

PROPERTIES GUIDE

VICTREX PIPES™

DURABILITY AND LIGHTWEIGHT
FOR HARSH ENVIRONMENTS



Material of choice...

As pipe applications are required to perform in increasingly demanding conditions engineers are challenged to develop solutions that provide enhanced performance including reliability and durability to increase service life and reduce maintenance downtime, weight reduction for fuel efficiency, lower cost and the ability to satisfy more stringent environmental and safety regulations combined with the ability to perform in extremely harsh environments.

Material selection is critical. Due to these mounting performance expectations the use of plastics to replace metal in downhole, offshore, aerospace and industrial applications is expanding and the development of high performance materials and advances in design and manufacturing methods is accelerating this trend.

Design engineers are focused on identifying new material solutions to achieve current and future performance requirements. Based on its track record of success and a unique combination of performance properties VICTREX™ PEEK polymer in a variety of forms has been used to replace metals and lower performing engineering thermoplastics in these markets for years.

Today VICTREX PEEK polymer is increasingly being specified to help engineers not only meet these growing demands but to enable them to develop innovative solutions that can help to differentiate their products to achieve competitive advantage in the marketplace. Representing the latest advances in both material and manufacturing technology, VICTREX Pipes™ are an innovative, next generation solution to deliver greater long-term reliability in demanding operating conditions.

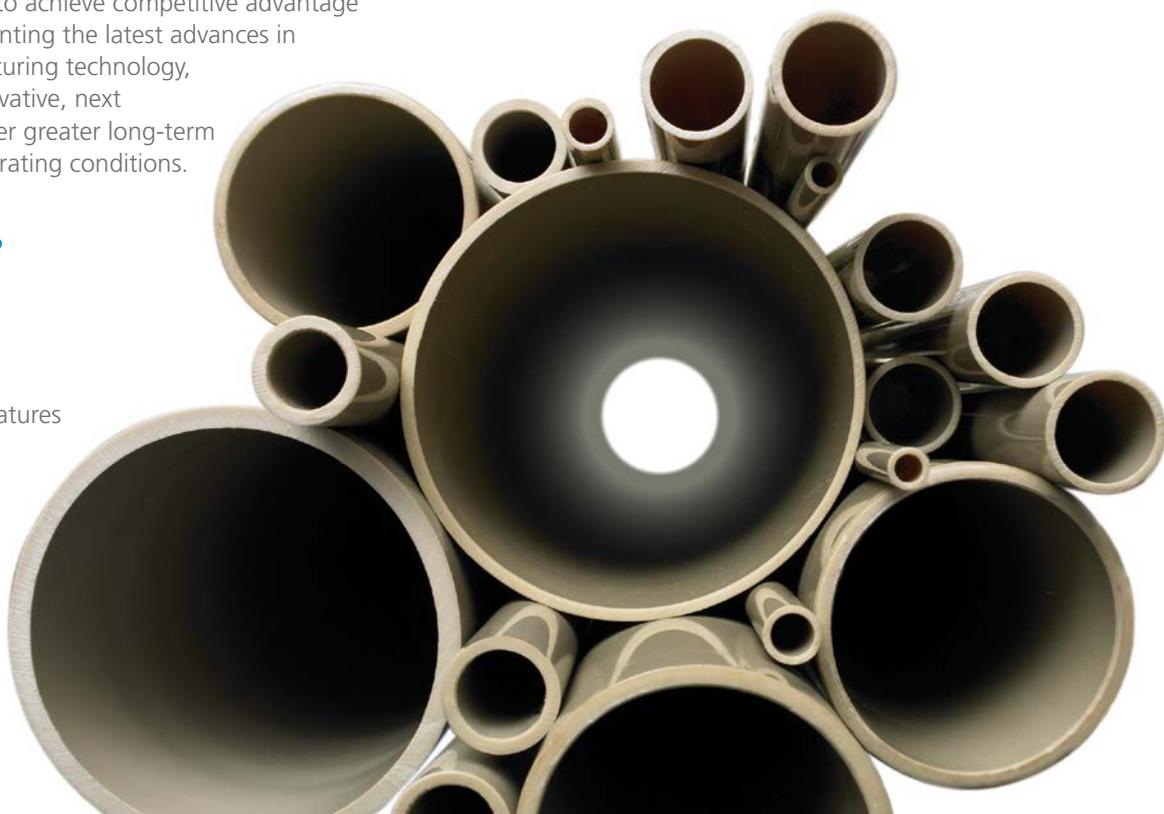
Why VICTREX Pipes?

- ▲ Capable of operating in harsh environments
- ▲ Reduce weight
- ▲ Raise operating temperatures
- ▲ Minimise corrosion
- ▲ Smooth bore to reduce friction and fouling
- ▲ Extend service life
- ▲ Reduce abrasion
- ▲ Reduce downtime

World class quality

Victrex Polymer Solutions is the world's leading manufacturer of high performance polyaryletherketones (PAEK) including VICTREX PEEK polymer. With over 30 years focus and expertise and a product portfolio with one of the broadest ranges of polyaryletherketones on the market Victrex Polymer Solutions is more than a material supplier.

Victrex offers unmatched product and technical service capability to deliver security of supply, capitalising on its unique integrated supply chain, three state-of-the-art technology centres and global technical, sales and marketing teams.



