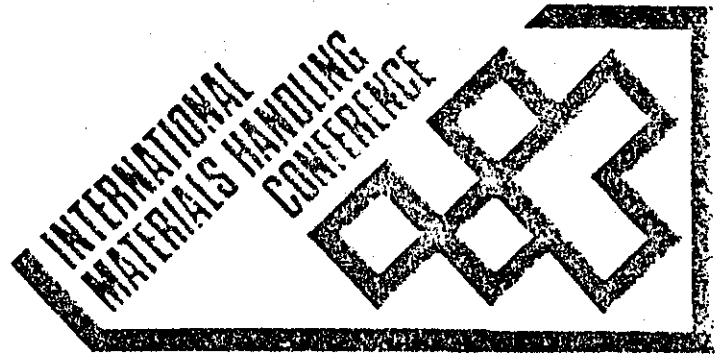


The Organising Committee
International Materials Handling
Conference
P O Box 95194
Grantpark
Johannesburg
2051
SOUTH AFRICA

Telephone (011) 728-4562

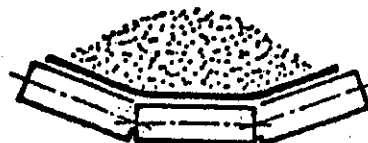


KEVLAR ARAMID FIBRE PERFORMANCE
IN CONVEYOR BELTS

B PULVERMACHER
DUPONT DE NEMOURS INTERNATIONAL SA
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BELTCON 2



BELT CONVEYORS - DESIGN, OPERATION AND OPTIMIZATION

KEVLAR* ARAMID,
A NEW FIBRE REINFORCEMENT
FOR CONVEYOR BELTING

B. Pulvermacher
Du Pont de Nemours International SA, Geneva, Switzerland

ABSTRACT

The high tenacity and modulus, and the low elongation and creep of "Kevlar" high strength aramid fibres paired with non-corrosion and excellent thermal and chemical resistance provide the rubber industry with a new reinforcement for high performance conveyor belting.

The development of aramid fibres is reviewed. Pertinent properties and characteristics of "Kevlar" are then compared with those of traditional reinforcing materials. European trade experience and advantages of aramid reinforced belting over steel cable and conventional textile fibre reinforced belting are summarized.

* Du Pont's registered trademark

INTRODUCTION

The development of the fiber reinforcement in belting has progressed from cotton to rayon and then to the organic fibres polyester and polyamide and to steel cords and cables. The organic fibres contribute high rot-resistance together with higher achievable strength ratings to beltings. The use of steel cords and cables extends the tensile strength range of the beltings even further, contributing to greater belt length and lift, lower elongation-in-use and minimum growth. Negatives of steel cord reinforced belting are corrosion propensity, risk of longitudinal slitting and high weight.

In what follows we present information on a new fibre reinforcement for conveyor belting which combines the high tenacity and modulus, and the low elongation and creep properties associated normally with steel cords with the low density, non-corrosion and wear characteristics of organic fibres.

The presentation is structured as follows: First we review the development of this class of fibres, the aromatic polyamides, today referred to generically as aramids. This material is included to provide a better understanding of the unique properties of these fibres.

In the second part of this presentation, properties, characteristics and conversion techniques associated with aramid as reinforcement in conveyor belting are compared with those of conventional reinforcing materials. Finally, the advantages of aramid reinforced belting over steel and textile reinforced belting as well as European trade experiences are reviewed.

DEVELOPMENT AND MOLECULAR STRUCTURE OF ARAMID FIBRES

The development of high tenacity aramid fibres dates back to the mid 60's. The state of the art at that time was exemplified by established polymers such as nylon and polyester. It was generally recognized that in order to achieve maximum tenacity and modulus, the polymer molecules must exist in extended chain formation and have nearly perfect crystalline packing. With flexible chain polymers such as nylon or polyester, this is accomplished by drawing the fibre after spinning. Since this requires chain disentanglement and orientation in the solid phase, achievable levels of tenacity and modulus are far from the theoretical possible values.

A novel approach providing almost perfect polymer chain extension, was discovered by Du Pont in 1965 in studies with poly-p-benzamide. It was shown that this polymer can form liquid crystalline solutions (1-3).

