

**KEVLAR®**



# TECHNICAL INFORMATION

PROPERTIES AND PROCESSING  
OF DUPONT KEVLAR® BRAND YARN  
FOR MECHANICAL RUBBER GOODS

## HOSES

- TRANSFER
- HYDRAULIC

## BELTS

- CONVEYOR
- POWER TRANSMISSION

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## Introduction

KEVLAR® is the registered trademark for DuPont's family of aramid fibers having a unique combination of high strength, high modulus, toughness, and exceptional thermal stability. These properties offer the means to increase strength and reduce the weight of reinforcement, as well as extend the useful wear life in a variety of end-use applications. Stress-strain curves of KEVLAR® compared to other industrial filament yarns and steel wire are presented in Figure 1.

The types of KEVLAR® yarns used in belts and hoses include Types 956, 956C, 956E and 965. KEVLAR® is also available in staple, floc, pulp, and Engineered Elastomer forms.

Except where noted, all tests reported in this bulletin were obtained using KEVLAR® Type 956 (commonly referred to as KEVLAR® 29). The data presented are those most commonly observed and are representative of the particular denier and type indicated.

## Descriptions of KEVLAR® Brand Yarns Used in Mechanical Rubber Goods

**KEVLAR® Type 956** (KEVLAR® 29) is specifically engineered for rubber products, combining outstanding strength and modulus with light weight, toughness, and durability. This unique balance of properties makes KEVLAR® Type 956 an excellent reinforcement for mechanical rubber goods such as hoses, power transmission belts, and conveyor belts.

**KEVLAR® Type 956C** (KEVLAR® 129) possesses the highest tenacity of the aramid yarns and is used in applications where strength is the primary concern.

**KEVLAR® Type 956E** (KEVLAR® 119) provides exceptional long-term service in high-fatigue applications, such as power transmission belts. It not only features the superior strength and temperature resistance characteristics of KEVLAR®, but also offers higher elongation, lower modulus, and greater tenacity compared to KEVLAR® Type 956.

**KEVLAR® Type 965** (KEVLAR® 49) has tensile strength equal to that of KEVLAR® Type 956, but has higher modulus and lower elongation. It is well suited for power transmission belts where very high modulus is required.

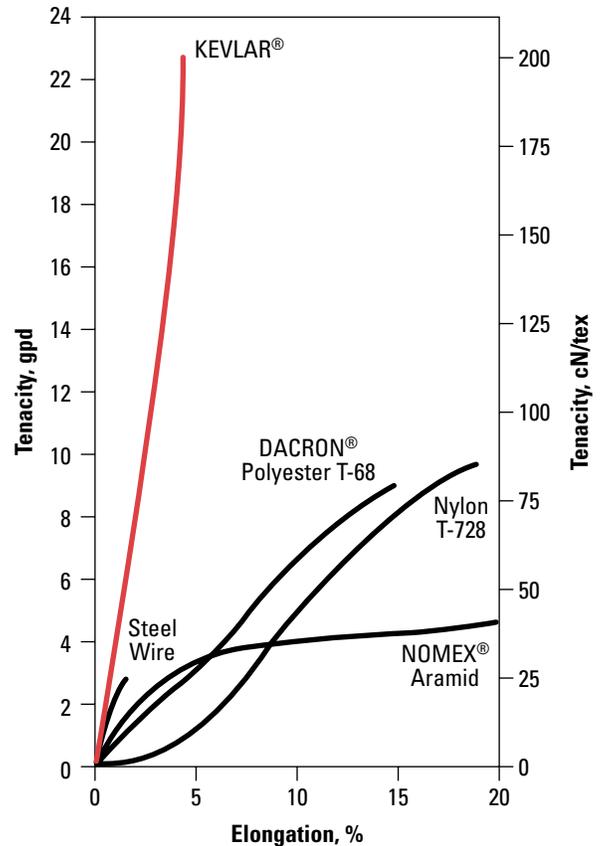


Figure 1. Stress-Strain Curves for Industrial Filament Yarns and Steel Wire

**KEVLAR® staple** are short fibers which have been cut to lengths typically ranging from 1/4 to 1/2 inch. Other lengths may also be available.

**KEVLAR® floc** are precision cut fibers of very short lengths, typically ranging from 1 to 5 mm.

**KEVLAR® pulp** fibers are very short and highly fibrillated, with many fine fibrils or subfibers attached to a core fiber. Core lengths typically range from 2 to 4 mm.

**KEVLAR® engineered elastomer** is a composite of KEVLAR® pulp and various elastomers. It enables the rubber compounder and designer to achieve performance, properties and designs not possible in the past. Compounds have been engineered to improve wear and abrasion, achieve better frictional properties, improve tear, improve shear resistance, replace reinforcing fabric, reduce part thickness, or lower rolling resistance.

**Table 1. Typical Physical Properties of KEVLAR® Brand Yarns**

PROPERTY	UNIT	TYPE 956	TYPE 956C	TYPE 956E	TYPE 965
		K29	K129	K119	K49
<b>Yarn</b>					
Denier (Decitex)	denier (dtex)	1500 (1670)	1500 (1670)	1500 (1670)	1420 (1580)
Specific Gravity	–	1.44	1.44	1.44	1.44
Commercial Moisture Regain (ASTM D 1909)	%	7.0	7.0	7.0	3.5
<b>Stress-Strain Properties*</b>					
<b>Straight Test on Yarns</b>					
Breaking Strength	lb(N)	75.1 (334)	83.3 (371)	78.7 (350)	69.5 (309)
Breaking Tenacity	gpd (cN/tex)	22.7 (200)	25.2 (222)	23.8 (210)	22.2 (196)
Elongation at Break	%	3.35	3.15	4.11	2.49
Initial Modulus	gpd (cN/tex)	591 (5216)	750 (6620)	424 (3742)	856 (7555)
<b>Loop Test on Yarns</b>					
Breaking Strength	lb (N)	76.0 (338)	56.2 (250)	80.7 (359)	52.8 (235)
Breaking Tenacity	gpd (cN/tex)	11.5 (102)	12.7 (112)	12.1 (107)	10.5 (93)
Elongation at Break	%	2.2	1.7	2.7	1.3

\*ASTM D 885-85 (tested at 1.1 Twist Multiplier)

**Table 2. Typical Thermal Properties of KEVLAR® Yarn**

PROPERTY		
<b>Shrinkage</b>		
In water at 212°F (100°C)	%	<0.1
In Dry Air at 351°F (177°C)	%	<0.1
<b>Shrinkage Tension</b>		
In Dry Air at 351°F (177°C)	gpd cN/tex	<0.1 <0.88
<b>Specific Heat</b>		
At 77°F (25°C)	J/(kg·°C)	1420
At 212°F (100°C)	Btu/lb·°F	0.34
At 356°F (180°C)		0.48
		0.60
<b>Thermal Conductivity</b>		
	Btu-in/(h·ft²·°F)	0.3
	W/(m·K)	0.04
<b>Coefficient of Thermal Expansion*</b>		
77-302°F (25-150°C)	in/(in·°F)	-2.2 x 10 <sup>-6</sup>
	cm/(cm·°C)	-4.0 x 10 <sup>-6</sup>
<b>Decomposition Temperature in Air**</b>		
	°F	800–900
	°C	427–482

\*Tested with zero twist yarn at 0.2 gpd (1.8 cN/tex) tension

\*\*Varies with rate of heating

**Properties of KEVLAR® Yarn**

Typical physical properties of KEVLAR® are shown in Table 1. Table 2 shows various thermal properties of KEVLAR®. Additional conversion factors can be found in Appendix A.

**Effects of Air Temperature**

KEVLAR® does not suffer significant, irreversible shrinkage like most other organic fibers when exposed to hot air or hot water. As seen in Table 2, KEVLAR® has a very small, negative coefficient of thermal expansion (CTE) in the longitudinal direction.

Figures 2 and 3 show the breaking tenacity and initial modulus of KEVLAR®, industrial nylon, DACRON® polyester, and steel wire in air at elevated temperatures. The yarns and steel wire were tested at temperature after five minutes of exposure in air. The breaking tenacity and modulus of KEVLAR® at 350°F (177°C) well exceeds that of nylon, DACRON® polyester, and steel wire at room temperature.