BENEFITS OF VICTREX PIPES

- ▲ Increased reliability and durability for extended service life
- ▲ Overall system cost reduction from lower maintenance and reduced downtime
- ▲ Lightweight
- ▲ Qualification, safety and regulatory approvals
- ▲ Fully integrated supply chain and Quality Management Systems

Advantages versus metals

- ▲ Cost-effective compared to expensive corrosion-resistant alloys
- ▲ Flexibility to ease installation, spooling
- ▲ Ductile behaviour
- ▲ High resistance to oilfield chemicals
- ▲ Resistant to stress corrosion cracking and pitting in harsh environments
- ▲ Lower thermal conductivity
- ▲ Lighter part weight to improve fuel efficiency
- ▲ Lower noise transmission
- ▲ Less fluctuation in raw material pricing allows for more reliable long-term supply



Crush resistance testing used to measure robustness of the pipe

Advantages versus other plastic pipe materials

- ▲ Extended performance range
- ▲ Excellent chemical, abrasion, permeation resistance at high temperatures
- ▲ High mechanical strength with high ductility
- ▲ Halogen-free
- ▲ Low flammability
- ▲ Low smoke and toxicity
- ▲ High purity with low extractables
- ▲ Low moisture absorption
- ▲ Excellent Rapid Gas Decompression (RGD) performance

Table 1 Comparative data for engineering thermoplastics (Excellent 5 – 0 Poor)

	Temperature Resistance	Chemical Resistance	Abrasion Resistance	Mechanical Strength
VICTREX PEEK	5	4	5	5
PTFE	5	5	2	1
PFA	5	5	3	2
PVDF	3	4	3	3
PPS	4	4	4	2 (unreinforced) 4 reinforced
PA11	2	3	5	3/4

As can be seen from the ranking order above, where VICTREX PEEK polymer has the advantage is in its unique combination of properties especially at high temperature.

ADVANCED TECHNOLOGY

VICTREX Pipes are durable, lightweight pipe and tube extruded from VICTREX PEEK polymer. An excellent alternative to metals and other polymers, VICTREX Pipes are a range of high performance products which can operate in conditions where a combination of high temperature, chemical and corrosion resistance together with excellent wear and abrasion resistance are key requirements, refer to Figures 1 to 3.

Additionally they offer low permeability, the low solubility of various fluids and gases in VICTREX PEEK combined with its high modulus ensures that it is not susceptible to the effects of Rapid Gas Decompression (RGD). VICTREX Pipes also have excellent radiation resistance, refer to Figure 10.

