DUPONT Nomex®

Nomex® fiber

Technical guide

Never quit™

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Section I

Introduction to Nomex® fiber

What is Nomex®?

Nomex® is a DuPont registered trademark for its family of aromatic polyamide (aramid) fibers. This family consists of staple fibers, continuous filament yarns, paper and spunlaced fabrics.

Uses for staple, yarn and spunlaced products include apparel fabrics to protect against flash fire and electric arc exposure; firefighter garments; fabrics and spun yarns for filtration applications; insulation in flame-resistant (FR) thermal protective apparel; rubber reinforcement; and in transportation textiles such as aircraft carpeting. Some uses for the paper products include insulation in electric motors and transformers, wire wrapping and honeycombed strength members in many aircraft. This technical guide focuses on products and end uses for the staple and yarn products. Information on other applications may be obtained by visiting the Nomex® Knowledge Center at nomex.com/knowledge

Unlike flame-retardant treated (FRT) materials, Nomex® fibers are inherently flame resistant: the flame resistance is an inherent property of the polymer chemistry. It will not diminish during the life of the fiber, and it cannot be washed out or worn away. The fiber's low stiffness and high elongation give it textile-like characteristics that allow processing on conventional textile equipment. These and other properties are discussed in detail in this guide.

In this guide, FR is used to designate materials that are inherently flame resistant, such as Nomex® and Kevlar®, while FRT is used to designate materials that have been treated with a flame-retardant chemical to make them flame resistant, such as FRT cotton.

Since its introduction, the product lines of Nomex® have been augmented to include a variety of natural and colored fibers and blends, each with unique properties designed to meet specific end-use requirements. The general classes of these products are discussed in the following section. Table I-2 on pages 4 and 5 lists some specific commercial products and their end uses.

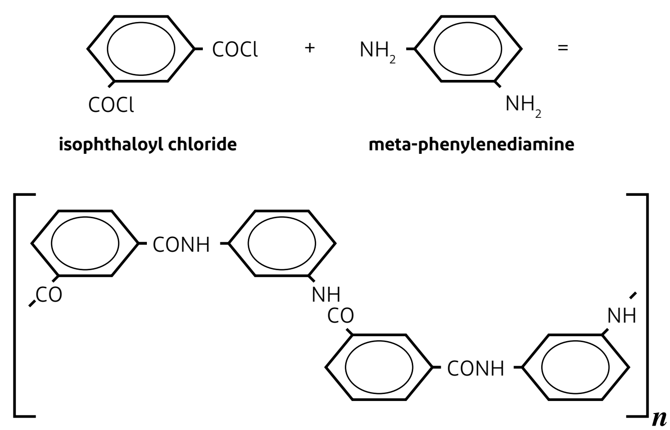
History of Nomex®

Nomex® was developed by a DuPont research team seeking a fiber with outstanding thermal resistance. Beginning in 1967, Nomex® was available at commercial scale in both paper and fiber form, with spunlaced constructions following in 1983. Today, DuPont combines that legacy with innovation to continue providing technical leadership in the thermal marketplace.

Molecular structure of Nomex®

Nomex® meta-aramid, poly(meta-phenyleneisophthalamide), is prepared from meta-phenylenediamine and isophthaloyl chloride in an amide solvent. It is a long chain polyamide where at least 85% of the amide linkages are attached directly to two aromatic rings. The meta-oriented phenylene forms bends in the polymer chain, reducing chain rigidity as compared to the para orientation in the chemically similar Kevlar® para-aramid chain. This flexible polymer chain gives Nomex® more textile-like qualities while retaining high-temperature properties similar to Kevlar®.

The aromatic rings and the conjugated amide bonds that link them together are particularly strong and resistant to chemical attack. They also provide a high degree of heat resistance to the polymer backbone. As a result, Nomex® does not melt and drip, and merely chars when exposed to high temperatures for prolonged periods.



Nomex® meta-aramid, poly(meta-phenyleneisophthalamide)

Figure 1.1 Nomex® meta-aramid synthesis

Products of Nomex®

This guide contains technical information on continuous filament yarns and staple fibers of Nomex®, including a listing of the products sold in North America. Because product names and type designations may be different outside North America, contact your local DuPont Representative for information specific to your region.

Type 430 Nomex®

Type 430 is a high crystallinity natural filament yarn of Nomex® with higher strength and chemical resistance than staple spun yarns. Type 430 is used where the aesthetics and properties of a filament yarn are required. It is available in light deniers for textile applications or higher deniers for rubber hose reinforcement applications. Type 430 is used in firefighters' turnout gear, coated fabrics, electrical insulation, radiator hoses and industrial laundry press covers.

Type 450 Nomex®

Type 450 is a naturally white staple fiber. It has higher crystallinity and strength than Type 455 and 462 fibers, and is sold as a 100% meta-aramid staple in various cut lengths. It is used in applications requiring high tensile properties, as well as chemical and thermal stability, such as in hot gas filtration fabrics, sewing threads, zipper tapes and firefighters' turnout facing fabrics. It is also used in its natural color for knit products such as balaclavas and underwear. Although dyeable, it is less dyeable than the Type 455 and 462 staple products, and is not available as a dye merged staple.

Type 455 Nomex® (Nomex® III)

Type 455 is a patented staple blend of Nomex® and Kevlar® fibers that was introduced to fill the need for higher performance thermal protective apparel. When converted to fabric, Type 455 staple is known commercially as Nomex® III. It offers several improvements compared to yarns or fabrics produced from Type 450 staple. However, because of its lower crystallinity, it produces yarn and fabrics that are slightly lower in strength than those produced from Type 450 staple.

Advantages versus Type 450 include:

- Increased resistance to break-open under thermal load. The presence of 5% Kevlar® inhibits thermal shrinkage, thus reducing the probability of break-open and the subsequent loss of the protective barrier.
- Easier dyeability. Type 455 Nomex® can be uniformly dyed in fabric or yarn form to the many colors required for civilian protective apparel. Type 455 Nomex® is sold as a dye merged staple.
- Fabric appearance. Crease retention and wrinkle resistance can be imparted to Nomex® III or Nomex® IIIA by autoclaving pressed garments at 30 psig steam pressure. Although not as strong as the memory of heat-set polyester, these memory forces provide significant advantages in appearance and ease of care vs. many competitive materials or unautoclaved garments.

Type 462 Nomex® (Nomex® IIIA)

Type 462 staple is a blend of Nomex® and Kevlar® fibers, and a proprietary static dissipative fiber. When converted to fabric, it is known commercially as Nomex® IIIA and is used for thermal protective apparel. It offers all the features of Type 455 staple plus a higher level of static dissipation in fabric form. The added antistatic fiber dissipates static generated from fabric-to-fabric and fabric-to-surface rubbing; minimizes the contribution of clothing to static hazards; and reduces apparent electric field strength and nuisance static. The staple is dye mergeable and can be package dyed as yarn for use in knit goods or sewing threads, or piece dyed as fabric for civilian protective apparel. Except for the static dissipative properties of Nomex® IIIA, all other properties are essentially the same as for Nomex® III. Properties reported in this guide should be considered applicable to both, unless a specific difference is noted in the text.

Type N101 and N102 filament yarn

Producer-colored filament yarn is available in a range of colors and deniers. Type N101 is entangled and Type N102 is a texturized filament yarn.

Type N104 dyeable filament yarn

Type N104 is a low crystallinity filament yarn available for applications where a dyed yarn is required. It dyes similarly to Types 455 and 462 Nomex®. Shrinkage of 7% to 8% may make package dyeing difficult.

Nomex® producer-colored fibers

Producer-colored Type N300 Series staple and Type N101 and N102 filament yarn are available in a range of colors. Custom colors can be produced with minimum volume restrictions. Staple blends similar to Type 455, Type 462 and yarns in different deniers are offered commercially. Staple blends with higher levels of Kevlar® are available for improved thermal performance. These staple and yarn fibers have high crystallinity similar to the Type 430 yarn and Type 450 staple fibers but with spun-in color. They have enhanced colorfastness and color uniformity, and higher yarn and fabric strength when compared to trade-dyed products.

Nomex® MHP

Nomex® MHP is a proprietary blend of 34% aramid, 33% lyocell, 31% modacrylic and 2% antistatic fibers. Nomex® MHP provides inherent multi-hazard FR protection against heat and flame, electric arc and small molten metal splash in a durable and comfortable fabric. Included antistatic fiber dissipates static generated from fabric-to-fabric and fabric-to-surface rubbing; minimizes the contribution of clothing to static hazards; and reduces apparent electric field strength and nuisance static.

DuPont™ Protera®

Protera® is an engineered blend of 33% Nomex® and Kevlar®, 65% modacrylic and 2% antistatic fibers. Protera® is designed to provide protection against electric arc and flash fire in a lightweight, inherent fabric so the protection cannot be washed out or worn away. Included antistatic fiber dissipates static generated from fabric-to-fabric and fabric-to-surface rubbing; minimizes the contribution of clothing to static hazards; and reduces apparent electric field strength and nuisance static.

Spunlaced fabrics

Spunlaced fabrics of Nomex® and Kevlar® fibers are durable, soft, conformable, saturable and lightweight—a unique combination of properties. Fabric integrity is based on the hydraulic jet entanglement of 0.75-inch staple fibers.

Resin binders, which detract from the aramid thermal properties, are not necessary, though they may be applied as a post treatment to impart stiffness or color. Fabrics are offered in a variety of basis weights from 0.7 oz/yd^2 to 8.0 oz/yd^2. They may be patterned or plain.

Converted widths match end-use requirements, typically less than 75-inches wide. Composition may be 100% Nomex®, 100% Kevlar® or blends of the two. Kevlar® in the blends provides resistance to flame break-open. The formed fabrics are, in some cases, processed further to modify properties for specific applications.

Product may be calendered to reduce thickness and increase modulus. Multiple layers of spunlaced fabric are quilted with woven face fabric of Nomex® to make durable, conformable and lightweight fire-blocking fabrics for transportation applications and thermal liners for fire service garments.

Table I-1 Product descriptions and types

Composition	Application	Type	Description
100% Nomex®	Filtration; apparel	E88	Calendered
	Business machines	E88C	
Nomex® and Kevlar® fibers	Apparel liners; moisture barrier substrate	E89	Nomex® E89™
100% Kevlar®	Fireblocking; calender roll	Z11	Narrow width tapes

Table I-2 shows the product line by type. The "N" series number identifies a product or product composition, while merge numbers identify the specific color. For inquiries about products other than those shown, contact your local DuPont Representative for details.

