A compilation on

High Modulus Polyethylene Fibers

(HMPE)

CSL

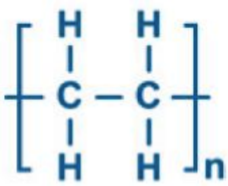
May 2010

Different Names

- HMPE (High modulus polyethylene)
- UHMWPE (Ultra high molecular weight polyethylene)
- UHMPE (Ultra high modulus polyethylene)
- HPPE (High performance polyethylene)

SEM image of HMPE

PE Chemical Formula



Polyethylene structural formula

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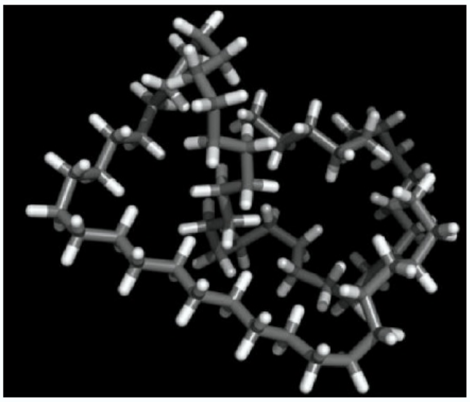
PE molecular chains

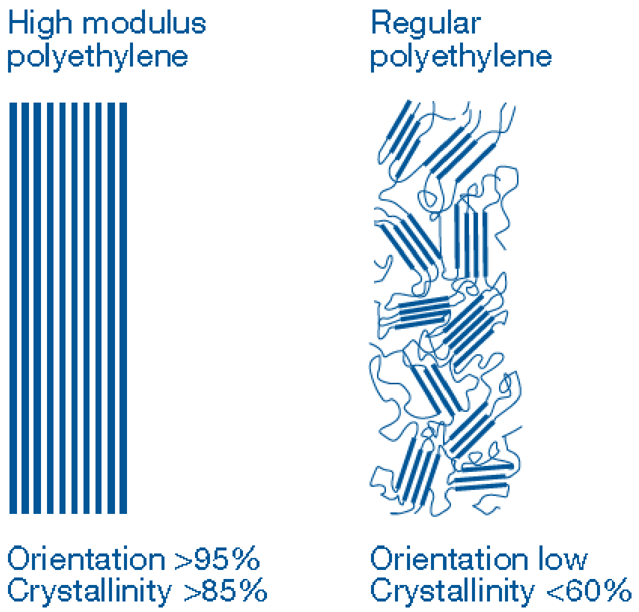


Molecular structure compared to p-Aramids

- Aramid molecules have straight rod-like structure even before polymer spinning into fiber;
- PE molecules are forced to have straight orientation in the fiber direction during spinning/stretching.

Normal PE vs. HMPE

Normal PE	HMPE
• Low molecular weight • Shorter molecular chains • The molecules are not well-orientated and are easily torn apart	• Ultra-high molecular weight • Longer molecular chains • To make strong fibers, the molecular chains are stretched, oriented and crystallised in the direction of the fiber



Unsuitability of melt spinning of HMPE

- Spinning is difficult because of extremely high melt viscosity
- Drawing is not efficient due to high entanglement of molecular chains

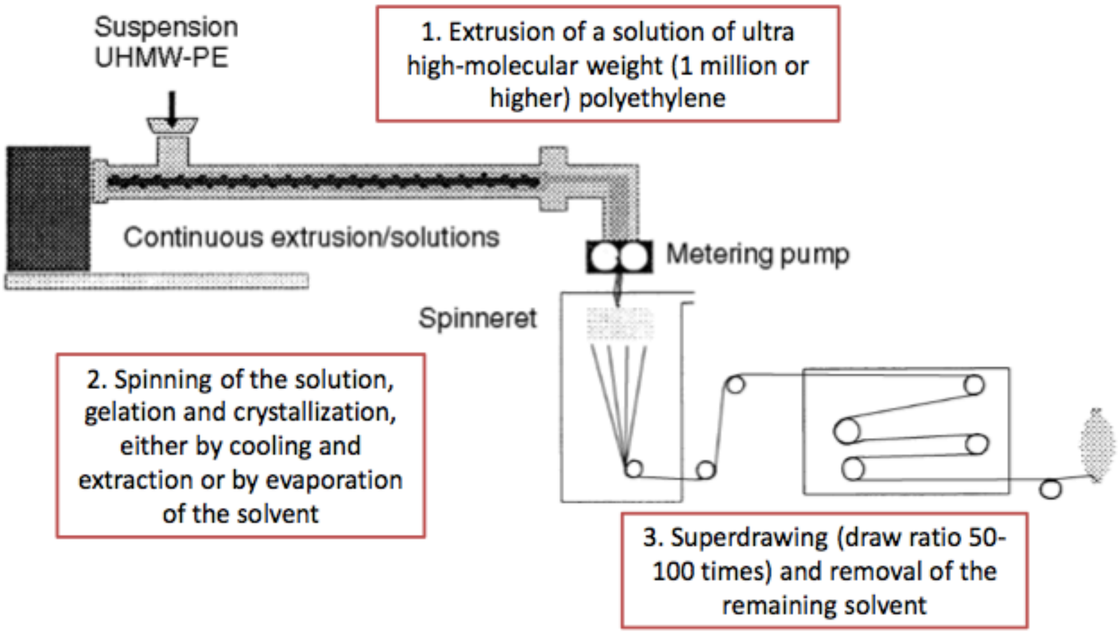
HMPE feedstock polymer for spinning

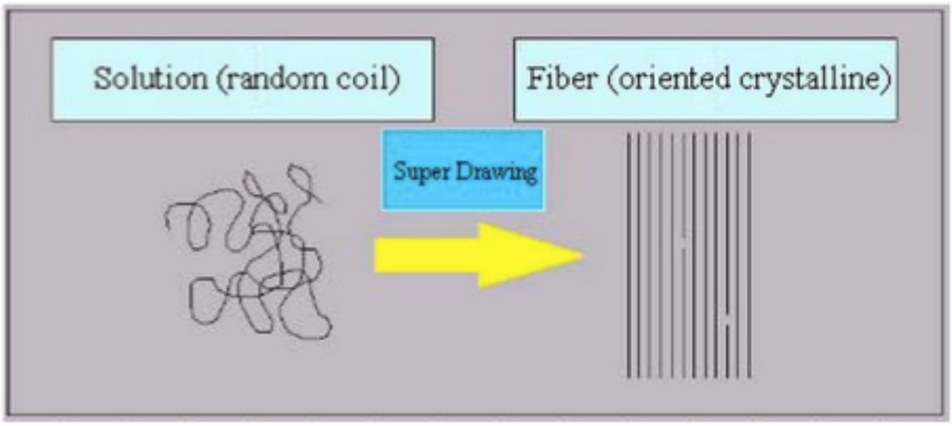
- Flexible PE polymer has a very weak interaction between the molecular chains
- Only the Van der Waals forces are active
- This interaction is so weak that for strong fibers, ultra-long chains with a high overlap lengths are required.
- Thus starting material for the high-performance polyethylene fibers is polyethylene with an average molecular weight of one million or more

