TECHNICAL WHITEPAPER

Performance of High Temperature Plastics

Introduction

Plastics are not often considered for high temperature applications because of the common misconception that they are only suitable for low temperatures. Despite this, some specific families of plastics are not only suitable for high temperature applications but can also be more suitable than the traditional materials.

What are High Temperatures for Plastics?

For plastics, the definition of 'high temperature' is taken to mean 'any temperature above 135°C and it is true that the majority of available plastics are suitable only for use at temperatures below this value. These plastics are generally called the 'commodity' plastics and constitute by far the largest volume of plastics used in the world today.

Despite this, the last few years have seen a rise in the importance of 'engineering' plastics and these have significantly improved performance at temperatures above 135°C. The table at right gives the approximate upper limit for the service temperature of a range of plastics families and the engineering plastics show significant improvements in service temperature over the commodity plastics.

Service Temperature

Assigning a "maximum service temperature" to any plastic should be undertaken with care. At high temperatures plastics not only soften but can also start to thermally degrade. A plastic that softens at a high temperature but which starts to degrade at a much lower temperature can only be considered for applications below the temperature at which it starts to degrade. Specifying the service temperature also requires knowledge of the thermal degradation performance of the material.

The physical 'softening point' of a plastic is defined largely by the type of plastic being used. For amorphous polymers (such as Ultem®, PMMA or PS) the important temperature is T_g – the glass transition temperature. For highly crystalline polymers (such as PTFE) the important temperature is T_m – the melting point. In either case the exact definition of the "softening point" will depend on the test method used.

Test Methods

There are two basic methods for assigning a value to the performance of plastics at high temperatures:

- **Vicat Softening Temperature** (VST) - ASTM D 1525 (ISO 306)
  This test measures the temperature at which a plastic starts to soften rapidly. A round, flat-ended needle of 1 mm2 cross section is placed on the surface of the test specimen under load and the temperature is raised at a uniform rate. The Vicat Softening Temperature (VST) is the temperature at which the penetration reaches 1 mm.

- **Deflection Temperature Under Load** (DTUL) - ASTM D 648 (ISO 75)
  This test measures short term performance under load at elevated temperatures for a by measuring the effect of temperature on stiffness. A defined surface stress is applied to the standard test specimen and the temperature is raised at a uniform rate.
  Note: When ISO 75 is used the result is referred to as the Heat Distortion Temperature or Heat Deflection Temperature (HDT).

Real Life Performance

Any test is only an approximation of the real life behavior. Tests are naturally accelerated to enable them to be carried out in a reasonable length of time and do not always reflect the real-life performance of the material or the product. Tests can only simulate a narrow range of conditions and for applications involving higher temperatures, increased loading or different support conditions the results obtained by any test method do not always represent the actual maximum service temperature.

It is also unwise in many cases to rely on a single data point where one number is used to assess the temperature resistance (such as the DTUL). A single number gives no information about how rapidly the plastic approaches the number or what it does after the number is exceeded. For example, crystalline polymers may have a low DTUL value and yet still have structural strength above this whereas amorphous polymers lose almost all of their structural strength above the DTUL because this is nearly the same as the glass transition temperature (T_g).

Time-Temperature Superpostion

Any mechanical property of a plastic is governed by the principles of time-temperature superposition - based on the original work of Williams Landel and Ferry (WLF). This principle shows that time and temperature can have the same (but inverse) effect - the strength of a plastic at high rates of loading and low temperatures can be effectively the same as the strength at low rates of loading and higher temperatures.

This means, fortunately, that information from testing at high temperatures and at fast rates can be used to estimate the properties at lower temperatures and at slower rates. Unfortunately, it also means that the effective service temperature of a plastic can vary significantly with the rate of loading. Apparently small load application rates at high temperatures can have the same effect as large load application rates at lower temperatures.

The Application

Assessing the performance of a plastic in a high temperature application is therefore a complex task. In real life, essential factors such as the rate of loading, the load itself and the nominal surface stress will inevitably be different from the testing conditions. The application is the important thing and detailed knowledge of this is necessary to specify the correct material.

The Decreasing Options

Despite the importance of the application details, it is immediately evident from the chart that as the specified service temperature increases then the number of possible and suitable plastics materials rapidly decreases. At room temperature the designer can choose from almost any of the available plastics but above 135°C there are a very limited number of plastics that are suitable.

