KEVLAR® ARAMID FIBER
TECHNICAL GUIDE

DUPONT®

Kevlar®

TABLE OF CONTENTS

SECTION I: INTRODUCTION TO DUPONT™ KEVLAR® ARAMID FIBER

WHAT IS KEVLAR®?

Kevlar® is an organic fiber in the aromatic polyamide family. The unique properties and distinct chemical composition of wholly aromatic polyamides (aramids) distinguish them—and especially Kevlar®—from other commercial, man-made fibers.

Kevlar® has a unique combination of high strength, high modulus, toughness and thermal stability. It was developed for demanding industrial and advanced-technology applications. Currently, many types of Kevlar® are produced to meet a broad range of end uses.

This guide contains technical information primarily about Kevlar® industrial yarns, as well as some basic information on Kevlar® short fibers. If you require any additional information including, information on the various applications and special forms of Kevlar®, please contact your DuPont Representative or call 1-800-931-3456. From outside the United States, call (302) 999-3358.

DEVELOPMENT AND MOLECULAR STRUCTURE OF KEVLAR®

In the mid-1960s, nylon and polyester represented the state of the art in man-made fibers. However, to achieve maximum tenacity (break strength) and initial modulus, the polymer molecules had to be in extended-chain configuration and almost perfect crystalline packing. With flexible-chain polymers, such as nylon or polyester, this could be accomplished only by mechanically drawing the fiber after melt spinning. This required chain disentanglement and orientation in the solid phase, so tenacity and modulus levels were far from the theoretically possible values.

In 1965, scientists at DuPont discovered a new method of producing an almost perfect polymer chain extension. The polymer poly-p-benzamide was found to form liquid crystalline solutions due to the simple repetitiveness of its molecular backbone. The key structural requirement for the backbone is the para orientation on the benzene ring, which allows the formation of rod-like molecular structures. These developments led us to our current formulation for Kevlar®.

To illustrate the difference between liquid crystalline polymers and flexible, "melt" polymers, consider what happens when rod-like polymer molecules are dissolved, as opposed to molecules with flexible chains. With flexible chain polymers, random coil configuration is obtained in solution, and even increasing the polymer concentration cannot generate a higher degree of order. In contrast, with rigid polymers, as the concentration increases, the rods begin to associate in parallel alignment. Randomly oriented domains of *internally* highly oriented polymer chains then develop.

Figure 1.1 Rod-Like Fiber Structure by the Radial Stacking of Hydrogen-Bonded Sheets.

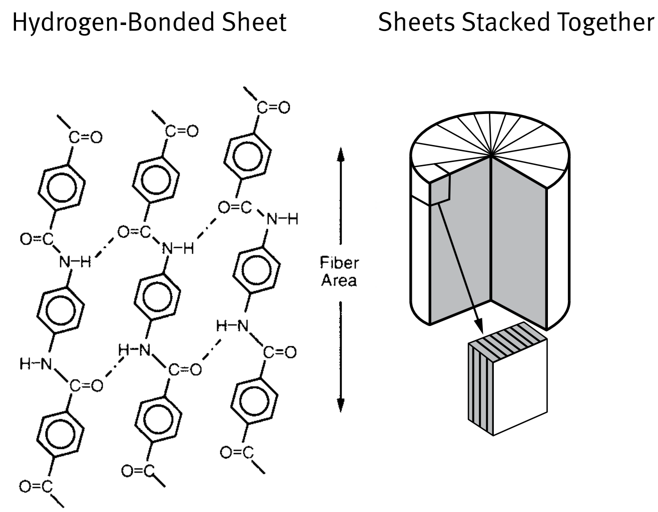
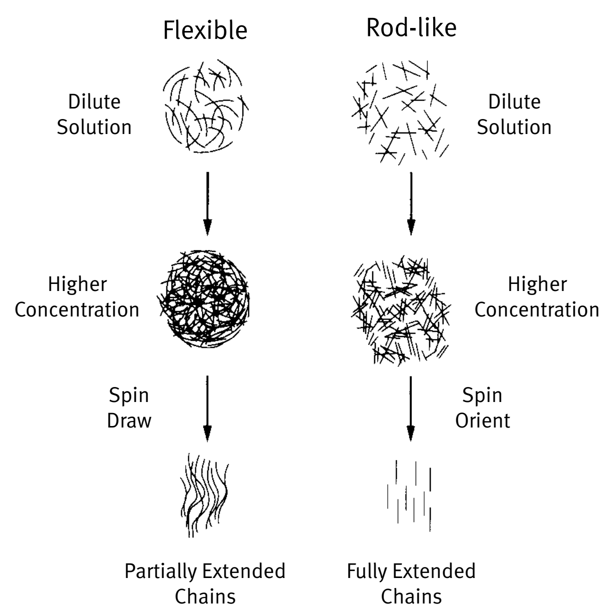


Figure 1.2 Differences in Behavior During Spinning Between Flexible and Rigid Polymers.



SECTION I: INTRODUCTION TO DUPONT™ KEVLAR® ARAMID FIBER

Liquid crystalline polymer solutions display a unique behavior under shear. This unique aspect opened up new dimensions in fiber manufacturing and processing. Under shear forces, as the solutions pass through a spinneret (orifice), the randomly oriented domains become fully oriented in the direction of the shear and emerge with near perfect molecular orientation.

The supramolecular structure is almost entirely preserved in the as-spun filament structure due to very slow relaxation of the shear-induced orientation. This process is a novel, low-energy way to highly orient polymer molecules and to achieve very strong fibers.

DuPont utilized this technology to develop a fiber of poly-para-phenylene terephthalamide, which was introduced as high-strength Kevlar® aramid fiber in 1971.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

This section lists and describes the typical properties of Kevlar®. The data reported are those most often observed, and are representative of the particular denier and type indicated. The properties are reported in both U.S. and S.I. units.

For information on safety and health, refer to the Kevlar® Material Safety Data Sheet.

TYPICAL AND COMPARATIVE PROPERTIES OF KEVLAR®

Table II-1 lists the typical yarn, tensile and thermal properties of Kevlar® 29 and Kevlar® 49 yarns.

Additional products in the Kevlar® family of fibers are available with different combinations of properties to meet your engineering design needs.

Please contact your DuPont Representative or call 1-800-931-3456 to discuss your specific application and determine the optimum Kevlar® fiber for you.

Table II-1 Typical Properties of DuPont™ Kevlar® 29 and Kevlar® 49 yarns

Property	Unit	Kevlar® 29	Kevlar® 49
Yarn			
Type	denier (dtex) # of filaments*	1,500 (1,670) 1,000	1,140 (1,270) 768
Density	$lb/in.^3$ (g/cm^3)	0.052 (1.44)	0.052 (1.44)
Moisture Levels			
As Shipped**	%	7.0	3.5
Equilibrium from Bone-Dry Yarn***	%	4.5	3.5
Tensile Properties			
Straight Test on Conditioned Yarns†			
Breaking Strength	lb (N)	76.0 (338)	59.3 (264)
Breaking Tenacity	g/d (cN/tex)	23.0 (203)	23.6 (208)
	psi (MPa)	424,000 (2,920)	435,000 (3,000)
Tensile Modulus	g/d (cN/tex)	555 (4,900)	885 (7,810)
	psi (MPa)	10.2×10^6 (70,500)	6.3×10^6 (112,400)
Elongation at Break	%	3.6	2.4
Resin Impregnated Strands††			
Tensile Strength	psi (MPa)	525,000 (3,600)	525,000 (3,600)
Tensile Modulus	psi (MPa)	12.0×10^6 (83,000)	18.0×10^6 (124,000)

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. For Kevlar® 29, the basis weight used to calculate denier is zero finish and 4.5% moisture. For Kevlar® 49, the basis weight used to calculate denier is zero finish and 0% moisture.

