Plastics Topics – Engineering thermoplastics

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1. Introduction

This Plastics Topic is a review of the field of ‘Engineering Plastics’ and it is designed to give an insight into this broad and important (but often poorly defined) group of plastics. In the plastics industry, the huge variety of products is generally divided into 3 categories:

- Commodity plastics – these are plastics that are not capable of carrying a significant load and are obviously both the cheapest and the most common plastics.
- Engineering plastics – these are plastics that are capable of carrying a significant load and these are obviously more expensive and less common than the standard commodity plastics.
- Performance plastics – these are plastics that are capable of carrying a significant load and which can also do so at elevated temperatures. These are obviously far more expensive and much less common than the commodity plastics.

This Plastics Topic concentrates on the Engineering Plastics and their main features and benefits.

2. Defining the groups

The various categories of plastics are not easily or well defined and the boundaries between the somewhat arbitrary categories are blurred. One man’s engineering plastic is often another man’s commodity plastic and the division is not made any easier by the existence of a wide and growing number of blends of various plastics.

Using the broad definitions given above regarding load bearing capability and temperature response, it is possible to provide a relative estimate of the sales volume (by weight) of the various categories and this is shown in Figure 1. Obviously, the sales value for the more expensive engineering plastics will be much greater than the tonnage value.

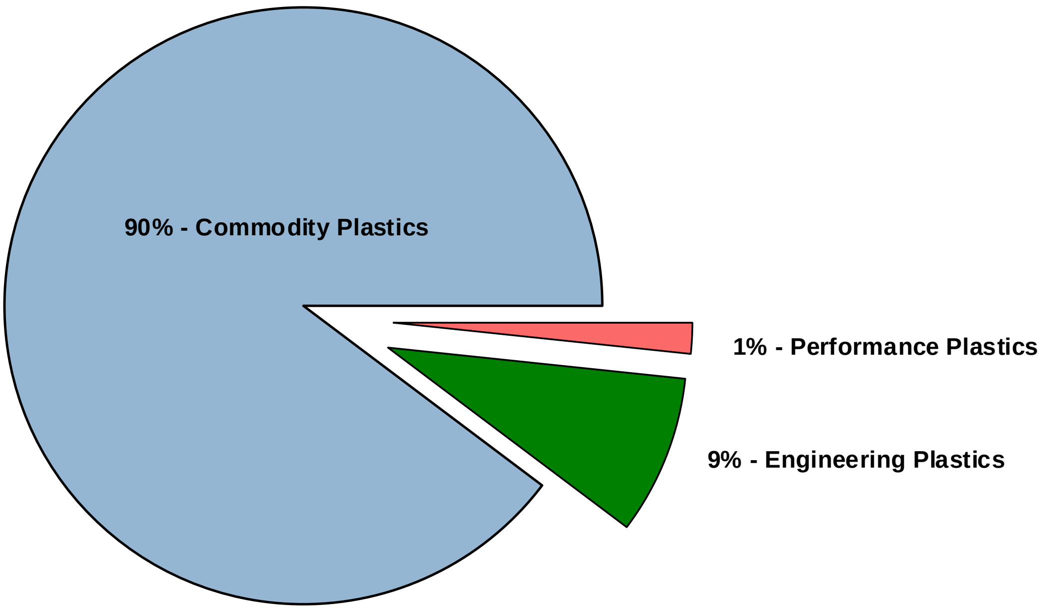

Figure 1: Approximate sales of the plastics groups (tonnage)

Despite the fact that engineering plastics only represent around 5% of the total tonnage, this volume is growing as the engineering plastics make inroads into applications that traditionally used metals or other materials.

Using the broad definition for engineering plastics it is possible to identify the 'engineering plastics' and these are shown in Figure 2. This shows the main engineering thermoplastics arranged according to approximate tensile strength (tensile strength increases moving to the right of the figure) and crystallinity (crystallinity increases moving down the figure).

The engineering thermoplastics are the central group of plastics and the grey blurred boundaries indicate the somewhat arbitrary nature of the classification of some of the plastics.

