VICTREX® PEEK

High Performance Polymers Designed for the Most Demanding Automotive Applications

victrex®

PASSION • INNOVATION • PERFORMANCE

VICTREX ADVANTAGES FOR AUTOMOTIVE APPLICATIONS

Benefits

Enhanced Fuel Efficiency

Improved Safety

Extended Part Life – Reliability

Smoother Operation – Less Noise

Weight Savings

Properties

Excellent Fatigue Resistance

Ability to Withstand High Strength

Resistance to Automotive Fluids

Low Coefficient of Friction

High Wear Resistance

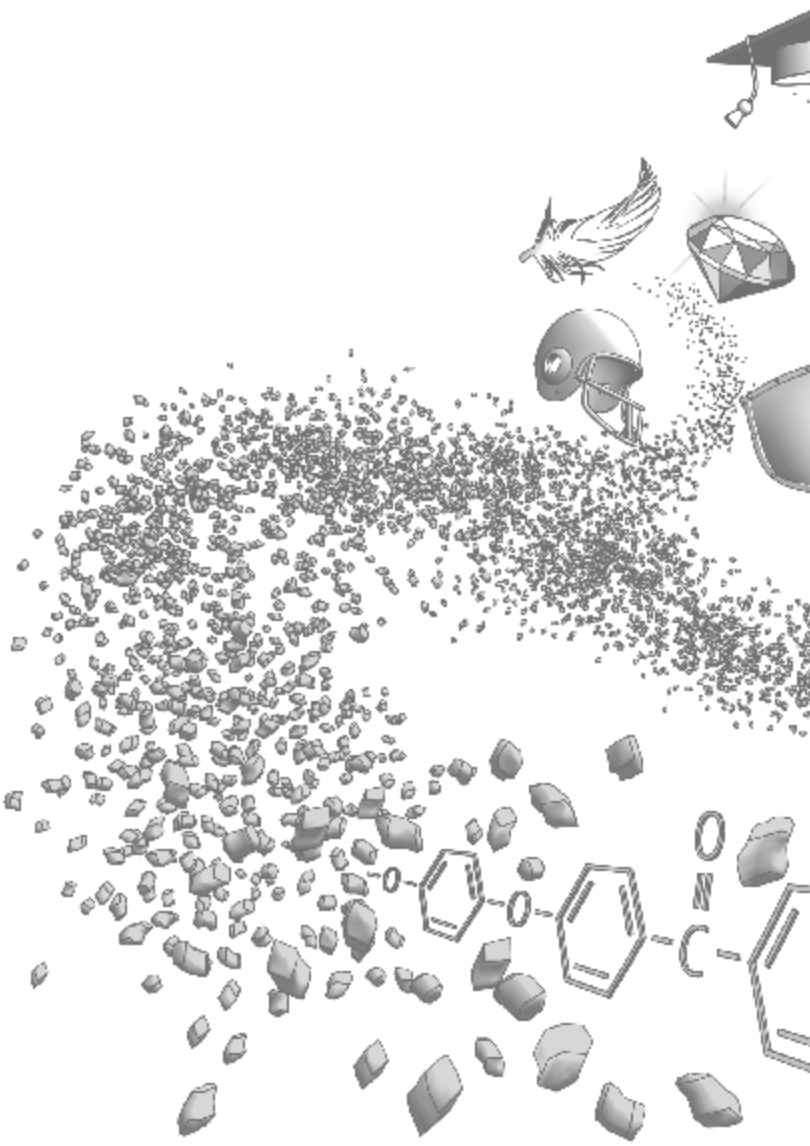
High Temperature Resistance

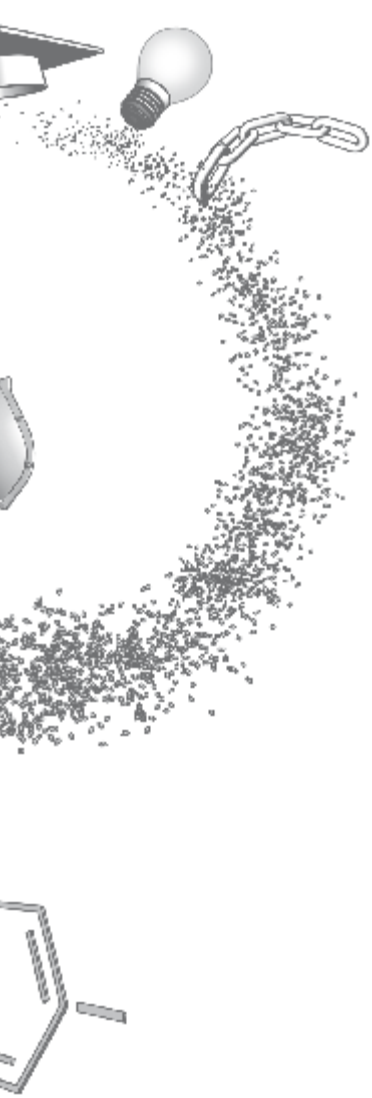
Expertise

Collaborative Approach to Application Design

Extensive Knowledge

Security of Supply – Worldwide





victrex®

aptiv®

VICOTE®

victrex pipes™

Automotive Requirements

- Improved energy efficiency
- Reduced system weight
- Longevity – extended component life
- Reduced maintenance, so lower costs and more uptime
- Lubricant free operation
- Ability to withstand high operating temperatures
- Lower noise generation
- Tight tolerances
- Miniaturization

Victrex Solutions

- Superior combination of high fatigue strength and ductility
- High mechanical properties through a wide range of temperatures
- Excellent chemical resistance against automotive fluids
- Good resistance to ageing
- High resistance to wear
- Low coefficient of friction
- Resists absorption of moisture
- Ability to match thermal expansion of metals
- Low specific gravity
- Ease of processing

The automotive industry is globally driven by environmental and safety standards and requires increased longevity due to extended warranty and lower costs of production. Consumers are demanding less frequent maintenance, more comfortable driving experiences, and better fuel economy, with no deterioration in performance.

