



A practical guide to high-temperature plastic shapes

HIGH-TEMPERATURE
ENGINEERING
PLASTICS

by Bob Alberts

As the requirements for plastic materials to perform in demanding services continue to increase, so too must the availability of stock shapes produced from these materials. Having these materials available for injection molding is not good enough. Either the volume is too low to justify the capital expenditure for a mold or the size is such that injection molding is not a viable option.

What materials are we discussing? For the purposes of this article, they must meet the three following criteria:

1. Operate continuously at a temperature of 400°F.
2. Maintain a minimum tensile strength of 4,000 psi at that temperature (400°F).
3. Be available as a stock shape from one or more manufacturers (stock shapes being rod, plate, tube or rings). In order to more effectively highlight the resin properties, the discussed materials are all available in shapes as "neat" resins (non-reinforcing additives) with one exception. Other formulations may be available, but the focus on properties is based on the basic polymer.

The reader should take as a given the fact that the higher the use temperature,

the more expensive the plastic material. The following descriptions begin with the highest temperature plastic material in declining order.

Polybenzimidinole (PBI)

PBI has better load carrying capability and wear resistance of any other plastic at its high use temperatures. It is a very "clean" (low ionic impurities) material in addition to having excellent ultrasonic transparency.

Advantages:

- $\approx 19,000$ psi tensile strength at 400°F.
- Continuous service temperature of $\approx 650^\circ\text{F}$.
- Can take short temperature "spikes" close to 1,000°F.
- Very low coefficient of thermal expansion (1.30×10^{-5}).

Disadvantages:

- Poor chemical resistance to acids, alkalis and steam.
- High water absorption.
- Difficult to machine.

Compression molded shapes available:

- Rod — to 3.75" O.D.
- Plate — to 1.5" thick.
- Tubular bars and discs (miscellaneous sizes).

Polyimides (PI)

Polyimides are descriptive of a wide range of materials; starting with the very intractable thermoset, to the high glass transition materials that are often referred to as "pseudo thermoplastics," to standard melt processible materials. As a whole, this group of materials shows lower temperature resistance, slightly higher coefficient of thermal expansion, slightly lower physical properties and somewhat better chemical and steam resistance than PBI.

More than any other polymer described here, a wide range of properties exists within the polyimide grouping itself. Varying types will yield markedly different results.

Advantages:

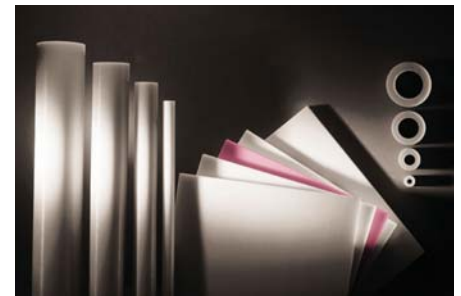
- Maximum continuous use temperature of 500°F (most are higher).
- Minimum tensile strength of $\approx 5,000$ psi at 500°F (most are higher).
- Moderate chemical resistance.

Disadvantages:

- Limited steam and hot water resistance.
- Moderate physical properties.

Shapes available:

- Rod — extrusion to 2" O.D., compression molded to 4" O.D.
- Plate — extruded to 2" thick, compression molded to 3" thick.
- Miscellaneous tubular bars, rings (up to 58" O.D.) and discs.



ENSINGER offers high-temperature plastics in a variety of shapes and sizes.



Examples of compression molded shapes of high-temperature plastics include a mold for making paper bowls made of 40 percent glass polyphenylene sulfide (PPS), gears made of 40 percent glass filled PPS, and a tray for charring computer chips made of a static dissipative polyetherimide (PEI) materials.

Polyamide-Imide (PAI)

This material is probably the toughest, melt processible plastic. (The thermoset type has slightly different properties.) Its glass transition temperature (T_g) is very close to its maximum use temperature of 500°F (typically the thermoset materials have a continuous use temperature of 580°F), so the material's properties fall off very quickly over 500°F. PAI has slightly better chemical resistance than either PBI or PI, but still not enough to strongly suggest its use when other materials are available.

