

# PEEK<sup>tm</sup>

## A Practical Design Guide For Injection Molded Components



[www.performanceplastics.com](http://www.performanceplastics.com)

4435 Brownway Avenue  
Cincinnati, OH 45209  
513.321.8404

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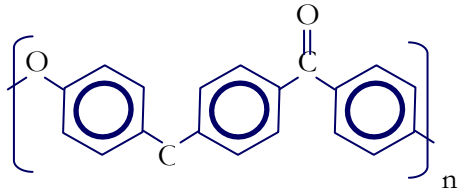
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# I. Why Use PEEK<sup>tm</sup>?

## Summary of Material Benefits and Key Characteristics:

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*PEEK<sup>tm</sup> repeating*

**poly (oxy-1,4-phenylene-oxy-1,4-phenylene-carbonyl-1,4-phenylene)**

PEEK<sup>tm</sup> from Victrex® is a linear aromatic thermoplastic. It can be modified with various filler technologies - including carbon fiber, glass, ceramics, aramid fiber, PTFE lubricated and others - to enhance performance. These combinations offer:

- **Excellent Chemical Resistance**
  - Insoluble in most common organic and inorganic chemicals with exception of extremely strong oxidizing acids.
- **High Temperature Performance**
  - Heat distortion temperature up to 599 °F (315 °C).
  - Continuous usage temperature of 500 °F (260 °C).
- **Increased Strength**
  - Allows for thin wall design which saves space, weight and cost.
  - Flexural moduli ranging 579,700 psi (4.0 GPa) to  $5.7 \times 10^6$  psi\* (*filler dependant*)
  - Tensile strength of 14,500 psi (100 MPa) to 36,000 psi (x MPa)\* (*filler dependant*)
- **Wear Resistance and Lubricity**
  - Inherently lubricious, outstanding wear resistance.
- **Low Flammability, Smoke and Toxic Gas Emission**
  - Allows for designs requiring thin wall thickness, but still require UL V-0 flammability ratings (V-0 rated down to .057" / 1.45 mm)
  - Out performs most if not all known engineering thermoplastics for smoke produced under ASTM E662 testing
- **Hydrolysis Resistance Polymer**
  - Performs well in pressurized steam applications and is not chemically attacked by water
  - Limited reduction in mechanical properties under continuous exposure in water at elevated temperatures
- **Radiation Resistance and Electrical Stability**
- **Sterilizability**

## Peek<sup>™</sup> Grades

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### Unfilled Grades

150G Easy flow grade  
450G General purpose grade  
90G High flow grade (Note 150G has higher ductility)

### Glassed Filled

150GL30 Easy flow, 30% glass fiber reinforced  
450GL30 General purpose, 30% glass fiber reinforced  
90GL30 / 90GL60 High flow material glass fiber

### Carbon Filled

150CA30 Easy flow, 30% carbon fiber reinforced  
450CA30 Standard viscosity, 30% carbon fiber reinforced  
90CA30 / 90CA50 high flow, 30 % & 50% carbon fiber

### Lubricated

150FC30 Easy flow, 30% carbon / PTFE grade  
450FC30 Stand viscosity, 30% carbon / PTFE grade  
450FC30 used to improve creep resistance and wear performance in dry environments

## Crystalline versus Amorphous Effects on Mechanical Properties

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A foundation question often overlooked or misunderstood is whether a specified thermoplastic material is amorphous or crystalline. The answer has an effect on mechanical and thermal performance, chemical resistance as well as dimensional and tolerance expectations. PEEK<sup>™</sup> is a linear aromatic semi-crystalline thermoplastic. Like all of the crystalline plastics, it has amorphous regions between and connecting the crystalline regions. **Figure 1** illustrates the difference between a crystalline and amorphous polymer chains. In general, the ordering of the crystallites makes a semi-crystalline material stiffer, stronger, more chemical resistant but sometimes less resistant to impact than amorphous materials. Amorphous materials tend to soften slowly resulting in a gradual change in mechanical performance such as stiffness, modulus and/or impact. They also exhibit better dimensional stability than semi-crystalline materials in an unfilled state. A designer needs to be aware that PEEK<sup>™</sup>, like other semi-crystalline materials, does experience a change in mechanical properties such as tensile strength, flexural strength, and/or flexural modulus at the glass transition temperature of material (T<sub>g</sub>). PEEK<sup>™</sup>'s glass transitional temperature is approximately 143 °C (289 °F). During heating when the temperature reaches the point of T<sub>g</sub> the randomly oriented molecules begin to move, rotate and slide around. This allows hard regions to become soft and flexible. From a structural point of view, mechanical properties gradually change at a material's T<sub>g</sub>. In general the strength and modulus will decrease and the elongation may increase. Before the glass transition point is reached mechanical properties will stay fairly constant.