The reduction of the vehicle weight, driven by the desire for lower CO_2 emissions and improved mileage, results into miniaturization of components and functional integration which are at the forefront of the automotive industry's efforts.

Subsequently OEMs are forced to identify materials that provide enhanced performance and efficiency, offer high specific strength and lower weight and enable more economic component solutions.

The demand for smaller components with an improved reliability made from lighter materials that withstand a higher temperature range and have an excellent strength as well as flow characteristics has increased. This demand can be met by producing thinner-walled parts made from high performance thermoplastics. In addition, there can be the added benefit of reducing overall costs by consolidating complex metal parts into a single injection-molded thermoplastic component.

Industry standards dictate that materials today need to perform at 150°C (302°F) or higher depending on the application, whereas years ago temperature range requirements were about 100–120°C (212–248°F). OEMs, for example, are searching for materials that can perform up to 180°C (356°F) in the lower areas of steering columns and 220°C (428°F) in turbocharger components. With these requirements in mind, and while still meeting the other drivers in this industry, it may not be feasible to use metal or traditional plastics in such hostile environments, where even light alloys show a loss in mechanical strength at temperature ranges around 200°C (392°F).

Victrex Polymer Solutions, a division of Victrex plc, manufactures polyaryletherketones (PAEK) including VICTREX® PEEK polymers. Exhibiting consistent mechanical properties at 150°C (302°F) and higher, these high performance thermoplastics meet the revised automotive industry requirements. A recent study demonstrates that VICTREX PEEK polymers maintained their original stiffness, tensile and impact strength after 5000 hours of use; conventional materials like heat-stabilized polyamide and nylon 4.6 recorded property losses up to 50% under the same conditions.

Victrex thermoplastic polymers have melting temperatures between 343°C (649°F) and 387°C (729°F) and glass transition temperatures between 143°C (289°F) and 162°C (324°F), allowing them to perform in the most aggressive environments.

Material Properties

High Mechanical Strength

Due to the semi-crystalline structure of VICTREX PEEK polymers its mechanical properties are maintained well past the glass transition temperature.
See figure 1

Dynamic Tensile Fatigue

VICTREX PEEK HMF grades are a high modulus carbon fiber-filled compounds which combine easy process ability with superior mechanical performance and improved fatigue performance compared to the existing high strength grade range of carbon fiber-filled VICTREX PEEK polymer.
See figure 2

Compressive Strength

As most automotive applications are also used under compressive load, Victrex supports customers by providing the relevant data with respect to compressive creep.
See figure 3

Thermal Expansion

The inclusion of fillers into VICTREX PEEK polymers result in a reduction in the coefficient of thermal expansion (CTE), to a level where it is comparable to metals, thus allowing direct replacement of metal components with polymer-based components without any risks arising due to differential expansion.
See figure 4

Tolerances

Tolerances of injection molded parts are usually in the range of 0.05% of the dimension required. More and more high precision injection molders are now able to hold tolerances down to 0.02mm and tighter.