Table I-2 Nomex® fiber products

Fiber type	Availability	Description	Primary end uses
Yarn			
Natural yarn 430	200 d, 100 filament 1200 d, 600 filament 1600 d, 800 filament 2400 d, 2,100 filament	Natural (bright luster), high crystallinity, low dyeability, continuous-filament yarn	Rubber reinforcement, sewing thread, filtration fabrics, protective apparel
N104	150 d, filament 200 d, 100 filament	Natural (bright luster), low crystallinity, dyeable, continuous-filament yarn	Protective apparel applications where a dyeable yarn is required
Producer-colored yarn N101	400 d, 100 filament 1200 d, 100 filament 1600 d, 100 filament	Continuous-filament yarn in a range of colors	Protective apparel
N102	900 d, 400 filament	Texturized continuous-filament yarn in a range of colors	Protective apparel
Staple			
Natural staple 450	1.0, 1.5 or 2.0 dpf; 2 or 3 in. 5.5 dpf; 3 in.	Natural (bright luster) staple fiber	Filtration fabrics, sewing thread, knit fabrics for protective apparel, paper makers, laundry, business machine felts
455 (Nomex® III)	1.5 dpf, 1.5 or 2 in.	Dye merged, natural (bright luster) staple fiber containing 5% Kevlar®	Woven fabrics for civilian protective apparel
462 (Nomex® IIIA)	1.5 dpf, 1.5 or 2 in.	Dye merged, static dissipative, natural (bright luster) staple fiber containing 5% Kevlar® and 2% static dissipative fiber	Fabrics for protective apparel requiring lowest potential for static discharge
E502	1.3 dpf, 2 in.	Natural (bright luster) staple fiber	Woven and knit fabrics
N330	1.5 dpf, 2 in.	Dye merged, static dissipative, natural (bright luster) staple fiber containing 5% Kevlar® and 3% static dissipative fiber	Fabrics for protective apparel requiring lowest potential for static discharge

d = denier; dpf = denier per filament

(continued)

Table I-2 Nomex® fiber products (continued)

Fiber type	Availability	Description	Primary end uses
Producer- colored staple			
N301	1.5 dpf, 1.5 or 2 in.	Staple fiber in a range of colors containing 5% Kevlar®	Protective apparel
N302	1.5 dpf, 2 in.	Staple fiber in a range of colors containing 5% Kevlar® and 2% static dissipative fiber	Protective apparel
N303	1.5 dpf, 2 in.	Staple fiber in a range of colors containing 5% Kevlar® and 3% static dissipative fiber	Military protective apparel
N305	1.5 dpf, 2 in.	Staple fiber in a range of colors containing 23% Kevlar® and 2% static dissipative fiber ("Delta I" fabric in Europe)	Protective apparel
N307	1.3 dpf, 2 in.	Staple fiber in a range of colors containing 5% Kevlar® and 2% static dissipative fiber ("Delta C" fabric in Europe)	Protective apparel
N308	1.5 dpf, 2 in.	Staple fiber in a range of colors containing 60% Kevlar® and 40% Nomex®	Protective apparel
N310	1.5 dpf, 2 in.	Staple fiber in a range of colors containing 50% Kevlar® and 50% Nomex®	Protective apparel

d = denier; dpf = denier per filament

Section II

Properties of Nomex®

This section describes the typical properties of Nomex®. The data reported are those most often observed and are representative of the specific denier and type indicated.

For information on safety and health, refer to the Nomex® Article Information Sheet (AIS) or Safety Data Sheet (SDS).

Fiber properties

Nomex® fiber, a member of the aramid family of fibers, offers excellent flame resistance, good textile properties, dimensional stability and resistance to degradation by a wide range of chemicals and industrial solvents. Most varieties have an oval to dog bone fiber cross section, as shown in Figure 2.1.

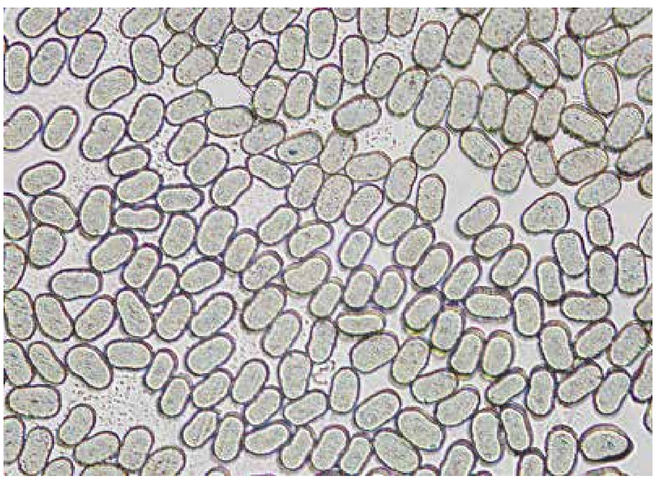


Figure 2.1 Photomicrograph of a typical cross section of type 462 yarn

Fiber and fabric test methods

Included in this technical guide are many physical and chemical properties of staple fibers, filament yarns, fabrics and garments. The results reported are those most often observed and are representative of particular samples. The tests are conducted using recognized standards, or in some cases, modifications of those standards, or methods developed by DuPont.

The Appendix in Section V lists the properties reported, the reference standard used and the general location within this technical guide where the information can be found. The properties listed should not be considered specifications. Contact your local DuPont Representative for copies of the most recent product specifications.

Tensile and thermal properties

Nomex® shows essentially no embrittlement or degradation at cryogenic conditions (temperatures as low as -320°F [-196°C]). At room temperature, the tensile properties are in the same range as those of nylon and polyester, making it easily processed on standard textile equipment. Typical room temperature stress-strain curves are shown in Figure 2.2. A summary of the tensile and thermal properties is shown in Table II-1.

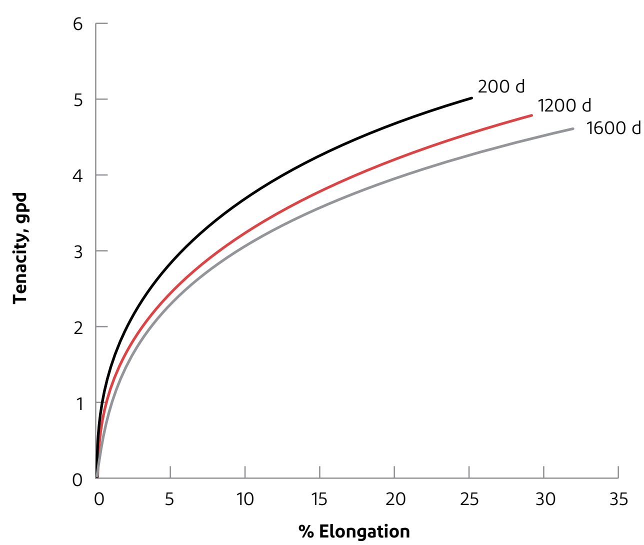


Figure 2.2 Typical stress-strain curves for type 430 natural Nomex® yarn (3 TPI, 10-in. gauge length, 12-in./minute extension rate)

Table II-1 Tensile and thermal properties of Nomex® fibers

Product tested	Type 430 1200 denier 2 dpf	Type 430 1600 denier 2 dpf	Type 450 1.5 dpf 32/2 CC	Type 455/462 1.5 dpf 32/2 CC	Type N301 1.5 dpf 22/1 CC
Density, g/cm^2	1.38	1.38	1.37	-	-
Moisture, %					
As shipped*	4.0	4.0	8.2	8.3	8.3
Billed (commercial, ASTM)	4.5	4.5	4.5	4.5	4.5
Tensile properties					
Straight test[1]					
Tenacity, gpd	5.0	4.9	2.9	2.6	2.8
Elongation, % (at break)	30.5	31.0	22	21	19
Initial modulus, gpd	94	85	-	-	-
Loop test					
Tenacity, gpd	4.1	3.9	-	-	-
Thermal properties					
Heat of combustion[2]					
BTU/lb	12100	-	12100	12100	12100
J/kg	28.1×10^6	-	28.1×10^6	28.1×10^6	28.1×10^6
Specific heat[3] at 77°F (25°C), cal/g•°C	0.30	-	0.30	0.26	0.29
Shrinkage in water at 212°F (100°C), %	1.3	1.1	4.0 max.	0.5	-
Shrinkage in dry air, 30 min.[4] at 545°F (285°C), %					
Aim	15	12	-	-	-
Max.	4.0	4.0	-	-	-
Thermal conductivity[5]					
W/(m•K)	0.25	-	-	-	-
BTU/(h•ft•°F)	0.14	-	-	-	-
Coefficient of linear expansion 78°F–266°F (26°C–130°C)					
cm/(cm•°C)	1.8×10^{-5}	1.8×10^{-5}	1.8×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
in./(in.•°F)	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}
Filament cross section Oval to dog bone shaped					
Major diameter, microns avg. (range)	20 (17-22)	-	17 (15-18)	18 (15-20)	18 (15-20)
Minor diameter, microns avg. (range)	11 (9-13)	-	10 (8-12)	10 (8-12)	10 (8-12)

dpf = denier per filament; CC=Cotton Count
*Typical moisture levels on fiber as shipped. Equilibrium moisture levels are dependent on humidity and processing conditions.
[1] Filament yarn tested at 3 TPI, 10-in. gauge length and 60%/minute extension rate. DuPont Test Method 12002.
[2] Per ASTM D2015, yarn dried in 90 TORR vacuum oven at 194°F (90°C) for 60 minutes before testing.
[3] TA Instruments Model 2920 modulated DSC, ASTM E1269.
[4] Yarn shrinkage per DuPont Test Method 12029.
[5] Per ASTM E1530 on 1.4 g/cc compressed paper; density equivalent to crystallized yarn.
Note: The data in this table are those most commonly observed and are representative of the particular denier and type indicated; they are not product specifications. Properties will vary with denier and type

Effect of yarn twist

Yarn twist has a significant influence on filament yarn properties. Benefits can be derived from using the optimum twist for all load-bearing yarns.

The influence of increasing yarn twist on physical properties of Nomex® filament yarns is shown in Figures 2.3 and 2.4 for 200-denier and 1200-denier Type 430 Nomex®, respectively. This influence can be summarized as follows:

- Elongation increases
- Initial modulus decreases sharply
- Tenacity increases as twist increases for 200 denier yarn
- Tenacity peaks at approximately 4 TPI then decreases with further twist for 1200 denier yarn

10-in. gauge length, 120%/minute extension rate

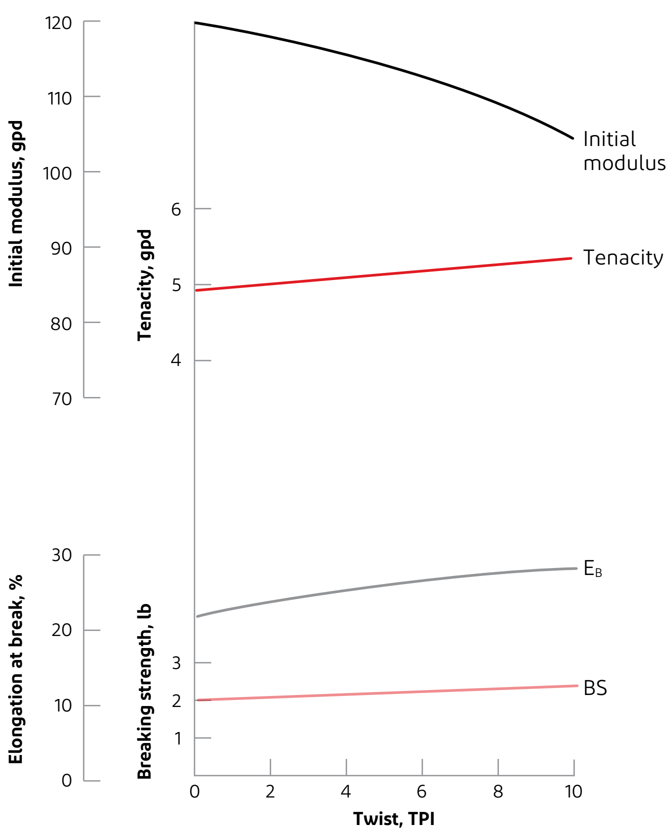


Figure 2.3 Effect of twist on 200-denier Nomex® yarn (200-100-0 type 430)

10-in. gauge length, 120%/minute extension rate

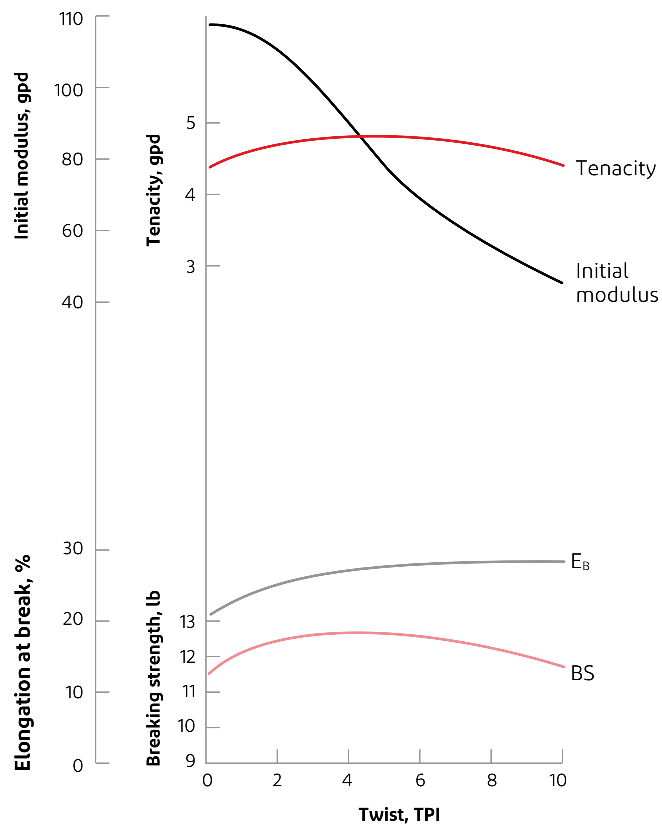


Figure 2.4 Effect of twist on 1200-denier Nomex® yarn (1200-600-0 type 430)

Effect of dry heat

Thermogravimetric analysis (TGA) of Type 455 Nomex® (Figure 2.5) shows less than 10% fiber weight loss up to approximately 752°F (400°C) in air or nitrogen. Rapid weight loss is seen at temperatures above 800°F (~427°C). Thermal oxidation in air is time/temperature dependent. Fabric scorching or charring can occur in as little as 30 seconds at 662°F (350°C) in air. Increasing the temperature will decrease the time to form char.