* Filament diameter is 0.00047 inches (12 microns).

** Typical moisture levels on yarn as shipped; they reflect values reached at normal, moderate temperature and humidity levels following fiber production, which is a wet process.

***Equilibrium values are determined by bone drying the fiber and conditioning at 75°F (24° C), 55% relative humidity (RH).

† ASTM D885-85, tested at 1.1 twist multiplier.

†† Epoxy-impregnated strands, ASTM D2343.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

Table II-1 Typical Properties of DuPont™ Kevlar® 29 and Kevlar® 49 yarns (continued)

Property	Unit	Kevlar® 29	Kevlar® 49
Thermal Properties			
Shrinkage			
In Water at 212°F (100°C)	%	<0.1	<0.1
In Dry Air at 351°F (177°C)	%	<0.1	<0.1
Shrinkage Tension			
In Dry Air at 351°F (177°C)	G/D (cN/tex)	<0.1 (0.88)	<0.2 (1.77)
Specific Heat			
At 77°F (25°C)	cal/g x °C (J/kg x K)	0.34 (1,420)	0.34 (1,420)
At 212°F (100°C)	cal/g x °C (J/kg x K)	0.48 (2,010)	0.48 (2,010)
At 356°F (180°C)	caJ/g x °C (J/kg x K)	0.60 (2,515)	0.60 (2,515)
Thermal Conductivity			
	BTU x in./(h x ft^2 x °F) (W/(m x K)]	0.3 (0.04)	0.3 (0.04)
Decomposition Temperature in Air[†††]	°F (°C)	800–900 (427–482)	800–900 (427–482)
Recommended Maximum Temperature Range for Long-Term Use in Air	°F (°C)	300–350 (149–177)	300–350 (149–177)
Heat of Combustion	BTU/lb (Joule/kg)	15,000 (35 x 10^6)	15,000 (35 x 10^6)
Poisson's Ratio			0.36

††† Varies with rate of heating.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

Table II-2 compares the properties of Kevlar® 29 and Kevlar® 49 to other yarns, such as glass, steel wire, nylon, polyester, polyethylene and carbon. Compared to Kevlar®, nylon and polyester have relatively low moduli and intermediate melting points. Polyethylene has a high initial modulus, which is offset by its relatively low melting point.

Table II-2 Comparative Properties of Dupont™ Kevlar® vs. Other Yarns

"Customary" (inch-pound) Units								
	Specific Density, lb/in.^{3}	Tenacity, 10^3 psi	Modulus, 10^6 psi	Break Elongation, %	Specific Tensile Strength,* 10^6 in.	CTE,** 10^{-6}/°F	Decomposition Temperature, °F	°C
Kevlar® 29	0.052	424	10.2	3.6	8.15	-2.2	800–900	427–482
Kevlar® 49	0.052	435	16.3	2.4	8.37	-2.7	800–900	427–482
Other Yarns								
S-Glass	0.090	665	12.4	5.4	7.40	+1.7	1,562†	850
E-Glass	0.092	500	10.5	4.8	5.43	+1.6	1,346†	730
Steel Wire	0.280	285	29	2.0	1.0	+3.7	2,732†	1,500
Nylon 66	0.042	143	0.8	18.3	3.40	–	490†	254
Polyester	0.050	168	2.0	14.5	3.36	–	493†	256
HS Polyethylene	0.035	375	17	3.5	10.7	–	300†	149
High-Tenacity Carbon	0.065	450	32	1.4	6.93	-0.1	6,332†	3,500

*Specific tensile strength is obtained by dividing the tenacity by the density.
**CTE is the coefficient of thermal expansion (in the longitudinal direction).
†Melt temperature.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

EFFECT OF CHEMICAL AGENTS ON KEVLAR®

Kevlar® is chemically stable under a wide variety of exposure conditions; however, certain strong aqueous acids, bases and sodium hypochlorite can cause degradation, particularly over long periods of time and at elevated temperatures. Table II-3 summarizes the effect of chemical agents on the breaking strength of Kevlar®.

Table II-3 Chemical Resistance of DuPont™ Kevlar® Aramid Yarn

Chemical	Concentration, %	Temperature, °F	Temperature, °C	Time, hours	Effect on Breaking Strength*
Acids					
Acetic	99.7	70	21	24	None
Acetic	40	70	21	1000	Slight
Acetic	40	210	99	100	Appreciable
Benzoic	3	210	99	100	Appreciable
Chromic	10	70	21	1000	Appreciable
Formic	90	70	21	100	None
Formic	40	70	21	10000	Moderate
Formic	90	210	99	100	Degraded
Hydrobromic	10	70	21	1000	Appreciable
Hydrochloric	37	70	21	24	None
Hydrochloric	10	70	21	100	Appreciable
Hydrochloric	10	160	71	10	Degraded
Hydrofluoric	10	70	21	100	None
Nitric	1	70	21	100	Slight
Nitric	10	70	21	100	Appreciable
Nitric	70	70	21	24	Appreciable
Oxalic	10	210	99	100	Appreciable
Phosphoric	10	70	21	100	None
Phosphoric	10	70	21	1000	Slight
Phosphoric	10	210	99	100	Appreciable
Salicylic	3	210	99	1000	None
Sulfuric	10	70	21	1000	Moderate
Sulfuric	10	70	21	100	None
Sulfuric	10	212	100	10	Appreciable
Sulfuric	70	70	21	100	Moderate

* 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

Table II-3 Chemical Resistance of DuPont™ Kevlar® Aramid Yarn (continued)

Chemical	Concentration, %	Temperature, °F	°C	Time, hours	Effect on Breaking Strength*
Bases					
Ammonium Hydroxide	28.5	70	21	24	None
Ammonium Hydroxide	28	70	21	1000	None
Potassium Hydroxide	50	70	21	24	None
Sodium Hydroxide	50	70	21	24	None
Sodium Hydroxide	40	70	21	100	None
Sodium Hydroxide	10	70	21	1000	Appreciable
Sodium Hydroxide	10	210	99	100	Degraded
Sodium Hydroxide	10	212	100	10	Appreciable
Sodium Hypochlorite	0.1	70	21	1000	Degraded
Salt Solutions					
Copper Sulfate	3	70	21	1000	None
Copper Sulfate	3	210	99	100	Moderate
Ferric Chloride	3	210	99	100	Appreciable
Sodium Chloride	3	70	21	1000	None
Sodium Chloride	10	210	99	100	None
Sodium Chloride	10	250	121	100	Appreciable
Sodium Phosphate	5	210	99	100	Moderate
Miscellaneous Chemicals					
Benzaldehyde	100	70	21	1000	None
Brake Fluid	100	235	113	100	Moderate
Cottonseed Oil	100	70	21	1000	None
Formaldehyde in Water	10	70	21	1000	None
Formalin	100	70	21	24	None
Lard	100	70	21	1000	None
Linseed Oil	100	70	21	1000	None
Mineral Oil	100	217	99	10	None
Phenol in Water	5	70	21	10	None
Resorcinol	100	250	121	10	None
Water, Ocean (Ocean City, NJ)	100		—	1 year	None
Water, Salt	5	70	21	24	None
Water, Tap	100	70	21	24	None
Water, Tap	100	212	100	100	None
Water, Tap	100	210	99	100	None

