.5

*This percentage is stated in terms of the rod length.

†The value for Grade G-7 is 1.5 percent.

NOTE–For method of measuring warp, see ASTM D 709.

NEMA Standard 11-16-1989.

4A.17 TOLERANCES IN LENGTH (RODS)

The length of rolled or molded rods shall be plus or minus 1 inch from the manufacturers' standard.

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4A.18 RANGE OF OUTSIDE DIAMETERS (RODS)

Grade	Outside Diameter, Inches	
	Minimum	Maximum
XX*	0.125	2.0
XXX*	0.125	2.0
C	0.250	4.0
CE	0.250	4.0
L	0.188	4.0
LE	0.188	4.0
G-3	0.250	2.0
G-5	0.250	2.0
G-9	0.250	2.0
G-10	0.250	2.0
FR-4	0.250	2.0

*Molded rods in these grades having a diameter greater than 1 inch can show checks and/or cracks between the laminations on machined or sawed edges.

NEMA Standard 11-16-1989.

4A.19 TOLERANCES IN OUTSIDE DIAMETERS (RODS)

Outside Diameter, Inches	Plus or Minus Tolerance, Inches
0.125–1.999 incl.	0.005
2.000–4.000 incl.	0.008

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Part 4B
DIMENSIONS AND TOLERANCES OF SHEETS, TUBES, AND RODS (METRIC UNITS)

4B.1 TOLERANCES FOR WARP OR TWIST (SHEETS)

Thickness, mm	Maximum Warp or Twist (Based on 914 mm Dimension), Percent*
0.79–1.57	5.00
1.58–3.16	2.50
3.17–6.34	1.00†
6.35–19.0	0.50
19.05–MAX	0.25

*In the case of warp, this percentage is stated in terms of the lateral dimensions (length or width); in the case of twist, the percentage is stated in terms of the dimensions from one corner to the diagonally opposite corner.

†The value for Grade G-7 is 1.5 percent.

NOTE 1—The values do not apply to cut pieces but only to sheet sizes as manufactured.

NOTE 2—For method of measuring warp and twist, see ASTM D 709.

NEMA Standard 9-15-1982.

4B.2 TOLERANCES IN LENGTH AND WIDTH (SHEETS)‡

The tolerance in length and width of manufacturers' standard size sheets shall be plus or minus 25 mm from the manufacturers' standard.**

‡For tolerances in the length and width of cut pieces, see LI 1-5B.01 and LI 1-5B.02.

**Because of variations in the size of press equipment, there is considerable variation in the length and width of manufacturers' standard size sheets. These standard sizes range between 457 and 1524 mm in width and between 610 and 3656 mm in length.

NEMA Standard 9-15-1982.

4B.3 TOLERANCES IN THICKNESS OF COMPONENT PARTS OF ENGRAVING STOCK GRADES (SHEETS)

	Tolerances in Thickness, mm			
	Surfaces		White Subcore	
Grade	Minimum	Maximum	Minimum	Maximum
ES-1	0.064	0.20	...	...
ES-2	0.064	0.20	0.51	0.89
ES-3	0.15	3.81	...	...

NEMA Standard 9-15-1982.

4B.4 RANGE OF THICKNESS (SHEETS)

	Thickness Range, mm	
Grade	Minimum	Maximum*
X	0.25	51.0
XP	0.25	6.4
XPC	0.8	6.4
XX	0.25	51.0
XXP	0.38	6.4
XXX	0.38	51.0
XXXP	0.38	6.4
XXXPC	0.8	6.4
ES-1	1.2	6.4
ES-2	2.2	6.4
ES-3	1.2	6.4
C	0.8	254.0
CE	0.8	51.0
L	0.25	254.0
LE	0.38	51.0
AA	1.6	51.0
G-3, G-7	0.25	51.0
G-5, G-9	0.25	89.0
G-10, G-11	0.25	100.0
N-1	0.25	25.0
FR-1, FR-2, FR-3	0.8	6.4
FR-4, FR-5	0.05	100.0
CEM-1, CEM-3	0.8	2.38

*Thicknesses greater or lesser than these may be available. If so, tolerances listed in LI 1-4B.5 apply.

NEMA Standard 9-15-1982.

4B.5 TOLERANCES IN THICKNESS (SHEETS)

At least 90 percent of the area of the sheet shall be within the tolerances given in Table 4B-1. At no point shall the thickness vary from the nominal by a value greater than 125 percent of this specified tolerance.

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Table 4B-1
TOLERANCES IN THICKNESS, MM

Nominal Thickness, mm	Grades X, XP, XPC, XX, XXP, XXX, XXXP, XXXPC, FR-1, FR-2, FR-3	Grades ES-1, ES-2, ES-3, CE	Grade C	Grade L	Grade LE	Grade AA	Grades G-3, G-5, G-7, G-9, G-10, G-11, FR-4, FR-5, CEM-1, CEM-3	Grade N-1
	Plus or Minus	Plus or Minus	Plus	Plus	Plus	Plus or Minus	Plus or Minus	Plus or Minus
0.25	0.050	—	—	0.08	—	—	0.05	0.08
0.38	0.064	—	—	0.89	0.089	—	0.08	0.089
0.51	0.080	—	—	0.10	0.10	—	0.11	0.11
0.64	0.089	0.13	—	0.114	0.114	—	0.13	0.114
0.80	0.089	0.165	0.165	0.13	0.13	—	0.165	0.165
1.2	0.114	0.191	0.191	0.140	0.140	—	0.191	0.191
1.6	0.130	0.191	0.191	0.15	0.15	0.46	0.191	0.191
2.4	0.180	0.230	0.230	0.18	0.18	0.46	0.23	0.23
3.2	0.200	0.250	0.250	0.20	0.20	0.51	0.30	0.25
4.0	0.230	0.280	0.280	0.23	0.23	—	0.38	0.28
4.8	0.250	0.318	0.318	0.25	0.25	0.61	0.48	0.318
5.6	0.280	0.360	0.360	0.28	0.28	—	0.53	0.36
6.4	0.31	0.38	0.76	0.61	0.31	0.71	0.56	0.38
8.0	0.368	0.445	0.89	0.77	0.368	0.86	0.66	0.61
9.5	0.43	0.51	1.02	0.86	0.43	0.97	0.76	0.81
11.1	0.48	0.56	1.12	0.97	0.48	1.12	0.84	1.02
12.7	0.53	0.61	1.22	1.07	0.53	1.22	0.91	1.22
15.9	0.61	0.69	1.35	1.22	0.61	1.47	1.02	1.37
19.1	0.69	0.74	1.47	1.37	0.69	1.73	1.09	1.47
22.2	0.76	0.79	1.57	1.52	0.76	1.93	1.17	1.57
25.4	0.84	0.84	1.65	1.65	0.84	2.18	1.24	1.68
28.6	0.89	0.89	1.75	1.75	0.89	—	1.35	—
31.8	0.94	0.94	1.85	1.85	0.94	2.69	1.38	—
35.0	0.99	0.99	1.96	1.96	0.99	—	1.47	—
38.1	1.04	1.04	2.06	2.06	1.04	3.15	1.55	—
41.3	1.09	1.09	2.16	2.16	1.09	—	1.63	—
44.5	1.14	1.14	2.26	2.26	1.14	3.68	1.70	—
47.6	1.19	1.19	2.36	2.36	1.19	—	1.78	—
50.8	1.24	1.24	2.46	2.46	1.24	4.06	1.85	—
57.2	1.34	—	2.68	2.68	—	—	2.01	—
36.5	1.42	—	2.87	2.87	—	—	2.16	—
69.9	1.52	—	3.07	3.07	—	—	2.29	—
76.2	1.65	—	3.30	3.30	—	—	2.46	—
88.9	1.84	—	3.71	3.71	—	—	2.79	—
101.6	2.07	—	4.14	4.14	—	—	3.10	—
127.0	2.42	—	4.83	4.83	—	—	3.62	—
139.7	2.65	—	5.33	5.33	—	—	4.00	—
152.4	2.92	—	5.84	5.84	—	—	4.38	—
165.1	3.05	—	6.10	6.10	—	—	4.56	—
177.8	3.30	—	6.60	6.60	—	—	4.95	—
190.5	3.54	—	7.11	7.11	—	—	5.33	—
203.2	3.67	—	7.37	7.37	—	—	5.53	—
215.9	3.92	—	7.87	7.87	—	—	5.90	—
228.9	4.05	—	8.13	8.13	—	—	6.10	—
241.3	4.32	—	8.64	8.64	—	—	6.48	—
254.0	4.57	—	9.14	9.14	—	—	6.84	—

NOTE 1—For a sheet having a nominal thickness not listed in the table, the tolerances shall be the same as for the next larger nominal thickness.

NOTE 2—The minimum and maximum thickness for each grade shall be in accordance with LI 1-4.04.

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4B.6 TOLERANCES FOR WARP (ROUND TUBES)

Thickness, mm	Maximum Warp or Twist (Based on 914 mm Dimension), Percent*
3.17–6.35, incl.	2.0
Over 6.35–19.0 incl.	1.0†
Over 19.05	0.5

*This percentage is stated in terms of the lateral dimensions (length or width).

†The value of Grade G-7 is 1.5 percent.

NOTE–For method of measuring warp, see ASTM D 709.

NEMA Standard 9-15-1982.

4B.7 RANGE OF SIZES (ROUND TUBES)

Grade	Inside Diameter, mm		Outside Diameter, mm		Wall Thickness, mm		Maximum Ratio of Wall Thickness Inside Diameter†
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum*	
X	3.2	1219	3.68	1257	0.25	19	0.250
XX	3.2	1219	3.68	1270	0.25	25	0.500
XXX	6.4	203	8.0	254	0.8	25	0.500
C	4.5	1219	12.7	1270	1.6	51	0.500
LE	4.8	1219	6.4	1270	0.8	25	0.500
G-3	6.4	1219	7.1	1270	0.4	25	0.500
G-5, G-9, G-10	3.2	1219	4.0	1270	0.4	25	0.500
G-7	9.5	6	11.1	171	0.8	9.5	0.125
FR-4	3.2	1219	4.0	1270	0.4	25	0.500
Molded Tubes							
XX, XXX	3.2	98	6.4	102	1.6	25	0.500
CE	6.4	98	9.5	102	1.6	25	0.500
L, LE	3.2	98	4.8	102	0.8	25	0.500
AA	9.5	95	15.9	102	3.2	25	0.500

NEMA Standard 9-15-1982.

*Tubes having a wall thickness greater than 12.7 mm can show surface cracks and cracks between the laminations on machined or sawed edges, or both.

†"Maximum ratio of wall thickness to inside diameter" means that, for any size of tube, the standard wall thickness shall be not greater than 0.125, 0.250, or 0.500 of the inside diameter, whichever value applies. For example, the maximum wall thickness of a Grade X rolled tube with a 3.2 mm inside diameter is 0.8 mm, with a 6.4 mm inside diameter it is 1.6 mm, with a 25 mm inside diameter it is 6.4, mm and with a 76 mm inside diameter and above it is 19 mm.

4B.8 TOLERANCES IN LENGTH (ROUND TUBES)

The length of rolled or molded tubes shall be plus or minus 25 mm from the manufacturers' standard.*

NEMA Standard 11-16-1989.

*Manufacturers' standard lengths may vary from 457 to 1219 mm, depending on outside diameters. In a number of grades, longer lengths are available.

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4B.9 STEPS IN INSIDE AND OUTSIDE DIAMETERS (ROUND TUBES)

Except as limited by 4B.8, the steps in the inside and outside diameters of all grades of round tubes shall be:

Nominal Inside and Outside Diameter, mm*		
From	Up to and Including	By Steps of†
3	25	0.8
26	76	1.6
77	152	23
153	203	6
204	635	13

†Steps in outside diameter apply to molded tubes only. Rolled tubes are ground to the size ordered.

*No standards have been developed for tubes having diameters above 635 mm. No standards have been developed for Grade G-5 tubes (melamine glass rolled) having an inside diameter above 203 mm.

NEMA Standard 9-15-1982.

4B.10 TOLERANCES IN WALL THICKNESS (ROUND TUBES)

4B.10.1 Rolled Tubes—Inside Diameters Up to 102 mm

Wall Thickness, mm	Plus or Minus Tolerance* from Average Wall Thickness of Individual Tube, mm				
	Grades X, XX, XXX	Grade LE Inside Diameters		Grade C	Grades G-3, G-5, G-7, G-9, G-10, FR-4
		4.8–12.7 mm, incl.	Over 12.7 mm		
0.25–0.39	0.08	...	...	...	...
0.4–0.79	0.13	...	...	...	0.15
0.8–1.59	0.15	0.25	0.20	...	0.20
1.6–3.19	0.18	0.28	0.23	0.38	0.23
13.2–6.39	0.23	0.33	0.28	0.51	0.28
6.4–12.7	0.28	0.38	0.33	0.51	0.33

4B.10.2 Molded Tubes—Inside Diameters Up to 98 mm

Wall Thickness, mm	Plus or Minus Tolerance* from Average Wall Thickness of Individual Tube, mm				
	Grades XX, XXX, L, LE Inside Diameter, mm			Grades CE, AA Inside Diameter, mm	
	3.2–6.4, incl.	Over 6.4–12.7, incl.	Over 12.7	6.4–12.7, incl.	Over 12.7
0.8–1.59	0.20	0.20	0.20	0.38	0.38
1.6–3.19	0.28	0.28	0.28	0.38	0.38
3.2–6.39	...	0.38	0.28	0.51	0.51
6.4–12.7	...	...	0.33	...	0.51

*Wall thickness, measured at any point in the wall of any one tube of a given size, must fall within the tolerances given. This provides a means for measuring both the tolerance in the wall thickness and the deviation from concentricity.

NOTE—See 4B.7 for the maximum wall thickness for any given inside diameter.

NEMA Standard 9-15-1983.

4B.11 TOLERANCES FOR WARP (SQUARE AND RECTANGULAR MOLDED TUBES)

Outside Dimension, mm	Maximum Warp (Based on 914 mm Dimension), Percent*
3.2–6.4, incl.	2.0
Over 6.4–19.0, incl.	1.0†
Over 19.0	0.5

*This percentage is stated in terms of the tube length.

†The value for Grade G-7 is 1.5 percent.

NOTE—For method of measuring warp, see ASTM D 709.

NEMA Standard 9-15-1982.

4B.12 RANGE OF SIZES (SQUARE AND RECTANGULAR MOLDED TUBES)

Grade	Inside Dimension, mm		Outside Dimension, mm		Wall Thickness, mm	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum*
X, XX, XXX	4.8	99	7.1	102	1.2	12.7
CE	9.5	98	12.7	102	1.6	12.7
L	6.4	99	8.7	102	1.2	12.7
LE	6.4	76	8.7	102	1.2	12.7
AA	12.7	95	19.0	102	3.2	12.7

NEMA Standard 9-15-1982.

*Tubes having a wall thickness greater than one-half of the minimum inside dimension are not recommended for many applications.

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4B.13 TOLERANCES IN LENGTH (SQUARE AND RECTANGULAR MOLDED TUBES)

The length of molded tubes shall be plus or minus 25 mm from the manufacturers' standard.‡

4B.14 TOLERANCES IN INSIDE AND OUTSIDE DIMENSIONS* (SQUARE AND RECTANGULAR MOLDED TUBES)

Nominal Inside Dimension, mm	Plus or Minus Tolerance†, mm, Inside Dimension All Grades	Nominal Outside Dimension mm	Plus or Minus Tolerances† mm	
			Grades X, XX, XXX, L, LE	Grades CE, AA
4.5–11.9	0.13	7.1–11.9	0.25	0.43
24.7–49	0.15	12.0–24.6	0.30	0.51
12.0–24.6	0.18	24.7–49	0.36	0.56
49.1–102	0.25	49.1–127	0.43	0.64

*These tolerances apply to tubes having a uniform nominal 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.

†The tolerances shall correspond to the appropriate inside or outside dimension. For example, for a rectangular tube having a nominal inside dimension of 6.4×25 mm, the tolerance will be plus or minus 0.13 mm for the 6.4 mm dimension and plus or minus 0.18 mm for the 25 mm dimension.

NEMA Standard 9-15-1983.

‡Manufacturers' standard lengths vary from 457 to 1219 mm depending on outside dimension. In a number of grades, longer lengths are available.

4B.15 TOLERANCES IN WALL THICKNESSES* (SQUARE AND RECTANGULAR MOLDED TUBES)

Average Wall Thickness for a Single Tube, mm	Plus or Minus Tolerance* from Average Wall Thickness of Individual Tube, mm, Inside Dimensions†				
	Grade X, XX, XXX		Grade L, LE Over 12.7 mm	Grade CE Over 9.5 mm	Grade AA Over 12.7 mm
	4.8–6.39 mm	6.4–12.7 mm, incl.			
1.2–1.6	0.20	0.20	0.25	...	...
1.7–3.2	0.28	0.25	0.33	0.38	0.64
3.3–6.4	0.38	0.36	0.41	0.51	0.76
6.5–12.7	...	0.46	0.51	0.64	0.76

*Wall thickness, measured at any point in any wall one tube of a given size, must fall within the tolerances given. This provides a means for measuring both the tolerance in wall thickness and the deviation from parallelism.

†For rectangular tubes, the tolerances shall apply to the maximum inside dimension.

NEMA Standard 1-16-1989.

NOTE—Tubes having a wall thickness greater than one-half of the minimum inside dimension generally do not meet the above tolerance.

Authorized Engineering Information 9-15-1982.

4B.16 TOLERANCES FOR WARP (MOLDED RODS)

Outside Dimension, mm	Maximum Warp (Based on 914 mm Dimension), Percent*
3.2–6.4, incl.	2.0
Over 6.4–19.0, incl.	1.0†
Over 19.0	0.5

*This percentage is stated in terms of the rod length.

†The value for Grade G-7 is 1.5 percent.

NOTE—For method of measuring warp, see ASTM D 709.

NEMA Standard 9-15-1982.

4B.17 RANGE OF DIAMETERS (RODS)

Grade	Outside Diameter, mm	
	Minimum	Maximum
XX*	3.2	51
XXX*	3.2	51
C	6.4	102
CE	6.4	102
L	4.8	102
LE	4.8	102
G-3	6.4	51
G-5	6.4	51
G-9	6.4	51
G-10	6.4	51
FR-4	6.4	51

NEMA Standard 11-16-1989.

*Molded rods in these grades having a diameter greater than 25 mm can show checks and cracks between the laminations on machined or sawed edges.

Authorized Engineering Information 11-16-1989.

4B.18 TOLERANCES IN LENGTH (RODS)

The length of rolled or molded rods shall be plus or minus 25 mm from the manufacturers' standard.*

NEMA Standard 11-16-1989.

*Manufacturers' standard lengths vary from 457 mm to 1219 mm depending on outside dimensions. In a number of grades longer lengths are available.

4B.19 TOLERANCE IN OUTSIDE DIAMETERS (RODS)

Diameter, mm	Plus or Minus Tolerance, mm
3.2–49, incl.	0.13
51–102, incl.	0.20

NEMA Standard 11-16-1989.

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PART 5A
DIMENSIONS AND TOLERANCES OF FABRICATED PARTS (CUSTOMARY UNITS)

The tolerance that can be held by the usual procedures followed in fabricating laminates are different from those held in fabricating metals. Therefore, the following tolerances are included for the guidance of design engineers and apply to parts fabricated from laminated sheets, rods, and tubes. Experience has shown that these tolerances are as close as can be expected with ordinary care in machining operations.

Closer tolerances may be possible but require different methods or special attention to machining and gauging operations and, accordingly, the necessity for them should be carefully considered.

Authorized Engineering Information 11-16-1989.

5A.1 TOLERANCES IN LENGTH AND WIDTH OF PIECES CUT BY SAWING (SHEETS)

Nominal Thickness, Inches	Plus or Minus Tolerance in Length or Width, Inches		
	6.0	Over 6.0–24.0	24.0 and Over
0.010–0.250	0.010	0.015	0.031
0.251–0.500	0.012	0.017	0.031
0.501–1.000	0.015	0.020	0.031
1.001–1.500	0.018	0.030	0.062
1.501–2.000	0.022	0.040	0.062

5A.1.1 For Grade N-1, the tolerance shall be twice the values given in the above table for each length and thickness.

NEMA Standard 11-16-1989.

5A.2 TOLERANCES IN LENGTH AND WIDTH OF PIECES CUT BY SHEARING (SHEETS) IN LENGTHS NOT OVER 48 INCHES (Not Applicable To Copper-clad Laminates)

5A.2.1 Squaring Sheared

Nominal Thickness, Inches	Plus or Minus Tolerances in Length or Width, Inches			
	2.0 and Under	Over 2.0–6.0, Incl.	Over 6.0–24.0, Incl.	Over 24.0
0.010–0.015	0.015	...	...	...
Over 0.015–0.031 incl.	0.007	...	...	...
Over 0.032–0.062 incl.*	0.005	0.007	0.031	0.047
Over 0.062–0.094 incl.†	0.010	0.031	0.047	0.047
Over 0.094–0.125 incl.‡	0.015	0.031	0.047	0.062

*Except Grades X, XX, and XXX.

†Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, AA, FR-1, FR-2 and FR-3.

‡Except Grades, X, XX, XXX, XP, XXP, XXXP, XXXPC, XPC, AA, FR-1, FR-2, and FR-3.

NEMA Standard 11-16-1989.

NOTE—Sawing is the recommended cutting method for the above excepted grades.

Authorized Engineering Information 11-16-1989.

5A.2.2 Rotary Sheared

Nominal Thickness, Inches	Plus or Minus Tolerances in Length or Width, Inches		
	0.078–0.750, Incl.	0.751–3.000, Incl.	Over 3.0
0.010–0.047	0.005	0.005	0.010
0.048–0.094*	...	0.005	0.015
0.095–0.156†	...	0.020	...

*Except Grades X, XX, XXX, and AA.

†Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, AA, FR-1, FR-2, and FR-3.

NEMA Standard 11-16-1989.

NOTE—Sawing is the recommended cutting method for the above excepted grades.

Authorized Engineering Information 11-16-1989.

5A.3 TOLERANCES FOR DRILLED HOLES

The following tolerances are recommended for drilled holes.

5A.3.1 Paper-Base and Cotton-Fabric-Base Grades

Diameter of Hole, Inches	Tolerances, Inches, for Thickness of					
	MIN.–0.250		0.251–0.500		0.501–1.000	
	Plus	Minus	Plus	Minus	Plus	Minus
0.030–0.061	0.001	0.003	...	...	...	...
0.062–0.250	0.002	0.004	0.002	0.006	...	...
0.251–0.500	0.002	0.004	0.002	0.006	0.003	0.007
0.501–1.000	0.002	0.006	0.003	0.007	0.003	0.007

5A.3.2 Asbestos-Base, Glass-Base, and Composite-Base Grades

The tolerances recommended are double those given in 5A.3.1.

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5A.4 TOLERANCES IN LENGTH OF CIRCULAR SAWED PIECES (ROUND TUBES)

Length, Inches	Plus or Minus Tolerance, Inches Outside Diameter			
	MIN.–1.999	2.000–4.000	4.001–8.000	8.001–MAX.
MIN.–3.000	0.010	0.010	0.030	...
3.001–6.000	0.010	0.015	0.030	...
6.001–12.000	0.015	0.020	0.030	...
12.001–48.000	0.031	0.031	0.047	...
48.001–72.000	0.062	0.078	...	0.188
72.001–96.000	0.094	0.094	...	0.250

NEMA Standard 11-16-1989.

5A.5 TOLERANCES IN LENGTH OF CIRCULAR SAWED PIECES (SQUARE AND RECTANGULAR MOLDED TUBES)

Length, Inches	Plus or Minus Tolerances, Inches Outside Diameter		
	0.100–2.000	2.001–4.000	4.001–MAX.
MIN.–3.000	0.010	0.010	0.030
3.001–6.000	0.010	0.015	0.030
6.001–12.000	0.015	0.020	0.030
12.001–48.000	0.031	0.031	0.047

NEMA Standard 9-15-1982.

5A.6 TOLERANCE IN LENGTH OF CIRCULAR SAWED PIECES (RODS)

Length, Inches	Plus or Minus Tolerances, Inches Outside Diameter	
	0.125–1.999 Incl.	2.0–4.0 Incl.
MIN.–3.000	0.010	0.010
3.001–6.000	0.010	0.015
6.001–12.000	0.015	0.020
12.000–48.000	0.031	0.031

NEMA Standard 9-15-1982.

5A.7 PUNCHED HOLES AND CONTOURS

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.

	Paper-base Grades					
	Cold Punching Laminates		Hot Punching Laminates		Cotton-Fabric-base Grades	
	0.062 Inch	0.125 Inch	0.062 Inch	0.125 Inch	0.062 Inch	0.125 Inch
Diameter of Hole, Inches	Plus or Minus Variation in Punched Holes, Inches					
MIN.–0.250	0.0025	0.003	0.003	0.004	0.003	0.004
0.251–0.500	0.003	0.004	0.004	0.005	0.0035	0.004
0.501–1.000	0.003	0.004	0.005	0.006	0.0035	0.005
Outside Diameters, Inches	**Plus or Minus Variation in Punched Contours, Inches**					
MIN.–1.000	0.003	0.004	0.0035	0.005	0.0035	0.004
1.0001–2.0	0.004	0.005	0.0045	0.006	0.004	0.005
2.001–3.0	0.005	0.006	0.005	0.006	0.005	0.006

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 0.062 inch.

Pierced holes tend to be tapered, particularly in thicker stocks.

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5A.8 TOLERANCES FOR SCREW MACHINE PARTS – ALL GRADES EXCEPT N-1

As a guide for design purposes, the normal tolerances for screw machine parts made from laminated thermosetting material are:

	Diameters		Lengths	
When Specified	Diameter, Inches	Plus or Minus Tolerance, Inches	Diameter, Inches	Plus or Minus Tolerance, Inches
As a decimal	MIN.–0.500	0.003		
	0.501–1.000	0.004	MIN.–1.000	0.005
	1.001–2.000	0.005	1.001–3.000	0.007
In fractions	MIN.–0.500	0.005	MIN.–1.000	0.007
	0.501–1.000	0.006	1.001–3.000	0.010
	1.001–2.000	0.008		

The concentricity of holes relative to an outer diameter should be specified if important. In fully machined parts having a maximum diameter of 2 inches, a total indicator reading of 0.005 inch may be produced.

Threading and tapping with National Form Threads should not be closer than Class 2 fit. See Federal Standard H-28, *Screw Thread Standards for Federal Service.*

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Section 5B
DIMENSIONS AND TOLERANCES OF FABRICATED PARTS (METRIC UNITS)

The tolerances that can be held by the usual procedures followed in fabricating laminates are different from those held in fabricating metals. Therefore, the following tolerances are included for the guidance of design engineers and apply to parts fabrication from laminated sheets, rods, and tubes. Experience has shown that these tolerances are as close as can be expected with ordinary care in machining operations.

Closer tolerances may be possible but require different methods or special attention to machining and gauging operations and, accordingly, the necessity for them should be carefully considered.

Authorized Engineering Information 11-16-1989.

5B.1 TOLERANCES IN LENGTH AND WIDTH OF PIECES CUT BY SAWING (SHEETS)

Nominal Thickness, mm	Plus or Minus Tolerance in Length or Width, mm		
	152 and Under	153–610	611–MAX
0.25–6.40	0.25	0.38	0.8
6.41–12.70	0.30	0.43	0.8
12.71–25.40	0.38	0.51	0.8
25.41–38.10	0.46	0.76	1.6
38.11–51.00	0.56	1.02	1.6

For Grade N-1, the tolerances shall be twice the values given in the above table for each length and thickness.

