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High Perfomance Fiber- Kevlar the Super Tough Fiber

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Abstract

In today's fast growing market, apart from general apparel clothing, some special applications are expected from textile fibers. Such fibers are used specifically for protective clothing and thus require certain high performance properties. This generation of fibers has been recently developed in the 20th century and are called high performance fibers. A class of these fibers have very high tenacity and high modulus which are used in applications such as bullet proof jackets, whereas another class of fibers would have high thermal or chemical resistance which can be used as flame resistant fabrics etc.

High performance fibers include polymeric fibers such as aramids, aromatic copolyesters, extended chain flexible polyolefin etc.; carbon fiber; glass fibers; ceramic fibers and metallic fibers. High performance polymeric fibers being used for high mechanical properties should be highly oriented, linear aliphatic or aromatic molecules since flexible chains would give low melting polymers and thus low thermal resistance. On the other hand, carbon fibers are planar graphite structures with outstanding mechanical properties. Inorganic fibers have a three dimensional structure compared to a one dimensional and two dimensional structure of polymeric materials and carbon fibers respectively. They have very good mechanical properties but are brittle and have the highest thermal resistance. However, carbon fibers as well as inorganic fibers (except glass fibers) are very expensive. In the following sections, particularly, polymeric fibers would be discussed in detail. Although in the past there were some research works had done and papers also been published, but this paper just simplifies the things as well as highlight some superb features of the Kevlar fiber. However this is not a research article rather than a review article.

Keywords: History • Chemical composition • Production • Properties

Introduction

Kevlar fibers are para aramid fibers rather than meta aramid structure of Nomex. The monomers normally used for the production of the polymer for Kevlar fibers are *p*-phenylene diamine and terephthaloyl chloride. In Kevlar, the para-substitution of the monomers allows the benzene rings to lie centrally along the molecular axis as shown in Figure 1. Due to this arrangement, greater number of intermolecular bonds and a stronger and a more thermally and chemically resistant fiber is formed than that for Nomex. These fibers have high tensile strength, high tensile modulus and high heat resistance because of the highly oriented rigid molecular structure. Kevlar is about five times lighter than steel in terms of the same tensile strength. This high strength Kevlar is produced by a special spinning process called the Liquid crystal spinning. Now there exists a series of first, second and third generations of *para*-aramids. For example,

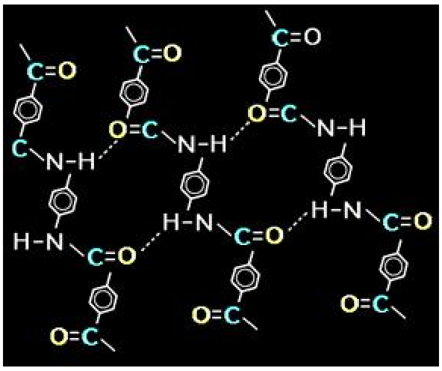

Figure 1. Hydrogen bonds form between the polar amide groups.

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Kevlar HT which has 20% higher tenacity and Kevlar HM which has 40% higher modulus than the original Kevlar 29 are largely used in the composite and the aerospace industries [1,2].

History

Poly-paraphenylene terephthalamide (K29)- branded Kevlar- was invented by Polish- American chemist Stephanie Kwolek while working for DuPont, in anticipation of a gasoline shortage. In 1964, her group began searching for a new lightweight strong fiber to use for light, but strong, tires. The polymers she had been working with at the time, poly-p-phenylene-terephthalate and polybenzamide, formed liquid crystal while in solution, something unique to those polymers at the time [3,4].

The solution was "cloudy, opalescent upon being stirred, and of low viscosity" and usually was thrown away. However, Kwolek persuaded the technician, Charles Smullen, who ran the spinneret, to test her solution, and was amazed to find that the fiber did not break, unlike nylon. Her supervisor and her laboratory director understood the significance of her discovery and a new field of polymer chemistry quickly arose. By 1971, modern Kevlar was introduced. However, Kwolek was not very involved in developing the applications of Kevlar. Kevlar 149 was invented by Dr. Jacob Lahijani of Dupont in the 1980s.