* 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

Table II-3 Chemical Resistance of DuPont™ Kevlar® Aramid Yarn (continued)

Chemical	Concentration, %	Temperature, °F	°C	Time, hours	Effect on Breaking Strength*
Organic Solvents					
Acetone	100	70	21	24	None
Acetone	100		Boil	100	None
Amyl Alcohol	100	70	21	1000	None
Benzene	100	70	21	1000	None
Benzene	100	70	21	24	None
Carbon Tetrachloride	100	70	21	24	None
Carbon Tetrachloride	100		Boil	100	Moderate
Chlorothene	100	70	21	24	None
Dimethylformamide	100	70	21	24	None
Ethyl Ether	100	70	21	1000	None
Ethyl Alcohol	100	170	77	100	None
Ethylene Glycol/Water	50/50	210	99	1000	Moderate
Freon™ 11	100	140	60	500	None
Freon™ 22	100	140	60	500	None
Jet Fuel (Texaco "Abjet" K-40)	100	70	21	24	None
Kerosene	100	140	60	500	None
Suva™ Centri-LP (HCFC-123)	100	70	21	1000	None
Gasoline, Leaded	100	70	21	1000	None
Gasoline, Leaded	100	70	21	24	None
Methyl Alcohol	100	70	21	1000	None
Methylene Chloride	100	70	21	24	None
Methylene Ketone	100	70	21	24	None
Perchloroethylene	100	210	99	10	None
Toluene	100	70	21	24	None
Trichloroethylene	100	70	21	24	None

* 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

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

EFFECT OF WATER AND PH ON KEVLAR®

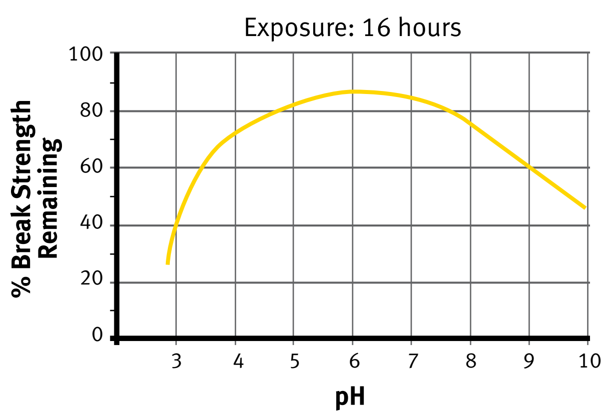
Hydrolytic and pH Stability

Degradation can occur when Kevlar® is exposed to strong acids and bases. At neutral pH (pH 7), the filament tenacity remains virtually unchanged after exposure at 149°F (65°C) for more than 200 days.

The further the pH deviates from pH 7, the greater the loss in tenacity. Acidic conditions cause more severe degradation than basic conditions at pH levels equidistant from neutral.

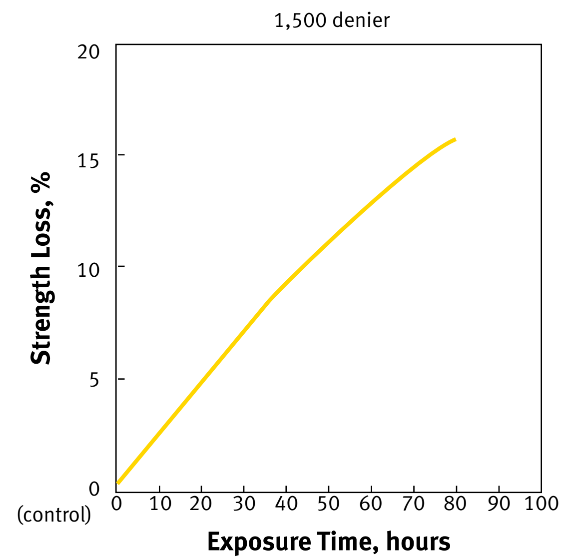
Similar behavior is seen in saturated steam generated from water at various pH levels. The results of the 16-hour exposure at 309°F (154 °C) show maximum strength retention in pH 6 to pH 7, with a sharper drop-off on the acidic side (Figure 2.1).

Figure 2.1 Hydrolytic Stability of Kevlar® in 309°F (154°C) Steam vs. pH of Water.



The resistance of Kevlar® to hydrolysis in saturated steam is measured in a sealed tube ("bomb") test. Kevlar® yarn (1,500 denier) in a skein form is held at 280°F (138°C) for various lengths of time in the presence of sufficient water (pH 7) to form saturated steam. The strength loss results are determined by comparing strength data measured at room temperature for control and exposed yarns (Figure 2.2).

Figure 2.2 Hydrolytic Stability of Kevlar® 29 in Saturated Steam at 280°F (138°C) vs. Exposure Time.



Moisture Regain

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

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

Bone-dried Kevlar® will reach a slightly lower equilibrium moisture level than fiber that has never been bone dried. Figure 2.3 illustrates this effect for Kevlar® 29. Figure 2.4 illustrates the effect of RH on the equilibrium moisture content obtained from a bone-dry yarn of Kevlar® 49. This relationship is linear throughout the entire RH range.

The tensile properties of Kevlar® are virtually unaffected by moisture content.

Figure 2.3 Moisture Regain of Kevlar® 29 (After Various Preconditionings).

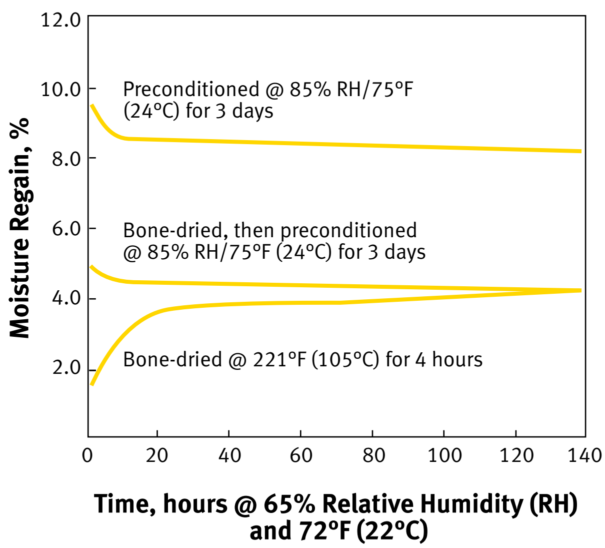
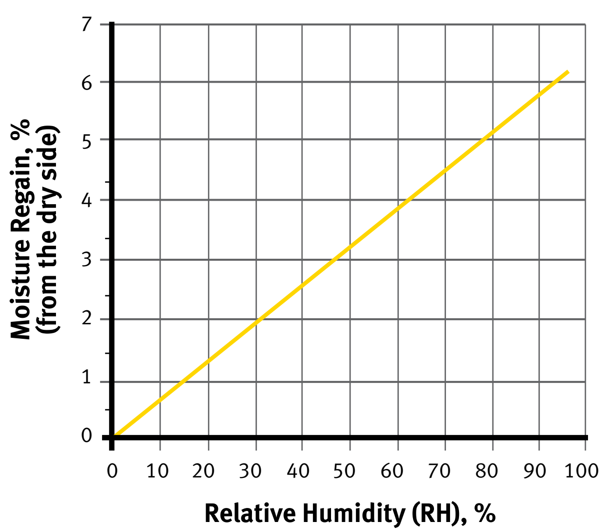


Figure 2.4 Equilibrium Moisture Content of Kevlar® 49 vs. Relative Humidity (RH) at Room Temperature.



