Table 8
PERFORMANCE REQUIREMENTS FOR SHEETS

Requirement	ASTM Test Method/Other	Condition	Unit	Thickness (inches)											
				.010	.015	0.031	0.062	0.094	0.125	0.188	0.250	0.500	0.750	1.000	1.001+
Minimum Breakdown Voltage	**D229**	**A**	**kV**	**---**	**---**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**10.0**
Minimum Izod Impact Strength[7,8]			ft-lb/in												
Lengthwise:	D229	E-48/50	(notch)	---	---	---	---	---	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Crosswise:				---	---	---	---	---	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Minimum Flexural Strength[7,9]															
Lengthwise:	D229	A	ksi	---	---	16.5	16.5	16.5	16.5	16.5	16.5	15.5	15.5	15.0	15.0
Crosswise:					---	14.5	14.5	14.5	14.5	14.5	14.5	14.0	14.0	13.5	13.5
Minimum Bonding Strength[10]		A		---	---	---	---	---	---	---	---	1,600	1,600	1,600	1,600
	D229	D-48/50	lbs	---	---	---	---	---	---	---	---	1,500	1,500	1,500	1,500
Maximum Water Absorption[9]	D229	D_1-24/23	%	8.50	7.70	6.00	2.50	1.90	1.60	1.30	1.10	0.90	0.75	0.70	0.70
Flammability[11]	UL 94	A	Class	---	---	HB	HB	HB	HB	HB	HB	HB	HB	HB	HB

[7] Maximum thickness tested shall be 2.00 inches.

[8] Specimens shall have a nominal thickness of 0.500 inches or shall be machined to 0.500 inches, from a thicker sheet. Unmachined specimens shall meet the tolerance given for 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.

[9] For intermediate thicknesses, the value for the next smaller thickness shall apply.

[10] Applicable for sheets having a thickness from 0.500 inches up to the maximum of 2.000 inches. 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 $\pm$0.005 inches.

[11] For the method of measuring flammability, see UL Standard for Safety 94.

Table 9
PERFORMANCE REQUIREMENTS FOR MOLDED TUBES

Requirement	ASTM Test Method/ Other	Condition	Unit	Inside Diameter	Wall Thickness (inch)							
					0.031 - 0.061	0.062 - 0.093	0.094 - 0.124	0.125 - 0.187	0.188 - 0.249	0.250 - 0.499	0.500 - 0.999	1.000
Min. Compressive Strength	D348	A	ksi	0.250-3.875	---	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Minimum Density	D348	A	g/cm^3	0.125-3.875	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Max. Water Absorption	D348	D_1-24/23	%	0.125-3.875	6.5	3.5	2.2	1.8	1.6	1.6	1.5	1.4

Table 10
PERFORMANCE REQUIREMENTS FOR MOLDED RODS

Requirement	ASTM Test Method/Other	Condition	Unit	Diameter (inches)				
				0.188-0.249	0.250-0.499	0.500-0.999	1.000	1.001-2.000
Minimum Flexural Strength	D349	A	ksi	16.0	16.0	16.0	16.0	--
Minimum Compressive Strength	D349	A	ksi	19.0	19.0	19.0	19.0	19.0
Minimum Density	D349	A	g/cm^3	1.28	1.28	1.28	1.28	1.28
Maximum Water Absorption	D349	D_1-24/23	%	2.5	2.0	1.5	1.2	1.2

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

Table 11
AUTHORIZED ENGINEERING INFORMATION

Test Condition or Property	Value
Temperature Index[12] - 0.031 to 0.062 inch - Electrical Test Index, °C	85
Temperature Index[12] - 0.031 to 0.062 inch - Mechanical Test Index, °C	85
Temperature Index[12] - 0.062 inch and over - Electrical Test Index, °C	115
Temperature Index[12] - 0.062 inch and over - Mechanical Test Index, °C	125
Tracking Resistance, Condition A	
Cu Electrodes:	139
Pt Electrodes: (CTI) ssee grade X	189
Arc Resistance (D-495) - sec:	---
Insulation Resistance[13], Condition C-96/35/90 Megohms:	---
Tensile Strength, ksi	
Lengthwise:	13.0
Crosswise:	9.0
Modulus of Elasticity[14], ksi, in Tension	
Lengthwise:	1,200
Crosswise:	900
Modulus of Elasticity[14], ksi, in Flexure	
Lengthwise:	1,100
Crosswise:	850
Compressive Strength, ksi	
Flatwise:	35.0
Edgewise:	23.5
Rockwell Hardness (M - Scale)	105
Density, Grams per Cubic Centimeter.	1.35
Specific Volume, Cubic Inches per Pound.	20.5
Thermal Expansion, 10^{-6}cm/cm/°C.	20.0
Thermal Conductivity, 10^{-4}Calories/Second/cm^2/(°C/cm)	
Sheets	7.0
Molded Tubes	7.0
Molded Rods	7.0
Specific Heat, Calories/gram/°C.	
Sheets	0.35 - 0.40
Molded Tubes	0.35 - 0.40
Molded Rods	0.35 - 0.40
Tensile Strength, ksi	
Molded Tubes	9.0

[12] See NEMA LI-6.

