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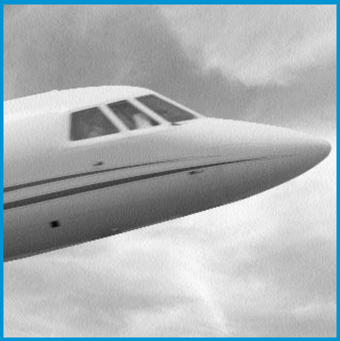
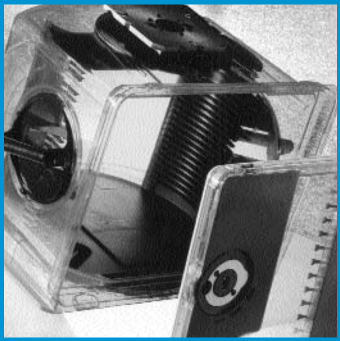
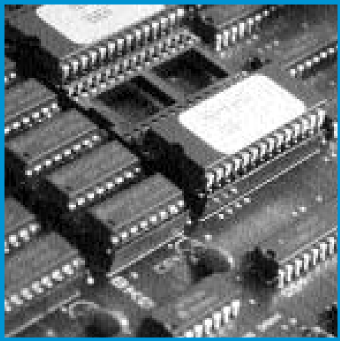
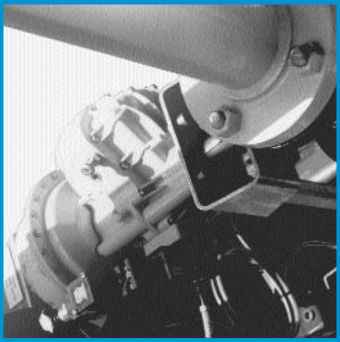
PROCESSING GUIDE









A comprehensive review of the processing guidelines of VICTREX® PEEK™ high performance polymer

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INTRODUCTION

VICTREX PEEK is a linear aromatic semi-crystalline thermoplastic. It is widely regarded as the highest performance material capable of being processed on conventional thermoplastic equipment.

VICTREX PEEK and compounds are supplied in the form of pellets, powder or ultrafine powder. Pellets are generally recommended for injection molding, extrusion, monofilament and wire coating operations. Powder is used for extrusion compounding, while fine powders are generally used for coating processes and compression molding.

PROCESS PREPARATION AND HANDLING OF VICTREX PEEK

VICTREX PEEK is supplied in a sealed polyethylene bag inside a heavy-duty cardboard box or a pallet sized box. It is strongly recommended that the materials remain sealed in the original packaging during subsequent transportation and storage. When material is required, the boxes should be opened in a clean environment and care taken to avoid contamination. Any remaining material should be re-sealed as soon as possible and stored in a dry place. As long as Victrex raw materials are kept sealed, dry, in their original box and are not left in direct sunlight they may be stored in excess of 10 years.

DRYING

Although VICTREX PEEK materials are supplied nominally dry, the pellet form of the polymer typically absorbs 0.5% w/w atmospheric moisture. For best results, powder and pellets should be dried to less than 0.02% w/w moisture (dew point of -40°). This is easily achieved by placing the material in an air circulating oven for a minimum of 3 hours at 150°C (302°F) or 2 hours at 160°C (320°F). The material should be spread out in trays in layers about 2.5 cm (1 in) deep. Care must be taken during drying or any other secondary handling operations not to introduce sources of contamination. Do not dry other materials in the same oven as VICTREX PEEK unless there is suitable isolation from extraneous contamination.

RE-WORK

It is common practice with most thermoplastic materials to re-work ground runners and sprues with virgin material to enhance production efficiency. VICTREX PEEK may also be re-worked in this way. However, the level of re-work may influence the quality of the molding and increase the chances of cross-contamination. Extraneous material, even at low levels, will have a serious effect on molding quality due to the high processing temperatures used for VICTREX PEEK. It is recommended that re-work be restricted to a maximum of 30% w/w for unfilled polymer and 10% w/w for filled compounds.

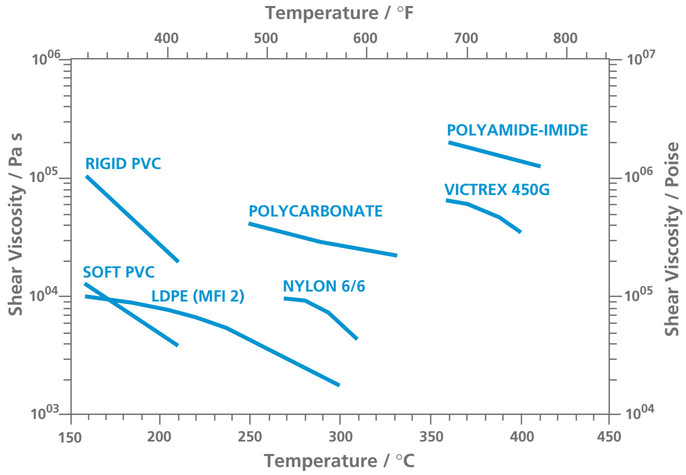
THERMAL STABILITY

VICTREX PEEK and compounds are thermally stable at processing temperatures. If any delay in melt processing causes the polymer residence time to increase up to one hour, the material can be maintained at 360°C (680°F) with no appreciable degradation. However, if the delay is more than one hour, the barrel temperatures should be reduced to 340°C (644°F). VICTREX PEEK materials are stable at this temperature for several hours, although barrel temperatures should be raised again to continue processing. If the delay is likely to result in a polymer residence time greater than 3 hours, the barrel should be purged (see Purging Injection Molders and Extruders, page 4). After any increase in residence time, it is advisable to discard the initial moldings produced on re-starting.

PROCESSABILITY

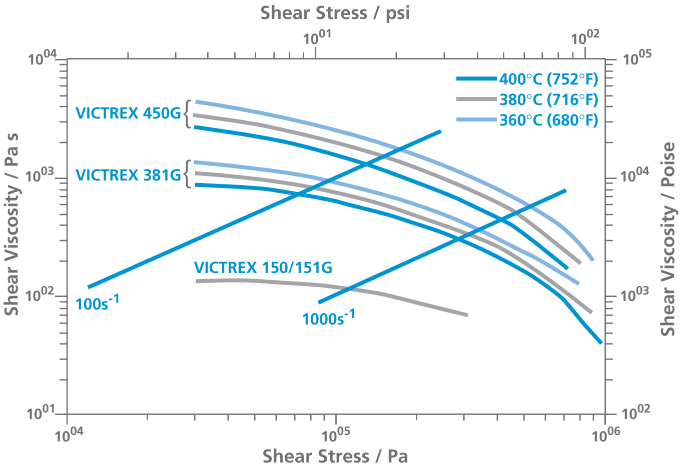
The melting temperature of VICTREX PEEK is 343°C (649°F). The melt is stable and workable with most conventional process equipment between 360°C and 400°C (680°F and 752°F). A comparative plot of melt viscosity versus temperature (over the stable melt range) for a range of conventional engineering polymers is shown in Figure 1.

Figure 1: Shear Viscosity Versus Temperature for a Range of Engineering Thermoplastics



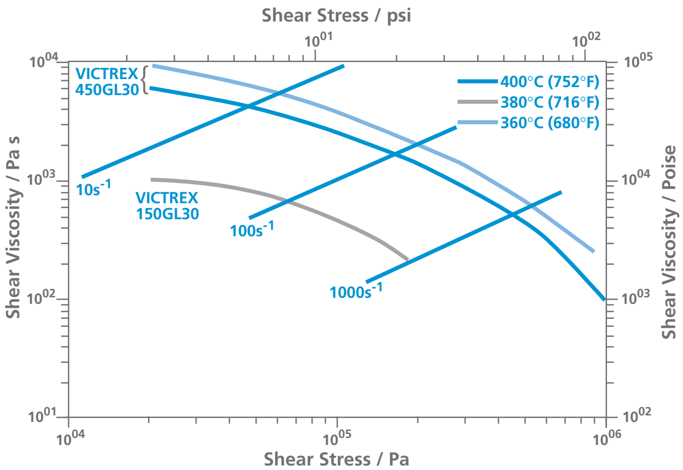
The data in Figure 1 show that, although VICTREX PEEK has one of the highest processing temperatures, typical viscosities of VICTREX 450G at those temperatures are similar to rigid PVC or polycarbonate melts. The viscosity has been shown to be shear rate and temperature sensitive. Polymer melts are usually classified by measuring their viscosity over a range of shear stresses or shear rates at constant temperature. The viscosities of VICTREX PEEK grades are plotted versus shear stress over two decades of shear rate in Figures 2, 3 and 4.