Figure 1 Tensile strength

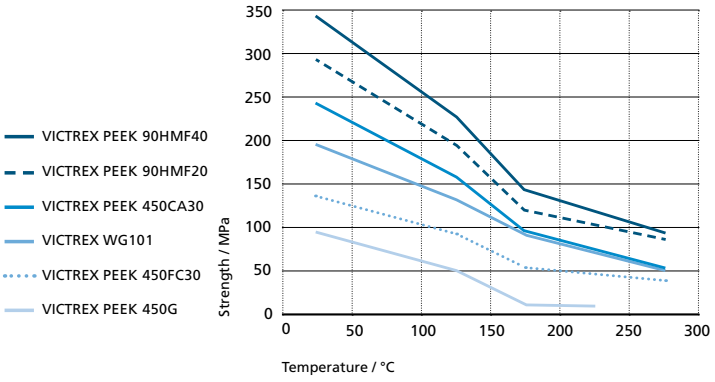


Figure 2 Tensile fatigue

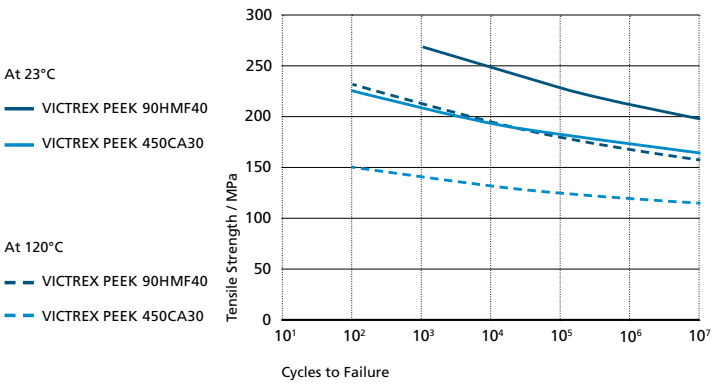


Figure 3 Compressive creep, stress of 50MPa at 120°C

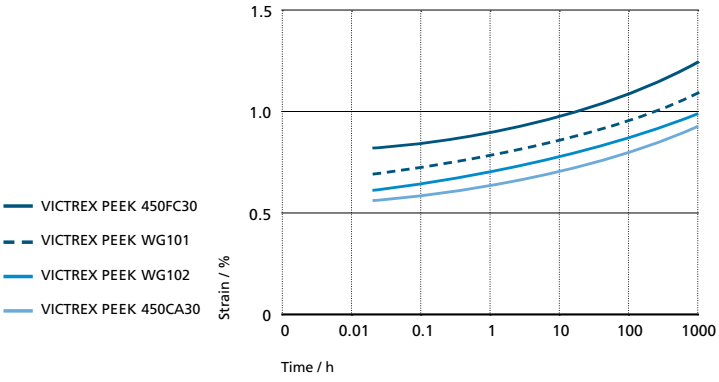
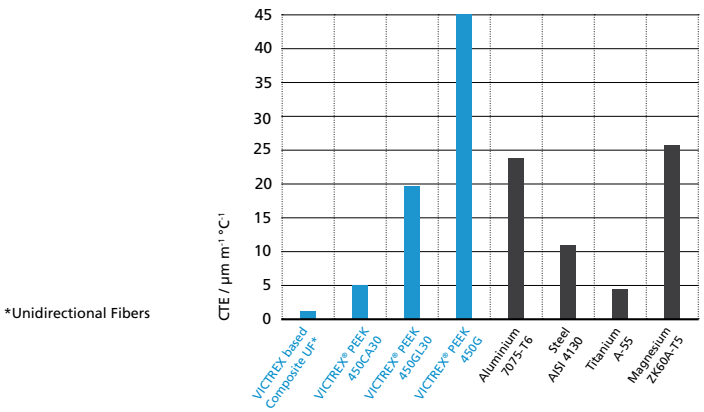


Figure 4 Coefficient of linear expansion along flow below Tg



Specific Strength

VICTREX PEEK polymers have high tensile strength and low density compared to metals. Reinforcing the polymer with chopped glass or carbon fibers yields strength-to-weight ratios that meet or exceed those of common lightweight materials. Continuous fiber reinforced composites made with a VICTREX PEEK polymer matrix have even higher strength and stiffness than some metals.
See figure 5

Long Term Behavior

VICTREX PEEK provides distinct advantages when compared to other technical plastics and leads to long-term benefits. The majority of properties displayed on data sheets reflect short term failure and cannot be used for part design. Usually temperature range in Automotive of -40°C to 150°C is required. Therefore it is essential to consider the permissible permanent stress and not compare data sheet values at room temperature.

Figure 6 illustrates the upper stress levels without exceeding 0.5% strain. PEEK with carbon fiber can be loaded 2.5 times higher [45 MPa] than PPS or PPA [17 MPa].

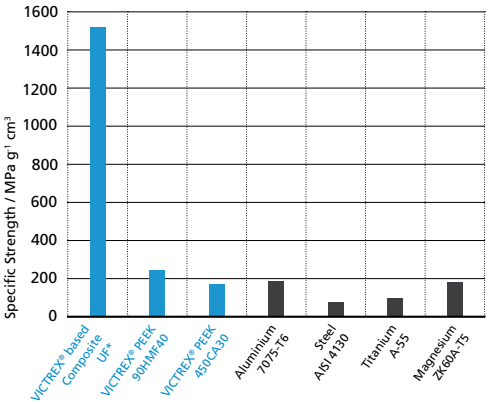
Positioning against Technical Plastics and Metals

When considering substitution of metal components with plastic, VICTREX PEEK 90HMF40 provides by far the lowest weight per volume ratio. It allows extremely high weight savings versus metals. The material is capable of outperforming standard aluminum alloys in weight and profile height, and is almost volume neutral when compared to tribo-alloy brass materials. Weight savings up to 80% are achievable when substituting VICTREX PEEK 90HMF40 for steel components and availability of only 20% more space.
See figure 7

When structural stiffness is more important than strength, VICTREX PEEK 90HMF40 provides by far the lowest weight to space ratio. Significant weight savings are achievable when compared to metals. The properties of VICTREX HMF materials are similar to those of aluminum but the lower density results in considerably lower weight.
See figure 8

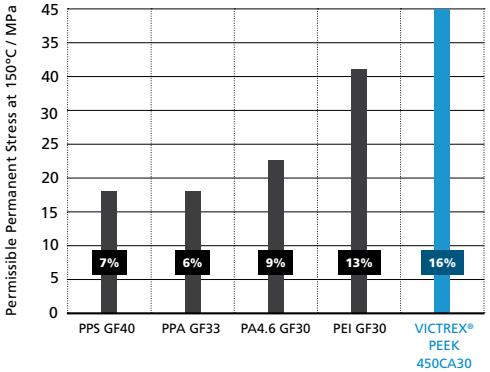
Dimensional stability and long-term stress performance showed improvements when compared to other materials in temperature ranges above 120°C (248°F).