NEMA Standard 9-15-1982.

5B.2 TOLERANCE IN LENGTH AND WIDTH OF PIECES CUT BY SHEARING (SHEETS) IN LENGTHS NOT OVER 1219 MM (Not Applicable To Copper-clad Laminates)

The tolerances in the length and width of fabricated panels cut from laminated sheets at temperatures of not more than 20°C (68°F) and not higher than 40°C (104°F) shall be as follows:

5B.2.1 Squaring Sheared

Nominal Thickness, mm	Plus or Minus Tolerance in Length or Width, mm			
	51 and Under	52–152	153–610	611–MAX.
0.25–0.38	0.38	—	—	—
0.39–0.79	0.18	—	—	—
0.80–1.60*	0.13	0.18	0.8	1.2
1.61–2.4†	0.25	0.80	1.2	1.2
2.41–3.2‡	0.38	0.80	1.2	1.6

*Except Grades X, XX, and XXX.

†Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, AA, FR-1, FR-2, and FR-3.

‡Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, XPC, AA, FR-1, FR-2, and FR-3.

NOTE—Sawing is the recommended cutting method for the above excepted grades. (This note approved as Authorized Engineering Information.)

5B.2.2 Rotary Sheared

Nominal Thickness, mm	Plus or Minus Tolerance in Length or Width, mm		
	2.0–19 mm	20–76 mm	77–152 mm
0.25–1.19	0.13	0.13	0.25
1.20–2.40**	—	0.13	0.38
2.41–3.96††	—	0.56	0.80

**Except Grades X, XX, XXX, and AA.

††Except Grades X, XX, XXX, XP, XXP, XXXP, XXXPC, AA, FR-1, FR-2, and FR-3.

NOTE—Sawing is the recommended cutting method for the above excepted grades. (This note approved as Authorized Engineering Information.)

NEMA Standard 9-15-1982.

5B.3 TOLERANCES FOR DRILLED HOLES

The following tolerances are recommended for drilled holes.

5B.3.1 Paper-Base and Fabric-Base Grades

Diameter of Hole, mm	Tolerances for Thickness of, mm					
	6.4 and Under		6.5–12.7		12.8–25	
	Plus	Minus	Plus	Minus	Plus	Minus
0.76–1.57	0.03	0.08	...	...	...	...
1.58–6.35	0.05	0.10	0.05	0.15	...	...
6.36–12.7	0.05	0.10	0.05	0.15	0.08	0.18
12.71–25.4	0.05	0.15	0.08	0.18	0.08	0.18

5B.3.2 Asbestos-Base, Glass-Base, and Composite-Base Grades

The tolerances recommended are double those given in 5B.3.1.

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5B.4 TOLERANCES IN LENGTH FOR CUT PIECES (ROUND TUBES)

Length, mm	Plus or Minus Tolerance, mm				
	4.8–51	52–102	103–Max	103–203	203–Max.
MIN.–76.2	0.25	0.25	0.76	...	...
76.2–152.4	0.25	0.38	0.76	...	...
152.5–304.8	0.38	0.51	0.76	...	...
304.9–1219.2	0.80	0.80	1.20	...	...
1219.3–1828.8	1.60	2.00	...	2.4	4.8
1828.9–2438.4	2.40	2.40	...	3.2	6.4

NEMA Standard 9-15-1982.

5B.5 TOLERANCES IN LENGTH FOR CUT PIECES (SQUARE AND RECTANGULAR MOLDED TUBES)

Length, mm	Plus or Minus Tolerance, mm		
	4.5–51	52–102	103–MAX.
MIN.–76.2	0.25	0.25	0.76
76.3–152.4	0.25	0.38	0.76
152.5–304.8	0.38	0.51	0.76
304.9–1219.2	0.80	0.80	1.20

5B.6 TOLERANCES IN LENGTH FOR CUT PIECES (RODS)

Length, mm	Plus or Minus Tolerance, mm	
	3.2–49	50–102
MIN.–76.2	0.25	0.25
76.3–152.4	0.25	0.25
152.5–304.8	0.38	0.51
304.9–1219.2	0.80	0.80

NEMA Standard 9-15-1982.

5B.7 PUNCHED HOLES AND CONTOURS

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.

	Paper-base Grades					
	Cold Punching Laminates		Hot Punch Laminates		Cotton-Fabric-base Grades	
	1.6 mm	3.2 mm	1.6 mm	3.2 mm	1.6 mm	3.2 mm
Diameter of Hole, mm	Plus or Minus Variation in Punched Holes, mm					
MIN–6.35	0.06	0.08	0.08	0.10	0.08	0.10
6.36–12.70	0.08	0.10	0.10	0.13	0.089	0.10
12.71–25.4	0.08	0.10	0.13	0.15	0.089	0.13
Outside Diameters, mm	Plus or Minus Variation in Punched Holes, mm					
MIN.–25.4	0.08	0.10	0.089	0.13	0.089	0.10
25.5–50.8	0.10	0.13	0.114	0.15	0.10	0.13
50.9–76.2	0.13	0.15	0.13	0.15	0.13	0.15

Holes should not be smaller than the thickness of the stock.

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 1.6 mm.

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

Authorized Engineering Information 9-15-1982.

5B.8 TOLERANCES FOR SCREW MACHINE PARTS – ALL GRADES EXCEPT N-1

As a guide for design purpose, the normal tolerances for screw machine parts made from laminated thermosetting material are:

When Specified	Diameter, mm		Length, mm	
	Diameter	Plus or Minus Tolerance	Diameter	Plus or Minus Tolerance
As a decimal:	MIN.–12.70	0.08	MIN.–25.4	0.13
	12.71–25.40	0.10	25.41–76.2	0.18
	25.41–50.80	0.13		
In fractions:	MIN.–12.70	0.13		
	12.71–25.40	0.15	MIN.–25.4	0.18
	25.41–50.80	0.20	25.41–76.2	0.25

The concentricity of holes relative to an outer diameter should be specified if important. In fully machined parts having a maximum diameter of 51 mm, a total indicator reading of 0.13 mm may be produced.

Threading and tapping with National Form threads should not be closer than a Class 6H Fit.

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Section 6
PHYSICAL AND ELECTRICAL PROPERTIES
GENERAL

6.1 VALUES

The values given in 6.5 to 6.22, inclusive, designate minimum or maximum standards except as noted in the tables of property values all values are for unclad sheets with surfaces as laminated. These values represent the average for the number of specimens specified for the particular test under the given conditions and serve as the basis for determining whether or not the requirements of these standards have been met.

For example, if the minimum flexural strength of a sheet having a certain thickness is specified as 15,000 psi in the lengthwise direction, then the average value for four specimens cut from a sheet in the stronger of the two directions should meet this limit if the sheet is to meet the requirements of these standards.

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6.2 VARIATION IN PROPERTIES WITH FORM

Because of differences in shape, structure, and method of manufacture, the physical tests, electrical tests, and properties will not be the same for sheets, tubes, and rods of the same grade.

Authorized Engineering Information 11-16-1989.

6.3 FACTOR OF SAFETY

As with other structural and insulating materials, good engineering practice demands an adequate factor of safety. Based on the standard properties of the various grades of sheets, tubes, and rods, a minimum factor of safety of 4 for mechanical strength and 6 for electric strength and dielectric strength is recommended.

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6.4 STANDARDS SET FOR CERTAIN PROPERTIES ONLY

In the interest of simplifying matters for both the consumer and the manufacturer, standards for any one grade are set only for those properties that have proven susceptible to manufacturing control and that are essential to the major applications of the grade. For example, both manufacturers and consumers of timing and rolling mill gears are interested in the mechanical and not in the electrical properties of such gears. In fact, good electrical properties often cannot be obtained without some sacrifice. Usually this means a considerable loss in mechanical properties, particularly in toughness or impact strength.

In addition to the properties contained in these standards, it is recognized that other properties may be of significance to certain grades, but these properties have not yet been incorporated into the standards for lack of a test method having the necessary degree of reproducibility or interlaboratory correlation. Specific examples are resistance to wet tracking under applied voltage and resistance to ignition under simulated insulation service conditions.

Authorized Engineering Information 11-16-1989.

6.4.1 Conditioning Procedures

The conditioning procedures are the same as those included in specifications of the military services for laminated thermosetting sheets and are described as follows:

6.4.1.1 Designating Type of Conditioning

The following letters shall be used to indicate the type of conditioning required:

Condition A – As received; not special conditioning.
Condition C – Humidity conditioning.
Condition D – Immersion conditioning in distilled water.
Condition D_1 – Immersions conditioning in distilled water following E-1/105.
Condition E – Temperature conditioning.
Condition T – Test condition.

NOTE – A conditioning letter that is followed by an inferior numeral 1 (for example, D) means that a prior temperature conditioning has been carried out. (This note is approved as Authorized Engineering Information.)

6.4.1.2 Designation

Conditioning procedures shall be designated in accordance with the following:

1. A capital letter indicating the general condition of the specimen to be tested, i.e., as received or conditioned to humidity, immersion, or temperature (see 6.4.1.1).
2. A number indicating the duration of the conditioning in hours.
3. A number indicating the conditioning temperature in degrees celsius.
4. A number indicating the relative humidity whenever the relative humidity is controlled.

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

EXAMPLES:

Condition C – 96/35/90 – Humidity conditioning – 96 hours at 35°C and 90 percent relative humidity.

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Condition D – 48/50 – Immersion conditioning – 48 hours in distilled water at 50°C.
Condition E – 48/50 – Temperature conditioning – 48 hours at 50°C.
Condition E – 24/150: T-150 – Temperature conditioning for 24 hours at 150°C: test at 150°C.
Condition D_1 – 24/23 – Means immersion conditioning for 24 hours in distilled water at 23°C following E-1/105, temperature conditioning for 1 hour at 105°C.

6.4.1.3 TIME TOLERANCES

After oven conditioning, the test specimen shall be cooled to room temperature (23°C) in a desiccator and, after immersion conditioning, the test specimen shall be cooled to room temperature in distilled water in accordance with the following:

Conditioning		Cooling		
Condition	Time Tolerance	Time	Time Tolerance	
E-48/50	–0 hours +2 hours	16 hours or more	–0 hours	Cool the specimen in a desiccator. Start the test within ½ hour after removing the specimen from the desiccator.
D-48/50 and D-24/23	–0 hours +½ hour	1 hour	–0 hours +2 hours	Cool the specimen by immersing it in a sufficient quantity of distilled water to reduce its temperature to 23°C within 1 hour. Remove the specimens individually as they are needed and wipe the surface water off with a cloth. Start the test within 1 minute after removing the specimen from the water.
E-24/125	–0 hours +1 hour	4 hours or more	–0 hours	See 7.12.
E-1/105	–0 minutes +6 minutes	2 hours or more	–0 hours	See water absorption test in 7.4.
E-1/150	–0 minutes +6 minutes	...	...	The test for flexural strength shall be made in the oven immediately after the conditioning period.
D-24/23	–0 hours +2 hours	...	...	See water absorption test in 7.4.
C-96/35/90	–0 hours +2 hours	...	...	Tests after humidity conditioning shall be made on specimens in the humidity chamber.

6.4.1.4 TEMPERATURE TOLERANCES

The tolerance in the nominal conditioning temperatures of 23°C (41.4°F), 35°C (63°F), 50°C (90°F), 105°C (189°F) and 150°(270°F) shall be ±2°C.

6.4.1.5 HUMIDITY TOLERANCES

The tolerance in the nominal relative humidity of 90 percent shall be plus or minus 2 percent.

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6.5 MINIMUM FLEXURAL STRENGTH (SHEETS)

	Minimum Flexural Strength Measured Flatwise Psi-Condition A (See 6.4.1) Thickness, Inches*																	
	0.031		0.062		0.094		0.125		0.188		0.250		0.500		0.750		1 and over	
Grade	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise
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
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	...	...	...	...	...	...
XPC	...	...	10,000	8,000	10,000	8,000	12,000	10,000	12,000	10,000	12,000	10,000	...	...	...	...	...	...
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
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	...	...	...	...	...	...
XXX	13,500	11,000	13,500	11,000	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
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	...	...	...	...	...	...
ES-1, ES-2, 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	16,500	14,000	16,500	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
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
AA	...	...	16,000	14,000	16,000	14,000	18,000	16,000	18,000	16,000	17,000	15,000	16,000	14,000	15,000	13,000	13,500	11,700
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†, FR-4, FR-5†	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
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
FR-1	12,000	10,000	13,000	11,000	13,000	11,000	14,000	12,000	12,000	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	...	...	...	...	...	...
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	...	...	...	...	...	...	...	...	...	...	...	...

*For intermediate thickness, the values given for the next smaller thickness shall apply.

†The flexural strength for a lengthwise specimen of Grades G-11 and FR-5, measured at 150°F Condition E-1/150, T-150 shall be no less than 30,000 psi for thickness 0.031–0.250 inch.

‡For intermediate thickness, the values given for the next higher thickness shall apply.

6.6 MAXIMUM WATER ABSORPTION (SHEETS)

6.6.1 Maximum Water Absorption, Percent—Condition D_1-24/23 (See 6.4.1)

	Thickness, Inches (mm)*													
	(0.25)	(0.38)	(0.64)	(0.80)	(1.2)	(1.6)	(2.1)	(2.4)	(3.2)	(4.8)	(6.4)	(12.7)	(19.1)	(25.4)
Grade	0.010	0.015	0.025	0.031	0.047	0.062	0.084	0.094	0.125	0.187	0.250	0.500	0.750	1.000–max
X	14.0	12.0	...	8.00	...	6.00	...	4.20	3.30	2.30	1.80	1.10	0.85	0.75
XP	9.60	8.40	...	5.60	...	3.60	...	2.80	2.20	1.70	1.30	...	...	...
XPC	...	...	...	8.00	...	5.50	...	4.00	3.00	2.00	1.60	...	...	...
XX	7.00	6.20	...	3.10	...	2.00	...	1.60	1.30	1.00	0.85	0.55	0.50	0.45
XXP	...	4.80	...	2.80	...	1.80	...	1.40	1.10	0.85	0.65	...	...	...
XXX	...	4.00	...	2.10	...	1.40	...	1.10	0.95	0.70	0.60	0.45	0.40	0.35
XXXP	...	2.50	...	1.30	...	1.00	...	0.85	0.75	0.65	0.60	...	...	...
XXXPC	...	...	...	1.30	...	0.75	...	0.65	0.55	0.50	0.40	...	...	...
ES-1	...	...	...	...	3.00	2.50	...	2.10	1.80	1.40	1.00	...	...	...
ES-2	...	...	...	...	...	...	...	2.10	1.80	1.40	1.00	...	...	...
ES-3	...	...	...	...	3.00	2.50	...	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
AA	...	...	...	...	...	3.00	...	2.80	2.50	1.80	1.50	1.25	1.10	1.00
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	1.5	1.0	0.9	0.50	0.40	0.25	...	0.20	0.15	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	...	...
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	...	...	...	0.50	0.40	0.25	...	0.20	0.15	0.15	0.13	0.10	0.10	0.10
CEM-1	...	...	...	0.50	...	0.25	...	0.20	...	...	...	...	...	...
CEM-3	...	...	...	0.50	...	0.25	...	0.20	...	...	...	...	...	...

*For intermediate thicknesses, the values given for the next smaller thickness shall apply.

†Condition D-24/23 following condition E-24/50 (See 6.4.1)

‡This value applies to Grade ES-2 sheets having a thickness of 0.084 inch.

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6.6.2 Maximum Water Absorption, mg – Condition, D_1-24/23 (See 6.4.1)

	Thickness, Inches (mm)*														
	(0.25)	(0.38)	(0.64)	(0.80)	(1.2)	(1.6)	(2.1)	(2.4)	(3.2)	(4.8)	(6.4)	(12.7)	(19.1)	(25.4)	(22.5)†
Grade	0.010	0.015	0.025	0.031	0.047	0.084	0.062	0.094	0.125	0.188	0.250	0.500	0.750	10.886†	0.005
X	...	410	423	437	460	480	...	519	560	640	722	1059	1393	1700	2040
XP	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XPC	...	410	423	437	460	480	...	519	560	640	722	...	...	...	...
XX	...	160	163	167	174	182	...	194	204	232	257	364	474	570	684
XXP	...	62	65	67	71	76	...	84	92	108	121	167	198	219	263
XXX	...	165	168	173	188	204	...	235	268	334	400	662	932	1150	1380
XXXP	...	44	45	47	50	53	...	58	64	76	87	133	179	222	266
XXXPC	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ES-1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ES-2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ES-3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
C	...	...	...	201	211	220	...	237	252	272	287	342	398	450	540
CE	...	...	...	133	139	145	...	156	163	174	185	228	271	311	373
L	...	186	194	201	211	220	...	237	252	272	287	342	398	450	540
LE	...	125	129	133	139	145	...	156	163	174	185	228	271	311	373
AA	...	...	...	...	305	318	...	343	370	422	474	678	884	1075	1290
G-3	...	80	89	95	105	116	...	137	157	197	234	359	452	525	630
G-5‡	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
G-7	...	28	29	31	33	35	...	38	41	49	57	89	121	150	180
G-9‡	...	103	110	116	129	142	...	168	194	246	298	502	709	900	1080
G-10, G-11	...	17	17	18	18	19	...	21	22	25	28	39	50	61	73
N-1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
FR-1	...	44	45	47	50	53	...	58	64	...	...	...	...	...	...
FR-2	...	30	31	33	37	41	...	49	56	66	79	...	...	...	...
FR-3	...	17	17	18	18	19	...	21	22	25	28	39	50	61	73
FR-4, FR-5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

*For intermediate thicknesses, the values given for the next smaller thickness shall apply.

†Sheets of nominal thicknesses greater than 1 inch shall be machined on one face to a thickness of 0.886 inch plus or minus 0.005 inch.

‡Condition D-24/23 following condition E-24/50 (See 6.4.1).

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6.7 MAXIMUM PERMITTIVITY AND DISSIPATION FACTOR

6.7.1 Maximum Permittivity (Sheets)

	Maximum Permittivity at 1MHz*									
	Condition A†	Condition D_1-24/23†								Condition D 48/50
	Thickness, Inches									
Grade	to Maximum	0.031	0.062	0.094	0.125	0.188	0.250	0.500	0.501–Max.	0.125 Only
XX	5.50	6.30	6.20	6.10	6.00	6.00	6.00	6.00	6.00	—
XXP	5.00	5.50	5.30	5.30	5.20	5.20	5.20	—	—	5.80
XXX	5.30	6.00	5.90	5.80	5.70	5.70	5.70	5.70	5.70	—
XXXP, XXXPC	4.60	4.80	4.80	4.80	4.80	4.80	4.80	—	—	5.30
LE	5.80	‡	‡	‡	6.00	6.00	6.00	6.00	6.00	—
G-5	**	‡	‡	‡	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	**	—	7.4	7.4	7.4	7.4	7.4	8.0	8.0	7.5
G-10, G-11	**	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.7	5.8
N-1	**	4.20	4.00	4.00	3.90	4.30	4.30	4.40	4.50	4.00
FR-1	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FR-2	4.60	4.80	4.80	4.80	4.80	4.80	4.80	—	—	5.30
FR-3	4.60	4.8	4.8	4.8	4.8	4.8	4.8	—	—	5.0
FR-4, FR-5	**	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.7	5.8
CEM-1	**	5.2	5.0	4.8	—	—	—	—	—	—
CEM-3	**	5.4	5.4	5.4	—	—	—	—	—	—

*Dielectric loss = dissipation factor × permittivity.

†See 6.4.1.

‡Dissipation factors and permittivity for Grades LE and G-5 sheets having thicknesses below 0.125 inch have a change from Condition A too great to be measured satisfactorily with the usual laboratory equipment.

**See 6.7.3.

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6.7.2 Maximum Dissipation Factor at 1 MHz (Sheets)

Grade	Maximum Dissipation Factor at 1 MHz*									
	Condition A‡	Condition D_1-24/23†								Condition D-48/50†
		Thickness, Inches								
	to Maximum	0.031	0.062	0.094	0.125	0.188	0.250	0.500	0.501–Max.	0.125 Only
XX	0.045	0.053	0.052	0.051	0.050	0.050	0.050	0.050	0.050	—
XXP	0.040	0.080	0.060	0.060	0.050	0.050	0.050	—	—	0.100
XXX	0.038	0.048	0.047	0.046	0.045	0.044	0.043	0.043	0.043	—
XXXP, XXXPC	0.038	0.040	0.040	0.040	0.040	0.040	0.040	—	—	0.050
LE	0.055	‡	‡	‡	0.070	0.070	0.070	0.070	0.070	—
G-5	0.020**	‡	‡	‡	0.080	0.080	0.080	0.080	0.080	—
G-7	0.003	0.070	0.050	0.035	0.022	0.022	0.022	0.022	0.022	—
G-9	0.017**	0.018	0.018	0.018	0.018	0.018	0.008	0.020	0.025	0.020
G-10, G-11	0.025	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.045
N-1	0.038	0.045	0.041	0.040	0.039	0.039	0.039	0.039	0.039	0.045
FR-1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
FR-2	0.038	0.040	0.040	0.040	0.040	0.040	0.040	—	—	0.050
FR-3	0.035	0.040	0.040	0.040	0.040	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	—	—	—	—	—	—
CEM-3	0.025	0.035	0.035	0.035	—	—	—	—	—	—

*Dielectric loss = dissipation factor × permittivity.

**For Grade G-5 sheets over 1 inch thick, the maximum dissipation factor is 0.025. For Grade G-9 sheets over 0.500 inch thick, the maximum dissipation factor is 0.020.

†See 6.4.1.

‡Dissipation factors and permittivity for Grades LE and G-5 sheets having thicknesses below 0.125 inch have a change from Condition A too great to be measured satisfactorily with the usual laboratory equipment.

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6.7.3 Maximum Permittivity at 1 MHz (Sheets)

Grade	Maximum Permittivity at 1 MHz—Condition A Thickness, Inches					
	0.031–0.062	0.063–0.125	0.126–0.250	0.251–0.500	0.500–1.000	1.001–Max.
G-5*	7.80	7.80	8.00	8.50	8.70	9.00
G-9*	7.2	7.2	7.2	7.5	7.5	—
G-10, G-11, FR-4, FR-5	5.2	5.2	5.2	5.2	5.5	—
CEM-1	5.0	4.6	—	—	—	—
CEM-3	5.2	5.2	—	—	—	—

*For Grade G-5 sheets over 1 inch thick, the maximum dissipation factor is 0.025. For Grade G-9 sheets over 0.500 inch thick, the dissipation maximum factor is 0.020.

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NOTE—No dielectric loss properties for Grades X, XP, XPC, C, CE, L, AA, and G-3 are included because these grades are not suitable for applications where low dielectric loss at radio frequencies is required. (This note is approved as Authorized Engineering Information).

6.8 MINIMUM IMPACT AND BONDING STRENGTH (SHEETS)

Minimum izod impact strength in the edgewise direction, ft-lb/1-inch notch. condition E-48/50, for sheets having a thickness from 0.125 inch up to the maximum thickness for the grade but not exceeding 2 inches.‡

Following are minimum bonding strength, pounds for sheets having a thickness from 0.500 inch up to the maximum thickness for the grade but not exceeding 2 inches†.

Grade	Lengthwise	Crosswise	Condition A†	Condition D-48/50†
X†	0.55	0.50	700	400
XX††	0.40	0.35	800	600
XXX††	0.40	0.35	950	700
C	1.90	1.70	1800	1600
CE	1.60	1.40	1800	1600
L	1.35	1.10	1600	1500
LE	1.25	1.00	1600	1500
AA	3.60	3.00	1800	1600
G-3	6.5	5.5	850	700
G-5	*	*	1570	1400
G-7	6.5	5.5	650	550
G-9	*	*	1700	1500
G-10, FR-4	7.0	5.5	2000	1600
G-11, FR-5	7.0	5.5	1600	1500
N-1	3.0	2.0	1000	1000

*The minimum impact strength of Grades G-5 and G-9 sheets shall be:

Thickness, Inches	Minimum Impact Strength, Ft-lb/1-inch Notch	
	Lengthwise	Crosswise
0.125–0.499	7.0	5.5
0.500–2.000	9.0	6.0

†See 6.4.1.

††Impact values are not applicable to thicknesses under 0.251 inch for Grades X, XX, and XXX.

‡Specimens shall have a nominal thickness of 0.500 inch or shall be machined to 0.500 inch, plus or minus 0.005 inch, from thicker sheets. Unmachined specimens shall meet the tolerances given for the 0.500-inch thickness of the grade being tested. For thicker sheets, the specimens shall be cut from the center of the cross-section, and approximately equal amounts shall be machined from each surface.

NEMA Standard 11-16-1989.

Bonding strength is an empirical quantity useful for comparing materials under the same standard conditions. It is not necessarily proportional to specimen thickness for significant departures from the standard 0.500±0.005 inch.

Authorized Engineering Information 11-16-1989.

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6.9 MINIMUM DIELECTRIC BREAKDOWN PARALLEL TO LAMINATIONS (SHEETS)

Grade	Minimum Dielectric Breakdown Parallel to the Laminations, kV, Using the Step-by-Step Test*			
	Condition A†		Condition D-48/50†	
	Thickness, Inches**			
	0.031–1.000	1.001–2.000	0.031–1.000	1.001–2.000
X	—	—	—	—
XP	40.0	—	—	—
XPC	—	—	—	—
XX	40.0	25.0	5.0	3.0
XXP	60.0	—	5.0	3.0
XXX	50.0	40.0	6.0	4.0
XXXP, XXXPC	60.0	—	15.0	—
C	15.0	10.0	—	—
CE	35.0	25.0	2.5	2.5
L	15.0	10.0	—	—
LE	40.0	30.0	3.0	3.0
G-5	23.0	15.0	5.0	3.0
G-7	32.0	25.0	15.0	—
G-9	60.0‡	—	#	#
G-10, G-11	45.0	—	40.0	—
N-1	60.0	50.0	40.0	30.0
FR-1	40.0	—	5.0	—
FR-2	60.0	—	15.0	—
FR-3	60.0	—	30.0	—
FR-4, FR-5, CEM-1, CEM-3	45.0	—	40.0	—

*See 7.6.1.

†See 6.4.1.

**This value applies only to the range of thickness for the particular grade shown in LI 1-4.4.

‡This value applies to sheets having a maximum thickness of 0.500 inch.

#See table below:

0.031–0.250 inch	55 kV
0.251–0.500 inch	50 kV
0.501–1.000 inch	45 kV
1.001–2.000 inch	40 kV

NEMA Standard 11-16-1989.

6.10 MINIMUM ARC RESISTANCE (SHEETS)

Grade	Minimum Arc Resistance, Seconds, Condition A or Condition D-48/50*, Thickness of 0.125–2.0 Inches, Incl. (Tungsten Electrodes)
G-5	180
G-7	180
G-9	180

*See 6.4.1.

NEMA Standard 11-16-1989.

6.11 FLAME RESISTANCE (THIN SHEETS —0.031–0.500 INCH MINIMUM)

Grades FR-1, FR-2, FR-3, FR-4, and FR-5 shall have a minimum flame resistance of UL 94 V1 and Grades G-5, G-7, G-9, CEM-1, and CEM-3 shall have a flame resistance of UL 94 V-O when tested in accordance with UL 94.