Low molecular weight compounds capable of forming liquid crystalline phases have been known for years. In the liquid crystalline state,

these compounds have the structure of solids. They exhibit birefringence and have molecular order, but at the same time these materials have the flow characteristics of fluids. This liquid crystalline behaviour has been extended to many high molecular weight polyamides as shown in Table I. The common feature of all these polymers is a structure which is inherently rigid and capable of high crystalline order. The key structure requirement is the para-orientation, forming a rod-like molecular structure.

Consider what happens when rod-like polymer molecules as opposed to flexible chain molecules are dissolved (Fig. 1). As the concentration increases, the rods begin to associate in parallel alignment. Randomly oriented domains of internally highly oriented polymer chains then develop. With flexible chain polymers, on the other hand, a random coil configuration is obtained in solution. An increase in polymer concentration cannot force a higher degree of order.

The unique aspect of liquid crystalline polymer solutions that can provide a new dimension in fibre processing, is their behavior under shear. The random domains become fully oriented in the direction of shear. This happens as these solutions enter a spinneret and emerge with almost perfect molecular orientation (Fig. 2). The supra-molecular 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 of achieving very high orientation of polymer molecules.

Through optimization of the critical polymer and solvent parameters entirely anisotropic solutions were obtained which, in turn, led to very strong fibres. High strength "Kevlar" fibres, with the selected substrate of poly-p-phenylene terephthalamide, were commercialized by Du Pont in 1972 through this technology.

PROPERTIES OF ARAMID FIBRES

After this background on the development and the molecular structure of aramids, let us review and compare their unique combination of properties with those of the conventional reinforcements used in conveyor belting. In our discussion we will concentrate on the aramid fibre specifically designed for the rubber industry and called "Kevlar". Two other high tenacity aramid fibres based on poly-p-phenylene terephthalamide have been developed by Du Pont: "Kevlar" 29 is used in speciality products such as ropes, cables, coated fabrics, ballistics and protective clothing. "Kevlar" 49 is the high modulus form of this aramid. It is finding increased use in aerospace and marine applications in fibre reinforced composites to replace metal or fiberglass reinforced structures at lower weight.

MECHANICAL PROPERTIES

Typical mechanical properties of the aramid fibre used in belting are shown in Table II and are compared to other organic fibres and steel wire. The aramid fibre has the highest strength to weight ratio, i.e. 2 to 3 times higher than other organic fibres and 5 times higher than steel. The elongation to break is 4%. The creep rates for "Kevlar" are low relative to nylon and polyester and only slightly higher than those of steel (Fig. 3). Extrapolation of stress rupture tests (life time under dead weight load) demonstrates that yarns and cables of "Kevlar" will support a load of half their breaking strength for long periods of time. Although an organic fibre, its high strength and modulus, its low elongation and creep position the aramid fibre alongside steel.

While the fibre has very high tensile properties, its compressional strength is moderate (about 18% of the tensile strength). However, selection of appropriate yarn, cord and fabric geometry for the amount of compression to be encountered in actual use provides the needed fatigue resistance.

THERMAL PROPERTIES

Fig. 4 gives the effect of elevated temperature ageing on the tensile strength of "Kevlar". The fibre also performs well at low temperatures and maintains its properties to well below -40 degrees C.

"Kevlar" is thus essentially unaffected by long term exposure to temperatures in the -40 degrees C to +130 degrees C range, covering the working temperature and ambient temperature range experienced in most belting applications.

CHEMICAL RESISTANCE

The basic chemical structure of the fibre, which is responsible for its good thermal stability, also provides very good resistance to a wide range of chemicals, common solvents, oils and most ingredients used in rubber compounds. Generally it requires long exposure to relatively concentrated acids and bases to affect the tensile strength significantly (Table III).

FATIGUE RESISTANCE

The tension-tension fatigue performance of this aramid is compared in Fig. 5 with that of nylon and steel wire. Both "Kevlar" and nylon have excellent fatigue resistance, superior to that of steel.

In fibre fatigue tests which involve compressive fatigue, the intrinsic flex resistance of aramid fibres appears to be less than that of nylon and polyester. However, proper choice of twist in yarn and in plied cord structure as well as changes in reinforcement design can supply fully acceptable flex resistance.