[13] Insulation resistance is tested in accordance with ASTM D229.

[14] Modulus of elasticity values are determined by measuring the slope of the stress strain curve at the origin. These values are not too highly significant for materials of 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, XXXP, XXXPC, FR-1, and FR-2.

Test Condition or Property	Value
Molded Rods	11.0

Specification Sheet – 16
NEMA GRADE LE

Definition: Grade LE is constructed from a woven cotton fabric with a phenolic resin binder. The cotton fabric shall weigh less than or equal to 4 ounces per square yard. The phenolic resin system is not flame retardant. This material is similar to Mil-I-24768/13 type FBE, with the exception that the impact strength is higher for the Mil. specification material.

Military and International Standards, Comparable Materials

Material Form	Military Specifications	IEC Specifications
Sheets	MIL-I-24768/13	60893, PF CC 204
Rolled Tubes	MIL-I-24768/13	61212, PF CC 21
Molded Tubes	MIL-I-24768/13	61212, PF CC 31
Molded Rods	MIL-I-24768/13	61212, PF CC 41

Characteristics:

Sheets—This material is intended for electrical applications requiring good moisture resistance. It has lower mechanical strength than materials with glass substrates, but has superior impact resistance when compared to paper based products. It is suitable for fine machining. LE possesses fairly good dielectric properties and medium dielectric loss.

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

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

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

Applications:

All Forms—Grade LE exhibits good wear resistance when in contact with steel or other plastics. This material has moderate heat resistance and the chemical resistance is good when exposed to organic solvents and oils.

DIMENSIONAL REQUIREMENTS FOR SHEETS, TUBES, AND RODS

Because of variations in the size of presses of sheets, and mandrel and press sizes for molded tubes and rods, the tolerance in length and width of manufacturers' standard length of sheets, rods and tubes, and width of sheets shall be ±1 inch from the manufacturers, standard. The standard sizes of laminating presses range from 18 to 60 inches in width, and from 24 to 144 inches in length. Mandrels for convolute wound tubes range from 36 to 110 inches in length. Typically, presses for molded tubes and rods range from 30 to 50 inches in length.

THICKNESS OF LAMINATED SHEETS

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

Table 1
THICKNESS OF LAMINATED SHEETS

Nominal Thickness (inches)	Permissible[1] Variations (± inch)	Nominal Thickness (inches)	Permissible[1] Variations (± inch)	Nominal Thickness (inches)	Permissible[1] Variations (± inch)
0.015	0.0035	0.219	0.011	1.125	0.035
0.020	0.004	0.250	0.012	1.250	0.037
0.025	0.0045	0.312	0.0145	1.375	0.039
0.031	0.005	0.375	0.017	1.500	0.041
0.047	0.0055	0.438	0.019	1.625	0.043
0.062	0.006	0.500	0.021	1.750	0.045
0.094	0.007	0.625	0.024	1.875	0.047
0.125	0.008	0.750	0.027	2.000	0.049
0.156	0.009	0.875	0.030	---	---
0.188	0.010	1.000	0.033	---	---

Table 2
MAXIMUM WARP OR TWIST FOR SHEETS

Thickness, Inches	Maximum Warp or Twist (Based on 36-inch Dimension), Percent[2]
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

[1] For sheets of nominal thickness not listed in this Table, the permissible variations shall be the same as for the next greater thickness.

[2] In case of warp, this percentage is stated in terms of the lateral dimension (length or width); in case of twist, the percentage is stated in terms of the dimension from one corner to that diagonally opposite corner. For method of measuring warp and twist, see ASTM D229.

Table 3
RANGE OF SIZES FOR ROUND ROLLED TUBES

Inside diameter (inches)		Outside diameter (inches)		Wall thickness (inch)		Maximum ratio of wall thickness to inside[3] diameter
Minimum	Maximum	Minimum	Maximum	Minimum	Maximum[4]	
0.188	48.000	0.250	50.000	0.031	1.000	1:2

Table 4
TOLERANCES FOR INSIDE AND OUTSIDE DIAMETERS FOR ROUND ROLLED TUBES

Nominal Diameter Inches	Plus or Minus Tolerance, Inches		
	Inside Diameter[5]		Outside Diameter Ground, 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	0.010	---	0.025
12.001 - 18.000	0.030	0.060	0.030
18.001 - 24.000	0.040	0.075	0.035
24.001 - 48.000	0.060	0.090	0.040

Table 5
TOLERANCES IN WARP FOR ROUND ROLLED AND MOLDED TUBES

Outside Diameter (inches)	Maximum Warp (based on 36 inch Dimension) Percent[6]
0.125 - 0.250	2.0
0.251 - 0.750	1.0
0.751 - Max	0.5

[3] "Maximum ratio of wall thickness to inside diameter" means that for any size of tube the standard wall thickness shall not be greater than 0.125, 0.250, or 0.500 times the inside diameter, whichever value applies. For example, the maximum wall thickness of a Grade LE rolled tube with a 0.250 inch inside diameter is 0.125 inches, and with a 1 inch inside diameter is 0.500 inches.