Gel Spinning

- The molecules are dissolved in a solvent and spun through a spinneret.
- In the solution the molecules become disentangled and remain in that state after the solution is spun and cooled to give filaments.
- The term ‘gel spinning’ derives its name from the gel-like appearance of the dissolved polymer/solidified filament
- Because of its low degree of entanglement, the gelspun material can be drawn to a very high extent
- As the fibre is superdrawn, a very high level of macromolecular orientation is attained

Gel spinning





HMPE is dissolved in a solvent and then spun through small orifices (spinneret). Successively, the spun solution is solidified by cooling, which fixes a molecular structure which contains a very low entanglement density of molecular chain. This structure gives an extremely high draw ratio and results in extremely high strength. The gel-like appearance of the solidified fiber is the origin of the name of this technology. The highly drawn fiber contains an almost 100% crystalline structure with perfectly arranged molecules, which promotes its extremely high strength, modulus and other excellent properties.

Key HMPE Properties

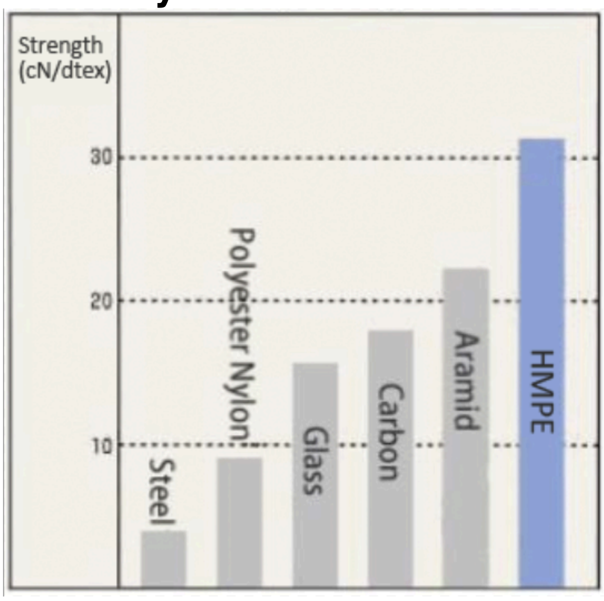
- High strength and high modulus with low density (<1, floats in water)
- Extremely high specific strength and specific modulus because of low density
- Low melting point
- Hydrophobicity
- Biological inertness

Chemical Name	Polyethylene
Short Form	PE
Density [g/cm]	0,97
Melting Point (°C)	150
Main Trade Names	Dyneema (DSM)
	Spectra (Honeywell)

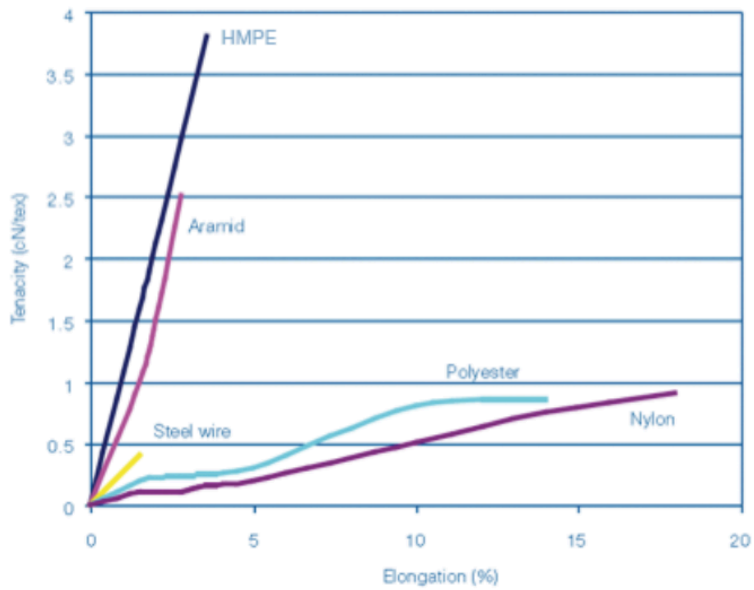
Reasons for high strength

- Ultra high molecular weight (> 1 million) polymer
- Ultra high spinning draw ratio (50-100 times)
- High molecular chain orientation
- High crystallinity