Figure 1 Wear and abrasion resistance of typical engineering polymers

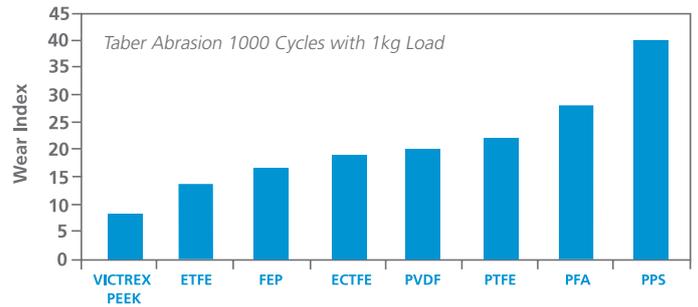


Figure 2 Hydrolysis resistance of VICTREX PEEK polymer at 14 bar and 200°C

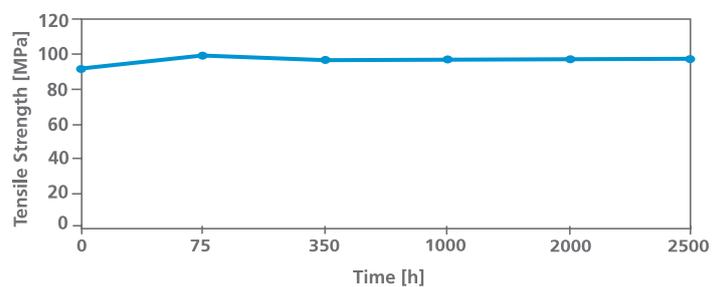


Figure 3 Continuous use temperature of engineering polymers

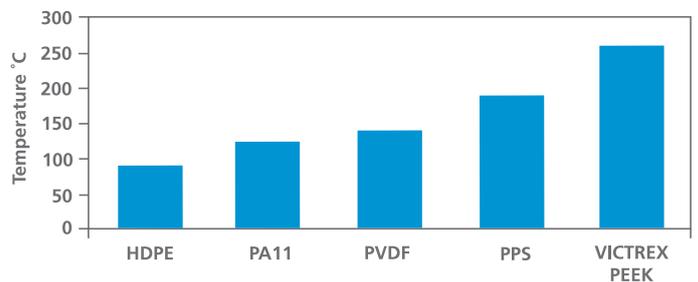


TABLE 2: PROPERTIES OF VICTREX PEEK POLYMER

Property	Conditions	Test Method	Units	VICTREX PEEK Polymer
Tensile Modulus	23°C	ISO 527	GPa	3.5
Tensile Strength	Yield, 23°C	ISO 527	MPa	100
Tensile Elongation	Break, 23°C	ISO 527	%	45
Melting Point		ISO 11357	°C	343
Glass Transition (T _g)		ISO 11357	°C	143
Continuous Use Temperature	Mechanical w/o impact		°C	240
Continuous Use	Mechanical w/ impact		°C	180
Water Absorption	24 hrs 23°C	ISO 62-1	%	0.07
Specific Gravity (density)	Crystalline	ISO 1183	g/cm ³	1.3
Coefficient of Thermal Expansion	Below T _g	ASTM D696	10 ⁻⁵ °C ⁻¹	4.7
Coefficient of Thermal Expansion	Above T _g	ASTM D696	10 ⁻⁵ °C ⁻¹	10.8
Abrasion	1000 cycles 1 kg load	Taber (CS10)	g	6
Rockwell Hardness	M scale	ASTM D785		99

PRODUCT RANGE

VICTREX Pipes are currently available in size ranges from 6 mm (0.24 in) outer diameter (OD) up to 206 mm (8 in) OD with wall thicknesses depending on the OD from 0.8 mm (0.03 in) up to 5 mm (0.2 in). They are available either as straight lengths or for smaller diameters in coiled lengths up to 3000 m (9842 ft). Please enquire for products outside these standard sizes and lengths.

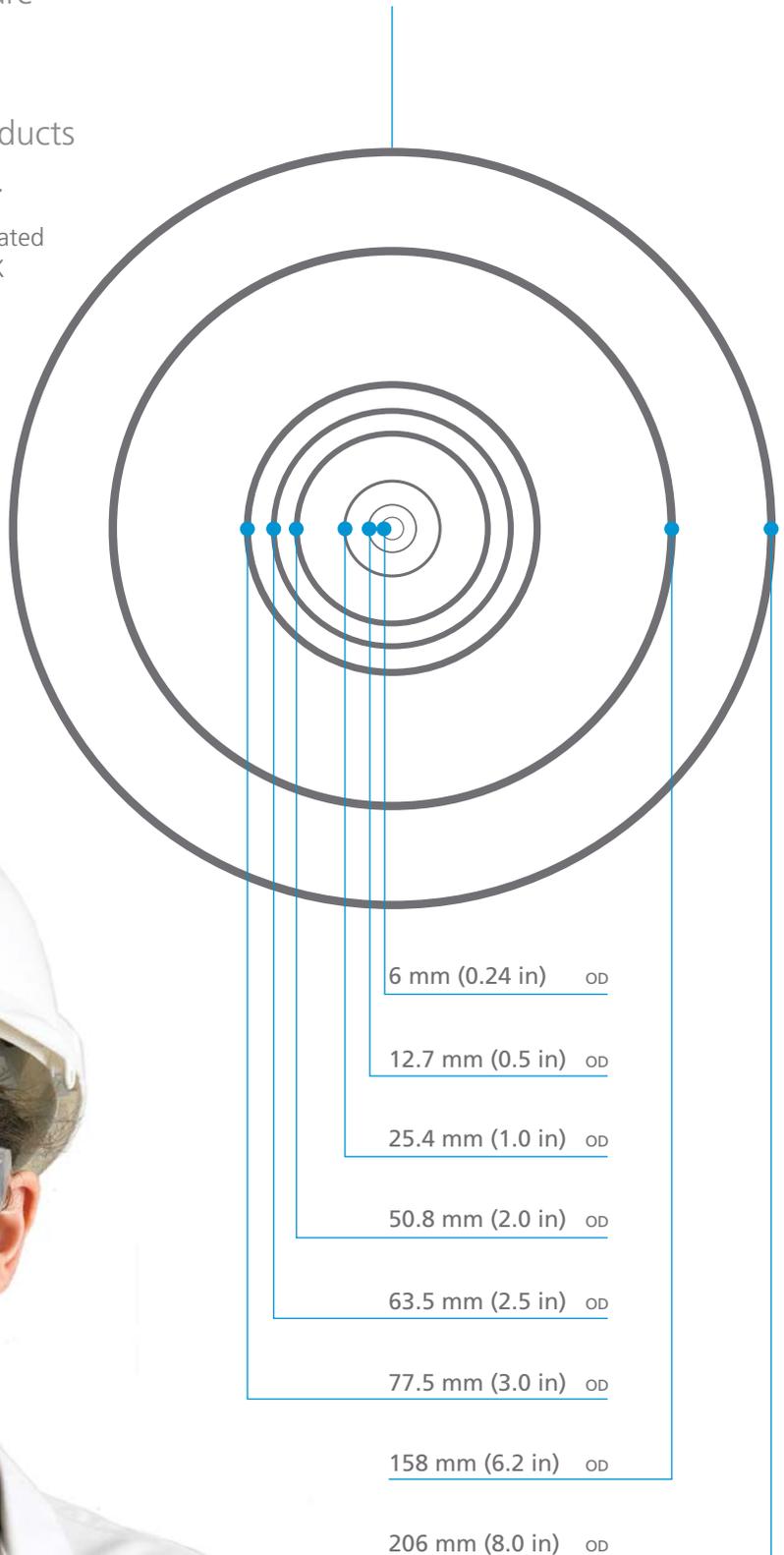
Victrex has in-house pipes extrusion lines that are dedicated to the production of pipe and tube made from VICTREX PEEK polymer. This dedication ensures focus on the manufacture of VICTREX PEEK polymer-based pipes without the distraction of making other polymer pipes. Victrex is unique in having a fully integrated supply chain from raw materials through to finished product to control and guarantee product quality, supply, consistency and performance.