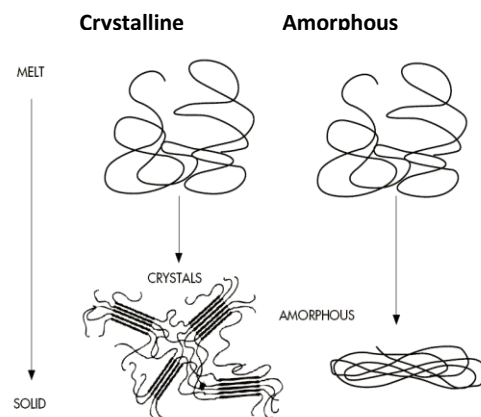
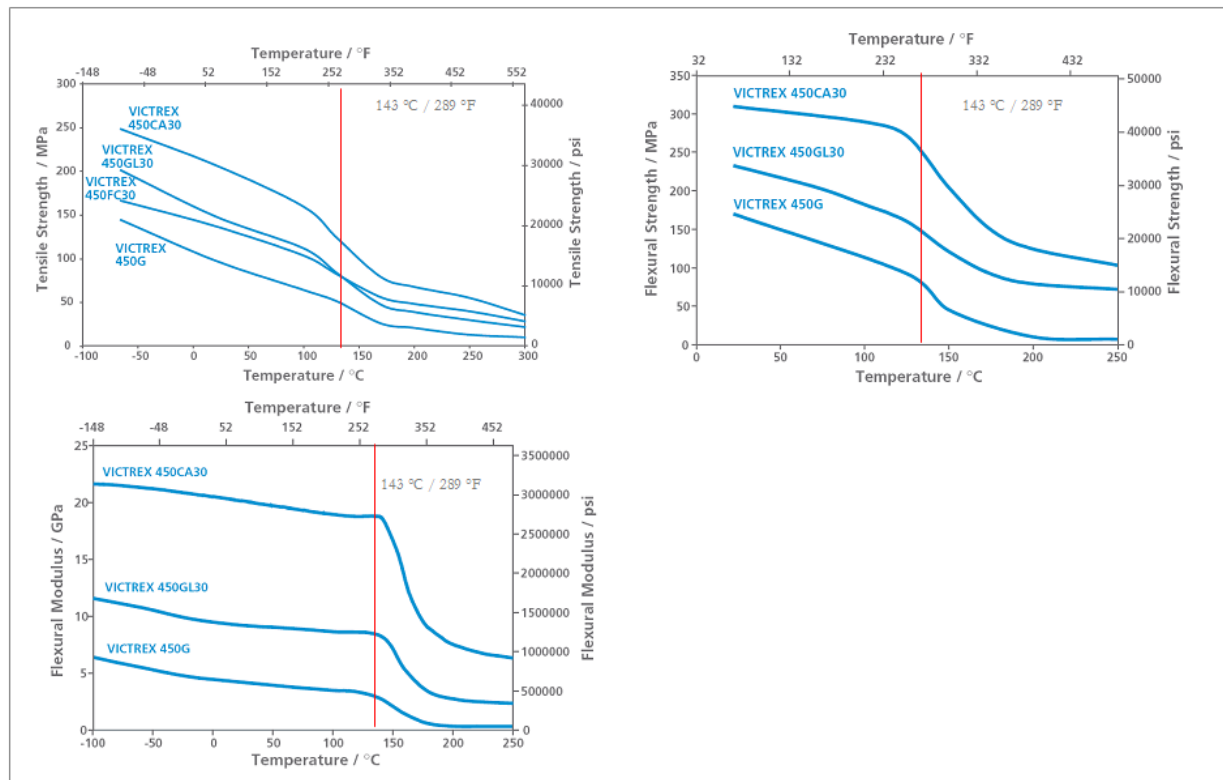


Figure 1

In **Figure 2** the red line in the graph illustrates the point of Tg, while the values for tensile strength, flex modulus,

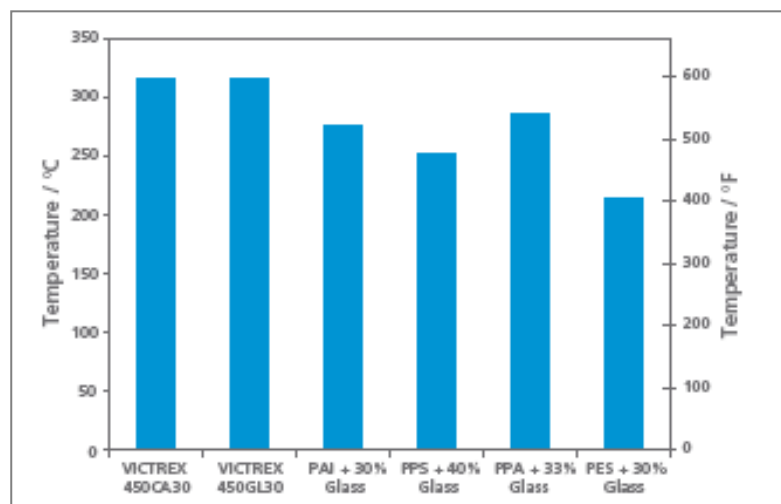


**Figure 2**

and flexural strength are significantly higher than most all other thermoplastic material available there is a rapid drop in properties at this point as compared with values below Tg. Temperatures ranges above a material's Tg whether amorphous or semi-crystalline will have an impact on the material's mechanical properties, this condition is not unique to PEEK™ only.

## High Temperature Stability

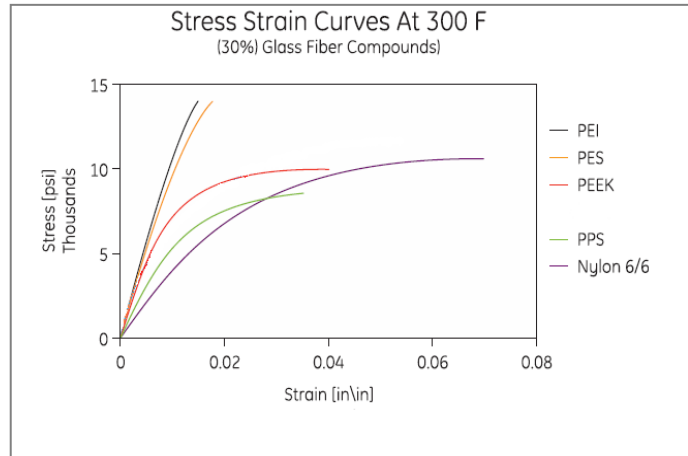
When evaluating applications with short term exposure to high temperatures, the Heat Deflection Temperature of a material is used to understand the material's performance. PEEK™ has an HDT value of 599 °F (315 °C) for grades that are filled with 30% carbon or glass. The test for HDT is ISO 75, which measures the temperature at which a defined deformation is observed in a sample under constant, defined applied stress of 1.8 MPa (264 psi) for a time period of less than 5 minutes. **Figure 3** compares a number of high performance materials using ISO 75 HDT test values. As shown PEEK™ grades are superior to



**Figure 3**

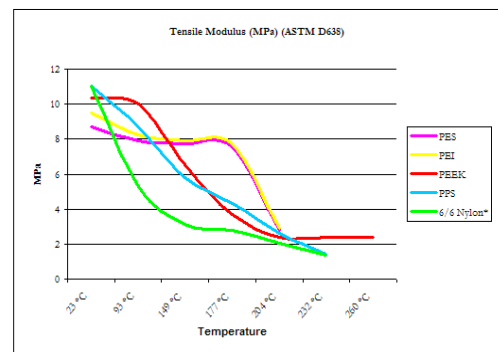
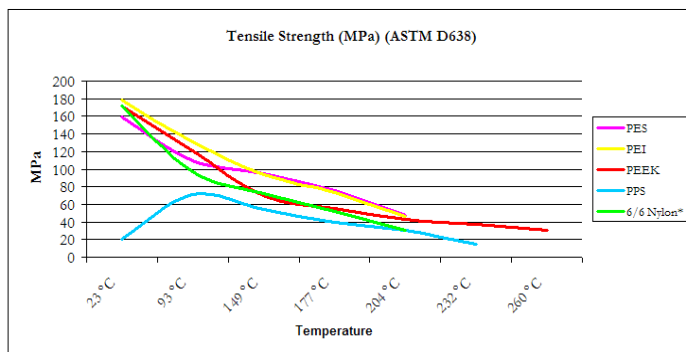
most other filled and unfilled thermoplastics. From a material comparison point of view, HDT can be thought of as the temperatures that the two materials will have the same relative modulus. It should only be used for short term exposure evaluations.