Figure 2: Shear Viscosity Versus Shear Stress for Natural VICTREX PEEK



The upper family of curves in Figure 2 represents typical melt viscosities of VICTREX 450G at various temperatures. The middle family of curves represents typical melt viscosities of VICTREX 381G and the lower curve represents the viscosity behavior of VICTREX 150G/151G. From this data it is clear that the effect of increasing temperature is to reduce the viscosity of the melt. These values of melt viscosity are used to classify natural VICTREX PEEK into low (VICTREX 150G/151G), medium (VICTREX 381G) and standard (VICTREX 450G) viscosity grades.

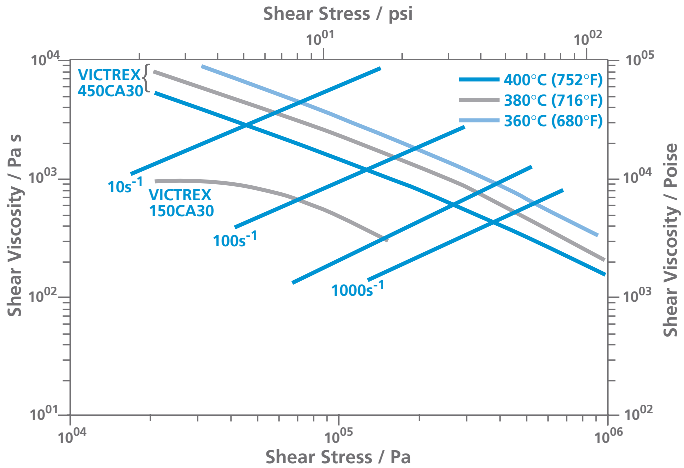
Figure 3: Shear Viscosity Versus Shear Stress for 30% Glass Fiber Filled VICTREX PEEK



PURGING INJECTION MOLDERS AND EXTRUDERS

VICTREX PEEK and compounds should ideally be processed on completely clean equipment. For extruders and injection molders this will mean removing the screw and barrel for cleaning. If the removal of the screw and barrel are not possible, then purging is essential. The ideal purge materials are those which are stable at 380°C (716°F), i.e., polyethersulphone and polyetherimide. Low MFI polyethylene = 0.3 MFI may

Figure 4: Shear Viscosity Versus Shear Stress for 30% Carbon Fiber Filled VICTREX PEEK



be used at such temperatures. However, these materials will partially degrade and adequate provision must be made for the resultant fumes. Also, there are commercially available purging compounds which are designed to be used at VICTREX PEEK processing temperatures. Consult the purge material manufacturer's Material Safety Data Sheets (MSDS) for any purge material used.

AN OVERVIEW OF START-UP PURGING

All traces of other polymers must be removed from the equipment before VICTREX PEEK materials are processed.

(a) Purging should take place at the temperature at which the material to be removed is normally processed.
(b) Purge is fed through the screw until there is no visible trace of the material to be removed.
(c) Stop purge feeding and allow the screw to empty.
(d) Set the barrel heaters to reach VICTREX PEEK processing temperatures.
(e) When processing temperatures are obtained, feed VICTREX PEEK into the screw and extrude until a clean melt develops.

AN OVERVIEW OF SHUT-DOWN PURGING

VICTREX PEEK must be removed from processing equipment before other materials are processed.

(a) Empty the barrel of VICTREX PEEK materials.
(b) Feed purge through the screw until there is no visible trace of the material.
(c) Reduce the settings of all the barrel zones to a stable purge temperature (e.g., 250°C (482°F)).
(d) Continue to feed purge into screw until the actual barrel temperature is below 300°C (572°F).
(e) Stop purge feeding and allow the screw to empty.

Note: This advice is based on our general experience with typical processing equipment. Special care must be taken with larger extruders or injection molders as residence times are increased.

MATERIALS OF CONSTRUCTION FOR VICTREX PEEK PROCESSING EQUIPMENT

The problem of machine wear is common to all engineering thermoplastics and can be particularly severe when extruding or injection molding fiber filled materials. To minimize wear in such processes, screws, dies and barrels should be hardened. The most common way of hardening tool steel is to coat with nitride. This technique provides the surface hardness necessary to resist excessive wear from the melt. Care must be taken to ensure that the VICTREX PEEK does not cool and solidify in contact with the nitride coating. The bond between the polymer and the nitride coating is often strong enough to lift the layer from the steel substrate.

The following steels are generally recommended for the construction of process equipment suitable for VICTREX PEEK:

- D2 Tool Steel (A martensitic chromium tool steel)
- WEXCO 777
- CMP-10V
- CMP-9V
- S32 219 Stainless Steel

Although not generally required, corrosion resistant and bi-metallic screws and barrels have proved satisfactory in service. Avoid copper alloys because they can cause degradation at VICTREX PEEK processing temperatures.

The surface finish of metallic components which are used in melt transportation should be smooth and highly polished. Increasing the surface roughness of these components causes the melt to adhere locally to the metal, which increases residence time and disturbs polymer flow.

INJECTION MOLDING

Most standard reciprocating screw injection molding machines are capable of molding VICTREX PEEK and compounds. Complex high performance components can be readily mass produced without the need for annealing or conventional machining.

MACHINE DESIGN

VICTREX PEEK and compounds based on VICTREX PEEK can be readily injection molded. However, due to the high melt temperature, certain design and process variables need to be considered. These are listed below.

BARREL TEMPERATURES

In order to successfully mold VICTREX PEEK materials, the cylinder heaters connected to the barrel of the injection molder must be able to reach 400°C (752°F). Most injection molding machines are capable of these temperatures without the need for modification. In the exceptional cases where modification is required, it is a simple task to install higher temperature range controllers and ceramic heaters.

In order to achieve correct hopper feeding, the feed throat should be maintained between 70°C and 100°C (158°F and 212°F). Thermal conduction along the screw and barrel to the hopper may reduce the feed efficiency. Thermal control in the feed section may be achieved by water cooling, but care must be taken to maintain the rear zone temperature.

BARREL CAPACITY

Residence times must be kept as short as possible due to the high processing temperatures of VICTREX PEEK. Ideally, the barrel capacity should be between 2 and 5 times the total shot weight including sprue and runners. If it is necessary to mold VICTREX PEEK on a machine which has a large number of shots in the barrel, then the rear zone temperature may be reduced by 10°C to 20°C (50°F to 68°F) below the recommended temperature settings (see Troubleshooting, page 9).

NOZZLES AND SHUT-OFF SYSTEMS

The nozzle of the barrel is in contact with the sprue-bush for a high percentage of the total cycle time during normal operations. The temperature of the sprue-bush is considerably lower than that of the melt and the nozzle. VICTREX PEEK has a sharp melting point and will solidify quickly if the melt temperature is allowed to fall below 343°C (649°F). Therefore, it is important to ensure that an adequately large heater is fitted to the nozzle to prevent freeze-off and "cold slugging." Extended nozzles are not generally recommended for use with VICTREX PEEK because they increase the likelihood of solidification in the nozzle. Over the recommended process temperatures, the viscosity of VICTREX PEEK is generally still high enough to allow an open nozzle system. Shut-off nozzles are not recommended because they frequently contain melt "dead spots" and restrict injection pressures. If excessive die drool is encountered, minor melt decompression can be employed in the process cycle.