Advantages:

- Very good at cryogenic temperatures.

- Very low coefficient of linear thermal expansion.
- Tensile strength of $\approx 12,000$ psi at 400°F.

Disadvantages:

- Moderate moisture absorption.
- Better than PI and PBI, but still not good in steam and hot water applications.

Shapes available:

- Extruded rod to 3.9" O.D.
- Compression molded rod to 4" O.D.
- Extruded plate to 1.575" thick.
- Compression molded plate to 4" thick.
- Miscellaneous tubular bars, rings (up to 58" O.D.) and discs.

Polyetheretherketone (PEEK)

As the most recognized of the ketone polymers, PEEK brings a high degree of versatility to the marketplace. While not as strong or capable of taking temperatures in the 500°F range, its ability to have broad brush chemical resistance and strength at 480°F, makes it a worthy contender for many applications.

Advantages:

- Excellent chemical resistance to most everything except concentrated acids.
- Excellent service in both steam and hot water.

Disadvantages:

- Lowest physical properties of the group at 400°F.

Shapes available:

- Extruded rod to 8" O.D.
- Extruded plate to 4" O.D.
- Compression molded rod to 3".
- Compression molded plate to 2½".
- Miscellaneous tubular bar, rings (up to 58" O.D.) and discs.

Polyphenylene Sulfide (PPS)

PPS is available as a branched or linear material. The branched material is not practical to extrude, and unless it has a minimum of 40 percent glass or carbon fiber (in which case it can be injection or compression molded), it is too brittle to be of any use. The linear material (while it can be extruded without fillers) has a low continuous service temperature (by the criteria described in this article) and rather mundane physical properties.

With 40 percent glass fiber, PPS is an excellent cost-effective material.

Advantages:

- Has no known solvent below 392°F.
- Excellent chemical and hydrolysis resistance.
- Resistant to creep, deformation under load and compression set.

Disadvantages:

- The material tends to be brittle.

Shapes available (reinforced only):

- Compression molded rod to 4" O.D.
- Compression molded plate to 3" O.D.
- Miscellaneous tubular bar, rings (up to 58" O.D.) and discs.

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Areas of commonality

All of the materials discussed in this article share the following characteristics:

- Flammability is 94VO, very low smoke generation and oxygen indices of 30 to 40 percent.
- Negligible out gassing and low ionic impurities.
- Most are inherently wear resistant and/or have bearing grades available as stock shapes.

Considerations on the negative side:

- These are not easy materials to fabricate; they are also notch sensitive. Therefore, fabrication should only be done by shops experienced in handling these types of materials.
- Prior to placing into service a part fabricated from PBI, PI or PAI that will be immediately exposed to service over 225°F, care must be taken to assure that the part is “dry.” If a “wet” part is immediately exposed to elevated temperatures, catastrophic failure could result.

Markets and applications

Applications in the following industries exist for these materials:

- Aerospace — vane and stator bushings, slide bearings, hydraulic pump components, electrical connectors.
- Automotive — transmission seal rings, check balls, fuel pump motor components, power steering gears, U-joint thrust washers.
- Compressors and pumps — wear rings, pump gears, labyrinth seals, valve plates, lantern rings, rod seals, piston rings.
- Electronics industries — clamp rings, wand tips, wafer carriers, chip nests.

The above markets are merely examples of where these materials are used; other severe applications exist or are being tested.

What lies ahead?

We are not part of a static industry. Even as this article is printed, developments in materials and compounds continue. For example:

- New improvements in ketone polymers are yielding pre-production quantities of PEKK (polyetherketoneketone) which has improved properties in temperature exposure and strength over PEEK materials.
- Improvements in polyphenylsulfone (PPSU) and polyethersulfone (PES) resins have yielded materials that can operate at or over 400°F.
- Nylon chemistry is developing materials that have minimal moisture absorption and can operate in the 400°F range.

These are just some of the developments that will see commercial applications in the next several years. After that, who knows what’s ahead — transparent aluminum? ■

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