CONVERSION OF ARAMID YARN INTO CONVEYOR BELT FABRICS

Before "Kevlar" aramid yarn is calendered into rubber or PVC to form the conveyor belt carcass, the yarn must be twisted for optimum balance of strength and fatigue resistance, woven into a fabric and treated to develop adhesion to rubber. Processing can be done on conventional textile equipment. Special considerations, however, are advisable. Recommendations on optimum twisting, weaving and dipping have been worked out and are available through our technical library.

CARCASS CONSTRUCTIONS FOR CONVEYOR BELTS REINFORCED WITH "KEVLAR"

Three different carcass types have been successfully developed for high strength belting reinforced with "Kevlar": cord, straight-warp and solid woven constructions. Conventional woven fabric constructions have found their place in lower strength, speciality belting. A fifth construction, based on ready-for-rubber cables (ropes) of "Kevlar" to replace steel cables is under evaluation for ultra high tension belting. Choice of the carcass type depends on the end-use requirements such as strength, elongation-in-use, type of cover and use of metal fasteners.

Full data is available from the individual converters and conveyor belt manufacturers. Some of the major results may be summarized as follows:

Cord construction: The aramid cord as the strength member of the warp lies straight within the construction, resulting in high strength efficiency combined with low elongation in use (< 0.5%). Breaking strength of up to 2000 N/mm is achievable with a single warp. As weak filling yarns are used, the conveyor belts require breakers for transversal impact resistance in most applications.

This carcass type is used in rubberized belting. Joining of the belts is generally done using a V-butt splice. For low strength belting an overlap splice is sometimes used. Mechanical fasteners have been used only for emergency repairs.

Straight-warp construction: High strength efficiency with low elongation in use (< 0.5%) are also characteristic of this construction. Breaking strength of up to 3150 N/mm is achievable with a double warp. Transversal impact resistance is provided through the straight warp construction. Use of breakers is thus not required, except for the splicing section. Joining of the belt is done as for the cord construction.

Solid woven construction: Within the monople solid woven carcass, the reinforcing fibre goes through crimp. This results in higher elongation in use (~ 1.0%). Due to the compact monople structure, belts with up to 4000 N/mm breaking strength are possible. The monople structure provides high impact absorption and good resistance to tearing and to spreading of tear. Solid woven belts can thus be joined by metal fasteners and by standard splicing techniques. The cover is selected according to the conditions of use and may be PVC or rubber (PVG).

Ready-for-rubber cables of "Kevlar": Ready-for-rubber cables of "Kevlar" are dipped structures and are currently being evaluated as conveyor belt reinforcement in ultra high tension belting of up to 5400 N/mm breaking strength. Ready-for-rubber cables range in size from 2 to 14 mm and in strength from 4 kN to 140 kN. High strength efficiency combined with low elongation in use (< 0.5%), as well as built-in adhesion to rubber, allow a direct replacement of steel cables within the steel belt manufacturing process.

ADVANTAGES OF "KEVLAR" OVER STEEL REINFORCEMENT

As a result of the aramid's unique combination of tensile and material properties and its processability on conventional textile equipment, "Kevlar" is increasingly used as reinforcement in conveyor belting. Let us describe now the fibre's main advantages in belting. We will start with a comparison to steel reinforcement.

o Non-corrosion

Aramid fibres do not corrode. The thickness of the rubber cover, top and bottom, can thus be reduced to a minimum, compatible with adequate wear since there is no risk of corrosion. This results in weight and energy savings.

Repairs due to cuts in top and bottom rubber cover are easier since the extent of damage is limited to the cut area. Repairs can be made when it is convenient, rather when the damage is observed, as no risk of further corrosion exists. This results in fewer production stops, lower maintenance cost and potentially in longer life.

o Five times lower weight of "Kevlar" aramid versus steel at equal strength

The high strength to weight ratio of "Kevlar" fibres translates into further weight savings. Depending on the installation 20 to 43% weight savings over steel reinforced belts are reported. In Table IV a straight-warp belt reinforced with "Kevlar" (2000 N/mm strength rating) is compared to a steel reinforced belt it replaced. The difference in weight is 16 kg per square meter or 42%. For a 2000 m interaxis installation, a 1.4 m wide aramid reinforced belt would be about 90 tons lighter than the corresponding steel cord reinforced belt.