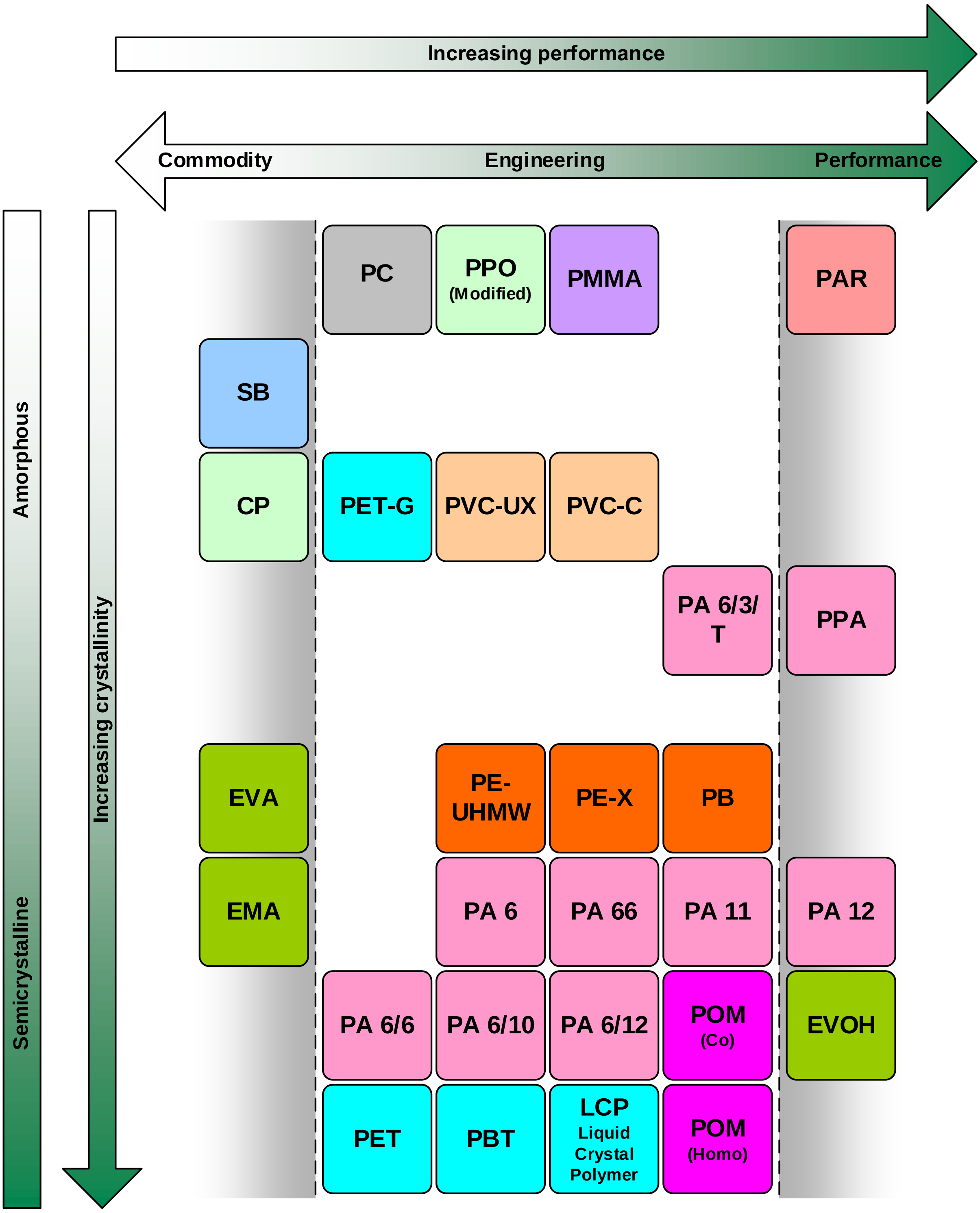

Figure 2: The engineering thermoplastics

Adapted from 'The Periodic Table of Thermoplastics' Tangram Technology Ltd. (www.tangram.co.uk)

Tensile strength

Tensile strength is a defining characteristic of the engineering plastics and enables them to carry significant loads. The plastics could also be arranged by the 'heat deflection temperature' – this would change the order inside the engineering plastics boundaries it would not lead to great changes in those plastics included in the group.