VICTREX Pipes can be bent, flared and formed using heat and conventional pipe bending equipment. Additionally, VICTREX PEEK polymer-based pipes can be joined using a range of adhesives and also using conventional welding equipment. VICTREX Pipes can be laser marked by using suitable equipment.

Current range:

6 mm – 206 mm
Outside Diameter (OD)

Diagram showing pipes at 50% of actual size



VICTREX Pipes™ for Oil and Gas

Today's oil and gas industry is facing complex geographic and environmental challenges. Obtaining access to oil and gas reservoirs now requires reliable performance at higher temperatures, higher pressures and extreme water depths. Reliability is paramount, given the large capital investment, and selection of the right materials is now a critical success factor.

VICTREX™ PEEK polymer offers an outstanding ability to withstand the harsh conditions encountered in both oil-field production and offshore exploration. The durability of VICTREX Pipes means a longer operational life cycle with increased asset availability, increased productivity and reduced maintenance costs.



VICTREX pipes have high permeation and chemical resistance at high temperature, properties are unaffected after 2,000 hours of exposure to steam at 200°C.



Long-term reliability

VICTREX Pipes perform within extreme ranges in temperature even when exposed to harsh chemical and wear conditions.



Greater design freedom

The flexibility of the pipes enables the potential for long continuous pipe lengths for umbilicals and similar applications.



Photo courtesy of Western Falcon.

Replacement for CRAs

VICTREX Pipes offer an opportunity to replace CRAs in pipes and piping systems by lining pipes manufactured in lower cost metals.

The VICTREX Pipes™ advantage

Drilling deeper to access crude oil reserves requires a material that will withstand the harshest conditions. It is not uncommon to find operating temperatures above 120°C in the presence of sand and grit, hydrogen sulfide (H₂S), methane, carbon dioxide, brine and crude oil. VICTREX PEEK polymer withstands these conditions, including when a high water cut is present or steam injection is used.

VICTREX Pipes were developed to replace the Corrosion Resistant Alloys (CRAs) used to make pipes and piping systems for extraction and transportation in the Oil and Gas industries, by lining pipes manufactured in lower cost metals.

Steel will rust and other metals such as CRA's and Titanium form passive or protective oxide layers which under certain service conditions such as high or low pH may locally attack the oxide layer and cause pitting and crevice corrosion.

As metal pipes corrode or oxidise then the opportunity for scale build up increases due to the rougher internal

surface. The smooth internal surface finish of VICTREX Pipes can potentially mitigate paraffin and asphaltene build-up and deposits and limit ongoing chemical treatments.

VICTREX PEEK polymer exhibits superior performance compared to other commonly used polymers as shown in Table 3.

Table 3 Comparison of VICTREX PEEK polymer properties versus other polymers used in oil and gas

Property	Units	VICTREX PEEK	HDPE	PA11	PVDF	PPS
Density	g/cm ³	1.3	0.96	1.03	1.78	1.31
Melting Point	°C	343	130	182	173	290
Glass Transition	°C	143	-100	45	-28	85
Tensile Strength	MPa	100	23	28	40	93
Flexural Modulus	GPa	4.1	0.9	1	1.5	2.4
Elongation at break	%	40	500	300	100	2
Shore D Hardness	na	85	63	50	70	85
Coefficient of Friction	na	0.34	0.28	0.34	0.3	na



The innovative product line of extruded pipes and tubing made from VICTREX PEEK polymer makes full use of the material's performance capabilities, including the ability to withstand harsh temperatures and corrosive conditions, refer to Figures 4 through 7. VICTREX Pipes open up a host of new application opportunities and in particular meet the requirements for a polymer pipe in applications such as lined production tubing and lined pipe. The flexibility of the pipes enables the potential for umbilicals and similar applications in the Oil and Gas industry.