[4] Tubing having a wall thickness greater than 0.500 inches can show checks and/or cracks between laminations on machined or sawed edges.

[5] In the absence of a steel mandrel of the precise required, tube 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 size smaller mandrel and then curing and grinding the tube to size.

[6] This percentage is stated in terms of tube length. For method, see ASTM D668.

Table 6
WALL THICKNESS TOLERANCES FOR ROUND ROLLED TUBES

Wall Thicknesses (inch)	Tolerances (± inch)	
	Inside Diameter (inches)	
	0.188 - 0.500	0.501 - Max
0.031 to 0.062	0.010	0.008
0.063 to 0.125	0.011	0.009
0.126 to 0.250	0.013	0.011
0.251 to 0.500	0.015	0.013

Table 7
RANGE OF SIZES FOR MOLDED ROUND TUBES

Inside diameter (inches)		Outside diameter (inches)		Wall thickness (inch)		Maximum ratio of wall thickness to inside diameter
Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
0.125	3.875	0.188	4.000	0.031	1.000	1:2

Table 8
WALL THICKNESS TOLERANCES FOR ROUND MOLDED TUBES

Wall Thicknesses (inch)	Tolerances (± inch)		
	Inside Diameter (inches)		
	0.125 - 0250	0.251 - 0.500	0.501 - Max
0.031 to 0.061	0.008	0.008	0.008
0.062 to 0.125	0.011	0.011	0.011
0.126 to 0.250	---	0.015	0.011
0.251 to 0.500	---	---	0.013

Table 9
SIZE AND TOLERANCE FOR MOLDED RODS

Diameter (inches)	Tolerances (± inch)
0.188 to 1.999	0.005
2.000 to 4.000	0.008

Table 10
RANGE OF DIAMETERS FOR MOLDED RODS

Outside diameter, Inches	
Minimum	Maximum
0.188	4.000

Table 11
MAXIMUM WARP FOR MOLDED RODS

Diameter.(inches)	Warp (based on 36 inch Dimension) Percent[7]
0.125 - 0.250	2.0
0.251 - 0.750	1.0
0.751 - Max	0.5

[7] This percentage is stated in terms of rod length. For method of measuring warp, see ASTM D668.

Table 12
PERFORMANCE REQUIREMENTS FOR SHEETS

Requirement	ASTM Test Method/Other	Condition	Unit	Thickness (inches)										
				0.015	0.031	0.062	0.094	0.125	0.188	0.250	0.500	0.750	1.000	1.001+
Minimum Breakdown Voltage	D229	A	kV	---	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	30.0
		D-48/50		---	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Maximum Permittivity	D229	A		---	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.80
@ 1 MHz		D-24/23		---	---	---	---	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Maximum Dissipation Factor	D229	A		---	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
@ 1 MHz		D-24/23		---	---	---	---	0.070	0.070	0.070	0.070	0.070	0.070	0.070
Minimum Izod Impact Strength[8,9]			ft-lb/in											
Lengthwise:	D229	E-48/50	(notch)	---	---	---	---	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Crosswise:				---	---	---	---	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Minimum Flexural Strength[8,10]														
Lengthwise:	D229	A	ksi	---	16.0	16.0	16.0	16.0	16.0	16.0	15.0	15.0	14.5	14.5
Crosswise:				---	14.0	14.0	14.0	14.0	14.0	14.0	13.5	13.5	13.0	13.0
Minimum Bonding Strength[11]	D229	A		---	---	---	---	---	---	---	1,600	1,600	1,600	1,600
		D-48/50	lbs	--	---	---	---	---	---	---	1,500	1,500	1,500	1,500
Maximum Water Absorption[10]	D229	D_1-24/23	%	5.80	4.00	1.95	1.55	1.30	1.00	0.95	0.70	0.60	0.55	0.55
Flammability	UL 94	A	Class	---	HB	HB	HB	HB	HB	HB	HB	HB	HB	HB

[8] Maximum thickness tested shall be 2.00 inches.

[9] Specimens shall have a nominal thickness of 0.500 inches or shall be machined to 0.500 inches, from a thicker sheet. Unmachined specimens shall meet the tolerance given for 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.

[10] For intermediate thicknesses, the value for the next smaller thickness shall apply.

[11] Applicable for sheets having a thickness from 0.500 inches up to the maximum of 2.000 inches. 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 $\pm$0.005 inches.