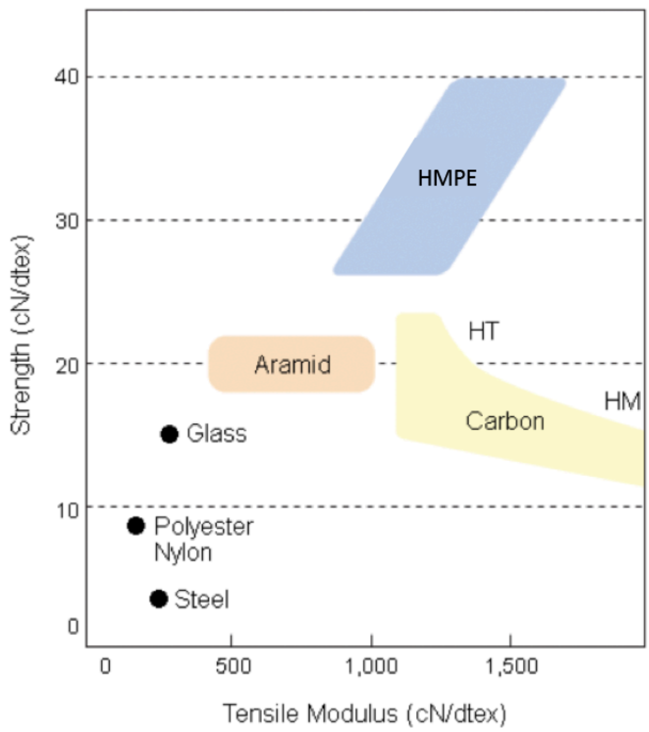
Tenacity



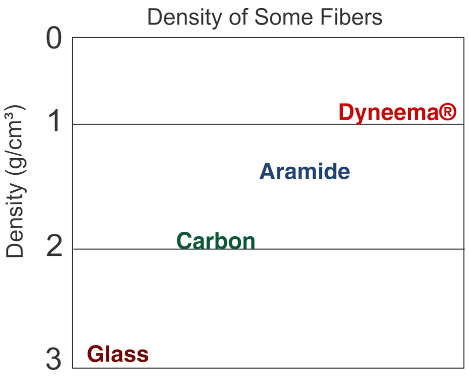
Stress-Strain Curve



Tenacity vs. Modulus

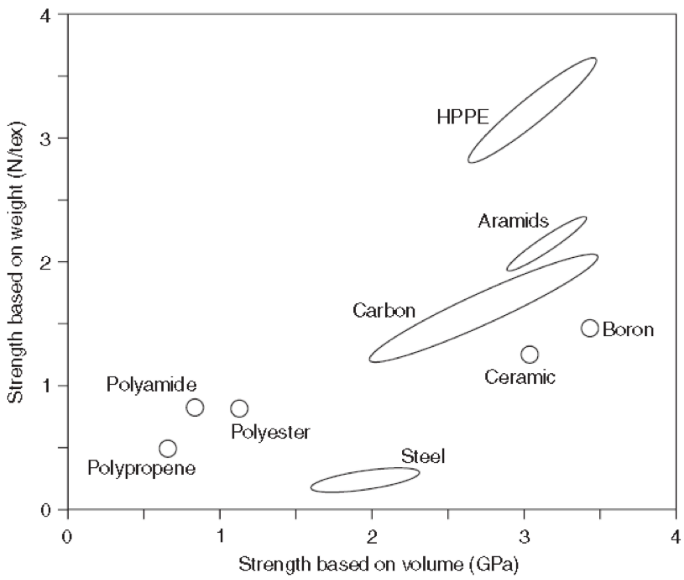


Specific Gravity

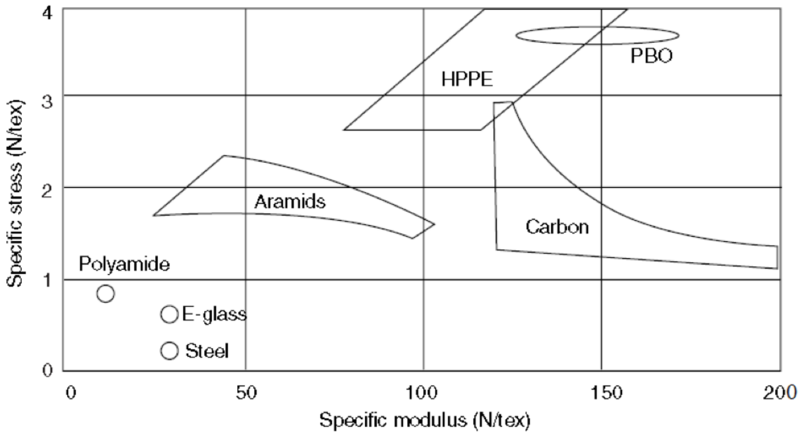


HMPE is the only high performance fiber that floats on water (density below 1.0 g/cm3)

Weight and volume saving

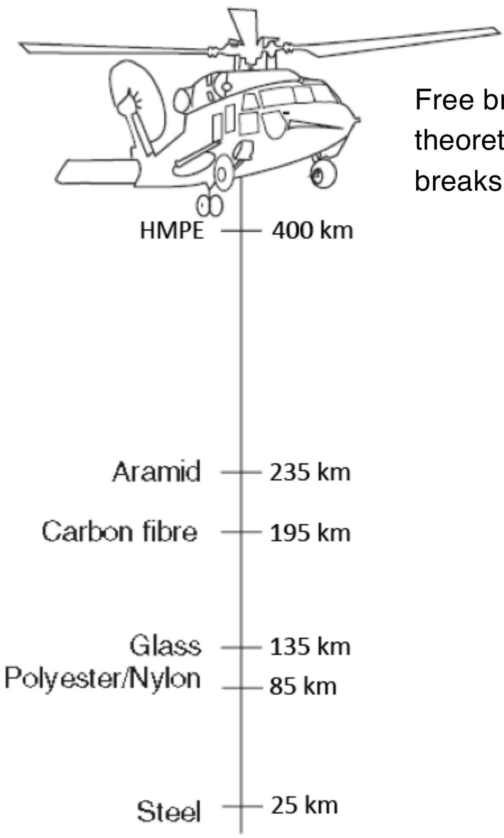


Specific modulus



The high specific modulus is also relevant in ballistic protection. The **sonic velocity** in the fiber determines the **speed of spreading energy** on ballistic impact and the sonic velocity is calculated as the square root of the specific modulus.

Free breaking length



Free breaking length is the theoretical length at which a rope breaks under its own weight

Chemical Stability

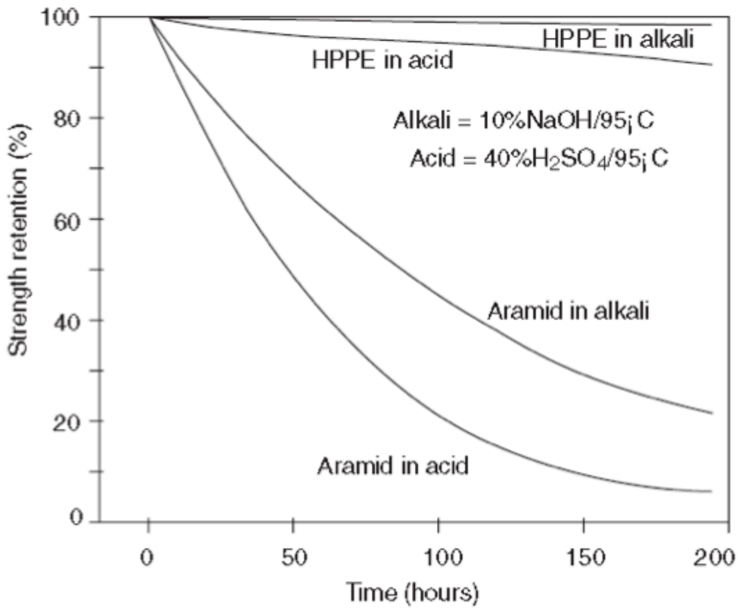
Table Resistance of fibres to various chemicals: 6 months immersed at ambient temperature

	HPPE	Aramid
Distilled water	***	***
Sea water	***	***
10% detergent	***	***
Hydrochloric acid (pH = 0)	***	*
Nitric acid (pH = 1)	***	*
Glacial acetic acid	***	***
Ammonium hydroxide	***	**
Sodium hydroxide (pH > 14)	**	*
Petrol	***	***
Kerosene	***	***
Toluene	***	**
Trichloromethane	***	***