Figure 5 Specific tensile strength at room temperature



*Unidirectional Fibers

Figure 6 Permissible permanent stress at 150°C (1.000 h)



Calculated according strain criteria (0.5%) according to IKV Germany

Percentage of tensile strength [data sheet values at 23°C]

Figure 7 More weight saving and less space requirement than aluminium

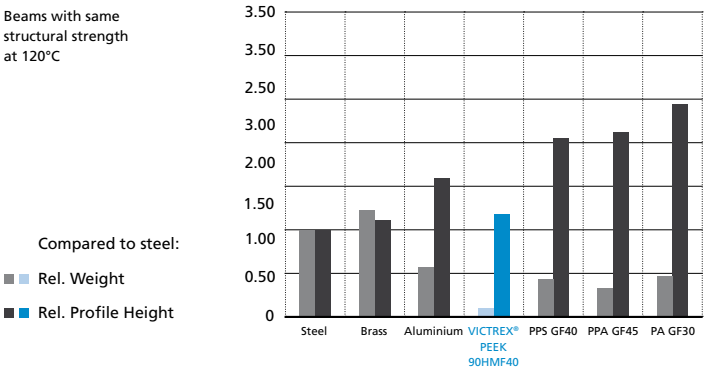
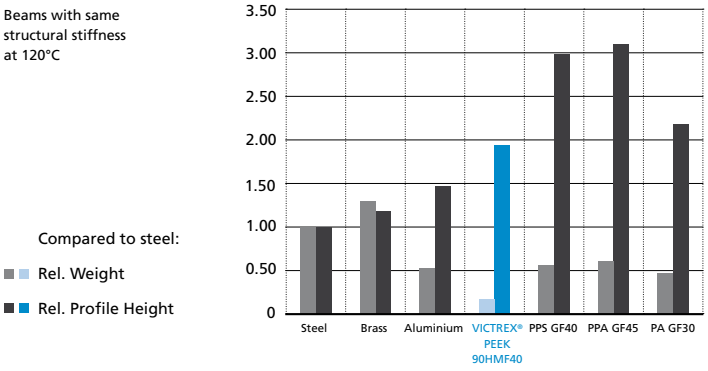


Figure 8 80% weight saving potential when compared to steel



Creep Resistance

Creep may be defined as the deformation observed in a sample versus time under a constant applied stress. VICTREX PEEK polymer has outstanding creep resistance for an engineering thermoplastic material and may sustain large stresses over a useful service life without significant time induced deformation.

The figure below displays the creep behavior of VICTREX PEEK 450G and 450CA30 with respect to applied stress, time and temperature. Victrex materials show outstanding creep resistance and may sustain large stresses over a useful service life with little time-dependent deformation. The creep strain for some of the high performance compounds from the VICTREX PEEK grade range are plotted against time in chart below.

At room temperature both filled and unfilled VICTREX PEEK polymer show excellent creep resistance. At temperatures beyond the glass transition temperature (T_g) only reinforced VICTREX PEEK polymer will be suitable for structural applications. The apparent modulus of VICTREX PEEK polymer is in many cases higher than tensile/flexural modulus of other high temperature thermoplastics.

See figure 9a and 9b

Tribology

Tribology is defined as the interaction of contacting surfaces under an applied load in relative motion. If the surface of a material is viewed on a microscopic scale, a seemingly smooth finish is, in fact, a series of peaks and troughs. When two materials are then placed in contact and moved relative to one another, the peaks of both surfaces collide. The removal of material from the top of the peaks may be considered as wear, and resistance to the motion as a frictional force. VICTREX PEEK polymers, and compounds based on VICTREX PEEK polymers, are used to form tribological components due to their outstanding resistance to wear under high pressure (p) and high velocity (v) conditions.

The friction and wear behavior of a material may be evaluated using one of several test geometries. The data given in this flyer were generated under dry conditions using the standard ASTM D3702 method on injection molded thrust washers.

Figure 9a Tensile strain versus time

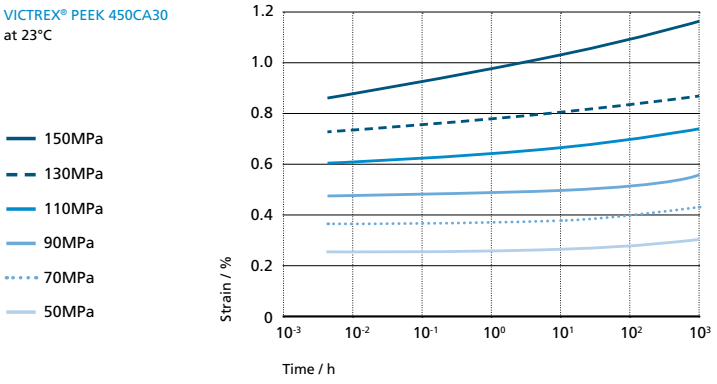
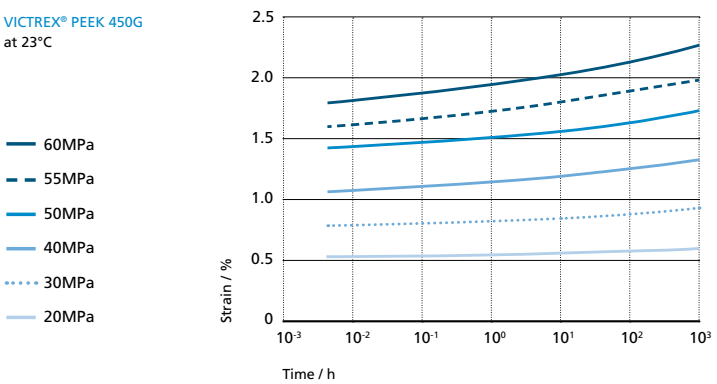