THERMAL PROPERTIES OF KEVLAR®

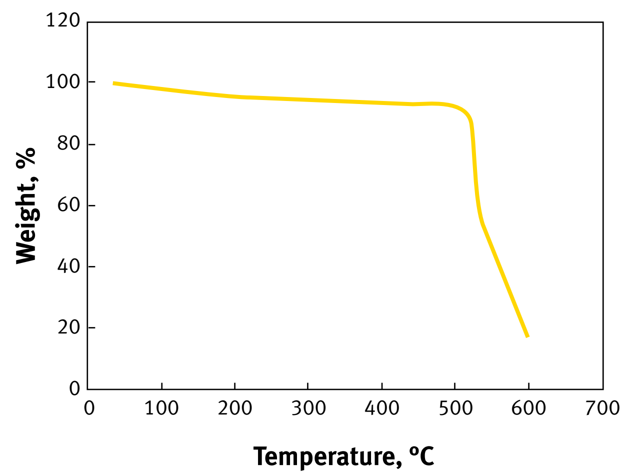
Decomposition Temperature

Kevlar® does not melt; it decomposes at relatively high temperatures (800°F to 900°F [427°C to 482°C] in air and approximately 1,000°F [538°C] in nitrogen), when tested with a temperature rise of 10°C/minute. Decomposition temperatures vary with the rate of temperature rise and the length of exposure.

Figures 2.5 and 2.6 show typical thermogravimetric analyses (TGAs) of Kevlar® 49 in air and nitrogen, respectively. TGAs are generated by an instrument that measures weight loss as a function of temperature rise over time. The analyses can be performed in air or in a variety of other atmospheres.

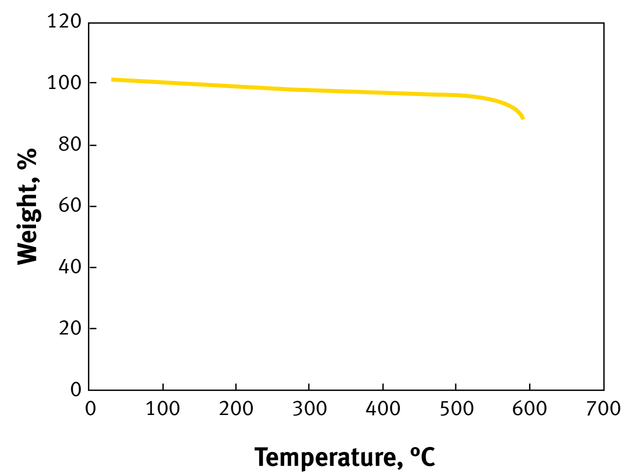
For Kevlar®, as temperature increases there is an immediate weight reduction, corresponding to water loss. The curve then remains relatively flat until decomposition, where a significant weight loss is observed.

Figure 2.5 Typical Thermogravimetric Analysis (TGA) of Kevlar® 49 in Air at a Temperature Rise of 10°C/Minute.



SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

Figure 2.6 Typical Thermogravimetric Analysis (TGA) of Kevlar® 49 in Nitrogen at a Temperature Rise of 10°C/Minute.



Effect of Elevated Temperatures on Tensile Properties

Increasing temperatures reduce the modulus, tensile strength and break elongation of Kevlar® yarns and other organic fibers. This should be taken into consideration when using Kevlar® at or above 300°F to 350°F (149°C to 177°C) for extended periods of time.

Figures 2.7 and 2.8 compare the effects of exposure to elevated temperatures on the tensile strength and modulus, respectively, of Kevlar® and other yarns.

Figure 2.7 Effect of Elevated Temperatures on the Tensile Strength of Kevlar® 29.

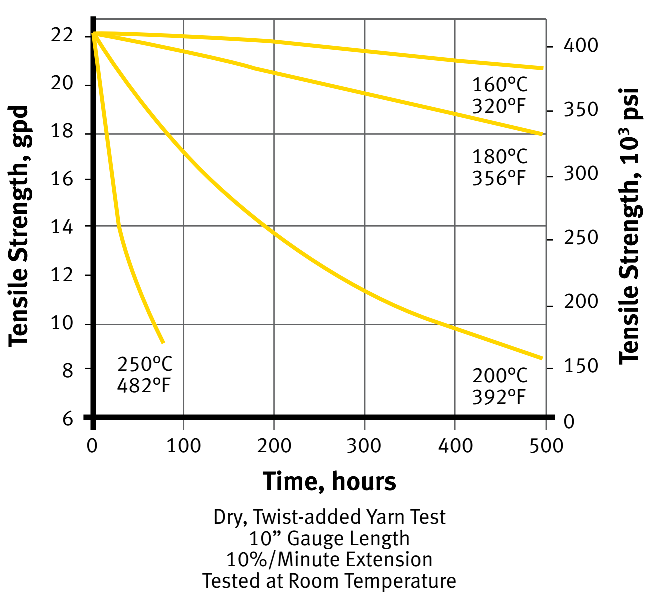
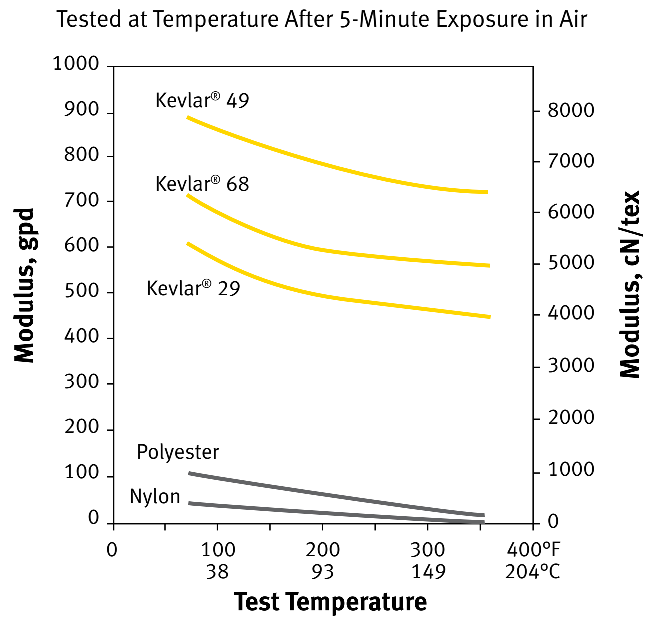


Figure 2.8 Comparative Effect of Elevated Temperatures on the Modulus of Various Yarns.



Effect of Elevated Temperatures on Dimensional Stability

Kevlar® does not shrink like other organic fibers when exposed to hot air or hot water. Most other fibers suffer significant, irreversible shrinkage.

Kevlar® has a very small, negative coefficient of thermal expansion (CTE) in the longitudinal direction. The value of the CTE of Kevlar® is dependent on measuring technique, sample preparation and test method (Table II-4).

Table II-4 Coefficient of Thermal Expansion (CTE) of DuPont™ Kevlar® 29 and Kevlar® 49*

Type of Kevlar®	Denier	Temperature Range °F	°C	CTE in./in./°F (cm/cm/°C)
Kevlar® 29	1,500	77–302	25–150	-2.2×10^{x} (-4.0×10^{x})
Kevlar® 49	1,420	77–302	25–150	-2.7×10^{x} (-4.9×10^{x})

*Tested with zero twist and 0.2 gpd tension at 72°F (22°C), 65% relative humidity (RH).

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

Heat of Combustion

The heat of combustion of Kevlar® is measured by an Emerson oxygen bomb calorimeter. Table II-5 compares the heat of combustion of Kevlar® to that of other polyamides and to an epoxy used in making rigid composites.