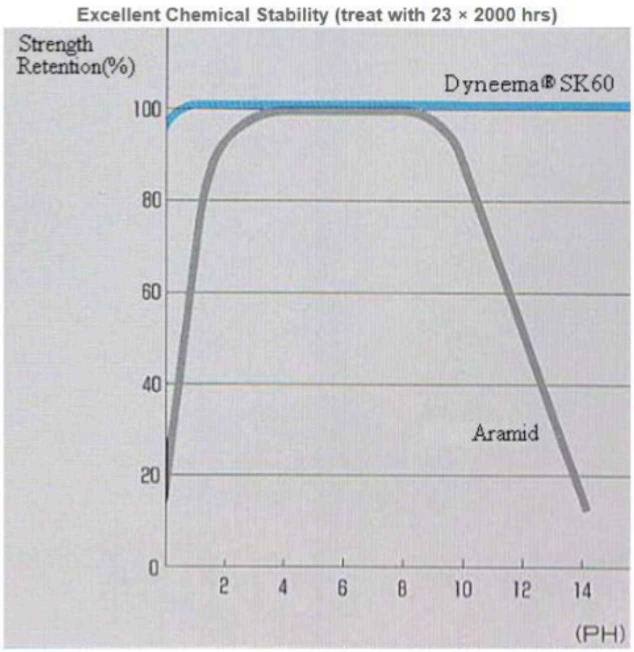
*** Unaffected ** slightly affected * seriously affected.

HMPE is sensitive to oxidizing media. In strongly oxidizing media, fibres will lose strength very fast.

Resistance to acids and alkalis



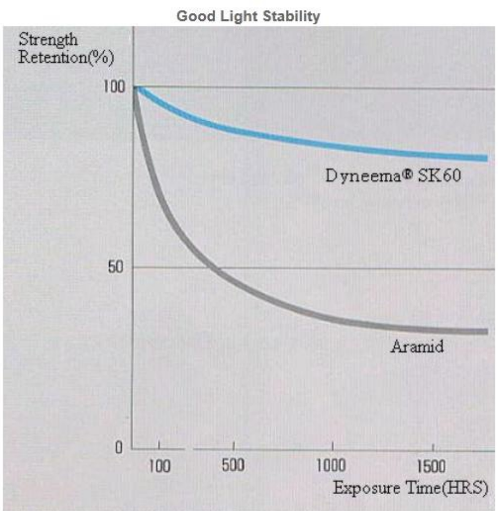
pH Stability



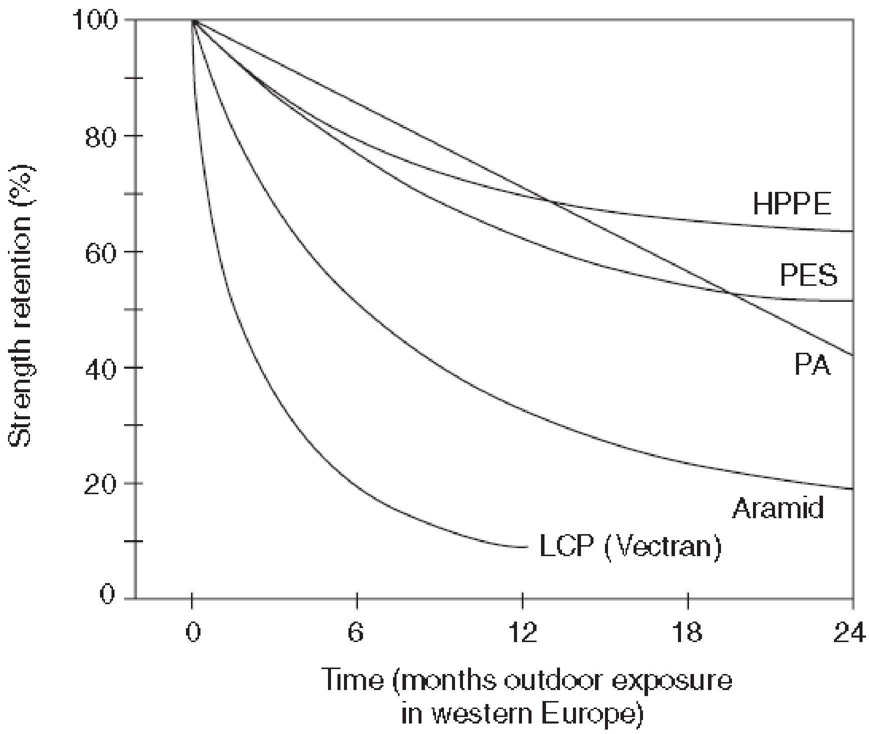
Hydrophobicity

- HMPE is not hygroscopic
- It does not absorb water

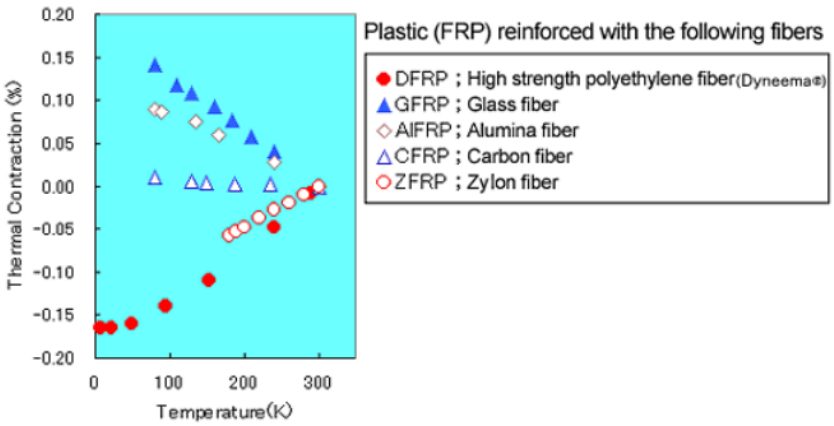
Light Stability



UV Resistance

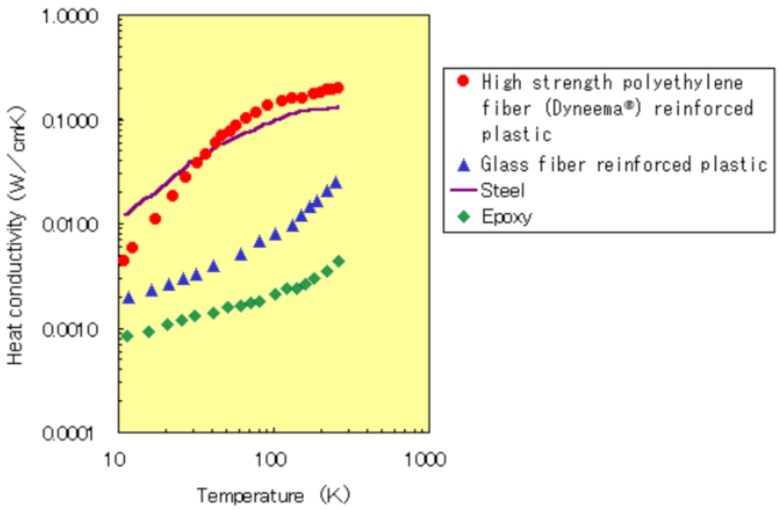


Contraction with Temp.



