DuPont™ Nomex® 410

Technical Data Sheet

Nomex® 410 is a family of insulation papers that offer high inherent dielectric strength, mechanical toughness, flexibility and resilience. Nomex® 410, the original form of Nomex® paper, is widely used in a majority of electrical equipment applications. Available in 11 thicknesses ranging from 0.05 mm to 0.76 mm (2 mil to 30 mil), Nomex® 410 is used in almost every known electrical sheet insulation application.

Electrical Properties

The typical electrical property values for Nomex® 410 are shown in Table I. The AC Rapid Rise dielectric strength data in Table I represent voltage stress levels withstood for 10 to 20 seconds at a frequency of 60 Hz. These values differ from long-term strength potential. DuPont recommends that continuous stresses in transformers designed with Nomex® 410 not exceed 40 V/mil (1.6 kV/mm) to help minimize the risk of partial discharges. The full wave impulse dielectric strength data shown in Table I are based on multiple sheets. These values are appropriate for applications that employ these materials in such configurations. Data based on single sheets of material are available upon request.

The geometry of the system has an effect on the actual impulse strength values of the material. The dielectric strength data are typical values and not recommended for design purposes. Design values can be supplied upon request.

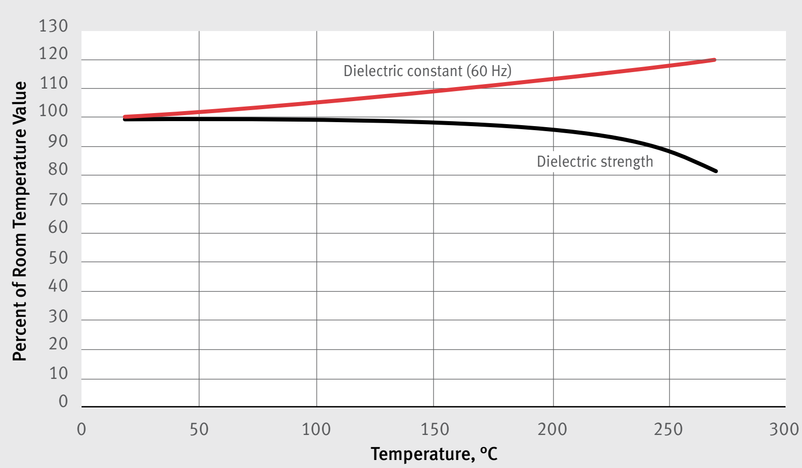
Table I. Typical Electrical Properties of DuPont™ Nomex® 410

Property	Nominal Thickness, mm (mil)											Test Method
	0.05 (2)	0.08 (3)	0.10 (4)	0.13 (5)	0.18 (7)	0.25 (10)	0.30 (12)	0.38 (15)	0.51 (20)	0.61 (24)	0.076 (30)	
Dielectric Strength AC Rapid rise, V/mil kV/mm	460 18	565 22	525 21	715 28	865 34	845 33	870 34	850 33	810 32	810 32	680 27	ASTM D149[1]
Full Wave Impulse, V/mil kV/mm	1000 39	1000 39	900 36	1400 55	1400 55	1600 63	N/A N/A	1400 55	1400 55	N/A N/A	1250 49	ASTM D3426
Dielectric Constant at 60 Hz	1.6	1.6	1.8	2.4	2.7	2.7	2.9	3.2	3.4	3.7	3.7	ASTM D150
Dissipation Factor at 60 Hz (x 10^{-3})	4	5	6	6	6	6	7	7	7	7	7	ASTM D150

1. Using 50-mm (2-in.) electrodes, rapid rise; corresponds with IEC 243-1 subclause 9.1, except for electrodes set-up of 50 mm (2 in.).

Temperature has a minor effect on dielectric strength and dielectric constant, as shown in Figure 1.