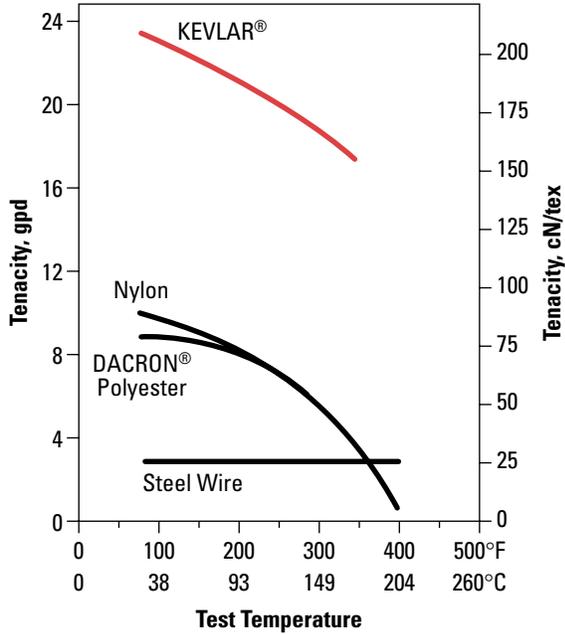


Figure 2. Breaking Tenacity of Industrial Filament Yarns and Steel Wire in Air at Elevated Temperatures.

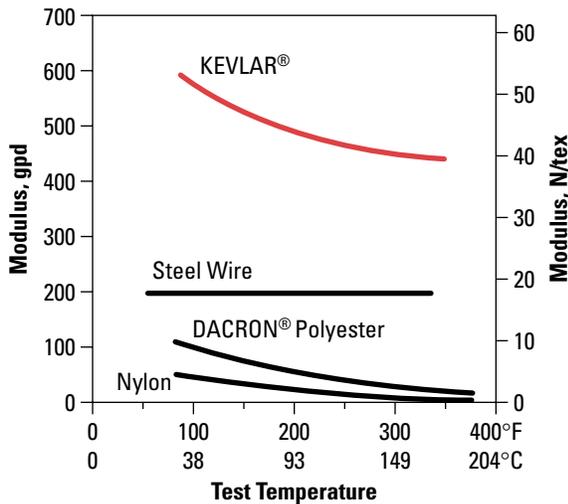


Figure 3. Initial Modulus of Industrial Filament Yarns and Steel Wire in Air at Elevated Temperatures.

Figure 4 shows the effect of temperature on the tensile strength of KEVLAR®, industrial nylon, and DACRON® polyester in dry air at 356°F (180°C). The yarns were tested at room temperature. KEVLAR® retains its tensile strength much better than either industrial nylon or polyester.

Exposure to arctic conditions (-50°F [-46°C]) does not adversely affect the tensile properties of KEVLAR® as seen in Table 3. 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. Figure 5 shows the tenacity of KEVLAR® versus time at various temperatures.

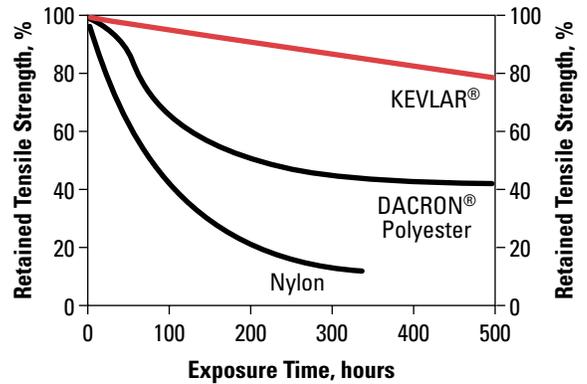
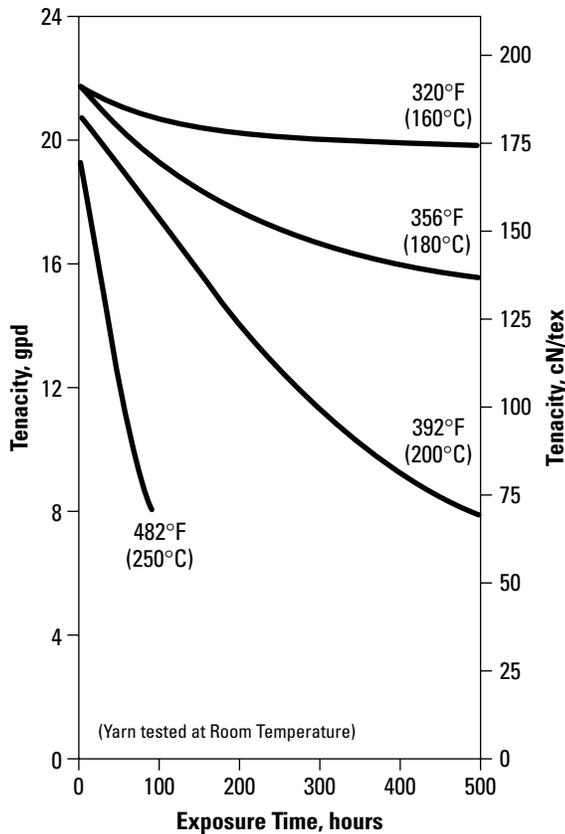


Figure 4. Effect of Temperature on Tensile Strength of Industrial Filament Yarns in Dry Air at 356°F (180°C); Yarns Test at Room Temperature

Table 3. Tensile Properties of Cords of KEVLAR® at Room and Arctic Temperatures

TEST TEMPERATURE	75°F(24°C)	-50°F(-46°C)
<b>Straight Properties</b>		
<b>Tenacity</b>		
gpd	19.1	19.8
cN/tex	169	175
<b>Modulus</b>		
gpd	425	478
cN/tex	3,753	4,221
<b>Break Elongation, %</b>	4.1	3.9
<b>Loop Properties</b>		
<b>Tenacity</b>		
gpd	8.3	7.7
cN/tex	73.3	68.0
<b>Break Elongation, %</b>	2.0	1.8

Note: 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.



**Figure 5. Tenacity of KEVLAR® vs. Time at Various Temperatures**

**Creep**

By definition, creep is the slow, continued growth or lengthening of a material under constant load. With organic fibers, this lengthening process is sometimes split into two regions. The first, somewhat abrupt change is called growth, and refers to the length change between 0 and 30 seconds. The second, much more gradual change is called creep, and lasts from 30 seconds until the end of 30 minutes. The entire 30-minute process is often referred to as creep-growth.

Table 4 compares growth and creep values of KEVLAR® with those of glass, wire, polyester, nylon, and rayon.

**Stress Rupture**

Stress rupture is the sudden failure of a material when it is held under a load less than its tensile strength. For practical purposes, stress rupture is measured under a constant load that causes the failure to take place over relatively long periods of time. The greater the load, the more quickly failure occurs. However, even the smallest load could theoretically cause stress rupture if enough time were allowed.

**Table 4. Growth and Creep Comparison**

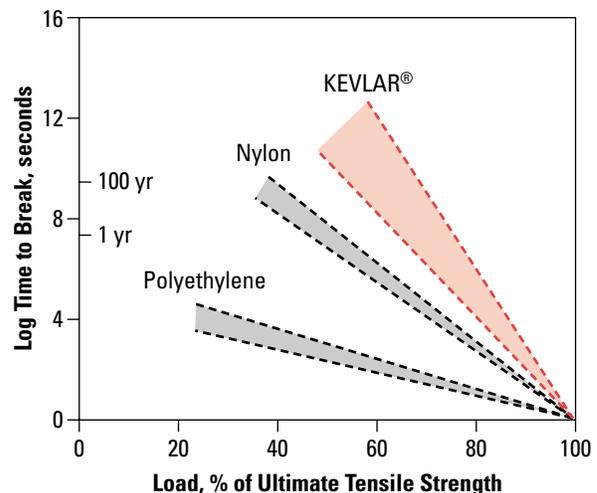
FIBER TYPE	% GROWTH	% CREEP
KEVLAR®	0.5	<0.03
Glass	0.5	<0.03
Wire	0.7	<0.03
DACRON® Polyester	2.1	0.3
Nylon	4.8	0.4
Rayon	4.9	1.4

Test Conditions:  
 1 gpd (8.83 cN/tex) load at 75°F (24°C).  
 Growth measured at 30 seconds.  
 Creep is the length change between 30 seconds and 30 minutes.

Figure 6 is a plot of log time to break versus load, expressed as a percent of the ultimate tensile strength, for KEVLAR®, nylon, and polyethylene. For KEVLAR®, loads below 50 percent of the ultimate tensile strength are of no practical importance, since stress rupture failure would only occur after more than a century.