INJECTION AND CLAMPING PRESSURES

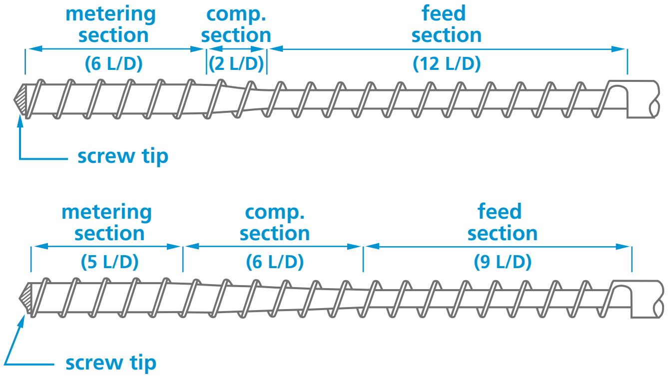
The injection pressures required for correct component molding are system dependent. However, in general, injection pressures rarely exceed 14 MPa (2030 psi) with secondary holding pressures of 10 MPa (1450 psi).

The projected area of the molding and runner determines the clamp force required to prevent the mold from opening under maximum injection pressure. This typically corresponds to 50-80 MPa (3.6-5.8 Tons in^{-2}) for natural VICTREX PEEK and 65-140 MPa (4.7-10 Tons in^{-2}) for the fiber reinforced compounds. However, parts with thin sections and long flow lengths will require higher clamping pressures than those with thick sections and short flow lengths.

SCREW DESIGN

Most general purpose and "nylon" type screws are suitable for processing VICTREX PEEK grades. Two such screws with appropriate length to diameter (L/D) ratios, are shown in Figure 5.

Figure 5: Screw Types Recommended for the Processing of VICTREX PEEK



The minimum recommended L/D ratio screw is 16:1. L/D ratios between 18:1 and 24:1 are preferred. Long feed sections are required to prevent compaction of unmelted pellets in the compression section of the screw. The compression ratio should be between 2:1 and 3:1. Check rings must always be fitted to the screw tip to ensure development of a full and sustained injection pressure. Ring clearance should allow for an unrestricted flow of material on forward movement of the screw. This typically corresponds to a 3 mm (0.12 in) clearance from the screw tip diameter for a medium size molding machine.

MOLD DESIGN

VICTREX PEEK and compounds can be readily processed using many existing molds. However, certain design criteria must be met for successful molding. It is recommended that the mold cavities and cores have Rockwell hardness 52-54 at VICTREX PEEK processing temperatures. Contact your local Victrex representative for more information.

MOLD TEMPERATURE

The recommended mold temperature range for processing VICTREX PEEK is from 175°C to 205°C (350°F to 400°F). These temperatures are the surface temperature of the mold and not the set temperature of the control unit. If an oil heater is used it would be normal for the set point on the controller to be somewhat higher due to heat losses (set points of 260°C (500°F) are typical). Electric cartridge heaters may be used but it is difficult to control the temperature locally, leading to problematic hot spots in large tools.

These temperatures have been found to give good mold filling and a high level of crystallinity within the moldings. Lower mold temperatures will tend to give moldings with non-uniform color and dark edges/corners due to decreased crystallinity (amorphous material) at the molding surface.

It is possible to crystallize amorphous VICTREX PEEK moldings by using an annealing process subsequent to molding, however this may lead to distortion and dimensional changes. Every effort should be made to mold components with the highest possible crystallinity by using the mold temperatures recommended above.

MELT FLOW

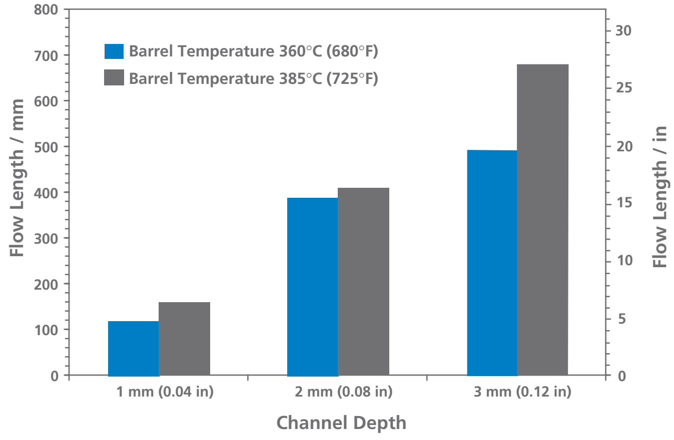
Sprues should be at least 4 mm (0.16 in) thick and as short as possible. Larger diameter sprues have been shown to aid filling in complex molds which feature long flow lengths and thin sections. VICTREX PEEK components require a minimum taper angle of 2° on the sprue and on the inside of the sprue-bush for successful de-molding. When possible, a "cold-slug" well should be incorporated into the sprue design.

VICTREX PEEK molds require circular or trapezoidal runners with large section thickness. Melt flow paths should be kept as short as possible and sharp changes of direction should be avoided.

The success of molding components with thin flow sections is a function of thermal, geometrical and pressure variables. An approximate guide to the effects of section thickness on the resultant flow length is shown in Figure 6.

The data in Figure 6 were derived from measurements made on a spiral flow mold with an injection pressure of 140 MPa (20,300 psi). It is not recommended to design molds for natural VICTREX PEEK with a section thickness of less than 1 mm (0.04 in) or 1.5 mm (0.06 in) for reinforced grades.

Figure 6: Flow Length Versus Barrel Temperature for Natural VICTREX 450G



GATING

The size and style of gating appropriate for a mold will depend on the melt volume, the number of cavities and the component geometry required. Most gate designs are suitable for VICTREX PEEK molding although long thin flow sections should be avoided. Gates should be as large as possible. The minimum recommended gate diameter or thickness is 1 mm (0.04 in) for natural VICTREX PEEK and 2 mm (0.08 in) for compounds. Sprue gates should be between 1-1.5 times the thickness of the molding. Submarine or tunnel gates should only be considered for thin wall or small parts. Advice on suitable gates for molding VICTREX PEEK is available on request from Victrex.

HOT RUNNER SYSTEMS

Hot runners and hot sprue bushings have been used successfully around the world for the injection molding of VICTREX PEEK for over 15 years. All materials in the Victrex range are suitable for use with hot runners and sprues.

The advantages of hot runner systems and hot sprue bushings are:

- The weight of the sprue and runner system is reduced.
- With direct gated thick walled shapes hot sprue bushings can offer a significant advantage in packing out thick sections.
- The molding window is often larger.
- While cold runner systems can be recycled, there are potential issues related to contamination and the quantity of regrind that can be tolerated within a molding.

The disadvantages of hot runner and hot sprue systems are:

- The initial capital costs of such tooling systems are higher.
- Purging hot runner systems can result in major contamination problems.
- Overall maintenance costs for a hot runner tool are higher than for a cold runner tool.

If considering the use of hot runner systems the following advice is offered:

- Always ensure that the runner system has external heating with no internal flow restrictions.
- The runner system needs to be able to operate, consistently, at 450°C (842°F).
- Nozzle tips should be generous and sited on the component surface, pin gating is not recommended.
- The temperature control of the individual runners needs to be very good in order to keep the tool balanced.
- Due to the high operating temperatures of hot runner molds for VICTREX PEEK and the consequent thermal expansion it is advisable to have the 'hot' section of the tool manufactured by the hot runner supplier.
- For tight toleranced parts it is recommended that the tool should be a maximum of 4 to 8 cavities.
- As with any process, time is required for a process to stabilize. The use of hot runners and sprues may lead to an increase in the settling time of the process.

Purging a hot runner system can lead to problems due to dead-spots in the material flow path. If using hot runners it is advisable not to purge the runners with anything other than VICTREX PEEK. When the production run is complete, the runner temperatures should be reduced in line with the values quoted in our literature for the barrel of the molding machine.

The cleaning of hot runners can present difficulties and it is sensible to discuss this with the supplier of the hot runner system. However, it must be emphasized that each tool design will have special requirements and the runner system must be appropriate to the specific tool design. For further information please contact your local Victrex representative.

SHRINKAGE AND TOLERANCES

Like all injection moldable thermoplastics, VICTREX PEEK components shrink while cooling in the mold. Shrinkage of VICTREX PEEK moldings is due to thermal contraction and the development of crystalline regions within the cooling melt.

VICTREX PEEK and compounds are semi-crystalline thermoplastics. Many of the outstanding physical properties which are associated with these materials are a function of the degree of crystallinity. The level of crystallinity is highly influenced by melt and mold temperatures. Using the recommended injection molding conditions (see Operating Conditions, page 8), VICTREX PEEK parts should be nominally 30% crystalline.