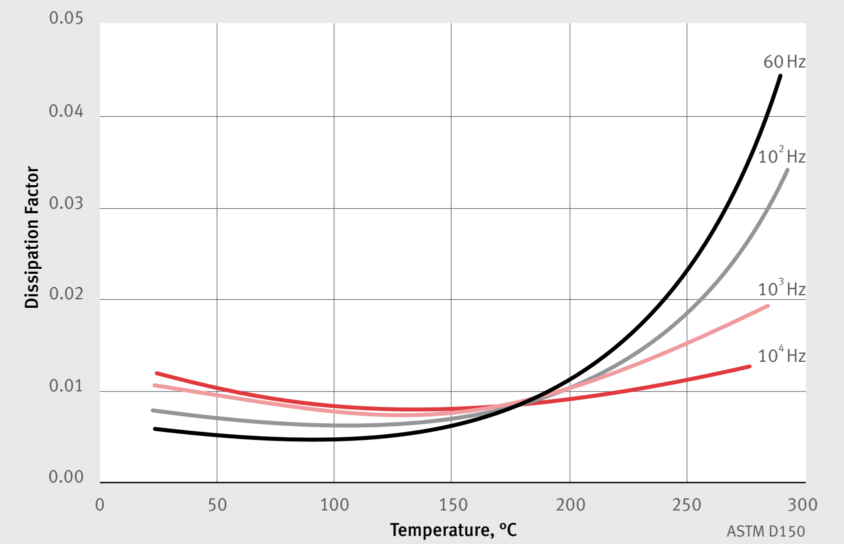
Figure 1. Effect of Temperature on Electrical Properties of DuPont™ Nomex® 410 — 0.25 mm (10 mil)



Dielectric constant—ASTM D150; Dielectric strength—ASTM D149

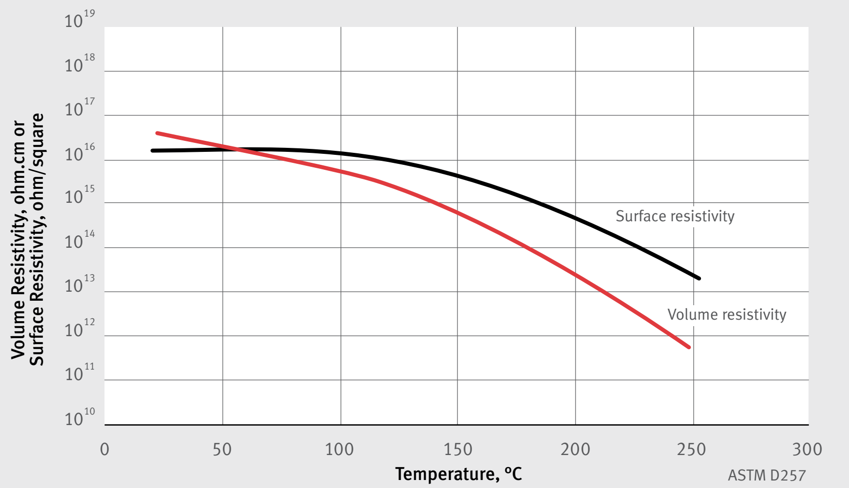
Variations in frequency up to 10^4 Hz have essentially no effect on the dielectric constant of Nomex® 410. The effects of temperature and frequency on dissipation factor of dry Nomex® 410 — 0.25 mm (10 mil) paper are shown in Figure 2. The 60 Hz dissipation factors of thinner papers are essentially the same as those for 0.25 mm (10 mil) at temperatures up to 200°C. At higher temperatures and frequencies, the thicker papers have somewhat higher dissipation factors than those shown for 0.25 mm (10 mil) paper.

Figure 2. Dissipation Factor versus Temperature and Frequency of DuPont™ Nomex® 410 — 0.25 mm (10 mil)



Surface and volume resistivities of dry Nomex® 410 — 0.25 mm (10 mil) paper are shown in Figure 3 as functions of temperature. The corresponding values for other thicknesses of Nomex® 410 are very similar.

Figure 3. Resistivity versus Temperature of DuPont™ Nomex® 410 — 0.25 mm (10 mil)



The relatively minor effects of moisture (humidity) on the electrical properties of Nomex® 410 — 0.25 mm (10 mil) are shown in Table II.

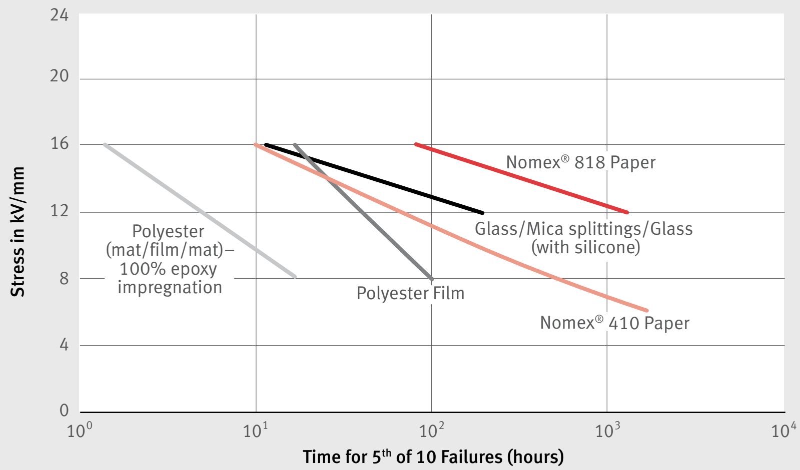
Table II. Humidity Effects on Electrical Properties of DuPont™ Nomex® 410 — 0.25 mm (10 mil)

