Turning Up the Heat: Considerations for High Temperature Applications

High Performance Plastics

by Keith Hechtel, DBA

Customers frequently ask salespeople about the maximum service temperatures for various high performance plastics. In many cases, an engineer has come across a single piece of information such as a material's heat deflection temperature, glass transition temperature or continuous service temperature, and the individual mistakenly believes that a single property value specifies the maximum temperature at which a thermoplastic can be used.

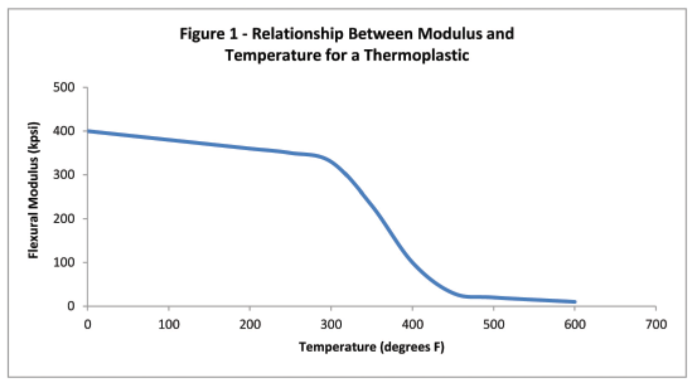
Although the maximum operating temperature for a plastic material may seem like a simple question, the answer actually involves considerable complexity and multiple characteristics of the polymer must be considered when making this determination. The purpose of this article is to examine some of these characteristics and provide a framework for richer discussions with customers about the use of plastics in high temperature applications.

Softening behavior: How soft is too soft?

Anyone who has microwaved leftover food in a plastic container has noticed the loss of strength and modulus (stiffness) of the container as it increases in temperature. This inverse relationship between the temperature and modulus of a thermoplastic can be represented on a graph as shown in figure 1. At this point it is important to mention that the graphs presented in this article can rarely be found in stock shape manufacturers' technical literature; however, they are almost always available in the design guides published by the major plastic resin manufacturers. Thermal properties graphs can also be found in many plastics reference manuals. One excellent example is *The Effect of Temperature and Other Factors on Plastics and Elastomers,* by Laurence McKeen, which is part of the Plastic Design Library series published by Elsevier B.V.

This plastic cup lost modulus (stiffness) and softened when it was filled with hot soup.

The graph shown in figure 1 yields important information about the mechanical properties of this polymer at various temperatures. This particular thermoplastic maintains much of its stiffness up to approximately 300°F/149°C and it rapidly loses stiffness at temperatures above 300°F/149°C. Depending on the mechanical property requirements for the application, this polymer may or may not be suitable for use at temperatures above 300°F/149°C.