Toshihiro Kajima et al: Summary of lecture at Cryogenics · Superconductivity Society 245 (1991)

Heat Conductivity



Fujishiro,H.,et al.: Jpn J.Appl.Phys.5633(1997)

Electrical Properties

Polyethylene is an insulator and has no groups with dipole character.

Volume Resistivity > 10^{14} Ωm
Very Low dielectric loss factor $(2x10)^{-4}$

- Low dielectric constant (2.2-2.5)
- As spun yarns contain a small fraction of spin oil of a hydrophilic nature. So, for applications where the electrical properties are important, the spin finish should be removed.

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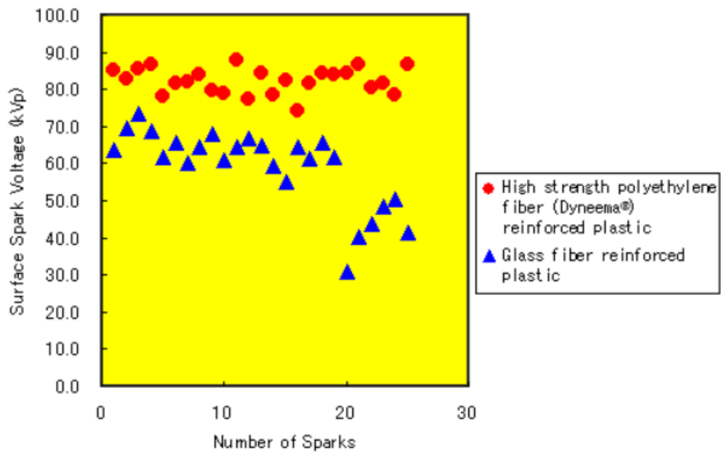
Dielectric Constant of different materials

Material	Min.	Max.	Material	Min.	Max.
Air	1	1	Nylon	3.4	22.4
Amber	2.6	2.7	Paper	1.5	3
Asbestos fiber	3.1	4.8	Paraffin	2	3
Bakelite	5	22	Plexiglass	2.6	3.5
Barium Titanate	100	1250	Polycarbonate	2.9	3.2
Beeswax	2.4	2.8	Polyethylene	2.5	2.5
Cambric	4	4	Polyimide	3.4	3.5
Carbon Tetrachloride	2.17	2.17	Polystyrene	2.4	3
Celluloid	4	4	Porcelain	5	6.5
Cellulose Acetate	2.9	4.5	Quartz	5	5
Durite	4.7	5.1	Rubber	2	4
Ebonite	2.7	2.7	Ruby Mica	5.4	5.4
Epoxy Resin	3.4	3.7	Selenium	6	6
Ethyl Alcohol	6.5	25	Shellac	2.9	3.9
Fiber	5	5	Silicone	3.2	4.7
Formica	3.6	6	Slate	7	7
Glass	3.8	14.5	Soil dry	2.4	2.9
Glass Pyrex	4.6	5	Steatite	5.2	6.3
Gutta Percha	2.4	2.6	Styrofoam	1.03	1.03
Isolantite	6.1	6.1	Teflon	2.1	2.1
Kevlar	3.5	4.5	Titanium Dioxide	100	100
Lucite	2.5	2.5	Vaseline	2.16	2.16
Mica	4	9	Vinylite	2.7	7.5
Micarta	3.2	5.5	Water distilled	34	78

The lower the value of the dielectric constant, the greater its resistance to the flow of an electrical current.

Dielectric Strength

High dielectric strength



Nitta,T.,et al.:Proc.of MT-15 1159(1197)

The maximum electric field strength that an insulating material can withstand intrinsically without breaking down, *i.e.*, without experiencing failure of its insulating properties

Miscellaneous

Vibration damping
Dyneema® has excellent vibration damping characteristcs.

Insulation
Fundamentally a form of polyethylene, Dyneema® possesses the same chemical properties, making it an outstanding insulator.

Environment
As indicated by its chemical formula -(CH2-CH2)n- Dyneema® is formed from carbon(C) and hydrogen(H). Consequently, even if Dyneema® is burned all that remains is water (H2O) and carbon dioxide(CO2) and no harmful substances are released.

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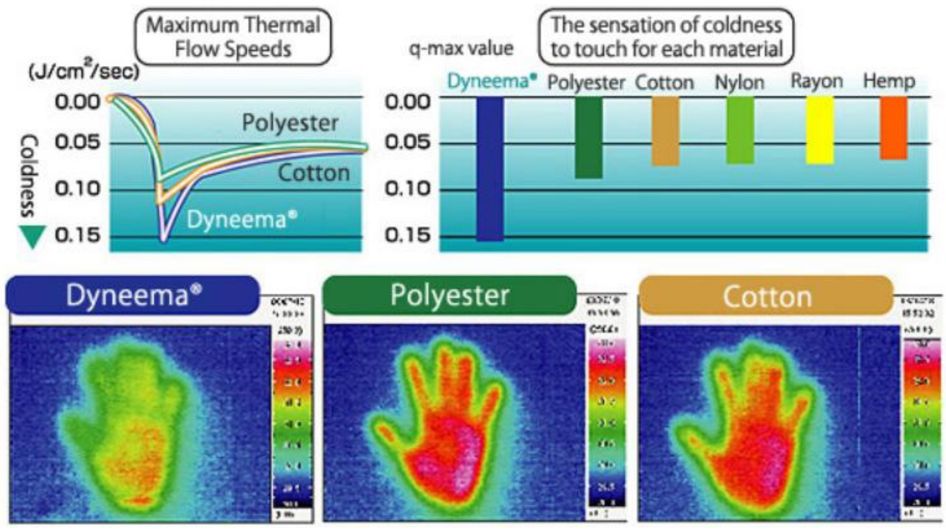
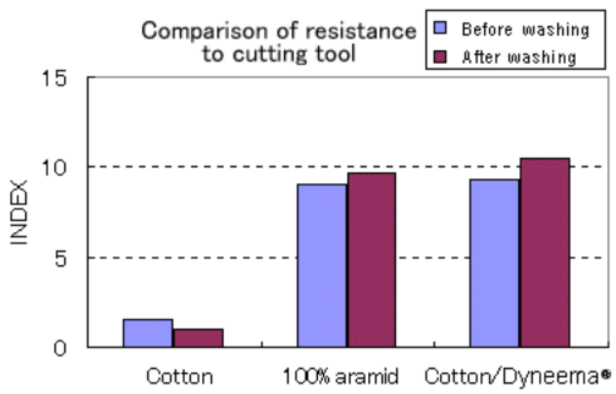
Coolness to Touch