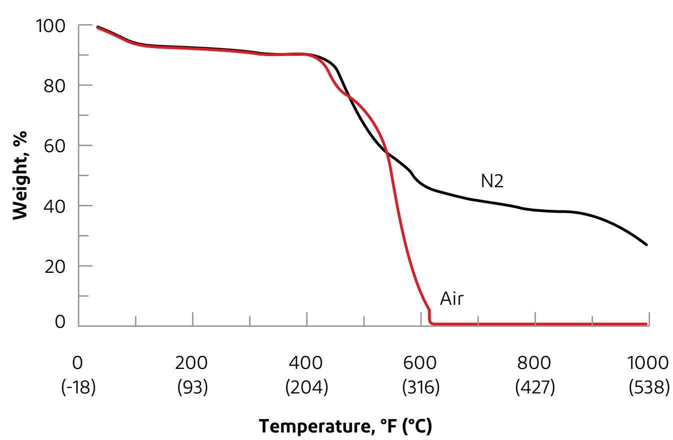


Figure 2.5 Thermogravimetric analysis (TGA) of type 455 Nomex® in nitrogen and air

Nomex® does not melt or drip. A typical Differential Scanning Calorimeter (DSC) curve for Type 462 (Figure 2.6) shows the change in energy input vs. temperature. It does not show a defined melting point for Nomex®. The inflection in the curve shown at 491.5°F (255.3°C) represents the melting point of the static dissipative fiber in Type 462. The DSC curves for Type 450 and 455 Nomex® will be similar, but without the antistatic fiber inflection at 491.5°F (255.3°C)

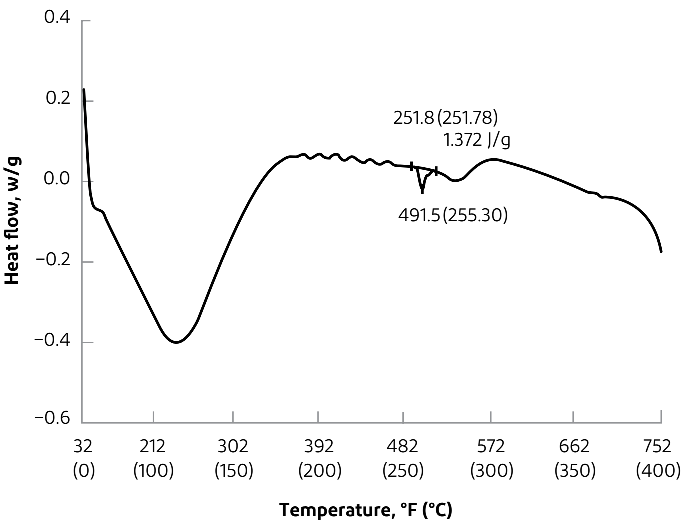


Figure 2.6 Differential scanning calorimeter (DSC) curve of type 462 Nomex® in nitrogen

The strength retention of Nomex® when exposed to heat is a function of time, temperature and environment. In applications such as hot gas filtration where exposures may be continuous for several months to years, and where fiber strength may impact filter bag life, a maximum continuous operating temperature of 400°F (204°C) is recommended. In applications such as firefighters' turnout gear where exposure temperatures may be much higher but of shorter duration, gear fabric may perform its intended function for many years and still exceed National Fire Protection Association (NFPA) strength guidelines.

Nomex® has good stress-strain properties at temperatures above the melting point of most other synthetic fibers. Increasing temperature reduces the tensile strength, modulus and break elongation of yarns of Nomex®.

Yarns tested after exposure to various temperatures for 5 minutes in dry air give the stress-strain curves shown in Figure 2.7. The relationships between temperature and breaking tenacity, breaking elongation and initial modulus are shown under the same conditions in Figure 2.8. At 489°F (254°C), the approximate melting point of nylon and polyester fibers, Nomex® has a breaking strength ~50% of that at room temperature.

200-denier, 100-filament yarn with 3 TPI, 60%/minute extension rate

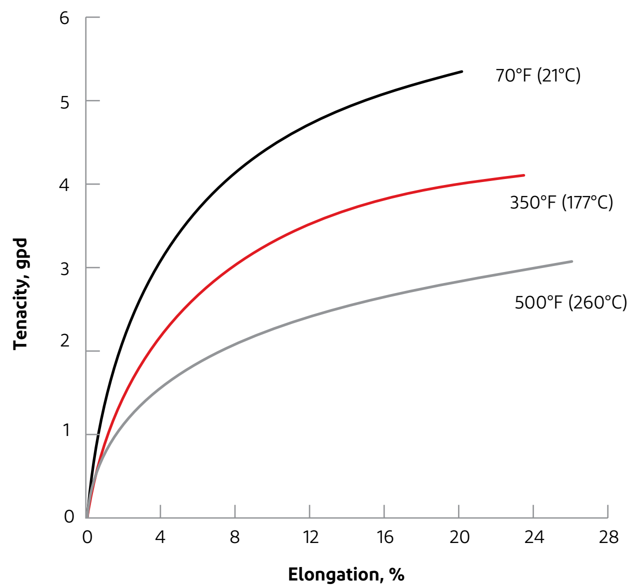


Figure 2.7 Stress-strain curve for 200-denier type 430 Nomex® tested at various temperatures after 5-minute exposure

1200- and 1600-denier yarn, 3 TPI, 60%/minute extension rate

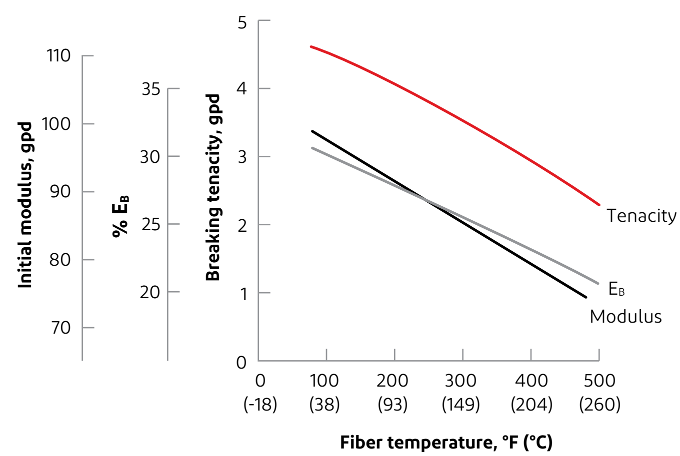


Figure 2.8 Tensile properties of type 430 Nomex® tested at various temperatures after 5-minute exposure

After exposing fibers of Nomex® to dry air at 500°F (260°C) for 1,000 hours and then returning them to room temperature, the breaking strength and toughness of Nomex® is approximately 65% of that exhibited before exposure. The effect of prolonged exposure is shown in Figures 2.9 and 2.10.

Tested at 70°F (21°C), 65% RH, 3 TPI, 120%/minute extension rate

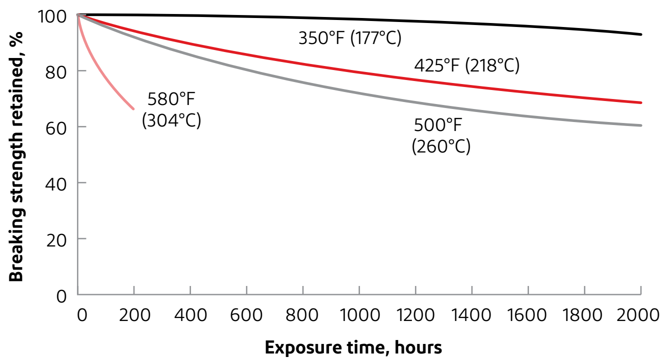


Figure 2.9 Strength retained by type 430 Nomex® after prolonged exposure to hot, dry air

Tested at 70°F (21°C), 65% RH, 3 TPI, 120%/minute extension rate

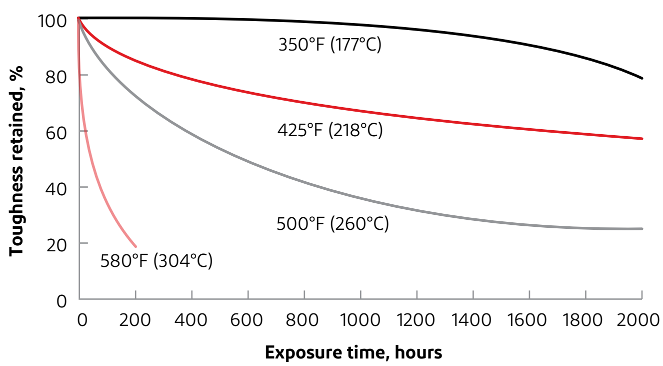


Figure 2.10 Toughness retained by type 430 Nomex® after prolonged exposure to hot, dry air

Effect of moisture

The presence of small amounts of water vapor in air or other gases has no apparent effect on the strength properties of Nomex®, even at elevated temperatures. Variations in relative humidity from 5% to 95% have virtually no measurable effect on the strength of Nomex® at room temperature.

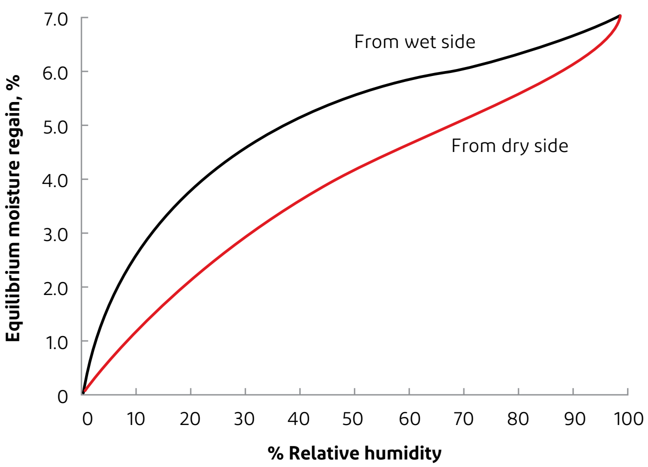
Tests have shown that thoroughly wet yarn of Type 430 Nomex® is approximately 75% as strong as dry yarn at the same temperature. At elevated temperatures, Nomex® fiber in intimate contact with water or saturated steam exhibits a progressive loss in strength.

Sealed-tube tests have shown a strength loss of approximately 70% for Nomex® fibers exposed for 1,000 hours at 300°F (149°C) in air saturated with water vapor. In contrast, nylon completely deteriorates in less than 100 hours under the same conditions.

Moisture regain and dimensional stability

Moisture regain is the tendency of most fibers to pick up or give off ambient atmospheric moisture until an equilibrium moisture content is reached. Relative humidity (RH) has a significant effect on the rate of moisture absorption and equilibrium level. The higher the RH, the faster Nomex® absorbs moisture during the initial phase of moisture gain, and the higher the final equilibrium level.

The effect of RH on the moisture regain of Type 430 Nomex® is shown in Figure 2.11. When tested in accordance with ASTM D2654 at 70°F (21°C) at 65% RH, fabrics of Nomex® IIIA contain 5% to 5.5% moisture at equilibrium levels. The moisture regain of Nomex® is significantly greater than polyester; slightly higher than nylon; and less than cotton.