When evaluating materials for product design at elevated temperatures, arguably one should use stress-strain properties at the service temperature. **Figure 4** shows typical stress-stain curves at 300°F for 30% glass fiber filled materials. Figure 5 displays two graphs, which show the tensile strength and tensile modulus for the 30% glass filled versions of the same materials at temperatures up to 500°F.



**Figure 4**

As shown in **Figure 4 and 5** PEEK™ provides an excellent balance of mechanical properties at elevated temperatures. PEEK™ can be used in applications requiring a continuous use temperature up to 500 °F (260 °C).



| Tensile Strength (Mpa) (ASTM D638) |       |       |        |        |        |        |        |  |
|------------------------------------|-------|-------|--------|--------|--------|--------|--------|--|
| 30% Glass Fiber Filled             |       |       |        |        |        |        |        |  |
| Material                           | 23 °C | 93 °C | 149 °C | 177 °C | 204 °C | 232 °C | 260 °C |  |
| PES                                | 159   | 110   | 95     | 76     | 48     | x      | x      |  |
| PEI                                | 178   | 131   | 94     | 74     | 46     | x      | x      |  |
| PEEK                               | 172   | 121   | 70     | 55     | 43     | 37     | 31     |  |
| PPS                                | 20    | 71    | 54     | 40     | 31     | 15     | x      |  |
| 6/6 Nylon*                         | 172   | 97    | 72     | 52     | 30     | x      | x      |  |

| Tensile Modulus (Mpa) (ASTM D638) |       |       |        |        |        |        |        |  |
|-----------------------------------|-------|-------|--------|--------|--------|--------|--------|--|
| 30% Glass Fiber Filled            |       |       |        |        |        |        |        |  |
| Material                          | 23 °C | 93 °C | 149 °C | 177 °C | 204 °C | 232 °C | 260 °C |  |
| PES                               | 8.69  | 7.93  | 7.72   | 7.58   | 2.76   | x      | x      |  |
| PEI                               | 9.51  | 8.27  | 7.93   | 7.72   | 2.9    | x      | x      |  |
| PEEK                              | 10.34 | 10    | 6.55   | 3.7    | 2.41   | 2.41   | 2.41   |  |
| PPS                               | 11.03 | 8.69  | 5.79   | 4.34   | 2.62   | 1.45   | x      |  |
| 6/6 Nylc                          | 11.03 | 5.3   | 3.1    | 2.76   | 2.07   | 1.38   | x      |  |

**Figure 5**

## Excellent Chemical Resistance

PEEK™ performs well in a number of varying chemical environments. PEEK™ is insoluble in most common organic and inorganic chemicals with the exception of extremely strong oxidizing acids. **Figure 6** illustrates how PEEK™ compares to other engineering materials.

|        | Weak Acids | Strong Acids | Weak Alkalis | Strong Alkalis | Organic Solvents | Alcohols | Hydro Carbons | Fuels | Gamma Radiation | UV Radiation |
|--------|------------|--------------|--------------|----------------|------------------|----------|---------------|-------|-----------------|--------------|
| PEEK   | E          | E            | E            | E              | E                | E        | E             | E     | E               | G            |
| PPS    | E          | E            | E            | E              | G                | E        | F             | G     | G               | F            |
| PES    | E          | P            | E            | E              | P3               | F        | P             | F     | G               | F            |
| PPA    | E          | G            | E            | G              | E                | G        | E             | G     | G               | F            |
| PA 6/6 | G          | P            | E            | F              | E                | G        | G             | G     | F               | P            |
| PEI    | E          | E            | E            | P              | P4               | F        | P             | F     | G               | F            |
| PFA    | E          | E            | E            | E              | E                | E        | E             | G     | G               | G            |

1 Attacked by oxidizing acids

2 Attacked by sulfuric acid

3 Soluble in aromatic and chlorinated hydrocarbons

4 Soluble in ketones and esters, aromatic and chlorinated hydrocarbons

5 Below 176 °F (80 °C)

6 At ambient temperature

7 Property retention with swelling

Ratings

E = Excellent

G = Good

F = Fair

P = Poor

Figure 6

## Hydrolysis Resistance

PEEK™ and PEEK™ compounds are not chemically attacked by water or pressurized steam. These materials retain a high level of mechanical properties when continuously conditioned at elevated temperatures and pressures in steam or water. The compatibility of these materials with steam was evaluated by conditioning injection molded tensile and flexural bars at 200°C (392°F) and 1.4 MPa (200 psi) for the times indicated in **Figure 7**. The data demonstrates the ability of components made from PEEK™ to continuously operate in, or be frequently sterilized by, steam (*see Figures 8*). The initial increase in the mechanical properties is due to the relaxation of molded-in stresses and further developments in crystallinity due to thermal treatment. Typical amorphous resins, like polycarbonate, polyetherimide, etc. are susceptible to stress cracking after repeated steam sterilization and lack good chemical resistance.

PEEK™ is an excellent candidate for product designs that require sterilization. PEEK™ materials have shown to maintain mechanical and chemical properties past 3,000 hours in high-pressure steam.

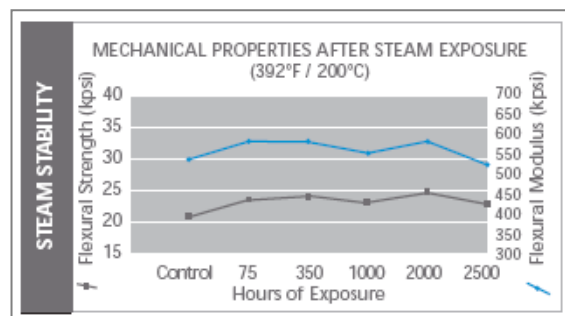


Figure 7

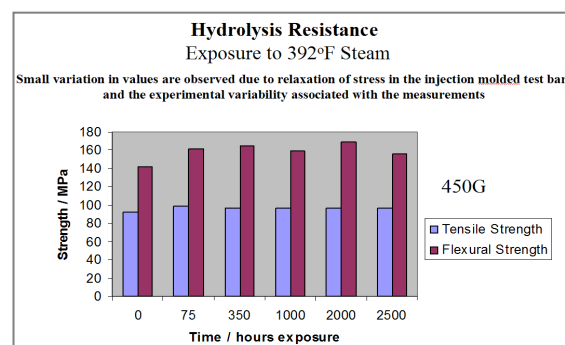


Figure 8

## Radiation Resistance

PEEK™ exhibits outstanding stability upon exposure to radiation. Thermoplastic materials exposed to electromagnetic or particle-based ionizing radiation can become brittle. Due to PEEK™'s chemical structure, components can successfully operate when exposed to high doses of ionizing radiation.