Crystallinity – a major divider

The semi-crystalline nature of some polymers and the dramatic effect it has on many of their properties is a major divider in all of the categories of polymers and this is also true for the engineering plastics. Some plastics are amorphous (glass-like in nature) and some are semi-crystalline (they have small areas of short-range order). The two types of plastic behave in very different ways particularly when subjected to high temperatures. Crystallinity in plastics is discussed in another Plastics Topic and at this stage it is sufficient to note that several of the main groups of engineering plastics are semi-crystalline in nature.

3. The major engineering plastics

The plastics in Figure 2 are color-coded according to the different families of plastics and there are five major families of engineering plastics.

Thermoplastic Polyesters (PET, PBT and LCP)

This is the largest engineering plastic family in volume terms and is an extremely diverse range of plastics which all have an ester group (–COO–) in the main polymer molecule. The thermoplastic polyesters are available in a wide range of formats for uses as diverse as moulding (both injection and blow moulding), fibre manufacture and film manufacture. Most people will be familiar with two main uses of these materials, as the ubiquitous clear stiff plastic soft drink bottle (generally a PET injection blow moulding) and as the soft fibre used for clothing (Terylene® or Dacron®). A major recent use of PET is for the manufacture of fleece materials used for cold weather clothing.

Nylons (PA)

The nylons are probably the second largest engineering plastic family in volume terms (although usage of PC is growing rapidly) and are again an extremely diverse range of plastics which all have an amide group (–CONH–) in the main polymer molecule. Nylon is a generic name for the polyamide polymers and was the original name given by Du Pont to the fibre discovered by Wallace Hume Carothers in 1934.

It is theoretically possible to produce many different types of PA polymers and all tend to be labelled under the heading of 'nylon'.

The largest volume sales are of the PA 6 and PA 6/6 variants. The other PA types tend to be specialist products and some (PA12) verge on being performance plastics rather than engineering plastics.

As a general family the PA group is rigid and translucent (as is normal for a semi-crystalline plastic) with good fatigue, creep and wear resistance. Chemical resistance varies with the specific variant but is generally good. The nylons are generally highly crystalline (although an amorphous nylon is available) and also generally have high moisture content (up to 2% in the natural state).

The PA family is often used with glass fibre reinforcement to increase the mechanical properties of the base polymer.

Polycarbonates (PC)

The polycarbonate family is related to the polyester family and has a series of carbonate groups (–O.CO.O–) linked with aromatic groups. This structure gives a material with high melt viscosity and resistance to high temperatures.

Polycarbonates were independently commercially developed in 1958 by Bayer in Germany (as Makrolon®) and by General Electric Co. in the USA (as Lexan®). The bis-phenol A polycarbonates are the largest volume polycarbonates but there are other members of the polycarbonate family.

Polycarbonates are amorphous engineering thermoplastics with very low water absorption and are used extensively for engineering products (particularly electrical components), for optical applications (due to the high transparency) and for the production of CDs and DVDs of all types.

Acrylics (PMMA)

PMMA is a member of the acrylic family of plastics and is one of the earliest engineering polymers (first produced in 1933 by ICI). PMMA is known around the world by a variety of trade names (Lucite®, Oroglas®, Perspex® and Plexiglas®). Originally PMMA was seen as a replacement for glass in a variety of applications and is currently used extensively in glazing applications. The material is one of the hardest polymers, rigid, glass-clear with glossy finish and good weather resistance.

One original proposed application as automotive windshields has not come to fruition due to the low scratch resistance of the PMMA relative to glass. Despite this PMMA was used extensively as aircraft windows for many aircraft and for many other optical applications due to the high transparency and optical clarity. In some applications, PC has replaced PMMA due to the higher impact resistance of the PC family.

Parts made of PMMA have high mechanical strength and good dimensional stability. Other properties include a high Young's modulus (E) and good hardness with low elongation at break.

Acetals (POM)

The acetal family is based on a repeat unit of (–CH_2-O-CH_2-O–) and was first commercialized by Du Pont in 1959 under the trade name 'Delrin®'. POM is a highly crystalline linear thermoplastic, which has predictable mechanical, chemical and other properties over a wide time and temperature range. POM is available as either a homopolymer or as a copolymer material.

POM has an ideal combination of strength, stiffness and toughness. The stiffness and strength, particularly in the temperature range 50 to 120°C, are greater than those of most other thermoplastics. At room temperature, POM has a distinct yield point at approximately 8 to 10% elongation. Below the yield point it has good elastic recovery, even when stressed repeatedly and this gives good spring capacity and suitability for snap fastenings.