The mold shrinkage of all VICTREX PEEK grades was evaluated using pre-dried materials in a circulated air oven overnight at 120°C (248°F), as per Victrex recommendations. The materials were molded into a variable thickness 150 mm x 150 mm (6 in x 6 in) single cavity plaque mold. Gating was via a fan gate of 2.5 mm (0.1 in) thickness and 1 mm (0.04 in) land length. Both sides of the mold were heated with cartridge heaters. Plaques were made on a 150 tonne injection molding machine. All process conditions were set according to the grade being injected following our normal processing procedures. Three plaques per material/temperature/thickness were chosen at random during short runs of each material. Three width and three length measurements were taken from each plaque approximately 1 week after molding. The dimensions of the corresponding cavities were measured when cold. To investigate the effects of a typical post

Table 1: Typical Mold Shrinkage Values for VICTREX PEEK				
Grade	**Thickness**	**Mold Temperature**	**Flow %**	**Across Flow %**
450G	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	1.2 1.4 1.6	1.5 1.7 1.9
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	1.7 2.3 2.3	1.8 2.2 2.4
381G	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	1.2 1.4 1.4	1.5 1.6 1.8
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	1.6 2.2 2.3	1.7 2.2 2.3
150/151G	3mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	1.3 1.6 1.8	1.5 1.8 2.0
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	1.9 2.1 2.3	1.9 2.1 2.3
450GL30	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	0.4 0.4 0.4	0.8 0.9 1.0
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	0.5 0.5 0.5	0.8 0.9 1.0
150GL30	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	0.3 0.3 0.4	0.9 1.0 1.2
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	0.4 0.4 0.4	0.9 1.1 1.1
450CA30	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	0.0 0.1 0.1	0.5 0.5 0.7
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	0.2 0.2 0.3	0.6 0.7 0.7
150CA30	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	0.0 0.0 0.0	0.6 0.6 0.7
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	0.1 0.1 0.1	0.6 0.6 0.7
450FC30	3 mm (0.118 in)	170°C (338°F) 210°C (410°F) Annealed	0.3 0.3 0.4	0.5 0.6 0.8
	6 mm (0.236 in)	170°C (338°F) 210°C (410°F) Annealed	0.4 0.4 0.4	0.7 0.7 0.7

mold treatment two samples for each material/ temperature/thickness were annealed in an oven set at 220°C (428°F) for 3 hours, samples were measured on their return to room temperature. Samples molded with a tool temperature of 210°C (410°F) were used to give the maximum mold shrinkage following annealing.

The difference between the "With Flow" and "Across Flow" shrinkage values in Table 1 represents typical minimum and maximum values observed in VICTREX PEEK molding. The fan-gated plaque mold orientates the melt, fibers and crystalline regions, so that a less orientated molding should exhibit mold shrinkage values between these two extremes. The annealed shrinkage values in Table 1 are obtained by post process thermal treatment in order to reach the maximum degree of crystallinity. These shrinkage values may be expected in components which are subsequently used in high temperature environments.

Most injection molding machines have the facility for a multi-stage injection. In order to reduce mold shrinkage and to enhance filling, a second stage packing pressure should be applied once the mold is full. The potential for severe mold shrinkage may be prevented at the tool design stage by minimizing section thickness. Molded component tolerance may be defined as the dimensional variation observed in seemingly identical moldings. The tolerances shown in Table 2 were determined using the fan-gated test plaques previously described.

Table 2: Typical Tolerance Values for VICTREX PEEK*				
	% Tolerance (Molded)		**% Tolerance (Annealed)**	
Grade	**With Flow**	**Across Flow**	**With Flow**	**Across Flow**
VICTREX 450G	0.05	0.07	0.05	0.07
VICTREX 450GL30	0.07	0.08	0.03	0.05
VICTREX 450FC30	0.04	0.04	0.04	0.06
VICTREX 450CA30	0.05	0.09	0.05	0.11

* This data represents variation from the mean found in 20 samples

OPERATING CONDITIONS

The optimum operating conditions for each individual injection molding machine will depend on many variables. This section presents an overview of the practical aspects of injection molding VICTREX PEEK based on general experience. Table 3 shows the recommended temperatures required to successfully mold VICTREX PEEK.

Table 3: Recommended Starting Temperatures for an Injection Molding Machine Prepared for VICTREX PEEK				
Grade	Rear Temp. °C (°F)	Middle Temp. °C (°F)	Front Temp. °C (°F)	Nozzle Temp. °C (°F)
VICTREX 150G/151G	350(662)	355(671)	360(680)	365(689)
VICTREX 381G	350(662)	360(680)	365(689)	370(698)
VICTREX 450G	355(671)	365(689)	370(698)	375(707)
VICTREX 450G Black 903	355(671)	365(689)	370(698)	375(707)
VICTREX 150GL30	355(671)	360(680)	370(698)	375(707)
VICTREX 450GL30	360(680)	365(689)	370(698)	375(707)
VICTREX 150CA30	360(680)	370(698)	380(716)	385(725)
VICTREX 450CA30	365(689)	380(716)	390(734)	395(743)
VICTREX 150FC30	355(671)	360(680)	370(698)	375(707)
VICTREX 450FC30	360(680)	365(689)	375(707)	380(716)

INJECTION PRESSURES AND SCREW SPEED

Hydraulic injection pressures of 70 to 140 MPa (10,150 to 20,300 psi) are initially used with hydraulic holding pressures of 40 to 100 MPa (5,800 to 14,500 psi). A nominal hydraulic back pressure of up to 30 bar (435 psi) is necessary to create an homogeneous melt and aid consistency of shot size.

A screw speed of between 50 and 100 rpm is optimum for the transport and melting of VICTREX PEEK. However, low screw speeds (50-60 rpm) are recommended for the reinforced grades to prevent excessive fiber breakdown. Screw speeds lower than 50 rpm should be avoided since this results in longer cycle times. Screw speeds higher than 100 rpm are not recommended because they can cause excessive localized shear heating.

Troubleshooting		
Fault	Possible Cause	Remedy
Dark Color and/or Transparent Edges	Low Mold Temperature	Increase Mold Temperature
Short Moldings	Insufficient Material Injected Inadequate Flow of Melt Incorrect Design	Increase Shot Size Increase Injection Pressure Increase Barrel Temperatures Increase Mold Temperatures Increase Injection Speed Increase Gates, Sprues or Runner Size Improve Gates, Sprues or Runner Design Change Position of Gate Increase Venting
Brittle Moldings	Overheating in the Barrel Molded-In Stresses Weld Lines	Reduce Barrel Temperatures Reduce Cycle Time Decrease Screw Speed Increase Barrel Temperatures Reduce Injection Pressure Increase Cycle Time Increase Mold Temperatures Increase Gates, Sprues or Runner Size Increase Barrel Temperatures Increase Injection Speed Increase Mold Temperatures Change Gate Design or Position
Cold Slug of Polymer	Material Freezing in the Nozzle	Increase Nozzle Temperature Thermally Insulate Nozzle Employ Decompression Use a Sprue Break