Ref: "Absorption and Desorption of Water by Some Common Fibers", John F. Fuzek, Eastman Kodak Company, Kingsport, TN 37662

Figure 2.11 Equilibrium moisture regain of type 430 Nomex® at 70°F (21°C)

A combination of moisture and heat produces greater shrinkage of Nomex® fiber than dry heat alone because it more fully releases internal fiber stresses. Boiling water, for example, produces an immediate shrinkage of approximately 1.3% in Type 430 Nomex®. Repeated 5-minute exposures in boiling water result in progressively greater shrinkage, for a total of 3.8% after 100 exposures.

Due to high shrinkage, uncrystallized Nomex® fibers (currently T455, T462 and N330 staple and N104 filament) require wider loom reed width than crystallized fibers to obtain desired fabric width after dyeing and/or finishing.

Woven fabrics of Nomex® III, Nomex® IIIA and producer-colored fibers exhibit a low level of shrinkage when laundered. In a laboratory test, fabrics of Nomex® were commercially laundered at 160°F (71°C). After five launderings, both shirt-weight (4.5 oz/yd^2) and pant-weight (6.0 oz/yd^2) fabrics shrunk an average of 2% in both the warp and fill direction. No additional shrinkage was seen in 45 subsequent launderings.

The longitudinal stability of Nomex® fiber is virtually unaffected by changes in RH. When exposed to dry air at 500°F (260°C), Type 430 Nomex® shrinks approximately 1% in length within a few seconds. Additional shrinkage of approximately 0.7% occurs within the first 10 minutes of exposure (Figure 2.12). Longer exposures at this temperature have essentially no further effect on yarn length. Properly constructed filtration fabrics of Nomex® will neither stretch nor shrink more than 1% when exposed to operating temperatures less than 400°F (204°C), nor will they change significantly in length with variations in RH.

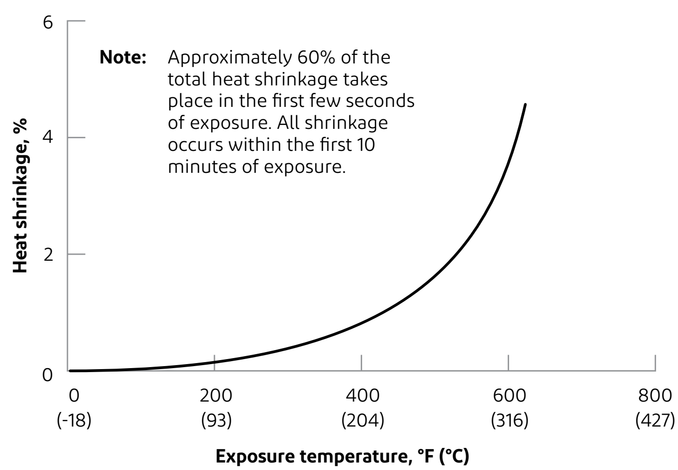


Figure 2.12 Shrinkage of type 430 Nomex® yarn in hot, dry air after 10 minutes at test temperature

Flammability, smoke and off-gas generation

The Limiting Oxygen Index (LOI) of Nomex® is approximately 28. Thus, when exposed to flame at room temperature in a normal air environment, Nomex® will not continue to burn when the flame is removed. At temperatures above approximately 800°F (427°C), Nomex® carbonizes and forms a tough char.

The composition and quantity of off-gases varies widely depending on rate of heating, presence of oxygen and other factors. Burning Nomex® fiber produces combustion products similar to those of wood, wool, cotton, polyester and acrylic. At combustion temperatures, Nomex® releases carbon dioxide and carbon monoxide. Sometimes, traces of hydrogen cyanide and nitrogen oxides are detected. Under less severe heating conditions, Nomex® degrades very slowly, releasing small quantities of a wide variety of organic compounds. These may include: carbon dioxide, acetone, acetamide, acetaldehyde, benzene, butane, toluene and many other compounds in trace amounts, depending on exposure conditions.

Resistance to degradation

Abrasion

Abrasion resistance is an important consideration in both protective apparel and filtration applications. Abrasion from wear and laundering is a primary cause of garment failure, whereas abrasion from dust exposure and cage wear often leads to filter bag failure.

Woven fabrics made from spun staple yarns of Nomex® consistently exhibit abrasion resistance superior to that of comparable, or in some cases, even heavier constructions of polyester/cotton blends and 100% cotton (Figure 2.13).
This advantage contributes to extended garment wear life.

Elmendorf tear test (lbf) ASTM D1424

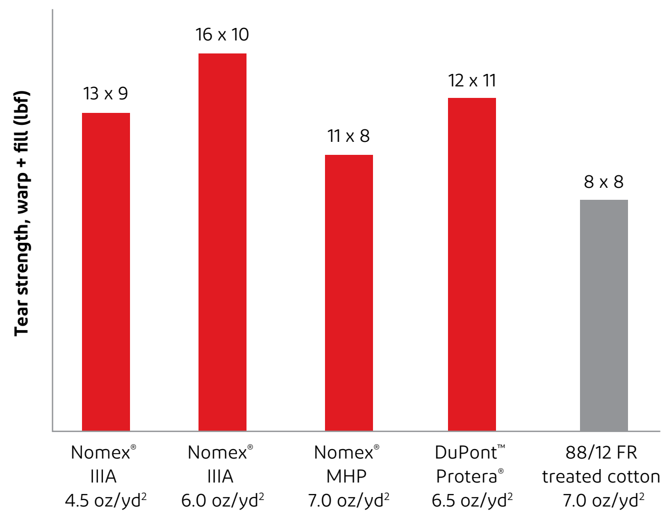


Figure 2.13 Elmendorf tear test for protective apparel fabrics ASTM D1424 warp x fill (lbf)

Laundering and wear life

Nomex® used in protective apparel applications can be of several types, as described in Section I. Nomex® III and Nomex® IIIA are used in shirts, pants, coveralls and outerwear garments. The use of a static dissipative fiber in Nomex® IIIA helps reduce nuisance static buildup and makes it the preferred product for most garments. Nomex® III and Nomex® IIIA perform similarly in laundering and chemical resistance; therefore, the performance data is interchangeable.

Garments of Nomex® fiber can be laundered or dry cleaned by conventional home or industrial cleaning methods. Due to its superior abrasion and chemical resistance, little decrease in fabric strength results from laundering. Colorfastness is best maintained through use of low alkalinity detergents and moderate (140°F [60°C]) wash water temperatures. Higher temperatures and alkalinity can be used, along with solvenated detergents, if required, to remove heavy oily soil. For more information, see the Laundering Guide for Nomex® Aramid Fiber.

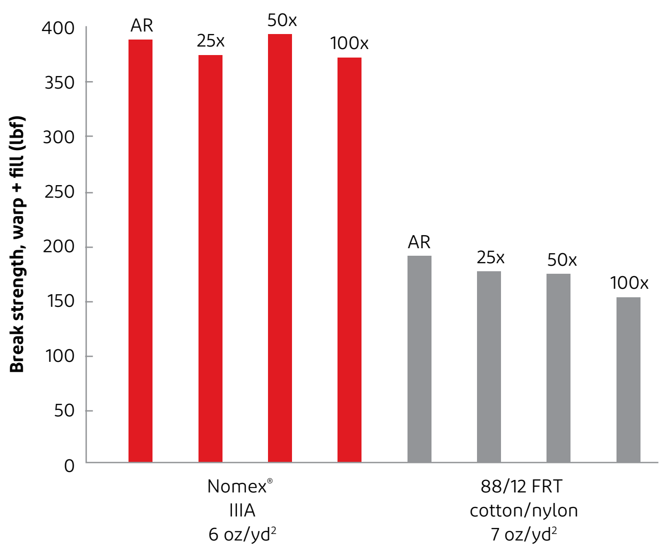


Figure 2.14 Effect of laundering on break strength–grab test (lbf) ASTM D5034 (warp + fill) as received (ar) and after 25, 50 and 100 washes

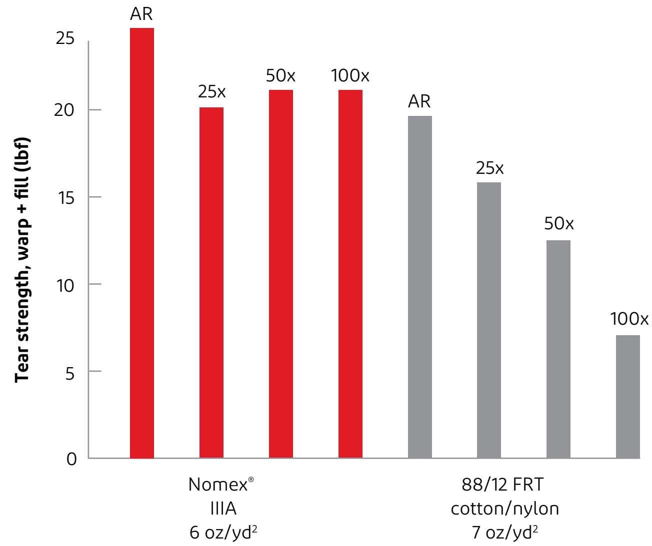


Figure 2.15 Effect of laundering on tear strength (lbf) ASTM D1424 Elmendorf tear test (warp + fill) as received (AR) and after 25, 50 and 100 washes

Chemical resistance

In general, Nomex® fiber exhibits very good resistance to many chemicals. It is highly resistant to most hydrocarbons and organic solvents. Chemical resistance during exposure in use and to chemicals and solvents used in cleaning contributes to the excellent durability and wear life of garments made of Nomex®.

The resistance of Nomex® to acid solutions is better than that of nylon, but not as good as that of polyester. However, at elevated temperatures, the resistance of Nomex® to acid vapors is better than that of polyester. Nomex® shows excellent resistance to alkalis at room temperature, but is degraded by strong alkalis at high temperatures. Type 430 Nomex® and Type 450 Nomex® have excellent resistance to sodium hypochlorite bleach, but Type 455 Nomex® and Type 462 Nomex® exhibit moderate (35%) strength loss in this exposure. Nomex® is resistant to degradation by fluorine-containing elastomers, resins and refrigerants at high temperatures. Additional information on the chemical resistance of Type 430 Nomex® is shown in Table II-2.

Table II-2 Chemical resistance of type 430* Nomex® filament yarn**

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	Effect on breaking strength***
Strong mineral acids					
Hydrochloric	1	160	71	10	Slight
	10	70	21	1,000	Appreciable
	10	160	71	10	Appreciable
	37	160	71	10	Degraded
	37	160	71	100	Degraded
Nitric	1	70	21	100	Slight
	10	70	21	100	Moderate
	70	70	21	100	Appreciable
Sulfuric	10	70	21	100	None
	10	250	121	100	Appreciable
	50	210	99	10	None
	70	70	21	100	None
	96	70	21	100	Degraded
Hydrobromic	10	70	21	1,000	Moderate
Phosphoric	10	70	21	1,000	None
	10	210	99	100	Slight
	70	210	99	100	Slight
	70	210	99	1,000	Degraded
Hydrofluoric	10	70	21	100	None
	10	210	99	10	Moderate

*Refer to text for a discussion of the effect of these chemicals on other products of Nomex®. Type 430 Nomex® is 1200-denier, 600-filament yarn.
**Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

***None 0 to 10% strength loss
Slight 11% to 20% strength loss
Moderate 21% to 40% strength loss
Appreciable 41% to 80% strength loss
Degraded 81% to 100% strength loss

(continued)

Table II-2 Chemical resistance of type 430* Nomex® filament yarn** (continued)

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	Effect on breaking strength***
Organic acids					
Acetic	5	210	99	1,000	None
	100	70	21	100	None
	100	210	99	100	None
Benzoic	3	210	99	100	None
Formic	40	70	21	1,000	None
	5	210	99	1,000	Moderate
	40	210	99	100	Moderate
	90	70	21	100	None
	90	210	99	100	Moderate
Oxalic	10	210	99	100	Moderate
	5	210	99	1,000	Appreciable
Chromic	10	70	21	1,000	None
	10	210	99	100	Degraded
	30	210	99	10	Degraded
Salicylic	3	210	99	1,000	Slight
Strong alkalis					
Ammonium hydroxide	28	70	21	1,000	None
Sodium hydroxide	1	210	99	1,000	Moderate
	1	250	212	1,000	Degraded
	10	70	21	1,000	None
	10	210	99	100	Degraded
	10	210	99	10	Moderate
	40	70	21	100	None
	40	70	21	1,000	Slight
	40	250	212	10	Degraded
Tetramethyl ammonium	10	70	21	1,000	None
Hydroxide	10	150	66	100	None