Figure 4 Taber abrasion of VICTREX PEEK polymer versus stainless steel

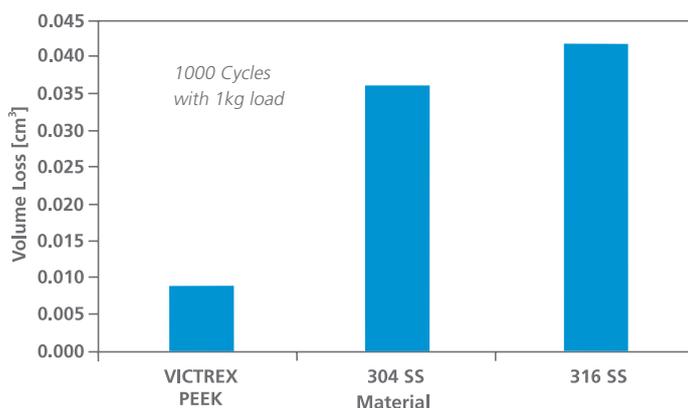


Figure 5 VICTREX PEEK polymer uptake of brent crude oil at 140°C

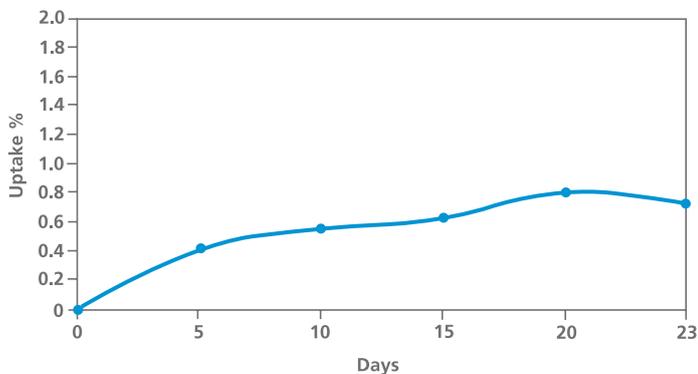
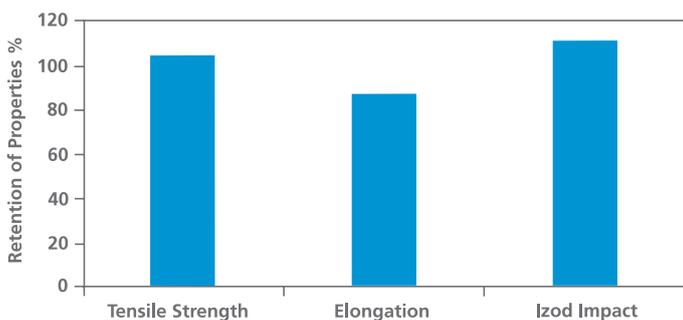
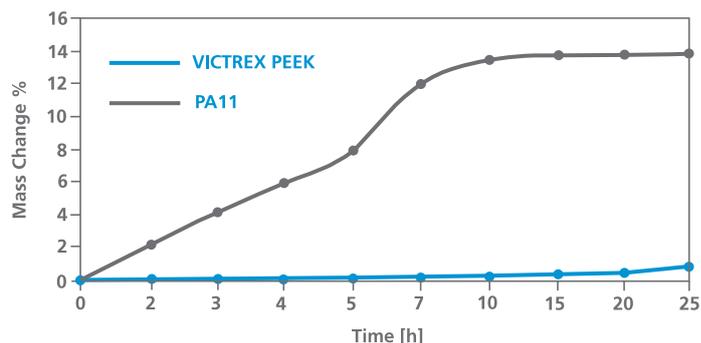


Figure 6 Retention of properties of VICTREX PEEK polymer after exposure to H₂S at 200°C for 7 days



Opposite: Victrex's fully integrated supply chain from raw materials through to finished product guarantees product quality and supply.

Figure 7 Mass change versus time for VICTREX PEEK polymer and PA11 immersed in methanol at 23°C



VICTREX Pipes have very low permeability, as shown in Table 4 and Table 5, the values stated are at least 100 times lower than those for PA11 and PVDF engineering thermoplastics. The effect of high pressure on VICTREX PEEK polymer is minimal; a 100 fold increase in pressure produces a 10 fold increase in permeation rate.

Table 4 Dry gas permeation and diffusion of H₂S and CO₂ derived from NORSOK M-710. Test pressure was 20 bar and temperature 175°C

Material	Permeation Coefficient Q (cm ² /s/atm) x 10 ⁻⁵	Diffusion Coefficient D (cm ² /s x 10 ⁻⁷)	Solubility Coefficient s (atm ⁻¹)
VICTREX PEEK	2	1.4	14
PPS	5.2	3.1	16

Table 5 Comparison of permeation properties for hydrogen sulfide gas in various polymers

Material	Temperature °C	Pressure (bar)	Permeation coefficient Q (cm ² /s/atm)	Diffusion coefficient D (cm ² /s)
VICTREX PEEK	155	17	6.2 x 10 ⁻⁹	6.5 x 10 ⁻⁸
VICTREX PEEK	110	17	1.2 x 10 ⁻⁹	1.3 x 10 ⁻⁸
PVDF	100	unknown	1.3 x 10 ⁻⁶	unknown
PA11	100	80	6.6 x 10 ⁻⁷	0.8 x 10 ⁻⁶
PA5	30	unknown	0.3 x 10 ⁻⁸	5 x 10 ⁻¹⁰
PVOH	26	unknown	5 x 10 ⁻¹¹	unknown

The pipes also exhibit excellent Rapid Gas Decompression (RGD) resistance. RGD or explosive decompression happens when a polymer becomes saturated with gas at high pressure and then undergoes a rapid pressure reduction. This can lead to crack propagation and failure of a pipe.

Table 6 shows the performance of VICTREX PEEK polymer based on a 90 / 10 Methane / Carbon Dioxide Mixture.

Table 6 Rapid Gas Decompression (RGD)

Temperature °C	Pressure MPa	Decompression Rate (MPa / Minute)	% Change in Volume
175	101	17.2	3.58
175	101	3.45	3.27
200	101	17.2	5.65

VICTREX Pipes™ for Aerospace

The requirements of the global aerospace industry are changing fast. Aircraft manufacturers are driven by the need to design the most lightweight and environmentally fuel-efficient aircraft possible. Metal has been the standard material for construction in the industry for many years. To respond to these trends aircraft manufacturers are turning to innovations in design, materials and manufacturing technologies in an attempt to get maximum performance for minimum cost with lighter weight materials and alternatives to metal.