**Figure 10** shows that 450G PEEK™ has a greater resistance to radiation than other materials. PEEK™ also exhibits good resistance to a wide variety of other radiations such as: alpha, beta, gamma, x-ray, and microwave. A comparative bar chart of thermoplastic materials is shown in Figure 10, where the recorded dose is at the point at which a slight reduction in flexural properties is observed.

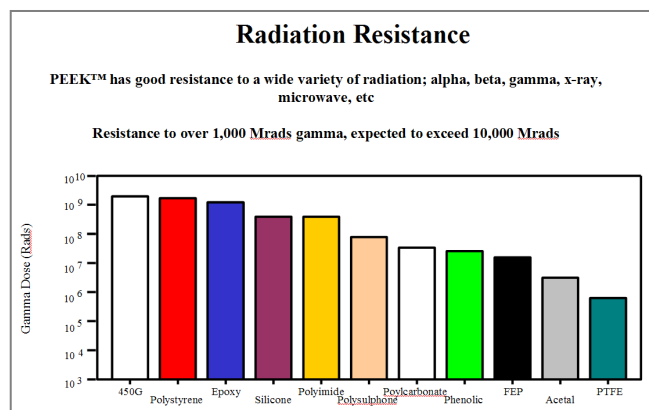


Figure 10

The Oxidative Gamma Radiation Dose at which a slight deterioration of Flexural Properties occurs. Resistance to over 1,000 Mrads gamma, expected to exceed 10,000 Mrads

## Electrical Properties

PEEK™ is often used as an electrical insulator with outstanding thermal, physical and environmental resistance.

### Volume Resistivity

Volume resistance and resistivity values are used as aids in choosing insulating materials for specific applications. The volume resistance of a material is defined as the ratio of the direct voltage field strength applied between electrodes placed on opposite faces of a specimen and the steady-state current between those electrodes. Resistivity may be defined as the volume resistance normalized to a cubical unit volume. As with all insulating materials, the change in resistivity with temperature, humidity, component

geometry and time may be significant and must be evaluated when designing for operating conditions. When a direct voltage is applied between electrodes in contact with a specimen, the current through the specimen decreases asymptotically towards a steady-state value. The change in current versus time may be due to dielectric polarization and the sweep of mobile-ions to the electrodes. These effects are plotted in terms of volume resistivity versus electrification time in **Figure 11**. The larger the volume resistivity of a material, the longer the time required to reach the steady-state current. Natural 450G PEEK™ has an IEC 93 value of  $6.5 \times 10^{16} \Omega \text{ cm}$  at ambient temperatures, measured using a steady-state current value for 1000 s applied voltage.

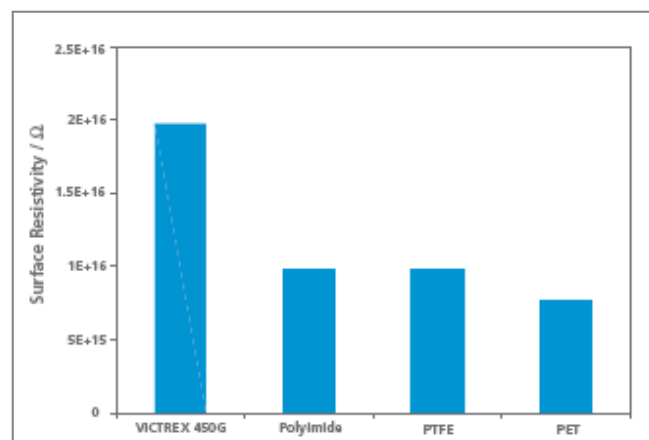
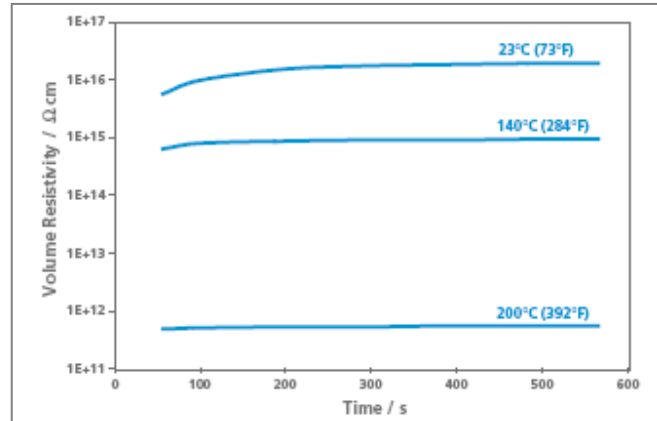


Figure 11

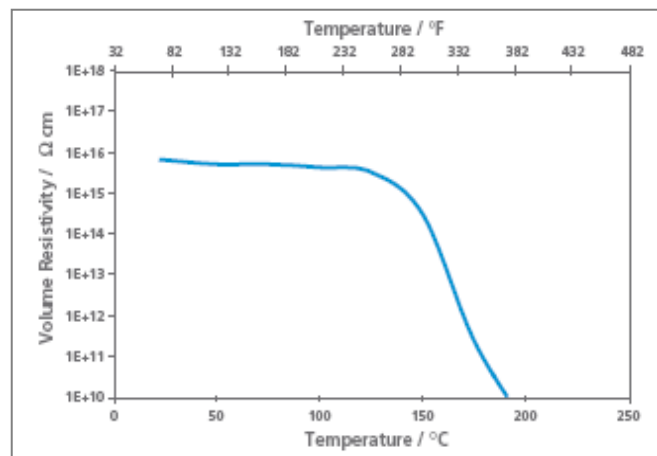
Using the same experimental technique, the volume resistivity of 450G PEEK™ is plotted versus temperature in **Figure 12**. This shows that high values for the volume resistance of natural PEEK™ are retained over a wide temperature range.