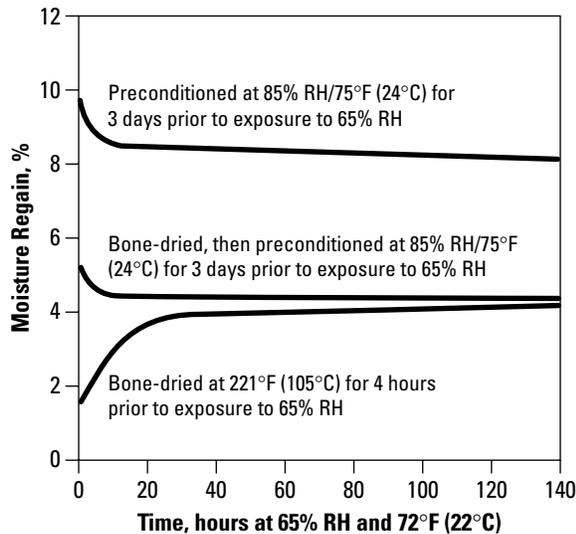
**Moisture Regain**

Moisture regain is the tendency of most organic fibers to pick up or give off ambient atmospheric moisture until they reach an equilibrium moisture content at a controlled relative humidity and temperature. It is defined as the percentage of moisture in an item brought into equilibrium with a standard atmosphere after partial drying, calculated as a percentage of the moisture-free weight (see Appendix A). The amount of moisture regain is important because the properties of most organic fibers are influenced by the fiber’s moisture content. In this respect, KEVLAR®



**Figure 6. Stress Rupture Behavior of Selected Yarns**

is unique since its tensile properties are virtually unaffected by moisture content. KEVLAR® is also unique because it reaches different equilibrium levels (depending on whether these levels are reached from a bone-dry or a wet condition). Figure 7 demonstrates this behavior.



**Figure 7. Moisture Regain of KEVLAR® Type 956 (after various preconditionings)**

### Hydrolysis and Chemical Resistance

KEVLAR® fiber is susceptible to hydrolysis whenever there is direct contact between the yarn and hot water or steam. Table 5 shows the resistance of 1500 denier (1670 dtex) KEVLAR® to hydrolysis in 280°F (138°C) saturated steam. The hydrolysis was measured in a sealed tube (bomb) test.

**Table 5. Hydrolysis Resistance of KEVLAR®**

EXPOSURE, HOURS	RETAINED STRENGTH, %
0	100
20	96
40	91
60	88
80	84

Although KEVLAR® has excellent chemical and heat resistance, some degradation will occur under extreme conditions. The effect of chemical agents on the breaking strength of KEVLAR® brand yarn is shown in Table 6.

Generally:

- Most aqueous salt solutions have no effect on KEVLAR®.
- Most organic solvents have little effect on KEVLAR®.
- Strong acids and bases attack KEVLAR® at elevated temperatures or at high concentrations.

Under extreme conditions, free radicals can attack KEVLAR®. Less than a 5 percent strength loss occurs when an RFL (resorcinol/formaldehyde and latex) dipped cord of KEVLAR® is cured in normal elastomeric compounds at standard conditions.

### Resistance to Ultraviolet Light

Similar to other polymeric materials, KEVLAR® fibers are sensitive to prolonged exposure to ultraviolet (UV) light resulting in surface degradation. Although this degradation is limited only to those filaments on the yarn surface due to the “self-screening” property of KEVLAR®, UV light exposure should be minimized during storage and handling by enclosing the KEVLAR® yarn in a light-proof bag or container.

### Testing Techniques

For INSTRON® testing of KEVLAR® yarn, twist samples to 1.1 twist multiplier, precondition for three hours at 122°F (50°C), condition for 14 hours at 75°F (24°C)/55% relative humidity, and test at 75° (24°C)/55% relative humidity. For yarns up to 1599 denier, use INSTRON Type 2714-004 (formerly 4C) air-actuated clamps; for yarns greater than 1599 denier, use INSTRON Type 2714-006 (formerly 4D) air-actuated clamps. Use a suitable clamp pressure so that the sample does not slip in the clamps or break at the grip edges. Do not exceed the specified clamp pressure for the air-actuated clamps.

The rate of extension during testing of KEVLAR® yarn should be 50 percent of the gauge length per minute.

For testing cord of KEVLAR®, use INSTRON Type 2714-010 air-actuated clamps. Use the same conditioning and rate of extension as described above for KEVLAR® yarn.

\*Instron Corporation registered trademark

Table 6. Chemical Resistance of KEVLAR® Brand Yarn

Chemical	Concentration, %	Temp., °F (°C)	Time, hrs	Effect on Breaking Strength*				
				None	Slight	Moderate	Appreciable	Degraded
<b>Acids</b>								
Acetic	40	70 (21)	1000		X			
Acetic	40	210 (99)	100				X	
Benzoic	3	210 (99)	100				X	
Chromic	10	70 (21)	1000				X	
Formic	90	70 (21)	100	X				
Formic	40	70 (21)	1000			X		
Formic	90	210 (99)	100					X
Hydrobromic	10	70 (21)	1000				X	
Hydrochloric	10	160 (71)	10					X
Hydrofluoric	10	70 (21)	100	X				
Nitric	1	70 (21)	100		X			
Nitric	10	70 (21)	100				X	
Oxalic	10	210 (99)	100				X	
Phosphoric	10	70 (21)	100	X				
Phosphoric	10	70 (21)	1000		X			
Phosphoric	10	210 (99)	100				X	
Salicylic	3	210 (99)	1000	X				
Sulfuric	10	70 (21)	100	X				
Sulfuric	70	70 (21)	100			X		
Sulfuric	10	210 (99)	10				X	
<b>Bases</b>								
Ammonium Hydroxide	28	70 (21)	1000	X				
Sodium Hydroxide	40	70 (21)	100	X				
Sodium Hydroxide	10	210 (99)	100					X
<b>Organic Solvents</b>								
Acetone	100	Boil	100	X				
Amyl Alcohol	100	70 (21)	1000	X				
Benzene	100	70 (21)	1000	X				
Carbon Tetrachloride	100	Boil	100			X		
Ethyl Ether	100	70 (21)	1000	X				
Ethyl Alcohol	100	170 (77)	100	X				
Ethylene Glycol/Water	50/50	210 (99)	1000			X		
SUVA® Centri-LP (HCFC-123)	100	70 (21)	1000	X				
Gasoline, Leaded	100	70 (21)	1000	X				
Methyl Alcohol	100	70 (21)	1000	X				
<b>Salt Solutions</b>								
Copper Sulfate	3	70 (21)	1000	X				
Copper Sulfate	3	210 (99)	100			X		
Ferric Chloride	3	210 (99)	100				X	
Sodium Chloride	3	70 (21)	1000	X				
Sodium Chloride	10	210 (99)	100	X				
Sodium Chloride	10	250 (121)	100				X	
Sodium Phosphate	5	210 (99)	100			X		
<b>Miscellaneous Chemicals</b>								
Benzaldehyde	100	70 (21)	1000	X				
Brake Fluid	100	235 (113)	100			X		
Cottonseed Oil	100	70 (21)	1000	X				
Formaldehyde in Water	10	70 (21)	1000	X				
Lard	100	70 (21)	1000	X				
Linseed Oil	100	70 (21)	1000	X				
Mineral Oil	100	210 (99)	10	X				
Phenol in Water	5	70 (21)	10	X				
Resorcinol	100	250 (121)	10	X				
Water, Tap	100	210 (99)	100	X				

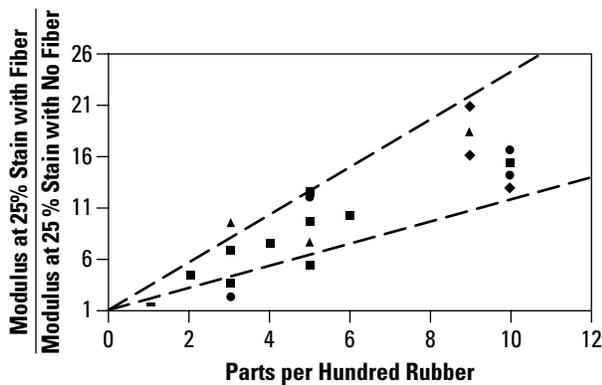
\* None 0 to 10% strength loss; Slight 11 to 20% strength loss; Moderate 21 to 40% strength loss; Appreciable 41 to 80% strength loss; Degraded 81 to 100% strength loss.

## KEVLAR® Engineered Elastomer

KEVLAR® brand engineered elastomer is an elastomeric composite of para-aramid pulp and elastomer that affords the rubber chemist opportunities to go beyond present limits in designing rubber compounds. It not only provides a vehicle for aramid pulp reinforcement of rubber compounds; but also, by its proprietary manufacturing process, maximizes the effectiveness of aramid pulp reinforcement.

As shown in **Figure 8**, engineered elastomer builds modulus at low loadings allowing compounds to be re-engineered to enhance properties and perform in new ways. It is possible to obtain very high modular anisotropy by extruding or milling a compound into a thin sheet. Compounds reinforced with engineered elastomer achieve high modulus with relatively low hysteresis. It is also highly effective in improving compound green strength.

Compounds have been engineered to improve wear and abrasion, achieve better frictional properties, improve tear, improve shear resistance, replace reinforcing fabric, reduce part thickness, or lower rolling resistance. KEVLAR® engineered elastomer enables the compounder and designer to achieve performance, properties and designs not possible in the past.