VICTREX Pipes are lightweight and inherently halogen-free, with low levels of smoke and toxic gas emissions, to satisfy the stringent safety, quality and performance regulations within the aerospace industry.



Polymers have a number of advantages over metals including, lighter weight, noise reduction, vibration dampening and chemical and corrosion resistance. Design engineers are exploiting the advantages of high performance polymers to increase processing flexibility, reduce manufacturing costs and provide durability in harsh environments.

Based on their numerous advantages, Victrex polymers are used extensively in the aerospace industry replacing metals such as aluminium, stainless steel and titanium.

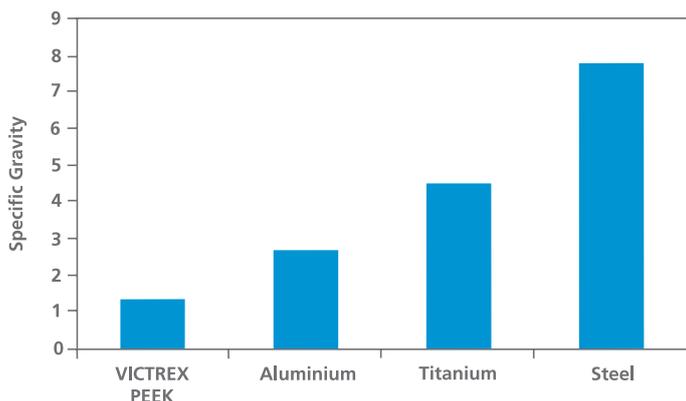
In the Aerospace industry significant weight savings can be realised by the use of lightweight VICTREX Pipes making them an attractive alternative to metals, refer to Figure 8. Weight reduction for a typical 1" pipe is:

- 65% compared to stainless steel
- 45% compared to titanium
- 30% compared to aluminium.

Furthermore, having the mechanical properties of VICTREX PEEK polymer which exceeds most engineering thermoplastics VICTREX Pipes are exceptionally stable and retain good mechanical properties when exposed to high temperature humid environments. VICTREX PEEK polymer has excellent resistance to a broad range of chemicals and specifically for Aerospace has excellent resistance to Jet Fuel.

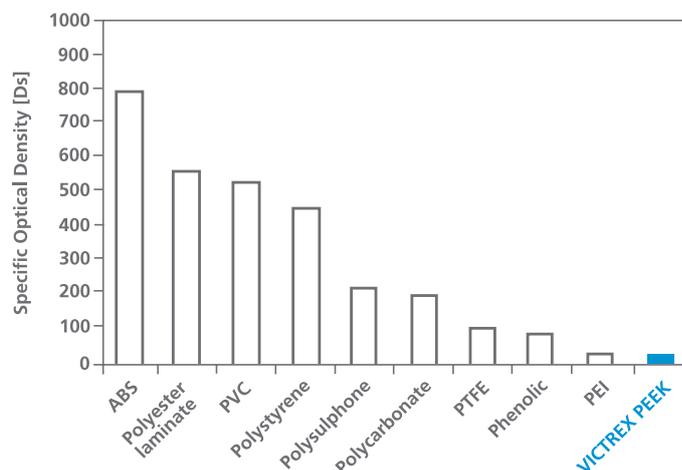
VICTREX Pipes are highly corrosion and chemical resistant as well as inherently halogen-free with low smoke and toxic gas emission to satisfy the stringent safety, quality and performance regulations in aerospace.

Figure 8 Specific gravity of VICTREX PEEK polymer compared to metals



NBS smoke chamber test results show VICTREX PEEK polymer has the lowest smoke density. It meets OSU 65/65 heat release and has a UL94 V-0 flame rating at 1.5 mm with a limiting oxygen index of 35% at 3.2 mm.

Figure 9 Forced combustion chamber smoke results for a range of polymers



QUALIFICATIONS AND APPROVALS

VICTREX PEEK polymers have been qualified by many aircraft manufacturers.

- ▲ Airbus AIMS04-01-000 - Thermoplastic moulding materials - Technical Specification
- ▲ Airbus AIMS04-01-012 - Thermoplastic moulding material - Polyetheretherketone (PEEK) - Material Specification
- ▲ Boeing material specification BMS 8-317A – Polyetheretherketone (PEEK) Thermoplastic injection moulding resin – Material Specification
- ▲ European Cooperation for Space Standardisation ECSS-Q-70-71A rev. 1 - Space product assurance - Data for selection of space materials and processes
- ▲ Military Specification MIL-P-46183 - Plastic moulding and extrusion material, Polyetheretherketone (PEEK)
- ▲ Military Specification MIL-STD-810G, method 508.6 – Fungus Growth Test

Refer to Victrex for additional approvals in Aerospace.