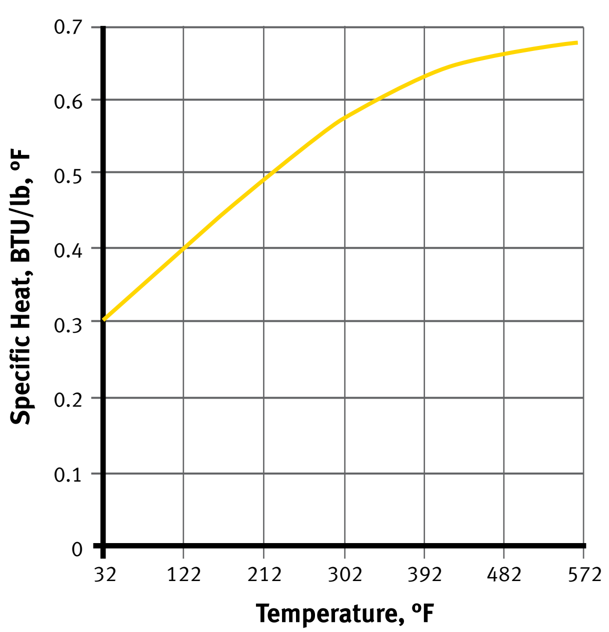
Table II-5 Heat of Combustion of DuPont™ Kevlar® 49 and Other Materials

	Heat of Combustion	
Material	**BTUlb**	**Joule/kg**
Kevlar® 49	14.986	34.8 x 10^{x}
Nylon, Type 738	15.950	37.1 x 10^{x}
Nomex® aramid	13.250	30.8 x 10^{x}
Shell Epon® 828/NMA/BDMA	12.710	29.5 x 10^{x}

Specific Heat

The specific heat of Kevlar® is markedly influenced by temperature. It more than doubles when the temperature is raised from 32°F (0°C) to 392°F (200°C), as seen in Figure 2.9. Further increases are more gradual.

Figure 2.9 Effect of Temperature on the Specific Heat of Kevlar® 49.



Effect of Arctic Conditions

Exposure to arctic conditions (-50°F [-46°C]) does not adversely influence the tensile properties of Kevlar® (Table II-6). The increase in modulus and the small decrease in break elongation at this low temperature can be attributed to a slight increase in molecular rigidity.

Effect of Cryogenic Conditions

Kevlar® shows essentially no embrittlement or degradation at temperatures as low as -320°F (-196°C).

Table II-6 Tensile Properties of DuPont™ Kevlar® 29 at Room and Arctic Temperatures

		Test Temperature,	
Property	**Unit**	**75˚F (24˚C)**	**-50˚F (-46˚C)**
Tenacity	gpd (cN/tex)	19.1 (169)	19.8 (175)
Tensile Strength	10^3 psi (MPa)	352 (2,430)	365 (2,510)
Elongation at Break	%	4.1	3.9
Modulus	gpd (cN/tex) 10^6 psi (MPa)	425 (3,750) 7.82 (53,900)	478 (4,220) 8.81 (60,800)

A 30-inch sample cord twisted to 6.5 twist multiplier was tested, of which 18 inches were exposed to the cold chamber at a 10%/minute strain rate.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

FLAMMABILITY, SMOKE AND OFF-GAS GENERATION PROPERTIES OF KEVLAR®

Kevlar® is inherently flame resistant, but can be ignited (limiting oxygen index of 29). Burning usually stops when the ignition source is removed; however, pulp or dust, once ignited, may continue to smolder. In laboratory testing (Table II-7), fabrics of Kevlar® do not continue to burn when the source of ignition is removed after 12 seconds of contact. Although the glow time increases with the thickness of the fabric, the burn length does not. No "drips" are experienced, which can cause flame propagation, a common problem with other organic fibers.

Kevlar® is not intended to be used as fuel, nor should it be deliberately burned under any circumstances. The laboratory data shown in Table II-8 were generated to provide important information in case Kevlar® is accidentally burned.

Burning Kevlar® produces combustion gases similar to those of wool—mostly carbon dioxide, water and oxides of nitrogen. However, carbon monoxide, small amounts of hydrogen cyanide and other toxic gases may also be produced, depending on burning conditions. The composition of off-gases from Kevlar® and other fibers under poor burning conditions is shown in Table II-8. For more detailed information, please refer to the Material Safety Data Sheet (MSDS) for Kevlar®.

Table II-7 Smoke Generation and Vertical Flammability of Fabrics of DuPont™ Kevlar® 49

Fabric				Smoke**	Vertical Flammability					
Style Number*	Fabric Weight	Thickness		Maximum Specific Optical Density	Burn Time	Drips	Glow Time	Burn Length		After-Burn Time
	oz/yd²	mil	mm		sec		sec	in.	cm	sec
120	1.7	4.5	0.11	0	12	none	3.0	1.55	3.94	0
281	5.1	10	0.25	7	12	none	5.3	0.97	2.46	0
328	6.8	13	0.33	4	12	none	6.5	0.96	2.44	0
Z-11††	1.5	12	0.29	0	12	none	1.0	2.50	6.35	0

* Selected fabric constructions commercially available at the time of test.
** National Bureau of Standards Smoke Chamber; Flaming Mode.
† Federal Aviation Administration Part 24, Sections 25, 833 (A) and (B).
†† Kevlar® Z-11 is a nonwoven fabric.

Table II-8 Composition of Off-Gases of DuPont™ Kevlar® and Other Fibers Under Poor Combustion Conditions*

	Combustion Products in mg/g of Sample									
	CO_2	CO	C_2H_4	C_2H_2	CH_4	N_2O	HCN	NH_3	HCl	SO_2
Kevlar®	1,850	50	—	1	—	10	14	0.5	—	—
Acrylic	1,300	170	5	2	17	45	40	3	—	—
Acrylic/Modacrylic (70/30)	1,100	110	10	1	18	17	50	5	20	—
Nylon 66	1,200	250	50	5	25	20	30	—	—	—
Wool	1,100	120	7	1	10	30	17	—	—	3
Polyester	1,000	300	6	5	10	—	—	—	—	—

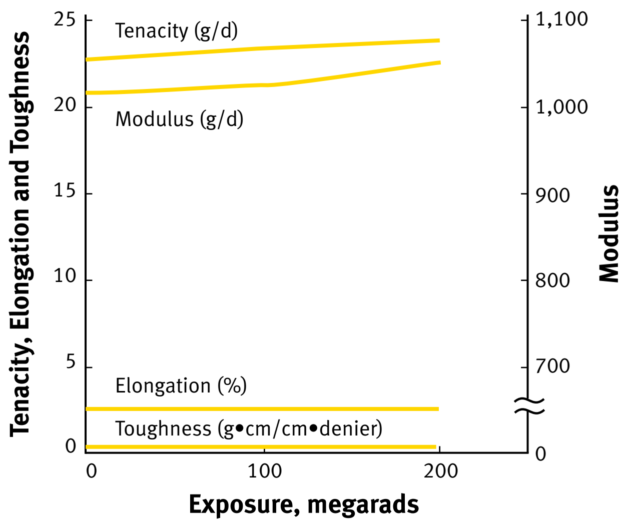
*The sample is placed in a quartz tube through which air is drawn at a controlled flow and heated externally with a hand-held gas-oxygen torch. Air flow and heating are varied to give a condition of poor combustion (i.e., deficiency of oxygen). Combustion products are collected in an evacuated tube and analyzed by infrared.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

EFFECT OF ELECTRON RADIATION ON KEVLAR®

Electron radiation is not harmful to Kevlar®. In fact, filaments of Kevlar® 49 exposed to 200 megarads show a very slight increase in tenacity and modulus (Figure 2.10).