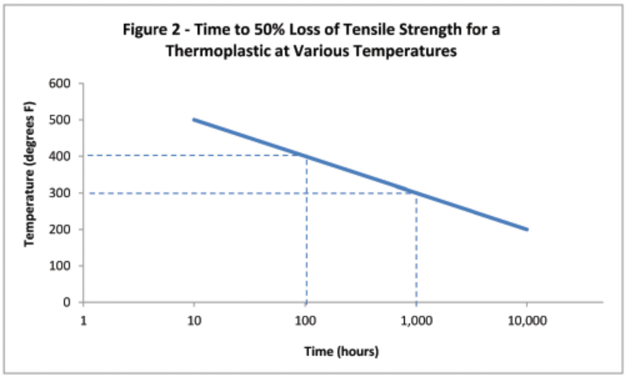


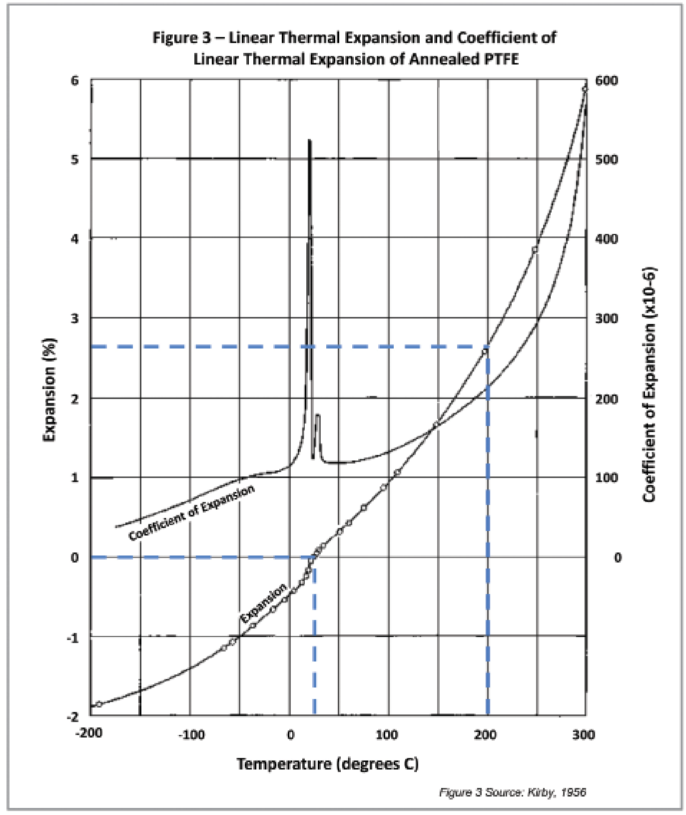
Thermal degradation: How long will the material maintain its strength?

Thermoplastics exposed to elevated temperatures for long periods of time will generally become brittle and lose both mechanical strength and toughness. This process will occur more slowly at moderate temperatures and more quickly as the operating temperature for a material is increased. This behavior is evident in older cooking appliances which often have degraded and chipped plastic handles. The rate of degradation will vary from material to material and the degradation rate for a particular polymer can be represented on a graph as shown in figure 2. A 50 percent loss of initial tensile strength is used as a standard to show the degradation rate of a material at various temperatures.

This plastic pot handle degraded and became brittle after many years of use at elevated temperatures.

As shown on the graph, this particular plastic material will lose half of its initial tensile strength when placed in a 300°F/149°C operating environment for 1,000 hours. When the same material is placed in a 400°F/204°C operating environment, it degrades more rapidly, losing half of its initial tensile strength in only 100 hours. Therefore the suitability of this polymer for use at elevated





temperatures depends on 1) the operating temperature for the application, 2) the minimum tensile strength required for the part to perform and 3) the desired service life of the device. Additionally, the design engineer may wish to include a safety factor, especially if the device is for a critical-service application such as aerospace or medical equipment.

Thermal expansion: Will the material grow too much?

Plastics generally have a higher rate of thermal expansion compared with other industrial materials such as metals, wood or ceramics. This is further complicated by the fact that the rate of expansion for many plastic materials changes throughout their operating temperature range. For example, the coefficient of thermal expansion (CTE) of PTFE (polytetrafluoroethylene) is shown on the graph in figure 3.

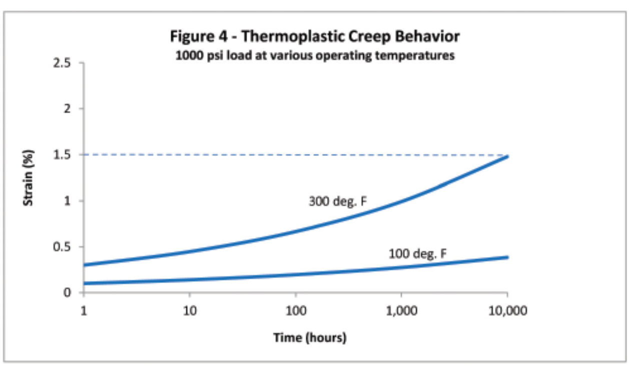
Although the coefficient of thermal expansion of PTFE is usually simplified and reported as a single number, the graph shows that the actual growth rate of PTFE changes as the material is heated from -328°F/-200°C to 572°F/300°C. In the case of PTFE, the rate of thermal expansion is lower below 77°F/25°C and becomes increasingly higher above 77°F/25°C.