NEMA Standard 11-16-1989.

6.12 FLAME RESISTANCE (THICK SHEETS)

The average ignition time shall be at least the value given and the average burning time shall not exceed the value given in the following when tested in accordance with 7.7.

Grade	Thickness, Inches	Average Time, Seconds	
		Ignition	Burning
G-9	0.125	70	50
G-9	0.250	140	100
FR-4	0.500	50	100
FR-5	0.500	50	100

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6.13 MAXIMUM WATER ABSORPTION (ROLLED TUBES)

Inside Diameters, Inches	Maximum Water Absorption, Percent, Condition D_1-24/23 following E-1/105*										
	Grade										
	X		XX		XXX	C	LE	G-5‡	G-7	G-9‡	G-10
Wall Thickness, Inches†	0.125–0.499	0.500–8.000	0.125–0.499	0.500–8.000	0.250–8.000	0.375–8.000	0.188–8.000	0.125–8.000	0.375–8.000	0.125–8.000	0.125–8.000
0.031–0.061	8.0	8.0	6.0	6.0	3.5	–	7.5	5.0	1.0	4.2	1.0
0.062–0.093	7.0	5.0	3.6	3.0	1.5	5.0	5.0	3.9	1.0	3.0	0.8
0.094–0.124	6.0	4.3	2.5	2.5	1.3	3.6	3.0	3.7	0.8	2.5	0.7
0.125–0.187	5.2	4.0	2.0	2.0	1.0	3.0	2.5	3.5	0.8	2.0	0.6
0.188–0.249	–	3.5	1.4	1.4	0.8	2.3	1.9	3.0	0.8	1.8	0.5
0.250–0.374	–	3.0	1.2	1.2	0.6	1.8	1.5	2.5	0.8	1.5	0.4
0.375–0.499	–	2.4	–	1.0	–	1.3	1.2	2.2	–	1.2	0.4
0.500–0.999	–	2.0	–	0.9	–	1.2	0.9	2.0	–	1.0	0.4
1.000–MAX.	–	–	–	0.8	–	0.9	0.8	1.8	–	1.0	0.4

*See 6.4.1.
†Applies to inside diameters of 0.250 to 2.000 inches, inclusive.
‡Condition D-24/23 following Condition E-24/50.

NEMA Standard 11-16-1989.

6.14 MINIMUM DENSITY AND COMPRESSIVE STRENGTH (ROLLED TUBES)

Grade	Inside Diameter, Inches	Minimum Density, Grams per Cubic Centimeter	Minimum Compressive Strength in the Axial Direction, psi*	
			0.031 Inch Wall	0.062–MAX. Inch Wall
X	0.125–0.499	1.10	10,000	10,000
	0.500–8.000	1.12	10,000	12,000
XX	0.125–0.499	1.10	10,000	10,000
	0.500–8.000	1.12	–	13,000
XXX	0.250–0.499	1.12	–	10,000
	0.500–8.000	1.12	–	13,000
C	0.375–8.000	1.12	–	12,000
LE	0.188–0.499	1.12	–	13,000
	0.500–8.000	1.14	–	13,000
G-5	0.125–8.000	1.70	–	13,000
G-7	0.375–0.999	1.55	–	6,000
	1.000–6.000	1.58	–	6,000
G-9	0.125–8.000	1.70	–	18,000
G-10	0.125–0.499	1.65	–	20,000
	0.500–8.000	1.70	–	20,000

*The values given for compressive strength apply to wall thicknesses of 0.032 inch and over, inside diameters of 0.250 inch and over, and outside diameters of 2.000 inches and less.

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6.15 MINIMUM ELECTRIC STRENGTH PERPENDICULAR TO LAMINATIONS (ROLLED TUBES)

	Maximum Electric Strength Perpendicular to Laminations, Volts per Mil, Using the Short-time Test* (Condition A†)									
Grade	X‡	XX		LE		G-5	G-7	G-9		G-10
Inside Diameters, Inches	0.125–8.000	0.125–0.499	0.500–0.800	0.188–0.499	0.500–8.000	0.125–8.000	0.375–8.000	0.125–8.000		0.125–8.000
Wall Thickness, Range, Inches								Condition		
								A	D-48/50	
0.031–0.047	400	310	400	**	70	200	100	250	150	350
0.048–0.062	400	310	400	120	120	200	100	250	150	350
0.063–0.125	325	290	290	140	140	160	125	200	100	250
0.126–0.250	200	200	200	120	120	110	115	160	80	200
0.251–0.500††	145	—	145	85	85	80	100	120	60	150
0.501–0.750	120	—	120	70	70	65	—	80	40	—
0.751–1.000	—	—	105	60	60	55	—	80	40	—

*See 7.3.
†See 6.4.1.
‡The electric strength of Grade X tubes decreases markedly under humid conditions.
**No electric strength is given due to the small number of laminations and the possibility of overlapping of resin filled interstices.
††The maximum wall thickness for Grade G-7 is 0.375 inch.

NEMA Standard 11-16-1989.

6.16 MINIMUM DIELECTRIC BREAKDOWN FOR GRADE XXX (ROUND ROLLED TUBES)

6.16.1 Parallel to Laminations†

The minimum dielectric breakdown parallel to laminations, using the short-time test (D-48/50)‡, shall be 18 kV for wall thicknesses of 0.031–0.500 inch, inclusive and inside diameters of 0.500–8.000 inches, inclusive.

6.16.2 Perpendicular to Laminations

The minimum electric strength perpendicular to laminations using the short-time test (D-48/50)‡, shall be:

Wall Thickness, Inches	Volts per Mil
0.062	225
0.125	250
0.250	250

NEMA Standard 11-16-1989.

†See 7.7.2.
‡See 6.4.1.

6.17 MINIMUM DIELECTRIC BREAKDOWN FOR GRADE G-9 (ROUND ROLLED TUBES)

	Minimum Dielectric Breakdown, kV, For Wall Thickness of	
Condition	0.031–0.125 Inch	0.126–1.000 Inch
A	50	45
D-48/50	30	20
D-336/50	15	10

NEMA Standard 11-16-1989.

6.18 MAXIMUM WATER ABSORPTION (ROUND MOLDED TUBES)

	Following Condition E-1/105* Wall Thickness, Inches†							
Grade	0.031	0.062	0.094	0.125	0.188	0.250	0.500	1.000
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	1.2	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

*See 7.3.
†For intermediate wall thicknesses, the values given for the next smaller thickness shall apply.

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6.19 MINIMUM DENSITY AND COMPRESSIVE STRENGTH (ROUND MOLDED TUBES)

Grade	Minimum Density*, Grams per Cubic Centimeter	Minimum Compressive Strength in Axial Directions, psi†
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

*The densities given apply to all tube sizes.
†The values given for compressive strength apply to wall thicknesses of 0.062 inch and over and to inside diameters of 0.250 inch and over.

NEMA Standard 11-16-1989.

6.20 MINIMUM ELECTRIC STRENGTH PERPENDICULAR TO LAMINATIONS (ROUND MOLDED TUBES)

	Minimum Electric Strength Perpendicular to Laminations, Volts per Mil, Using the Short-Time Test* (Condition A)† Wall Thickness, Inches			
Grade	0.062	0.063–0.125	0.126–0.250	0.251–0.500
XX	300	220	150	110
XXX	300	220	150	110
CE	**	175	125	90
LE	150‡	175	125	90

*See 7.3.
†See 6.4.1.
**No value is contemplated because of the weakness of the tube at the molded seams.
††The molded seam has a more pronounced effect on the electric strength of tubes having a wall thickness of 0.062 inch than on the electric strength of tubes having a wall thickness over 0.062 inch.

NEMA Standard 11-16-1989.

6.21 MINIMUM DENSITY, FLEXURAL STRENGTH, AND COMPRESSIVE STRENGTH (ROUND MOLDED RODS)

	Condition A*			
Grade	Diameter, Inches	Minimum Density, Grams per Cubic Centimeter	Minimum Flexural Strength†, psi	Minimum Compressive Strength in the Axial Direction, psi
XX	0.125–2.000	1.30	15,000	20,000
XXX	0.125–2.000	1.25	13,000	20,000
C	0.250–2.000	1.28	16,000	19,000
CE	0.250–2.000	1.26	13,000	20,000
L	0.188–2.000	1.28	16,000	19,000
LE	0.188–2.000	1.26	12,000	20,000
G-5	0.250–2.000	1.80	30,000	22,000
G-10	0.250–2.000	1.70	35,000	35,000

*See 6.4.1.
†These values apply to rods having a diameter of 1.0 inch and less.

NEMA Standard 11-16-1989.

6.22 MAXIMUM WATER ABSORPTION (RODS)

Diameter, Inches†	Maximum Water Absorption, Percent, Condition D_1-24/23* Grades							
	XX	XXX	C	CE	L	LE	G-5	G-10
0.125	2.5	1.5	—	—	2.5‡	2.2‡	—	—
0.250	1.5	1.0	2.5	1.7	2.0	1.4	4.5	0.75
0.500	1.0	0.75	2.0	1.3	1.5	1.1	3.0	0.50
1.000	1.0	0.75	2.0	1.0	1.2	1.0	3.0	0.50
1.001–2.000	1.3	0.75	1.5	1.2	1.2	1.0	3.5	0.50

*See 6.4.1.
†For intermediate diameters under 1.0 inch, the values given for the next smaller diameter shall apply.
‡These values apply to rods having a diameter of 0.188 inch.
Condition D-24/23 following Condition E-24/50.

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Section 7
TESTING

7.1 TEST METHODS FOR SHEETS, TUBES, AND RODS

All test values given in these standards are based on the test methods of the American Society for Testing and Materials, unless otherwise specified. Unless otherwise specified, the value reported shall be the average of the values determined for the number of specimens required by the specific test method.

The test values given in these standards are based upon specimens that have been conditioned as specified in 6.5 to 6.22 which cover the properties of sheets, tubes, and rods. The conditioning procedures are described in 6.4.1. Unless otherwise specified, tests on the conditioned samples shall be made at a room temperature of 23°F±8°F, and under the prevailing laboratory humidities. When required, tests shall be made under the standard laboratory atmosphere of 23°F±1.1°F, and 50 percent ±2 percent, relative humidity.

NEMA Standard 9-15-1982.

7.2 DIRECTION OF MATERIAL UNDER TEST

In conducting test, "lengthwise" shall be interpreted to mean that the direction of the sheet known to be stronger in flexure. "Crosswise" shall then be that direction of the sheet known to be weaker in flexure and shall be at 90 degrees to the lengthwise direction.

NEMA Standard 11-16-1989.

7.3 TEST METHOD AND NUMBER, SIZE, AND CONDITIONING OF TEST SPECIMENS (SHEET)

Property Being Tested	Test Method*	Number of Specimens	Condition (See 6.4.1)	Specimen Size
Flexural strength (tested flatwise)	D790			
Cut lengthwise		4	A	See 7.6.4
Cut crosswise		4	A	See 7.6.4
Grade G-11 and FR-5 cut lengthwise		4	E-1/150: T-150	4 inches×1 inch×0.125 inch thick.
Impact strength (tested edgewise)	D 256			2.5 inch×0.5 inch× the thickness of the sheet, notched, without build up. Specimens over 0.5 inch shall be machined down to 0.500 inch thickness, ±0.005 inch. See 6.8.
Cut lengthwise	Method A	4	E-48/50	
Cut crosswise		4	E-48/50	
Bonding strength	D 229	4	A	1 inch×1 inch×0.5 inch thick (± the standard tolerance for the grade) or machined down to 0.500 inch thick, ±0.005 inch, from thicker sheets. See 6.8.
		4	D-48/50	
Water absorption	D 229	3	D_1-24/23	3 inches×1 inch× the thickness of the sheet.
Water absorption (alternate)	D 229	3	D_1-24/23	2 inches×2 inches× the thickness of the sheet.
Dielectric breakdown parallel to lamination—step-by-step test	D 229†	5‡	A	3 inches×2 inches× the thickness of the sheet.
	D 229†	5‡	5 D-48/50	
Dissipation factor and Permittivity at 1 MHz	D 1502	2	A	See 7.6.3
	D 1502	2	D-24/23 or D-48/50	
Arc resistance**	D 495, par.4(i)(1) (tungsten electrodes)	3	A	2 inches×3 inches× the thickness of the sheet.
Flame resistance	UL 94	5	A	5 inches×0.500 inch×thickness of the sheet.
		5	E-24/125	
Flame resistance	LI 1-7.7	5	A	10 inches×0.500 inch×0.062, 0.125, 0.250, 0.500 inch.

*The numbers given in this column refer to publications of the American Society for Testing and Materials (see Appendix).
†See 7.6.2.
‡The average short-time breakdown voltage of five specimens shall be used to establish the starting voltage for the step-by-step test.
**This property refers to Grade G-5, G-7, and G-9 sheets only.

NEMA Standard 9-15-1982.

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7.4 TEST METHOD AND NUMBER, SIZE AND CONDITIONING OF TEST SPECIMENS (TUBES)

Property Being Tested	Test Method*	Number of Specimens	Condition (See 6.4.1)	Specimen Size
Density	D 348	2†	A	1 inch long for inside diameters up to 3 inches. 0.500 inch and 2 inches cut from wall for inside diameters over 3 inches.
Water absorption	D 348	3	D_1-24/23	1 inch long for inside diameters up to 3 inches, 1 inch×3 inches cut from wall for inside diameters over 3 inches.
Compressive strength in the axial direction	D 348	4	A	1 inch long.
Electric strength perpendicular to laminations	D 348	3	A	12 inches long D-48/50‡.
Dielectric breakdown parallel to laminations	LI 1-7.6.2	4	D-48/50	3 inches long.
Dissipation factor and permittivity	D 348	2	A	4 inches long.
Bursting strength	D 1180**	5	A	See table in ASTM D 1180.

*The numbers given in this column refer to ASTM and NEMA publications (see Appendix).

†One from each end.

‡This condition applies to Grade XXX rolled tubes only.

**The speed of the crosshead, when testing shall be (a) 0.1 inch per minute when using snug-fitting steel plugs with Buna N rubber having a durometer reading of 65 plus or minus 5, or the equivalent, between the metal plugs or (b) 0.2 inch per minute if silicone rubber (bouncing putty) is used between metal plugs.

NEMA Standard 9-15-1982.

7.5 TEST METHOD AND NUMBER, SIZE, AND CONDITIONING OF TEST SPECIMENS (RODS)

Property Being Tested	Test Method*	Number of Specimens	Condition (See 6.4.1)	Specimen Size
Flexural strength	D 349	4	A	5 inches long.
Compressive strength in the axial direction	D 349	4	A	See ASTM D 349.
Density	D 349	2†	A	1 inch long for diameters up to 1 inch, inclusive. 0.500 inch long for diameters over 1 inch.
Water absorption	D 570	3	D 24/23	1 inch long for diameters up to 1 inch, inclusive. 0.500 inch long for diameters over 1 inch.

*The numbers given in this column refer to ASTM publications (see Appendix).

†One from each end.

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7.6 SPECIAL TEST METHODS OR MODIFICATIONS OF STANDARD TEST METHODS

7.6.1 Dielectric Breakdown Parallel to Laminations (Sheets)

Specimens—The test specimens shall be 2 inches×3 inches×the thickness of the sheet. American National Standard tapered pins, having a taper of 0.250 inch per foot, shall be used. Drill two 0.188 inch-diameter holes, centrally located, 1 inch apart, center to center, and perpendicular to the faces of the specimen. Ream holes to a sufficient depth to allow the pins to extend approximately 1.500 inches from the small end of the hole, reaming the holes with the taper preferably in opposite directions for the two holes.

For test specimens having a thickness over 0.500 inch to 2.0 inches, inclusive, No. 4 American National Standard tapered pins* 4 inches long and having a diameter at the large end of 0.250 inch shall be used. Drill two 0.188 inch-diameter holes, centrally located, 1 inch apart, center to center, and perpendicular to the faces of the specimen. Ream holes to a sufficient depth to allow the pins to extend approximately 1 inch from the small end of the hole, reaming the holes with the taper preferably in opposite directions for the two holes.

The electrode pins shall be inserted after conditioning of the test specimens. They must fit their tapered holes closely throughout the entire thickness of the specimen. Brass balls 0.500 inch in diameter shall be fitted to the ends of the tapered pins to reduce the tendency to flashover.

Procedure—The container for the test medium (transformer oil or dibutyl phthalate) shall have a minimum volume of 10 gallons. The medium shall be filtered, as needed, to remove carbon, oil, or other impurities and to maintain the required minimum breakdown voltage of 26 kV in accordance with ASTM D 877.

Tests shall be made in accordance with the short-time and step-by-step methods given in ASTM D 229, only one specimen being tested by the short-time method in order to establish a basis for the initial voltage of the step-by-step test.

*For information on tapered pins, see Kent's **Mechanical Engineers Handbook**, 12th Edition, "Design and Production," pages 15-14.

7.6.2 Dielectric Breakdown (Tubes)

The dielectric breakdown parallel to laminations shall be tested in accordance with ASTM D 229, par. 24(c)(3), adapted for testing tubes, by locating the tapered pins in a plane containing the longitudinal axis of the tube along one of the lines of intersection of this plane with the tube wall. In small diameter tubes, it may be necessary to drill a clearance hole opposite the reamed hole.

7.6.3 Permittivity and Dissipation Factor (Sheets)

Specimens—The specimen shall be rectangular samples cut from sheets. The size of the test specimens shall be in accordance with the following table. The electrodes shall cover both sides of the sheet and shall consist of silver paint sprayed or painted on or of metal foil held in place by a thin layer of petrolatum. When the same specimen is used for Condition A and after immersion in water and when metal foil electrodes are used, the metal foil electrodes shall be removed and the petrolatum cleaned off with a suitable solvent before immersion.

Thickness of Sheet, Inches	Size of Test Specimen, Inches
Up to 0.047	2×2
0.048–0.094	3×3
0.095–0.250	4×4
0.251–2.000	4×8

Procedure—The test method described in ASTM D 150 shall be followed using a suitable bridge method, namely, impedance-bridge-circuit, resonant-circuit-resistance-variation, or resonant-circuit resonant-rise method. Measurements shall be made at a frequency of 1 MHz.

7.6.4 Flexural Strength in the Flatwise Direction (Sheets)

The size of the specimens shall be in accordance with the following table. For paper and cotton fabric base grades having a nominal thickness over 1 inch and glass and nylon fabric base grades having a nominal thickness over 0.500 inches, the specimens shall be machined on one surface only to a thickness of 1 inch and 0.500 inch respectively. The original surface shall be placed in the tension position.

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Nominal Thickness of Specimen, Inches	Width of Specimen, Inches	Length of Specimen, Inches	Span Inches	Speed of Test, Inches per Minute
0.031	1.000	2.500	0.625*	0.025
0.062	1.000	3.000	1.000	0.026
0.094	1.000	3.500	1.500	0.040
0.125	1.000	4.000	2.000	0.053
0.188	0.500	5.000	3.000	0.080
0.250	0.500	6.000	4.000	0.106
0.375	0.500	8.000	6.000	0.160
0.500	0.500	10.000	8.000	0.213
0.750	0.750	12.000	12.000	0.320
1.000	1.000	18.000	16.000	0.426

*This span-depth ratio is greater than 16 to 1 in order to give clearance between the moving head and the specimen supports.

NEMA Standard 9-15-1982.

7.6.5 Water Absorption (Alternate) (Sheets)

The water absorption shall be tested in accordance with ASTM D 229 except the specimen size shall be 2 inches ×2 inches×the thickness of the sheet. Sheets of nominal thickness over 1 inch shall be machined on one face to a thickness of 0.886 inch plus or minus 0.005 inch. The absolute weight gain shall be reported in milligrams for comparison with Table 6.6.2.

NEMA Standard 11-16-1989.

7.7 METHOD OF TEST FOR FLAME RESISTANCE OF THICK SHEETS

(For GPO grades, see 11.14.)

7.7.1 Flame Test Apparatus and Accessories

The flame test apparatus and accessories shall consist of:

1. Flame test apparatus. (See Drawings 546D115, 546D116, 546D117, and 546D118 (available from NEMA).
2. Stop watch. (A watch with a 100-second full scale is recommended.) (This sentence approved as Authorized Engineering Information.)
3. Balance, sensitive to 0.1 gram.
4. Optical pyrometer, direct reading for emissivity of oxidized Nichrome V, or else a correction factor of 0.9 shall be applied if the pyrometer is calibrated for true blackbody temperature.

7.7.2 Specimens

Test specimen shall be 0.5 inch plus or minus 0.010 inch wide×10 inches ±0.062 inch long and of one of the following nominal thicknesses: 0.062, 0.125, 0.250, or 0.500 inch. For any of these thicknesses, the specimen preferably shall be cut from a laminate of that nominal thickness, with the tolerance given in 4.5. Specimens shall have a nominal thickness of 0.500 inch or shall be machined to 0.500 inch, plus or minus 0.005, from thicker sheets. Unmachined specimens shall meet the tolerances given for the 0.500 inch thickness of the grade being tested. For thicker sheets, the specimens shall be cut from the center of the cross-section, and approximately equal amounts shall be machined from each surface. The specimens shall be machined or lightly sanded to leave the cut surfaces smooth and free from projecting fibers or ridges.

7.7.3 Conditioning Procedure

All specimens shall be tested in the as-received condition.

For referee tests, or where it is known that the material to be tested is subject to moisture pickup from the atmosphere, specimens should be preconditioned for 168 hours under the standard laboratory atmosphere specified in 7.1. (This sentence approved as Authorized Engineering Information.)

7.7.4 Adjustments of Test Apparatus

Test specimens that are 0.500 inch thick shall be inserted in the specimen holder and secured only at their lower end by tightening the locking screw. For specimens 0.062, 0.125, or 0.250 inch thick, an alignment guide of the corresponding size (Drawing 546D118) shall be inserted with the lower end of the specimen in the specimen holder to insure that the vertical axis of the heating coil is coincident with the vertical axis of the heating coil (Drawing 546D115); in addition, the top end of these specimens shall be located positively by means of a finger of the appropriate size (Drawing 546D118).

Using a dummy test specimen in the specimen holder, adjust the heating coil so that the lower end of the coil is 9.500 inches above the top of specimen holder and so that the total height of the coil is 1.500 inches, with 0.250 inch spacing of the free turns of the coil. Position the coil so that it surrounds the specimen symmetrically.

Adjust the tungsten wires of the spark gap so that the gaps are 0.188 inch, plus or minus 0.062 inch, and the arc is in a horizontal plane. The line connecting the two electrodes of a pair is to be at a horizontal distance of 0.125 inch from the adjacent side of the specimen and at a vertical distance of 0.500 inch from the top of the heating coil.

With no specimen in the apparatus, close the door and energize the blower. Energize the coil at about 55 amperes for specimens 0.125, 0.250, or 0.500 inch thick or at about 51 amperes for 0.062 inch thick specimens,

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and allow the coil to come to equilibrium temperature (about 60 seconds). A new coil must be maintained at the test temperature for 24 hours to develop a stable oxide coating before it can be used in a test.

Measure the temperature of the coil with the optical pyrometer. The temperature of the outside of the middle turn of the coil, nearest the front of the apparatus, shall be measured through the peephole in the door. Adjust the current to give an equilibrium temperature of 860°C±5°C for specimens 0.125, 0.250, or 0.500 inch thick or 770°C±5°C for 0.062 inch-thick specimens. Note the current setting at equilibrium and make a fiducial mark on the dial of the variable ratio autotransformer to aide in repeating the temperature setting in subsequent tests.

7.7.5 Procedure

With the coil and all adjacent parts of the test apparatus at room temperature, insert into the specimen holder a specimen with a weight that has been determined to the nearest 0.1 gram†. Orient the specimen with the plane of the laminations parallel to the front of the apparatus.

Bring the spark gap to its proper position near the specimen. Energize the blower, which can be run continuously while the test apparatus is attended.

Simultaneously close the arc switch and the heating coil switch and start the stop watch.

The current through the coil shall be set at the value which was found to give coil temperature of 860°C±5°C for specimens 0.125, 0.250, or 0.500 inch thick or 770°C± 5°C for specimens 0.062 inch thick.

When the specimen ignites (flame is propagated from the spark gaps to the specimen within the coil and continues to burn), note this elapsed time as the ignition time, I, (in seconds). Continue the spark and heating coil power for 30 seconds for specimens 0.125, 0.250, or 0.500 inch thick or 15 seconds for 0.062 inch thick specimens, after the ignition time; then open both the arc and heater switches and move the spark gaps away from the specimen.

Continue timing the burning of the specimen until all flame has disappeared. Note the burning time, B, (in seconds) as the time elapsed from the time the power is shut off the heating coil until the flame has disappeared.

Remove the burned specimen carefully and allow it to cool; then weigh it again to the nearest 0.1 gram.†

Use an air jet to cool the coil to room temperature after each test, brush any soot or contamination from the coil, and blow out any soot or debris from the test enclosure before repeating the test.

†Specimens 0.062 inch thick need not be weighed.

7.7.6 Calculation of Results

The results of the test shall be considered to be the average value of the set of specimens for ignition time and for burning time. Experience has shown that frequently one observation out of the five for either ignition time or for burning time may appear obviously out of line with the other four values. A suspected abnormal single value shall be tested by the following procedure and eliminated from the average if it is found to be an outlier:

Arrange the five values in increasing order of magnitude, as I_1, I_2, I_3, I_4, and I_5 (for ignition time for example). Compute the following ratios,

$$\frac{I_2-I_1}{I_5-I_1} \text{ and } \frac{I_5-I_4}{I_5-I_1}$$

If either of these ratios exceeds the value 0.642, then I_1 in the first ratio, or I_5 in the second ratio is judged to be abnormal and shall be eliminated from the set of observations. The ignition time or burning time, as the case may be, shall then be calculated as the average of the remaining four values.

Calculate the weight loss of each specimen, except 0.062 inch thick specimens, and average the values of the set of specimens.

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7.8 TEST METHOD FOR PEEL STRENGTH AT ELEVATED TEMPERATURE

7.8.1 Introduction and Background

In 1961 at the University of Delaware, the NEMA Industrial Laminate Section developed a test method to determine the hot peel strength of copper-clad industrial laminates used for printed circuit applications.

In an effort to determine interlaboratory reproductibility and to establish a broad base of interest among customers and manufacturers, a joint Task Group comprised of representatives of the National Electrical Manufacturers Association, Institute of Printed Circuits, and the Electronic Industries Association was formed to conduct round-robin testing. Subsequently, the U.S. Naval Avionics Facility joined the program as a representative of military users.

Seven round robins were conducted, and the test method described herein is the result of the problems uncovered and explored in the course of interlaboratory testing. While the current method does not give a specific test temperature, it does specify that the test shall be made after the sample has been immersed for 6 minutes in Dow Corning DC 710 silicone oil (or essentially at equilibrium conditions). The choice of the silicone fluid and the equilibrium test condition stems directly from erratic results encountered with the use of

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Hydrofol Tinfat 50 at less than equilibrium conditions (i.e., 15 seconds after immersion).

The Hydrofol Tinfat 50, while possessing a higher heat transfer rate than silicone fluid, is unstable at 260°C (500°F). This fact was brought out in USNAF Materials Test Report 58-63, dated 23 April 1963, and subsequently verified by NEMA round-robin testing. The thermal stability of Dow Corning DC 710 silicone fluid has been verified in two reports from USNAF, namely, Materials Test Report 82-64, dated 21 July 1964, and Materials Test Report 83-64, dated 7 July 1964.