Chemical composition of Kevlar fibre

The chemical composition of Kevlar is poly para-phenyleneterephthalamide (PPD-T) and it is more properly known as a para-aramid. It is oriented para-substituted aromatic units. Aramids belong to the family of nylons. Common nylons, such as nylon 6, 6 do not have very good structural properties, so the para-aramid distinction is important. Aramid fibers like Nomex or Kevlar, however, are ring compounds based on the structure of benzene as opposed to linear compounds used to make nylon. The aramid ring gives Kevlar thermal stability, while the para structure gives it high strength and modulus. Like nylons, Kevlar filaments are made by extruding the precursor through a spinneret. The rod form of the para-aramid molecules and the extrusion process make Kevlar fibers anisotropic- they are stronger and stiffer in the axial direction than in the transverse direction. In comparison, graphite fibers are also anisotropic, but glass fibers are isotropic [5,6].

It is made from a condensation reaction of para-phenylene diamine and terephthaloyl (PPD-T) chloride. The resultant aromatic polyamide contains aromatic and amide groups which makes them rigid rod like polymers. The rigid rod like structure results in a high glass transition temperature and poor solubility, which makes fabrication of these polymers, by conventional drawing techniques, difficult Instead, they are melt spun from liquid crystalline polymer solutions as described later. The Kevlar fiber is an array of molecules oriented parallel to each other like a package of uncooked spaghetti. This orderly, untangled arrangement of molecules is described as a crystalline structure. Crystallinity is obtained by a manufacturing process known as spinning, which involves extruding the molten polymer solution through small holes [7-10].

When PPD-T solutions are extruded through a spinneret and drawn through an air gap during fiber manufacture, the liquid crystalline domains can orient and align in the flow direction. Kevlar can acquire a high degree of alignment of long, straight polymer chains parallel to the fiber axis. The structure exhibits anisotropic properties, with higher strength and modulus in the fiber longitudinal direction than in the axial direction. The extruded material also possesses a febrile structure. This structure results in poor shear and compression properties for aramid composites. Hydrogen bonds form between the polar amide groups on adjacent chains and they hold the individual Kevlar polymer chains together [11,12].

Grades of Kevlar

There are three grades of Kevlar available: Kevlar 29, Kevlar 49, and Kevlar 149. Tensile modulus is a function of molecular orientation. As a spun fiber, Kevlar 29 (a high toughness variant) has a modulus of 62 GPA (9 Mpsi). Heat treatment under tension increases crystalline orientation. The resulting fiber, Kevlar 49, has a modulus of 131 GPA.

Method of Kevlar production

Kevlar is synthesized in solution from the monomers 1,4-phenylene- diamine (*para*-phenylenediamine) and terephthaloyl chloride in a condensation reaction yielding hydrochloric acid as a by-product. The result has liquid-crystalline behaviour, and mechanical drawing orients the polymer chains in the fiber's direction. Hexamethylphosphoramide (HMPA) was the solvent initially used for the polymerization, but for safety reasons, DuPont replaced it by a solution of *N*-methyl-pyrrolidone and calcium chloride. As this process had been patented by Akzo (see above) in the production of Twaron, a patent war ensued.

The reaction of 1, 4-phenylene-diamine (*para*-phenylenediamine) with terephthaloyl chloride yielding Kevlar as shown in Figure 2.

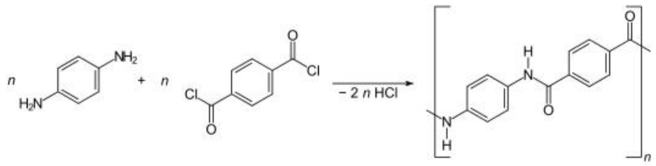


Figure 2. Structure of Kevlar.

Kevlar (poly paraphenylene terephthalamide) production is expensive because of the difficulties arising from using concentrated sulfuric acid, needed to keep the water-insoluble polymer in solution during its synthesis and spinning.

Several grades of Kevlar are available:

Kevlar K-29 – in industrial applications, such as cables, asbestos replacement, tires, and brake linings

Kevlar K49 – high modulus used in cable and rope products.

Kevlar K100 – colored version of Kevlar

Kevlar K119 – higher-elongation, flexible and more fatigue resistant

Kevlar K129 – higher tenacity for ballistic applications

Kevlar K149 – highest tenacity for ballistic, armor, and aerospace applications

Kevlar AP – 15% higher tensile strength than K-29

Kevlar XP – lighter weight resin and KM2 plus fiber combination

Kevlar KM2 – enhanced ballistic resistance for armor applications

Properties of Kevlar fibre

Kevlar is a very strong fiber. In fact, it is the strongest textile fiber available today. It has tenacity in the range 22-26 gpd with a breaking elongation of 2.5-4.4%. The fiber is cylindrical in the longitudinal view of microscopic view and circular in cross-sectional view. It is a dense fiber with density of 1.44-1.47g/cc. Similar to nomex, it has average moisture regain of about 4.3% in standard atmosphere. Due to the aromatic structure of the polymer, Kevlar is difficult to ignite. Para aramids generally have high glass transition temperatures nearing 370°C and do not melt or burn easily, but carbonise at and above 425°C.