continued

Troubleshooting

Fault	Possible Cause	Remedy
Voids and Surface Sinking	Insufficient Time or Pressure in Mold	Increase Injection Pressure Increase Holding Time Reduce Barrel Temperatures
	Incorrect Mold Design	Increase Gates, Sprues or Runner Size Increase Holding Pressure
Streaking	Overheated Material	Reduce Barrel Temperatures Reduce Nozzle Temperature Reduce Residence Time Reduce Injection Speed Reduce Screw Speed
	Damp Material	Dry Material
	Dead Spots in Barrel	Streamline Barrel and Nozzle Clean Screw, Barrel and Nozzle Check for Damages, Pitting, etc.
Burn Marks	Air Trapped in Cavity	Reduce Injection Pressure Reduce Injection Speed Improve Venting of Cavity Change Gate Position, Size or Type
Flashing or Mold Opening	Inadequate Locking Force	Reduce Injection Pressure Reduce Injection Speed Reduce Cylinder Temperature Reduce Mold Temperature Reduce Speed Setting Increase Locking Force
	Incorrect Mating or Bending of the Mold	Re-Grind and Re-Align the Mating Surfaces Install Heavy Backing Plates Check for Foreign Matter Between the Plates
Warping or Distortion	Temperature Difference in the Mold	Adjust Temperature so It Is the Same on Both Halves of the Mold
	Lack of Section Symmetry	Consider Re-Design of Cavity, Runners and Gates Use a Temperature Differential Between the Two Halves of the Mold to Compensate Use a Cooling Jig Increase Cooling Time
	Early Ejection	Increase Cooling Time Reduce Mold Temperatures Add More Ejector Pins
	Orientation of Fibers in Material	Change Gate Position Reduce Injection Speeds
	Insufficient Rigidity	Change Design of Components (e.g., Add Ribs, etc.) Increase Section Thickness
Jetting	Material Entering the Cavity too Quickly	Reduce Injection Speed Change Position and/or Type of Gate
	Melt too Cold	Increase Melt Temperature
Excessive Shrinkage	Processing Conditions	Reduce Tool Temperature Increase Injection Pressure Increase Holding Pressure
	Gate too Small	Increase Gate Size
Surface Frosting (Reinforced Grades)	Insufficient Injection Speed	Increase Injection Speed Increase Mold Temperatures Increase Barrel Temperatures
	Over-Shearing the Melt	Decrease Screw Speed

EXTRUSION

Many polymer processing techniques are essentially an extrusion operation employing specific downstream equipment. These techniques include wire coating, profile extrusion, film, sheet and monofilament production.

MACHINE DESIGN

VICTREX PEEK and compounds are readily extruded using conventional processing technology. There are specific requirements which are detailed below.

BARREL TEMPERATURES

Cylinder heaters must be capable of reaching 400°C (752°F) and maintaining set temperatures to within ± 2°C (4°F). Therefore, cast aluminum heaters are not suitable and should be replaced with either high temperature alloy or ceramic heaters. Cylinder heaters should cover all exposed metal surfaces to ensure an even temperature distribution. Areas which cannot be heated directly should be covered with high temperature thermal insulation to prevent the formation of "cold spots."

BARREL CAPACITY AND RESIDENCE TIME

The size and the output of the extruder should be matched to obtain a short residence time, typically 5 to 10 minutes. There should be no "dead spots" i.e., gaps around flanges or badly fitting blanking plugs. All internal surfaces should be cleaned and polished before extrusion commences.

SCREW DESIGN

The materials in the VICTREX PEEK grade range are compatible with most conventional screw designs. The only screw specifically not recommended is a continuous compression "PVC" type. This screw has virtually no feed section which results in the compacting of polymer, leading to excessive torque. For a more detailed overview of screw design, see Screw Design, page 6.

WIRE AND CABLE COATING

VICTREX PEEK is widely used in the wire and cable industry. Applications include primary insulation, sheathing and as top coat material for wires and cables.

DIE AND CROSSHEAD DESIGN

VICTREX PEEK insulation is generally applied using a pressure die or a "tube-on" system. Pressure dies allow a specific thickness of coating to be metered directly onto the conductor as it is pulled through the die. Tube-on dies extrude the polymer outside the crosshead and the conductor is drawn through the die and melt. The melt is drawn and adheres to the conductor, forming an insulating layer of the desired thickness. The "draw-down" is expressed as a ratio of the cross sectional area of the annulus to that of the final coating. The recommended draw-down ratio for natural VICTREX PEEK is between 3:1 and 10:1. Tube-on die systems are more frequently used as they allow thinner coatings of VICTREX PEEK to be applied.

The crosshead design for tube-on systems is not critical to the process. However, the preferred design is a single flow splitter which redirects the melt through 90° while maintaining good stream-lined flow. Although more complex flow splitters have proved satisfactory in service, these systems are more difficult to clean.

WIRE AND CABLE CRYSTALLINITY

Many of the outstanding physical properties of natural VICTREX PEEK result from its semi-crystalline morphology. In wire and cable coating, the melt is drawn from the die crosshead and allowed to cool in the air for approximately 1 meter. While cooling, the color of natural VICTREX PEEK changes from transparent dark brown to an opaque grey. This change in color is due to cooling and crystallization of the surface of the insulation. Once this transition has taken place, additional water cooling may be used since crystallization within the bulk of the molten polymer will not be affected.

The temperature of the conductor may retard crystallization in wire and cable coating operations. Therefore, whenever possible, it is advisable to heat the conductor prior to entry into the crosshead. The preheat temperature will depend on the nature and geometry of the conductor, but excellent results have been achieved with temperatures in the 120°C to 200°C (248°F to 392°F) range. If the desired level of crystallinity cannot be achieved on-line, it is possible to post-crystallize the insulation by subsequent thermal treatment.

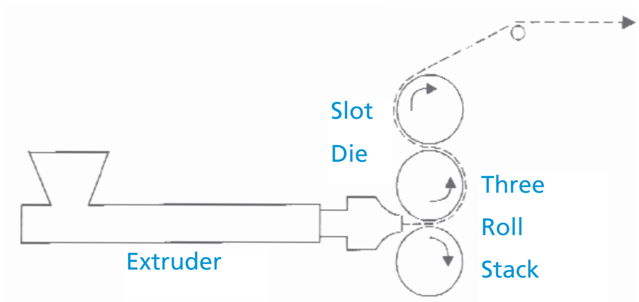
EXTRUDER SIZE AND CONTROL

The residence time of the polymer in the process equipment influences the quality of the final insulation. The thermal stability of VICTREX PEEK is exceptional, but gel formation can occur during processing and manifest itself as a gritty surface on the insulation. The screen packs disperse these gels very effectively in the melt, but any gels created downstream will be present in the extrudate. Therefore, the capacity and throughput of the extruder should be matched.

SHEET MANUFACTURE

Natural VICTREX PEEK may be used to form sheets. The processing is carried out using a conventional extruder with suitable die and haul-off equipment, as depicted in Figure 7.

Figure 7: Sheet Producing Equipment



A general guide to the processing conditions required to successfully form sheets from VICTREX PEEK is given in Table 4.

Table 4: Typical Conditions for Extruding Sheets Using VICTREX PEEK

Screw	32 mm (1.26 in) Diameter Screw		
Die	300 mm (11.81 in) Slot die		
Screw Speed	40 rpm		
Filters	2 layers of 400# woven stainless steel mesh plus supporting mesh fitted into the breaker plate		
	Rear	Middle	Front
Cylinder Temperatures	340°C (644°F)	375°C (707°F)	375°C (707°F)
Die Lips	380°C (716°F)		
Die Temperatures	380°C (716°F)		

DIE DESIGN

Slot dies are recommended for processing natural VICTREX PEEK into sheets. These systems should have a streamlined melt flow with polished interiors to prevent hold-up or die stick-slip. The temperature of the die lip is crucial for good surface finish and dimensional control. Die lips should be maintained at 380°C (716°F) ± 2°C (4°F).

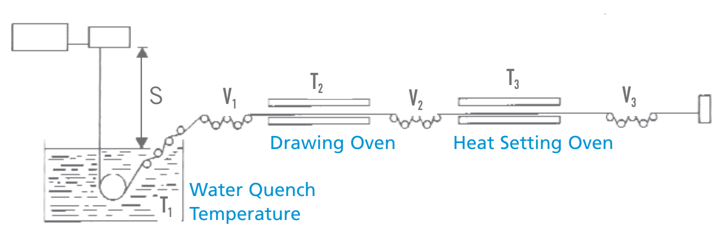
THIN FILM AND SHEET CRYSTALLINITY

Thin sheet [500 μ (< 0.02 in)] may be produced in either semi-crystalline or amorphous form by controlling the temperature of the casting drums. A drum temperature of 50°C (122°F) will produce an amorphous transparent film, while a 170°C (338°F) temperature will give opaque semi-crystalline film. As the thickness of the film increases [500 μ (< 0.02 in)], it becomes more difficult to control the degree of crystallinity. If necessary, the level of crystallinity within films can be optimized through post process thermal treatment.