Figure 9b Tensile strain versus time



Benefits For Wear Applications

- Enables bearings to survive longer under poor lubrication conditions for periods of time
- Eliminates traditional assembling operations
- Thermoplastic based bushings can be over moulded
- Higher efficiency
- 25–75% lower wear rate
- 70% of weight saving compared to metal bushing
- Lower moment of inertia
- Less critical than metal in dirty environment – no blocking from particles
- Improved lifetime compared to other plastics
- Smoother operation – noise reduction compared to metal

VICTREX® WG™ – Premium Wear Grades

VICTREX® WG™ polymers offer a lower coefficient of friction compared to other established wear grades from Victrex and also against thermoset materials such as polyamide-imide (PAI) and polyimide (PI).

Within tribological systems the coefficient of friction varies depending on the choice of counterface material and its surface roughness, as well as on the specific conditions of speed and pressure as shown in figure 10. The specific wear rate shown in figure 11 is another important consideration in design.

Under these specific conditions, VICTREX® WG™ polymers are shown to be among the highest performing wear grade materials. Bearings for many applications are produced in large numbers, and production speed and costs are critical. Victrex polymers are one of the few high performance tribological materials which can be injection molded to form finished components without further thermal treatment. Although PV values are a useful guide to comparative tribological performance, there are no absolute values because identical experimental conditions cannot be reproduced.

Typical Application Areas

Oil and Vacuum Pumps

When used in vane-type pumps, gear-oil pumps and centrifugal type pumps, Victrex materials offer the following benefits:

- Reduced energy consumption – lower moment of inertia
- 70% of weight saving potential
- Up to 10% better power efficiency
- 1–2% fuel saving according to NEFZ
- Less critical than metal in dirty oil – no blocking of particles
- Improved lifetime compared to other plastics
- Smoother running – noise reduction compared to metal

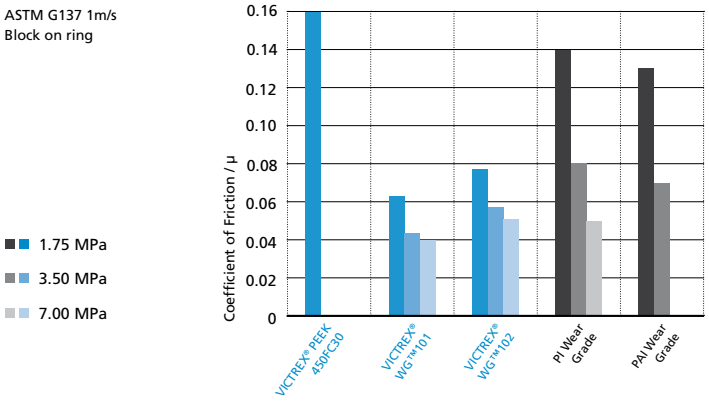
▶ **CO_2 reduction – longer lifetime**

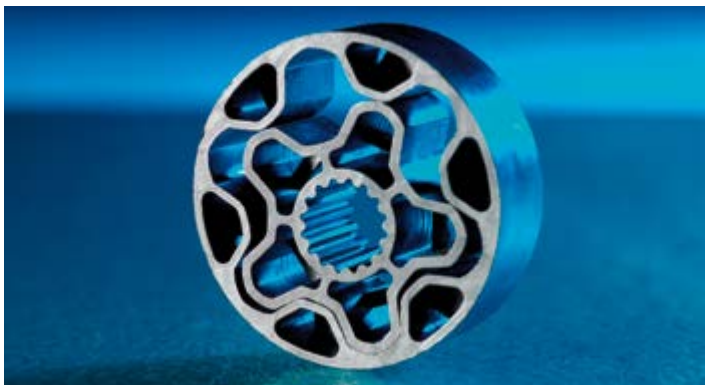
See pictures 1 and 2

Seals and Supporting Rings

Seals and supporting rings made with VICTREX PEEK polymers have been used in automotive applications for many years replacing metal and PTFE seals. The material provides benefits such as:

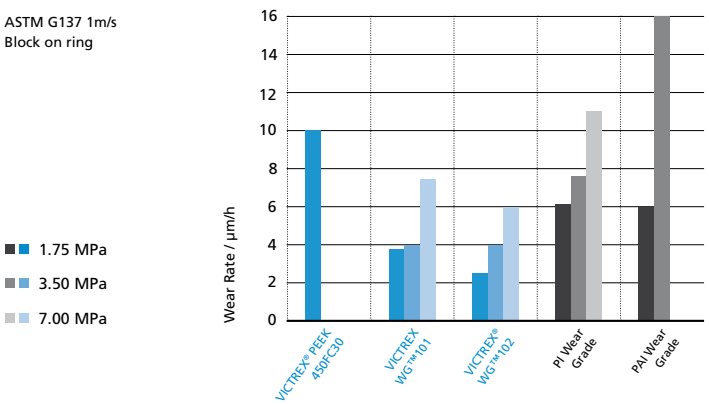
Figure 10 Up to 20% higher efficiency





Picture 1 Pumps: 10 –15% higher efficiency – lower noise

Figure 11 Longer lifetime – more uptime



Picture 2 Pumps: up to 2% reduction in fuel consumption – longer lifetime

- Reliable operation also in extreme conditions
- Low density – low moment of inertia – less power consumption
- Reduced friction – supporting CO_2 reduction
- Excellent compressive creep resistance
- Allows use at higher oil pressures
- Maintenance free operations