The variation attributed to the short-time (15-second-immersion) test is due to the fact that, 15 seconds after immersion, the temperature of the sample changes so rapidly that a time error of only plus or minus 1 second results in a sample temperature difference of about plus or minus 7°F (3.9°C).

7.8.2 Test Equipment

The test equipment shall consist of the following:

7.8.2.1 Melting Pot

Dee melting pot, Model 269-K2 or the equivalent, filled with silicone oil to a depth of 3.500 inches (see par.B.9). Model 269-K2 has inside dimensions of 8 inches×12 inches×a depth of 4 inches and will regulate temperatures above 150°C (300°F) only. An external regulating device producing temperature regulation within plus or minus 1°C shall be used for lower temperatures (see 7.8.2.3 and 7.8.2.4 for suitable examples).

7.8.2.2 Melting Pot Cover

A 12-inch×16-inch×0.125-inch-thick piece of a heat-resistant laminate to cover the melting pot to minimize heat loss and increase the safety factor during operation of the oil-filled melting pot shall be used. This cover shall be fabricated with a rectangular hole and two round holes in accordance with Figure 7-1 to accommodate the peel-strength testing head, stirrer shaft, and bimetallic thermoregulator.

7.8.2.3 Bimetallic Thermoregulator

An Aminco Bimetallic Thermoregulator Quick Set 4-239B shall be used in conjunction with the Aminco 4-08F Simplex Temperature Controller (see 7.8.2.4) to control melting pot temperatures below 150°C (300°F). The Bimetallic Themoregulator element fits through the 0.750 inch hole in the cover and is immersed in the silicone oil to a depth of 0.250 inch from the bottom of the melting pot. An equivalent thermoregulator may be used as long as its controlling accuracy is within plus or minus 1°C.

7.8.2.4 External Temperature Controller

An Aminco 4-08F Simplex Temperature Controller to externally control melting pot temperatures below 150°C (300°F) shall be used.

7.8.2.5 Exhaust Fan

An exhaust fan capable of exhausting approximately 500 cubic feet of air per minute over the surface of the cover of the melting pot shall be used. Any equivalent blower system that will provide approximately the same air flow may be used.

7.8.2.6 Stirrer and Motor

A 1500-rpm heavy-duty stirrer motor (e.g., Bodine Model 103), using an 8-inch-long stirring rod having a 30-degree pitch propeller attached to one end, to agitate the hot silicone oil. The propeller shall consist of a single blade having a length of 1.750 inches from tip to top and shall be immersed in the hot silicone oil to a depth of 1 inch below the surface of the oil.

7.8.2.7 Force Gauge

A Hunter force gauge (Type L-2), or the equivalent, capable of reading forces up to a maximum of 2 pounds and having divisions of 0.02 pound and an accuracy of plus or minus 0.5 percent of full scale shall be used.

7.8.2.8 Hot Peel Strength Assembly

Hot peel strength assembly shall consist of a testing head, lowering device, and drive assembly capable of continuously pulling the copper strips at a 90-degree angle at a speed of 2 inches per minute as shown in Figure 7-2. Equivalent apparatus may be used if it provides a constant pull at 90 degrees at a speed of 2 inches per minute.

7.8.2.9 Heat Medium

Dow Corning DC-710 silicone oil shall be used as the heat medium. (Reasons for the selection of this fluid over other heating media are discussed in 7.8.1.

7.8.2.10 Specimen Holder

The specimen holder shall be a 0.250-inch-thick piece of NEMA Grade G-9 laminate in accordance with Figure 7-3 and with a well drilled in one of four alternate locations to accommodate a conveniently sized thermocouple.

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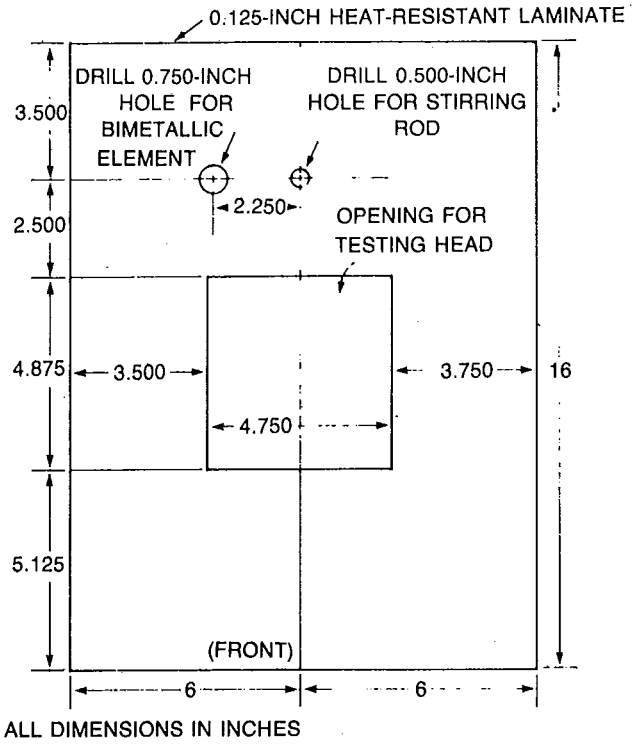


Figure 7-1
MELTING POT COVER

The hole can be located at any position as indicated in Figure 7-2. These are equivalent positions with the choice left to the individual testing facility so that the thermocouple indicator can be conveniently positioned. The center of this hole for the thermocouple well is to be midway between the G-9 laminate surfaces, and the hole should be 1 inch in depth. It should be noted here that the thermocouple wires should be insulated so that the only contact between the dissimilar wires of the thermocouple will be at the junction positioned deep in the thermocouple well. The thermocouple wire used should be no larger than B&S 28 gauge and the diameter of the hole for the thermocouple well should be not larger than that which will permit a tight fit of the insulated thermocouple wire.

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7.8.2.11 Calibrating Specimen

A calibrating specimen which is representative of the test specimen described herein shall be prepared by molding a B&S 30 gauge thermocouple, with lead extended through the edge, in the center of the specimen. Before use, the accuracy of the calibrating specimen shall be determined by an accepted means, e.g., immersion in boiling water or ice bath.

7.8.2.12 Clamp

The clamp shall be a Type 45C battery clip to clamp the copper strip to the force gauge.

7.8.2.13 Stop Watch

7.8.2.14 Suitable Safety Equipment

Suitable safety equipment to protect the operator from hot silicone oil, and such shall be used.

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7.8.2.15 Thermometer or Thermocouple (When Used)

A thermometer (calibrated for emergent stem correction) or thermocouple may be used to measure the temperature of the hot oil 1 inch beneath the surface of the oil. If used, it can be inserted through the cover in either the rectangular or thermoregulator hole.

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7.8.3 Specimens

Two specimens shall be cut from each sheet, preferably from diagonally opposite corners. Each specimen shall be 2 inches×3 inches and etched to provide four copper strips, each 0.125 inch wide and 3 inches long.

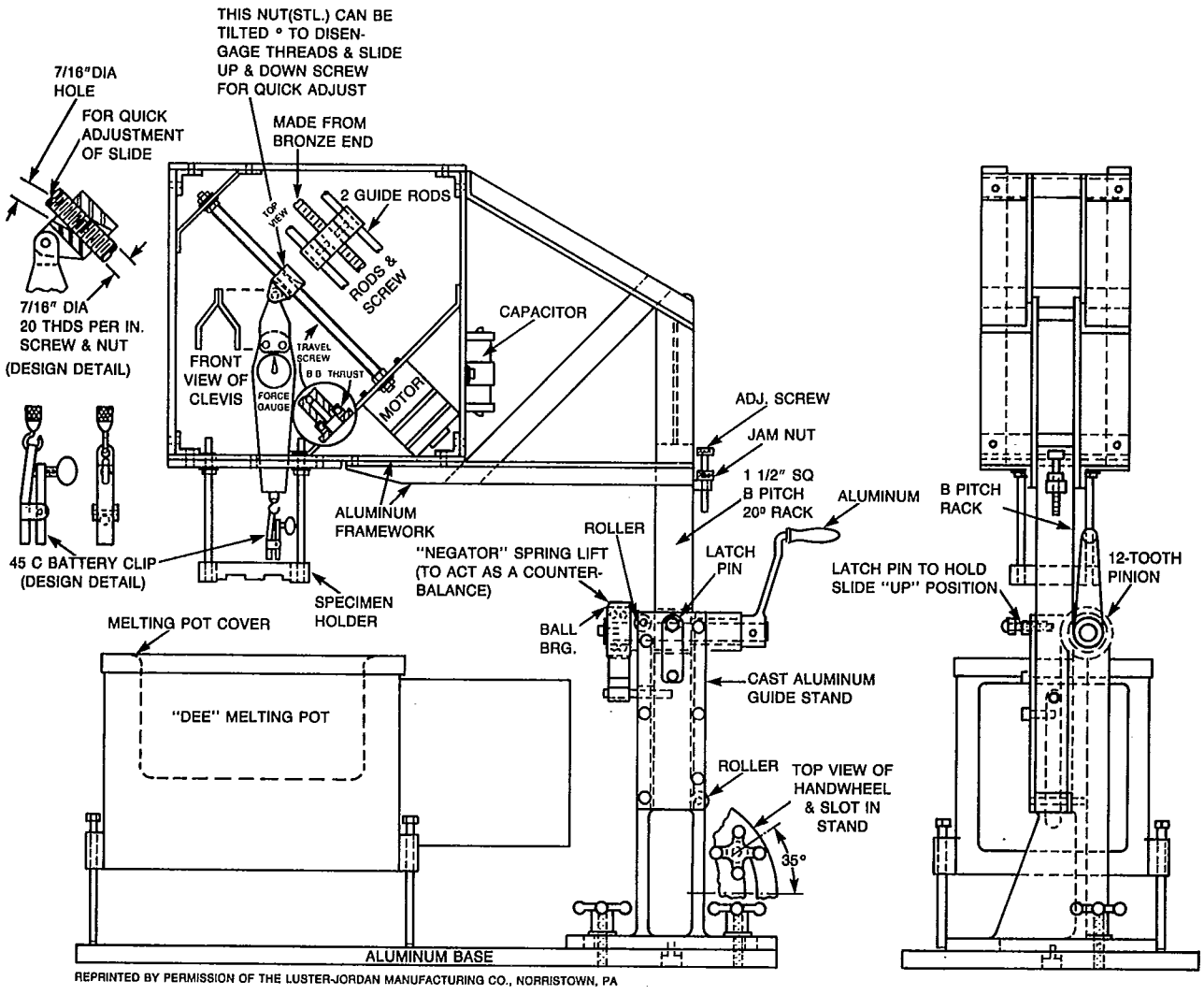
Other specimens such as shown in Figure 3 of MIL-P-13949G, omitting the 0.031 inch etched line, are also suitable.

7.8.4 Procedure

The following procedures shall be followed:

1. Assemble the test equipment in accordance with Figure 7-2.
2. Turn on the stirrer motor and raise the temperature of the oil in the Dee melting pot to that specified in applicable standards.
3. Turn on the exhaust fan.
4. Attach the 45C battery clip to the force gauge, and zero the gauge. If the gauge is operating properly, this initial zeroing procedure will remain stable. It is an easy matter to observe the zero prior to attaching the clip to the test specimen.
5. Bring the specimen holder to room temperature. (This step is not too critical at equilibrium conditions.)
6. By hand, peel back one of the copper strips on the test specimen for a distance of approximately 1 inch.
7. Position the test specimen and specimen holder beneath the testing head so that the copper strip to be peeled is approximately centrally located in the testing slot. Position the peeled portion of the copper strip (par.D6) vertically through the slot in the testing head and attach it to the 45C battery clip on the force gauge. (The method of attaching

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Figure 7-2
LUSTER-JORDAN HOT PEEL ASSEMBLY

the clip to the copper strip is not believed to be critical, and any technique that will provide a secure grip and, at the same time, provide a straight non-twisting pull on the strip is acceptable.) (This sentence approved as Authorized Engineering Information.)

8. Turn on the motor until the force gauge reads 0.2 to 0.3 pounds. This force will keep the peeled strip vertical and, at the same time, will hold the specimen and specimen holder in place on the underside of the testing head without the use of clips or other holding devices.
9. Immerse the specimen holder in the melting pot to a depth that will provide ¾ inch of oil above the top of the specimen (½ inch of oil above the top of the specimen holder).
10. At the instant the sample is immersed, start the stop watch. Six minutes later, pull the copper strip. Five seconds after starting the pull, the apparent average shall be determined* for a total period of 25 seconds plus or minus 5 seconds. Immediately at the end of this period, lift the specimen holder and test specimen out of the oil.

*If recording apparatus is available, the visual average may be read from the chart.

When using a mercury thermometer, it is absolutely necessary to have the thermometer positioned so that the constriction at the top of the mercury well is exactly 1 inch beneath the surface of the oil.

It is also necessary to determine and apply the emergent stem correction. If this is not done, errors from 10

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to 25 degrees (depending upon the configuration of the thermometer) can be present in determining the temperature of the oil at the working temperature of this test.

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If, for any reason, the test specimen should fall from the specimen holder during the test and into the bottom of the melting pot, it should be retrieved immediately and cooled down to room temperature before proceeding with the test.

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11. Repeat steps 1 through 10 for each of the three remaining copper strips on the test specimen after the specimen has returned to room temperature.

7.8.5 Test Data

The force in pounds, as recorded from the force gauge, shall be multiplied by 8 to obtain the peel strength in pounds per inch of width for each strip.

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7.9 TWO-FLUID THREE-TERMINAL TEST METHOD FOR MEASUREMENT OF PERMITTIVITY AND DISSIPATION FACTOR

7.9.1 Scope

This test method describes the measuring sequence required to determine the permittivity and dissipation factor. The main advantage of the two-fluid system is that unknown dielectric properties are determined independently of physical dimensions. Accurate knowledge of specimen thickness, electrode diameter, and spacing, or the dielectric properties of the measuring fluids are not required. The accuracy of the test is limited only by the accuracy of the capacitance and loss determining circuits of the bridge used.

In general, the measuring procedure shall be as follows. The capacitance of the cell that is filled with the first fluid (air) is determined with the cell spacing preset at the desired amount. The specimens are placed into the cell, and the capacitance is remeasured. The specimens are removed from the cell, and the second fluid (1-centistoke silicone fluid) is poured into the cell. The capacitance and conductance of the cell containing the second fluid are read from the bridge. The specimens are then reintroduced into the liquid-filled cell, and the capacitance and conductance are again determined.

The permittivity then can be calculated directly from the four capacitance values. The dissipation factor is calculated from the capacitance and conductance values obtained from the second fluid and from the dielectric constant of the specimen. The total specimen thickness can also be calculated from the permittivity of the specimen, the permittivity of either fluid, and the capacitance values measured when that fluid was in the cell.

7.9.2 Test Equipment

The following test equipment shall be used:

1. Boonton Electronics 75B-S8, or the equivalent, direct capacitance bridge and instruction manual.
2. Balsbaugh LD-3 micrometer electrode, three-terminal cell, or the equivalent.
3. Supply of 1-centistoke Dow-Corning silicone fluid, Type 200, or the equivalent.
4. Paper cutter for trimming thin specimens to size.
5. One "low" bridge-to-cell lead with a female BNC connector at the bridge end and a General Radio Type 874 at the cell end, or the equivalent.
6. One "high" bridge-to-cell lead with a female BNC connector at the bridge end and a banana plug at the cell end with the shield trimmed back ½ inch so that it cannot short against the banana plug.
7. Small beaker to catch the overflow from the cell.
8. Forceps to remove the specimens or to position them in the cell.
9. Filter funnel and ring stand.
10. Filter paper.

7.9.3 Specimens

Specimens shall be 3.250 inches×3.250 inches×the thickness. The thickness of low-loss material is nominally 0.125 inch. Multilayer material is built up to a thickness in the range of 0.015 to 0.020 inch.

The copper shall be removed by etching in accordance with MIL-P-13949G, par. 4.7.1.3.2.1 (Method B). 4.7.1.3.2 specifies method 2.3.6, 2.3.7, or 2.3.7.1 in accordance with IPC-TM-650.

7.9.4 Test Condition

The test shall be performed in a controlled atmosphere of 23°C (73°F)±1°C (0.6°F) and 50 percent relative humidity. The temperature of the cell, fluid and specimens shall be in equilibrium at the time of measurement.

Specimens used for low-humidity conditioning [23°C (73°F)±1°C (0.6°F) and 20 percent relative humidity] shall be measured immediately upon their removal from the conditioning number.

7.9.5 Cleaning Procedures

Since 1-centistoke silicone fluid evaporates without leaving any residue or fill, the only special care required is to blow the cell free of dust with clean dry compressed air prior to each series of measurements.

Used silicone fluid should be filtered to remove dust and lint before it is reused. (This sentence approved as Authorized Engineering Information.)

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7.9.6 Procedure

1. Turn on the bridge and allow it to warm up for 1 hour before using it. Perform the preliminary adjustments given on page 5 of the instruction manual.
2. Adjust the cell spacing so that the specimen thickness is greater than 50 percent of the spacing.
3. Connect the "low" lead to the bridge and cell.
4. Connect the "high" lead to the bridge but do not insert the banana plug into the cell.
5. Set the "Divide G, Multiply R" switch to 1000.
6. Set the "Multiply C" switch to 0.1.
7. Set the "Capacitance" dial to zero.
8. Set the "Conductance" dial to zero.
9. Alternately adjust the "R/G Zero" and "C Zero" coarse and fine dials to obtain a null zeroing of the instrument.
10. Connect the banana plug into the receptacle on the cell barrel.
11. Alternately adjust the "Capacitance" and "Conductance" dials to obtain a null.
12. Read the capacitance and record it as C1.
13. Disconnect the banana plug.
14. Insert the specimens into the cell. (If specimens have been conditioned at D-24/23 or D-48/50, remove them from the water bath, immediately dry them with a lint-free towel or cloth, and insert them into the cell without delay. Rapid action is necessary to preserve the conditioning.)
15. Readjust zero with "R/G Zero" and "C Zero" coarse and fine dials and, if necessary, with appropriate changes of the "Divide G, Multiply R" and "Multiply C" switches as outlined on page 5 of the instruction manual.
16. Connect the banana plug.
17. Alternately adjust the "Capacitance" and "Conductance" dials to obtain a null.
18. Read the capacitance and record it as C3.
19. Remove the specimens from the cell. (If specimens have been conditioned at D-24/23 or D-48/50, immediately immerse them in a container of distilled or deionized water to preserve the conditioning.)
20. If there is another set of specimens to be measured, return to Step 13 and repeat the subsequent steps.
21. Place a small breaker under the overflow tube of the cell to catch excess liquid.
22. Fill the cell to overflowing with 1-centistoke silicone fluid.
23. Remove the banana plug from the cell receptacle.
24. Readjust zero with "R/G Zero" and "C Zero" coarse and fine dials and, if necessary, with appropriate changes of the "Divide G, Multiply R" and "Multiply C" switches as outlined on page 5 of the instruction manual.
25. Connect the banana plug.
26. Adjust the "Capacitance" and "Conductance" dials to the null position of the meter.
27. Read the capacitance and record it as C2.
28. Read the conductance and record it as G1.
29. Disconnect the banana plug.
30. Insert the specimens into the cell. (If specimens have been conditioned at D-24/23 or D-48/50, remove them from the water bath, immediately dry them with a lint-free towel or cloth, and insert them into the cell without delay. Rapid action is necessary to preserve the conditioning. If built-up specimens are used, insert one "built-up" at a time to avoid trapping air bubbles between layers.)
31. Readjust zero with "R/G Zero" and "C Zero" coarse and fine dials and, if necessary, with appropriate changes of the "Divide G, Multiply R" and "Multiply C" switches as outlined on page 5 of the instruction manual.
32. Connect the banana plug.
33. Adjust the "Capacitance" and "Conductance" dials to the null position of the meter.
34. Read the capacitance and record it as C4.
35. Read the conductance and record it as G2.
36. Remove the specimens from the cell.
37. If there is another set of specimens to be measured, return to step 29 and repeat the subsequent steps.
38. Empty the silicone fluid from the cell.
39. Filter the fluid through filter paper before returning it to its container.
40. Blow the cell dry with clean compressed air.

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7.9.7 Calculations

1. Dielectric Constant

$$K = \frac{1}{C0}\left[C1 + \frac{\Delta C1 \times C4 \times (C2 - C1)}{\Delta C1 \times C4 - \Delta C2 - C3}\right]$$

2. Dissipation Factor

$$D = D2 + \frac{(K \times C0 - C4)}{\Delta C2}(D2 - D1)$$

3. Total Specimen Thickness

$$T_s = \frac{T_a \times K \times \Delta C2}{C4\,(K - K2)}$$

Where:
C0 = C1/1.00058
C1 = See Step 12.
C2 = See Step 27.
C3 = See Step 18.
C4 = See Step 34.
ΔC1 = C3–C1
ΔC2 = C4–C2

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d = Diameter of guarded electrode = 2.5 inches
D = Dissipation factor of specimen.
D1 = G1/(W×C2)
D2 = G2/(W×C4)
G1 = See Step 28.
G2 = See Step 35.
K = Permittivity of specimen.
K2 = Permittivity of silicone fluid = C2/C0.
T_a = $(0.1766 \times d^2)/C0$ = cell spacing.
T_s = Total specimen thickness.
W = 2 × frequency in MHz = 6.2832.

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7.10 RECOMMENDED CONTROL TESTS (SHEETS)

Where a grade of laminated thermosetting sheets has been found satisfactory for some particular application, the number of tests required to ascertain the uniformity of the product and whether or not it meets these standards may be greatly decreased.

In most cases, the following are recommended as being ample control tests.

Grade	Flexural Strength	Impact Strength	Bonding Strength*	Water Absorption	Dielectric Breakdown Parallel to Laminations, Condition A†	Dissipation Factor and Permittivity Condition D-24/23†	Arc Resistance	Flame Resistance
X	X	–	X	X	–	–	–	–
XP	X	–	–	X	–	–	–	–
XPC	X	–	–	X	–	–	–	–
XX	X	–	–	X	–	–	–	–
XXP	X	–	–	X	–	X	–	–
XXX	X	–	–	X	–	X	–	–
XXXP, XXXPC	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	–	–
AA	X	X	X	X	–	–	–	–
G-3	X	X	X	X	–	–	–	–
G-5, G-9	X	–	X	X	X	–	X	–
G-7	X	–	X	–	–	X	X	–
G-10, G-11	X	–	–	X	–	X	–	–
N-1	X	–	X	–	–	X	–	–
FR-1	X	–	–	X	–	X	–	X
FR-2, FR-3	X	–	–	X	–	X	–	X
F-4, FR-5	X	–	–	X	–	X	–	X
CEM-1, CEM-3	X	–	–	X	–	X	–	X

*This test applies to sheets 0.500 inch and over in nominal thickness.
†See 6.4.1.

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Section 8
COPPER-CLAD LAMINATES

SCOPE

This section covers Grades XXXP, XXXPC, FR-1, FR-2, FR-3, FR-4, FR-5, G-10, G-11, CEM-1, and CEM-3 laminates having copper foil bonded to one or both surfaces and intended primarily for use in printed wiring boards.

8.1 MATERIAL

8.1.1 Laminate Base

The base material shall be of the following types:

NEMA Grade	Comparable Military Designations from MIL-P-13949*	Type
XXXP	—	Paper base, phenolic resin
XXXPC	—	Paper base, phenolic resin
FR-1	—	Paper base, phenolic resin, flame resistant
FR-2	—	Paper base, phenolic resin, flame resistant
FR-3	Type PX	Paper base, epoxy resin, flame resistant
FR-4	Type GF	Glass fabric base, epoxy resin, general purpose, flame resistant
FR-5	Type GH	Glass fabric base, epoxy resin, temperature and flame resistant
CEM-1	—	Glass cloth surfaces cellulose paper core, epoxy resin, flame resistant
CEM-3	—	Glass cloth surfaces, nonwoven glass core epoxy resin, flame resistant
G-10	Type GE	Glass fabric base, epoxy resin, general purpose
G-11	Type GB	Glass fabric base, epoxy resin, temperature resistant

*Approved as Authorized Engineering Information.

8.1.2 Copper Foil Surfaces

The surfaces shall be copper foil having a minimum purity of 99.50 percent† (silver considered as copper) and the following nominal weights, thicknesses, and tolerances:

Nominal Weight		Nominal Thickness*	
Ounces per Square Foot	Plus or Minus Tolerance, Percent	Inches	Plus or Minus Tolerance, Inches
0.146	10	0.0002	—
0.263	10	0.00036	—
0.350	10	0.00052	—
0.50	10	0.0007	0.0001
1.00	10	0.0014	0.0002
2.00	10	0.0028	0.0003
3.00	10	0.0042	0.0004
4.00	10	0.0056	0.0006
5.00	10	0.0070	0.0007

*Approved as Authorized Engineering Information.
NEMA Standard 9-15-1982.

†The analysis for determining the minimum purity of the copper shall be made in accordance with ASTM E 53-82.

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8.2 THICKNESSES AND TOLERANCES

Nominal Overall Thickness, Including Copper, Inches	Plus or Minus Thickness Tolerances of Copper-clad Sheet, Inches				
	Class I Tolerances			Class II Tolerances*	
	Grades XXXP, XXXPC, FR-2, and FR-3 1-ounce Copper, Two Sides		Grades FR-4, FR-5, CEM-1, CEM-3, G-10 and G-11	All Weights and Copper, One and Two Sides	
	1-ounce Copper, One Side	2-, 3-, 4-, and 5-ounce Copper, One and Two Sides	All Weights of Copper, One and Two Sides	Grades XXXP, XXXPC, FR-2, and FR-3	Grades FR-4, FR-5, CEM-1, CEM-3, G-10, and G-11
(0.031)	0.0040	0.0045	0.0065	0.0030	0.004
(0.046)	0.0050	0.0055	0.0075	0.0035	0.005
(0.062)	0.0055	0.0060	0.0075	0.0040	0.005
(0.093)	0.0070	0.0075	0.0090	0.0050	0.007
(0.125)	0.0085	0.0090	0.0120	0.0060	0.009
(0.156)	0.0095	0.0100	0.0150	0.0070	0.010
(0.187)	0.0100	0.0220	0.0190	0.0080	0.011
(0.218)†	0.1100	0.0120	0.0210	0.0090	0.012
(0.250)†	0.1200	0.0120	0.0220	0.0090	0.012

*Where the intended use requires Class II tolerances, the purchaser should so specify.

†These values do not apply to Grades XXXPC and FR-2.

Authorized Engineering Information 9-15-1982.

The thickness tolerances shall not apply to the outer one inch of the trimmed laminates sheet.

At least 90 percent of the area of a sheet shall be within the tolerances given and at no point shall the thickness vary from the nominal by a value greater than 125 percent of the specified tolerance.

Cut panels less than 18 inches × 18 inches shall meet the applicable thickness tolerances in 100 percent of the area of the panel.

For a sheet having a nominal thickness not listed in the table, the tolerances shall be the same as for the next higher nominal thickness.

NEMA Standard 9-15-1982.

8.3 TOLERANCES IN LENGTH AND WIDTH

The tolerances in length and width of manufacturers' standard size sheets shall be plus or minus 1 inch from the manufcturers' standard.‡

NEMA Standard 9-15-1982.