MONOFILAMENT

VICTREX PEEK may be processed to form monofilament using an extruder with downstream haul-off and draw facilities. Extruders used for the production of monofilament are generally fitted with gear pumps. These ensure that an accurately metered supply of melt is fed to the die at constant pressure. Other non-metered systems have proved satisfactory in service. A typical monofilament production line is depicted in Figure 8. The post-extruder processing depicted in Figure 8 can be considered in two distinct parts: melt orientation and relaxation. During melt orientation the extrudate is air and water cooled at a haul-off velocity of V_1. The filament is drawn at a velocity V_2 through an oven which is set above the glass transition of the material. The difference in velocities V_1 and V_2 serves to draw the polymer, reducing the diameter and orienting the filament.

Figure 8: A Schematic Representation of Monofilament Production Equipment



During melt relaxation, the polymer is "heat set" by passing through a second oven (velocity V_3) which is close to the melt temperature of the material. The difference in velocities V_2 and V_3 serves to relax the polymer, increasing the diameter of the monofilament. Typical values of temperature and velocity for the production of a 0.4 mm (0.016 in) diameter monofilament from a 40 mm (1.57 in) diameter single screw extruder are given in Table 5.

Table 5: Typical Monofilament Production Conditions for a Single Screw Extruder	
Melt Temperature	375°C (707°F)
Filter Pack	3 x 200#
Die to Water Surface Distance (S)	700 mm (27.5 in)
Water Quench Temperature T_1	60°C (140°F)
Draw Down Ratio $V_2 : V_1$	3.5:1
Drawing Oven Temperature T_2	200°C (392°F)
Heat Setting Oven Temperature T_3	280°C (536°F)
Draw Relaxation $V_3 : V_2$	0.95:1
Output	3.1 kg h^{-1} (6.8 lb h^{-1})
Die (16 Hole)	1.12 mm (0.044 in)
Monofilament Diameter	0.4 mm (0.016 in)

MONOFILAMENT ORIENTATION

The physical properties of natural VICTREX PEEK can be modified by solid state orientation. If the filament is to be oriented in a second stage process, it must be quenched upon leaving the die so that it becomes amorphous. However, care must be taken not to cool the filament too rapidly or voids will form. Air cooling followed by immersion in a water bath or direct immersion into a heated water bath have both proven successful in service. The optimum distance from the die to the water bath and the temperature of the water depend on the thickness of the filament. However, a small diameter [0.25 mm (0.01 in)] filament would typically require a 100 to 200 mm (4 to 8 in) air cooling followed by a water quench at 20°C to 50°C (68°F to 122°F). If the monofilament temperature is too high, then the water in the bath will boil locally causing marring on the polymer surface.

VICTREX PEEK will be oriented using either a single stage (Figure 8) or a two stage draw where the filament is necked at 120°C (248°F) and then drawn at 200°C (392°F). The properties which develop in the drawn filament will be dependent on the level of draw-down. Draw-down ratios between 2.5:1 and 3:1 are recommended. Above 3:1, the knot strength of the filament decreases rapidly. The maximum sustainable draw-down that has been achieved using VICTREX PEEK is 3.8:1.

When orientation is developed in the monofilament, it is necessary to heat set it under tension. Heat setting is usually carried out at a temperature approaching the melting point of the polymer (typically 6 seconds at 280°C (536°F) under a draw relaxation of 0.95:1). The resultant monofilament is tough, highly oriented, and has a controlled diameter which will retain its set form above the glass transition temperature of the material. Typical physical properties of such monofilaments are shown in Tables 6 and 7.

Table 6: Properties of a 0.5 mm (0.02 in) Monofilament Prepared as Specified in Table 5	
Energy to Break	1.24 J (0.91 ft lbs)
Tensile Load at 2% Elongation	1.18 kg (2.6 lbs)
Tensile Load at 5% Elongation	1.77 kg (3.9 lbs)
Tensile Load at 10% Elongation	2.66 kg (5.86 lbs)
Tensile Load at Break	5.81 kg (12.8 lbs)
Elongation to Break	22.0%
Knot Strength	2.42 kg (5.34 lbs)
Shrinkage in Air at 200°C (392°F)	3.5%

Table 7: Retention of Monofilament Properties at Elevated Temperatures

Test Temperature	Tensile Stress (yield) MPa (psi)	Tensile Stress (break) MPa (psi)	Modulus GPa (psi)
23°C (73°F)	110 (16,000)	325 (47,100)	6.9 (1,000,000)
100°C (212°F)	70 (10,200)	280 (40,600)	5.7 (827,000)
150°C (302°F)	45 (6,500)	250 (36,300)	5.3 (769,000)
250°C (482°F)	20 (2,900)	120 (17,400)	0.9 (131,000)
300°C (572°F)	6 (870)	90 (13,100)	0.25 (36,300)

COMPRESSION MOLDING

The following information is only a guide to produce compression molded parts based on historical information and data generated over several years. Processors may well have to modify their conditions i.e. pressures and temperatures according to the parts being produced.

BASIC PROCESS

The polymer, which will be generally VICTREX 450PF (bulk density <0.6 g cm^{-3}) grade fine powder needs to be pre-dried for 3 hours at 150°C (302°F) or overnight at 120°C (248°F), to try and avoid the problems of porosity/bubbles. Normal VICTREX PEEK powder or pellets can be compression molded but granular boundary marks will always be evident and will be a weak point in the molding. Drying the polymer in the mold itself is acceptable but drying times may need to be adjusted depending on the depth of material. The mold tools themselves should be pre-dried at around 150°C (302°F) before use. A small amount (2-3%) of PTFE lubricant grade powder compounded into the VICTREX PEEK may aid part ejection.

The dried polymer with ~ 102% of the theoretical weight of polymer required to form the component is compacted in the mold with a pressure of between 350 to 700 bar (5000 and 10,000 psi) to enable the trapped air in the mold to escape before the mold is heated up. The heating of the mold can be accomplished by preferably internal and external heater bands or if heater bands are not available an air-circulating oven can be used. Prior to heating the mold, the pressure should be "backed off" to 140 bar (2000 psi).

The temperature of the mold is raised to 390 - 400°C (734 - 752°F) as fast as the heaters will allow until the polymer is fully molten. The pressure should be held for 15 minutes for every 25 mm (1 in) section thickness. Some flashing may occur but this is normal.

The molding is then cooled down at a rate of approximately 40°C (72°F) per hour while still under pressure until the part has reached <150°C (302°F) when the part can be ejected. The use of thermocouples should be used to monitor cooling rate.

EQUIPMENT REQUIREMENTS

Press: Should be capable of delivering sufficient pressure. Typically up to 700 bar (10,000 psi).

Molds: Should be corrosion resistant metals. Good results have been obtained with Stavax, Duplex (Ni/Chromium) and hard chrome plated stainless steel, also P20 hard tool steel with a Rockwell hardness of 50 has been used with success. Mild steel and steels containing copper should not be used. Mold surfaces in the line of draw should be polished to aid ejection.

A mold release agent is recommended such as one of the Frekote products (without silicon) to aid ejection. Clearance between sliding parts should be between 0.075 and 0.125 mm (0.003 and 0.005 in). PTFE, aluminum, steel (20-30 Rockwell) sealing rings have been used with effect between the punch plate and the molten polymer.

Internal and external heater bands are preferable but a hot air circulating oven capable of achieving at least 400°C (752°F) can be used. Care should be taken to avoid thermal degradation of the polymer.

COMPRESSION MOLDING CHARACTERISTICS

Properties of compression molded VICTREX PEEK parts differ from injection molded parts. As a general rule the compression molded parts are more crystalline, have a higher modulus and tensile strength, are harder but have a lower ductility and can be more brittle.

Milled fibers (glass and carbon) may be compounded into VICTREX PEEK for compression molding albeit with loss of anisotropy, lower strength, different C.T.E. and different tribological properties than injection molded parts.

Very thick sections may be subject to cracking and a post processing thermal treatment (annealing) should be used to relieve stresses. See Victrex literature on annealing.

Close tolerances cannot be achieved directly therefore components must be machined. See Victrex literature on machining. The outer and inner surfaces of moldings may be discolored due to the mold release agent and being in contact with the tooling, these surfaces should be skimmed to remove the discoloration.

POWDER COATING

VICTREX PEEK in fine powder form may be used to coat metal substrates. Thick coats of up to 2 mm (0.078 in) can be applied by electrostatic spraying or fluidized bed coating. Coatings as thin as 25 μ (0.001 in) may be obtained using dispersion techniques.