### Surface Resistivity

The surface resistance of a material is defined as the ratio of the voltage applied between two electrodes forming a square geometry on the surface of a specimen and the current which flows between them. The value of surface resistivity for a material is independent of the area over which it is measured. The units of surface resistivity are the Ohm ( $\Omega$ ), although it is common practice to quote values in units of ohm per square. A comparative bar chart of surface resistivity's for some high performance engineering polymers at ambient temperatures is shown in Figure 13. This shows that natural 450G PEEK™ has a surface resistivity typical of high performance materials.



**Figure 12**



**Figure 13**

Surface Resistivity's for Various Engineering Polymers tested at 25°C (77°F) with 50% Humidity

## PEEK versus Metal

PEEK™ is often used in situations where metal has traditionally been the material of choice. However, PEEK™ offers many advantages over metal such as comparable strength/mass, chemical resistance, low extractables (outgassing, leaching), wear performance, manufacturing advantages via consolidation of parts and shorter manufacturing time.

### Wear Advantages

Performance Plastics and Victrex have had multiple examples where PEEK™ was shown to be an excellent material replacement for applications where conventional bronze alloy gears have historically been used. **Figure 14** is an example where PEEK™ was used to replace a bronze alloy distributor gear. The PEEK™ composite gear showed 5x improvement in service life and an 81% reduction in weight.



**Figure 14**

## Strength / Mass

**Figure 15** displays comparable mass and strength data for various grades of PEEK™ versus commonly used metals in the medical industry. PEEK™ also offers coefficient of linear thermal expansion values that are close to metals for applications where metal to plastic is being considered.

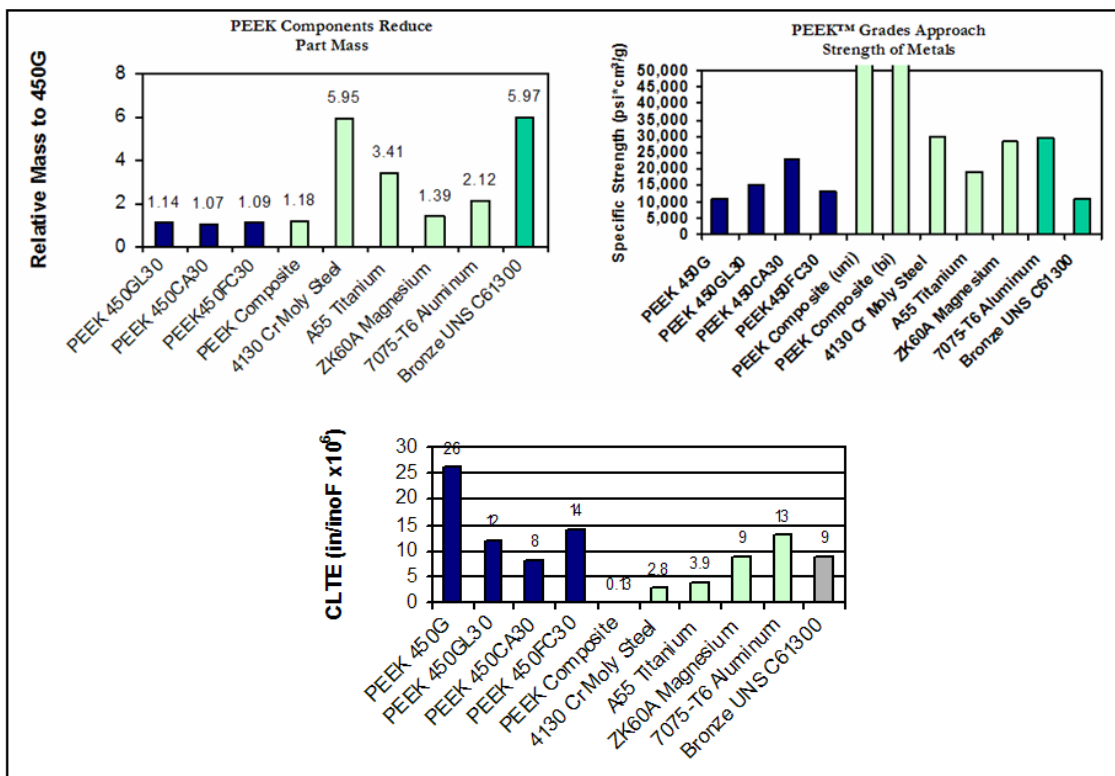


Figure 15

## Chemical Resistance

PEEK™ is often used in place of metal due to chemical resistance needs. Below are some comparisons.

### PEEK

Strong oxidizing acids  
Halogens  
Some halogen related hydrocarbons  
Phenol  
Amines (elevated Temperatures)

### 316 Stainless Steel

Salts  
Strong acids  
Halogens  
Aromatic hydrocarbons  
Some sulfur compounds  
Pentane, ink, bleach/hypochlorites, sea water

### Titanium

Strong acids  
Strong bases  
Halogens  
halogen related hydrocarbons  
Ammonia, sodium hydroxide, bleach

### Bronze

Salts  
Strong acids  
Strong bases  
Halogens  
Aromatic Hydrocarbons  
Bleach, some food products

## II. Part Design Guidelines

### Design Considerations

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When designing components using high performance thermoplastics, several important factors should be considered to insure material compatibility. If significant performance requirements for at least three or more of the following criteria are present, PEEK™ merits serious consideration.

#### What are my performance requirements?

- **Thermal Properties** - Short Term (Tg, Tm, HDT), Long Term (CUT, creep)
- **Flammability** - Resistance of Burning, smoke generation and toxicity
- **Chemical exposure** - What solvents / chemicals will my part be exposed to?
- **Wear friction**
- **Electrical properties** - Does my application require insulative properties? Does my application need dissipation qualities?
- **Dimensional / Tolerance** - What are my tolerance expectations for my application? Is flatness, roundness, or straightness important?
- **Mechanical performance**
- **Radiation / Sterilization requirements**

### Weldlines

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The term “weldline” is used to describe the location on an injection molded part where two flow fronts of thermoplastic material converge back together. **Figure 16** illustrates this condition. When designing with PEEK™ or other thermoplastic materials, weldlines are difficult to avoid and result in regions within a molded part that can reduce mechanical properties from 20% to 60%. The reduction is influenced by the ability of the two flow fronts to converge back to together in a homogeneous manner. The process of converging back together to obtain maximum property strength is influenced by a number of variables including the material, molding process, mold design and part geometry.