In addition to easier handling, the lower weight translates into reduced energy consumption for existing installations. For new installations it allows the engineers to build lighter and cheaper conveying systems.

o Reduced belt thickness and lower belt weight

The lower weight and reduced belt thickness translate into longer belt sections. Less splices will be needed for a given length installation. The splice being the weakest link within a belt, overall safety increases. Fewer splices, furthermore, lower the installation cost.

Reduced belt thickness and the flexibility of the reinforcing carcass increase the troughing propensity of the belts.

o Extreme non-flammability

The high decomposition temperature of this aramid (> 425 degrees C), its low thermal conductivity and non-sparking when exposed cords hit metal pulleys, make the belt carcass inherently flame-resistant. Belts covered on both sides with flame-resistant polychloroprene rubber or PVC have successfully passed the flammability tests of the leading mining authorities in Germany and are certified as suitable for use in coal mines and surface mines. In 1981 20 belts reinforced with "Kevlar" aramid from 5 different belt suppliers were, for example, approved for use in German coal mines (4).

ADVANTAGES OF "KEVLAR" ARAMID OVER CONVENTIONAL TEXTILE REINFORCEMENT

o Higher strength

In the belt strength classes 2000 N/mm and below, the high specific strength of "Kevlar" allows a single ply cord or straight-warp construction. This results in thinner and lower weight belts versus conventional multiply polyester/nylon reinforced belts. Thinner belts allow increased section belt lengths, which, in turn, reduce number of splices, improving overall safety and reducing installation cost.

Lower belt weight, furthermore, translates into easier handling and reduced energy consumption.

The high specific strength of the aramid allows one to move to stronger belts. Solid woven conveyor belts reinforced with "Kevlar" aramid, for example, range up to T-4000 (4000 N/mm) while the limit for polyester reinforced belts is T-2000 (2000 N/mm).

o Lower elongation and lower growth

The lower elongation and higher strength of "Kevlar" allow longer distance belts. Elongation-in-use of less than 0.5% for straight-

warp and cord constructions and less than 1.0% for solid woven constructions can be achieved, thus reducing the number of mechanical installations. Lower growth than polyester or nylon minimises and in some cases eliminates resetting the belts.

o Improved safety

Improved safety is derived from three areas: the inherently flame resistant carcass reduces fire propagation and improves performance in the flammability tests of the leading mining authorities (e.g. Gallery test of Tremonia, Germany). "Kevlar" aramid passes the filter test, because the decomposition products are not detrimental to the efficiency of the oxygen mask. Finally, the better impact resistance of the aramid reinforced carcass versus an E/P carcass reduces the chance for accidental failures.

TRADE EXPERIENCE

European conveyor belt manufacturers have developed products reinforced with "Kevlar". Belts have successfully passed non-flammability and durability tests. More than 40,000 meters of belts with a carcass of "Kevlar" aramid are now in operation. Table V gives a summary of the installations by year, by length and by strength range. The table indicates that between 1978 and 1981 the total length installed was in the range of 6000 to 8000 m per year. This was the time when the leading mines in Europe extensively tested the new belts to see if the technical advantages, as described above translated into reduced cost at the mining level. Since 1982 we are witnessing a substantial increase in installations.

The belt strength range has increased with experience gained and is now covering the 1250 to 4000 N/mm range, previously mainly served by steel reinforced belts.

Some of the belts have now been operating for up to seven years with excellent reliability. To round-off this picture the experiences of the conveyor belt manufacturers using "Kevlar" aramid reinforcement will be presented in a separate paper.

CONCLUSION

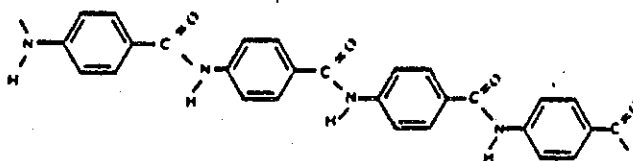
"Kevlar" high strength aramid fibres occupy a unique position in the textile fibre spectrum. They possess high tenacity and modulus, thermal stability and low elongation and creep normally associated with inorganic fibres while retaining the low density, non-corrosion and processability of organic fibres. Therefore, conveyor belt manufacturers can now produce belts which meet the increasingly severe requirements of the trade, such as improved safety, reliability and increased productivity through reduced maintenance and repairs.