‡Because of variations in the size of press equipment, there is considerable variation in the length and width of manufacturers' standard size sheets. These standard sizes range between 18 and 60 inches in width and between 24 and 144 inches in length.

8.4 TOLERANCES IN LENGTH AND WIDTH OF CUT PIECES

Nominal Thickness, Inches	Plus or Minus Tolerance in Length or Width, Inches			
	Min.–6.000	6.001–18.000	18.001–24.000	24.001–Max.
0.031–0.250	0.015	0.020	0.031	0.062

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8.5 MAXIMUM BOW OR TWIST OF COPPER-CLAD SHEET AS MANUFACTURED

Range of Thickness, Inches	Paper Grades—XXXP, XXXPC, FR-1, FR-2, and FR-3; Glass Grades—G-10, G-11, FR-4, FR-5, CEM-1, and CEM-3					
	Maximum Warp or Twist (Based on 36-inch Dimension*), Percent					
	Class A Bow or Twist			Class B Bow or Twist		
	1-and 2-ounce Copper, One Side	1-and 2-ounce Copper, Two Sides		1-and 2-ounce Copper, One Side	1-and 2-ounce Copper, Two Sides	
		Glass	Paper		Glass	Paper
0.031–0.047	12	5	6	10	2	5
0.048–0.062	10	5	6	5	1	2.5
0.063–0.125	8	3	3	5	1	2.5
0.126–0.250	5	1.5	1.5	5	1	1.5

*These values apply only to sheet sizes as manufactured and to cut pieces having either dimension not less than 18 inches. In the case of bow, this percentage is stated in terms of the dimension from one corner to the diagonally opposite corner.

†Where the intended use requires Class B bow or twist, the purchaser should so specify. (This note has been approved as Authorized Engineering Information.)

NOTE—For the method of measuring bow or twist, see ASTM D709. For any standard sheet size other than 36 inches, use the following formula:

$$\frac{Dx}{D_{36}} = \frac{Lx^2}{(36)^2}$$

Where—

Dx = permissible deviation from straight edge in inches for the given length.

D_{36} = permissible deviation in inches for 36-inch length.

Lx = the given length in inches.

This formula is not applicable to cut pieces where Lx is less than 18 inches because of the effects of strains put in by machine or sawing operations.

NEMA Standard 9-15-1982.

PROPERTIES OF COPPER-CLAD SHEETS

8.6 MARKING

Unless otherwise required, each full-size copper-clad laminate, as furnished, can be internally marked with the manufacturer's identification. Each 3-inch×3-inch section of each sheet shall be so marked.

Such marking of flame resistant laminates shall be red in color. Laminates that are not flame resistant shall not be marked in red.

8.7 FINISH

8.7.1 Phenolic Grades—XXXP, XXXPC, FR-1, FR-2

Copper surfaces shall be free from defects that may affect serviceability, such as blisters, wrinkles, cracks, holes, pits, dents, and scratches.

The number of pin holes exceeding an average diameter greater than 0.005 inch shall not exceed one in a square foot. There shall be no pin holes with an average diameter greater than 0.015 inch.

Inclusions larger than 0.020 in length shall not exceed five in a square foot or ten per standard size sheet (approximately 10 square feet).

8.7.2 Epoxy Grades—FR-3, FR-4, FR-5, CEM-1, CEM-3, G-10, G-11

Copper surfaces shall be free from defects that may affect serviceability and, in addition, shall meet the requirements of 8.7.2.1 through 8.7.2.5.

8.7.2.1 Pits and Dents

The maximum total point count for pits and dents per square foot of material inspected shall be 30. The point system shall be as follows:

Longest Dimension, Inches	Point Value
0.005–0.010, incl.	1
0.011–0.020, incl.	2
0.021–0.030, incl.	4
0.031–0.040, incl.	7
Over 0.040	30

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Pits are defined as small depressions occurring as imperfections that materially reduce the thickness of the copper foil.

Dents are defined as depressions in the copper foil that do not significantly decrease the thickness of the copper foil.

8.7.2.2 PINHOLES

The area of any one or number of pinholes in a 5-square-foot area shall not exceed the area of a 0.005-inch-diameter circle.

Pinholes are defined as small holes occurring as imperfections that penetrate entirely through the copper foil.

8.7.2.3 INCLUSIONS

There shall be no inclusions 0.005 inch or greater in the longest dimension. The average number of inclusions between 0.001 and 0.005 inch in the longest dimension shall not exceed one per square foot.

Inclusions are defined as foreign particles which may or may not be enclosed in the mass of copper foil.

8.7.2.4 SCRATCHES

Any number of scratches less then 140 microinches deep shall be permitted. Scratches that have a depth of 140 microinches and over:

a. Shall not exceed 4 inches in length and
b. Shall not exceed one-fifth of the copper foil thickness in depth and
c. Shall not exceed five per square foot in number.

8.7.2.5 SURFACE FINISH

The surface finish shall not exceed 20 microinches arithmetic average.

None of the foregoing conditions applies to the area within 0.500 inch of the edge of full sheets.

NEMA Standard 9-15-1982.

8.8 PROPERTY VALUES

See Tables 8-1 to 8-11, inclusive.

NEMA Standard 9-15-1982.

8.9 OVEN BLISTER TEST

No blistering shall occur when the material is subjected to an oven test in accordance with 8.21 and the following:

Grade	Temperature, Degrees C, ±2°C	Duration, Minutes
XXXP, XXXPC, FR-1, FR-2	120	30
FR-3, CEM-1	120	60
FR-4, FR-5, CEM-3, G-10, G-11	140	60

NEMA Standard 9-15-1982.

8.10 SOLVENT RESISTANCE

The laminate, after the copper has been removed by etching, shall not delaminate nor blister when suspended for 2 minutes in trichloroethane vapor over the boiling liquid at atmospheric pressure.

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Table 8-1
PROPERTY VALUES FOR GRADE XXXP LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F(260°C), Etched and Unetched Minimum Time, Seconds**	A	5	10	10	10	10
Peel Strength after Solder Float, Minimum, Pounds per Inch of Width*†						
1-ounce copper	A	6	6	6	6	6
2-ounce copper	A	7	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^4	10^4	10^4	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^3	10^3	10^3	...
Water Absorption, Maximum Average, Percent‡	D-24/23	1.3	1.0	0.85	0.75	...
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	D-48/50	15	15	15	15	15
Permittivity, Maximum Average, at 1 MHz	D-24/23	4.8	4.8	4.8	4.8	...
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.04	0.04	0.04	0.04	0.04
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	12,000	12,000	12,000	12,000	12,000
Crosswise	A	10,500	10,500	10,500	10,500	10,500

Table 8-2
PROPERTY VALUES FOR GRADE XXXPC LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F(260°C), Etched and Unetched Minimum Time, Seconds**	A	5	10	10	10	10
Peel Strength after Solder Float, Minimum, Pounds per Inch of Width*†						
1-ounce copper	A	6	6	6	6	6
2-ounce copper	A	7	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^4	10^4	10^4	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^3	10^3	10^3	...
Water Absorption, Maximum Average, Percent‡	D-24/23	1.30	0.75	0.65	0.55	...
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	D-48/50	...	15	15	15	...
Permittivity, Maximum Average, at 1 MHz	D-24/23	4.8	4.8	4.8	4.8	...
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.04	0.04	0.04	0.04	0.04
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	12,000	12,000	12,000	12,000	...
Crosswise	A	10,500	10,500	10,500	10,500	...

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.
†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.
‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.
**No blistering, delamination, or interlaminar blistering.

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Table 8-2A
PROPERTY VALUES FOR GRADE FR-1 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches			
		0.031	0.062	0.094	0.125
Solder Float at 500°F(260°C), Etched and Unetched Minimum Time, Seconds**	A	5	10	10	10
Peel Strength after Solder Float, Minimum, Pounds per Inch of Width*†					
1-ounce copper	A	6	6	6	6
2-ounce copper	A	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^3	10^3	10^3
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^2	10^2	10^2
Water Absorption, Maximum Average, Percent‡	D-24/23	5.60	3.60	2.80	2.20
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	D-48/50	5	5	5	5
Permittivity, Maximum Average, at 1 MHz	D-24/23	6.0	6.0	6.0	6.0
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.06	0.06	0.06	0.06
Flexural Strength, Minimum Average, psi*‡					
Lengthwise	A	12,000	13,000	13,000	14,000
Crosswise	A	10,000	11,000	11,000	12,000
Flame Resistance, Minimum	A	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1
	E-24/125	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1

Table 8-3
PROPERTY VALUES FOR GRADE FR-2 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches			
		0.031	0.062	0.094	0.125
Solder Float at 500°F(260°C), Etched and Unetched Minimum Time, Seconds**	A	5	10	10	10
Peel Strength after Solder Float, Minimum, Pounds per Inch of Width*†					
1-ounce copper	A	6	6	6	6
2-ounce copper	A	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^4	10^4	10^4
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^3	10^3	10^3
Water Absorption, Maximum Average, Percent‡	D-24/23	1.30	0.75	0.65	0.55
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	D-48/50	...	15	15	15
Permittivity, Maximum Average, at 1 MHz	D-24/23	4.8	4.8	4.8	4.8
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.04	0.04	0.04	0.04
Flexural Strength, Minimum Average, psi*‡					
Lengthwise	A	12,000	12,000	12,000	12,000
Crosswise	A	10,500	10,500	10,500	10,500
Flame Resistance, Minimum	A	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1
	E-24/125	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.
†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.
‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.
**No blistering, delamination, or interlaminar blistering.

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Table 8-4
PROPERTY VALUES FOR GRADE FR-3 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	5	10	10	10	10
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float						
1-ounce copper	A	8	8	8	8	8
2-ounce copper	A	9	9	9	9	9
3-, 4-, and 5-ounce copper	A	10	10	10	10	10
At elevated temperature						
1-ounce copper	E-1/105:T-105	5	5	5	5	5
2-ounce copper	E-1/105:T-105	6	6	6	6	6
3-, 4-, and 5-ounce copper	E-1/105:T-105	7	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^4	10^4	10^4	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^3	10^3	10^3	...
Water Absorption, Maximum Average, Percent‡	D-24/23	1.00	0.65	0.60	0.50	0.25
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	D-48/50	30	30	30	30	30
Permittivity, Maximum Average, at 1 MHz	D-24/23	4.8	4.8	4.8	4.8	4.8
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.040	0.040	0.040	0.040	0.040
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	20,000	20,000	20,000	20,000	20,000
Crosswise	A	16,000	16,000	16,000	16,000	16,000
Flame Resistance, Minimum	A	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1
	E-24/125	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.

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Table 8-5
PROPERTY VALUES FOR GRADE FR-4 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20	20	20	20	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float						
1-ounce copper	A	8	8	8	8	8
2-ounce copper	A	10	10	10	10	10
3-, 4-, and 5-ounce copper	A	11	11	11	11	11
At elevated temperature						
1-ounce copper	E-1/125; T-125	5	5	5	5	5
2-ounce copper	E-1/125; T-125	6	6	6	6	6
3-, 4-, and 5-ounce copper	E-1/125; T-125	7	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^6	10^6	10^6	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^4	10^4	10^4	...
Water Absorption, Maximum Average, Percent‡	D-24/23	0.50	0.25	0.20	0.15	0.13
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	45.0	45.0	45.0	45.0	45.0
	D-48/50	40.0	40.0	40.0	40.0	40.0
Permittivity, Maximum Average, at 1 MHz	D-24/23	5.4	5.4	5.4	5.4	5.4
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.035	0.035	0.035	0.035	0.035
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	60,000	60,000	60,000	60,000	60,000
Crosswise	A	50,000	50,000	50,000	50,000	50,000
Flame Resistance, Minimum	A	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1
	E-24/125	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.

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Table 8-6
PROPERTY VALUES FOR GRADE FR-5 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20	20	20	20	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float						
1-ounce copper	A	8	8	8	8	8
2-ounce copper	A	10	10	10	10	10
3-, 4-, and 5-ounce copper	A	11	11	11	11	11
At elevated temperature						
1-ounce copper	E-1/150; T-150	3	3	3	3	3
2-ounce copper	E-1/150; T-150	4	4	4	4	4
3-, 4-, and 5-ounce copper	E-1/150; T-150	5	5	5	5	5
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^6	10^6	10^6	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^4	10^4	10^4	...
Water Absorption, Maximum Average, Percent‡	D-24/23	0.50	0.25	0.20	0.15	0.13
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	45.0	45.0	45.0	45.0	45.0
	D-48/50	40.0	40.0	40.0	40.0	40.0
Permittivity, Maximum Average, at 1 MHz	D-24/23	5.4	5.4	5.4	5.4	5.4
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.035	0.035	0.035	0.035	0.035
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	60,000	60,000	60,000	60,000	60,000
Crosswise	A	50,000	50,000	50,000	50,000	50,000
Flame Resistance, Minimum	A	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1
	E-24/125	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1	UL 94 V-1

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.

**No blistering, delamination, or interlaminar blistering.

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Table 8-7
PROPERTY VALUES FOR GRADE G-10 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20	20	20	20	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float						
1-ounce copper	A	8	8	8	8	8
2-ounce copper	A	10	10	10	10	10
3-, 4-, and 5-ounce copper	A	11	11	11	11	11
At elevated temperature						
1-ounce copper	E-1/125; T-125	5	5	5	5	5
2-ounce copper	E-1/125; T-125	6	6	6	6	6
3-, 4-, and 5-ounce copper	E-1/125; T-125	7	7	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^6	10^6	10^6	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^4	10^4	10^4	...
Water Absorption, Maximum Average, Percent‡	D-24/23	0.50	0.25	0.20	0.15	0.13
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	45.0	45.0	45.0	45.0	45.0
	D-48/50	40.0	40.0	40.0	40.0	40.0
Permittivity, Maximum Average, at 1 MHz	D-24/23	5.4	5.4	5.4	5.4	5.4
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.035	0.035	0.035	0.035	0.035
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	60,000	60,000	60,000	60,000	60,000
Crosswise	A	50,000	50,000	50,000	50,000	50,000

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next higher thickness shall apply.

**No blistering, delamination, or interlaminar blistering.

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Table 8-8
PROPERTY VALUES FOR GRADE G-11 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches				
		0.031	0.062	0.094	0.125	0.250
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20	20	20	20	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float						
1-ounce copper	A	8	8	8	8	8
2-ounce copper	A	10	10	10	10	10
3-, 4-, and 5-ounce copper	A	11	11	11	11	11
At elevated temperature						
1-ounce copper	E-1/150; T-150	3	3	3	3	3
2-ounce copper	E-1/150; T-150	4	4	4	4	4
3-, 4-, and 5-ounce copper	E-1/150; T-150	5	5	5	5	5
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^6	10^6	10^6	...
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^4	10^4	10^4	...
Water Absorption, Maximum Average, Percent‡	D-24/23	0.50	0.25	0.20	0.15	0.13
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	45.0	45.0	45.0	45.0	45.0
	D-48/50	40.0	40.0	40.0	40.0	40.0
Permittivity, Maximum Average, at 1 MHz	D-24/23	5.4	5.4	5.4	5.4	5.4
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.035	0.035	0.035	0.035	0.035
Flexural Strength, Minimum Average, psi*‡						
Lengthwise	A	60,000	60,000	60,000	60,000	60,000
Crosswise	A	50,000	50,000	50,000	50,000	50,000
Flexural Strength at Elevated Temperature, Minimum Average** Lengthwise	E-1/150:T-150	30,000	30,000	30,000	30,000	30,000

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.

**No blistering, delamination, or interlaminar blistering.

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Table 8-9
Property Values for Grade FR-6 Laminates

Property to be Tested (See 8.11 through 8.20)	Conditioning Procedure (See 6.4.1)	0.062 Inch Thickness
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float		
1-ounce copper	A	7
2-ounce copper	A	8
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	10^6
Surface Resistance, Minimum, Megohms	C-96/35/90	10^4
Water Absorption, Maximum Average, Percent‡	D-24/23	0.4
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	40.0
	D-48/50	30.0
Arc Resistance, Minimum Average, Seconds	A	100
Permittivity, Maximum Average, at 1 MHz	D-24/23	4.3
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.03
Flexural Strength, Minimum Average in Weakest Direction, psi*‡	A	15000
Flame Resistance	A	Class 1
	E-168/70	Class 1
Impact, Izod, Edgewise Notch, Minimum for Either Crosswise or Lengthwise Direction, Ft-lb/in.	A	3

*For any on thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.

**No blistering, delamination, or interlaminar blistering.

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Table 8-10
PROPERTY VALUES FOR GRADE CEM-1 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches		
		0.031	0.062	0.094
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20	20	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float				
1-ounce copper	A	7	7	7
2-ounce copper	A	9	9	9
3-, 4-, and 5-ounce copper	A	10	10	10
At elevated temperature				
1-ounce copper	E-1/125; T-125	5	5	5
2-ounce copper	E-1/125; T-125	6	6	6
3-, 4-, and 5-ounce copper	E-1/125; T-125	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^6	10^6
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^4	10^4
Water Absorption, Maximum Average, Percent‡	D-24/23	0.50	0.30	0.25
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	45.0	45.0	45.0
	D-48/50	40.0	40.0	40.0
Permittivity, Maximum Average, at 1 MHz	D-24/23	5.2	5.0	4.8
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.040	0.040	0.040
Flexural Strength, Minimum Average, psi*#				
Lengthwise	A	50,000	35,000	30,000
Crosswise	A	40,000	28,000	25,000
Flame Resistance, Minimum	A	UL 94 V-0	UL 94 V-0	UL 94 V-0
	E-24/125	UL 94 V-0	UL 94 V-0	UL 94 V-0

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

#For intermediate thicknesses, the values given for the next higher thickness shall apply flexural strength.

**No blistering, delamination, or interlaminar blistering.

‡For intermediate thicknesses, the values given for the next smaller thicknesses shall apply (permittivity).

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Table 8-11
PROPERTY VALUES FOR GRADE CEM-3 LAMINATES

Property to be Tested (See 8.11 through 8.21)	Conditioning Procedure (See 6.4.1)	Thickness, Inches		
		0.031	0.062	0.094
Solder Float at 500°F (260°C), Etched and Unetched Minimum Time, Seconds**	A	20	20	20
Peel Strength, Minimum, Pounds per Inch of Width*† after Solder Float				
1-ounce copper	A	8	8	8
2-ounce copper	A	10	10	10
3-, 4-, and 5-ounce copper	A	11	11	11
At elevated temperature				
1-ounce copper	E-1/125; T-125	5	5	5
2-ounce copper	E-1/125; T-125	6	6	6
3-, 4-, and 5-ounce copper	E-1/125; T-125	7	7	7
Volume resistivity, Minimum, Megohm Centimeters	C-96/35/90	...	10^6	10^6
Surface Resistance, Minimum, Megohms	C-96/35/90	...	10^4	10^4
Water Absorption, Maximum Average, Percent‡	D -24/23	0.50	0.25	0.20
Dielectric Breakdown Parallel to Laminations, Minimum Average, kV, Step by Step	A	45.0	45.0	45.0
	D-48/50	40.0	40.0	40.0
Permittivity, Maximum Average, at 1 MHz	D-24/23	5.4	5.4	5.4
Dissipation Factor, Maximum Average, at 1 MHz	D-24/23	0.035	0.035	0.035
Flexural Strength, Minimum Average, psi#				
Lengthwise	A	50,000	40,000	33,000
Crosswise	A	40,000	32,000	27,000
Flame Resistance, Minimum	A	UL 94 V-0	UL 94 V-0	UL 94 V-0
	E-24/125	UL 94 V-0	UL 94 V-0	UL 94 V-0

*For any one thickness, half of the number of specimens shall be cut lengthwise and the other half shall be cut crosswise.

†No blistering or delamination shall be evident upon removal of the specimens from the solder pot.

‡For intermediate thicknesses, the values given for the next smaller thickness shall apply.

**No blistering, delamination, or interlaminar blistering.

#For intermediate thicknesses, the values given for the next larger thickness shall apply.

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TEST METHODS

NOTE—The citing of a specific manufacturer's equipment or product is for illustrative purposes only and is not intended to exclude similar equipment or products from other sources.

8.11 SOLDER FLOAT TEST

8.11.1 Unetched Specimens

Specimen—Two unconditioned specimens 1 inch×1 inch×the thickness of the sheet shall be tested.

Procedure—The specimen shall be floated (copper-side-to-be-tested down) in clean molten solder at the times and temperatures given in Tables 8-1 through 8-11, ±2°C (3.6°F). At the end of the time specified for each grade, the specimen shall be removed and examined for interlaminar blistering of the base material and blistering and delamination of the copper foil.

For specimens having copper on both sides, a fresh specimen shall be used for testing the other side.

8.11.2 Etched Specimens

Specimen—The pattern shown in Figure 8-1 shall be etched on two unconditioned specimens 2 inches×2 inches×the thickness of the sheet to be tested.

Procedure—The specimen without flux shall be floated (copper-side-to-be-tested down) in clean molten solder at the times and temperatures given in Tables 8-1 through 8-11, ±2°C (3.6°F). At the end of the time specified for each grade, the specimen shall be removed, allowed to cool to room temperature, and then examined for interlaminar blistering of the base material and blistering and delamination of the copper foil.

For specimens having copper on both sides, a fresh specimen shall be used for testing the other side.

If no blistering or delamination occurs, the specimens shall be used for the peel-strength test described in 8.12.

NEMA Standard 9-15-1982.

8.12 PEEL STRENGTH AFTER SOLDER FLOAT TEST

8.12.1 Specimens

The etched specimens from the solder float test (see 8.11) shall be used for this test.

8.12.2 Procedure

The copper foil shall be peeled back from the 0.250-inch end of the copper strip for approximately 1 inch so that the line of peel is perpendicular to the edge of the specimen.

Each specimen shall be clamped or held on a horizontal surface with the peeled copper strip up, providing a 1-inch span.

The end of the peeled strip shall be gripped between two knurled jaws of a clamp with a chain attachment to a dial indicating force indicator that has been adjusted to compensate for the weight of the chain and clamp.

The jaws shall cover the full width of the copper strip and shall be clamped parallel to the line of peel.

Holding the force indicator in a vertical plane, a steady vertical pull (approximately 2 inches per minute) shall be exerted until the needle indicator shows a constant reading.

If the full width of the strip does not peel, the result shall be discarded and the test repeated.

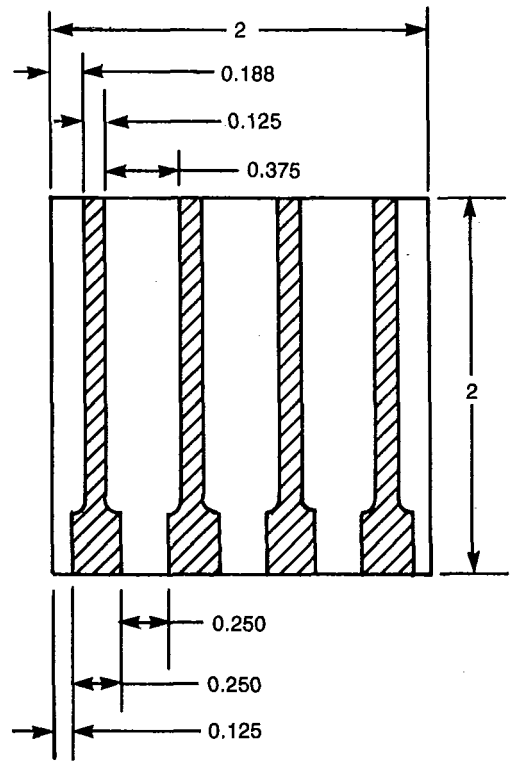
Where both sides of the laminate are copper clad, the test shall be repeated for the second side using the same specimen.

NEMA Standard 9-15-1982.

8.13 PEEL STRENGTH AT ELEVATED TEMPERATURE

This test shall be made in accordance with 7.8.

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ALL DIMENSIONS IN INCHES. TOLERANCE OF 0.125-INCH ETCHED STRIP IS PLUS OR MINUS 0.005 INCH.

Figure 8-1

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8.14 VOLUME RESISTIVITY AND SURFACE RESISTANCE

8.14.1 Specimens

Specimens shall be approximately 4 inches square by the thickness of the sample, with electrodes applied to both opposing surfaces as detailed below. Two such specimens shall be prepared for the test.

Copper-clad Both Sides – As preferred, either etch off all copper from both sides of the specimen, then paint on the patterns shown in Figure 8-2 with porous, conducting silver paint, or alternately etch the patterns of Figure 8-3 on opposite sides of the specimens, then fill in the areas bordered by the narrow copper lines of the guarded electrode (A), the guard electrode (G), and the larger guard electrode (B) with the silver paint.

Copper-clad One Side – As preferred, either etch off all copper from the specimen, then paint with porous, conducting silver paint the large guard electrode (G) of Figure 8-2 on the side that had been copper clad, and paint with the silver paint the ring and disk pattern of Figure 8-2 on the unclad side, or alternately etch the pattern of the large guard electrode (B) of Figure 8-3 on the copper border with the silver paint. In this alternate, the ring-and-disk electrodes of Figure 8-3 must still be painted with silver paint on the unclad side.

Use of Specimen Holders – If specimen holders containing the required opposing electrodes, fabricated of a compliant conducting rubber are used, the specimen shall be etched free of all copper, and the large guard electrode (B) shall contact that side that has had copper removed by etching if the sample is of one-side copper-clad laminate. Suitable care must be exercised to assure that these electrodes make intimate, low resistance contacting with the surfaces of the specimen to avoid introducing errors of measurement.

8.14.2 Procedure

The electrometer (or megohm bridge) shall be connected as shown in Figure 8-4 or 8-5 and in accordance with the instrument shown. A dc voltage of 500 volts shall be applied for 60 seconds (plus 5, minus 0 seconds), using batteries or a high-stability dc power supply. Tests

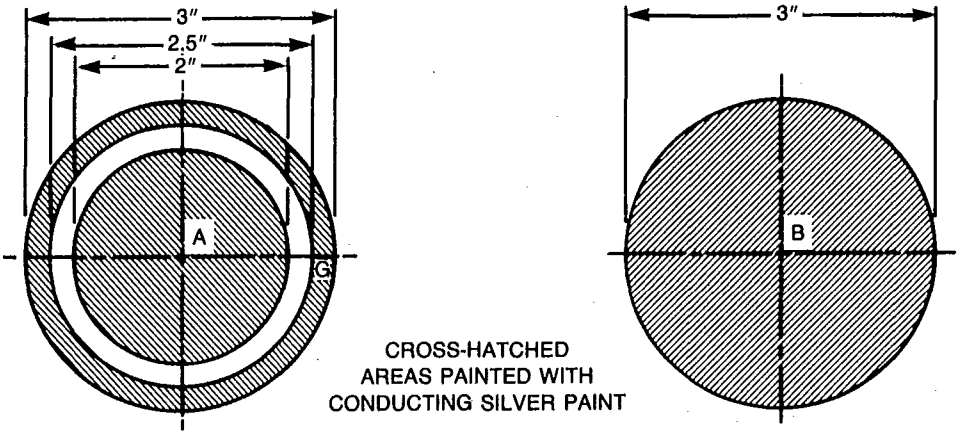


Figure 8-2

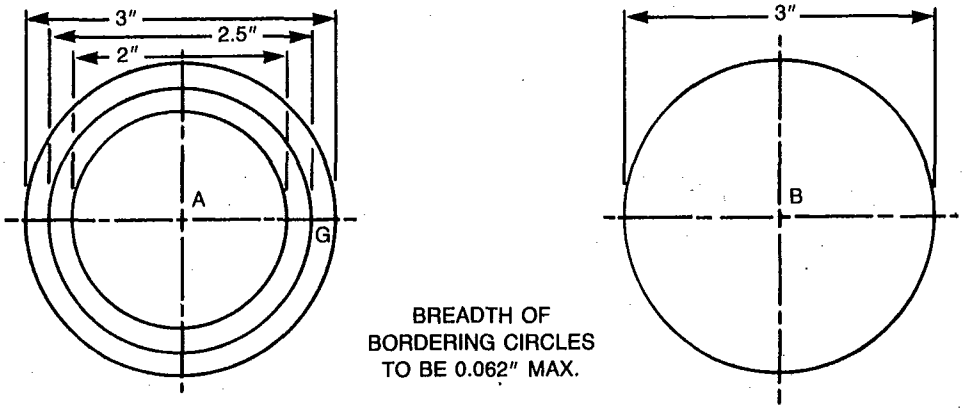


Figure 8-3

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made after humidity conditioning shall be made in the chamber.