Figure 2.10 Effect of Electron Radiation on the Tenacity, Elongation, Modulus and Toughness of Filaments of Kevlar® 49.



A G.E. resonant transformer is used at 0.5 milliamps and 2 megavolts to generate 1 megarad every 13.4 sec. The filament distance from the radiation source is 30 cm [11.8 in.]. The filament is wrapped in aluminum foil and kept over dry ice.

EFFECT OF UV LIGHT ON KEVLAR®

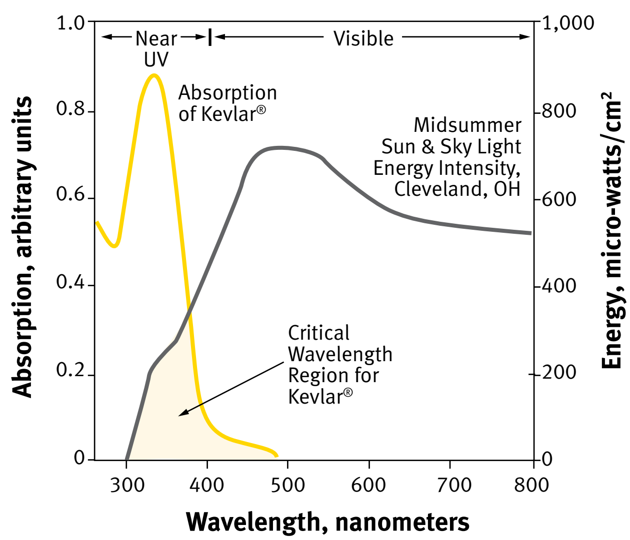
Like other polymeric materials, Kevlar® is sensitive to UV (ultraviolet) light. Unprotected yarn tends to discolor from yellow to brown after prolonged exposure. Extended exposure to UV can also cause loss of mechanical properties, depending on wavelength, exposure time, radiation intensity and product geometry. Discoloration of fresh yarn after exposure to ordinary room light is normal and is not indicative of degradation.

Degradation, which occurs only in the presence of oxygen, is not enhanced by moisture or by atmospheric contaminants, such as sulfur dioxide. Two conditions must be fulfilled before light of a particular wavelength can cause fiber degradation:

- Absorption by the polymer; and
- Sufficient energy to break the chemical bonds.

Figure 2.11 shows the absorption spectrum of Kevlar®, along with that of sunlight. The overlap region of these two curves—especially between 300 nm to 450 nm—should be considered when specifying outdoor use of unprotected Kevlar®. This range includes the so-called near UV and part of the visible region. For effective protection of Kevlar® from UV degradation, this kind of light must be excluded.

Figure 2.11 Overlap of the Absorption Spectrum of Kevlar® with the Solar Spectrum.



Only small amounts of this light occur in artificial light sources, such as ordinary incandescent and fluorescent bulbs, or in sunlight filtered by window glass. However, to avoid possible damage, yarn should not be stored within one foot of fluorescent lamps or near windows.

SECTION II: PROPERTIES OF DUPONT™ KEVLAR®

Kevlar® is intrinsically self-screening. External fibers form a protective barrier that shields interior fibers in a filament bundle or fabric. UV stability increases with size—the denier of a yarn, the thickness of the fabric or the diameter of a rope.

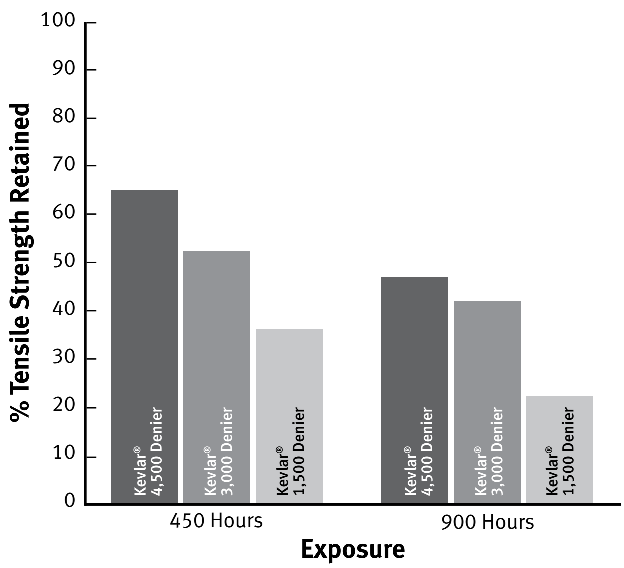
Extra UV protection can be provided by encapsulation:

- By overbraiding with other fibers; or
- By applying an extruded jacket over ropes and cables.

Whenever a coating, extrudate or film is used, it should not be UV-transparent. Rather, it should have the proper pigmentation to absorb in the 300-nm to 450-nm range.

Figure 2.12 shows the UV stability of Kevlar® obtained with a "Fade-Ometer" equipped with a xenon arc.

Figure 2.12 Ultraviolet (UV) Stability of Kevlar® Yarns.



SECTION III: DUPONT™ KEVLAR® SHORT FIBERS

Kevlar® is available in several short forms, including staple and floc (precision cut) and pulp (fibrillated).

KEVLAR® PULP

Kevlar® pulp (Figure 3.1) is a highly fibrillated form of the fiber that can be dispersed into many different matrix systems. The fibrillation (Figure 3.2) results in a high surface area of 7 m^2/g to 10 m^2/g (170 yd^2/oz to 240 yd^2/oz).

Figure 3.1 Photograph of Kevlar® Pulp.

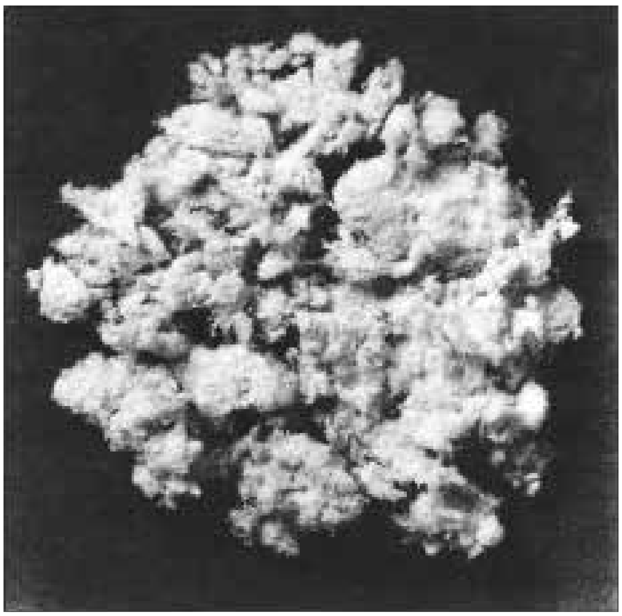


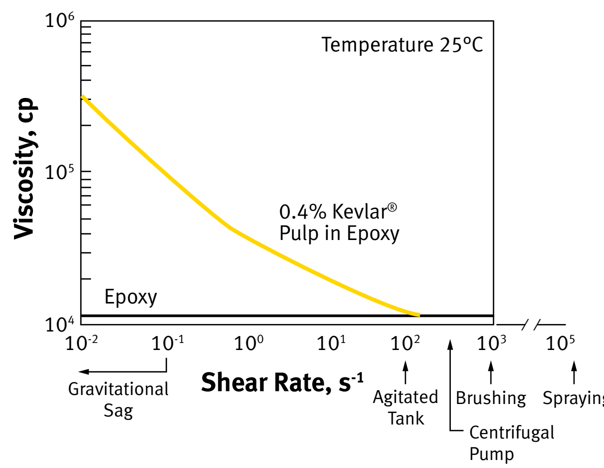
Figure 3.2 Photomicrograph of Kevlar® Pulp.