*Refer to text for a discussion of the effect of these chemicals on other products of Nomex®. Type 430 Nomex® is 1200-denier, 600-filament yarn.
**Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

***None — 0 to 10% strength loss
Slight — 11% to 20% strength loss
Moderate — 21% to 40% strength loss
Appreciable — 41% to 80% strength loss
Degraded — 81% to 100% strength loss

(continued)

Table II-2 Chemical resistance of type 430* Nomex® filament yarn** (continued)

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	Effect on breaking strength***
Oxidizing and reducing agents					
Peracetic acid pH 4	2	70	21	1,000	None
	2	210	99	100	Slight
	0.2	210	99	1,000	Slight
Sodium chlorite	0.7 pH 4	210	99	100	Appreciable
	0.7 pH 8	210	99	100	Appreciable
Sodium hypochlorite	0.01 pH 10	70	21	1,000	None
	0.01 pH 10	160	71	100	Slight
	0.4 pH 11	70	21	1,000	Slight
	0.4 pH 11	160	71	100	Slight
Hydrogen peroxide	0.4 pH 7	70	21	1,000	None
	0.4 pH 7	160	71	100	None
	0.2 pH 11	70	21	1,000	None
Sodium perborate	0.2 pH 11	160	71	100	None
	1	70	21	1,000	None
	1	210	99	100	None
Sodium hydrosulfite	1	160	71	100	None
Sodium sulfoxylate formaldehyde	1 pH 4	210	99	100	None
Sodium bisulfite	1 pH 4	210	99	100	None

*Refer to text for a discussion of the effect of these chemicals on other products of Nomex®. Type 430 Nomex® is 1200-denier, 600-filament yarn.
**Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

***None 0 to 10% strength loss
Slight 11% to 20% strength loss
Moderate 21% to 40% strength loss
Appreciable 41% to 80% strength loss
Degraded 81% to 100% strength loss

(continued)

Table II-2 Chemical resistance of type 430* Nomex® filament yarn** (continued)

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	Effect on breaking strength***
Organic chemicals					
Acetaldehyde (water)	10	70	21	1,000	None
Acetone	10	70	21	1,000	None
	100	133	56	100	Slight
Amyl alcohol	100	70	21	1,000	None
Benzaldehyde	100	70	21	1,000	None
Benzene	100	70	21	1,000	None
Carbon disulfide	100	70	21	1,000	None
Carbon tetrachloride	100	171	77	100	None
	100	70	21	1,000	None
Chloroform	100	70	21	1,000	None
Cottonseed oil	100	70	21	1,000	None
Dimethyl formamide	100	70	21	1,000	None
Ether	100	70	21	1,000	None
Ethyl acetate	100	70	21	1,000	None
Ethyl alcohol	100	70	21	1,000	None
	100	170	77	100	None
Ethylene glycol	50	210	99	1,000	Slight
Formaldehyde (water)	10	70	21	1,000	None
Freon™ 113 refrigerant	100	70	21	1,000	Appreciable
Gasoline (leaded)	100	70	21	1,000	None
Glycerine	100	210	99	10	None

*Refer to text for a discussion of the effect of these chemicals on other products of Nomex®. Type 430 Nomex® is 1200-denier, 600-filament yarn.
**Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

***None 0 to 10% strength loss
Slight 11% to 20% strength loss
Moderate 21% to 40% strength loss
Appreciable 41% to 80% strength loss
Degraded 81% to 100% strength loss

(continued)

Table II-2 Chemical resistance of type 430* Nomex® filament yarn** (continued)

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	Effect on breaking strength***
Organic chemicals					
Iodine in ethyl alcohol	3.5	70	21]	10	None
Lard	100	70	21	1,000	None
Linseed oil	100	70	21	1,000	None
Methyl alcohol	100	70	21	1,000	None
Mineral oil	100	210	99	10	None
Nitrobenzene	100	70	21	10	None
Perchloroethylene	100	210	99	10	None
Phenol (water)	5	70	21	10	None
	100	210	99	1	None
Resourcinol (water)	5	70	21	10	None
	5	70	21	100	None
	100	250	212	10	None
Stoddard solvent	100	160	71	10	None
Tetrachloroethene	100	70	21	1,000	None

*Refer to text for a discussion of the effect of these chemicals on other products of Nomex®. Type 430 Nomex® is 1200-denier, 600-filament yarn.

**Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

***None 0 to 10% strength loss
Slight 11% to 20% strength loss
Moderate 21% to 40% strength loss
Appreciable 41% to 80% strength loss
Degraded 81% to 100% strength loss

(continued)

Table II-2 Chemical resistance of type 430* Nomex® filament yarn (continued)**

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	Effect on breaking strength***
Salt solutions					
Copper sulfate	3	70	21	1,000	None
	3	210	99	100	None
Ferric chloride	3	210	99	100	Moderate
Sodium carbonate	5	250	212	100	Slight
Sodium chloride	3	70	21	1,000	None
	3	210	99	100	None
	10	70	21	1,000	None
	10	210	99	100	None
	10	250	212	100	Slight
Sodium metasilicate	10	210	99	100	Moderate
Sodium phosphate	5	210	99	100	None
Zinc chloride	3	210	99	100	None

*Refer to text for a discussion of the effect of these chemicals on other products of Nomex®. Type 430 Nomex® is 1200-denier, 600-filament yarn.
**Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

***None 0 to 10% strength loss
Slight 11% to 20% strength loss
Moderate 21% to 40% strength loss
Appreciable 41% to 80% strength loss
Degraded 81% to 100% strength loss

The effects of various chemicals on Type 430 filament yarn and Type 450 and Type 455 spun yarns of Nomex® are shown in Table II-3. When exposed to chemicals that cause degradation, the more crystalline Type 430 and Type 450 yarns generally have higher resistance to degradation than spun yarns of Type 455 and Type 462. The spun yarns generally have lower chemical resistance than filament yarns.

It is particularly important to note that the chemical resistance discussed here is the resistance of the fiber to degradation by specific chemicals, not the resistance of fabrics of Nomex® to penetration by those chemicals. Specially designed, laminated or coated fabrics of Nomex® are available for use in protective apparel where barrier protection against hazardous chemical penetration is required.

Table II-3 Comparative chemical resistance of filament and spun yarns of Nomex® fibers*†

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (hr)	pH	Strength retained (%) Filament type 430* Nomex®	Spun type 450* Nomex®	Spun type 455* Nomex®
Organic chemicals								
Dimethyl sulfoxide	100	200	93	10	-	82.5	69.9	8.9
Formic acid	91 in. H_2O	200	93	10	-	95.8	92.8	78.6
Butyrolactone	100	200	93	10	-	100	98.8	91.4
Propylene carbonate	100	200	93	10	-	99.2	94.0	92.9
Salt solutions								
Ferric chloride	Saturated	200	93	10	-	62.5	55.4	37.1
Sodium thiocyanate	Saturated	200	93	10	-	100	100	85.7
Silver nitrate	Saturated	200	93	10	-	100	97.6	95.7
Oxidizing and reducting agents								
Sodium chlorite	0.60	210	99	10	4.5	95.0	85.5	72.9
Peracetic acid	2.0	210	99	10	6.0	67.5	49.4	22.9
Sodium hypochlorite	0.30	160	71	10	10.6	100	97.6	65.7
Sodium bisulfite	3.0	210	99	10	4.7	99.2	100	92.9
Sodium thiosulfate	3.0	210	99	10	8.3	100	100	88.6
Acids and alkalis								
Hydrochloric acid	10.0	160	71	10	-	62.5	53.0	27.1
Nitric acid	1.0	210	99	10	-	75.0	69.9	50.0
Sulfuric acid	10.0	210	99	10	-	90.8	74.7	50.0
Sodium hydroxide	10.0	210	99	10	-	53.3	9.0	Dissolved
Distilled water	-	210	99	10	6.7	100	100	98.6

*Type 430 Nomex® is 1200-denier, 600-filament yarn. Type 450 Nomex® and Type 455 Nomex® are 16/4 cotton count spun yarn (4 ply, each ply is 16 singles).
†Based on testing commissioned by DuPont and performed at Lowell Technological Institute Research Foundation Testing Division, Lowell, MA, Project No. 2229-T Report No. 39624.

Vapors

The resistance of Nomex® to degradation by vapors is an important consideration in hot gas filtration applications (depending on their concentration in the gas stream). Acidic gases such as HCl, SO_2 and NO_x can significantly reduce the service life of filter bags made of Nomex®. Organic vapors generally have little effect on Nomex®.

UV light

Like other natural and synthetic textile materials, most types of Nomex® are impacted by prolonged exposure to ultraviolet (UV) radiation from both sunlight and artificial light sources. After prolonged exposure, unprotected natural yarn tends to discolor from its natural light tone to deep bronze. Similarly, dyestuffs, if present, also may change color or fade. Fabrics made from producer-colored fiber have better colorfastness than dyed fabrics, although dyeing technology has advanced to maximize the colorfastness of dyed fabrics. Thus, in applications where colorfastness is critical, special attention should be given to color selection.

Color change or fading is not necessarily indicative of fiber degradation. However, extended exposure to UV radiation can also cause loss of mechanical properties, depending on wavelength, exposure time, radiation intensity and product geometry.

Two conditions are necessary for light of a particular wavelength to cause fiber degradation. First, the light must be absorbed by the polymer. Second, sufficient energy must be present to break the chemical bonds.

The absorption spectrum of Nomex® overlaps with the energy spectrum produced by natural sunlight in the near-UV and lower visible regions. Nomex® absorbs its maximum energy at the high end of the UV spectrum (approximately 360 nanometers), where the relative intensity of the UV component of most light sources is greatest.

Exposing samples to a xenon arc light in a weatherometer allows an accelerated product performance comparison to be made under laboratory UV light exposure conditions. Under these laboratory conditions, 200-denier Type 430 yarn of Nomex® retains approximately 70% of its original strength after 40 hours of exposure, and approximately 55% after 80 hours of exposure (Figure 2.16). Fabric made of Nomex® III under the same conditions retains approximately 70% of its original strength after 40 hours of exposure, and 50% after 80 hours of exposure (Figure 2.17). Although the strength is reduced under these conditions, the inherent flame resistance is not impacted.

The rate of color fading of dyed fabric made of Nomex® III when exposed to UV light is dependent on the dyed color and dye concentration in the fabric. Darker colors with high dye concentrations generally have better resistance to fading than light colors. However, dyed fabric color (Figure 2.17) has no significant impact on fabric strength retention when exposed to UV light.

In the workplace, natural sunlight exposure time and intensity varies widely with job assignment and location. Although xenon arc exposure in the laboratory attempts to simulate an accelerated natural sunlight exposure, it cannot duplicate the variety of exposure conditions experienced in the workplace. Thus, strength retention results from accelerated xenon arc exposure in the laboratory cannot be directly correlated to garment fabric strength retention in actual use. The laboratory results can only be used for comparing samples exposed to UV light under those specific laboratory conditions.

The strength loss that accompanies UV exposure has no effect on the inherent thermal properties of Nomex®. Despite strength loss after UV exposure, the thermal protective performance (TPP rating) and vertical flammability (char length) of fabrics made of Nomex® III remain unaffected (Table II-4).

Storage in a dark environment is recommended to minimize color change and strength loss. Garments or other articles made of Nomex® should never be stored in direct or indirect sunlight. Small amounts of UV light occur in artificial light sources, such as ordinary incandescent and fluorescent bulbs, or in sunlight filtered by window glass.