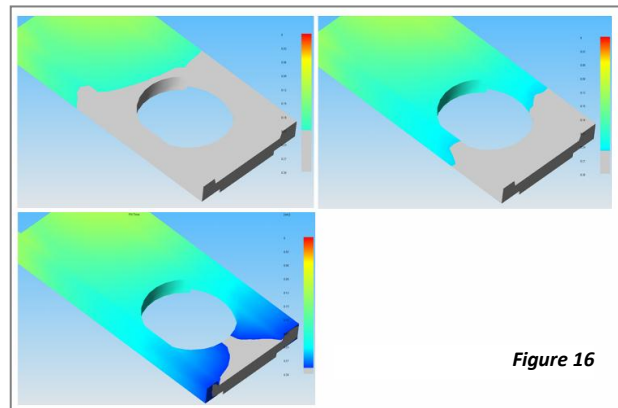
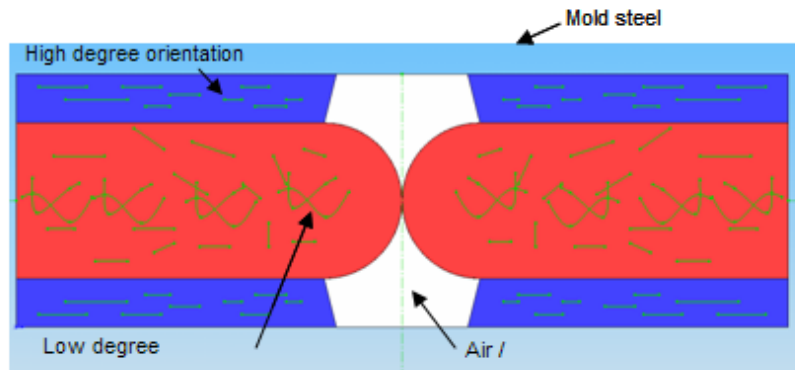


Figure 16

#### Material

Thermoplastic materials have different intrinsic levels of weld-line strength based on chemical formulation. Unfilled Thermoplastics have excellent tensile strength and, as a result, reflects better than average weld line strength values.

When designing for applications that use glass or carbon filled grades of PEEK™ the weld line strength is greatly influenced by amount of filler used, the size of the filler fibers (diameter and length) and the orientation of the filler in the molded part. As a rule, the percentage loss of strength at the weld line in filled grades of PEEK™ and other thermoplastic materials is greater than unfilled grades but, the absolute strength of a weld line in a filled grade will be greater. This is due to fountain flow principle of thermoplastic materials. PEEK™ flows inside out, due to heat loss and frictional forces as the polymer comes into contact with the steel of the mold. The polymer and reinforcement filler layout onto the steel surface with a high degree of molecular and fiber orientation. The head and center section of the flow fronts on the other hand, tends to be more disoriented and random. This condition results in the two fronts coming together with improper fiber orientation with only the base resin at head of the flow front. The result is weld line tensile strength values that are at or slightly above the base resins tensile strength. **Figure 17** illustrates this condition.



**Figure 17**

### Molding Process and Mold Design

In evaluating the molding process / mold design, the number one culprit for reduced weld line strength with PEEK™ and other thermoplastic materials is lack of venting at the weld line. The gasses that are at forefront of the polymers melt front start to compress and prevent the material from welding together. When proper venting is designed into the mold at the weld lines, this gas build-up is relieved to reduce restrictions resulting in improved weld line strength. Other molding process parameters which can influence weld line strength include melt temperature, hold time due to gate freeze and injection pressure.

### Part Design / Geometry

A common misconception is that wall thickness has an effect on weld line strength. Performance Plastics is not aware of any data that supports this theory. Our own empirical data from actual applications and test results from material suppliers indicate wall thickness has no effect on weld strength. An additional misconception is that the use of overflow tabs at the weld line will increase weld line strength. Our experience and the test results with PEEK™ and other thermal plastics materials reflect that this is a false conception.

### Geometry Considerations:

#### Wall Thickness

When considering use of based and/or highly filled grades of PEEK™ a rule of thumb design for wall thicknesses is .060" to .125" (1.5 mm to 3 mm). *Note - flow length highly influences this thickness number.* **Figure 18** compares spiral flow results with various percentages of glass and carbon filler. Small to micro-molding geometries can

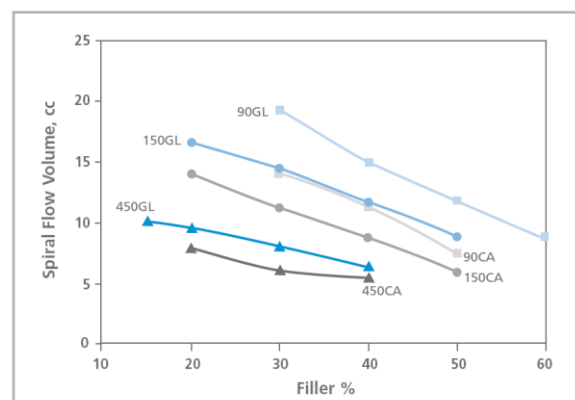




Figure 19

be designed using wall thicknesses ranging from .008" to .040" (.2 mm to 1 mm) when using 90G/150G base product grades. *Note - maximum wall thickness without porosity as a rule is approximately .300 to .350 thick and gating and geometry dependent.*

**Figure 19** is an example of PEEK™ 90G selected due to its superior ductility, dimensional stability and thermal aging. Note the wall cross sections were less than 0.2 mm (.008 in). The device requirements called for the drive mechanism to spin at over 5,000 rpm continuously for over 2,000

hours without creep deformation. It is also noteworthy that the aluminum was ruled out due to a lower moment of inertia and due to the customer's efforts to reduce drive mechanism size and cost.

### Uniformity in Wall Thickness

Uniform wall thickness with PEEK™ and most thermoplastic materials is a key design consideration. Non-uniform walls tend to exacerbate pressure losses across a molded part during the injection molding process which commonly lead to sinks and porosity. Additionally, because PEEK™ is a semi-crystalline material, uniform wall thicknesses helps reduce natural, non-anisotropic material behaviors. This increases dimensional potential and reduces the propensities for warpage and other non-desirable characteristics. **Figure 20** cut-a-way and print are examples this issue.