REFERENCES

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3. S.L. Kwolek, P.W. Morgan, J.R. Schaeffgen, and L.W. Gulrich, Macromolecules, 10, 1930 - 1936 (1977).
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Liquid crystallinity in aromatic polyamide solutions

Key to solution structure is rod-like nature of para-oriented aromatic polyamide molecules.



Random rods in dilute solution
(contrast random coils with flexible molecules).

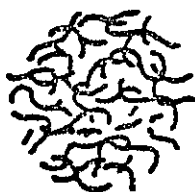
Above a certain critical concentration rod-like molecules become parallel packed in domains, which are randomly oriented with respect to one another.



Random rods



Randomly oriented domains
(Liquid crystalline)



Random coils



Random coils
(Higher concentration)

FIGURE 1

Effect of shear on liquid crystal solutions

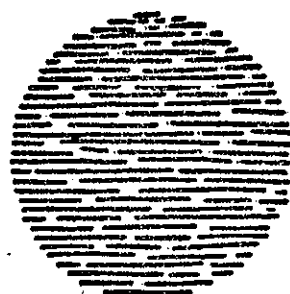
- Stir – opalescence
- Alignment of domains in spinning



Randomly oriented domains



Partially oriented
e.g., within spinneret



Fully oriented
e.g., as-spun fibres

- Novel way to orient polymer molecules
- Very slow relaxation

FIGURE 2

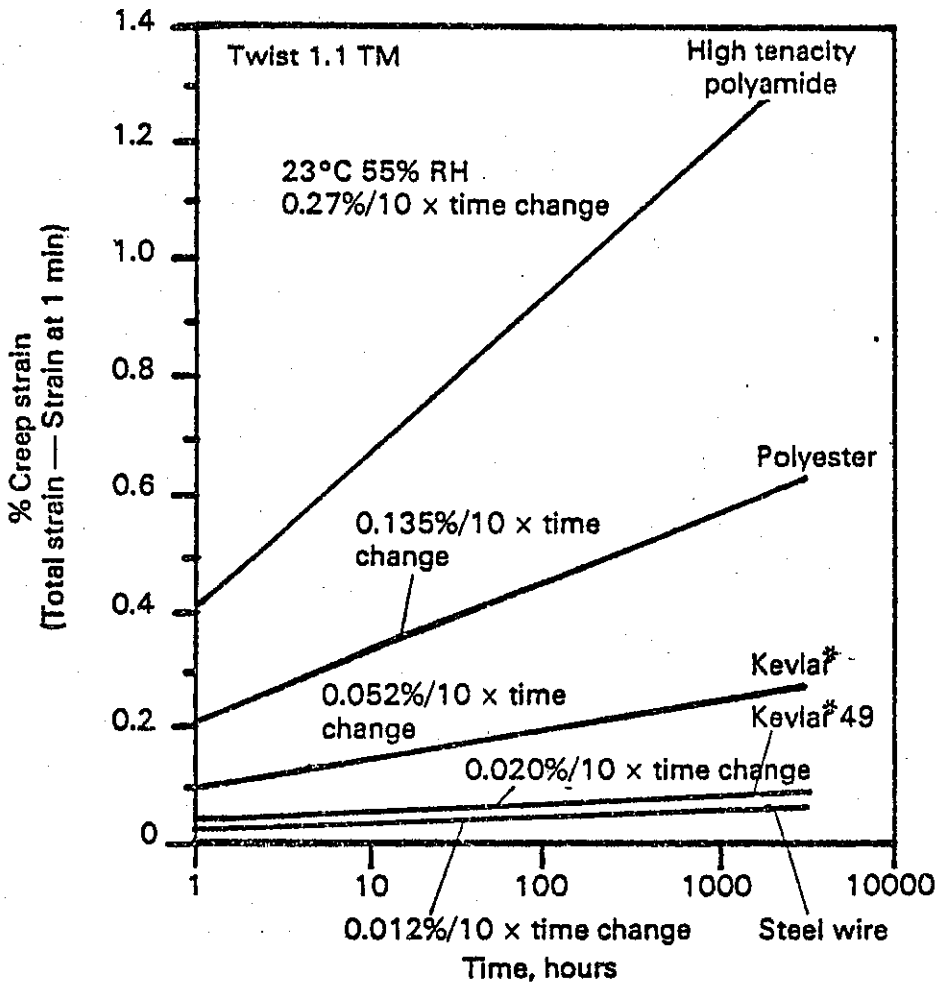


FIGURE 3 COMPARATIVE STRESS-CREEP OF INDUSTRIAL FIBRES

The effect of temperature on the tensile strength of KEVLAR

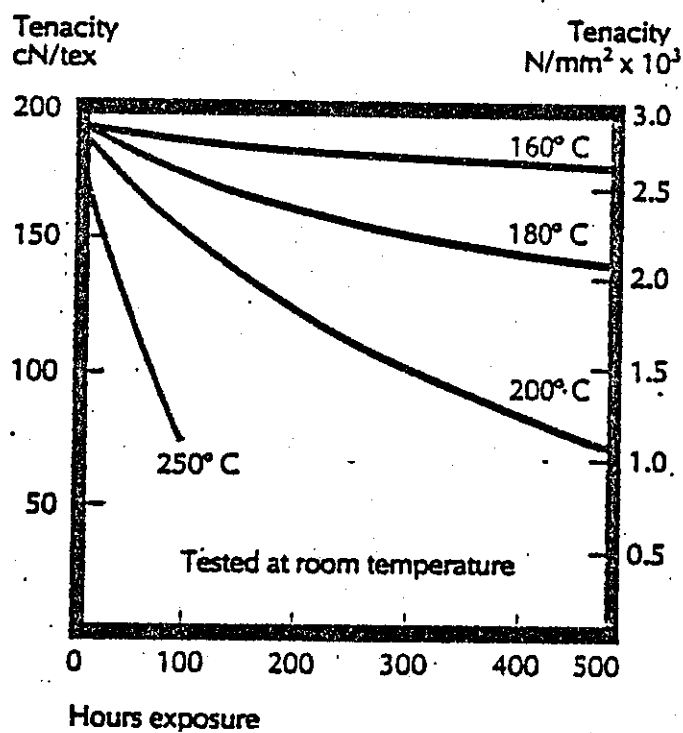


FIGURE 4

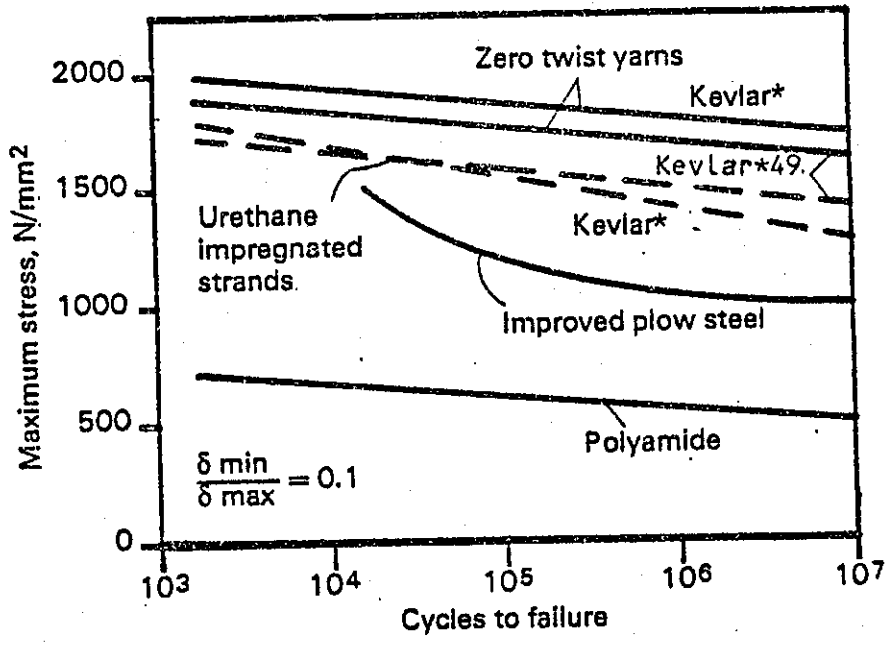


FIGURE 5 COMPARATIVE TENSION-TENSION FATIGUE PERFORMANCE

Polyamides yielding liquid crystalline solutions

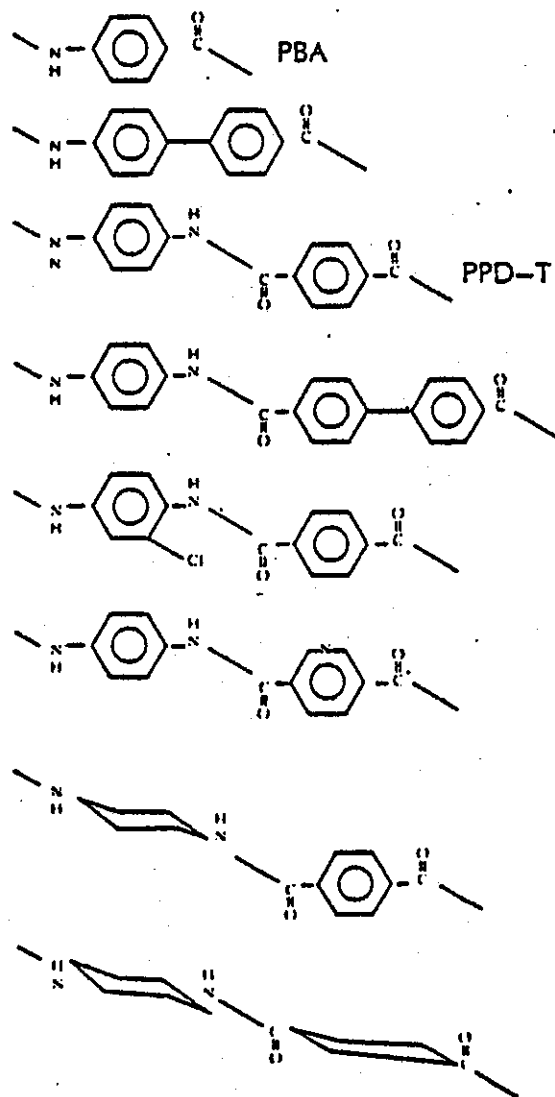


TABLE 1

Properties of industrial fibres

	KEVLAR	KEVLAR 49	Nylon	Polyester	Steel wire (stranded)
Tenacity (dN/tex)	19.0	19.0	8.6	8.2	3.0-3.5
Tenacity (N/mm ²)	2760	2760	990	1150	2400-2800
Modulus (dN/tex)	400	830	49	97	180-250
Modulus (KN/mm ²)	59	120	5.5	13.8	150-200
Elongation at break (%)	4	2.5	17	14.0	2
Density (g/cc)	1.44	1.45	1.14	1.38	7.85

TABLE II

Chemical resistance

Environment (100 hr* exposure at 21°C)	Tensile strength loss %
ACID	
Formic (90%) _____	10
Hydrochloric (10%) _____	12