Specimens exposed per AATCC standard test method 16E

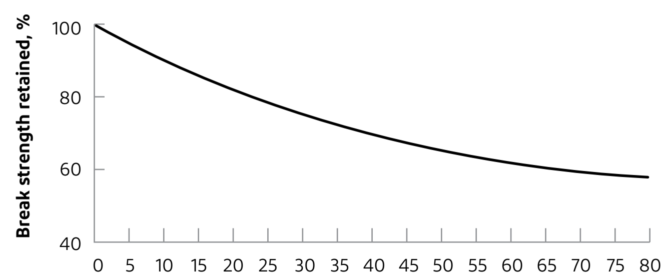


Figure 2.16 Strength retained by untwisted 200-denier type 430 Nomex® yarn after xenon arc-light exposure in a weatherometer

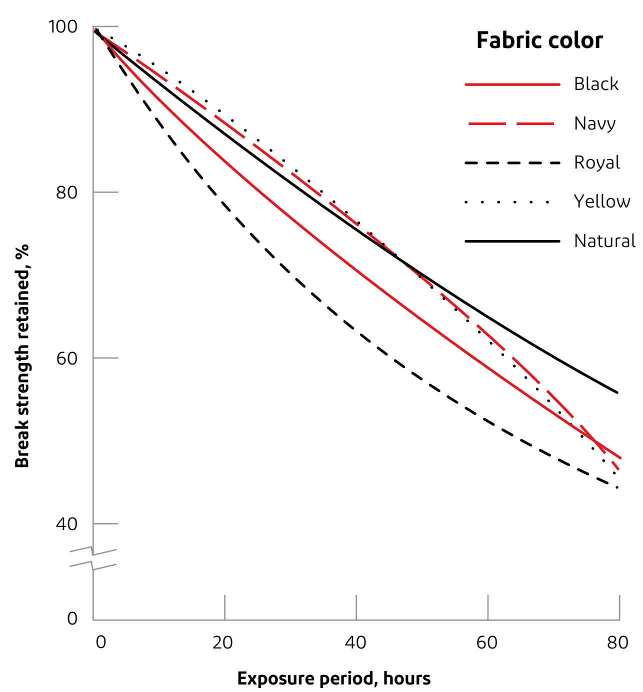


Figure 2.17 Strength retention by fabric made of Nomex® III after exposure in a weatherometer

Where indoor storage is used, incandescent lighting is preferable to fluorescent lighting because the UV component of incandescent light in the 360-nanometer range of the spectrum is significantly less intense.

Storage near windows should be avoided because the 360-nanometer range of the spectrum exceeds the point at which common window glass absorbs most UV radiation.

Table II-4 Strength retention and thermal resistance of fabrics made of Nomex® III after 80 hours xenon-arc exposure

Fabric description	Original weight (oz/yd^2)	Strength (% of original)	TPP value* (% of original)	Vertical flammabilty** char length (in.) original/after exposure
Natural	5.8	55.2	105.0	2.8/3.3
Yellow	5.9	45.3	101.6	3.2/4.1
Navy	6.2	46.3	102.3	3.6/3.5
Black	6.3	47.6	103.1	3.7/4.0

* ASTM D4108 (replaced with ISO 17492) with combined convective and radiant heat source, single-layer fabric configuration.
** Federal Test Standard 191A, Method 5903.1; average of warp and fill measurements.

Radiation

Nuclear power plants and other high-energy radiation operations often require the use of fiber products capable of withstanding the deteriorating effects of gamma and UV radiation. The outstanding resistance of Nomex® to degradation by such radiation is illustrated by the data shown in Table II-5. Nomex® does not, however, provide protection against radiation.

Insects and fungi

Nomex® is not digestible and is not attacked by insects. Nomex® spunlace, consisting of the same polymer as fibers of Nomex®, is resistant to fungi growth when tested per ASTM G21, Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi.

Storage and shelf life

DuPont does not specify a shelf life for Nomex® fiber. Nomex® fiber, when properly stored, maintains its inherent flame resistance and other chemical and mechanical properties. Proper storage includes protecting the fiber from exposure to UV (sunlight)and storing the fiber in a clean, dry environment in the original shipping package. The finishing agents may face the effects of soak-in and/or evaporation after long periods of storage. This influence will be minimized if the fibers are kept within their original compressed packages and stored according to the proper conditions.

Table II-5 Resistance of type 430 Nomex® filament yarn to radiation degradation

Radiation type	Level	Breaking strength retained (%)	
		Nomex®	Nylon
As received	-	100	100
Gamma	1.72×10^8 rads	100	30
Ultraviolet	6.04×10^{-2} W/in.^{2}	80	80
Ultaviolet + gamma	4.07×10^{-3} W/in.^{2} 6.88×10^6 rads	105	70
Ultraviolet + gamma	1.2×10^{-2} W/in.^{2} 1.72×10^8 rads	95	5

Section III

Applications information

Applications overview

Because of its excellent physical and thermal properties, Nomex® fiber is used in a wide variety of applications, including industrial coated fabrics; ironing- or pressing-machine covers; rubber hose reinforcement; felt scrims; and the three leading applications—thermal protective apparel, filtration and thermal resistant furnishings.

Thermal protective apparel applications

Because of its unique combination of textile and thermal properties, Nomex® is used in a broad range of thermal protective apparel applications wherever the risk of a fire or electric arc exposure is present. These applications include industrial workwear for petroleum, petrochemical and chemical operators, mechanics and electricians, as well as electrical utility employees. Nomex® is also used by race car drivers and their crews; the military; and National Aeronautics and Space Administration (NASA) astronauts, space shuttle crew and rocket fuel handlers. In addition, Nomex® is used when there is an expectation that the individual will be exposed to flames (e.g., in firefighter turnout coats and stationwear). Garments made of Nomex® may also be suitable for protection against molten metal splatter in industrial settings

Industrial applications

Occupational Safety and Health Administration (OSHA) regulations, American Society for Testing and Materials (ASTM) standards and corporate safety guidelines drive adoption of flame-resistant clothing for worker protection where a flash fire or electric arc hazard is identified. Chemical, petrochemical and utility workers wear clothing made of Nomex® as a protective barrier against the intense heat from flash fires and electric arcs, and to give the wearer a few seconds of escape time. Shirts, pants, coveralls, sweatshirts, rainwear, cold weather coveralls, coats, balaclavas and lab coats are commercially available.

Military applications

U.S. military personnel began wearing clothing made of Nomex® in the mid-1960s. The military uses producer-colored fibers, with colorants incorporated during the fiber-spinning process, for improved consistency in appearance and lightfastness. The largest application is the flight suit adopted by the four major services of the U.S. military. Coveralls of Nomex® are used for combat vehicle crews and shipboard engineering crews. Nomex® is also used in selected applications in gloves, underwear, balaclava head coverings and cold weather gear.

NASA uses fabrics made of Nomex® for the outer layer of astronaut launch and re-entry suits and as a component of its extravehicular activity suits.

Emergency response applications

Blends of Nomex® and Kevlar® are used in firefighter protective apparel all over the world. These inherently flame-resistant materials provide thermal protection in turnout gear, station uniforms, wildland apparel, hoods, gloves and boots. Nomex® and Kevlar® also are used in sewing thread for these items.

Thin, lightweight, nonwoven spunlaced sheets of Nomex® E89™, a blend of Nomex® and Kevlar®, are used as thermal liners and substrates for moisture barriers.

Nomex® Preferred Turnout Systems provide high levels of thermal protection, comfort and reduced heat stress. Nomex® EMS Wear provides flash fire protection in addition to meeting NFPA 1999 standards. Nomex® Stationwear offers the highest levels of durability and thermal protection.

Race car driver and support personnel applications

Race car drivers and their crews wear clothing made of Nomex® to help protect themselves from fires that often accompany crashes on the track and in pit accidents. Race car drivers supplement their protective suits with underwear, socks and gloves made of Nomex®.

The outer shell of the uniforms may be woven spun yarns or knit filament yarns. These are backed with thermal batts of aramid fibers to provide extra insulation against flash fires resulting from fuel spills.

Support personnel, including the crew and standby firefighters, are protected by flame-resistant apparel made of Nomex® in case of a pit fire.

Molten metal applications

Fabrics made of Nomex® III and Nomex® IIIA provide thermal protection from molten metal splatter, where small drops of metal are generated during light welding or where portions of the conductor melt in an electric arc discharge.

Fabrics made of Nomex® III and Nomex® IIIA will develop small, charred holes where large drops of metal heat the fiber to its carbonization temperature, but these fabrics will not ignite, continue to burn, or become a hazard to the wearer. Heavier fabrics made of Nomex® will provide greater thermal insulation and longer garment life. Wearing appropriate outer garments in welding applications, such as aprons or arm guards, will further increase thermal insulation and extend garment life.

Field experience has shown that fabrics made of Nomex® III, Nomex® IIIA or Nomex® MHP provide effective resistance to molten metal splash with low-temperature metals, such as lead, zinc or pot metal. However, fabrics made of Nomex® are not recommended for protection from high-temperature metal splash, such as aluminum or steel, where the molten metal may have a temperature in excess of 1,000°F (538°C). Fabric blends, including Nomex®/Kevlar®; 100% Kevlar®, or flame-retardant treated (FRT) rayon blends with Kevlar® are commercially available for welding and molten metal splash protection.

To determine if fabrics made of Nomex® and Kevlar® fibers meet your requirements, testing should be conducted under actual exposure conditions. Contact DuPont for additional information on protective apparel in applications involving potential exposure to molten metals.

Essential characteristics

The flame resistance of Nomex® is an essential characteristic that is inherent or built into the fiber. Thus, the actual chemical structure of the fiber itself is not flammable. Unlike natural fibers and most synthetic fibers, Nomex® does not ignite and burn in air, nor does Nomex® melt or drip. Garments made of Nomex® act as a protective barrier and help reduce burn injury.

The high-temperature integrity of Nomex® results from a unique mechanism in the fiber. When exposed to intense heat, the Nomex® fiber carbonizes and becomes thicker, forming a protective barrier between the heat source and the skin. This protective barrier stays supple and flexible until it cools, giving the wearer extra seconds of protection for escape.

The Nomex® fiber helps to reduce burn injury in three ways:

1. The fiber itself absorbs heat energy during the carbonization process.

2. The fiber swells and seals openings in the fabric, decreasing air movement and the associated convective heat transfer. Figure 3.1 shows a graphic representation of this fiber thickening under intense heat.

3. Both the fiber and the fabric thicken, increasing the insulative barrier and reducing conductive heat transfer. Figure 3.2 shows carbonization and thickening of fabric made of Nomex® III. Fabric made of Nomex® IIIA, which contains a static dissipative fiber, performs in a similar manner

Thickness represents nominal overall thickness

Figure 3.1 Representation of thickening of Nomex® III when exposed to heat and flame, in accordance with ISO 17492 TPP testing

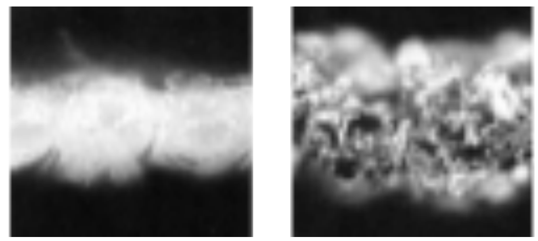


Figure 3.2 Representation of carbonization and thickening of Nomex® III when exposed to heat and flame, in accordance with ISO 17492 TPP testing

Nomex® shares many of the same characteristics of Kevlar®: excellent thermal stability, inherent flame resistance and good chemical and corrosion resistance. However, because of their chemical bonding arrangement, Nomex® fibers are softer and more textile-like than fibers of Kevlar®. Therefore, Nomex® fibers are favored for use in apparel. Mechanical toughness of the fiber results in a much higher fabric strength and durability than cotton fabrics of greater weight. High resistance to tearing and abrasion result in a much longer useful garment life than that obtained with FRT cotton fabrics.

Where flash fire or electric arc exposure is a possibility, Kevlar® is combined with fibers of Nomex® to reduce flame shrinkage and fabric "break open" during flame exposure. This latter phenomenon can result in the loss of the barrier material and insulating air layer between the flame and the wearer, potentially increasing burn injury. In the case of electric arc exposure, multiple layers of garments made of Nomex® may be needed.