Cut Resistance

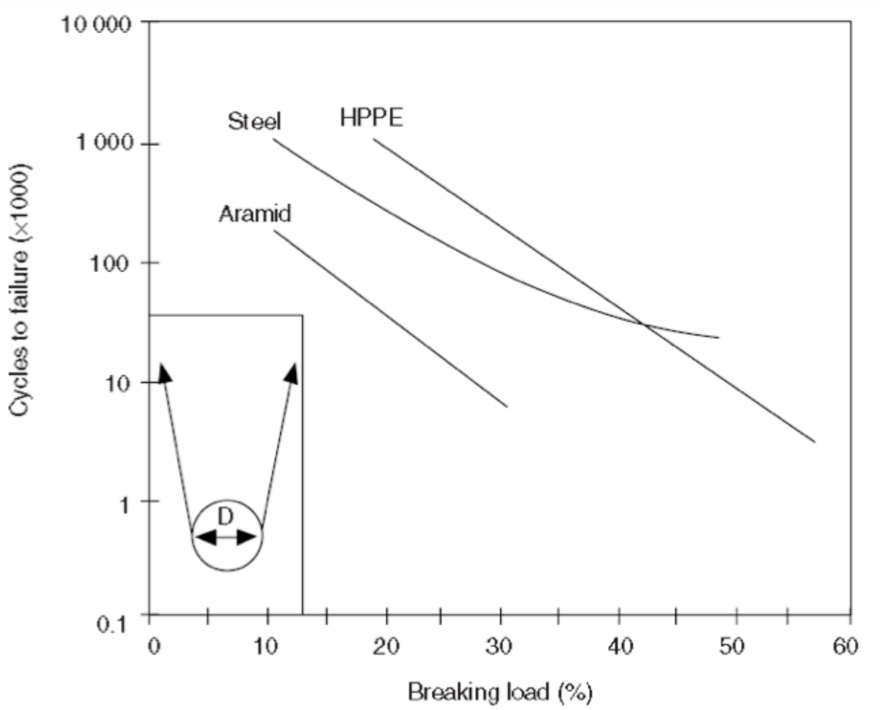


Impact Strength & Energy Absorption

- Dyneema® SK60 has an extremely high impact strength.
- Extremely high amounts of energy absorption
- This property is utilized in products for:
  - ballistic protection,
  - cut-resistant gloves
  - helmets

Fatigue

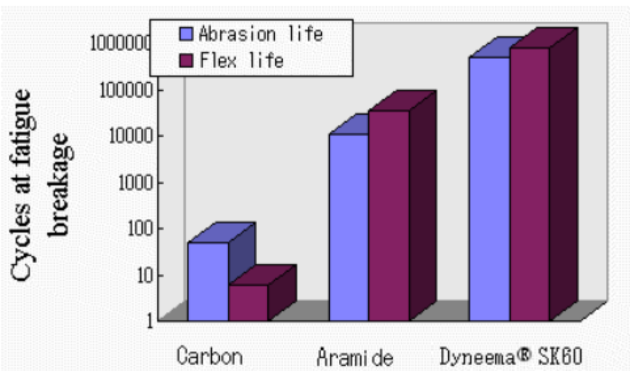
- Good fatigue resistance properties
- Carbon fibers may have high modulus but are brittle whereas HPPE is flexible and has longer flex life
- In **tension fatigue** testing, a rope is repeatedly loaded in tension and relaxation cycles
- In **bending fatigue or flex-life testing**, a loaded rope is moving over two or three sheaves



Abrasion Resistance and Flex Life

Dyneema® has excellent abrasion and fatigue resistance. Due to its ability to be processed easily. (weaving, knitting etc.), this leads to wide applications for industrial use.

Abrasion Resistance and Flex Life



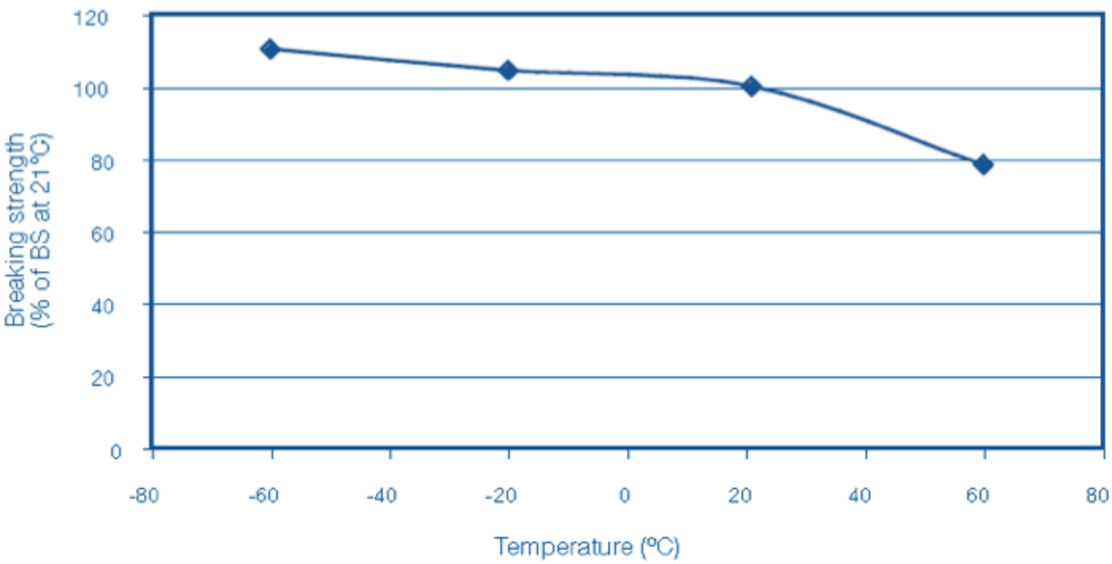
Biological Resistance & Toxicity

- HMPE is not sensitive to attach by micro-organisms
- HMPE is considered as biologically inert fiber
  - Suitable for medical applications

Thermal Properties

HMPE fiber has a melting point between 144ºC and 152ºC. The tenacity and modulus decrease at higher temperatures but increase at sub-zero temperatures. There is no brittle point found as low as -150ºC, so the fiber can be used between this temperature and 70ºC.

Figure: Influence of temperature on Dyneema® fiber breaking strength.