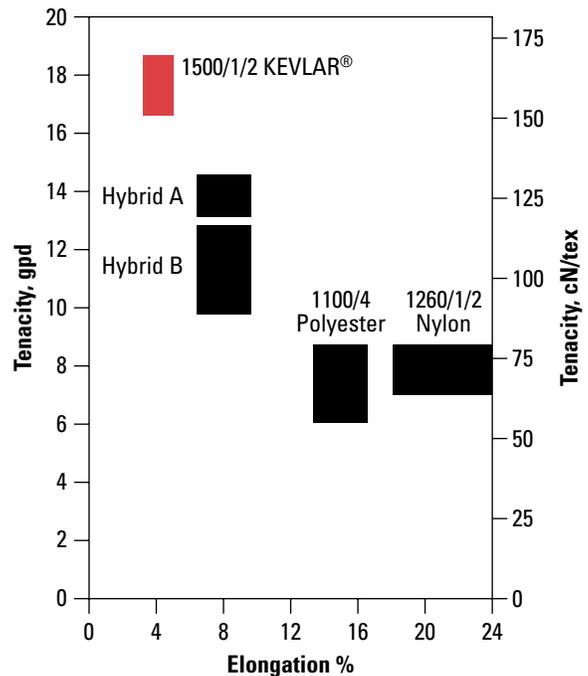
**Figure 8. Modulus Ratio at 25% Strain**

## Hybrid Cords

Hybrid cords, made by combining different yarns during the cabling step, make it possible to engineer specific cord properties. There is an almost unlimited number of hybrid cord combinations.

Compared to a cord of 100% KEVLAR®, a hybrid cord containing KEVLAR® can offer improved fatigue resistance, higher elongation, lower modulus, controlled shrinkage, and better or equivalent strength-to-cost ratio. In general, hybrid cords of KEVLAR® and nylon are preferred for best fatigue resistance and compatibility with adhesive dips. Hybrid cords of KEVLAR® and polyester have higher initial modulus and lower growth than corresponding hybrid cords with nylon and may be useful for applications where dimensional stability is critical.

**Figure 9** shows a comparison of the tenacity and elongation of two hybrid cords with conventional cords. The tenacity and elongation of the hybrid cords fall between those of the KEVLAR® and the polyester and nylon cords. Hybrid A is a three-ply cord made up of two plies of 1500 denier KEVLAR® and one ply of 1260 denier nylon. Hybrid B is constructed of two plies of 1500 denier KEVLAR® and one ply of 1600 denier polyester.



**Figure 9. Hybrid and Conventional Cords**

## Introduction

Aramid yarns require somewhat different procedures during processing than conventional manmade yarns such as nylon and polyester. This section is intended to aid those processing KEVLAR® yarns and describes operations starting with the receipt of the yarn until it is transformed into a dipped cord or fabric. It includes discussions on the storage, handling, twisting, dipping and hot-stretching, cutting and joining procedures, as well as the equipment which is recommended for processing KEVLAR® aramid yarns.

## Storage and Handling

The following are guidelines related to the storage and handling of KEVLAR® yarn.

- Upon receipt of the yarn, check the “merge” number on each carton. Different merge numbers should not be mixed as they often indicate an important product difference that could affect the customer’s operations.
- Shipping cartons with yarn should be stored in a suitable warehouse under normal climatic conditions. Extreme temperature and/or humidity levels should be avoided.
- Keep shipping cartons dry, upright and minimize handling.
- Use shipments in order received, i.e., yarn should be used on a first in, first out basis.
- Minimize handling of bobbins to prevent yarn damage and to avoid potential difficulty in processing the yarn later. Cartons should be opened 24 to 48 hours before usage to permit “conditioning” and yarn bobbins should be removed from the cartons only as needed.
- Leave each bobbin in its polyethylene bag until it is ready to be used. A partially used bobbin should be placed back in its polyethylene bag and put in the original carton to avoid merge mix-ups and prevent ultraviolet light degradation.
- Proper long-term storage of KEVLAR® yarn in closed original cartons does not affect its physical properties. Experience shows that it is possible to use the products even after seven years of storage.

## Twisting of Yarn and Cord

### Twisting Guidelines

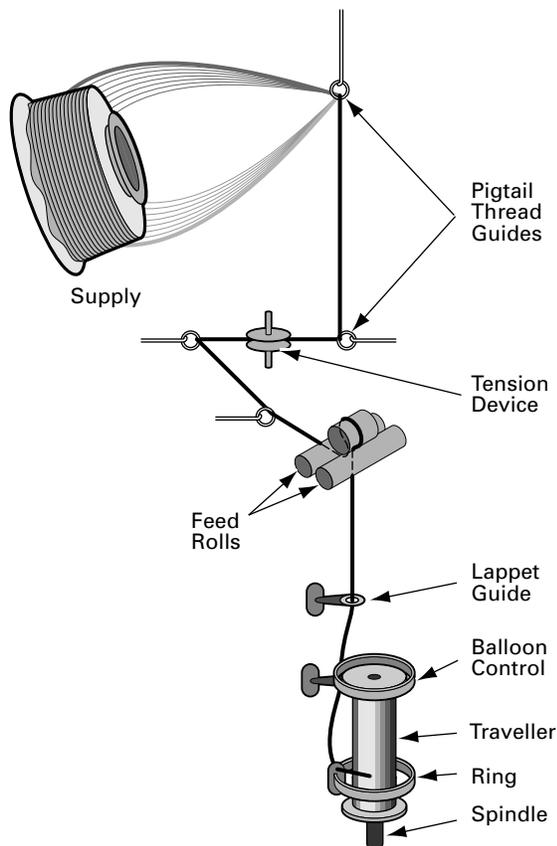
KEVLAR® yarns can be twisted successfully on standard textile equipment, provided the following recommendations are followed to ensure high-quality processing:

- Allow the yarn to condition for 24 to 48 hours before processing. As with other fibers, the preferred processing conditions for KEVLAR® are 72°–80°F (22°–27°C) and 60 to 68% relative humidity. Low relative humidity tends to dry out the yarn and increase the frictional forces. As static charges build up, the filaments separate and are susceptible to damage when contacting yarn guides.
- Rewinding should be avoided to prevent damage to the yarn. Direct feed to the twisting machine will ensure maximum conversion of fiber strength into yarn or cord strength.
- Provide good alignment between supply packages and the first guides, and maintain yarns as parallel as possible (i.e., the distance between supply package and the site of actual twisting should be the same for each yarn) for best results.
- Take special care when parallel plying two or more yarns together to ensure that equal and uniform tension is maintained.
- Various tensioning systems are available. Before adopting any particular system, users should ascertain its compatibility with the production process.
- Use as few guides as possible and minimize the change in yarn direction. Use rolling guides whenever possible to reduce friction and minimize yarn damage.
- Matte-finished chrome guides are preferred. Guides which have high wear resistance include chrome oxide coated guides or ceramic guides with an average surface roughness of 15-40 microinches (0.4-1.0 micrometers) and a maximum coefficient of friction of 0.25.
- Use a ring traveller that will provide adequate balloon control. Maintain balloon tensions between 0.10 and 0.15 grams per denier (0.88 cN/tex and 1.33 cN/tex) for ply and cable twisting.
- Inspect and change travellers frequently to minimize yarn damage.
- Maintain smooth yarn traverse and use eyelets sized to fit the yarn.

- **Figure 10** shows a typical set-up for single-end dountwisting. The feed rolls should be free of yarn overlaps and the take-up package free of ridges, trapped ends, and build-up at the flanges. Spindle speed should not exceed 6,000 rpm for rings of 4.5 inches in diameter.
- **Figure 11** shows the string-up for volumetric cabling which uses “volumetric thread guides” to achieve higher yarn strength conversion due to more uniform twist and reduced catenary. The volumetric thread guide provides for equal threadline distances between the volumetric thread guide and the lappet guide where cable-forming takes place. Its use is more critical for shorter distances between the stop motion detector and the lappet guide, because the relative length difference between the center threadline and the outside threadline is more pronounced.