Like most synthetic fibers, Nomex® is electrically non-conductive. As a result, static generated on the body or in garments through fabric-to-fabric or fabric-to-surface contact is not quickly dissipated. In such cases, it is theoretically possible for electrostatic discharge (ESD) to occur with sufficient intensity to cause ignition of some flammable gas/air mixtures. This possibility is of particular concern in the petroleum, petrochemical and chemical industries, where employees frequently work in areas where hazardous fuel/air mixtures may be present. Usually, greater electrostatic discharges are available from the human body (e.g., hands) than from clothing on the body due to the higher capacitance of the body.

Nomex® IIIA, Nomex® MHP and Protera® all incorporate antistatic material to dissipate static generated from fabric-to-fabric and fabric-to-surface rubbing. This minimizes the contribution of clothing to static charge buildup on the human body; reduces the apparent electric field strength on the fabric; and reduces nuisance static, thus increasing garment comfort.

Antistatic filaments consist of a carbon core and insulating sheath, which through induction attracts static charges from the fabric until their intensity becomes sufficient to ionize the surrounding air molecules, thus reducing the accumulated static charge. Wearing garments made of Nomex® IIIA, Nomex® MHP or Protera® does not eliminate the need to follow proper electrostatic safety procedures, including grounding of personnel and equipment in hazardous areas where ignitable gases may be present, or where static may affect electronic instruments.

In high humidity conditions, conventional work clothing of polyester/cotton blends or 100% cotton depends on water absorption of cotton to provide limited antistatic performance. In low humidity conditions, the water content of the cotton fiber is no longer sufficient to provide antistatic performance. Nomex® IIIA, Nomex® MHP and Protera® maintain static dissipation qualities even in low humidity conditions.

Test methods

Fabrics for thermal protective apparel are evaluated for physical, thermal, durability, comfort and wearability properties using a broad range of test methods based on industry standards. A summary of these tests, cross-referenced with where they are cited in this technical guide, see the Appendix in Section V.

Four laboratory test procedures demonstrate the unique flame-resistant characteristics of Nomex®, especially as they are used for protective apparel. These test procedures include the vertical flame test; thermal protective performance (TPP) test; instrumented manikin test for flash fires; and instrumented manikin and panel tests for electric arc exposure. A static charge decay test can also be used to demonstrate the reduction in nuisance static in fabrics made of Nomex® IIIA, Nomex® MHP or Protera®. In addition, a range of other physical and chemical tests can be used to determine specific fabric performance characteristics of interest.

Vertical flame test (flame resistance or flammability)

The vertical flame test (ASTM D6413) measures the relative flammability of a fabric specimen rigidly held in a three-sided frame. A methane burner provides a small igniting flame that is allowed to impinge on the bottom edge of the fabric for 12 seconds. The char length, afterflame (the amount of time flames continue on the fabric surface after the burner is turned off or removed), afterglow (the amount of time the fabric continues to glow after any afterflame stops) and relevant observations are recorded.

This test is a qualitative pass/fail indicator of fabric flammability and is important for protective apparel because a fabric that ignites and burns can contribute to burn injury rather than reducing it. However, the vertical flame test does not measure TPP. Table III-1 shows typical results of vertical flammability tests on fabrics made of Nomex® IIIA, Nomex® MHP, Protera® and cotton.

Everyday fabrics of polyester/cotton and 100% cotton ignite within a few seconds of exposure and continue to burn until the entire sample length (12 inches) is consumed. Fabrics from some synthetic fibers, such as polypropylene, polyester or nylon, can melt, drip and ignite. Fabric ignition, melting and dripping in a garment can significantly increase the extent and severity of burn injury due to the added heat transfer to the wearer. In contrast, fabrics made of Nomex® do not ignite or continue to burn, nor do they melt and drip. Thus, they do not contribute to the hazard but instead provide a protective layer that can reduce burn injury.

Fabrics made of Nomex® pass industry vertical flammability standards that require a char length of no more than 4 or 6 inches and an afterflame time of no more than 2 seconds (Table III-2).

Table III-1 Vertical flammability test results*

Fabric	Nominal weight (oz/yd^2)	Char length (in.)	Afterflame (s)
Nomex® IIIA	4.5	3.3	0
Nomex® IIIA	6.0	3.1	0
Nomex® MHP	7.0	2.9	0
DuPont™ Protera®	6.5	3.2	0
DuPont™ Protera®	7.0	3.5	0
DuPont™ Protera®	8.0	3.1	0
65%/35% Polyester/cotton	9.0	12.0	48.5
100% Cotton	9.0	12.0	36.0

*Average of warp and fill determinations. Fabrics were home laundered prior to testing. Test utilizes a fabric specimen of 12 inches in length.

Table III-2 Vertical flammability performance requirements

Standards	Application	Maximum char length (in)	Maximum afterflame (s)	Maximum afterglow (s)
ASTM F1506-15	Electrical workers exposed to momentary electric arc and related thermal hazards	6.0	2.0	-
NFPA 1971, 2018 edition	Protective clothing for structural firefighting	4.0	2.0	-
NFPA 1977, 2016 edition	Wildland firefighting	4.0	2.0	-
MIL-C- 83429B	Aviation, tank crews, shipboard engineering	3.5	2.0	25.0

Thermal protective performance (TPP) test

The thermal protective properties of fabrics and fabric systems can be demonstrated through the use of the TPP test, as described in NFPA Standard 1971 and ISO 17492. This test also can be used to assess the integrity of fabrics under thermal load—an important consideration in protective apparel. The TPP test is not applicable to non-flame-resistant fabrics.

The equipment required to perform the TPP test is shown in Figure 3.3. As normally practiced, a combined convective/radiant heat source with a heat flux of 2 cal/cm^2-sec is impinged on the outer surface of a 4-inch by 4-inch area of the fabric system, and the time required to reach the equivalent of a second-degree burn at the calorimeter on the other side of the fabric system is recorded. This time (in seconds), multiplied by the heat flux of the exposure, gives the TPP rating of the system. The higher the TPP value, the more protection a fabric or system provides the wearer.

ISO 17492 specifies two methods for TPP testing. When testing single-layer fabrics, a ¼-inch spacer is placed between the fabric sample and the heat sensor to simulate the normal fit of protective clothing, as well as to allow the fabric to reach as high a temperature as would occur in an actual flame exposure. TPP results for single-layer fabrics are listed in Table III-3. When testing multi-layer fabrics or systems, such as firefighters' turnout coats, the ISO standard specifies that the sample and heat sensor be in contact with the innermost fabric layer of the system. No spacer is used for multi-layer fabric samples. The results of several such tests are shown in Table III-4. NFPA Standard 1971 (2018 Edition) requires that firefighters' turnout gear have a minimum TPP rating of 35.

Recommended configuration for single-layer fabrics

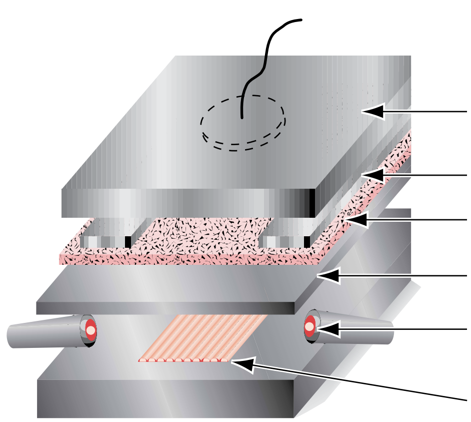


Figure 3.3 TPP test apparatus, ISO 17492 with combined convective and radiant heat source as specified in NFPA 1971

Table III-3 TPP ratings of single-layer fabrics, ISO 17492 with combined convective and radiant heat source

Fabric	Nominal weight (oz/yd^2)	TPP (cal/cm^2)
Nomex® IIIA	4.5	11.8
Nomex® IIIA	6.0	13.3
Nomex® IIIA	7.5	15.3
Nomex® MHP	7.0	12
DuPont™ Protera®	6.5	12
DuPont™ Protera®	7.5	12
DuPont™ Protera®	8.0	13
65%/35% Polyester/cotton		N/A - ignites
100% Cotton		N/A - ignites

Table III-4 TPP ratings* of multiple-layer systems, NFPA 1971 (2018 edition) with combined convective and radiant heat source

Component	Fabric	Composite weight (oz/yd²)	TPP (cal/cm²)
Nomex®/Kevlar® spun yarn plus Kelvar® filament			
Outer shell	67% Kevlar®/33% Nomex® 6.5 oz/yd²	17.0-18.2	39-41
Moisture	ePTFE with Nomex® fabric woven		
Thermal liner	0.6 oz/yd² Nomex® nano 2.3 oz/yd² spunlace 60% Nomex® filament yarn with 40% Nomex®/Lenzing FR® blend spun yarn for facecloth		
Nomex®/Kevlar® spun yarn			
Outer shell	Kevlar®/Nomex® blend 6.6 oz/yd²	18.4-19.6	40-42
Moisture barrier	ePTFE with Nomex® fabric woven		
Thermal liner	1.5 oz/yd² spunlace 2.3 oz/yd² spunlace Kevlar® filament yarn with Nomex® lenzing blend for facecloth		

*2.0 cal/cm2-sec heat flux. Tested as received.

Instrumented manikin test (flash fire simulation)

DuPont™ Thermo-Man® is an instrumented laboratory manikin that utilizes skin model software to determine the predicted burn injury in a carefully controlled, reproducible, laboratory short duration fire that simulates actual flash fire conditions (Figure 3.4).

Data obtained from 122 heat sensors distributed over the 6-foot-1-inch manikin body are used to measure the heat transmitted from the fire through the test garment to the surface of the manikin. A sophisticated computer program then calculates the predicted percentage of second- and third-degree burns and indicates the burn injury locations for the selected simulated flash fire exposure conditions. Thermo-Man® testing is conducted according to ASTM F1930.

Before exposure During exposure After exposure

Figure 3.4 Simulated flash-fire testing with DuPont™ Thermo-Man®, an instrumented laboratory manikin

The Thermo-Man® thermal protection evaluation system is used to compare the relative TPP of garments by exposing full size garments to laboratory simulations of a flash fire condition pursuant to ASTM F1930. These conditions may not be typical of the conditions encountered in actual situations. The results of these tests are only predictions of body burn injury under these specific laboratory conditions. Because the dynamics of real flash fires vary greatly and can be more or less intense than the fire used in the manikin test, these results do not duplicate or represent garment or fabric performance under actual flash fire conditions.

Electric arc testing using manikins and instrumented panels (electric arc simulation)

Exposure to electric arcs can cause electric shock injury because some or all of the arc current passes through or along the surface of the human body. It is not as well recognized that the intense radiant and convective energy from an electric arc, and subsequent ignition of work clothing or other elements in the work environment, can cause serious burn injury. This can occur even if there is no actual contact with the arc. These non-contact human burn injuries make up the majority of the injuries resulting from electric arc accidents.

NFPA 70E, Standard for Electrical Safety in the Workplace, requires that FR or FRT clothing and personal protective equipment (PPE) be used by employees within a flash boundary. The determination of risk may be based on the calculated incident energy exposure or the specific task involved. A hazard assessment should be done to understand the electric arc hazard or risk.

The protective performance of various fabrics or systems in an electric arc exposure is determined using two procedures. ASTM F1958/F1958M is the standard test method for determining the ignitability of non-flame-resistant materials for clothing by electric arc exposure method using manikins. This test method is used to identify materials that are ignitable and that can continue to burn when exposed to an electric arc. It determines the incident exposure energy that causes ignition, as well as the probability of ignition. ASTM F1959/F1959M is the standard test method for determining the arc rating of materials for clothing. This test method is used to measure the arc rating of materials intended for use as flame-resistant clothing for workers exposed to electric arcs that would generate heat flux from 84 to 25 120 kW/m^2 [2 to 600 cal/cm^2s]. FR materials must be worn in Hazard Risk Category 1–4 areas.