Regardless of whether a part is coated by the electrostatic or dispersion process, the appearance of the coating can be modified via the last heat cycle. Three surface finishes are possible; standard crystalline (air cooled), amorphous (quenched in cold water*) or gloss (quenched in cold water and subsequently annealed to achieve a gloss finish).

* Parts that are quenched can generate steam and localized boiling water.

ELECTROSTATIC SPRAY AND FLUIDIZED BED COATING

Electrostatic spray and fluidized bed coating are both methods of transporting solid VICTREX PEEK powder onto the heated surface of the metal substrate. Once the fine powder comes into contact with the metal, the particles adhere to the surface and eventually form a cohesive layer.

Electrostatic spray techniques generally involve the air transportation of fine powder to the nozzle of an electrostatic spray gun. A large potential difference is applied between the nozzle and the substrate, which serves to direct the jet of fine powder. Fluidized bed techniques use pressurized gases to circulate a given mass of fine powder material in a fixed volume. A controlled cloud of powder is created into which the heated substrate may be lowered.

Before coating, substrates should be prepared by grit blasting and degreasing in appropriate solvents. This will remove contamination and properly prepare the surface of the metal for polymer adhesion. The metal substrate should be heated to between 400°C and 420°C (752°F and 788°F) and the fine powder coating applied. Oxidation will reduce the surface energy of the metal and lead to poor adhesion. Therefore, freshly prepared surfaces are recommended for the best results and exposure of the heated metal to oxygen should be minimized or avoided, if possible.
After the final coating the part should be placed into the oven for final "flow-out" of the VICTREX PEEK coating and then removed from the oven and allowed to cool. The degree of crystallinity within the coating may be controlled by the cooling regime imposed. Amorphous layers are frequently post conditioned to reach the optimum level of crystallinity by placing the component in an air circulating oven at 200°C (392°F) for 30 minutes.

When coating components with a large thermal mass, slower cooling rates will cause the development of high levels of crystallinity which may cause cracking of the coating. Levels of crystallinity can be controlled by ensuring that the coating is cooled at an appropriate rate, for example, by the use of a cool air flow. Water quenching may lead to thermal shock and is not recommended.

DISPERSION SPRAY COATING

VICTREX PEEK-based coatings in a range of 25 to 100 μ (0.001 to 0.004 in) thickness can be applied using dispersions of VICTREX PEEK fine powder in an aqueous medium. Dispersions can be used to coat stainless and carbon steels, aluminum, castings and ceramics. Since they are based on high-flow VICTREX PEEK, dispersions are ideal for coating complex geometries and provide superior coverage around holes, deep draws and recesses.

Like other types of VICTREX PEEK-based coatings, dispersion coatings have very low wear and friction properties, superior chemical and steam resistance, excellent mechanical properties (hardness, creep resistance, etc.) as well as low extractable content and good purity.

FINISHING OPERATIONS

Components made from VICTREX PEEK and compounds may be used in a number of finishing operations such as machining, bonding, coloring or metallization.

MACHINING

Often, for prototype designs or short production runs, it is not economically viable to manufacture an injection molding tool. Under such circumstances, it is common to machine VICTREX PEEK materials to form components. VICTREX PEEK may be machined and finished using the same techniques and equipment as for other engineering thermoplastics. However, due to the excellent physical properties and wear characteristics of these materials, it is necessary to use carbide or diamond tipped tools and bits.

Machining and finishing operations on polymeric materials can release molded-in or residual stresses. Before machining, components formed from VICTREX PEEK should be annealed to relieve stress. An annealing protocol is detailed in the section on Annealing. During machining or finishing, further stresses may be built-up within the material by localized heating at the cutting point. Therefore, if a large amount of machining and finishing is to be carried out on a component, a second annealing procedure prior to finishing is recommended. The thermal conductivity of all polymeric materials is lower than that of metals, so heat build-up during machining is rapid. A cooling fluid should be used to remove some of the heat generated by working the material. Water is generally recommended for use with all the VICTREX PEEK based materials. A summary of the suggested machining guidelines is shown in Table 8 (page 16) .

PROTOTYPE PERFORMANCE

Prototype components are generally the best way to evaluate the performance of a material under a certain set of application-specific conditions. However, the physical performance of a machined component will differ slightly from that of a seemingly identical injection-molded component. This phenomenon may be explained in terms of the inherent physical consequences of a molding procedure, including the production of skin/core effects and fibre orientation.

Table 8: Guidelines for the Machining and Finishing of VICTREX PEEK			
	Units	VICTREX PEEK	Reinforced VICTREX PEEK Compounds
TURNING			
Cutting Speed	m min^{-1} (ft min^{-1})	300 (984)	120-180 (394-590)
Feed	mm rev^{-1} (in rev^{-1})	0.4 (0.016)	0.2 (0.008)
Relief Angle	°	5	5
Top Rake Angle	°	6-12	6 - 12
Cutting Depth	mm (in)	6.5 (0.25)	7.5 (0.29)
Coolant		None	None
MILLING			
Cutters	-	Standard or Carbide Tip	Carbide Tip or Diamond Tip
Cutter Speed	m min^{-1} (ft min^{-1})	590-754 (180-230)	78-110 (256-361)
Coolant	-	Water/Oils	Water/Oils
DRILLING			
Cutting Speed	m min^{-1} (ft min^{-1})	120 (394)	75-120 (246-394)
Feed	mm rev^{-1} (in rev^{-1})	0.05-0.20 (0.002-0.008)	0.05-0.20 (0.002-0.008)
Lip Angle	°	118	118
Clearance Angle	°	12	12
Coolant	-	Water/Oils	Water/Oils
REAMING			
Runners	-	Spiral Flute	Spiral Flute
Speed	rev min^{-1}	100-200	100-200
Coolant	-	Water/Oils	Water/Oils

ANNEALING

Components formed from VICTREX PEEK can be annealed to increase levels of crystallinity, remove any thermal history, limit subsequent dimensional changes at high temperatures, or to remove stresses. The appropriate annealing procedure will depend on the objective of the process.

AN OVERVIEW OF ANNEALING FOR OPTIMUM CRYSTALLINITY

Increasing crystallinity within a component may be necessary if a brown amorphous skin is observed (this can also be eliminated by increasing mold temperature), or enhanced strength and chemical resistance is required.

(a) Dry the component for a minimum of three hours at 150°C (302°F).
(b) Allow the component to heat up at 10°C (18°F) per hour until an equilibrium temperature of 200°C (392°F) is reached.
(c) The holding time for components is dependent on section thickness. It is recommended that annealing temperatures are held for at least 4 hours.
(d) Allow the component to cool at 10°C (18°F) per hour until the system falls below 140°C (284°F).
(e) Switch off the oven and allow the component to cool down to room temperature.

Annealing temperatures close to 300°C (572°F) have been used to maximize mechanical performance (strength and modulus) and chemical resistance. However, these effects may be accompanied by embrittlement and surface oxidation because of the high annealing temperature.

AN OVERVIEW OF ANNEALING TO REMOVE STRESSES

Injection molding or machining operations may add stresses to a component. These stresses reduce the physical performance of devices and may be removed by annealing the sample as described above, with a holding temperature up to 250°C (482°F).

AN OVERVIEW OF ANNEALING TO REMOVE THERMAL HISTORY AND SHRINKAGE

Dimensional stability over a wide temperature range may be crucial to some applications. Components may be annealed to remove distortion effects or thermal history.

(a) Dry the component for a minimum of three hours at 150°C (302°F).
(b) Allow the component to heat up at 10°C (18°F) per hour until an equilibrium temperature which exceeds the normal service temperature is reached.
(c) The holding time for components is dependent on section thickness. It is generally recommended that temperatures are maintained for at least 4 hours.
(d) Allow the component to cool at 10°C (18°F) per hour until the system falls below 140°C (284°F).
(e) Switch off the oven and allow the component to cool down to room temperature.