### Contact Surfaces

When processing KEVLAR® yarns, the threadline on equipment should be as straight as possible to minimize fiber contact with guide surfaces and to avoid filament breaks caused by shear forces. Build-up of “fluff balls” is a typical sign of yarn damage by the guides. Contact

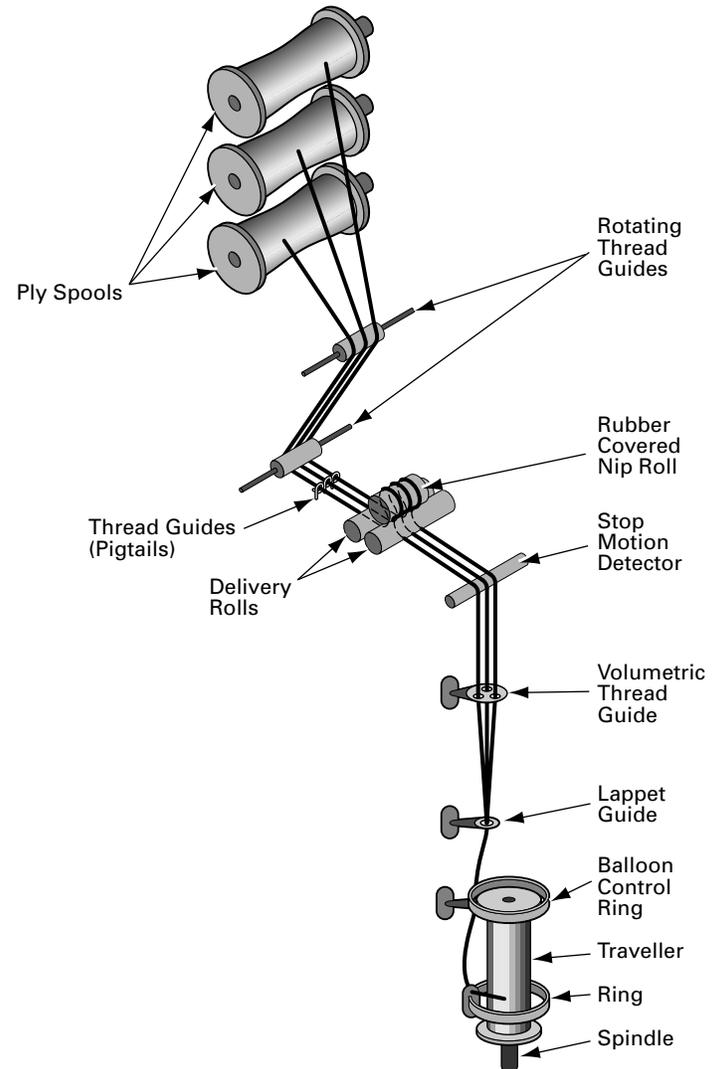


**Figure 10. Dountwisting KEVLAR® Brand Yarn**

DuPont at (800) 453-8527 for representative list of manufacturers who supply yarn guides and/or tensioners for KEVLAR® yarn.

### Creels

- Each tube holder on the creel should firmly support the KEVLAR® yarn bobbin. The tube holder should be aligned with the first guide.
- Placement of a soft pad (foam, felt, etc.) under each bobbin will prevent yarn from getting trapped under the bobbin.
- Static eliminators or passing yarn over a damp cloth or damp felt can solve static problems.
- Both yarn contact surfaces and sharp yarn angles should be minimized or eliminated where possible.



**Figure 11. String-Up for Volumetric Cabling**

## Guides

- Chrome oxide, matte finished chrome or ceramic guide surfaces which are clean and nick-free are preferred. Average surface roughness of 15–40 microinches (0.4–1.0 micrometers) and a coefficient of friction not exceeding 0.25 are preferred. *Polished chrome, steel, brass, porcelain, and glass are not recommended.*
- Rolling guides should be used where possible.
- Minimize or eliminate yarn contact surfaces where possible.
- If an entrance tube or slot is used, finishing the tube with a matte finish or lining it with a ceramic insert is suggested.
- Clean guides and contact surfaces frequently to prevent deposit buildup.

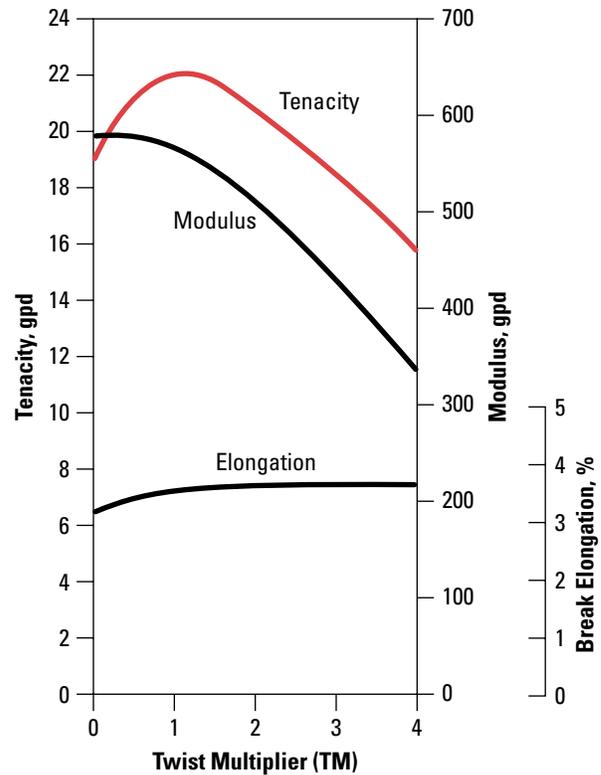
## Tensioners

- Yarn tensions must be uniform and equal on all ends (0.05 grams per denier [0.44 cN/tex] or more suggested, but 0.01 grams per denier [0.09 cN/tex] is satisfactory).
- Spring loaded tensioners, ball and cone tensioners, alligator gate tensioners, or electromagnetic brake rolls can be used to control yarn tension.
- Measure yarn tension with a tensiometer. *Never touch running yarn.*

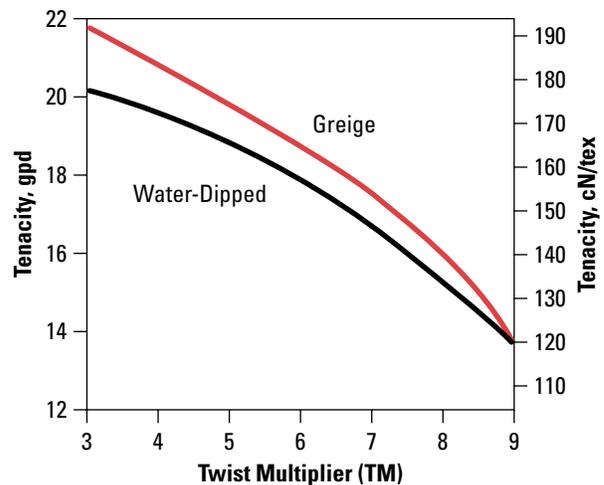
## Influence of Twist on Yarn/Cord Properties

The level of twist in a yarn or cord will affect its physical properties (tenacity, modulus, and elongation), as well as its fatigue performance. **Figure 12** shows the influence of twist on the yarn tensile properties of 1500 denier (1670 dtex) KEVLAR®. Yarn tenacity is maximized at a twist multiplier of about 1.1. Modulus declines with increasing twist level; slowly at low twist levels, and more rapidly at higher twist levels. Elongation increases slightly with increasing twist. Twist multiplier is related to the added twist (in turns per unit of yarn length) and the yarn denier (or dtex), as defined in **Appendix A**.

**Figures 13, 14, and 15** show the effect of twist on tenacity, modulus and elongation for greige and water dipped 1500 denier (1670 dtex)/1/2 cords of KEVLAR®. As can be seen, dipping has little effect on cord tenacity. Cord modulus, on the other hand, is “set” during dipping (which also involves stretching under tension) resulting in higher modulus and lower elongation. **Figure 16** shows the effect of twist “balance” on the breaking strength of a 1500 denier/1/3 cord of KEVLAR®. Note that maximum strength is obtained with an unbalanced twist, where the yarn twist level slightly exceeds the cord twist level.



**Figure 12.** Effect of Twist on Properties of 1500 Denier (1670 dtex) KEVLAR® Yarn.



**Figure 13.** Effect of Twist on Cord Tenacity (balanced twist)

Figure 14. Effect of Twist on Cord Modulus (balanced twist)

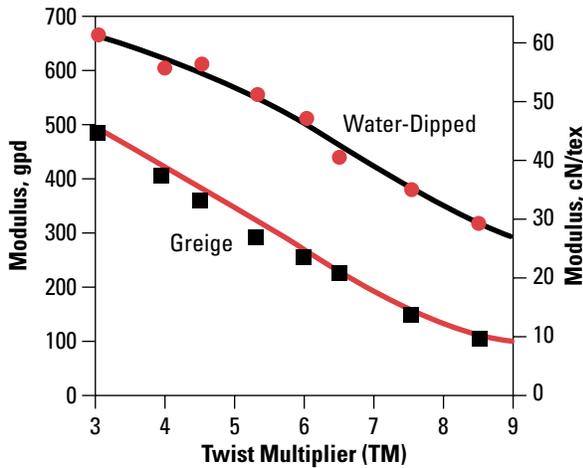


Figure 16. Effect of Twist “Balance” on Cord Break Strength

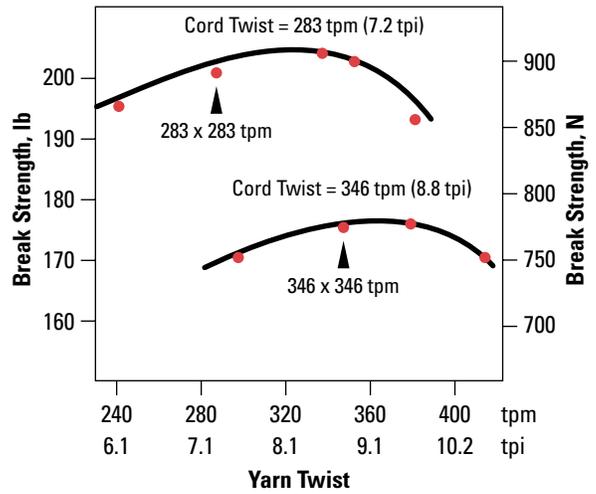


Figure 15. Effect of Twist on Cord Elongation (balanced twist)