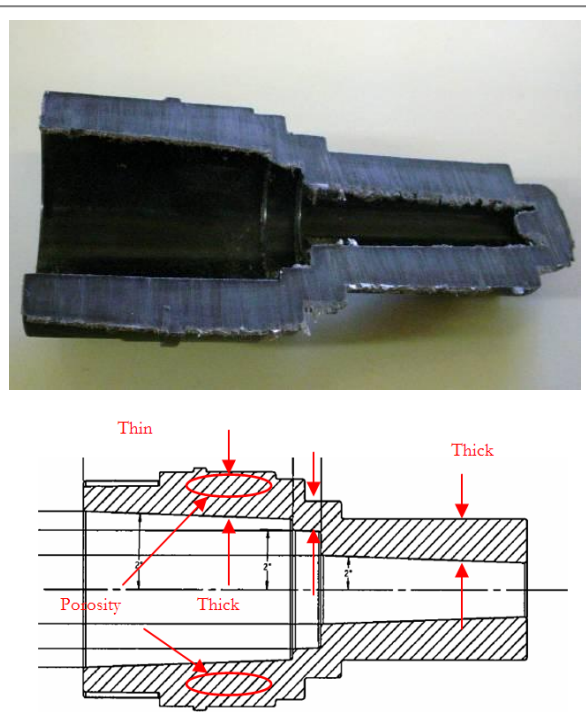


Figure 20

## General Economic Assumptions

PEEK™ materials can range from \$35 per pound to \$90 per pound depending on volume buys and filler make up. Other cost drivers that heavily influence plastic part cost when using PEEK™:

### Wall Thickness

- Thicker wall sections obviously use more material at \$35 to \$90/lb.
- Thicker wall sections tend to extend cycle times and reduce the number of pieces produced which has a direct influence on part cost.

### Tolerances

- Tight tolerances can be over specified for convenience as opposed to need. This has a direct impact on capital cost and capital items lead-times.
- Cycle time may be extended to meet tolerance requirement reducing pieces yields.

- Tight requirements often dictate the type of part gating that can be used which may require secondary operations for gate removal.
- Tight requirements can also limit the number of cavities that may be used which also reduces yields.

#### Undercut Features

- Undercut features have direct impact on capital cost and capital item lead-times.
- Undercut features increase maintenance cost to maintain the mold mechanisms
- Cycle time is increased to allow for undercut mechanisms to actuate, again reducing cycle times/yields.

## Dimensional and Tolerance Capabilities

Figure 28 provides a general tolerance expectation for unfilled PEEK™ and should only be used as a “guideline”. Tighter tolerances are possible with filled grades of PEEK™. When considering dimensional and tolerance capabilities, two aspects need to be considered. First, a strategy to select the correct initial shrink value, with regard to the differences between shot to shot variation and selecting the correct initial shrink value. Second is a strategy to address the anisotropic behavior of PEEK™.

Performance Plastics has shown PEEK™ injection molded parts can have a shrink range of .009”/” to .018”/” depending on wall thickness, flow length and/or part design. This variation illustrates the need for a strategy to predict the correct initial shrink value. For example, the part print specification calls for a nominal specification 1.450” +/- .005. Let us assume the molder chose a .018”/” and the mold was constructed to 1.4766. If .018”/” is realized, the molded part would measure 1.450”. However, if a .009”/” shrinkage value is realized, the molded part would measure 1.4633” or .0133” over the nominal specification. In these cases where the shrinkage range potential is greater than the required design tolerance, a molder should develop a steel safe or iterative process to allow for the mold steel to be cut twice insuring the molded part meets the design feature specification. Once the initial shrink value has been defined and realized through a molded part trial, PEEK™ has extremely low shot to shot variation. For example, on a feature that is 1.450” in size, a typical part to part repeatability range would be .003”.

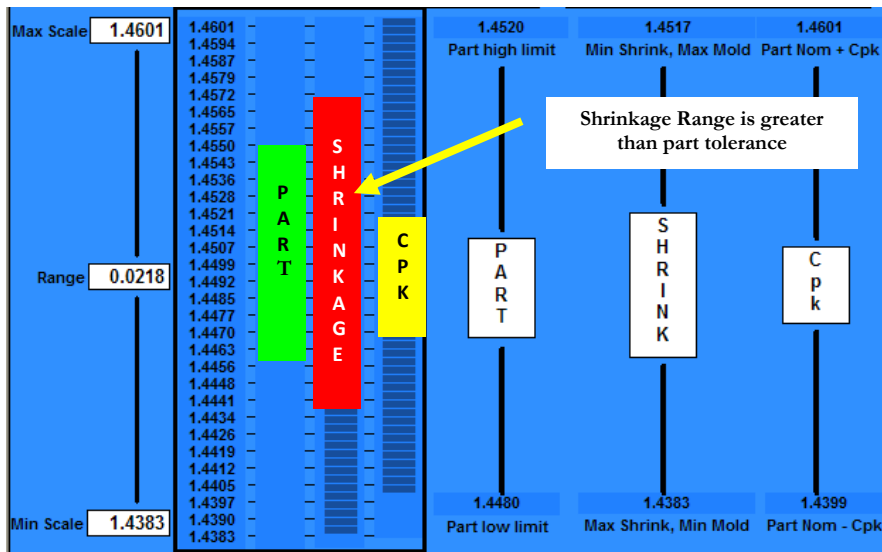


Figure 21

A strategy to address the anisotropic behavior of PEEK™ is also required. The difference between these two considerations goes back thermoplastic. Semi-crystalline materials will see differing amounts of shrinkage in the direction of flow and/or orientation of the fibers

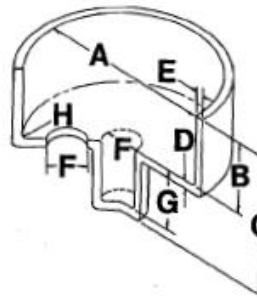


Figure 22

(shown in blue) as opposed to transverse flow direction and/or perpendicular to fiber orientation (shown in red) What this means to a designer is that the development of certain critical features may also require “sizing” or an iterative process to achieve a feature’s design intent. An elementary example would be a 1” round hole. It will not be 1” round but elliptical in shape or egg shaped in the molded part. To resolve this condition mold makers will need to fabricate an elliptical core pin that is an inverse profile of the molded part in order to achieve a 1” round hole. Note this also is true of other geometric features. The following guidelines will provide some guidance on ability of the PEEK™ material to meet dimensional and tolerance expectation.