The volume resistivity and surface resistance measurements shall be made on the same specimens by interchanging the connections to the guard (G) and electrode B.

8.14.3 Calculations

Volume resistivity = 10R/T

Surface resistance = R for the electrode dimensions in 8.14.1

Surface resistivity = 30R

Where—

T = thickness in inches.

R = ohms or megohms.

NEMA Standard 9-15-1982.

8.15 WATER ABSORPTION

8.15.1 Specimens

Three specimens 3 inches×1 inch×the thickness of the sheet to be tested shall have the copper removed by etching.

8.15.2 Procedure

The tests shall be conducted in accordance with ASTM D 229.

NEMA Standard 9-15-1982.

8.16 DIELECTRIC BREAKDOWN PARALLEL TO LAMINATIONS

8.16.1 Specimens

Five specimens 2 inches×3 inches×the thickness of the sheet shall have the copper removed by etching.

8.16.2 Procedure

The tests shall be conducted in accordance with ASTM D229, as modified by 7.6.

NEMA Standard 9-15-1982.

8.17 PERMITTIVITY AND DISSIPATION FACTOR

Four specimens 4 inches×4 inches×the thickness of the sheet shall have the copper removed by etching.

The electrodes shall cover both sides of the sheet and shall consist of silver paint sprayed or painted on. The test shall be performed on the specimens within 1 minute after they are removed from the water.

The test shall be conducted in accordance with ASTM D 150.

8.18 FLEXURAL STRENGTH (FLATWISE)

8.18.1 Specimens

Four specimens, two in the lengthwise direction and two in the crosswise direction shall have the copper

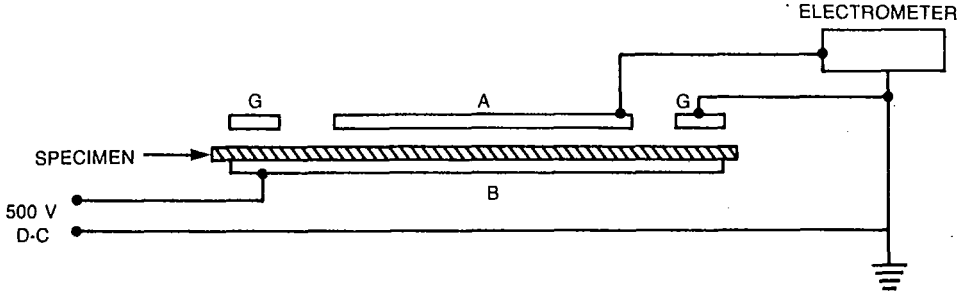


Figure 8-4
CONNECTIONS FOR VOLUME RESISTIVITY

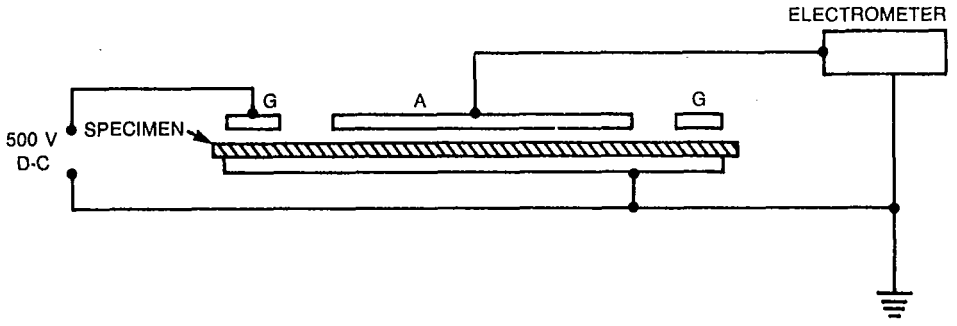


Figure 8-5
CONNECTIONS FOR SURFACE RESISTANCE OR SURFACE RESISTIVITY

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NEMA LI*1 89 ■ 6470247 0019828 7 ■

removed by etching. See 7.6 for the size of the specimens.

8.18.2 Procedure

The tests shall be conducted in accordance with ASTM D 790, as modified by 7.6.4.

NEMA Standard 9-15-1982.

8.19 FLEXURAL STRENGTH (FLATWISE) AT ELEVATED TEMPERATURES FOR GRADES G-11 AND FR-5

8.19.1 Specimens

Four specimens cut in the lengthwise direction shall have the copper removed by etching. See 7.6 for the size of the specimens.

8.19.2 Procedure

The general procedure for the flexural strength test shall be in accordance with 7.6.4. For the flexural strength test at elevated temperature, an enclosure in which a temperature of 150°C (302°F) ±2°C (3.6°F) can be maintained shall be provided about the fixture of the testing machine. The specimens shall be placed in the oven at 150°C (302°F) for 60 (plus 6, minus 0) minutes, at the end of which period they shall be placed in the fixture of the testing machine and tested.

NEMA Standard 9-15-1982.

8.20 FLAME RESISTANCE

The test shall be conducted in accordance with UL 94, using specimens from which the copper has been removed by etching.

NEMA Standard 9-15-1982.

8.21 OVEN BLISTER TEST

8.21.1 Specimen

One unconditioned specimen 6 inches×6 inches×the thickness of the sheet shall be tested.

8.21.2 Procedure

The specimen shall be supported vertically in a nonmetallic rack in a horizontal-flow air-circulating oven maintained at the temperature indicated in 8.9. The plane of the specimen must be parallel to the air flow.

At the end of the time specified for each grade in 8.9, the specimen shall be removed from the oven and examined for blisters.

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Section 9
COPPER-CLAD THIN LAMINATES
(Intended primarily for multilayer printed circuits)

SCOPE

This part covers Grades G-10 and FR-4 laminates having 0.5-, 1- or 2- ounce copper foil bonded to one or both surfaces and intended primarily for use in multilayer printed wiring. This part shall be limited to materials having a nominal laminate thickness of less than 0.031 inch.

GENERAL

9.1 MATERIALS

9.1.1 Laminate Base

The base material shall be of the following types:

NEMA Grade	Type
G-10	Glass fabric base, epoxy resin
FR-4	Glass fabric base, epoxy resin, general purpose flame resistant

9.1.2 Copper Foil Surfaces

The surfaces shall be copper foil having a minimum purity of 99.50 percent† (silver considered as copper) nominal weights, thickness, and tolerances:

Nominal Weight		Nominal Thickness*	
Ounces per Square Foot	Plus or Minus Tolerance, Percent	Inches	Plus or Minus Tolerance, Percent
0.146	10	0.00020	—
0.263	10	0.00036	—
0.350	10	0.00052	—
0.500	10	0.00070	0.0001
1.000	10	0.00140	0.0002
2.000	10	0.00280	0.0003
3.000	10	0.00420	0.0004
4.000	10	0.00560	0.0006
5.000	10	0.00700	0.0070

*Approved as Authorized Engineering Information.

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†The analysis for determining the minimum purity of the copper shall be made in accordance with ASTM E 53.

DIMENSION

9.2 THICKNESSES AND TOLERANCES

9.2.1 Base Laminate

Nominal Thickness Excluding Copper, Inches	Plus or Minus Thickness Tolerances of Base Laminate After Etching, Inches	
	Class I	Class II
0.0020–0.0045	0.0010	0.0007
0.0046–0.0065	0.0015	0.0010
0.0066–0.0120	0.0020	0.0015
0.0121–0.0200	0.0025	0.0020
0.0201–0.0300	0.0030	0.0025

9.2.2 Sheets

The tolerance in the length and width of sheets shall be plus 1, minus 0 inch from the stated size.

9.2.3 Copper-Clad Panels

Plus or Minus Tolerance in Length or Width, Inches		
12 inches and under	12–24 inches, Incl.	Over 24 inches
0.031	0.063	0.125

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9.3 FINISH

Copper surfaces shall be free from defects that may affect serviceability and, in addition, shall meet the following specific requirements.

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9.3.1 Pits and Dents

The maximum total point count for pits and dents per square foot of panel inspected shall be less than 30. The point system shall be as follows:

Longest Dimension, Inches	Point Value
0.005–0.010, incl.	1
0.011–0.020, incl.	2
0.021–0.030, incl.	4
0.031–0.040, incl.	7
Over 0.040	30

Pits are defined as depressions occurring as imperfections that materially reduce the thickness of the copper foil.

Dents are defined as depressions in the copper foil that do not significantly decrease the thickness of the copper foil.

9.3.2 Scratches

Any number of scratches less than 140 microinches deep shall be permitted.

Deeper scratches are permitted within 0.250 inch of the edge for sheets and 0.125 inch of the edge for panels.

9.3.3 Indentations from Handling

Indentations from handling are large areas (0.500 inch to 3 inches in the longest dimensions) that appear as convex or concave departures from the laminate surface. Any number of such occurrences shall be permitted provided that neither resin nor glass fibers are fractured.

NEMA Standard 9-15-1982.

9.4 PROPERTY VALUES

See Table 9-1.

NEMA Standard 9-15-1982.

9.5 SOLVENT RESISTANCE

After the copper has been removed by etching, the laminate shall not delaminate nor blister when suspended for 2 minutes in trichlorethane vapor over the boiling liquid at atmospheric pressure.

NEMA Standard 9-15-1982.

9.6 WORKMANSHIP

There shall be no evidence of resin-starved areas, blisters, or voids in the core material.

NEMA Standard 9-15-1982.

9.7 FOREIGN PARTICLES

After etching the surface of the laminate shall be substantially free from foreign material or contamination, such as copper oxide, carbonized resins, dirt, lint, or other extraneous matter.

The unclad surface (of laminates having copper on one side) shall be free of oils, grease, silicone, or other substances that would render the laminate unusable for subsequent bonding or laminating processes.

NEMA Standard 9-15-1982.

9.8 PEEL STRENGTH TEST

9.8.1 Specimens

The pattern shown in Figure 9-1 shall be etched on two unconditioned specimens 2 inches × 2 inches × the thickness of the sheet to be tested. The specimens shall be bonded to a rigid backing material for testing. 3M No. 465 adhesive transfer tape or the equivalent shall be used for bonding the test specimen on the rigid backing.

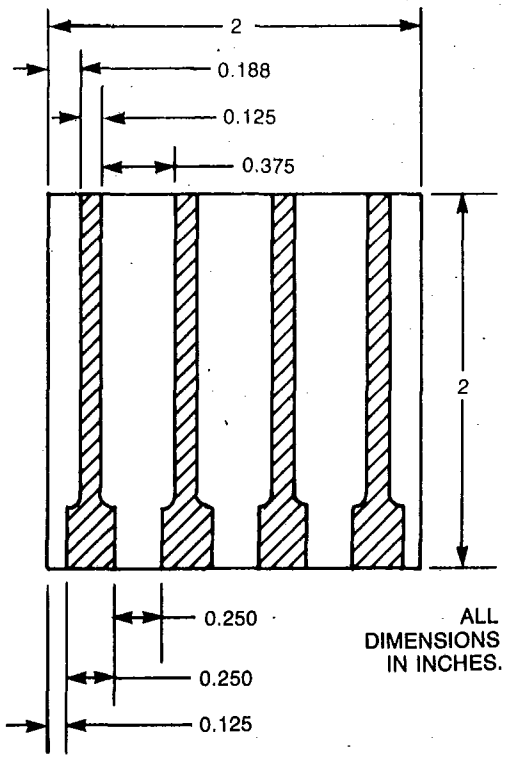


Figure 9-1
ETCHED TEST PATTERN FOR COPPER PEEL STRENGTH

9.8.2 Procedure

The copper foil shall be peeled back from the 0.250-inch end of the copper strip for approximately 1 inch so that the line of peel is perpendicular to the edge of the specimen.

Each specimen shall be clamped or held on a horizontal surface with the peeled copper strip up, providing a 1-inch span.

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Table 9-1
PROPERTY VALUES FOR GRADES G-10 AND FR-4 LAMINATES

Property to be Tested	Conditioning Procedure (See 6.4.1)	Grade G-10	Grade FR-4	Test Methods Paragraph
Peel Strength, Minimum Pounds per Inch of Width	A	4.5	4.5	9.8
0.500 ounce copper	A	6	6	9.8
1-ounce copper	A	8	8	9.8
2-ounce copper				
Volume Resistivity, Minimum, Megohm Centimeters	C-96/35/90	10^4	10^4	9.9
Surface Resistance, Minimum, Megohms	C-96/35/90	10^4	10^4	9.9
Permittivity, Maximum Average at 1 MHz	C-40/24/50	5.4	5.4	9.10
Dissipation Factor, Maximum Average at 1 MHz	C-40/24/50	0.035	0.035	9.10
Flame Resistance	A	...	Class A	9.11
Electric Strength, Min. V/mil	D48/50	750	750	ASTM D 229
Water Absorption*	...	...	...	...

*No standards for water absorption of thin copper-clad laminates are established because considerable investigation of this property has shown that the experimental error of the test is so large that the results are meaningless. Furthermore, the application for thin laminates in multilayer circuits does not expose them to environmental conditions in which their water absorption is important. (This note is approved as Authorized Engineering Information.)

The end of the peeled strip shall be gripped between two knurled jaws of a clamp with a chain attachment to a dial indicating force indicator that has been adjusted to compensate for the weight of the chain and clamp.

The jaws shall cover the full width of the copper strip and shall be clamped parallel to the line of the peel.

Holding the force indicator in a vertical plane, a steady vertical pull (approximately 2 inches per minute) shall be exerted until the needle indicator shows a constant reading.

If the full width of the strip does not peel, the result shall be discarded and the test repeated.

Where both sides of the laminate are copper clad, the test shall be repeated for the second side.

NEMA Standard 9-15-1982.

9.9 VOLUME RESISTIVITY AND SURFACE RESISTANCE

See 8.14.

9.10 PERMITTIVITY AND DISSIPATION FACTOR

The test specimens and the test procedure, using 1-inch diameter discs, shall be in accordance with ASTM D 229.

NEMA Standard 9-15-1982.

9.11 FLAME RESISTANCE OF MULTILAYER PRODUCTS

This laboratory test method for industrial laminates and impregnated cloth will not necessarily produce information with regard to performance under a full-scale fire condition. It does, however, provide a means of comparing materials under controlled laboratory conditions.

Authorized Engineering Information 9-15-1982.

9.11.1 Specimens

Six test specimens, each 1 inch wide by 18 inches long (25 mm wide by 460 mm long), shall be cut from the sample, three with the long dimension parallel to the warp direction of the glass cloth and three with the long dimension parallel to the fill direction. The specimens shall be distributed uniformly across the width of the sample sheet, but no part of any specimen shall be closer than 1 inch (25 mm) from an edge. Copper shall be removed from laminates by etching.

A line shall be marked across the width of each strip 6 inches (150 mm) from one end, with the ends of the line defined by small nicks cut into the edge of the strip at the termination of the line.

9.11.2 Apparatus

The enclosure shall be a shield constructed from sheet metal or other fire-resistant material. The inside dimensions shall be 12 inches in width, 12 inches in depth from front to back, and 30 inches in height (30 cm wide by 30

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cm deep by 76 cm high). The shield shall be so constructed as to provide a ventilating opening approximately 1 inch (25 mm) in height around the bottom. It shall have a viewing window in one side of sufficient size and in such a position that the entire length of the specimen under test can be observed. One side of the shield shall be hinged so that it can be readily opened and closed to facilitate the mounting and ignition of the specimen.

A clamping device shall be provided within the enclosure so that the specimen will hang with its length in a vertical position, coincident with the central vertical axis of the enclosure. As clamped for the test, the lower end of the specimen shall be 1 inch (25 mm) above the unlit Tirrill burner which will be used to provide the ignition. There shall be a remote-access rod passing through one wall of the enclosure for positioning the burner without opening the enclosure after the specimen has been positioned.

9.11.3 Procedure

Specimens shall be tested in the "as-received" condition (equivalent to 24 hours in the standard laboratory ambient condition).

The specimen shall be clamped in the vertical position. If the product under test is a laminate, the 6-inch gauge mark shall be at the upper end of the specimen. For specimens of impregnated glass cloth (prepreg), the gauge mark shall be at the lower end.

A 100-gram weight shall be attached to the lower end of the specimen to prevent it from curling during burning. Ignition shall be provided by a Tirrill burner that is supplied with gas having a heat of combustion of 1000 btu per cubic foot (40 kilojoules per cubic meter), such as natural gas composed of substantially pure methane. The flame of the burner shall be adjusted to a non-luminous cone 1 inch (25 mm) high.

With the specimen in position, the burner shall be placed centrally beneath the specimen. The flame shall be allowed to impinge upon the lower end of the specimen for 5 seconds and shall then be removed.

Upon removal of the flame, the burning shall be timed with a stopwatch and the time recorded when the burning has stopped. When the burning has stopped, it also shall be noted whether the burning has progressed to the gauge mark, which is 6 inches from the lower end for impregnated cloth and 12 inches from the lower end for laminates.

9.11.4 Evaluation of Results

Two of the three specimens for each direction shall meet the applicable requirement. Products that fail to meet either the "maximum" burning time or "maximum" extent of burning requirement shall be designated as Class B.

	Laminate		Impregnated Cloth	
	Class A	Class B	Class A	Class B
Burning time, seconds	15 max	over 15	15 max	over 15
Extent of burning, inches	12 max	over 12	6 max	over 6

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Section 10
EPOXY-RESIN-IMPREGNATED GLASS CLOTH (PREPREG)

SCOPE

This Section covers epoxy-resin-impregnated glass cloth in the semicured stage, intended for bonding together the individual circuit layers of multilayer printed wiring boards.

10.1 TYPE DESIGNATIONS OF PREPREG

Designation	Description
A-1	General purpose epoxy resin, 1 mil glass cloth
A-2	General purpose epoxy resin, 2 mil glass cloth
A-3	General purpose epoxy resin, 3 mil glass cloth
A-4	General purpose epoxy resin, 4 mil glass cloth
A-6	General purpose epoxy resin, 6 mil glass cloth
B-1	Flame resistant epoxy resin, 1 mil glass cloth
B-2	Flame resistant epoxy resin, 2 mil glass cloth
B-3	Flame resistant epoxy resin, 3 mil glass cloth
B-4	Flame resistant epoxy resin, 4 mil glass cloth
B-6	Flame resistant epoxy resin, 6 mil glass cloth

10.2 MATERIALS

10.2.1 Resins

The resins shall be either general purpose or flame resistant epoxy resin, similar to those used in Grades G-10 and FR-4 copper-clad thin laminates.

10.2.2 Glass Cloths

The glass cloth shall be plain-weave fabrics, woven from continuous filament E-glass fiber yarns.

10.3 PROPERTIES AND DESIGNATIONS OF GLASS CLOTHS

Glass cloths used in prepreg covered by this standard are listed in the following table, along with their commonly used designations and properties when in the unimpregnated state:

Type	Designation Textile Industry	Representative Thickness and Tolerances	Nominal Weight Ounces per Square Yard
1 mil	104	0.0010±0.0005	0.56
	106	0.0012±0.0005	0.73
2 mil	107*	0.0015±0.0005	1.05
	108*	0.0022±0.0005	1.40
	1080	0.0020±0.0005	1.40
	2112	0.0030±0.0010	2.05
3 mil	112*	0.0036±0.0010	2.10
	113*	0.0032±0.0010	2.43
	2113	0.0029±0.0010	2.30
4 mil	116*	0.0038±0.0010	3.10
	2116	0.0036±0.0010	3.10
	1675	0.0046±0.0010	2.90
6 mil	1528*	0.0065±0.0010	5.95
	7628	0.0067±0.0010	6.00

*Glass cloths woven from plied yarns.

NEMA Standard 9-15-1982.

10.4 TOLERANCES IN LENGTH AND WIDTH

10.4.1 Cut Sheet Pieces

The tolerance of prepreg supplied in cut-to-size sheets shall be:

Plus or Minus Tolerance in Length or Width, Inches		
12 inches and under	12–24 inches, Incl.	over 24 inches
0.063	0.125	0.188

10.4.2 Rolls

The tolerance of prepregs supplied in full width rolls shall be ±1 inch (25 mm) in width and ±36 inches (900 mm) in length from nominal dimension. The tolerance in width of prepreg material that is slit to order shall be ±0.062 inch (1.57 mm).

10.5 SPLICES IN ROLLS

There shall be no more than two splices per 100 yards.

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PROPERTIES OF PREPREG

10.6 APPEARANCE

There shall be no foreign matter present that will be detrimental to the intended use of the prepreg.

NEMA Standard 9-15-1982.

10.7 SHELF-LIFE

The properties of prepregs shall remain within the limits of these standards for a minimum of three months from date of receipt provided the prepregs are kept under storage conditions of 21°C (70°F) maximum ambient temperature and 50 percent maximum relative humidity and provided there is no ultraviolet light or other catalyst in the environment.

NEMA Standard 9-15-1982.

In all cases, prepregs should be stored under the manufacturer's recommended storage condition.

Authorized Engineering Information 9-15-1982.

10.8 TEST FOR PROPERTIES

Because prepreg material by its very nature is perishable in that its resin flow and degree of resin advancement change rapidly following the time of manufacture, these property values will change with time.

10.9 RESIN CONTENT

The resin content of prepregs, when measured in accordance with 10.16, shall be as follows:

NEMA Designation	Resin Content, Percent	
	Nominal Range*	Plus or Minus Tolerance in Resin Content
A-1 and B-1	60–85	5
A-2 and B-2	55–75	5
A-3 and B-3	50–70	5
A-4 and B-4	40–60	5
A-6 and B-6	35–50	5

*For nominal resin contents within this range, the manufacturer should be consulted. (This note approved as Authorized Engineering Information.)

NEMA Standard 9-15-1982.

10.10 RESIN FLOW

For the nominal value of resin flow, the manufacturer should be consulted. (This sentence approved as Authorized Engineering Information.) The tolerance on the resin flow of prepregs, when measured in accordance with 10.16 shall be as follows:

Resin Flow, Percent	Tolerance
2 and under	+0, –2
Over 2	±5

NEMA Standard 9-15-1982.

10.11 VOLATILES CONTENT

The volatiles content of all types of prepregs, when measured in accordance with 10.16 shall be no greater than 0.75 percent.

NEMA Standard 9-15-1982.

10.12 GEL TIME (FOR RESIN FLOW GREATER THAN 2 PERCENT NOMINAL)

The nominal gel time of the resin in prepreg when measured in accordance with 12.19 shall be as follows:

Nominal Range, seconds	Tolerance, seconds
Up to 100	±15
101–150	±20
151–200	±25
201–	±30

10.13 FLAME RESISTANCE

The flame resistance of prepregs, when measured in accordance with 9.11, shall be as follows:

NEMA Designation	Flame Resistance
A-1, A-2, A-3, A-4	Class B
B-1, B-2, B-3, B-4	Class A

NEMA Standard 9-15-1982.

10.14 ELECTRICAL PROPERTIES

The electrical properties of a laminate made from two plies of prepreg and cured according to the manufacturer's recommendations, shall be as follows when tested in accordance with ASTM D 229:

1. Permittivity, Maximum, at 1 MHz – 5.4. C40/23/50
2. Dissipation Factor, Maximum, at 1 MHz – 0.035. C40/23/50
3. Electric Strength, Minimum V/mil – 750 D48/50.

NEMA Standard 9-15-1982.

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TEST PROCEDURES

10.15 TEST FOR VOLATILES CONTENT

10.15.1 Specimens

Three specimens shall be cut from the prepreg in the form of squares with their diagonals parallel to the warp yarns. The specimen shall be cut from the center of the width of the prepreg and one near each edge, but not closer than 1 inch (25 mm) from the adjacent edge. A small clean hole shall be punched in one corner of each specimen to permit hanging them in an oven. All loose particles and projecting fibers shall be removed from the specimens.

10.15.2 Procedure

Each specimen* shall be weighed to the nearest 0.001 gram and then hung from a hook and heated for 15 minutes in a circulating air oven at 163°C±8°C (325°F±5°F). At the end of this time, the specimens shall be removed one at a time* and, within 5 seconds, weighed again to the nearest 0.001 gram. The volatiles content shall be calculated from the equation:

$$\text{Volatiles Content, Percent} = \frac{\text{Loss in weight}}{\text{Original weight of specimen}} \times 100$$

The average of the three specimens shall be used, except for Types A-1 and B-1*.

If the weighing after heating cannot be completed within 5 seconds, the specimens shall be placed in a desiccator until they can be weighed within 5 seconds after their removal from the dissicator.

*For Types A-1 and B-1, the three specimens shall be taken together and weighed as one specimen.

10.16 TEST FOR RESIN CONTENT

10.16.1 Specimens

Three specimens shall be cut from the prepreg material in the form of squares with their diagonals parallel to the warp yarns. The specimens shall have a minimum side of 4 inches (10 cm) or shall weigh a minimum of 7 grams each. One specimen shall be cut from the center of the width of the prepreg, and one near each edge, but not closer than 1 inch (25 mm) from the adjacent edge. All loose particles and projecting fibers shall be removed from the specimens.

10.16.2 Procedure

The three specimens shall be weighed together to the nearest 0.1 gram in a previously weighed crucible. The crucible containing the specimens shall be heated in a muffle furnace at 480 to 600°C (900 to 1100°F) until a constant weight is reached but not for less than 30 minutes. If the residue shows evidence of glass fusion, a lower temperature must be used, but the residual glass cloth must be completely white at the end of the ignition period. The crucible and residue shall be cooled to room temperature in a desiccator reweighed to the nearest 0.1 gram. The loss in the weight of the specimens represents the resin content, which shall be calculated from the following equation:

$$\text{Resin Content, Percent} = \frac{\text{Loss in weight}}{\text{Original weight of specimen}} \times 100$$

10.17 TEST FOR RESIN FLOW

10.17.1 Specimens

The test specimen shall be comprised of a number of squares, each 4 inches ± 0.010 inches (100 mm ± 0.3 mm) on a side, to aggregate a minimum of 20 grams. The squares shall be cut from the prepreg with their diagonals parallel to the warp yarns, with no square closer than 1 inch (25 mm) to an edge of the prepreg. The total number of squares cut shall be distributed as evenly as possible across the width of the prepreg. All loose particles and projecting fibers shall be removed from the squares.