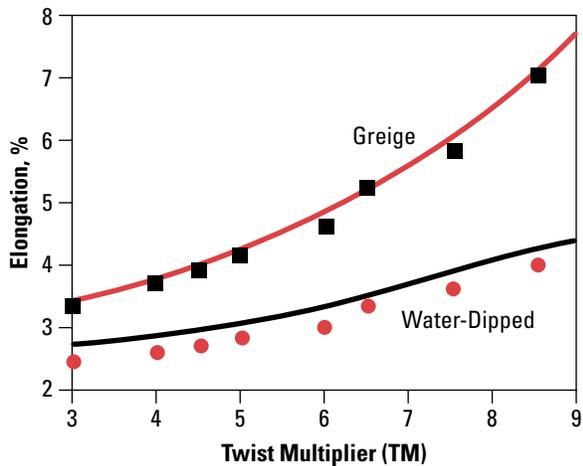
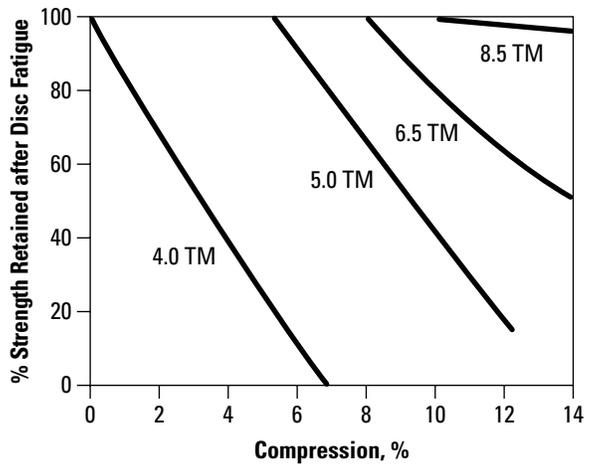


Figure 17. Effect of Compression and Twist on Fatigue Strength of Cords of KEVLAR® (balanced twist, 0% extension for 8 hrs at 2700 rpm disc speed)



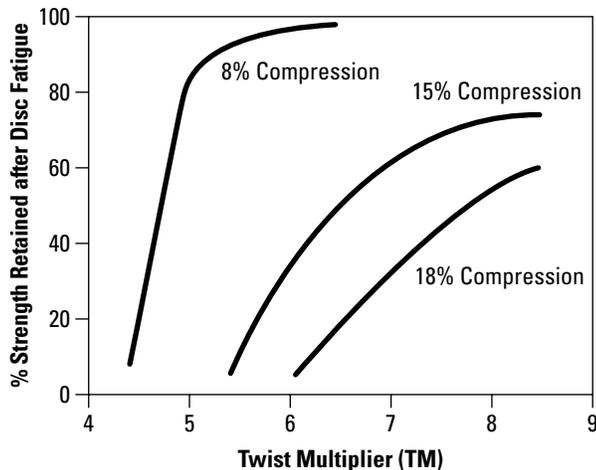
**Fatigue Resistance**

In a discussion of fatigue resistance, especially for high-modulus fibers, fatigue should be separated into three categories:

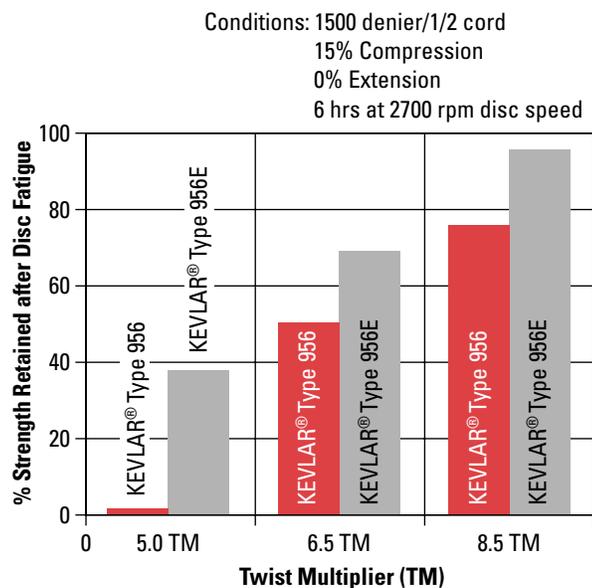
- Flex fatigue is the result of compression or compression and abrasion which occurs when a specimen is repeatedly subjected to flexing or bending over a given radius.
- Abrasion fatigue occurs when the filaments of yarn rub against each other or against a contact surface.
- Tension-tension fatigue takes place when the internal molecular/crystalline structure is subjected to a pull-pull type fatiguing motion.

Although abrasion may be present, the most damaging component in flex fatigue is compression. The fatigue performance of all cords can be improved by increasing the cord’s twist level which mitigates the effects of compressive stress by reducing buckling and compressive strain. Figures 17 and 18 show the effects of twist multiplier and compression on the fatigue performance of a 1500 denier/1/2 cord of KEVLAR®.

KEVLAR® Type 956E provides exceptional long-term service in high-fatigue applications. Figure 19 shows the higher fatigue performance of KEVLAR® Type 956E compared to KEVLAR® Type 956.



**Figure 18. Effect of Twist on Fatigue Strength of Cords of KEVLAR® (balanced twist, 0% extension for 6 hrs at 2700 rpm disc speed)**



**Figure 19. High Fatigue-Resistant KEVLAR® Type 956E**

## Adhesion and Hot-Stretching

### Introduction

In mechanical rubber goods, the role of the reinforcing member is to provide dimensional stability to the rubber/reinforcer composite. This dimensional stability is achieved by the modulus, tenacity, creep, stress decay, and shrinkage characteristics of the reinforcer. Some of these properties can be altered through the process known as “hot-stretching,” but none of these can be effectively utilized unless there is sufficient adhesion between the reinforcement and the rubber matrix.

The processes for applying and drying the adhesive and stabilizing the properties of the cord or fabric of KEVLAR® are usually combined because the equipment and the conditions needed for both dipping and hot-stretching are integrated. In developing adhesion, one has to choose the appropriate dip system and apply the proper time-temperature history to dry and activate the dip.

### Adhesion Systems

Excellent adhesion of KEVLAR® to most compounds can be obtained with a two-dip system based on an epoxy or polyaryl-polyisocyanate subcoat and a resorcinol-formaldehyde-latex topcoat. For applications requiring a stiffer reinforcement (e.g., V-belts), polyaryl-polyisocyanate subcoat in a solvent carrier is recommended. [Appendix B](#) shows a typical adhesive system (dip formulations and treating conditions) for KEVLAR® used in mechanical rubber goods. Please consult your Technical Marketing Representative for adhesive system optimization.

### Dip Hot-Stretching

Dip hot-stretching refers to the combined operation of applying a liquid adhesive dip to the item, then drying and heating (during) the dip and stretching the item in a series of ovens. The treating conditions required to prepare the cords or fabrics of KEVLAR® differ markedly because of differences in cord and fabric constructions, differences in chemistry and complexity of the adhesive system, and differences in the hot-stretching equipment. Although typical treating conditions are listed in [Appendix B](#), your Technical Marketing Representative should be consulted to optimize treating conditions for your specific application.

Dipping is achieved by passing the item through a trough or tank containing a dip which is typically an aqueous dispersion or solution. If a solvent-based dip is used, precautions must be taken to avoid contaminating the atmosphere with the solvent vapor and, in case of flammable solvents, steps must be taken to avoid ignition sources. The preferred method of multiple dipping is to perform these operations in a continuous sequence, without any interruption. Before a second dip can be applied, the first one must be thoroughly dried.

In general, hot-stretching has two purposes: to consolidate the filament bundle and to improve thermal stability. Since KEVLAR® is already thermally stable, the main reasons for dip hot-stretching are to dry and activate the dip system, and to develop equal load sharing among the numerous, very fine filaments constituting the yarn or cord bundle.

Hot stretching is performed in a series of heated chambers under carefully monitored tensions and exposures to transfer controlled amounts of heat to the yarn or textile item. It is important to point out that substantial differences exist between treating units in terms of heat transfer characteristics, location of monitoring sensors, and other equipment variables. Such differences preclude exact duplication of results between different treating units even when operated under the same nominal conditions.