Regarding the chemical properties of the fiber, the fiber is unaffected by most acids under normal conditions and has good resistance to alkalis and solvents, but not resistant to bleaches. It also has excellent resistance to mildew and aging. All aramid fibers are however prone to photodegradation and need protection against the sun when used out of doors.

Applications

Protection

Cryogenics: Kevlar is often used in the field of cryogenics for its low thermal conductivity and high strength relative to other materials for suspension purposes. It is most often used to suspend a paramagnetic salt enclosure from a superconducting magnet mandrel in order to minimize any heat leaks to the paramagnetic material. It is also used as a thermal standoff or structural support where low heat leaks are desired.

Pieces of a Kevlar helmet used to help absorb the blast of a grenade as shown in Figure 3. Kevlar is a well-known component of personal armor such as combat helmets, ballistic face masks, and ballistic vests. The PASGT helmet and vest used by United States military forces, use Kevlar as a key component in their construction. Other military uses include bulletproof face masks and spall liners used to protect the crews of armoured fighting vehicles. *Nimitz*-class aircraft carriers use Kevlar reinforcement in vital areas. Civilian applications include: high heat resistance uniforms worn by firefighters, body armour worn by police officers, security, and police tactical teams such as SWAT.

Figure 3: Armor.

Personal protection

Kevlar is used to manufacture gloves, sleeves, jackets, chaps and other articles of clothing designed to protect users from cuts, abrasions and heat. Kevlar-based protective gear is often considerably lighter and thinner than equivalent gear made of more traditional materials.

Sports

Kevlar is a very popular material for racing canoes as shown in Figure 4.

Personal protection

It is used for motorcycle safety clothing, especially in the areas featuring padding such as shoulders and elbows. In fencing it is used in the protective jackets, breeches, plastrons and the bib of the masks. It is increasingly being used in the *peto*, the padded covering which protects the picadors' horses in the bullring. Speed skaters also frequently wear an under-layer of Kevlar fabric to prevent potential wounds from skates in the event of a fall or collision.

Figure 4. Kevlar is a very popular material for racing canoes.

Equipment

In *kyudo*, or Japanese archery, it may be used as an alternative to more expensive hemp for bow strings. It is one of the main materials used for paraglide suspension lines. It is used as an inner lining for some bicycle tires to prevent punctures. In table tennis, plies of Kevlar are added to custom ply blades, or paddles, in order to increase bounce and reduce weight. Tennis racquets are sometimes strung with Kevlar. It is used in sails for high performance racing boats.

Shoes

In 2013, with advancements in technology, Nike used Kevlar in shoes for the first time. It launched the Elite II Series, with enhancements to its earlier version of basketball shoes by using Kevlar in the anterior as well as the shoe laces. This was done to decrease the elasticity of the tip of the shoe in contrast to nylon used conventionally as Kevlar expanded by about 1% against nylon which expanded by about 30%. Shoes in this range included LeBron, HyperDunk and Zoom Kobe VII. However these shoes were launched at a price range much higher than average cost of basketball shoes. It was also used in the laces for the Adidas F50 adiZero Prime football boot.

Cycle tires

Several companies, including Continental AG, manufacture cycle tires with Kevlar to protect against punctures.

Folding-bead bicycle tires, introduced to cycling by Tom Ritchey in 1984,[use Kevlar as a bead in place of steel for weight reduction and strength. A side effect of the folding bead is a reduction in shelf and floor space needed to display cycle tires in a retail environment, as they are folded and placed in small boxes.

Music

Audio equipment

Kevlar has also been found to have useful acoustic properties for loudspeaker cones, specifically for bass and mid-range drive units. Additionally, Kevlar has been used as a strength member in fiber optic cables such as the ones used for audio data transmissions.

Bowed string instruments

Kevlar can be used as an acoustic core on bows for string instruments. Kevlar's physical properties provide strength, flexibility, and stability for the bow's user. To date, the only manufacturer of this type of bow is Coda Bow.