Engineering plastics offer substantial performance improvements at high temperatures but often at substantially increased costs compared to the commodity plastics. Despite this, engineering plastics can also offer substantial product improvements over traditional materials due to their easier processing, easier handling and improved application.

Making the Choice: Ashby Diagram for Temperature & Strength

Prof. M. Ashby at the University of Cambridge, UK has developed a very easy and visual method of materials selection and this can help in making the choice of which material to use at high temperatures. A typical Ashby chart for strength at failure (*sf*) versus The chart gives a birds-eye view of the areas of stress and temperature in which each material class, and material, is usable. The bubble for each material or material class is designed to represent the typical range of properties that might be achieved for the various grades of a family or class of materials.

The value used for the maximum service temperature in the Ashby chart takes into account the effect of thermal degradation or oxidization and the effect of creep at high temperatures for plastics – it is generally unsafe to use a plastic above this temperature.

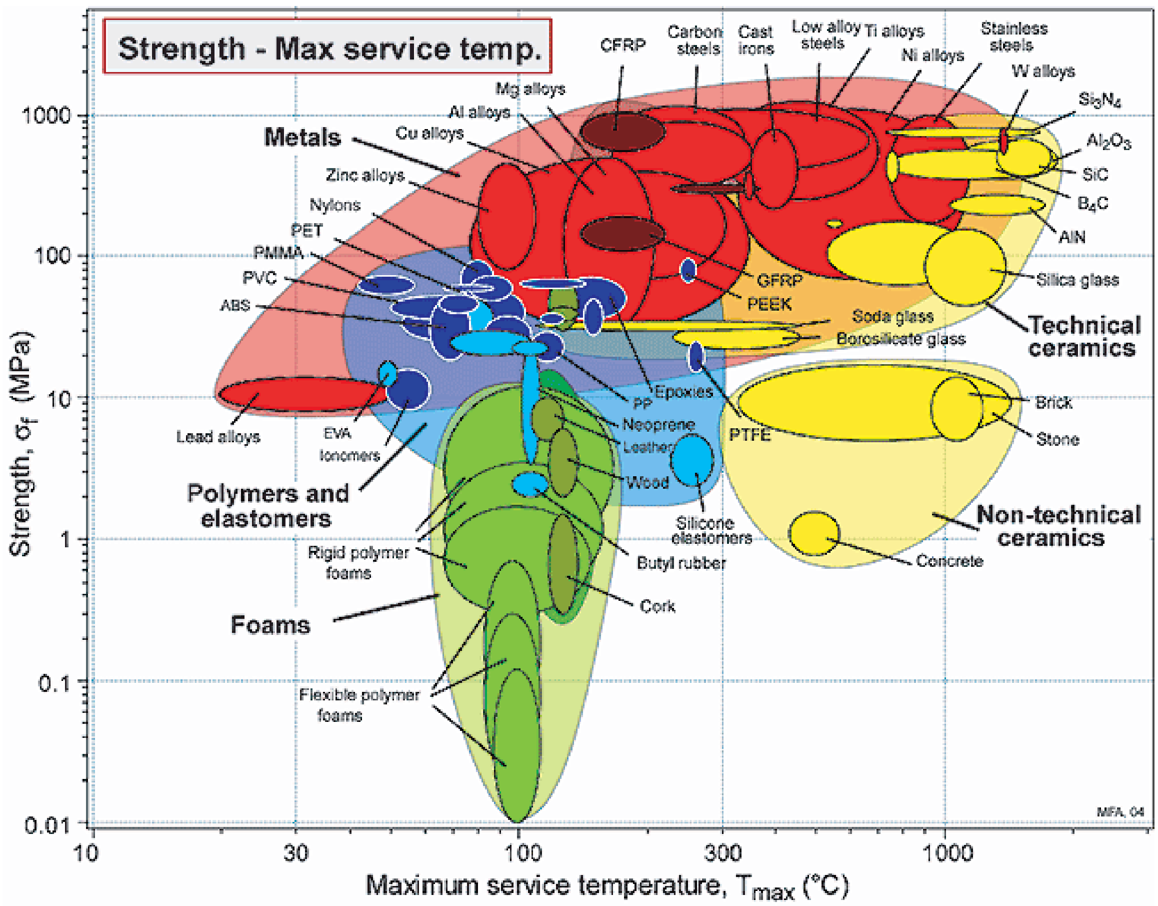

Chart: (c) Copyright Granta Design Ltd, Cambridge, England. Reproduced with Permission.
www.grantadesign.com