Flame Retardance

- LOI index lower than 20
- HMPE is thermoplastic, melts at about 150°C and decomposes over 300°C.
- Aramid fibres are thermosets, there is no melting point and gas emission starts at about 400°C.
- Polyethylene contains only carbon and hydrogen and no nitrogen or other hazardous chemical elements
    - Toxicity of the gases is relatively low

Compressive Yield Strength

In contrast to the high tensile strength, the gel-spun fibre has a low compressive yield strength, approximately 0.1 N/tex.

Viscoelasticity

- Polyethylene is a viscoelastic material, i.e.
- Its tenacity, tensile modulus and elongation at break depend on the temperature and the strain rate
- At high strain rates, or alternatively at low temperatures, both modulus and strength are significantly higher
    - Important in ballistic protection

Creep

- The fibre is prone to creep;
- The deformation increases with loading time, resulting both in a lower modulus and a higher strain at rupture
    - Important in ropes
- Creep is different in different fiber grades

Acoustic Properties

As with all mechanical properties, the acoustic properties are strongly anisotropic. In the fibre direction, the sound speed is much higher (10 – 12x10^3 m/s) than in the transverse direction (2x10^3m/s).

Summary of HMPE Properties

Water and chemicals	
Moisture regain	zero
Attack by water	none
Resistance to acids	excellent
Resistance to alkalis	excellent
Resistance to most chemicals	excellent
Resistance to UV light	very good
Thermal	
Melting point	144–155 °C
Boiling water shrinkage	<1%
Thermal conductivity (along fibre axis)	20 W/mK
Thermal expansion coefficient	-12×10^{-6} per K
Electrical	
Resistance	$>10^{14}$ Ohm
Dielectric strength	900 kV/cm
Dielectric constant (22 °C, 10 GHz)	2.25
Loss tangent	2×10^{-4}
Mechanical	
Axial tensile strength	3 GPa
Axial tensile modulus	100 GPa
Creep (22 °C, 20% load)	1×10^{-2} % per day
Axial compressive strength	0.1 GPa
Axial compressive modulus	100 GPa
Transverse tensile strength	0.03 GPa
Transverse modulus	3 GPa

ACL: Typical strength of human ligaments and tendons is 50 – 105 MPa

Bone: Typical tensile strength of human long bones is 120 – 150 MPa

Hair: Typical tensile strength of human hair is 190 MPa

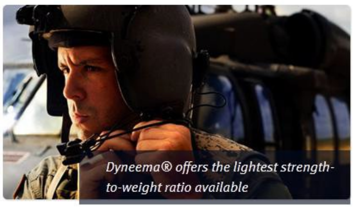
Spider's silk: Typical tensile strength of Spider's silk is 1400 MPa

Dyneema Purity Typical tensile strength of Dyneema Purity is 3000 MPa

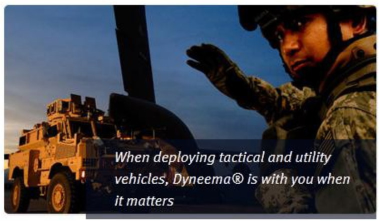
Applications: Ballistic Protection

Boats and Ships

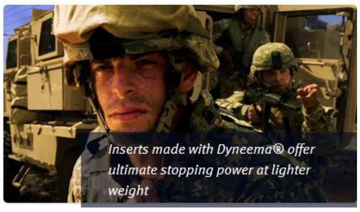
Aircraft



Land Vehicles



Inserts

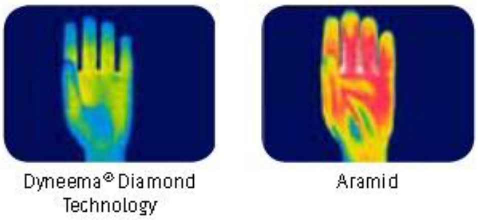


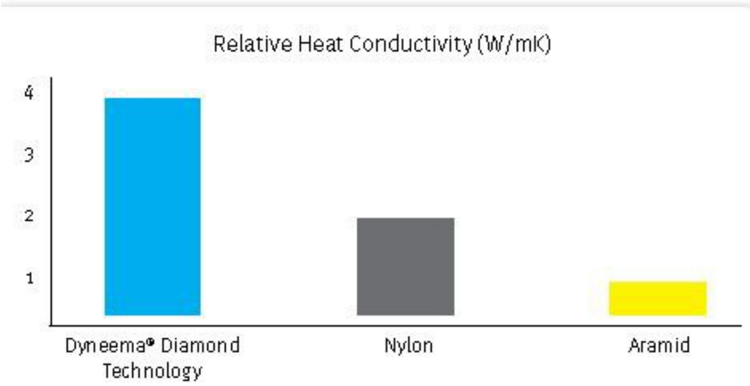
Vests

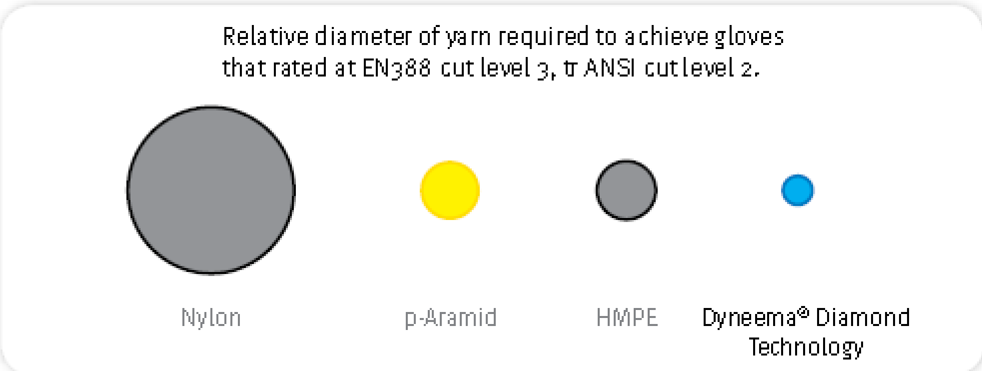
Helmets

Ballistic Shields

Applications: Safety Gloves





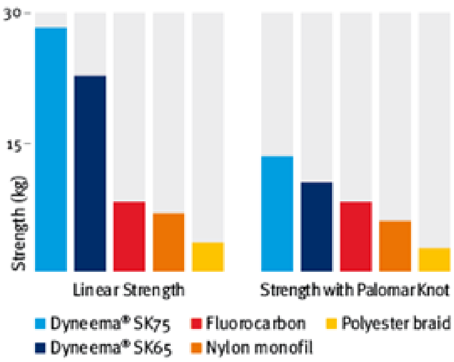


Applications: Ropes

- High Strength
- Light Weight

Mooring ropes made with HMPE are used to secure ultra-large ships in the 250.000t and 300.000t class to the port, such as ore carriers, crude oil tankers, LNG tankers. Also, that's the rope used by tug boats.