Table 9: Bond Strength of Various Adhesives with VICTREX PEEK-Based Materials

			Failure Stress / MPa (psi)			
Adhesive	**Type**	**Manufacturer**	**23°C**	**120°C**	**150°C**	**200°C**
S-4215 RA	Acrylic tape	ATP Adhesive Systems	0.2 (29) CF	0.03 (4.3) CF	-	-
Araldite AV138M + HV 998	Epoxy	Huntsman	5.5 (800) IF + CF	3.4 (500) CF	-	-
Araldite AV 119	Epoxy	Huntsman	41.8 (6000) SF	4 (575) CF	1.5 (225) IF + CF	-
HAF 8401	Nitrile rubber phenolic resin	Tesa AG	47.3 (6850) SF	2.4 350) IF	1.9 (275) IF	-
Duralco 4460	Epoxy	Cotronics Corp.	1.7 (250) ICF	-	0.5 (75) CF	0.4 (58) IF +CF
Duralco 4703	Epoxy	Cotronics Corp.	16.7 (2400) SF	-	3.4 (500) CF	1 (145) CF
EPO-TEK 353 ND	Epoxy	Epoxy Technology	36.2 (5250) SF	-	3.1 (450) CF	1 (145) IF + CF
Duralco 4525	Epoxy	Cotronics Corp.	3.3 (475) CF	-	-	0.6 (87) CF

IF - adhesive failure at the adhesive / substrate interface
CF - cohesive failure of the adhesive, leaving adhesive on both sides of the substrate
SF - the adhesive is of sufficient strength to cause failure within the VICTREX PEEK substrate
ICF - mixed mode failure with fracture propagation switching between interfacial and cohesive failure

ADHESIVE BONDING

VICTREX PEEK and compounds may be bonded using a variety of common adhesives. For specific adhesive applications please contact Victrex for recommendation.

ADHESIVE TYPES

Most adhesive types are compatible with the VICTREX PEEK-based materials. Epoxy, cyanoacrylate, anaerobic and silicone adhesives have been shown to successfully bond VICTREX PEEK. A list of typical adhesives and their corresponding bond strengths is shown in Table 9.

From the data shown in Table 9 it is clear that some of the epoxy systems tested give superior bond strengths to other conventional adhesives.

SURFACE PREPARATION

Surfaces which are to be joined by an adhesive bond should be clean, dry and free from grease and other contamination.

There are a variety of surface treatments available which increase the strength of adhesive bonds made with VICTREX PEEK. A comparison of bond strengths achieved using the most common of these techniques is made in Table 10. For these measurements VICTREX 450G samples were bonded together in a single overlap shear geometry with a two-component epoxy from Ciba (AV138M/HV998) and using a 15 minute 100°C (212°F) curing cycle.

WELDING

VICTREX PEEK may be bonded using conventional thermoplastic welding techniques. However, these materials have exceptionally high melt temperatures, and considerable amounts of energy must be put into the interface to achieve a good bond. Satisfactory results have been obtained using hot plate, friction and near-field ultrasonic welding.

Table 10: Comparison of Surface Preparation Techniques for Adhesive Bonds to VICTREX 450G

	Bond Strength/MPa (psi)
Untreated	0.7 (102)
Roughening	2.1 (305)
Acid Etch	5.5 (798)
Excimer Laser	5.6 (812)
UV Lamp	5.0 (730)
Plasma Chamber	5.0 (722)

VACUUM METALLIZATION

VICTREX PEEK materials may be used as substrates in a thermoplastic metallization process. Care should be taken when injection molding or machining such components to ensure a good surface finish. A poor finish will result in a non-uniform coating. Substrates must be clean, dry and free of contamination before the application of the metal coating.

COLORING VICTREX PEEK

VICTREX PEEK is available in a natural grey color or as a black material. The color is modified by its constituents, i.e., carbon reinforced materials are black in color while glass fiber reinforced materials are a light grey. VICTREX PEEK may be colored using a masterbatch additive.

POLYMER SPECIFICATIONS AND APPROVALS

VICTREX PEEK and compounds are recognized or approved by the following bodies:

AEROSPACE/MILITARY	
FAR 25-853	VICTREX 381G, 450G, 450GL30 and 450CA30 meet the fire, smoke and toxicity standard FAR 25-853 for aircraft cockpit use.
ATS 1000.001	VICTREX 381G and 450G meet the fire, smoke and toxicity standard ATS 100.001 for optical density and toxicity of fumes from burning.
SP-R-0022A	VICTREX 450G meets the NASA standard SP-R-0022A for vacuum stability of polymeric materials in spacecraft applications.
BMS 8-317A	VICTREX PEEK unfilled glass and carbon filled polymers can be supplied to Boeing specification BMS 8-317A for use in aircraft applications.
MIL-P-46183	VICTREX PEEK and compounds can be supplied to the military specification MIL-P-46183.
Staining Test	VICTREX 381G complies with the Boeing Aircraft staining test.
#DMSRR 1018	VICTREX CA30 complies with the Rolls Royce standard #DMSRR 1018.
75-T-2-3007-4-1	VICTREX CA30 meets the Deutsche Aerospace/Airbus standard 75-T-2-3007-4-1.
MS29.02.03	VICTREX 450GL30 can be supplied to Sundstrand Aerospace materials specification MS29.02.03
JAR 25.853	VICTREX 381G meets the fire, smoke and toxicity standard JAR 25.853 for flame resistance.
S26 4625	VICTREX 381G meets the fire, smoke and toxicity standard S26 4625 for non-flaming smoke generation.
VPRM85-10A	VICTREX 381G meets the fire, smoke and toxicity standard VPRM85-10A for peak and total heat release when heated.
299-947-362	All grades of VICTREX PEEK can be supplied to Bell Helicopter specification 299-947-362.
P6240	All grades of VICTREX PEEK can be supplied to General Dynamics specification P6240.
HS13534	VICTREX 450FC30 can be supplied to Hamilton Standard (United Technologies) specification HS13534.

AUTOMOTIVE	
WSK-M 4D-838-A	VICTREX 150G and 450G can be supplied to the Ford worldwide specification WSK-M 4D-838-A.
WSS-M-4D X1-X1	VICTREX 150FC30 can be supplied to the Ford worldwide specification WS-SM 4D X1-X1.
MS DB406, Rev C	VICTREX 150FC30 can be supplied to DaimlerChrysler material specification MS DB406, Rev C.

FLAMMABILITY RATING	
UL94 V-0	VICTREX 450G and compounds (E161131) VICTREX 450GL30 and 450CA30 have an UL94 V-0 rating at .057 in (1.45 mm) thickness.

FOOD AND BEVERAGE	
21CFR 177.2415	All grades of unfilled VICTREX PEEK have been manufactured and tested to be compliant with the requirements of FDA regulation 21CFR 177.2415 for use in food contact applications. Victrex plc accepts no responsibility for the compliance of the final material if other substances have been added during subsequent processing stages. End users and processors should note that it is the responsibility of the manufacturer of the food contact article to assure compliance of the extractive limitations of 21CFR 177.2415.
Sanitary Standard 3-A	All unfilled grades of VICTREX PEEK comply with Sanitary Standard 20-21 as multiple-use plastic materials for use as product contact surfaces for dairy equipment.
EEC 93/9/EEC	VICTREX 150P, 380P, 450P, 151G, 381G and 450G complies with an EEC directive 93/9/EEC for plastic in contact with foodstuffs.
WRCA BS 6920	VICTREX 450G, 450GL30, 450CA30, and 450FC30 meet the Water Research Council Approval BS 6920 Report M100216/(A-D) for non-metallics in contact with water for human consumption.

INDUSTRIAL	
WS-340, Rev. A.	VICTREX 450G meets Whitey (Swagelok Valve) material specification WS-340, Rev. A.

WIRE AND CABLE	
61-12	VICTREX 450G passes the UK defense standard 61-12 (Part 18, issue 2) as a type 2 wire. This is a standard for limited fire hazard equipment.
RME 620A	VICTREX 450G is approved to London Transport Specification RME 620A for cable covering in railway rolling stock.
ST 808	VICTREX 450G has been approved by French Railways Standard ST 808.
E/TSS/EX5/6053	VICTREX 450G has been approved by the Central Electricity Generating Board Standard E/TSS/EX5/6053, issue 3.
EDF HN 3280	VICTREX 450G coated wires pass the French Electricity Generating Board to specification EDF HN 3280.

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