▶ Maintenance free – longer lifetime

See pictures 3 and 4

Hydraulic Valves

In hydraulic valves VICTREX PEEK polymer can substitute the steel valve poppets which act upon the valve cones and ball valves by offering benefits such as:

- Excellent dynamic fatigue resistance = higher pulsing frequencies – longer life- and uptime
- Superb creep resistance – long term proven = lower leakage – higher pressure applicable
- Outstanding wear resistance and low coefficient of friction = potentially also protecting mating partner – higher system efficiency
- Tighter tolerances for less pressure loss

▶ Enhanced durability reducing system lifetime cost

Picture 3 Very stable leakage (0,075l/min) – around 40% less than other plastics

Picture 4 Supporting Rings made of VICTREX® PEEK can withstand five times higher loads than PTFE

Gears

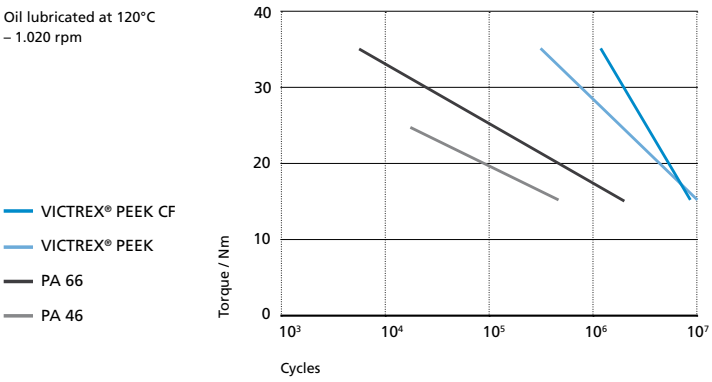
Gear wheels are required to meet a complex spectrum of demands because various types of loads always occur in combination. The correct functioning of a gear wheel depends on good tribological and mechanical properties, resistance to aggressive media, durability and heat resistance, and of course dimensional accuracy.
Figure 12 demonstrates that the durability of VICTREX PEEK polymer-based gears is higher than gears made from other polymers. This means gears and the assemblies around them can be made smaller, provide weight and cost savings, while delivering the same or even longer lifetime.

Features of Gear Materials:

- High mechanical strength at elevated temperatures
- Excellent dynamic fatigue resistance at temperatures above 120°C (248°F)
- High strength and stiffness
- Low moisture absorption ensuring dimensional integrity and improved stability
- Increased design flexibility
- Ease of processing – gears can be injection molded to high accuracy

Gears in Mass Balancer Systems demonstrated the benefits of PEEK with up to 69% weight reduction resulting in 78% reduction in inertia compared to grey iron gear.

Figure 12 Lifetime of standard 2mm-module gear



- 3 dB improvement in NVH compared to grey cast iron gear set
- 9% reduction in torque required to operate

▶ Higher operation efficiency
See picture 5

Thrust Washers

VICTREX PEEK polymer in thrust bearing material can provide the following benefits:

- Reduce heat generated by the bearing due to lower coefficient of friction
- VICTREX PEEK polymer can tolerate shock loads
- Maintenance-free
- High volume production via injection molding

▶ Increased system efficiency
See picture 6

Rolling Bearing Elements

VICTREX PEEK polymer as bearing cage material can provide the following benefits:

- Reduces energy consumption
- Accommodates shock loads and high centrifugal forces
- Enables the bearing to survive longer under poor lubrication conditions
- Quieter performance

▶ Extended bearing service life

Advantages of VICTREX PEEK polymers in automotive applications include high resistance against aging and creep at high operating temperatures and high circumferential speeds.
See picture 7

Electrical Components

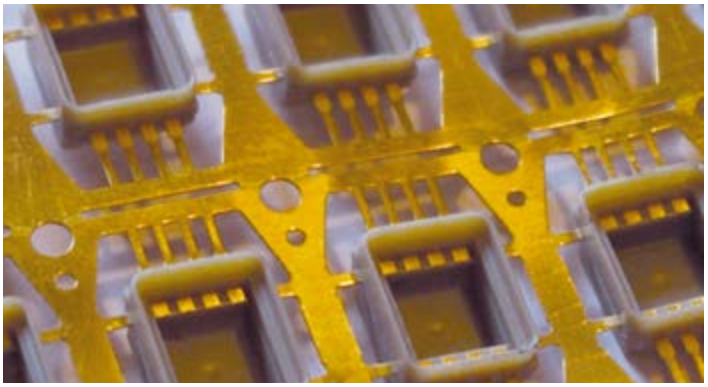
With the introduction of hybrid or electrical powered vehicles, the demands on electronic components such as connectors and sensors have changed. New opportunities including flexible printed circuit substrates and wire and cable protection benefit from the advantages offered by VICTREX PEEK polymer:

- Heat deflection temperature (HDT) over 300°C (572°F)
- Maintains strength and dimensional stability with the increased processing temperature associated with lead-free solder systems
- No deformation following reflow at 250–280°C (482–536°F) for 5–10 sec for multiple cycles
- Significantly stronger impact strength and weld-line