The Available Materials

The Ashby chart shows the clear differentiation between the engineering plastics, such as PTFE and PEEK™ and the commodity plastics such as PVC and PMMA. For high temperature applications, the most suitable materials, in ascending order of maximum service temperature, are:

- PTFE (260°C)
- PFA (260°C)
- PEEK™ (260°C)
- FEP (200°C)
- PEI (Ultem®) (180°C)
- PET/PBT (170°C)

It may appear that the designer has limited choices but these plastics more than adequately cover a wide range of temperatures and can be very successfully used at high temperatures.

The Available Processes

Fortunately for the designer the engineering plastics can be processed by the same methods as for the commodity plastics. The exception to this is PTFE, which requires special techniques due to the extremely low co-efficient of friction. This means that extrusion of the engineering plastics is possible to create a range of extruded products suitable for use at high temperature.

The extrusion process allows the production of tight tolerance tubing in a variety of formats such multi-lumen tubing, tubing with integral monofilament, heat shrinkable tubing and in some cases lay-flat tubing.

Fillers such as radio-opaque products, glass fibers, carbon or other special fillers can be used to further modify tubing products for specific applications.

Extrusion also allows the design and production of custom profiles for specific customer applications.

Typical Applications

High temperature plastics have a variety of applications and are often used as to replace more conventional materials to reduce weight, cost or meet a specific application requirement. Some typical applications for high temperature plastics include:

- Aircraft/aerospace interiors.
- Aircraft/aerospace electrical components
- Automotive applications (under-hood).
- Wire insulation for extremely high temperature applications, cable couplings and connectors.
- Electrical/electronic applications at high service temperatures.
- Medical tubing or other products that require sterilization.
- Monofilament for the production of woven products for filters, belting and meshes.

Case Study: Catheter Fusing Sleeve

Minimally invasive surgery has revolutionized modern medicine. The construction of guiding catheters requires a precise assembly of diverse components to achieve the performance properties surgeons requires. Typical catheter construction involves the lamination of sections of tubing with different durometers to achieve the flexibility required to access deep regions of the human vascular system.

Catheter manufacturers utilize Zeus FEP heat shrink to act as a fusing sleeve in the manufacturing process. The combination of a high shrink initiation temperature, optimal wall thickness, and excellent hoop strength allow the FEP heat shrinkable tubing to melt flow the nylon, PU, and PE layers of the catheters and fuse them into a unified tube. After the fusing process is compete, the lubricity of the FEP aids in its removal from the catheter assembly.

Case Study: Aerospace

The critical demands of the aerospace industry make PTFE tubing the standard for high temperature insulation. Zeus PTFE tubing meets or exceeds the critical environments in aviation programs worldwide. PTFE tubing has become an effective means of applying a tight jacketing that stands up to the hostile environments of 500° F (260° C) heat, abrasion and shock, while also passing the critical smoke and toxins test to meet FAA criteria for use in the cabin.

PTFE Tubing is available in spiral cut, AWG, convoluted and a wide range of heat shrinkable extrusions that are widely used for harnessing and insulating wires, cable, hoses, and other bundles.

Conclusion

"High temperature plastics" is not a contradiction in terms. The correct specification and application of plastics can give excellent results for long-term service temperatures up to 260°C and for even higher temperatures in the short-term.
This opens the door for further substitution of more traditional materials with plastics that are specifically designed for demanding applications.

How Zeus Can Help

With a technical inside and outside sales force backed up with engineering and polymer experts, Zeus is prepared to assist in material selection and can provide product samples for evaluation. A dedicated R&D department staffed with PHD Polymer chemists and backed with the support of a world-class analytical lab allows Zeus an unparalleled position in polymer development and customization.

Since 1966 Zeus has been built upon the core technology of precision extrusion of high temperature plastics. Today, with a broad portfolio of engineered resins and secondary operations, Zeus can provide turnkey solutions for development and high-volume supply requirements.

Contact Us

Visit **http://www.zeusinc.com** for more information about our products and capabilities, or give us a call at (toll-free) **1-866-272-4118**