Property	Typical Value			Test Method
Relative Humidity, %	Oven Dry	50	96	
Dielectric Strength, V/mil kV/mm	850 33.5	845 33.2	780 30.7	ASTM D149[1]
Dielectric Constant at 60 Hz at 1 kHz	2.5 2.3	2.7 2.6	3.2 3.1	ASTM D150
Dissipation Factor at 60 Hz (x 10^{-3}) at 1 kHz (x 10^{-3})	6 13	6 14	11 25	ASTM D150
Volume Resistivity, ohm.cm	6 x 10^{16}	2 x 10^{16}	2 x 10^{14}	ASTM D257

1. Using 50-mm (2-in.) electrodes, rapid rise; corresponds with IEC 60243-1 subclause 9.1 except for electrode set-up of 50 mm (2 in.).

Like other organic insulating materials, Nomex® paper is gradually eroded under attack by partial discharges. Partial discharge intensity is a function of voltage stress, which, in turn, depends almost entirely on design parameters such as spacing between circuit elements, smooth vs. sharp contours, etc. Although corona does not occur during normal operation of properly designed electrical equipment, any device may be subject to occasional overvoltages that produce brief corona discharges; and it is important that the insulation not fail prematurely under these conditions. The voltage endurance (time to failure under corona attack) of Nomex® 410 is superior to other commonly used organic insulations and even compares favorably with some inorganic compositions, as shown in Figure 4. These data were obtained in all cases on single layers of 0.25 mm (10 mil) materials at room temperature, 50% relative humidity, and 360 Hz frequency. Times to failure at 50–60 Hz are approximately 6 to 7 times as long as indicated.

Figure 4. Voltage Endurance of Various Insulating Materials — Single-Layer DuPont™ Nomex® 410 — 0.25 mm (10 mil)



This data is provided for comparative purposes only and should not be used as design values.

Mechanical Properties

The typical mechanical property values for Nomex® 410 are shown in Table III.

Table III. Typical Mechanical Properties of DuPont™ Nomex® 410

Property	Nominal Thickness, mm (mil)											Test Method
	0.05 (2)	0.08 (3)	0.10 (4)	0.13 (5)	0.18 (7)	0.25 (10)	0.30 (12)	0.38 (15)	0.51 (20)	0.61 (24)	0.076 (30)	
Typical Thickness,												
mm	0.06	0.08	0.11	0.13	0.18	0.26	0.31	0.39	0.52	0.61	0.78	ASTM D374[1]
mil	2.2	3.1	4.2	5.2	7.2	10.2	12.2	15.3	20.4	24.2	30.6	
Basis Weight, g/m²	41	64	88	115	174	249	310	395	549	692	839	ASTM D646
Density, g/cc	0.72	0.81	0.83	0.88	0.95	0.96	1.00	1.02	1.06	1.13	1.08	
Tensile Strength, N/cm												
MD	43	68	93	141	227	296	380	462	610	728	816	ASTM D828
XD	19	34	49	71	116	161	185	252	374	500	592	
Elongation, %												
MD	10	12	12	16	20	22	23	22	23	21	21	ASTM D828
XD	7	9	9	13	15	18	18	16	18	16	17	
Elmendorf Tear, N												
MD	0.8	1.2	1.9	2.3	3.7	5.6	7.1	9.0	14.3	N/A	N/A	TAPPI 414
XD	1.5	2.4	4.4	4.8	7.2	10.6	13.7	16.7	24.8	N/A	N/A	
Initial Tear Strength, N												
MD	11	16	24	31	48	69	88	110	158	191	233	ASTM D1004[2]
XD	6	9	14	17	27	42	55	71	114	153	193	
Shrinkage at 300°C, %												
MD	1.8	0.8	0.4	0.4	0.5	0.2	0.2	0.2	0.0	0.0	0.0	
XD	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	

MD = Machine Direction; XD = Cross Direction

1. Method D; using 17 N/cm².

2. Data presented for initial tear strength is listed in the direction of the sample per ASTM D1004. The tear is 90 degrees to sample direction; hence, for papers with a higher reported machine direction initial tear strength, the paper will be tougher to tear in the cross direction.