Kevlar® pulp is non-brittle, so standard mixing and dispersion equipment will not affect the fiber size. Kevlar® pulp is available in wet form (approximately 50% moisture)* for dilute, aqueous dispersions and dry form (6% moisture) for solvent-based dispersions and dry mixes. Various fiber lengths are available to meet your engineering design needs.

Kevlar® pulp enhances the performance of elastomers, thermoplastics and thermoset resins, especially where high-temperature performance is required.

Kevlar® UltraThix™ is available for use as a thixotrope in adhesives, sealants and coatings (Figure 3.3). Kevlar® UltraThix™ disperses easily and provides both viscosity control and reinforcement in most resin systems.

Figure 3.3 Viscosity vs. Shear Rate of Kevlar® Pulp in Epoxy.



*Moisture specifications vary with fiber length and merge.

SECTION III: DUPONT™ KEVLAR® SHORT FIBERS

PRECISION-CUT, SHORT FIBERS

Kevlar® Staple

Kevlar® staple (Figure 3.4) consists of precision-cut, short fibers, ¼ inch or longer. It is used to manufacture spun yarns, which provide enhanced wear resistance and comfort vs. filament yarns. Because spun yarns are discontinuous fibers, their applications generally take advantage of the barrier properties of Kevlar®, rather than the tensile and modulus properties.

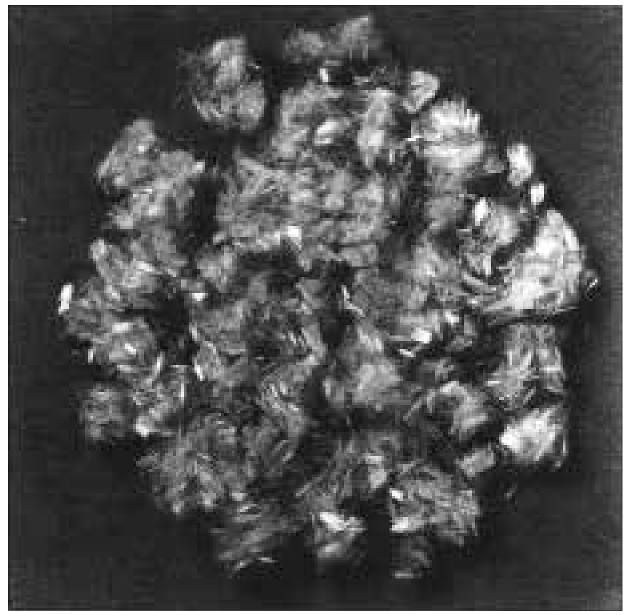
Figure 3.4 Photograph of Kevlar® Staple.

Kevlar® staple is also used in felts and nonwovens to increase thermal insulation and vibration-dampening properties. Other applications include thermoset and thermoplastic resin systems where Kevlar® increases strength and wear resistance over a wide range of temperatures.

Kevlar® Floc

Kevlar® floc (Figure 3.5) refers to precision-cut short fibers, shorter than staple, down to 1 mm in length. It can be used as a reinforcement in a wide variety of resin systems. In thermoplastics, it provides increased wear resistance with minimal abrasion on opposing surfaces. In thermoset resins, it provides increased strength without significantly affecting the viscosity of the system.

Figure 3.5 Photograph of Kevlar® Floc.

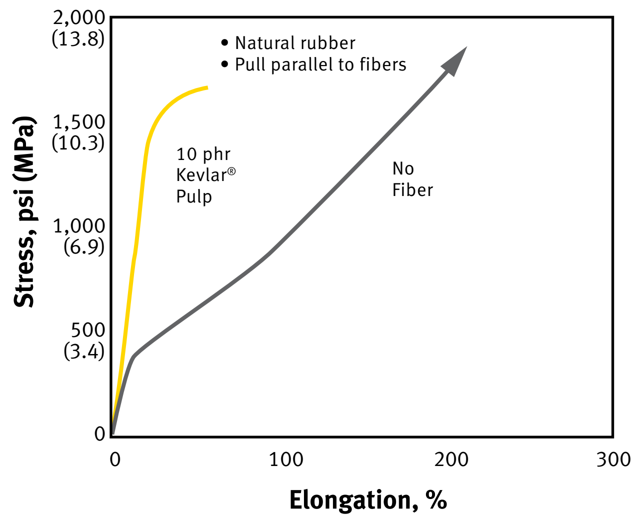


SECTION III: DUPONT™ KEVLAR® SHORT FIBERS

KEVLAR® M/B MASTERBATCH

Short Kevlar® pulp is available in a masterbatch form for easy, uniform dispersion in viscous elastomers. When Kevlar® pulp is blended with various elastomers it gives enhanced tensile strength (Table III-1) at elevated temperatures. It also increases the modulus (Figure 3.6), tear resistance, wear resistance and puncture resistance of the resulting compounds. To make it easier to incorporate pulp into elastomers, DuPont offers Kevlar® M/B a masterbatch concentrate. Kevlar® M/B can also be blended with other elastomers to give desired end-use properties.

Figure 3.6 Stress-Strain Curve.



Kevlar® M/B more than triples the modulus in the machine direction vs. an unreinforced elastomer.

Table III-1 Typical Improvements in Properties of Elastomeric Compounds with DuPont™ Kevlar®

3 phr Kevlar® Pulp in Viton™ GF

	Machine Direction (MD)	Cross Machine Direction (CMD)
Room Temperature		
Modulus at 50% Elongation	7X	1.4X
Tensile Strength	1X	1X
Tear Strength	1.7X	1.3X
300°F (149°C)		
Modulus at 30% Elongation	6X	—
Modulus at 50% Elongation	—	1.5X
Tensile Strength	1.6X	1.3X

20 phr Kevlar® Pulp in Nordell 1040/Neoprene FB (80/20)**

	(MD)	(CMD)
Room Temperature		
Modulus at 20% Elongation	9.4X	3.3X
Tensile Strength	1X	0.6X
Tear Strength	1.5X	1.4X
300°F (149°C)		
Modulus at 8% Elongation	15X	—
Modulus at 20% Elongation	—	3.9X
Tensile Strength	2.3X	1.3X
Tear Strength	1.9X	1.5X