When plastic and metal components are used together in a device that must operate over a wide temperature range, the relatively high thermal expansion of polymers becomes an important design consideration. For example, the blue lines on the graph indicate an operating temperature range of 77°F/25°C to 392°F/200°C for a particular application for which PTFE is being considered as a possible material. For this example, the PTFE will be used in contact with a 1 meter long steel mating part. Throughout this temperature range, PTFE has a coefficient of thermal expansion of approximately 151 x 10-6 per °C. In contrast, steel has a much lower CTE of approximately 13 x 10-6 per °C. This results in a CTE mismatch of 138 x 10-6 per °C when PTFE and steel components are used together in the finished device. In this example, when the part is heated from 77°F/25°C to 392°F/200°C, at the upper end of the temperature range the PTFE component will grow approximately 24 mm longer than the mating metal part. This dimensional mismatch may make PTFE unsuitable for the application even if the other thermal characteristics of the material such as loss of modulus and the rate of thermal degradation are acceptable.

It is noteworthy that there are a number of ways to reduce the CTE of a plastic material including introducing fillers and reinforcements into the formulation. This is a common practice that is often used when dimensionally stable plastics are required for elevated temperature applications.

Creep behavior: How much will the part deform over a long period of time?

Plastic parts have a tendency to deform under load over long periods of time. To observe this behavior, one only needs to load a lightweight plastic shelf with bricks and then leave the shelf in a warm garage over the summer. Over a period of weeks, the plastic shelf will gradually bend under the heavy load. This "creep" behavior is much more pronounced in plastics compared with other industrial materials and it increases with higher loads and/or higher operating temperatures. When high performance polymers are being considered for elevated temperature applications, creep behavior becomes an important design consideration. Creep can be represented on a graph showing the degree to which a part deforms (strain) over a given period of time. Figure 4 shows creep curves for a part subjected to a 1,000 psi load at operating temperatures of both 100°F/38°C and 300°F/149°C. For this particular thermoplastic, a specimen subjected to a 1,000 psi load and a 100°F/38°C operating temperature exhibits only minimal strain (less than 0.5 percent) after 10,000 hours. However, when the same material is subjected to a 1,000 psi load with the operating temperature increased to 300°F/149°C, it exhibits significantly higher deformation of 1.5 percent after 10,000 hours. This increased deformation may make the material unsuitable for use in a 300°F/149°C environment if dimensional stability under load is critical-to-quality for the application.



Other temperature-dependent behaviors

In addition to mechanical property loss, thermal degradation, thermal expansion and creep, elevated operating temperatures may affect a number of other performance characteristics of a thermoplastic. These include electrical properties, chemical resistance, environmental stress crack resistance, fatigue resistance and the ability of the polymer to perform in friction and wear applications, all of which tend to be reduced at the upper end of a material's operating temperature range.

Some good questions to ask

As plastics distribution salespeople, it is our job to connect material science with real-world applications as we interact with the engineering community. The temperature-related behaviors presented in this article are intended to help salespeople to engage in richer discussions with customers. Moving forward, when a customer asks about the maximum temperature at which a particular plastic can be used, instead of providing them with a standard properties sheet, consider asking a number of pertinent questions including:

- What strength and modulus (stiffness) are required at the upper end of the operating temperature range?
- Is dimensional stability important? What tolerances are required throughout the operating temperature range of the device?
- Are there mating metal components that must be considered when designing the plastic components?
- What is the expected service life of the device?
- What loads will the plastic part be under while exposed to elevated temperatures?
- Will the part be subjected to cyclic stresses and/or wear at elevated temperatures?
- Will the part be exposed to any chemicals during elevated temperature service?

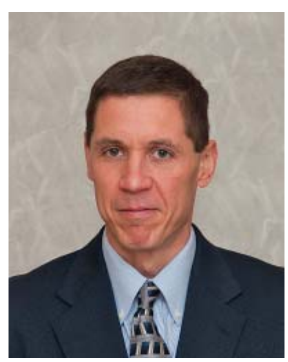
By asking more in-depth questions and providing customers with richer design data, distribution salespeople can quickly build credibility and help customers to avoid potential problems when they specify high performance plastics.

References and suggestions for further reading

In addition to properties guides from manufacturers, the following resources are helpful for a better understanding of these issues:

Kirby, R. (1956). Thermal expansion of polytetrafluoroethylene from -190 degrees to +300 degrees C. Journal of Research of the National Bureau of Standards, 57(2), 91-94.

McKeen, L. (1992). The Effect of Temperature and Other Factors on Plastics and Elastomers (2nd edition). Waltham, MA: Elsevier.



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