A typical arrangement for dip hot-stretching of KEVLAR® is shown in Figure 20. The fabric, yarn, or cord first passes through an accumulator and tension device [a], then enters the first dip tank [b] containing the subcoat. A series of tensioning and drive rolls [c] controls its exposure and stretching tension in the first oven [d]. After the topcoat is applied in the second dip tank [e], the fabric, yarn, or cord enters the next oven(s) [f, g] where the dip is fully cured. After passing through an exit accumulator [h], the item is wound up [i]. After each dip tank, excess dip may be removed from the fabric via vacuum suctioning devices [k].

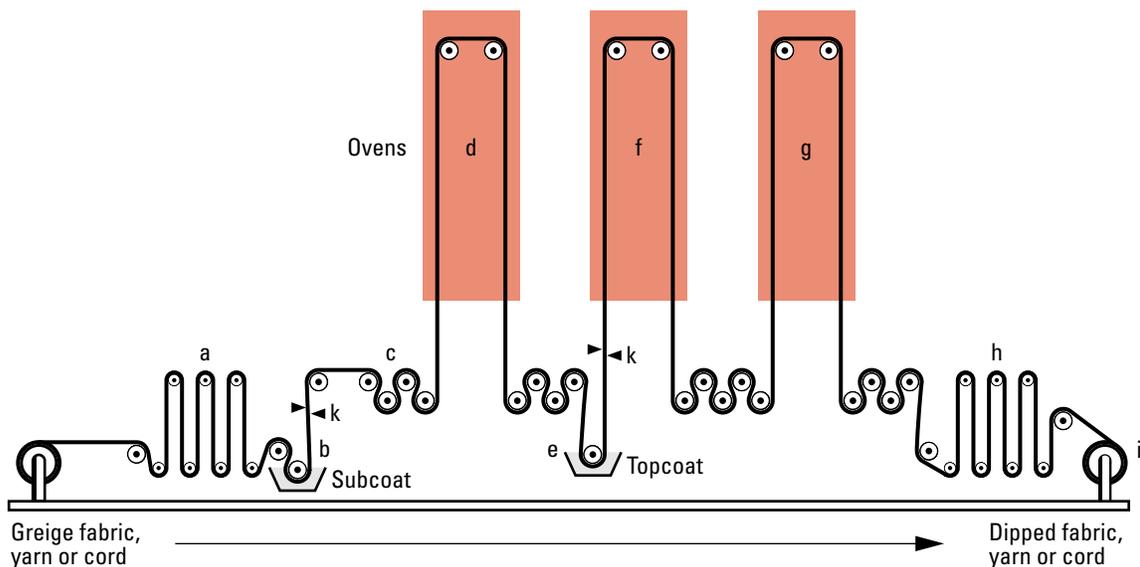


Figure 20. Typical Dip Hot-Stretching Arrangement for KEVLAR®

## Auxiliary Processing Equipment

### Cutting Yarn or Fabric Containing KEVLAR®

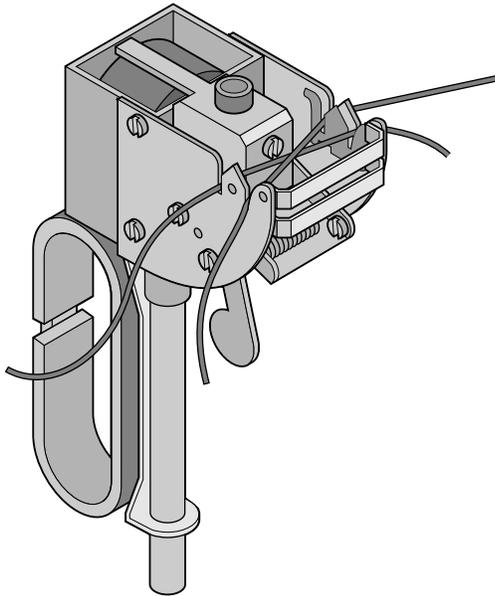
Special tools are required to cut KEVLAR® because the fiber is smooth, flexible, and inherently “tough.” Tools to be used for cutting or trimming yarns and woven or felted fabrics must be sharp, clean, and properly aligned. Specially designed shears, having a minimal clearance between cutting surfaces, are typically made of machine tool grade steel or contain a ceramic cutting edge. The cutting edges are usually serrated to hold the yarn or fabric firmly during cutting. Contact DuPont to obtain materials on the safe handling and machining of KEVLAR®.

Contact DuPont at (800) 453-8527 for a list of sources for a variety of special tools (shears and rotary cutters) developed for cutting yarns or fabrics containing KEVLAR®. Some shears are also available with a proprietary wear-resistant surface treatment which extends the useful life of the tools. Most items can be resharpened and reconditioned.

### Splicing Yarn and Cord of KEVLAR®

Short ends of yarn remaining on bobbins after the twisting operation may be recovered for other uses by splicing them together. A compressed air driven splicing tool is suggested for this purpose. A typical hand-held yard splicer is shown in Figure 21. The splicer requires 85-100 psi (586-690 kPa) unlubricated, clean (25-micron filter) air

supply because impure air will result in insufficient filament mingling. When properly used, this splicer will provide a splice with more than 90% of the yarn break strength. From experience, yarns up to 7100 denier (7890 dtex) can be spliced.



**Figure 21. Typical Air Splicer for KEVLAR® Yarn**

Cords of KEVLAR® may also be spliced. Cords have typical splice strengths of 50-70% of the constituting cord. Contact DuPont to obtain a list of sources for yarn splicing equipment.

### **Equipment for Manufacturing Mechanical Rubber Goods**

The most common end uses for KEVLAR® yarn and cord in mechanical rubber goods are power transmission belts, timing belts, conveyor belts and low- and high-pressure hoses. For power transmission and timing belts, the reinforcing fiber is drum wound from a single supply package. For conveyor belts, a fabric is woven from yarn or cord which is either supplied on a warp beam or from a creel. Hoses can be one of five construction types: braided, spiral-wound, wrapped, knitted, or loom (circular woven). Braided and knitted hose constructions require special machinery because of the multitude of sharp turns and rubbing surfaces which the KEVLAR® yarn encounters in the manufacturing process. Contact DuPont at (800) 453-8527 for a list of hose braiding and knitting equipment.

### **Health Hazard Information**

As shipped, KEVLAR® brand fiber products do not pose a hazard. KEVLAR® staple and pulp contain a small amount of respirable fibers which may become airborne during opening, mixing, carding, or regrinding waste products containing KEVLAR®. When mechanically working KEVLAR® fiber or materials containing KEVLAR® in operations such as cutting, machining, grinding, crushing or sanding, airborne respirable fibers may be formed. Repeated and prolonged inhalation of excessive concentration of respirable fibers may cause permanent lung injury.

Avoid breathing fibers or dust. Follow good industrial hygiene practices for ventilation and cleanup. In particular, avoid the use of air jets to blow off equipment; instead, use vacuum cleaners with high-efficiency particulate air (HEPA) filters.

A detailed presentation of toxicology and safety information is available in the Material Safety Data Sheet for KEVLAR® aramid fiber. Key results of workplace air monitoring and animal and human toxicity testing show that KEVLAR® presents no significant health risk to processors of the fiber or products containing it when proper precautions are observed.

DuPont is committed to assisting its customers in the use of DuPont products in a safe and environmentally sound manner through our “Responsible Care®” Product Stewardship Program. For help with safety, health and environmental concerns relating to KEVLAR®, call the KEVLAR® Product Steward at 1-800-453-8527.

### **Additional Information**

Additional information describing KEVLAR®, NOMEX®, and other DuPont industrial filament yarns is available from DuPont and listed in [Appendix C](#). Please contact your DuPont Sales Representative or call one of our Applications Specialists at 1-800-453-8527 for more information.