Picture 5 Balance shaft gear: up to 78% reduced moment of inertia

Picture 7 Bearing Cages: extended bearing service life

Picture 6 Thrust washers: increased system efficiency



Picture 8 More reliable airbag sensor housings

strength compared with liquid crystal polymers (LCP)
- High stiffness and minimum level of creep
- Low dielectric constant and dissipation factor at various frequency ranges at room temperature and elevated temperature
- RoHS compliant
- Flame retardant properties – certain grades of VICTREX PEEK polymer can meet UL94 V-0 rating at the minimum thickness down to 0.5mm (0.021 in)

See picture 8

Data Generation for Applications

More and more demanding application areas ask for the resistance against aggressive automotive fluids and extreme temperatures which are close to the melting point of many technical plastics. To meet these demands, Victrex Polymer Solutions generated compatibility data for Victrex products in:

- AdBlue®
- Transmission oils
- Testing fluids (DIN51604) FAM-A/B
- Alternative fuels (Biodiesel M35/M85/E15/E85)
- Brake fluids
- Exhaust condensate VDA 230-214
- Water glycol

Data available on request:
- High heat creep data
- Material properties at 150°C (302°F) / 5,000 hours
- Ageing up to 300°C (572°F) (12 weeks)

Victrex is committed to ensuring full REACH compliance for all our current and future products whilst ensuring no disruption in the marketing and supply of those products. The majority of our products comply with the requirements of the GADSL Reference List dated July 2010.

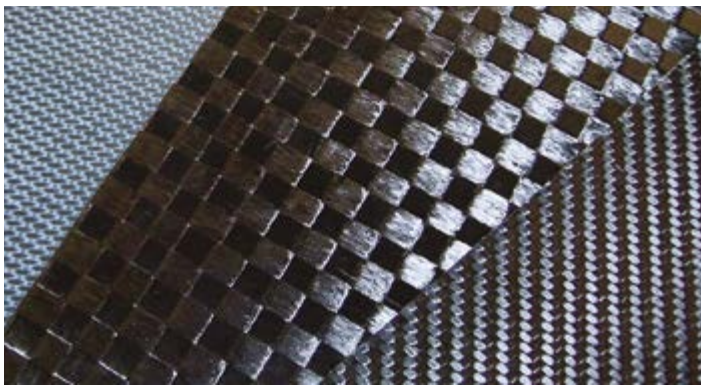
IMDS entries on request via imds@victrex.com

Speciality Products

APTIV® Films

APTIV® films are among the most versatile and high performing thermoplastic films on the market today. They are produced by Victrex in thicknesses ranging from 6–750µm and in widths up to 1450mm (57in). A range of grades are available depending on application requirement.
APTIV film is compatible with a wide range of secondary processes including thermoforming, adhesive-free lamination (see picture 9), heat sealing, laser welding and metallization.
APTIV is used in a range of automotive applications including

Picture 9 Harsh environment RFID tags



Picture 10 Carbon fabric

Benefits of APTIV film insulation

Absorption and permeation of water lower than PI and PEI films
Insulation Di-electric strength better than PI and PTFE films, much better than NMN paper Package Excellent
Break down voltage values saves space – more wire within a given volume Heat Transfer double heat transfer than NMN paper Inherent Flame Resistant
Halogen free, flammability rating up to UL V0
Assembling more reliable – higher strength/stiffness
Trusted for E-Mobility
Consistent electrical properties

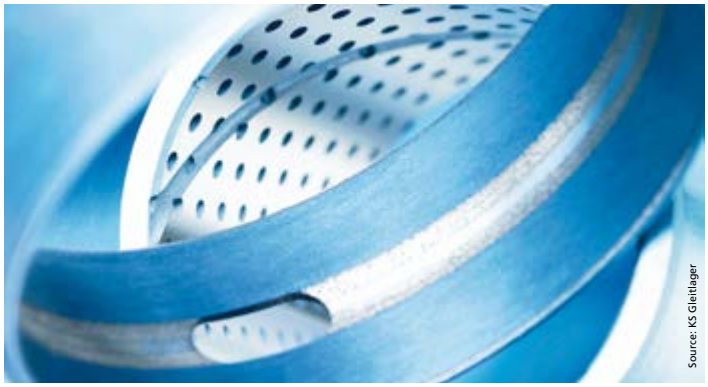
electrical insulation for motors and alternators gaskets, high temperature circuit substrates labels, RFID tags, pressure sensor diaphragms and other demanding film applications.

PAEK-based Composites

In addition to standard VICTREX PEEK grades for injection molding or extrusion, VICTREX PEEK polymer can be used as a matrix for thermoplastic composite pre-pregs made of carbon, glass or aramid continuous fibers. Its outstanding properties make it an excellent substitute for metals and thermoset composite structures for demanding applications with dynamic loads at elevated temperatures. Composites with PAEK polymers offer lightweight opportunities. VICTREX PEEK polymer-based composites are available as consolidated fabrics (see picture 10) unidirectional tape.

To use composite parts with Victrex PAEK-based materials result in benefits:

- weight reduction potential up to 80% compared to steel
- more than 5 times the specific strength of light metals
- safety and environmental compliance
- enabling design freedom
- more efficient trough out-of-autoclave processing
- reduced manufacturing costs
- longer shelf life than thermosets



Picture 11 High performance lead free bushing

Picture 12 VICOTE® needle roller bearings

VICOTE® Coatings

VICOTE® Coatings and Dispersions are based on Victrex's range of polymers and provide reduced coefficient of friction along with enhanced wear, scratch, abrasion resistance, high heat resistance and resistance to chemical attack. All of the key properties of VICTREX PEEK polymer are present once a thin [25–50microns (0.001–0.002in)] layer is applied to any metallic substrate. VICOTE Coatings are non-solvent based and have some of the industry's lowest content of volatile organic compounds (VOC) of any commercially available coating. The majority of VICOTE Coatings grades are GADSL and RoHS compliant.