*Note: The Commercial values shown below represent common production tolerances at the most economical level. The Fine values represent closer tolerances that can be held but at a greater cost. Any addition of fillers will compromise physical properties and alter dimensional stability. Please consult the manufacturer.*

| Drawing Code                               | Dimensions (Inches)                                         | Plus or Minus in Thousands of an Inch |        |    |    |    |
|--------------------------------------------|-------------------------------------------------------------|---------------------------------------|--------|----|----|----|
|                                            |                                                             | 5                                     | 10     | 15 | 20 | 25 |
| A = Diameter<br>(See note #1)              | 0.000                                                       |                                       |        |    |    |    |
|                                            | 0.500                                                       |                                       |        |    |    |    |
|                                            | 1.000                                                       |                                       |        |    |    |    |
|                                            | 2.000                                                       |                                       |        |    |    |    |
|                                            | 3.000                                                       |                                       |        |    |    |    |
|                                            | 4.000                                                       |                                       |        |    |    |    |
| B = Depth<br>(See note #3)                 | 5.000                                                       |                                       |        |    |    |    |
|                                            | 6.000                                                       |                                       |        |    |    |    |
| C = Height<br>(See note #3)                | 6.000 to 12.000<br>for each additional<br>inch add (inches) | Comm. ±                               | Fine ± |    |    |    |
|                                            |                                                             | 0.003                                 | 0.002  |    |    |    |
| D = Bottom Wall                            | (See note #3)                                               | 0.004                                 | 0.002  |    |    |    |
| E = Side Wall                              | (See note #4)                                               | 0.005                                 | 0.002  |    |    |    |
| F = Hole Size<br>Diameter<br>(See note #1) | 0.000 to 0.125                                              | 0.002                                 | 0.001  |    |    |    |
|                                            | 0.126 to 0.250                                              | 0.003                                 | 0.002  |    |    |    |
|                                            | 0.251 to 0.500                                              | 0.003                                 | 0.002  |    |    |    |
|                                            | 0.501 & over                                                | 0.005                                 | 0.003  |    |    |    |
| G = Hole Size<br>Depth<br>(See note #5)    | 0.000 to 0.250                                              | 0.004                                 | 0.002  |    |    |    |
|                                            | 0.251 to 0.500                                              | 0.004                                 | 0.003  |    |    |    |
|                                            | 0.501 to 1.000                                              | 0.005                                 | 0.004  |    |    |    |
| H = Corners,<br>Ribs, Fillets              | (See note #6)                                               | 0.021                                 | 0.013  |    |    |    |
| Flatness<br>(See note #4)                  | 0.000 to 3.000                                              | 0.010                                 | 0.004  |    |    |    |
|                                            | 3.001 to 6.000                                              | 0.015                                 | 0.007  |    |    |    |
| Thread Size<br>(Class)                     | Internal                                                    | 1                                     | 2      |    |    |    |
|                                            | External                                                    | 1                                     | 2      |    |    |    |
| Concentricity                              | (See note #4) (F.I.M.)                                      | 0.005                                 | 0.003  |    |    |    |
| Draft Allowance<br>Per Side                |                                                             | 1.5°                                  | 0.5°   |    |    |    |



#### REFERENCE NOTES

1. These tolerances do not include allowance for aging characteristics of material.
2. Tolerances are based on 0.125 inch wall section.
3. Parting line must be taken into consideration.
4. Part design should maintain a wall thickness as nearly constant as possible. Complete uniformity in this dimension is sometimes impossible to achieve. Walls of non-uniform thickness should be gradually blended from thick to thin.
5. Care must be taken that the ratio of the depth of a cored hole to its diameter does not reach a point that will result in excessive pin damage.
6. These values should be increased whenever compatible with desired design and good molding techniques.

Figure 23

# III. Processing Guidelines

PEEK™ and compounds are supplied in the form of granules, powder or ultra-fine 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. For this discussion we will focus on injection molding.

## Injection Molding

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

### Machine Design

PEEK™ and compounds based on 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 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 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 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.

#### *Nozzles and Shut-Off Systems*

The nozzle of the barrel is in contact with the sprue bushing for a high percentage of the total cycle time during normal operations. The temperature of the sprue bushing is considerably lower than that of the melt and the nozzle. 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 PEEK™ because they increase the likelihood of solidification in the nozzle. Over the recommended process temperatures, the viscosity of 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.

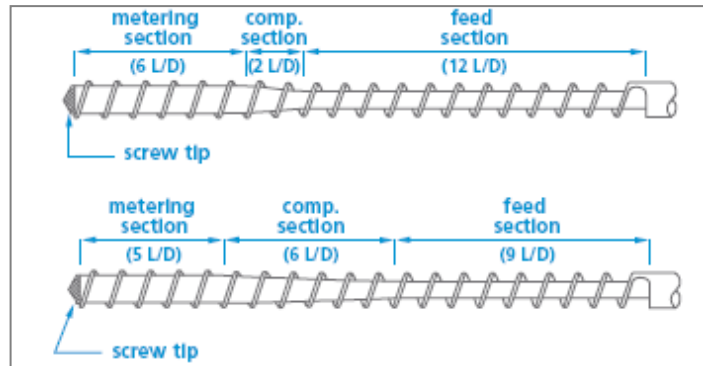
#### *Injection and Clamping Pressure*

The injection pressures required for correct component molding are system dependent. However, in general, injection pressures are approximately 14 MPa (2030 psi) with secondary holding pressures of 10 MPa (1450 psi) (Note thin wall applications can exceed 3,000 psi injection pressures). 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 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 PEEK grades. 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



**Figure 24**

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**

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 56-58 at PEEK™ processing temperatures.

### ***Mold Temperature***

The recommended mold temperature range for processing 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 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. 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. 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.

### ***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 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 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.

### Shrinkage

Like all injection moldable thermoplastics, PEEK™ components shrink while cooling in the mold. Shrinkage of PEEK™ moldings is due to thermal-contraction and the development of crystalline regions within the cooling melt. 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, PEEK™ parts should be nominally 30% crystalline. The mold shrinkage of all PEEK™ grades was evaluated using pre-dried materials in a circulated air oven overnight at 120°C (248°F). 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 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 **Figure 25** represents typical minimum and maximum values observed in 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.

| Grade           | % Tolerance (molded) |             | % Tolerance (Annealed) |             |
|-----------------|----------------------|-------------|------------------------|-------------|
|                 | 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

Figure 25

## **V. Appendix**

**(Victrex Peek data sheets summary Info)**