**Definitions and Conversion Factors****Break Strength**

$$1 \text{ lbf} = 4.448 \text{ N} = 0.4536 \text{ kgf}$$

$$1 \text{ N} = 0.2248 \text{ lbf} = 0.102 \text{ kgf}$$

**Density**

$$1 \text{ g/cc} = 10^3 \text{ kg/m}^3 = 62.43 \text{ lb/ft}^3 = 0.03613 \text{ lb/in}^3$$

**Length**

$$1 \text{ m} = 39.37 \text{ inches}$$

$$1 \text{ inch} = 25.4 \text{ mm}$$

**Linear Density or Yarn “Fineness”**

$$1 \text{ denier} = 0.1111 \text{ tex} = 1.1111 \text{ dtex}$$

$$1 \text{ dtex} = 0.9 \text{ denier}$$

**Mass**

$$1 \text{ lb} = 0.4536 \text{ kg}$$

$$1 \text{ kg} = 2.205 \text{ lbs}$$

**Temperature**

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32^{\circ})/1.8$$

$$^{\circ}\text{F} = (^{\circ}\text{C} \times 1.8) + 32^{\circ}$$

**Twist**

$$1 \text{ turn/meter (tpm)} = 0.0254 \text{ turns/inch (tpi)}$$

$$1 \text{ turn/inch (tpi)} = 39.37 \text{ turns/meter (tpm)}$$

**Twist Multiplier**

$$\text{Twist Multiplier} = \frac{\text{Turns Per Inch} \sqrt{\text{Denier}}}{73}$$

$$= \frac{\text{Turns Per Meter} \sqrt{\text{dtex}}}{3000}$$

$$= \frac{\text{Turns Per Meter} \sqrt{\text{Tex}}}{957}$$

$$= \frac{\text{Turns Per Meter} \sqrt{\text{Denier}}}{2874}$$

**Moisture**

$$\text{Moisture Content (\%)} = \left( \frac{\text{Original Weight} - \text{Dry Weight}}{\text{Original Weight}} \right) \times 100$$

$$\text{Moisture Regain (\%)} = \left( \frac{\text{Original Weight} - \text{Dry Weight}}{\text{Dry Weight}} \right) \times 100$$

**Tenacity, Tensile Strength, Modulus, and Stress**

Tenacity = Break strength per unit linear density

Tensile Strength = Break strength per initial cross-sectioned area

Modulus = Ratio of change in stress to change in strain

Stress = Load divided by initial cross-sectional area or linear density

$$1 \text{ gram/denier (gpd)} = 8.826 \text{ cN/tex}$$

$$1 \text{ lbf/in}^2 \text{ (psi)} = 6895 \text{ Pa (pascal)}$$

$$= 7.031 \cdot 10^{-2} \text{ kgf/cm}^2$$

$$1 \text{ psi} = 6.895 \cdot 10^{-3} \text{ N/mm}^2 = 6.895 \text{ kPa}$$

**For:**

KEVLAR®	1 gpd = 1.843 · 10 <sup>4</sup> psi
Steel	1 gpd = 10.071 · 10 <sup>4</sup> psi
Nylon	1 gpd = 1.461 · 10 <sup>4</sup> psi
Polyester and NOMEX®	1 gpd = 1.768 · 10 <sup>4</sup> psi
Rayon	1 gpd = 1.948 · 10 <sup>4</sup> psi
High-strength polyethylene	1 gpd = 1.230 · 10 <sup>4</sup> psi
S-glass	1 gpd = 3.178 · 10 <sup>4</sup> psi
E-glass	1 gpd = 3.255 · 10 <sup>4</sup> psi

**For KEVLAR® only:**

$$1 \text{ gpd} = 12.96 \text{ kgf/mm}^2 = 12.96 \cdot 10^6 \text{ kgf/m}^2$$

$$1 \text{ g/tex} = 1.44 \text{ kgf/mm}^2 = 1.44 \cdot 10^6 \text{ kgf/m}^2$$

$$1 \text{ kgf/mm}^2 = 0.07716 \text{ gpd} = 0.6944 \text{ g/tex}$$

**Viscosity**

$$1 \text{ centipoise} = 10^{-3} \text{ Pa}\cdot\text{s (pascal second)}$$

$$1 \text{ centistokes} = 10^{-6} \text{ m}^2/\text{s}$$

Note: For a more complete list of conversion factors, please consult ASTM E 380-91a titled “Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System).”

## Treating Conditions

Oven Conditions	Oven 1	Oven 2
Dip Applied	Subcoat	Topcoat
Oven Temperature, °F (°C)	470 (243)	450 (232)
Residence Time, seconds	60	60
Oven Exit Tension, gpd (cN/tex)	1.0 (8.8)	0.3 (2.6)

## Subcoat Composition and Mixing Procedures (2.29% solids)

Ingredients	Parts by Weight
Water (soft, 75°–78°F)	9.685
Sodium Carbonate (catalyst, 10% solution)	0.037
“Aerosol” OT (wetting agent, 5% solution)	0.056
Glycidyl Glyceryl Ether (“NER 010A” epoxy resin)	0.222
<b>TOTAL</b>	<b>10.000</b>

American Cyanamid Company supplies “Aerosol”

Nagase America Corporation supplies “NER 010A”

## Mixing Procedure

1. Mix the portions of water, 10% sodium carbonate, and 5% “Aerosol” OT together until thoroughly blended.
2. Slowly pour the epoxy resin into the water-sodium carbonate-“Aerosol” solution while stirring at moderate speed. **NOTE: DO NOT REVERSE THIS ADDITION**; the epoxy resin must be added to the water-sodium carbonate-“Aerosol” solution!
3. Age the total solution with low speed stirring for 15 minutes at room temperature prior to use.
4. The shelf life is 12 hours after the 15-minute ageing period. A pH of 9.5 to 10 is normal.
5. Stir slowly for 15 minutes before each use.

Note: The above treating conditions and subcoat formulation and mixing procedures should result in adequate yarn-to-elastomer adhesion (when coupled with the topcoat) in most mechanical rubber goods applications. To optimize adhesion for your specific application, please consult your Technical Marketing Representative.

## Topcoat Composition and Mixing Procedures (26.1% solids)

Phase	Ingredients	Parts by Weight
I	Water (soft, 75°–78°F)	9.317
	Ammonium Hydroxide (28% solution)	0.403
	Preformed RF Resin (75% active ingredients)	1.453
		11.173
II	Vinyl Pyridine Butadiene-Styrene Latex (41% emulsion)	16.123
III	Formaldehyde (37% solution)	0.726
	Water (soft, 75°–78°F)	3.396
		4.122
IV	“Heveamul” M-111B Wax Dispersion (45% solid/40% active)	0.788
V	HAF Carbon Black Dispersion (25% slurry)	3.984
<b>TOTAL</b>		<b>36.190</b>

Heveatex Corporation supplies “Heveamul” M-111B

1. Weigh out the soft water into a stainless steel or plastic container.
2. Add the ammonium hydroxide to the preweighed water and stir until blending is complete. While stirring the ammonium hydroxide-water solution, slowly add the preformed RF resin and wait until the resin is completely dissolved (Phase I).
3. Weigh out the vinyl pyridine butadiene-styrene latex in a stainless steel or plastic container in which the final dip will be stored (Phase II).
4. Weigh out the formaldehyde and add it to the remaining water needed to make up the batch of dip (Phase III).
5. Immediately after the preformed RF resin is dissolved into the ammonium hydroxide-water solution, add the solution (Phase I) to the vinyl pyridine butadiene-styrene latex (Phase II), and blend them together. Then immediately add the water-formaldehyde solution (Phase III).
6. Age the mixture for 12 hours at 70° to 72°F (temperature is critical and must be controlled during aging). This mixture is the base dip and can be stored in a temperature controlled tank at 52° to 58°F for up to 5 days.
7. The final dip is made by adding and mixing the required amounts of the wax and carbon black dispersions (Phase IV and Phase V), in that order, to the base dip. The dip must be made up fresh every 8 hours for continuous dipping operations.

Note: The above topcoat formulation and mixing procedures should result in adequate yarn-to-elastomer adhesion (when coupled with the subcoat at the recommended treating conditions) in most mechanical rubber goods applications. To optimize adhesion for your specific application, please consult your Technical Marketing Representative.

## **Bulletins**

Technical Guide for KEVLAR® Brand Fiber

KEVLAR® Fiber Products – Material Safety Data Sheet

Technical Guide for NOMEX® Brand Fiber

## **Source Lists**

Suppliers of Yarn Guides and Tensioners

Manufacturers of Tools for Cutting Yarns or Fabrics Containing KEVLAR®

Converters of KEVLAR® Brand Yarn

Manufacturers of Hoses Reinforced with KEVLAR® Brand Fiber

Manufacturers of Power Transmission Belts Reinforced with KEVLAR® Aramid

Manufacturers of Conveyor Belts Reinforced with KEVLAR® Aramid

Manufacturers of Thermoplastic Hoses Reinforced with KEVLAR® Aramid

Suppliers of Twisted and Treated Yarns/Cords of KEVLAR® and NOMEX® Aramid

Commercial Weavers of Fabrics of KEVLAR® Brand Fiber

Coaters and Laminators for Fabrics of KEVLAR® Brand Fiber

Note: The products presented in this bulletin are commercial products. Other products of KEVLAR®, with end-use tailored properties, are continuously being developed by DuPont. Please contact your DuPont Sales Representative or call one of our Applications Specialists at 1-800-453-8527 for more information.

**United States and South America:**

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](mailto:afscdt@usa.dupont.com)

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Fax: ++ 41-22-717 60 21

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Australia  
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(905) 821-5193  
Fax: (905) 821-5177  
E-Mail: [products@can.dupont.com](mailto:products@can.dupont.com)

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Chuo-ku, Tokyo 103  
Japan  
Tel: 81-3-3245-5080  
Fax: 81-3-3242-3183

**Web Address: [www.kevlar.com](http://www.kevlar.com)**

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