VICTREX Pipes™ for Industrial

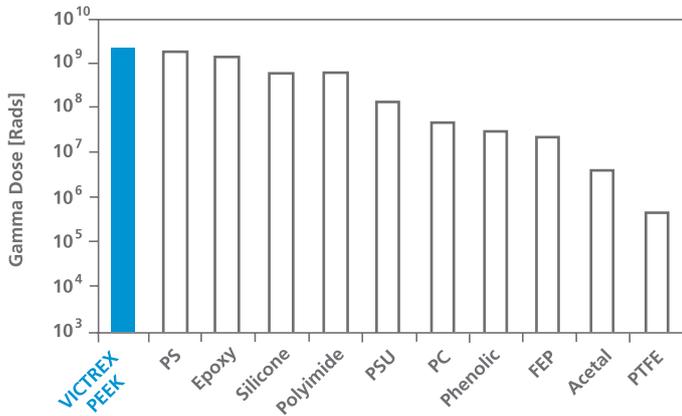
As companies are striving to increase productivity and reduce overall costs, a critical element is reducing maintenance downtime. To address these challenges manufacturers are increasingly turning to high performance polymers which have advantages over metals. Polymers offer design freedom, compliance to environmental and safety regulations, lighter weight and increased performance and reliability. By using these materials manufacturers can extend the service life of their applications as well as reduce maintenance downtime which leads to overall reduced cost.

Reliability for industrial applications that demand electrical insulation, mechanical stability and fatigue strength, as well as chemical, corrosion, hydrolysis and wear resistance at high temperatures.



With its high temperature performance and unique combination of properties including excellent chemical, wear and abrasion resistance, thermal stability, mechanical strength and hydrolysis resistance, VICTREX PEEK polymer is specified in a wide variety of industrial applications in harsh environments. VICTREX PEEK polymer demonstrates excellent resistance to gamma radiation without embrittlement.

Figure 10 Radiation resistance of VICTREX PEEK polymer compared to various polymers



Exhibiting the inherent properties of its base polymer VICTREX Pipes are well-suited for use in a range of industrial applications such as geothermal power plant, mining, sheathing for critical components, transportation power cables and electrical environments, steam pipes and lined pipes.

Compared to other polymer pipes located in harsh and aggressive environments VICTREX Pipes offer enhanced burst strength for a given Standard Dimension Ratio (SDR), as shown in Figure 11. This performance is maintained over a wide temperature range, as shown in Figure 12.

Figure 11 Comparison of calculated burst strength as a function of SDR for different polymer types at 23°C

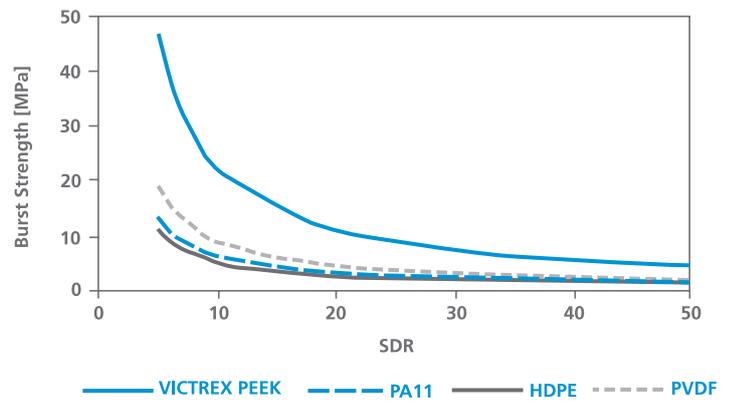
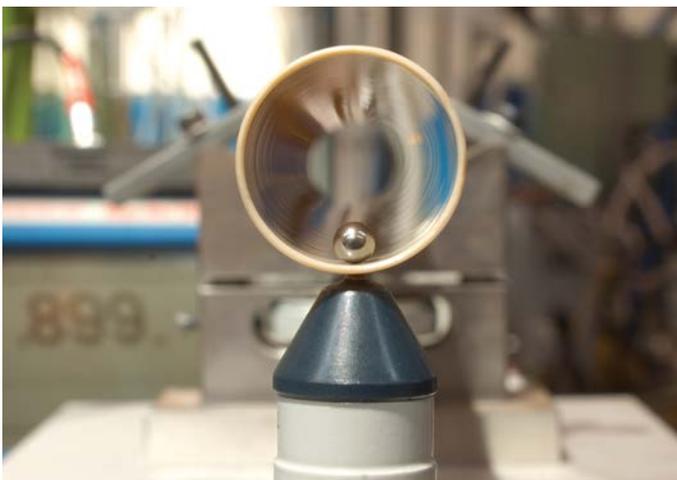
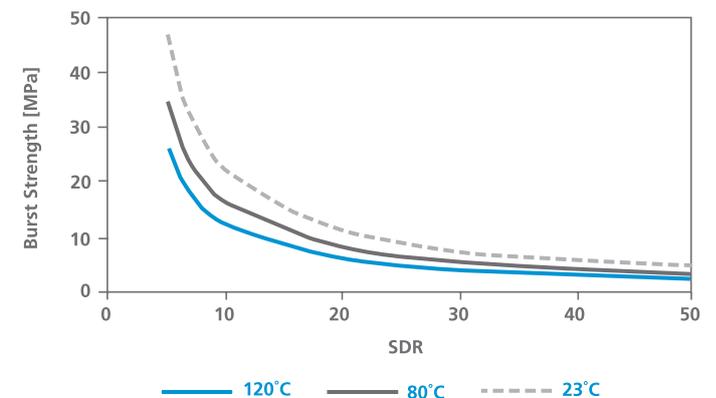


Figure 12 Comparison of calculated burst strength for VICTREX Pipes as a function of SDR at different temperatures



Magnetic bearing that measures the thickness of the pipe wall, giving accurate data on pipe quality and control.