10.17.2 Procedure

The squares shall be stacked together with their edges in careful alignment and may be fastened together with a staple or other suitable means. The stack of squares shall then be weighed to the nearest 0.01 gram. The test specimen shall be laminated between stainless steel caul plates 0.062 inch (1.6 mm) thick and 7 inches (178 mm) square in a press that has been preheated to a temperature of 171°C±2.8°C (340°F±5°F). The press shall be closed and the pressure increased to 200 lbs/in^2 (138N/cm^2) ±10 percent in a maximum elapsed time of 5 seconds. This pressure shall be held until there is no further flow of resin (approximately 10 minutes). When the laminate is cured sufficiently to permit handling it without damage, the press shall be opened and the specimen removed and allowed to cool. With a suitable punch-and-die set, a disk 3.192 inches±0.010 inch (79.8 mm±0.3 mm) in diameter shall be punched from the center of the specimen and weighed to the nearest 0.01 gram. The resin flow shall be calculated from the equation:

$$\text{Resin Flow, Percent} = \frac{\text{Original Weight} - (2 \times \text{Weight of disk})}{\text{Original Weight}} \times 100$$

NEMA Standard 9-4-1969.

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10.18 GEL TIME

10.18.1 Specimens

One specimen approximately 10 inches×10 inches (250 mm×250 mm), shall be cut from the prepreg from a location as to give a random sample, but no part of the specimen closer than 1 inch (25 mm) from the edge.

10.18.2 Test Apparatus

The test apparatus shall consist of:

1. Round toothpicks with tapered ends;
2. Polyester film;
3. A heated platen or hot plate held at a temperature of 191°C±1.5°C (340°F±3°F) in a test area free from chilling currents of air; and
4. A stop watch or other suitable timer readable to 1-second intervals.

10.18.3 Procedure

Extract dry resin from prepreg (B-stage) by folding or crushing. Allow B stage resin to fall onto a smooth clean sheet of polyester film. Pour collected resin through number 60 mesh wire sieve onto another sheet of film. Carefully weigh 200±20 milligrams (mg) of the resin onto a 3"×3" sheet of clean waxed paper. Set temperature of cure plate (platen, hot plate, or melting point apparatus) to 171±0.5°C (340°±3°F) on the surface. Make sure that all resin residue from any previous test has been scraped from the surface of the cure plate. Lubricate the surface of the cure plate with montan wax (or other suitable mold release agent). Wipe surface clean – free of visible mold release agent – with a clean paper towel. Pour the 200 mg sample of resin on the center of the cure plate. Start stop watch immediately. Place the tapered end of a round toothpick against the surface of the cure plate (end of toothpick not in contact with surface of cure plate will have to be elevated slightly). Roll toothpick back and forth, maintaining contact with surface of cure plate until 20 seconds have elapsed. At this time start stroking the resin immediately, using a circular motion 0.375 to 0.500 inches in diameter. Stroke in such a manner that every circle moves part of the resin from the outside of the pool toward the center. Care shall be taken to limit the pool size to an area 0.750 to 0.875 inches in diameter. Keep the toothpick in contact with resin and surface of the cure plate at all times. As the resin becomes stiff, it will not be possible to continue exchanging outside resin with inside resin, but continue stroking with as much exchange as possible without breaking the toothpick. If resin breaks up, continue stroking the largest piece. If this breaks up, continue stroking the remaining piece of this portion even though now a larger piece of the original pool may be present at some other place on the hot plate. When the stroked pieces separate from the hot plate, stop the watch. This is the end-point, and the total elapsed time is the gel time.

NEMA Standard 9-15-1982.

10.19 TEST FOR FLAME RESISTANCE

See 9.11.

NEMA Standard 1-14-1975.

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Section 11
ELECTRICAL-MECHANICAL GRADES GPO-1, GPO-2, AND GPO-3, AND PUNCHING GRADES GPO-1P, GPO-2P, AND GPO-3P POLYESTER GLASS MAT SHEET LAMINATES

SCOPE

This section covers Grades GPO-1, GPO-2, and GPO-3 polyester glass-mat-sheet laminates intended for both mechanical and electrical applications. Grade GPO-1 laminates are suitable for general-purpose applications. Grade GPO-2 laminates for applications where flame resistance is required, and GPO-3 laminates for applications where resistance to carbon tracking and flame resistance is required. GPO-1P, GPO-2P, and GPO-3P are the corresponding grades, primarily intended for good punching characteristics – with some loss in electrical and mechanical properties. For these grades, properties are tabulated for thicknesses of 0.062 to 0.188 inch inclusive, only.

GENERAL

11.1 DESCRIPTION

Grade GPO-1, GPO-2, GPO-3, GPO-1P, GPO-2P and GPO-3P sheets are made from a mat of random-laid glass fibers that is saturated with polyester resin combined with suitable fillers, cured by applying heat and pressure and meeting the performance requirements specified herein.

Authorized Engineering Information 9-15-1982.

11.2 QUALITY AND WORKMANSHIP

All GPO grade laminates shall be uniform in quality and free from delaminations.

NEMA Standard 9-15-1982.

11.3 SHEET SIZE AND TOLERANCES IN LENGTH AND WIDTH

Because of variations in the size of press equipment, there is considerable variation in the length and width of sheets being manufactured. The sizes range between 24 and 48 inches in width and between 36 and 96 inches in length. There are some manufacturers who may produce other sizes outside of these ranges.

Authorized Engineering Information 9-15-1982.

11.3.1 Untrimmed Sheets

The tolerances in the length and width of a manufacturers' standard size untrimmed sheet shall be ±0.250 inch for lengths and widths up to and including 4 feet, and ±0.500 inch for lengths and widths over 4 feet.

11.3.2 Trimmed Sheets

The tolerance in the length and width of a manufacturer's standard size trimmed sheet shall be ±1 inch.

11.3.3 Cut Pieces

The tolerances in the length and width of pieces cut from sheets shall be:

Nominal Thickness, Inches	Plus or Minus Tolerances in Length or Width, Inches		
	6 inches and Under	6–18 inches, Incl.	18–24 Inches, Incl.
0.031–0.250	0.010	0.015	0.031
0.251–0.500	0.012	0.017	0.031
0.501–1.000	0.015	0.020	0.031
1.001–1.500	0.018	0.030	0.062
1.501–2.000	0.022	0.040	0.062

NOTE – 0.062 to 0.188 inch, inclusive, for GPO-1P, GPO-2P, and GPO-3P.

NEMA Standard 9-15-1982.

11.4 EDGES OF UNTRIMMED SHEETS

Untrimmed sheets shall have edges as molded but shall be free from sharp flash.

The outer portion of an untrimmed sheet for a distance of 0.500 inch back from the edge shall not be required to conform with these standards.

NEMA Standard 9-15-1982.

11.5 TOLERANCES FOR WARP AND TWIST

Thickness, Inches	Maximum Warp or Twist (Based on 36-inch Dimension), Percent
0.031–0.125	2.5
0.126–0.250	1.5
0.251–0.750	0.5
0.751–MAX	0.25

NOTE 1 – In the case of warp, this percentage is stated in terms of the lateral dimensions (length or width); in the case of twist, the percentage is stated in terms of the dimensions from one corner to the diagonally opposite corner. For method of measuring warp and twist, see ASTM D709.

NOTE 2 – These values do not apply to cut pieces but only to sheet sizes as manufactured.

NOTE 3 – 0.062 to 0.188 inch, inclusive, for GPO-1P, GPO-2P, and GPO-3P.

Authorized Engineering Information 11-16-1989.

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DIMENSIONS

11.6 NOMINAL THICKNESSES AND TOLERANCES

Nominal thicknesses and tolerance shall be given in the following table.

At least 90 percent of the area of the sheet shall be within the tolerances given, and at no point shall the thickness from the nominal be a value greater than 125 percent of this specified tolerance.

Nominal Thickness, Inches	Plus or Minus Tolerances	Nominal Thickness, Inches	Plus or Minus Tolerances
0.031	0.0075	0.625	0.0270
0.062	0.0075	0.750	0.029
0.094	0.0090	0.875	0.031
0.125	0.0100	1.000	0.033
0.156	0.0110	1.125	0.035
0.188	0.0125	1.250	0.037
0.219	0.0140	1.375	0.039
0.250	0.0150	1.500	0.041
0.312	0.0175	1.625	0.043
0.375	0.0200	1.750	0.045
0.438	0.0220	1.875	0.047
0.500	0.0240	2.000	0.049

NOTE—0.062 to 0.188 inch, inclusive, for GPO-1P, GPO-2P, and GPO-3P.

NEMA Standard 9-15-1982.

STANDARD PROPERTIES
(See Section 6 for conditioning procedures)

11.7 FLEXURAL STRENGTH

The minimum flexural strength (average of four test specimens), measured flatwise, when tested under condition A1 in accordance with ASTM D 790, shall be 18,000 psi for Grades GPO-1, GPO-2, and GPO-3 for thicknesses of 0.062 to 0.500 inch, inclusive, and 16,000 psi for Grades GPO-1P, GPO-2P, and GPO-3P for thicknesses of 0.0062 to 0.188 inch, inclusive.

NEMA Standard 9-15-1982.

11.8 TENSILE STRENGTH

The minimum tensile strength (average of four specimens), when tested under Condition A in accordance with ASTM D 638, shall be 8,000 psi for grades GPO-1, GPO-2, and GPO-3 for thicknesses 0.062 to 0.500 inch, inclusive, and 8,000 psi for Grades GPO-1P, GPO-2P, and GPO-3P for thicknesses 0.062 to 0.188 inch, inclusive.

11.9 IMPACT STRENGTH

The minimum Izod impact strength (average of five test specimens tested edgewise under condition E-48/50 in accordance with ASTM D 229) shall be 8 ft-lb/1-inch notch in both directions for thicknesses of 0.125 to 0.500 inch, inclusive, for Grades GPO-1, GPO-2, and GPO-3; and 5 ft-lb/1-inch notch in both directions for thicknesses of 0.125 to 0.188 inch, inclusive, for Grades GPO-1P, GPO-2P, and GPO-3P.

NEMA Standard 9-15-1982.

11.10 COMPRESSIVE STRENGTH, FLATWISE

The minimum flatwise compression strength (average of four specimens) is 30,000 psi for Grades GPO-1, GPO-2, and GPO-3 for thicknesses 0.062 to 0.500 inch, inclusive; and 20,000 psi for Grades GPO-1P, GPO-2P, and GPO-3P for thicknesses 0.062 to 0.188 inch inclusive. This will be tested in accordance with ASTM D 695, Condition A.

11.11 BONDING STRENGTH

The minimum bonding strength for Grades GPO-1, GPO-2, and GPO-3 (average of four test specimens) for the 0.500-inch thickness, when tested in accordance with ASTM D 229, shall be 850 pounds under Condition A and 800 pounds under Condition D-48/50.

NEMA Standard 9-15-1982.

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11.12 DIELECTRIC BREAKDOWN, PARALLEL TO LAMINATIONS

The minimum dielectric breakdown parallel to laminations (average of four test specimens), using the step-by-step test, shall be 40 kV under Condition A_1 and 15 kV under Condition D-48/50_1 for thicknesses of 0.062 to 0.500 inch, inclusive for Grades GPO-1, GPO-2, and GPO-3; and 5 kV under Condition D-48/50_1 for thicknesses of 0.062 to 0.188 inch, inclusive, for Grades GPO-1P, GPO-2P, and GPO-3P.

The test shall be made in accordance with 7.6.1.

NEMA Standard 9-15-1982.

11.13 ELECTRIC STRENGTH, PERPENDICULAR TO LAMINATIONS

The minimum dielectric breakdown, perpendicular to laminations (average of four specimens) using the short time method, in Condition A, shall be 300 volts per mil for the 0.062 thickness. (The values for this test will vary with thickness of the laminate).

NEMA Standard 11-16-1987.

11.14 ARC RESISTANCE

The minimum arc resistance (average of five test specimens), when tested under Condition A_1 in accordance with ASTM D 495, using tungsten electrodes, shall be 100 seconds for Grades GPO-1, GPO-2, GPO-1P, and GPO-2P, and 150 seconds for Grades GPO-3 and GPO-3P.

NEMA Standard 9-15-1982.

11.15 WATER ABSORPTION

The maximum water absorption (average of three test specimens, each 3 inches×1 inch×thickness), when tested in accordance with ASTM D 229, shall be as shown in Table 11-1.

NEMA Standard 9-15-1982.

Table 11-1
MAXIMUM WATER ABSORPTION, PERCENT

Thickness, Inches	Condition D-24/23					
	GPO-1	GPO-2	GPO-3	GPO-1P	GPO-2P	GPO-3P
0.062	1.00	0.8	0.6	1.0	0.8	0.6
0.125	0.70	0.6	0.5	0.7	0.6	0.5
0.500	0.35	0.25	0.25	—	—	—

11.15a WATER ABSORPTION (ALTERNATE) (SHEETS)

The water absorption shall be tested in accordance with ASTM D 229 except the specimen size shall be 2 inches×2 inches×the thickness of the sheet. The absolute weight gain shall be reported in milligrams as shown in Table 11-2.

Suggested Standard for Future Design 9-15-1982.

Table 11-2
MAXIMUM WATER ABSORPTION, MILLIGRAMS

Thickness, Inches	Condition D-24/23					
	GPO-1	GPO-2	GPO-3	GPO-1P	GPO-2P	GPO-3P
0.062	43	43	43	43	43	43
0.125	56	56	56	56	56	56
0.500	115	115	115	115	115	115

11.16 FLAME RESISTANCE (GPO-2, GPO-3, GPO-2P, AND GPO-3P) (SHEETS ONLY)

11.16.1 Thicknesses of 0.500 to 2 Inches, Incl.

The flame resistance for Grades GPO-2 and GPO-3 shall be only 75 seconds minimum average ignition time and 85 seconds maximum average burning time when measured in accordance with 7.7.

11.16.2 Thicknesses of 0.0062 to Less Than 0.500 Inch for GPO-2 and GPO-3, through 0.188 inch for GPO-2P and GPO-3P

The flame resistance shall be Class O when tested in accordance with 7.11.

NEMA Standard 9-15-1982.

11.17 TRACKING RESISTANCE (GPO-3 and GPO-3P) (SHEETS ONLY)

Under Condition A, with specimens 0.250 inch in thickness, the minimum time to track to the 1-inch mark shall be 300 minutes when tested in accordance with ASTM D 2303.

NEMA Standard 9-15-1982.

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ENGINEERING INFORMATION
(TYPICAL VALUES, NOT MINIMUM OR MAXIMUM VALUES)

11.18 TYPICAL VALUES

The following typical values represent average values for a specific property taken from a number of tests on the products of several laminators and serve only as a general guide in design. These typical values are not intended as standards.

1. Flexural strength, psi, Condition E 1/130; T-130 for 0.125 to 0.500 inch thickness, inclusive – 6000 for Grades GPO-1, GPO-2, and GPO-3; and up to 0.188 inch thickness, inclusive, for Grades GPO-1P, GPO-2P, and GPO-3P.
2. Modulus of elasticity in flexure, flatwise, Condition A, psi$\times 10^6$ for 0.125 inch thickness.
   Lengthwise – 1.2
   Crosswise – 1.0
3. Density, grams per cubic centimeter (varies greatly with the type of filler used) – 1.5 to 1.9 for Grades GPO-1, GPO-2, GPO-1P, and GPO-2P and 1.70 to 1.95 for Grades GPO-3 and GPO-3P.
4. Permittivity for 0.062 inch thickness
   At 1 MHz (Grade GPO-1 and GPO-1P)
   Condition A* – 4.3
   Condition D-24/231 – 4.4
   At 60 Hz (Grades GPO-1, GPO-2, and GPO-3)
   Condition A – 4.5
   At 60 Hz (Grades GPO-1P, GPO-2P, and GPO-3P)
   Condition A – 6.0
5. Dissipation factor for 0.062 inch thickness
   At 1 MHz (Grade GPO-1 and GPO-1P)
   Condition A – 0.03
   Condition D 24/23 – 0.06
   At 60 Hz (Grades GPO-1, GPO-2, and GPO-3)
   Condition A – 0.05*
   At 60 Hz (Grades GPO-1P, GPO-2P, and GPO-3P)
   Condition A – 0.09
6. Rockwell hardness, M-100 (all thicknesses).
7. Modulus of elasticity in tension for 0.125 inch thickness.
   Lengthwise – 1,000,000 psi
   Crosswise – 900,000 psi
8. Compressive strength, psi, Condition A for Grades GPO-1, GPO-2, and GPO-3
   Edgewise – 20,000 psi
9. Thermal expansion: -2.0×10^{-5} cm/cm/°C for 0.125 inch thickness between –30°C and +30°C.
10. Shear strength, psi, Condition A[1], for 0.125 inch thickness:
    For Grades GPO-1, GPO-2, and GPO-3 – 14,000
    For Grades GPO-1P, GPO-2P, and GPO-3P – 10,000
11. Temperature index, °C, for 0.062 inch thickness and over:
    Electrical test
    For Grade GPO-2 – 130
    For Grade GPO-3 – 120
    Mechanical Test
    For Grade GPO-2 – 160
    For Grade GPO-3 – 140

Authorized Engineering Information 9-15-1982.

NOTE – Items 8, 9, and 10 apply to Grades GPO-1 and GPO-3 only.

*In accordance with ASTM D 150 for Grades GPO-1 and GPO-3 and ASTM D 229 for Grade GPO-2.

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11.19 SUMMARY OF STANDARD PROPERTIES

Testing Detail	Grade					
	GPO-1	GPO-2	GPO-3	GPO-1P	GPO-2P	GPO-3P
11.7 Flexural strength, psi, min.	18,000	18,000	18,000	16,000	16,000	16,000
11.8 Tensile strength, psi, min.	8,000	8,000	8,000	8,000	8,000	8,000
11.9 Impact strength,ft.lbs./in., min.	8	8	8	5	5	5
11.10 Compressive strength, flatwise, psi,min.	30,000	30,000	30,000	20,000	20,000	20,000
11.11 Bonding strength lbs., min. Condition A	850	850	850	—	—	—
Condition D 48/50	800	800	800	—	—	—
11.12 Dielectric breakdown, parallel to lam. min., Condition A and D 48/50	40/15	40/15	40/15	40/05	40/05	40/05
11.13 Electric breakdown, min. Perpendicular to laminations, 0.062 Thk volts/mil	300	300	300	300	300	300
11.14 Arc resistance, seconds, min.	100	100	150	100	100	150
11.15 Water absorption, % max.						
0.062	1.0	0.8	0.6	1.0	0.8	0.6
0.125	0.7	0.6	0.5	0.7	0.6	0.5
0.500	0.35	0.25	0.25	—	—	—
11.15a Values from Table 11-2						
11.16 Flame resistance, seconds						
11.16.1 0.500 to 2 inches, incl:						
Ignition time	—	75	75	—	—	—
Burning time	—	85	85	—	—	—
11.16.2 0.062 to less than 0.500 inch	—	Class O	Class O	—	Class O	Class O
11.17 Tracking, minutes	—	—	300	—	—	300

NOTE—All values tested under Condition A unless otherwise specified.

*Specimen size 0.500 inch±0.10 inch wide by 5.0 inch long for thickness 0.062–0.250.

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11.20 SUMMARY OF AUTHORIZED ENGINEERING INFORMATION (TYPICAL VALUES, NOT MINIMUM, NOT MAXIMUM)

Testing Detail		Grade					
		GPO-1	GPO-2	GPO-3	GPO-1P	GPO-2P	GPO-3P
11.18.1	130°F flex, psi	6,000	6,000	6,000	6,000	6,000	6,000
11.18.2	Modulus in flex, psi – LW	1.2	1.2	1.2	1.2	1.2	1.2
	($\times 10^6$) – CW	1.0	1.0	1.0	1.0	1.0	1.0
11.18.3	Density, gm/cm^3	1.5–1.9	1.5–1.9	1.7–1.95	1.5–1.9	1.5–1.9	1.7–1.95
11.18.4	Permittivity – 1 MHz A	4.3	–	–	4.3	–	–
	D24/23	4.4	–	–	4.4	–	–
	60 Hz A	4.5	4.5	4.5	6.0	6.0	6.0
11.18.5	Dissipation Factor – 1MHz A	0.03	–	–	0.03	–	–
	D24/23	0.06	–	–	0.06	–	–
	60 Hz A	0.05	0.05	0.05	0.09	0.09	0.09
11.18.6	Rockwell hardness	M-100	M-100	M-100	M-100	M-100	M-100
11.18.7	Modulus of elasticity in tension, $\times 10^6$ psi – LW	1.0	1.0	1.0	1.0	1.0	1.0
	– CW	0.9	0.9	0.9	0.9	0.9	0.9
11.18.8	Compression, strength – edgewise	20,000	20,000	20,000	–	–	–
11.18.9	Thermal expansion cm/cm/°C	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}
11.18.10	Shear strength – Condition A, psi	14,000	14,000	14,000	10,000	10,000	10,000
11.18.11							
	Temperature Index, Electrical (0.062 inch and over)	–	130	120	–	–	–
	Temperature Index, Mechanical (0.062 inch and over)	–	160	140	–	–	–

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Section 12
POST-FORMING GRADE CF SHEET LAMINATES

SCOPE

This section covers Grade CF post-forming laminates intended for industrial purposes. The term "post-forming" refers to the process of forming laminated sheets after manufacture into various shapes by the application of heat and forming dies.

GENERAL

12.1 DESCRIPTION

Grade CF sheets used for post-forming are made from a cotton fabric weighing more than 4 ounces per square yard and having a thread count of not more than 72 threads per inch in the filler direction nor more than a total of 140 threads per inch in both the warp and filler directions.

The fabric shall be impregnated with a thermosetting phenolic type of synthetic resin and cured under heat and pressure.

NEMA Standard 9-15-1982.

12.2 ORDERING INFORMATION

Orders for Grade CF laminates should specify the following:

1. Sheet size and thickness required;
2. Color if other than natural (see 12.3); and
3. If non-afterglow properties are required, the order should specify "Grade CF Non-afterglow."

Authorized Engineering Information 9-15-1982.

12.4 FINISH

Sheets shall have a semigloss finish.

NEMA Standard 9-15-1982.

12.5 THICKNESSES AND TOLERANCES

Nominal Thickness, Inches	Plus or Minus Tolerances, Inches
0.031	0.0065
0.047	0.0075
0.062	0.0075
0.094	0.0090
0.125	0.0100
0.156	0.0110
0.188	0.0125
0.219	0.0140
0.250	0.0300 (plus only)

NEMA Standard 9-15-1982.

12.6 SHEET SIZE* AND TOLERANCES IN LENGTH AND WIDTH

The tolerances in the length and width of a manufacturer's standard size sheet shall be ±1 inch except in cases where test specimens have been removed to ensure conformity with these standards. In the event that these tests are necessary, not more than 4 square feet shall be cut from a given production lot.†

NEMA Standard 9-15-1982.

*Due to variations in the size of press equipment, there is considerable variation in the length and width of manufacturer's standard size sheets. The standard sizes range between 24 and 50 inches in width and between 36 and 120 inches in length. There are some manufacturers, however, whose standard sizes may be outside of these ranges.

†A production lot shall consist of all sheets of a given machine run and of a particular thickness. A machine run shall consist of all the material pressed from a coating operation in which the basic resin and filler and treating conditions are the same. Ten percent of the sheets in the lot shall be used for testing but, in any case, not less than one nor more than three sheets shall be used for the purpose.

NEMA Standard 11-16-1989.

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PHYSICAL PROPERTIES

12.7 BEFORE POST-FORMING

Physical properties of the sheets before post-forming shall be in accordance with Tables 12-1 and 12-2 when the sheets are tested in accordance with the latest applicable test methods of the NEMA LI 6, Section 7.

NEMA Standard 9-15-1982.

12.8 POST-FORMING PROPERTIES

The post-forming properties of sheets shall be in accordance with the following:

1. Hot-bending (see 12.10);
2. Dimensional stability (see 12.11);
3. Depth of draw (see 12.12).

NEMA Standard 9-15-1982.

TEST METHODS

12.9 AFTERGLOW

When sheets having non-afterglow are required, the average duration of the visible afterglow shall not exceed the values given in Table 12-1 when sheets are tested in accordance with the requirements outlined in 12.9.1 through 12.9.3.

12.9.1 Specimens

Three specimens, each 6× 0.500 inch, shall be tested.

12.9.2 Test Apparatus

The test apparatus shall consist of a Meker or similar large top burner having a flame 1 inch long.

12.9.3 Procedure

The test specimens shall be placed in a shielded area having subdued lighting (such as in an unlighted fume hood) and shall be mounted with the 6-inch length in a horizontal direction and the 0.500 inch width turned at an angle of 45 degrees to the horizontal. The specimen shall be mounted at a height sufficient to exceed the height of the burner.

The tip of the flame of the burner shall be brought into contact with the specimens so that 1 inch of each specimen is covered by the flame. The specimens shall be heated for 15 seconds for each 0.031 inch of thickness or fraction thereof.

At the end of the heating period, the burner shall be removed, and the flame on the specimens shall be extinguished. The duration of the visible afterglow shall be noted.

NEMA Standard 9-15-1982.

12.10 HOT BENDING

After post-forming there shall be no breaks in the fabric reinforcement of sheets due to splitting or delamination when the sheets are tested in accordance with the requirements of 12.10.1 through 12.10.3.

Note that sheets shall not be considered as having failed this test if they contain small cracks or checks up to 0.125 inch long×0.016 inch wide or blisters up to 0.250 inch in diameter, provided that there are no more than four blisters per square foot per side and that the blisters do not appear in clusters.

12.10.1 Specimens

Test specimens shall be 2×6 inches. Three specimens shall be cut from sheets in the longitudinal direction and three in the transverse direction.

12.10.2 Test Apparatus

The test apparatus shall consist of:

1. A forced-circulative type of air oven maintained at a temperature between 246°C and 274°C (475°F and 525°F).
2. Wooden or cast resin forms conforming to the bending fixture shown in Figure 12-1. The male form shall have a radius in accordance with Column 3 of Table 12-3.

12.10.3 Procedure

The test specimens shall be heated in the oven at between 264°C and 274°C (475°F and 525°F) for the optimum heating time specified in Column 2 of Table 12-3.

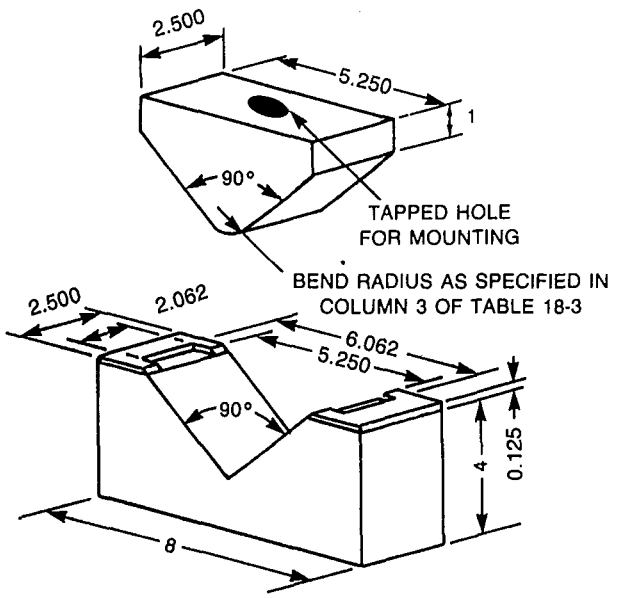
The optimum heating time shall have at least a 5-second spread within the range given in Table 18-3. The optimum heating time shall be recorded.