SECTION IV: GLOSSARY

Break Strength	The force needed to cause failure in a material, irrespective of the cross-sectional area of the sample. The most commonly used units are "pounds [force]" (lb); "grams [force]" (g); "kilograms [force]" (kg); and "Newtons" (N).
Bobbin	Smallest production unit of yarn or roving, including its appropriate (usually cardboard tube) support. Sometimes also referred to as a "package."
Coefficient of Thermal Expansion (CTE)	Describes the length change per unit of temperature based on the original length of the sample. Its units are either °F^{-1} or °C^{-1}, because the length units appear in both the numerator and the denominator: $\text{CTE} = \frac{\text{length}}{\text{length x temperature}}$
Count	Cross section or thickness of yarn or roving expressed as "denier" or "(deci)tex."
Denier	Property unique to the fibers industry to describe the fineness (and, conversely, the cross-sectional area) of a filament, yarn, rope, etc. It is defined as the weight in grams of 9,000 meters of the material. An alternative unit is "dtex" (decitex): 1 dtex = 0.9 denier.
Density	The denseness of a material is expressed as mass per unit volume, either as "pounds per cubic inch" (lb/in.^{3}) or as "grams per cubic centimeter" (g/cm^3).
dtex	Standard abbreviation for "decitex." This is a property unique to the fibers industry to describe the fineness (and, conversely, the cross-sectional area) of a filament, yarn rope, etc. It is defined as the weight in grams of 10,000 meters of the material. Its U.S. equivalent is "denier:" 1 dtex = 0.9 denier.
Elongation at Break	Also called "break elongation," it is the change in length of the specimen compared to its no-load length at the moment of failure under load. It is usually expressed as percent (%).
Equilibrium Moisture Content	Maximum moisture attained after long exposure.
Filament	Smallest component of a yarn.
Finish	Mixture or emulsion often consisting of oil(s), which is applied to the fiber surface primarily to reduce friction and to improve processing and/or end-use performance.
Heat of Combustion	The amount of heat released when one gram molecule of a substance is burned in oxygen.
LASE	"Load At Specified Elongation." The load required to produce a given elongation of a yarn or cord. Its units are lb, kg or g force, etc., at X% elongation. A related property is SASE, "Stress At Specified Elongation." Its units are "pounds per square inch" (psi), "grams per denier" (gpd), "kilograms per square millimeter" (kg/mm^2), "pascals" (Pa), "Newtons per square meter" (N/m^2) etc., at X% elongation.
Merge	Identification code assigned to a specific product with its corresponding production process and quality control parameters. Usually only shipments with identical merge numbers can be mixed during subsequent processing, although in some cases merge-mixing is permissible. Check with your DuPont representative *before* mixing different merges.
Metered Length	Standard yarn length on a package, controlled within narrow tolerances. This permits matching the length to your process needs and significantly reduces waste.

SECTION IV: GLOSSARY

Modulus	The property describing a material's resistance to extension. Young's modulus or modulus of elasticity represents the stress required to produce a given strain or change in length. Modulus is area-specific, that is, it is expressed based on a unit of the original (i.e., no-load) cross section. Modulus units are the same as those for "tenacity." The most common examples are "pounds per square inch" (psi); "grams per denier" (gpd); "Newtons per tex" (N/tex); and "pascals" (Pa).
Moisture Regain	The tendency of most fibers to pick up or give off ambient atmospheric moisture until they reach an equilibrium moisture content at a given temperature and humidity level.
Poisson's Ratio	The ratio of the strain perpendicular to the loading direction to the strain along the loading direction; relevant to composites.
SASE	"Stress At Specified Elongation. "The stress required to produce a given elongation of a yarn or cord. Its units are "pounds per square inch" (psi), "grams per denier" (gpd), "kilograms per square millimeter" (kg/mm^2), "pascals" (Pa), "Newtons per square meter" (N/m^2), etc., at X% elongation.
Specific Heat	The ratio of the amount of heat required to raise the temperature of a given mass of a substance one degree to the amount of heat required to raise the temperature of an equal mass of water one degree.
Strain	In fibers terminology, it is synonymous with elongation and expressed in % (i.e., % change in original length).
Stress	The force exerted on a material, expressed per unit of the original (i.e., no-load) cross section. The units are the same as those for "tenacity." The most common examples are "pounds per square inch" (psi); "grams per denier" (gpd); "Newtons per tex" (N/tex); and "pascals" (Pa).
Tenacity/Tensile Strength	The ultimate strength exhibited by a material at the moment of failure based on a unit of the original (i.e., no-load) cross section. The most commonly used units are "pounds per square inch" (psi); "grams per denier" (gpd); "Newtons per tex" (N/tex); and "pascals" (Pa). Frequently, the term tensile strength is used synonymously with ultimate stress.
Tex	The basic property, unique to the fibers industry, to describe the fineness (and, conversely, the cross-sectional area) of a filament, yarn, rope, etc. It is defined as the weight in grams of 1,000 meters of the material. Its U.S. equivalent is "denier:" 1 tex = 9 denier. In many instances, "decitex" (dtex) is used to keep fineness numbers about the same as the "denier" values.
Throwster	Company that specializes in putting twist and/or texture into yarns.
Twist (Noun)	The number of turns about its axis per unit length of yarn. The most common units are "turns per inch" (tpi) and "turns per meter" (t/m): 1 tpi = 39.37 t/m.
Twist Multiplier	A property defined by a mathematical formula to describe the helix angle in a twisted structure. Twisted bundles with the same twist multiplier (TM) have the same theoretical helix angle, regardless of their cross-sectional area. The mathematical formula of the twist multiplier is: $TM = \frac{\text{twist [tpi] x denier}^{1/2}}{73} = \frac{\text{twist [t/m] x dtex}^{1/2}}{3{,}000}$
Yarn	Bundle (assembly) of individual filaments.
Yield	Length of yarn, rope, etc. contained in a unit weight of package. The most common units are "yards per pound" (yd/lb) and "meters per kilogram" (m/kg).

SECTION IV: GLOSSARY

ORDERING INFORMATION FOR DUPONT™ KEVLAR®

DuPont produces and sells Kevlar® filament, pulp, staple and floc, as well as specialized forms, including: Kevlar® M/B masterbatch and Kevlar® Wearforce™ injection moldable composites. Please note that all Kevlar® yarns are sold with zero twist.

For more information on DuPont products, call your DuPont Representative. For additional information, including source lists for fabrics, other products made from Kevlar®, and for throwsters, to add twist to yam, call 1-800-931-3456. Outside the United States, call (302) 999-3358.

To place an order call:

Kevlar® Yarn

1-800-344-8986 or 1-800-441-2767

Kevlar® Pulp, Kevlar® Staple,
Kevlar® Floc, Kevlar® EE

1-800-441-0969

TERMS

- Net 30 days from date of invoice
- FOB shipping point, freight prepaid our route within continental limits of United States, excluding Alaska.
- All prices subject to change without notice.

Table IV-1 Conversion Table for Yarn Length to Weight

Denier	Number of Filaments	Yield yd/lb	Yield m/kg
55	25	81,175	163,636
195	90	22,895	46,155
195	134	22,895	46,155
200	134	22,320	44,997
380	180	11,749	23,684
380	267	11,749	23,684
400	267	11,160	22,500
720	490	6,200	12,500
750	490	5,952	12,000
840	534	5,314	10,714
1,000	666	4,464	9,000
1,140	768	3,916	7,895
1,420	1,000	3,144	6,338
1,500	1,000	2,976	6,000
2,160	1,000	2,097	4,228
2,250	1,000	1,984	4,000
2,840	1,333	1,572	3,169
2,840	1,000	1,572	3,169
3,000	1,333	1,488	3,000
4,320	2,000	1,048	2,110
4,560	3,072	979	1,974
6,000		744	1,500
7,100	5,000	630	1,268
8,640	4,000	524	1,057
10,800	5,000	413	833
11,400		391	789
15,000	10,000	298	600

FOR MORE INFORMATION OR TO REQUEST A PRODUCT SAMPLE, CALL OR CONTACT:

DuPont
Advanced Fibers Systems
Customer Inquiry Center
5401 Jefferson Davis Highway
Richmond, VA 23234
Tel: (800) 453-8527
(804) 383-4400
Fax: (800) 787-7086
(804) 383-4132
E-Mail: afscdt@usa.dupont.com

kevlar.com