POM is rigid, translucent and tough with good spring like qualities, it has good wear and electrical properties and it is generally resistant to creep and most organic solvents. The high heat distortion temperature makes it suitable for many applications at elevated temperatures and it can also be used at temperatures down to -40°C.

This combination of properties and the fact that it is in conjunction with good wear resistance and a low dynamic friction coefficient make it suitable for demanding industrial applications such as watch parts, rollers, bearings, gearwheels, housing parts, pump parts, valves and gears.

The POM family is often used with glass fibre reinforcement to increase the mechanical properties of the base polymer.

4. The minor engineering plastics

Apart from the major families of engineering plastics there are several other plastics that can claim to be engineering plastics. These are:

Polyolefins (PE-UHMW, PE-Cross linked, PB)

The polyolefins are generally regarded as commodity plastics but three members of the family can be classed as engineering plastics.

Ultra-high molecular weight PE is a type of PE with very long polymer chains and is very different to the standard PE grades. It is tough, highly resistant to abrasion, has a very low coefficient of friction and is highly resistant to most chemicals.

Cross-linked PE is produced by radiation, peroxide or silane methods to produce a stiff and highly stable network plastic with some excellent high temperature properties.

Polybutylene is a member of the polyolefin family that has excellent creep resistance and has primarily been used for piping materials although with some mixed success.

PVC (Cross linked, chlorinated)

PVC is also regarded as a commodity plastic but the basic structure can also be cross-linked or post-chlorinated to improve the mechanical properties and produce plastics that are capable of bearing significant loads. Cross-linked PVC is used extensively for moderate performance shrink fit tubing and PCV-C is used largely for piping applications.

PPO (modified)

Raw PPO polymer has some excellent properties but very little is manufactured. The ability of PPO to be blended with polystyrene lead to the introduction in 1966 of 'Noryl®' by General Electric Plastics. This family is sometimes called PPO but in fact is more correctly a blend of PPO and polystyrene. These types of material have some excellent properties and the price point (more than ABS but less than PC) means that applications are plentiful – especially when some of the excellent properties can be used to their full extent. PPO blends have a high heat distortion resistance, low water absorption and high strength. PPO blends have a wide application temperature range (-40 to 130°C). Typical applications include pump housings and impellers, power tool housings, portable mixers, hairdryers and electrical products such as cable connectors and bulb sockets.

5. Engineering the engineering plastics – polymer alloys

As with PPO, one of the most exciting topics in the area of engineering plastics is that of 'polymer alloys' or 'polymer blends'. The development of new polymer types is rare and has virtually stopped because most of the possible combinations have been investigated. When new materials have been developed these tend to be very expensive and in the area of the performance plastics. However, the area of polymer alloys – generally a blend of an engineering plastic and a commodity plastic – has been one of great activity. The use of engineering plastics has grown rapidly as manufacturers seek to both reduce costs and to improve the processing characteristics of the materials. This has led to the development of a wide, and increasing, range of polymer alloys. Typical of these are:

- PS/PPO – the 'Noryl'® family.
- PS/PMMA
- ABS/PA
- ABS/PC
- ABS/PBT
- ASA/PBT
- ASA/PC

Additional alloys have also been developed using combinations of the engineering plastics such as:

- PPO/PA – this is often used as a replacement for PA in automotive applications that may need to with stand paint stoving lines.
- PC/PBT
- PC/PMMA

Polymer alloys represent a new challenge to the materials specifier and the industry. For the specifier, the range of available materials has increased significantly and choosing the right material is now an even greater challenge than it was before. For the industry, the rapidly expanding range of materials presents issues of stock management, profitability and perhaps more importantly, the issue of recycling and how the new polymer blends are treated and recycled. One of the advantages of plastics is the ease of recycling but this depends on good separation techniques – the advent of polymer blends presents a new challenge to the industry.

6. Summary

Engineering plastics are a major grouping of plastics where the materials are suitable for load-bearing applications. The engineering plastics may be much lower in volume terms than the commodity plastics but their unique properties enable them to be used for some of the most advanced applications that are seen in the plastics industry.