The effects of high temperatures on tensile strength and elongation are illustrated in Figure 5. Nomex® sheet structures also retain good mechanical properties at very low temperatures. At the boiling point of liquid nitrogen (minus 196°C or 77 K) the tensile strength of Nomex® 410 — 0.25 mm (10 mil) paper exceeds its room temperature value by 30% to 60% (depending on direction), while elongation to break is still greater than 3% (better than most inorganic materials at room temperature). This allows Nomex® 410 to work well in cryogenic applications.

The effects of moisture (humidity) on tensile strength and elongation are shown in Figure 6. Like elongation, the tear strength and toughness of Nomex® 410 are also improved at higher moisture contents.

The dimensions of bone-dry Nomex® 410 exposed to 95% relative humidity (RH) conditions will increase at most 1% in the machine direction and 2% in the cross direction (due to moisture absorption). This swelling is largely reversible when the paper is re-dried. The rate of change in dimensions will depend, of course, on paper thickness and configuration (e.g., individual sheets versus tightly wound rolls). Variations in environmental humidity will usually produce dimensional changes that will be less than 1%.

However, even small dimensional changes—especially if they are non-uniform—can cause or accentuate non-flatness (e.g., sag, puckers, etc.) in the sheet, which can cause problems in critical operations like laminating or creping. Therefore, Nomex® paper intended for these applications should be kept sealed in its protective polyethylene wrapper to maintain uniform moisture content until just before use. For more information on the effects of moisture on Nomex® insulation and how to appropriately protect the rolls, request our moisture brochure.

Figure 5. Effect of Temperature on Mechanical Properties of DuPont™ Nomex® 410 — 0.25 mm (10 mil)

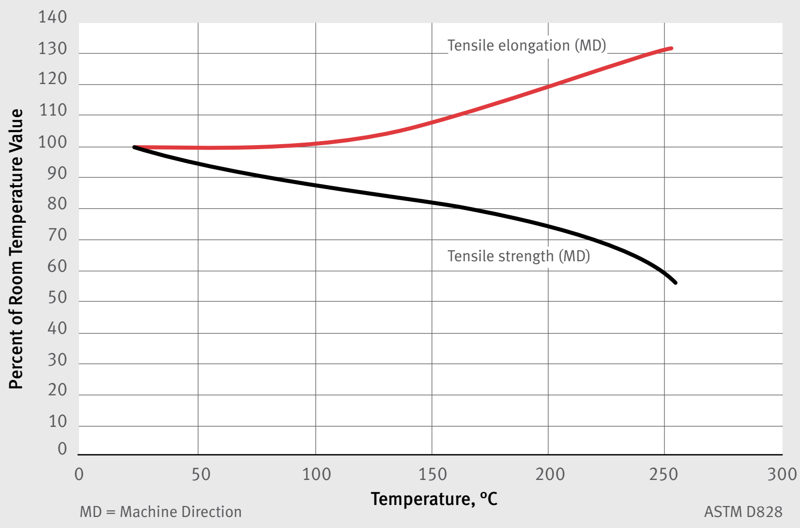
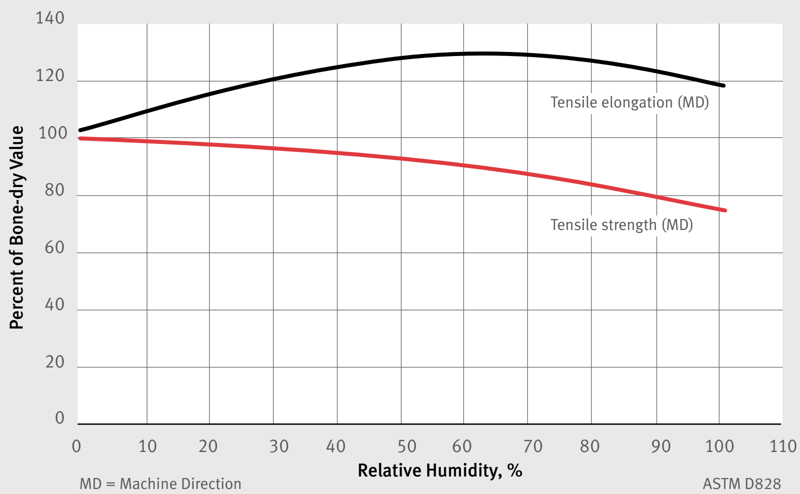