Kevlar is also presently used as a material for tailcords (a.k.a. tailpiece adjusters), which connect the tailpiece to the endpin of bowed string instruments.

Drumheads

Kevlar is sometimes used as a material on marching snare drums. It allows for an extremely high amount of tension, resulting in a cleaner sound. There is usually a resin poured onto the Kevlar to make the head airtight, and a nylon top layer to provide a flat striking surface. This is one of the primary types of marching snare drum heads. Remo's Falam Slam patch is made with Kevlar and is used to reinforce bass drum heads where the beater strikes.

Woodwind reeds

Kevlar is used in the woodwind reeds of Fibracell. The material of these reeds is a composite of aerospace materials designed to duplicate the way nature constructs cane reed. Very stiff but sound absorbing Kevlar fibers are suspended in a lightweight resin formulation.

Motor vehicles

Chassis and bodywork

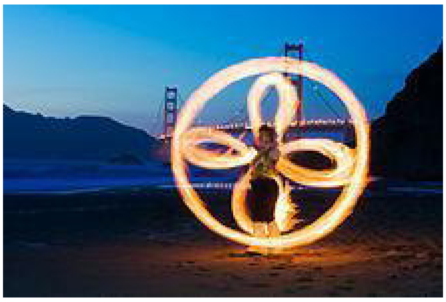
Kevlar is sometimes used in structural components of cars, especially high-value performance cars such as the Ferrari F40

Brakes

The chopped fiber has been used as a replacement for asbestos in brake pads. Indeed, aramids release a lower level of airborne fibres than asbestos brakes. Asbestos fibres are known for their carcinogenic properties.

Other uses

Fire dancing



Fire poi on a beach in San Francisco

Wicks for fire dancing props are made of composite materials with Kevlar in them. Kevlar by itself does not absorb fuel very well, so it is blended with other materials such as fiberglass or cotton. Kevlar's high heat resistance allows the wicks to be reused many times.

Frying pans

Kevlar is sometimes used as a substitute for Teflon in some non-stick frying pans.

Rope, cable, sheath

Kevlar mooring line- The fiber is used in rope and in cable, where the fibers are kept parallel within a polyethylene sleeve. The cables have been used in suspension bridges such as the bridge at Aberfeldy in Scotland. They have also been used to stabilize cracking concrete cooling towers by circumferential application followed by tensioning to close the cracks. Kevlar is widely used as a protective outer sheath for optical fiber cable, as its strength protects the cable from damage and kinking. When used in this application it is commonly known by the trademarked name Parafil.

Electricity generation

Kevlar was used by scientists at Georgia Institute of Technology as a base textile for an experiment in electricity-producing clothing. This was done by weaving zinc oxide nanowires into the fabric. If successful, the new fabric will generate about 80 milliwatts per square meter.

Building construction

A retractable roof of over 60,000 square feet (5,575 square metres) of Kevlar was a key part of the design of Montreal's Olympic stadium for the 1976 Summer Olympics. It was spectacularly unsuccessful, as it was completed 10 years late and replaced just 10 years later in May 1998 after a series of problems.

Expansion joints and hoses

Kevlar can be found as a reinforcing layer in rubber bellows expansion joints and rubber hoses, for use in high temperature applications, and for its high strength. It is also found as a braid layer used on the outside of hose assemblies, to add protection against sharp objects.

Particle physics

A thin Kevlar window has been used by the NA48 experiment at CERN to separate a vacuum vessel from a vessel at nearly atmospheric pressure, both 192 cm in diameter. The window has provided vacuum tightness combined with reasonably small amount of material (only 0.3% to 0.4% of radiation length).

Smartphones

The Motorola RAZR Family, the Motorola Droid Maxx, OnePlus 2, and Pocophone F1 have a Kevlar backplate, chosen over other materials such as carbon fiber due to its resilience and lack of interference with signal transmission.

Marine current turbines and wind turbines

The Kevlar fiber/epoxy matrix composite materials can be used in marine current turbines (MCT) or wind turbines due to their high specific strength and light weight compared to other fibers.

Conclusion

Kevlar mainly use for two reasons, and both are about performance: It's lightweight and easy to integrate. A thin blanket can serve as structural reinforcement or ballistic protection, everywhere from seismic shear walls to bank counters. Sprinkle the fibres into carbon composites to cut weight and boost strength: The grades Kevlar 49 and 149 are the lightest and most robust; Kevlar 29 is comparable in potency to glass fibre, but weighs less. The fact is, Kevlar is still expensive costs need to come down

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