Immediately afterwards (within 10 seconds), the test specimens shall be bent through an angle of 90 degrees between the wooden or cast resin forms and allowed to cool in the forms. The bends shall be across the 2-inch dimension.

Material shall be considered acceptable which bends successfully anywhere between 475°F with the minimum heating time specified for the thickness under test given in Column 2 of Table 12-3 and 525°F with the maximum heating time. Factors such as air velocity and support of specimen in the oven influence the test results.

After being removed from the form, the specimen shall retain an angle of not more than 93 degrees.

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DIMENSIONS IN INCHES.
BOTH MEMBERS SHALL BE MADE OF FABRIC-BASE LAMINATE, CAST RESIN OR OTHER MATERIAL OF SUITABLY LOW THERMAL CONDUCTIVITY.

NEMA Standard 9-15-1982.

Figure 12-1
BENDING FIXTURE

Table 12-1
STANDARD VALUES

Minimum flexural strength in the flatwise direction, psi	16,000
Minimum Izod impact strength in the edgewise direction, ft-lb/1-inch notch	1.5
Maximum afterglow	*

Maximum water absorption

Thickness of Sheet Inches	Maximum Water Absorption Percent
0.031	7.5
0.047	5.2
0.062	4.4
0.094	3.2
0.125	2.5
0.156	2.2
0.188	1.9
0.219	1.8
0.250	1.6

*When sheets having non-afterglow are required, the maximum afterglow shall be as follows when tested in accordance with 12.9.

0.061 inch and under	4 seconds
Over 0.061–0.125 inch, incl.	6 seconds
Over 0.125–0.250 inch, incl.	10 seconds

NEMA Standard 9-15-1982.

Table 12-2
ENGINEERING INFORMATION – TYPICAL VALUES†

Average compressive strength in the flatwise direction, psi	30,000
Average tensile strength, psi	7,500
Average modulus of elasticity in tension, psi	825,000
Average density, grams per cubic centimeter	1.35

†Typical values represent the average values for a specific property taken from a large number of tests and serve only as a general guide in design. These typical values are not intended as standards.

Authorized Engineering Information 9-15-1982.

Table 12-3
HEATING AND BENDING RADII PER NOMINAL THICKNESS

(1) Nominal Thickness, Inches*	(2) Heating Time Range, Seconds	(3) Inside Bending Radius, Inches
0.031	20–35	0.031
0.047	30–50	0.062
0.062	40–70	0.094
0.094	60–95	0.188
0.125	80–120	0.312
0.156	100–160	0.438
0.188	130–200	0.562
0.219	160–240	0.812
0.250	180–260	1.000

*For intermediate thickness not listed in this table, the values given for the next higher thickness shall be used.

NEMA Standard 9-15-1982.

12.11 DIMENSIONAL STABILITY

After being tested in accordance with 12.10, the test specimens shall be immersed in water having a temperature of 82°C±1.1°C (180°F±2°F). After being immersed for 1 hour, the specimens shall be removed from the water and allowed to cool without being restrained in any way.

The springback shall not exceed the values given in Table 12-4.

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Table 12-4
DIMENSIONAL STABILITY SPRINGBACK VALUES

Nominal Thickness, Inches*	Springback, Degrees
0.031	32
0.047	27
0.062	25
0.094	20
0.125	15
0.156	12
0.188	9
0.219	7
0.250	6

*For intermediate thicknesses not listed in this table, the values given for the next higher thickness shall be used.

12.12 DRAW TEST

12.12.1 Specimens

Test specimens shall be 6 inches in diameter by the thickness of the sheet. Six specimens shall be cut from the sheet.

12.12.2 Test Apparatus

The test apparatus shall consist of:

1. A forced circulation oven as described in item 1 of 12.10.2.
2. A suitable air or hydraulic operated press to accommodate the dimensions shown in Figure 12-2 and depths of draw in Table 12-5.

Plunger—The plunger (male die) force must be sufficient to produce the draws shown in Table 12-5 and must have adequate throttling to complete stroke from contact to full draw in 1 to 2 seconds. The piston shall be provided with a stroke adjustment for the draw depths in Table 12-5. A 6-inch-diameter air cylinder under 80 psi air pressure shall be sufficient. The plunger or mandrel shall be a 3-inch-diameter cylinder with a 1.5 inch spherical radius on the contact end.

Clamp Ring—The clamp ring shall have an approximate inside diameter of 3.5 inches and an approximate outside diameter of 6 inches. This ring shall be so arranged in the jig that it can quickly apply a pressure of 20 psi on the specimen uniformly over the contact area.

Draw Ring—The draw ring (female die) shall have an inside diameter of 3 inches plus 2.5 times the material thickness. The inside of the draw ring shall be provided with a draw radius of 0.125 inches and the entire draw ring shall be designed to maintain a temperature of 275°F to 300°F.

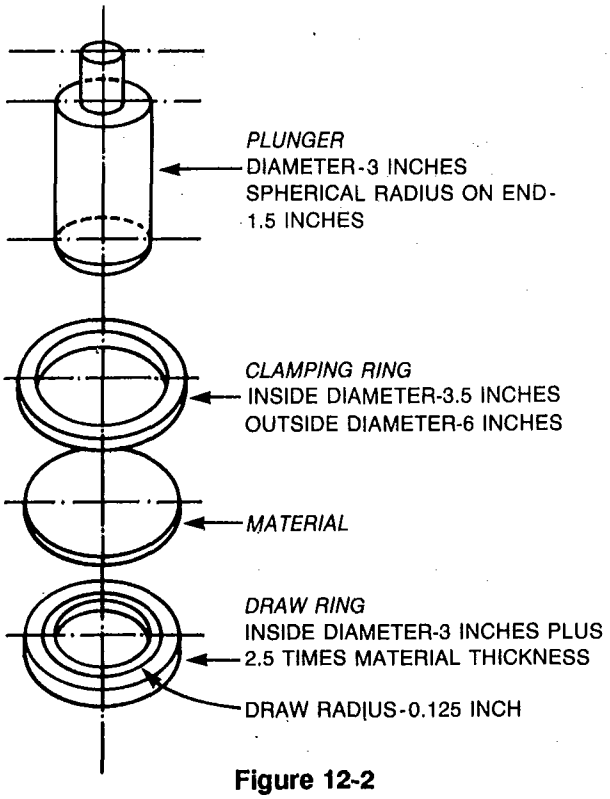


Figure 12-2
DRAW TEST APPARATII

Table 12-5
DRAW DEPTH BY THICKNESS

Nominal Thickness, Inches*	Depth of Draw, Inches
0.031	1.375
0.047	1.375
0.062	1.250
0.094	1.125
0.125	0.750

*For intermediate thicknesses not listed, the depth of draw and draw ring diameter for the next larger thickness shall be used.

12.12.3 Procedure

Specimens shall be heated as specified in 12.10 for the optimum heating time. Immediately (within 10 seconds) the specimen shall be removed from the oven and placed in the test press. The clamping pressure shall be applied and the drawing die closed. The drawing pressure shall be left on for at least 10 seconds to allow the test specimen to cool after forming.

NEMA Standard 11-16-1989.

12.13 RECOMMENDED CONTROL TESTS

Control tests shall include the following:

1. Hot bending (see 12.10);
2. Dimensional stability (see 12.11); and
3. Flexural strength (see Table 12-1).

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Sheets shall not be considered as having failed this test if they contain small cracks or checks up to 0.125 inch long ×0.016 inch wide or blisters up to 0.250 inch in diameter, provided that there are no more than six blisters per six specimens per side and that the blisters do not appear in clusters.

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Section 13
AUTHORIZED ENGINEERING INFORMATION ON THE PROPERTIES OF SHEETS, TUBES, AND RODS

13.1 TYPICAL VALUES

The typical values given in this part represent the average values for a specific property taken from a large number of tests on the products of the several laminators for that particular grade and serve only as a general guide in design. These typical values are not intended as standards.

Authorized Engineering Information 9-15-1982.

13.2 TYPICAL VALUES FOR SHEETS FOR CONDITION A (Based on ASTM Test Methods, Unless Otherwise Noted)

ASTM and NEMA Grades Equivalent MIL-P or Federal (LP) Spec Number	X LP 509 (1/19/65)	XP LP 509	XPC LP 509	XX LP 513 (12/19/68)	XXP LP 509	XXX LP 513	XXXP LP 513	XXXPC LP 509	ES-1 LP 509	ES-2 LP 509	ES-3 LP 509
MIL-P or Federal Type (see Note I)	...	...	...	PBG	...	PBE	PBE-P	PBE-P	NDP	NDP	NDP
	NEMA Temperature Units (see NEMA LI 6)										
0.03A to 0.062 inch											
electrical test index	130	130	130	130	130	130	125	125	...	...	...
mechanical test index	130	130	130	130	130	130	125	125	...	...	...
0.062 inch and over											
electrical test index	130	130	130	140	140	140	125	125	...	...	...
mechanical test index	130	130	130	140	140	140	125	125	...	...	...
Electrical Strength* Perpendicular to Laminations, Volts per Mil Short Time											
0.031 inch thickness	950	900	850	950	950	900	900	900	...	...	...
0.062 inch thickness	700	650	600	700	700	650	650	650	750	...	...
0.125 inch thickness	500	470	425	500	500	470	470	470	...	550	...
Step by Step											
0.031 inch thickness	700	650	625	700	700	650	650	650	...	...	...
0.062 inch thickness	500	450	425	500	500	450	450	450	550	...	...
0.125 inch thickness	360	320	290	360	360	320	320	320	...	400	...
Insulation Resistance, Condition C-96/35/90, Megohms	...	...	...	60	500	1000	20,000	50,000	...	...	...

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13.2 TYPICAL VALUES FOR SHEETS FOR CONDITION A (Based on ASTM Test Methods, Unless Otherwise Noted) (Continued from previous page)

ASTM and NEMA Grades	X	XP	XPC	XX	XXP	XXX	XXXP	XXXPC	ES-1	ES-2	ES-3
Tensile Strength psi—											
lengthwise	20,000	12,000	10,500	16,000	11,000	15,000	12,400	12,400	12,000	13,000	15,000
crosswise	16,000	9,000	8,500	13,000	8,500	12,000	9,500	9,500	8,500	9,000	12,000
Modulus of Elasticity, psi (see Note II)											
In tension—lengthwise	1,900,000	1,200,000	1,000,000	1,500,000	900,000	1,300,000	1,000,000	1,000,000	...	...	...
crosswise	1,400,000	900,000	800,000	1,200,000	700,000	1,000,000	800,000	800,000	...	...	...
In flexure—lengthwise	1,800,000	1,200,000	1,000,000	1,400,000	900,000	1,300,000	1,000,000	1,000,000	...	...	...
crosswise	1,300,000	900,000	800,000	1,100,000	700,000	1,000,000	700,000	700,000	...	...	...
Compressive Strength, psi—											
flatwise	36,000	25,000	22,000	34,000	25,000	32,000	25,000	25,000	...	...	...
edgewise	19,000	...	...	23,000	...	25,500	...	...	...	...	...
Rockwell Hardness (M) at room temperature	M-110	M-95	M-75	M-105	M-100	M-110	M-105	M-95	M-118	M-118	M-120
Deformation and Shrinkage, Cold Flow at 4000 psi for 1/8-inch Thickness, Percent Change (see Note III)	...	...	...	0.90	...	0.80	0.80	...	1.45	...	...
Density, Grams per Cubic Centimeter	1.36	1.33	1.34	1.34	1.32	1.32	1.30	1.30	19.1	1.40	1.38
Specific Volume, Cubic Inches per Pound	20.4	20.8	20.6	20.6	21.0	21.0	21.3	21.3	19.1	19.8	20.1
Thermal Expansion, cm/cm/°C	2.0×10^{-6}										

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13.2 TYPICAL VALUES FOR SHEETS FOR CONDITION A (Based on ASTM Test Methods, Unless Otherwise Noted) (Continued from previous page)

Thermal Conductivity, Calories/ Second/cm^2/°C/cm	7.0×10^{-4}
Specific Heat, Calories/grams/°C	0.35 to 0.40
Effect of Acids	All grades except G-5 and G-9 are resistant to dilute solutions of most acids.
Effect of Alkalies	Not recommended for use in alkaline solutions except for melamine Grades G-5 and G-9, which are resistant to dilute alkaline solutions.
Effect of Solvents	Unaffected by most organic solvents except acetone, which may soften the punching grade stocks. Aromatic hydrocarbons and chlorinated aliphatics may affect silicone Grade G-7.

ASTM and NEMA Grades	C	CE	L	LE	G-3	G-5	G-7	G-9	G-10	G-11
Equivalent MIL-P or Federal (LP) Spec Number	15035	15035	15035	15035	LP 509	LP 509	997	15037 (1/14/68)	18177 (10/14/75)	18177 (12/15/61)
MIL-P or Federal Type (Note I)	FBM	FBG	FBI	FBE	...	GMG	GSG	GME	GEE	GEB
NEMA Temperature Indices (see NEMA Publication LI 6)										
0.03A to 0.062 inch—electrical test index	85	85	85	85	140	**	170	**	130	140
mechanical test index	85	85	85	85	170	140	220	140	140	160
0.062 inch and over—electrical test index	115	115	115	115	140	**	170	**	130	170
mechanical test index	125	125	125	125	170	140	220	140	140	180
Electrical Strength* Perpendicular to Laminations, Volts per Mil Short Time										
0.031 inch thickness	...	...	...	700	750	...	450	450	750	750
0.062 inch thickness	...	500	...	500	700	350	400	400	700	700
0.125 inch thickness	...	360	...	360	600	260	350	350	550	550
Step by Step										
0.031 inch thickness	...	...	...	450	550	...	400	400	500	500
0.062 inch thickness	...	300	...	300	500	220	350	350	450	450
0.125 inch thickness	...	220	...	220	450	160	250	275	350	350
Insulation Resistance, Condition C-96/35/90, Megohms	...	...	...	...	...	100	2,500	10,000	200,000	200,000
Tensile Strength psi—										
lengthwise	10,000	9,000	13,000	12,000	23,000	37,000	23,000	37,000	40,000	40,000
crosswise	8,000	7,000	9,000	8,500	20,000	30,000	18,500	30,000	35,000	35,000
Modulus of Elasticity, Psi (see Note II)										
In tension—lengthwise	1,000,000	900,000	1,200,000	1,000,000	2,000,000	2,300,000	1,000,000	2,300,000	2,500,000	2,500,000
crosswise	900,000	800,000	900,000	850,000	1,700,000	2,000,000	1,800,000	2,000,000	2,000,000	2,000,000
In flexure—lengthwise	1,000,000	900,000	1,100,000	1,000,000	1,500,000	1,700,000	1,400,000	2,500,000	2,700,000	2,000,000
crosswise	900,000	800,000	850,000	850,000	1,200,000	1,500,000	1,200,000	2,000,000	2,200,000	2,300,000

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ASTM and NEMA Grades	C	CE	L	LE	G-3	G-5	G-7	G-9	G-10	G-11
Equivalent MIL-P or Federal (LP) Spec Number	15035	15035	15035	15035	LP 509	LP 509	997	15037 (1/14/68)	18177 (10/14/75)	18177 (12/15/61)
MIL-P or Federal Type (Note I)	FBM	FBG	FBI	FBE	...	GMG	GSG	GME	GEE	GEB
Compressive Strength, psi — flatwise	37,000	39,000	35,000	37,000	50,000	70,000	45,000	70,000	68,000	60,000
edgewise	23,500	24,500	23,500	25,000	17,500	25,000	14,000	25,000	35,000	35,000
Rockwell Hardness (M) at room temperature	103	105	105	105	100	120	100	120	111	112
Deformation and Shrinkage, Cold Flow at 4000 psi for ⅛-inch Thickness, Percent Change (see Note III)	...	...	...	...	0.30	0.30	0.30	0.25	0.25	0.20
Density, Grams per Cubic Centimeter	1.36	1.33	1.35	1.33	1.65	1.90	1.68	1.90	1.80	1.80
Specific Volume, Cubic Inches per Pound	20.4	20.8	20.5	20.8	16.8	14.6	16.5	14.6	15.3	15.3
Thermal Expansion, cm/cm/°C	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	1.8×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	0.9×10^{-5}	0.9×10^{-5}
Thermal Conductivity, Calories/Second/cm^2/°C/cm	7.0×10^{-4}	7.0×10^{-4}	7.0×10^{-4}	7.0×10^{-4}	...	12.0×10^{-4}	7.0×10^{-4}	7.0×10^{-4}	7.0×10^{-4}	7.0×10^{-4}
Specific Heat, Calories/grams/°C	0.35–0.40	0.35–0.40	0.35–0.40	0.35–0.40	0.30	0.26	0.25	0.35–0.40	0.35–0.40	0.35–0.40
Effect of Acids	All grades except G-5 and G-9 are resistant to dilute solutions of most acids.									
Effect of Alkalies	Not recommended for use in alkaline solutions except for melamine Grades G-5 and G-9, which are resistant to dilute alkaline solutions.									
Effect of Solvents	Unaffected by most organic solvents except acetone which, may soften the punching grade stocks. Aromatic hydrocarbons and chlorinated aliphatics may affect silicone Grade G-7.									

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13.2 TYPICAL VALUES FOR SHEETS FOR CONDITION A (Based on ASTM Test Methods, Unless Otherwise Noted) (Continued from previous page)

ASTM and NEMA Grades	AA	FR-1	FR-2	FR-3	FR-4	FR-5	N-1
Equivalent MIL-P or Federal (LP) Spec Number	LP-509		LP-509	22324	18177	18177	15047 (6/11/71)
MIL-P or Federal Type (see Note I)	...	...	PBE-P	PEE	GEE	GEB	NPG
NEMA Temperature Indices (see NEMA Publication LI 6)							
0.03A to 0.062 inch –							
electrical test index	140	130	75	90	130	140	...
mechanical test index	140	130	75	90	140	160	...
0.062 inch and over –							
electrical test index	155	130	105	110	130	170	...
mechanical test index	155	130	105	110	140	100	...
Electrical Strength* Perpendicular to Laminations, Volts per Mil Short Time							
0.031 inch thickness	...	900	800	650	750	750	850
0.062 inch thickness	...	650	650	600	700	700	600
0.125 inch thickness	...	470	470	475	550	500	450
Step by Step							
0.031 inch thickness	...	650	550	500	500	500	650
0.062 inch thickness	...	450	450	450	450	450	450
0.125 inch thickness	...	320	320	325	350	350	300
Insulation Resistance, Condition C-96/35/90, Megohms	...	...	20,000	100,000	200,000	200,000	50,000
Tensile Strength psi –							
lengthwise	12,000	12,000	12,500	14,000	40,000	40,000	8,500
crosswise	10,000	9,000	9,500	12,000	35,000	35,000	8,000
Modulus of Elasticity, psi (see Note II)							
In tension–lengthwise	1,700,000	1,200,000	1,000,000	1,200,000	2,500,000	2,500,000	400,000
crosswise	1,500,000	900,000	800,000	1,000,000	2,000,000	2,000,000	400,000
In flexure–lengthwise	1,600,000	1,200,000	1,100,000	1,300,000	2,700,000	2,800,000	600,000
crosswise	1,400,000	900,000	900,000	1,000,000	2,200,000	2,300,000	500,000
Compressive Strength, psi –							
flatwise	38,000	25,000	25,000	29,000	60,000	60,000	+
edgewise	21,000	...	...	...	35,000	35,000	+
Rockwell Hardness (M) at room temperature	103	95	97	100	222	114	105
Deformation and Shrinkage, Cold Flow at 4000 psi for 1/8-inch Thickness, Percent Change (see Note III)	...	...	0.85	0.50	0.25	0.20	...

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13.2 TYPICAL VALUES FOR SHEETS FOR CONDITION A (Based on ASTM Test Methods, Unless Otherwise Noted) (Continued from previous page)

ASTM and NEMA Grades	AA	FR-1	FR-2	FR-3	FR-4	FR-5	N-1
Equivalent MIL-P or Federal (LP) Spec Number	LP-509		LP-509	22324	18177	18177	15047 (6/11/71)
MIL-P or Federal Type (see Note I)	...	...	PBE-P	PEE	GEE	GEB	NPG
Density, Grams per Cubic Centimeter	1.70	1.33	1.33	1.42	1.85	1.85	1.15
Specific Volume, Cubic Inches per Pound	16.3	20.8	21.0	19.5	14.9	14.9	24.1
Thermal Expansion, cm/cm/°C	1.5×10^{-5}		2.0×10^{-5}		1.0×10^{-5}		0.9×10^{-5}
Thermal Conductivity, Calories/Second/cm^2/°C/cm	7.0×10^{-4}		...		12.0×10^{-4}		7.0×10^{-4}
Specific Heat, Calories,/grams/°C	0.35–0.40		0.30		0.26	0.25	0.35–0.40
Effect of Acids	All grades except G-5 and G-9 are resistant to dilute solutions of most acids.						
Effect of Alkalies	Not recommended for use in alkaline solutions except for melamine Grades G-5 and G-9, which are resistant to dilute alkaline solutions.						
Effect of Solvents	Unaffected by most organic solvents except acetone, which may soften the punching grade stocks. Aromatic hydrocarbons and chlorinated aliphatics may affect silicone Grade G-7.						

*For typical electric strength values over the full range of sheet thickness for a particular grade, see the curves shown in Figures 13-1, 13-2, and 13-3.

**Not recommended for electrical applications at elevated temperatures.

+Insulation resistance is tested in accordance with ASTM D 257, using specimens 2 inches×3 inches× the thickness of the sheet, with 3/16-inch taper-reamed holes spaced on 1-inch centers, and using tapered-pin electrodes.

#Grade N-1—Because of high cold flow of this material, compressive strength cannot be measured accurately. Compressive yield strength flatwise is approximately 20,000 psi.

NOTE I—MIL-P Specifications No. 15035, 15037, 15047, 18177.

NOTE II—Modules 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 a plastic nature as thermosetting laminates. They become less significant for the softer and more plastic grades such as Grade N-1, nylon base, and the punching grades XP, XPC, XXP, and XXXP.

NOTE III—Cold flow is measured according to ASTM D 621 (Method A), using specimens preconditioned for 4 hours at 65°F, conditioned for 68 hours at 35 and 90 percent relative humidity, and then tested at 50°C.

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13.3 TYPICAL VALUES FOR TUBES AND RODS FOR CONDITION A (SEE 7.3)

Grade	Tensile Strength* psi	Dissipation Factor 1 MHz	Permittivity 1 MHz	Specific Heat	Thermal Conductivity‡
Rolled Tubes	8,500	†	†	...	...
XX	8,000	0.040	5.0	...	...
C	6,000	†	†	...	...
LE	7,000	†	†	...	...
G-5	25,000	0.012	7.0	...	...
G-7	...	0.003	4.2	...	...
Molded Tubes					
XX	11,000	0.040	5.5	0.35–0.40	7×10^{-4}
XXX	9,000	0.040	5.3	0.35–0.40	7×10^{-4}
CE	8,500	...	...	0.35–0.40	7×10^{-4}
L	9,000	...	...	0.35–0.40	7×10^{-4}
LE	8,500	...	...	0.35–0.40	7×10^{-4}
Molded Rods					
XX	10,000	...	...	0.35–0.40	7×10^{-4}
XXX	9,000	...	...	0.35–0.40	7×10^{-4}
C	9,000	...	...	0.35–0.40	7×10^{-4}
CE	8,000	...	...	0.35–0.40	7×10^{-4}
L	11,000	...	...	0.35–0.40	7×10^{-4}
LE	10,000	...	...	0.35–0.40	7×10^{-4}
G-5	30,000	...	...	0.26	7×10^{-4}

*See ASTM D 349.
†No value recommended.
‡Calories/second/cm^2/°C/cm.

13.4 TYPICAL VALUES FOR BURSTING* STRENGTH OF TUBES

Grade	Inside Diameter, Inches	Wall Thickness, Inches	Bursting Strength Range, psi
X	1	0.062	1200–2400
	1	0.125	3000–5000
XX	1	0.062	1000–2000
	1	0.125	2000–3000
C	1	0.062	1000–1400
	1	0.125	2200–3000
LE	1	0.062	1000–1400
	1	0.125	2200–3000

*See 7.4 for test method. These values are the fluid pressure in pounds per square inch required to burst a specimen of tube of the size tested. The unit hoop stress in the wall cross section, which can be used to calculate the bursting strength of any size tube in terms of its ability to resist a fluid pressure of P psi, is given by the relation $S = P\times r/t$, where S is the hoop stress, P is the fluid pressure, r is the radius in inches of the tube, and t is the wall thickness in inches.

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APPENDIX
REFERENCED STANDARDS

The titles of standards to which reference is made in this publication are as follows. Copies are available from the sources indicated.

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

D 150-87	*Tests for A-C Loss Characteristics and Dielectric Constant (Permittivity) of Solid Electrical Insulating Materials*
D 229-86	*Testing Rigid Sheet and Plate Materials Used for Electrical Insulation*
D 256-88	*Test for Impact Resistance of Plastics and Electrical Insulating Materials*
D 257-78 (R 1983)	*Test for D-C Resistance or Conductance of Insulating Materials*
D 348-89	*Testing Laminated Tubes Used for Electrical Insulation*
D 349-87	*Testing Laminated Round Rods Used for Electrical Insulation*
D 495-84	*Tests for High-voltage, Low-current Arc Resistance of Solid Electrical Insulating Materials*
D 570-81 (R 1988)	*Test for Water Absorption of Plastics*
D 621-64 (R 1988)	*Test for Deformation of Plastics Under Load*
D 709-87	*Specifications for Laminated Thermosetting Materials*
D 790-86	*Test for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials*
D 877-87	*Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*
D 1180-57 (R 1978)	*Test for Bursting Strength of Round Rigid Plastic Tubing*
D 2303-85	*Test for Liquid-contaminant, Inclined-plane Tracking and Erosion of Insulating Materials*
E 53-86	*Method of Chemical Analysis of Copper (Electrolytic Determination of Copper)*

Institute of Electrical and Electronics Engineers
445 Hoes Lane
Piscataway, NJ 08855-1331

1-1986	*General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electric Insulation*
98-1984	*Guide for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulation Systems for Electric Equipment*
99-1980	*Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electrical Equipment*
101-1972 (R 1987)	*Guide for Statistical Analysis of Test Data*

National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, DC 20037

LI 6-1983	*Temperature Indices of Industrial Thermosetting Laminates*

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Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

94-1980

Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

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NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status, are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below.

Purpose of Standards

National Electrical Manufacturers Association standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist purchasers in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p.8)

Categories of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

(Standardization Policies and Procedures, pp. 7 & 16)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment, and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 7 & 16)

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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INDUSTRIAL LAMINATES SECTION
OF THE
NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

MEMBER COMPANIES

Accurate Plastics, Inc.
Yonkers, NY 10705

Coptec, Incorporated
Warren, OH 44482-4069

Current, Inc.
East Haven, CT 06512

Franklin Fibre Lamitex Corporation
Wilmington, DE 19899

GE
Fairfield, CT 06431

Glasteel Industrial Laminates
Duarte, CA 90101

Glastic Corporation
Cleveland, OH 44121

Haysite Reinforced Plastics Company
Erie, PA 16509

Industrial Dielectrics, Inc.
Noblesville, IN 46060

Norplex Oak, Inc.
LaCrosse, WI 54602-1448

NVF Company
Yorklyn, DE 19736

Spaulding Composites Co.
Tonawanda, NY 14151

Westinghouse Electric Corporation
Pittsburgh, PA 15222

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