The electric arc hazard and potential for burn injuries can be quantified in terms of the incident energy in cal/cm^2 that a worker would be exposed to under a specified set of arc parameters. The incident energy from an arc increases with arc current, arc duration and arc gap. The incident energy decreases approximately with the square of the distance from the arc. Incident energy can be calculated using available software programs or measured empirically in laboratory arc exposures. Generally, the incident energy from an arc exposure is greater than the heat energy due to a flash fire exposure, even though the typical arc duration is less than a second and the flash fire duration may be several seconds.

Some examples of protective clothing made of Nomex® that would comply with the NFPA 70E Hazard Risk Categories are shown in Table III-5.

Table III-5 Examples of protective clothing that complies with NFPA 70E

Fabric	Nominal weight (oz/yd^2)	Arc thermal performance value (ATPV)
Nomex® IIIA	4.5	4.5-5.2
Nomex® IIIA	6.0	5.6-6.0
Nomex® MHP	7.0	8.4
DuPont™ Protera®	6.5	8.5
DuPont™ Protera®	7.5	9.5
DuPont™ Protera®	8.0	12.3

Static test (static dissipation)

Static can be generated in fabric by sliding across a car seat or removing a jacket. The static dissipation performance of fabrics can be measured by a charge decay test. Fabrics such as those made of Nomex® IIIA, which incorporate static dissipative fibers, show a very short charge decay time, or very good static dissipation.

Table III-6 Charge decay test results (70°F [21°C], 20% RH)*

Fabric	Number of launderings	kV accepted	Seconds to discharge to 10% of kV accepted
Nomex® IIIA	0	3.95	0.01
	25	3.75	0.02
	50	3.45	0.01
	100	3.10	0.01
Nomex® III	0	4.50	8.9
	25	1.35	>10
	50	1.35	>10
	100	1.35	>10
100% Cotton	0	3.82	>10
	25	2.14	>10
	50	2.03	>10
65%/35% Polyester/cotton	0	4.90	4.3
	25	2.20	>10
	50	2.25	>10

*Federal Test Standard 191A, Method 5931

Table III-6 shows the results of a series of charge decay tests on typical protective apparel and conventional work clothing fabrics. In this procedure (Federal Test Standard 191A, Method 5931), the fabric specimen is mounted between two electrodes and exposed to a 5-kV potential. To meet DuPont requirements for acceptable antistatic performance, the fabric must accept at least a 3-kV potential and must discharge to 10% of the accepted voltage within one-half second after grounding the electrodes. Fabrics are tested at 70°F (21°C) and 20% RH.

Fabrics made of Nomex® IIIA and Nomex® MHP have been tested using test method EN 1149-3:2004 and certified to meet test standard EN 1149-5:2008 for electrostatic dissipative behavior. The short staple fibers of the antistatic material do not provide a continuous conductive pathway throughout the fabric or garment. This feature eliminates the possibility of the garment creating a conductivity hazard, which is of particular concern to the electric utility industry.

Because the main hazard of electrostatic discharge (ESD) in potentially explosive environments is from ungrounded personnel, and not from the garments they wear, personnel grounding is always the first line of defense. Discharging static from the body before entering a potentially explosive atmosphere; wearing a wristlet connected to the ground; and using conductive footwear and flooring are all recommended. Wearing garments made of Nomex® IIIA does not eliminate the need to follow proper safety procedures, including grounding of personnel and equipment.

Cleaning

Flammable contaminants will reduce the thermal performance of any FR garment. Proper and periodic cleaning is essential to maintain thermal protection. Protective clothing made of Nomex® fiber can be cleaned by traditional methods, such as home laundering, commercial laundering or dry cleaning.

For maximum protection, brand new protective garments made of Nomex® should be cleaned prior to wearing to remove any processing aids or finishes from the manufacturing process that could adversely affect the performance of the fabric made of Nomex®. They should be cleaned frequently thereafter to ensure no greases, oils, soils or other flammable contaminants are present when the garment is worn.

For more information about cleaning garments made of Nomex®, refer to the Laundering Guide for Nomex® Aramid Fiber.

Filtration applications

Filter bags made of Nomex® are the leading choice in many different filtration applications due to their high operating temperatures, good chemical resistance and good abrasion resistance, which result in long bag life. Filter bags made of Nomex® permit facilities to operate at high temperatures, which significantly improves capacity, lowers power costs and eliminates condensation.

Temperature resistance

The maximum continuous operating temperature recommended for Nomex® is 400°F (204°C). If temperature surges above this limit are expected on a frequent basis, it may be necessary to adjust the average operating temperature downward to extend filter bag life.

Environment also affects the durability of filter bags made of Nomex®. In a highly acidic environment, it may be necessary to reduce the average operating temperature to extend filter bag life. Nomex® fiber is inherently flame resistant; however, if combustible materials are collected on filter media of Nomex® and exposed to an ignition source, they can ignite and burn, resulting in destruction of the filter bag.

Acid resistance

In general, Nomex® fiber exhibits very good resistance to many chemicals. Materials that do attack Nomex® are strong acids, strong alkalis and/or strong oxidizing agents. Water vapor is also necessary for activation of the degrading reactions; thus, care must be used in estimating performance when the moisture level is unknown or uncontrolled. Frequently, reduced filter life occurs due to acid attack when gases containing sulfur dioxide or trioxide are filtered. If acid attack is a possibility, or flue gas components are unknown, filter bags made of Nomex® should be tested prior to installation.

Section IV

Availability of Nomex®

Packaging

Filament yarn packages

Filament yarns of Nomex® fiber are shipped on recyclable paper-tube cores (Figure 4.1). The sizes of the tube and yarn package are listed in Table IV-1. A label inside each tube gives the yarn description and merge number. The package can be used directly for down-twisting or other processing.

Table IV-1 Sizes of tube and yarn package for Nomex® fiber

Tube core	
Length	6 ½ in. (165 mm)
Diameter	2 in. (51 mm)
Taper	None
Yarn package	
Diameter	7 1/8 in. (181 mm)
Transverse of yarn	5 1/2 in. (140 mm)
Net weight (max.)	7.5 lb (3.4 kg)

Figure 4.1 Filament yarn package of Nomex® yarn

Shipping containers

Filament yarns of Nomex® are shipped in smooth-faced, corrugated cardboard cartons (Figure 4.2). Staple is shipped in bales wrapped with polypropylene (Figure 4.3). These containers are designed to prevent damage from normal shipping and handling procedures. Their capacities and approximate dimensions are given in Table IV-2.

For information on recycling packaging materials, contact DuPont at 1-800-931-3456. Because package forms and shipping containers may vary outside the United States, please contact your local DuPont Representative for details.

Figure 4.2 Shipping carton for filament yarns of Nomex® yarn

Figure 4.3 Bales of Nomex® staple with polypropylene wrapping

Table IV-2 Details of shipping containers

Putup	Outside dimensions						Weight			
	Length (in.)	Length (cm)	Width (in.)	Width (cm)	Height (in.)	Height (cm)	Net (lb)	Net (kg)	Gross (lb)	Gross (kg)
Yarn carbon										
32 unit/case	22 3/4	58	21	53	27 3/4	70	192	87	217	98
Staple bale*										
Type 450, 1.5-denier staple	36	91	30	76	56	142	650	295*	-	
Type 450, 2-denier staple	36	91	30	76	56	142	650	295*	-	
Type 450, 5.5-denier staple	36	91	30	76	56	142	450	204*	-	
Type 455, 462 staple	36	91	30	76	56	142	600	272*	-	
1.5-denier producer-colored staple	36	91	30	76	56	142	450 or 600	204 or 272*	-	

*±50 lbs

Staple bale size and compaction

Staple bale outside dimensions are similar regardless of net weight. The lighter weight bales are compacted less during the baling operation, resulting in a lower density bale that may have less bale bloom when the strapping is removed. The outside dimensions of the lighter weight bale may be one to three inches smaller in any dimension than the heavier weight bales.

Section V

Appendix

Test method descriptions and technical guide references

Reference test method	Description	Test title	Technical guide references
AATCC 124	Surface appearance	Smoothness appearance of fabrics after repeated home laundering	-
AATCC 132	Colorfastness to dry cleaning	Colorfastness to dry cleaning	-
AATCC 135	Home laundering	Dimensional changes of fabrics after home laundering	-
AATCC 158	Dry cleaning	Dimensional changes on drycleaning in perchloroethylene: Machine method	-
AATCC 16	Colorfastness to light	Colorfastness to light: outdoor, carbon-arc and xenon-arc	Section II, figure 2.17
AATCC 61	Colorfastness to laundering	Colorfastness to laundering: accelerated	-
ASTM D1388	Bending stiffness	Standard test method for stiffness of fabrics	-
ASTM D1424	Tear resistance (Elmendorf)	Standard test method for tearing strength of fabrics by falling-pendulum (Elmendorf-type) apparatus	Figure 2.13
ASTM D1440	Staple cut length	Standard test method for length and length distribution of cotton fibers (array method)	Tables I-1, II-1
ASTM D1505	Density	Standard test method for density of plastics by the density-gradient technique	Table II-1
ASTM D1907	Denier (yarn)	Standard test method for linear density of yarn (yarn number) by the skein method	Tables I-1, II-1
ASTM D1907	Denier per filament	Standard test method for linear density of yarn (yarn number) by the skein method	Tables I-1, II-1
ASTM D1909	Commercial moisture regain	Standard tables of commercial moisture regains and commercial allowances for textile fibers	Table II-1
ASTM D2257	Finish	Standard test method for extractable matter in textiles	-
ASTM D2654	Moisture	Standard test method for moisture in cotton by oven-drying	Table II-1
ASTM D3512	Pilling resistance (random tumble)	Standard test method for pilling resistance and other related surface changes of textile fabrics: random tumble pilling tester	-
ASTM D3776	Basis weight	Standard test methods for mass per unit area (weight) of fabric	Tables III-1, III-3, III-4

(continued)

Test method descriptions and technical guide references (continued)

Reference test method	Description	Test title	Technical guide references
ASTM D3786	Bursting strength (Mullen burst)	Standard test method for bursting strength of textile fabrics—diaphragm bursting strength tester method	-
ASTM D3822	Tensile properties: elongation, modulus, tenacity	Standard test method for tensile properties of single textile fibers	Table 11-1
ASTM D3886	Abrasion resistance	Standard test method for abrasion resistance of textile fabrics (inflated diaphragm apparatus)	Figure 2.13
ASTM D5034	Breaking strength and elongation (grab test)	Standard test method for breaking strength and elongation of textile fabrics (grab test)	Figure 2.14
ASTM D6413	Vertical flame test	Standard test method for flame resistance of textiles (vertical test)	Tables III-1, III-3, III-4
ASTM D737	Air permeability	Standard test method for air permeability of textile fabrics	-
ASTM E1269	Specific heat capacity	Standard test method for determining specific heat capacity by differential scanning calorimetry	Table II-1
ASTM E1530	Thermal resistance	Standard test method for evaluating the resistance to thermal transmission of materials by the guarded heat flow meter technique	Table II-1
ASTM F1002	Molton substances	Standard performance specification for protective clothing and materials for use by workers exposed to specific molten substances and related thermal hazards	-
ASTM F1506	Flame and electric arc	Standard performance specification for flame resistant and electric arc rated protective clothing worn by workers exposed to flames and electric arcs	Table III-2
ASTM G21	Fungal resistance	Standard practice for determining resistance of synthetic polymeric materials to fungi	Section II
FTMS 191A-5931	Antistatic performance	Federal standard: textile test methods	Table III-6
ISO 17492	Heat transmission	Clothing for protection against heat and flame—determination of heat transmission on exposure to both flame and radiant heat	Table III-3
MIL-C-83429B	Aramid fabrics	Military specification: cloth, plain and basket weave, aramid	Table III-2
NFPA 70E	Electrical safety	Standard for electrical safety in the workplace	Table III-5
NFPA 1971	Fire fighting protective ensembles	Standard on protective ensembles for structural fire fighting and proximity fire fighting	Tables III-2, III-4
NFPA 1975	Emergency services work clothing	Standard on emergency services work clothing elements	-
NFPA 1977	Wildland fire-fighting clothing	Standard on protective clothing and equipment for wildland fire fighting	Table III-2

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Product safety information is available upon request.

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