VICOTE® coatings provide:

- Exceptional abrasion resistance, very hard, tough, and scratch resistant
- Excellent wear, creep and cut-through resistance
- Extremely durable at high temperatures
- One of the lowest coefficients of friction
- Excellent levels of elongation

VICOTE® Coatings are one of the highest performing thermoplastic coatings on the market. Highly resistant to creep and flow caused by compression, these are key factors which can contribute to automotive applications lasting longer and working more efficiently.
See pictures 11 and 12

Conclusion

The use of Victrex's materials is gaining momentum in the automotive industry, as engineers and designers use the exceptional combination of material properties, in conjunction with the ease of processing, to facilitate achieving their objectives. Parts made out of Victrex materials are economical to produce, and facilitate overall systems cost reductions by eliminating secondary operations for parts, such as machining, as well as facilitating a reduction in part count when compared with metal parts.

In addition, the use of Victrex PAEKs facilitates the achievement for vehicles of a reduction in weight, enhanced fuel consumption, lower CO_2 emissions, and reductions in noise, vibration and harshness, and finally as thermoplastics are fully recyclable, meeting another key driver in the industry.

By utilizing Victrex materials, automotive suppliers and manufacturers are able to better meet the constantly increasing demands of this important industry, and their consumers. With over 30 years of Polyaryletherketone experience in serving the automotive industry, Victrex Polymer Solutions can help you identify your material and processing needs.

Properties Overview

Property	Conditions	Test Method	Units	VICTREX® PEEK 450FE20	VICTREX® PEEK 450G	VICTREX® PEEK 450FC30	VICTREX® WG™101	VICTREX® PEEK 450CA30	VICTREX® PEEK 90HMF40
General									
Density	Crystalline	ISO 1183	gcm^{-3}	1.40	1.30	1.45	1.44	1.40	1.45
Water Absorption (3.2 mm thick tensile bar)	24h, 23°C	ISO 62-1	%		0.07		0.04	0.04	0.03
	Equilibrium, 23°C				0.40		0.3	0.3	0.3
Mechanical									
Tensile Strength	23°C	ISO 527	MPa	78 at yield	100 at yield	140 at break	180 at break	260 at break	330 at break
	Break, 125°C				50	95	125	160	225
	Break, 225°C				13	45	65	50	110
Tensil Elongation	Break, 23°C	ISO 527	%	25	45	2.2	1.9	1.7	1.2
Flexural Strength	23°C	ISO 178	MPa	125	165	230	280	380	480
Flexural Modulus	23°C	ISO 178	GPa	3.2	4.1	11.5	17	23	37
Compressive Strength	23°C	ISO 604	MPa	105	125	170	230	300	310
	120°C			65	70	110	160	200	250
Izod Impact Strength	0.25 mm notch, 23°C	ISO 180/A	kJm^{-2}	7.5	7.5	6.0	5.5	9.5	10.5
	Unnotched, 23°C	ISO 180/U		no break	no break	40	35	45	60
Thermal									
Melting Point		ISO 11357	°C	343	343	343	343	343	343
Glass Transition (Tg)		ISO 11357	°C	143	143	143	143	143	143
Specific Heat Capacity	23°C	DSC	$kJkg^{-1}$ °C		2.2	1.8		1.8	1.8
Coefficient of Thermal Expansion	Along flow below Tg	ISO 11359	ppm °C	40	45	15	9	5	3
	Average below Tg			60	55	45	35	40	35
	Along flow above Tg			120	120	20	10	6	1
	Average above Tg			140	140	115	85	100	80
Heat Deflection Temperature	1.8 MPa	ISO 75A-f	°C	150	152	315	343	336	349
Thermal Conductivity	23°C	ISO/CD 22007-4	Wm^{-1} °C^{-1}		0.29	0.87	1.30	0.95	
Relative Thermal Index (RTI)	Electrical	UL 746B	°C		260				
	Mechanical w/o impact				240	240		240	
	Mechanical w/impact				180	180		200	
Fire, Smoke & Toxicity									
Flammability Rating		UL94	n/a		V-0 at 1.5mm	V-0 at 0.75mm		V-0 at 0.5mm	
Limiting Oxygen Index	0.4mm thickness	ISO 4289	$\%O_2$		24	43			
	3.2mm thickness				35				
Electrical									
Dielectric Strength	2.0mm thickness	IEC 60243-1	$kVmm^{-1}$	26	23				
	50µm thickness				190				
Loss Tangent	23°C, 1MHz	IEC 60250	n/a	0.004	0.004				
Dielectric Constant	50Hz, 0–150°C	IEC 60250	n/a	2.8	3.0				
	50Hz, 200°C	IEC 60250			4.5				
Volume Resistivity	23°C	IEC 60093/ ASTM D4496	Ωcm	10^{16}	10^{16}	10^{10}	10^{6}	10^{5}	10^{5}
ShoreD hardness	23°C	ISO 868		81	84.5	83	85	87.5	88.5

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