Figure 6. Effect of Moisture on Mechanical Properties of DuPont™ Nomex® 410 — 0.25 mm (10 mil)



Thermal Properties

The effects of long-time exposure of Nomex® 410 — 0.25 mm (10 mil) to high temperature on important electrical and mechanical properties are shown in Figures 7 and 8. These Arrhenius plots of aging behavior are the basis for the recognition of Nomex® paper as a 220°C insulation by Underwriters Laboratories and have been utilized for almost 50 years in commercial applications. These curves can also be extrapolated to higher temperatures. Measurements show, for example, that Nomex® 410 will maintain 300 V/mil (12 kV/mm) dielectric strength for several hours at 400°C, which is the performance predicted by the Arrhenius plot.

Figure 7. Useful Life versus Temperature for DuPont™ Nomex® 410 — 0.25 mm (10 mil)

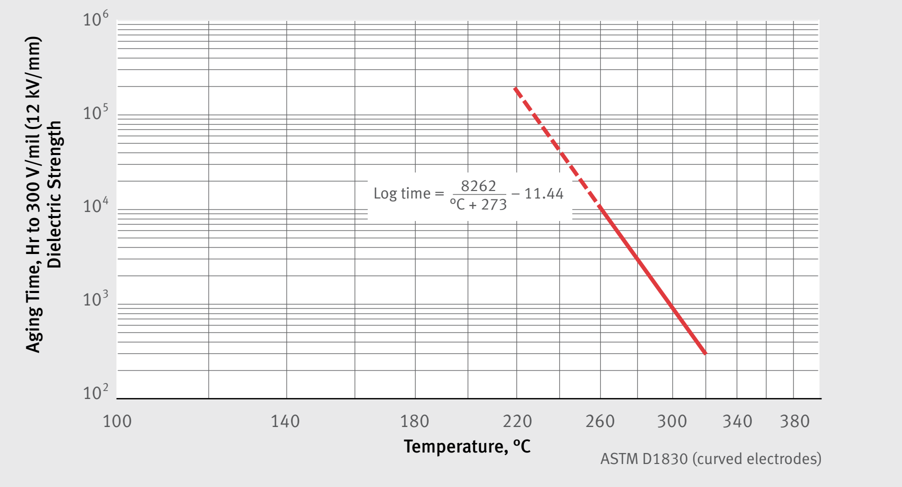
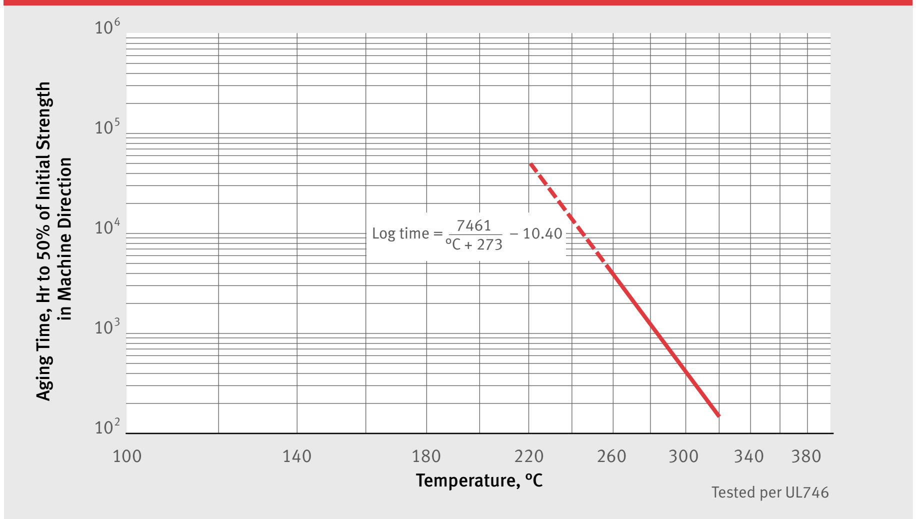


Figure 8. Useful Life versus Temperature for DuPont™ Nomex® 410 — 0.25 mm (10 mil)



The thermal conductivity of Nomex® 410 — 0.25 mm (10 mil) paper is shown in Figure 9. These values are similar to those for cellulosic papers and, as with most materials, are primarily determined by specific gravity (density). Therefore, thinner grades of Nomex® 410 will have slightly lower conductivity and thicker grades will have higher conductivities, as is seen in Table IV. The total system construction may affect the overall thermal conductivity; therefore, care should be taken in applying individual sheet data to actual situations. For example, two sheet insulations with identical thermal conductivities may have quite different effects on heat transfer from a coil due to the differences in stiffness or winding tension, which affect the spacing between the insulation layers.