Applications: Fishing line/Cord



Applications: Sail Cloth

Sail Cloth

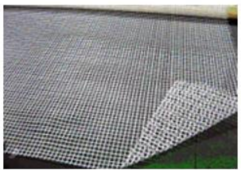
Delivering the perfect balance of strength and weight, Dyneema® fiber is the ideal material for today's revolutionary new sail designs.

With low stretch characteristics that let sails retain an optimal shape and a pure white appearance that's resistant to abrasion, as well as chemicals, salt and UV rays. And that's why the sails' useful service life exceeds that of other materials- exponentially.

Applications: Nets




Applications: Fiber-reinforced cement (FRC) and Fiber-reinforced plastic (FRP)



Applications: Unidirectional Laminates

Dyneema® fibers are layered in a criss-cross (0/90°) orientation to provide ultimate energy absorption

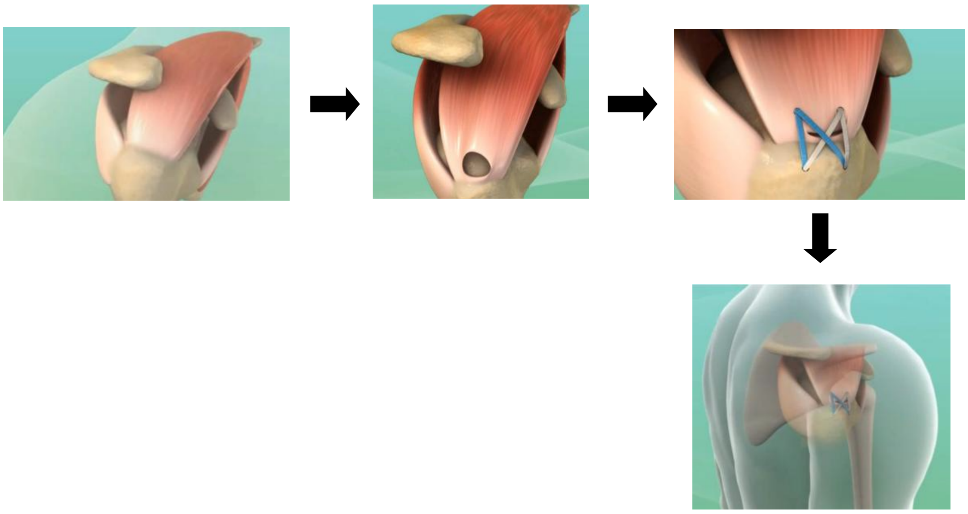
Dyneema® Unidirectional (UD) technology is a composite laminate that provides excellent energy absorption and enhance protection at low weight.
The energy from an impact to be distributed along the fibers much faster and more evenly than conventional, woven fabrics Dyneema® UD is ideal for personal protection applications (vests, helmets, and inserts) and vehicle armor of all types (land, air, and sea).

Dyneema Purity® SGX fiber: in Medtech

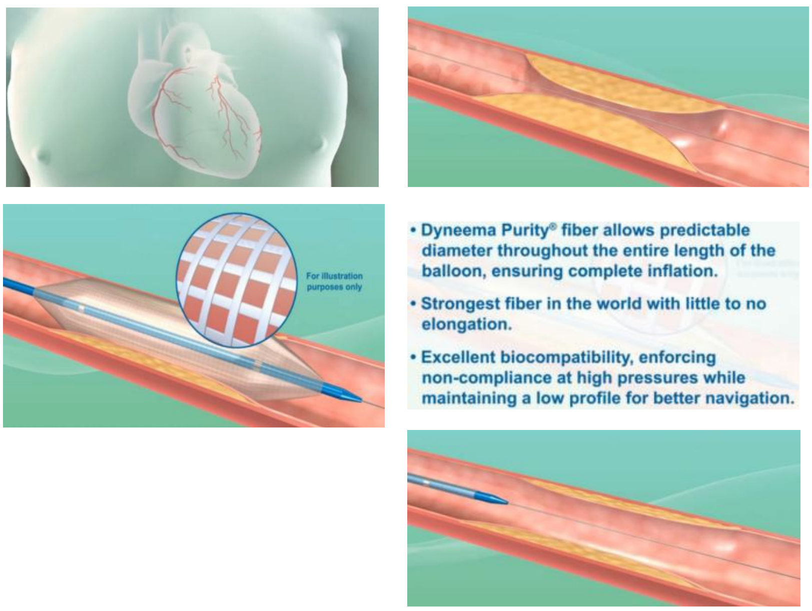
•15 times stronger than steel,
•40% stronger than aramids on a weight-by-weight basis
•3 times stronger than polyester on a volume basis

Dyneema Purity: Surgical Implants

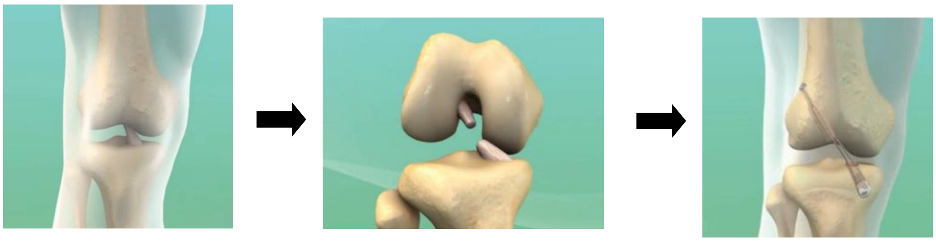
- High strength and high modulus
- High pliability and softness
- Lower profile with equivalent strength
- Proven biocompatibility
- Non-hemolytic
- Cut resistant
- Low friction coefficient



Dyneema Purity in Cardiovascular Application



Dyneema Purity in Ligament Repair



Applications: Cargo Containers

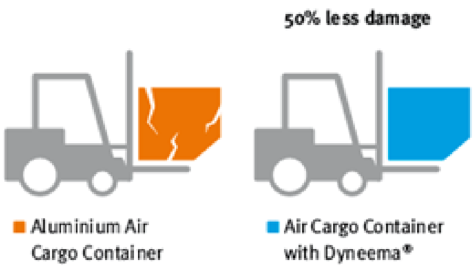
Air Cargo Containers

Thinking outside the box

Next-generation air containers made with Dyneema® are redefining air cargo operations for customers like Lufthansa and DoKaSch. Composite panels and fabrics made from our flexible and ultra-lightweight materials are contributing to super-strong, durable containers that are up to 50% lighter than metals - reducing fuel and carbon emissions even further.

Air Cargo Nets

Securing your investment



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