Nitric (70%) _____	82
Sulfuric (70%) _____	86
BASES	
Ammonium Hydroxide 24 hr _____	0
Potassium Hydroxide 24 hr _____	25
Sodium Hydroxide 24 hr _____	10
Other Chemicals	
Brake Fluid (312 hr) _____	2
Greases (moS ₂ and Lithium base) _____	0
Jet Fluid (JP-4) (300 hr) _____	0
Ozone (1000 hr) _____	0
Tap Water _____	0
Boiling Water _____	0
Superheated Water 156°C (313°F) 80 hr _____	16

*Except where noted.

KEVLAR

TABLE III CHEMICAL RESISTANCE OF "KEVLAR"

TABLE IV

T - 2000 CONVEYOR BELT

<u>REQUIREMENT</u>	<u>STEEL ROLL</u>	<u>NON-STEEL ROLL</u>
RUBBER	CR	CR
TOTAL THICKNESS	22 MM	13 MM
THICKNESS OF COVERS TOP AND BOTTOM	6+6 MM	5+3 MM
WEIGHT	38 KG/M ²	22 KG/M ²

TABLE V

CONVEYOR BELTS REINFORCED WITH
"KEVLAR" ARAMID

INSTALLATIONS

<u>YEAR</u>	<u>TOTAL LENGTH</u>	<u>STRENGTH RANGE (N/MM)</u>
1975	600	630 - 1000
1976	700	1250 - 2000
1977	2500	400 - 2500
1978	7300	1000 - 4000
1979	5600	1000 - 3150
1980	8500	1250 - 2000
1981	6700	1250 - 4000
1982	12000	1250 - 1600
1983	>15000 (EXPECTED)	1250 - 4000