Figure 9. Thermal Conductivity versus Temperature for DuPont™ Nomex® 410 — 0.25 mm (10 mil)

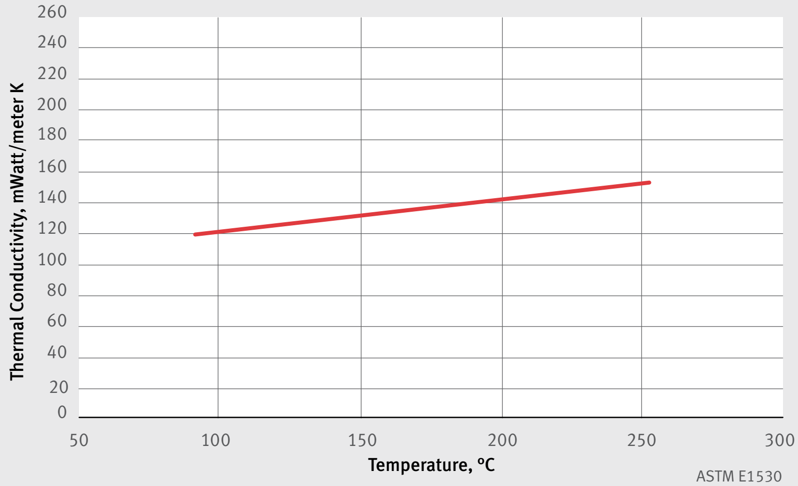


Table IV. Thermal Conductivity of DuPont™ Nomex® 410

Nominal Thickness, mm / mil	0.05 / 2	0.08 / 3	0.10 / 4	0.13 / 5	0.18 / 7	0.25 / 10	0.38 / 15	0.51 / 20	0.76 / 30
Density, g/cc	0.72	0.81	0.83	0.88	0.95	0.96	1.02	1.06	1.08
Thermal Conductivity,[1] mWatt/meter K	103	114	117	123	143	139	149	157	175

1. All data taken at 150°C

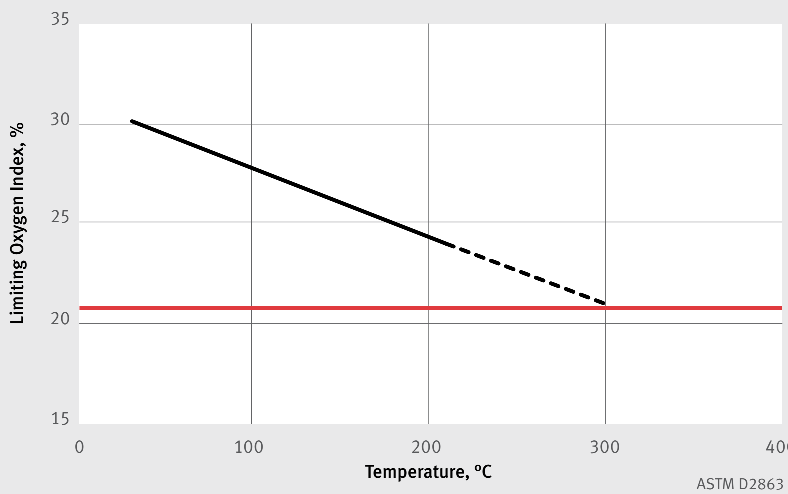
ASTM E1530

Chemical Stability

The compatibility of Nomex® papers and pressboards with virtually all classes of electrical varnishes and adhesives (polyimides, silicones, epoxies, polyesters, acrylics, phenolics, synthetic rubbers, etc.), as well as with other components of electrical equipment, is demonstrated by the many UL-recognized systems comprising Nomex®, including use in commercial applications for almost 50 years. Nomex® papers are also fully compatible (and in commercial use) with transformer fluids (mineral and silicone oils and other synthetics) and with lubricating oils and refrigerants used in hermetic systems. Common industrial solvents (alcohols, ketones, acetone, toluene, xylene) have a slight softening and swelling effect on Nomex® 410, similar to that of water. These effects are mainly reversible when the solvent is removed.