KEY FEATURES

▲ Extreme temperature range

VICTREX PEEK polymer has a melting temperature of 343°C and is capable of withstanding continuous operating temperatures of up to 260°C.

▲ High permeation resistance and RGD resistance

Permeation values for VICTREX PEEK polymer are at least 100 times lower than those for PA11 and PVDF engineering thermoplastics. Excellent resistance to Rapid Gas Decompression.

▲ Aggressive chemical and corrosion resistance

Insoluble in all common solvents, VICTREX PEEK polymer has excellent resistance to acids, bases, oxidising agents, hydrocarbons, salts and steam. Chemical resistance is superior to that of many exotic metals.

▲ Excellent wear and abrasion performance

High abrasion and cut through resistance combined with low coefficient of friction.

▲ Low moisture absorption

Moisture uptake can adversely affect electrical, dimensional and mechanical properties of other polymer materials. VICTREX PEEK has a low moisture absorbance of 0.07% in 24 hours.

▲ Low smoke and toxic gas emission

Good flame resistance without the use of flame retardant additives and low toxicity of combustion gases. UL94 rating of V-0 at 1.5 mm.

▲ Environmentally friendly

Lightweight, recyclable, halogen free in accordance with IEC 61249-2-21. RoHS and GADSL compliant.

▲ Electrical stability

Very stable dielectric properties over a wide range of temperatures, frequencies and humidity.

▲ Radiation resistance

Demonstrates excellent resistance to gamma radiation without embrittlement.

▲ Hydrolysis resistance

Exceptional stability and retention of mechanical properties when exposed to high temperature humid environments including steam and sterilisation. After 2,000 hours of exposure to steam at 200°C properties are unaffected.

▲ FDA food contact certified

VICTREX Pipes are FDA 21 CFR 177.2415 and EU 2002/72/EC approved and may be safely used for repeated food contact and are 3-A Sanitary Standards compliant.

Table 7 Chemical resistance of VICTREX PEEK polymer

Chemical*	Temperature °C	Rating
Benzene	100	A
Biocide	200	A
Brake Fluid (Mineral / Polyglycol)	200	A
Calcium Nitrate	200	B
Corrosion Inhibitor (100%)	80	A
Ethylene Glycol (50% aqueous)	200	A
Glutaraldehyde (50% aqueous)	80	A
Hydrochloric Acid (10%)	100	A
Hydrogen Sulfide (Gas)	200	A
Heavy Aromatic Naphtha (100%)	200	B
Jet A Fuel	23	A
Kerosene	23	A
Methanol	100	A
Methane Gas	200	A
Mineral Oil	200	B
Motor Oil	200	A
Naphtha (100%)	100	A
Petroleum Oils	100	A
Sea Water	200	A
Skydrol* Hydraulic fluid	23	A
Sodium Bisulphite (50% aqueous)	200	B
Sodium Bisulphite (50% aqueous)	80	A
Sodium Hydroxide (50%)	200	A
Sodium Nitrate	80	A
Trimethylbenzene	200	B

Ratings Description: A = No Attack B = Slight Attack

Satisfactory use will depend on application. For more comprehensive chemical resistance data contact Victrex.

* Skydrol is a registered trademark of Solutia Inc.

+ Victrex polymers are exempt from the REACH registration requirements

Chemical resistance testing is an ongoing focus of the Victrex technical team and new data is routinely generated. Please refer to Victrex for more comprehensive test data.

A FLEXIBLE ALTERNATIVE TO METALS AND OTHER POLYMERS

For years VICTREX PEEK polymer has been used to displace metals and lower performing polymers in a wide range of oil and gas, aerospace and industrial applications where the demand to extend service life, reduce cost, decrease weight and comply with environmental and safety regulations is driving the need for innovative solutions that can meet these challenging performance requirements. Today, engineers and designers have the option of using VICTREX Pipes with the same exceptional high temperature performance and combination of material properties to satisfy the increasing demands of applications designed for use in harsh environments.



APPLICATIONS

Oil & Gas

- ▲ Production tubing and lined pipe
- ▲ Risers
- ▲ Umbilicals



Industrial

- ▲ Critical component sheathing
- ▲ Sheathing for power cables in mass transport applications
- ▲ Lined pipes
- ▲ Steam pipes



Aerospace

- ▲ Fluid transport pipes
- ▲ High performance sheathing





Based in the UK, Victrex is an innovative and world leading global provider of high-performance polymer solutions for the aerospace, automotive, electronics, energy and medical industries. Every day, millions of people rely on products and applications containing our polymers – from smart phones, aircraft and cars all the way to medical devices and oil and gas installations. With over 35 years' experience, we provide cutting-edge technological solutions that shape future performance for our customers and markets and drive value for our shareholders.

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