The Limiting Oxygen Index (LOI) of Nomex® 410 at room temperature ranges between 27% and 32% (depending on thickness and density); at 220°C, it ranges between 22% and 25%. Materials with LOI above 20.8% (ambient air) will not support combustion. Nomex® 410 must be heated between 240°C and 350°C (again depending on thickness) before its LOI declines below the flammability threshold. The LOI data for Nomex® 410 — 0.25 mm (10 mil) is shown in Figure 10.

Figure 10. Limiting Oxygen Index (LOI) for DuPont™ Nomex® 410 — 0.25 mm (10 mil)



Radiation Resistance

The effect of 6400 megarads (64 Mgy) of 2 MeV beta radiation on the mechanical and electrical properties of Nomex® 410 is shown in Table V. (By comparison, a laminate of polyester film and polyester mat of the same thickness, 100% epoxy-impregnated, crumbled after 800 megarads, or 8 Mgy). Similar results were obtained on exposure to gamma radiation.

The outstanding radiation resistance of Nomex® paper has led to its use in critical control equipment for nuclear power installations.

Table V. Radiation Resistance of DuPont™ Nomex® 410 — 0.25 mm (10 mil) to 2 MeV Electrons (Beta Rays)

Property	Dose, Mgy								Test Method
	0	1	2	4	8	16	32	64	
Tensile Strength, % of original									ASTM D828
MD	100	96	100	100	94	87	81	65	
XD	100	100	99	99	97	86	81	69	
Elongation, % of original									ASTM D828
MD	100	89	92	96	76	60	36	18	
XD	100	92	91	88	82	47	27	16	
Dielectric Strength,									ASTM D149[1]
V/mil	860	860	840	840	840	860	890	790	
kV/mm	34	34	33	33	33	34	35	31	
Dielectric Constant									ASTM D150
at 60 Hz	3.1	3.0	3.0	3.0	3.0	3.1	2.3	2.5	
at 1 kHz	3.0	3.0	2.9	3.0	2.9	3.1	2.3	2.5	
at 10 kHz	2.9	2.9	2.9	2.9	2.8	3.0	2.2	2.4	
Dissipation Factor (x 10^{-3})									ASTM D150
at 60 Hz	8	14	10	12	9	14	7	10	
at 1 kHz	13	16	15	16	13	16	11	13	
at 10 kHz	18	21	20	20	19	20	15	17	

MD = Machine Direction; XD = Cross Direction
1. With a 6.4-mm (1.4-in.) diameter electrode.

UL Ratings

Table VI shows the UL ratings for Nomex® 410 papers. Descriptions of the numerical values for each of the UL ratings are detailed in the UL website on Component Materials, which can be accessed at **iq.ul.com/ul/cert.aspx?ULID=230937**

Table VI. UL Ratings for DuPont™ Nomex 410

Nominal Thickness, mm	Nominal Thickness, mil	UL94 Flame Class	UL746A HWI Rating	UL746A HAI Rating	UL746B RTI Electrical	UL746B RTI Mechanical	UL746A HVTR Rating	UL746A CTI Rating
0.05	2	—	0	3	220	220	3	3
0.08	3	—	0	3	220	220	3	3
0.10	4	VTM-0	0	3	220	220	3	3
0.13	5	V-0	0	1	220	220	3	3
0.18	7	V-0	0	1	220	220	3	3
0.25	10	V-0	0	0	220	220	3	3
0.30	12	V-0	0	0	220	220	3	3
0.38	15	V-0	0	0	220	220	3	3
0.51	20	V-0	0	0	220	220	3	3
0.61	24	V-0	0	0	220	220	3	3
0.76	30	V-0	0	0	220	220	3	3

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The properties in this technical data sheet are average values and should not be used as specification limits. Unless otherwise noted, all properties were measured in air under "standard" conditions (in equilibrium at 23°C, 50% relative humidity). Note that, like other products of papermaking technology, Nomex® papers have somewhat different properties in the papermaking machine direction (MD) compared to the cross direction (XD). In some applications it may be necessary to orient the paper in the optimum direction to obtain its maximum potential performance.