Materials — Polymers

Introduction

Polymers exist in two main forms: thermoplastics and thermosets. Thermoplastics are polymers that soften when heated and can be formed into a new shape and thermosets can not be changed in shape after initial setting without a significant change in material properties. Thermosets require a chemical reaction to set.

Depending on the construction of the polymer at the molecular level different polymers can be produced from the combinations of identical or different monomers. A homopolymer is a polymer that constitutes a structure formed from multiple identical monomers and a copolymer is a mixture of two or more different monomer multiples to provide a combination of their individual properties to provide the desired performance.

Initial forms of thermosets are powder, resin or pre-formed shape. Thermoplastics are supplied as granules. Thermosets can be formed into their product shape by moulding or pultruding and the inclusion of a chemical reaction. Resulting components can be machined to final shapes and sizes.

The methods available for forming thermoplastic products are more varied and depend on the supplied material form.

Bar, sheet, film, and fibre can be produced from granules by techniques such as extrusion or spinning. Sometimes additional processes such as rolling are used to provide extra control over the extruded material size. Co-extruding of thermoplastics is performed to generate resulting materials with properties that utilise the best properties of each constituent material.

Granules can also be formed into finished components by the use of compression moulding, vacuum casting, injection moulding, rotational moulding and blow moulding processes.

Bar, sheet and film can be transformed into part or fully finished products by the use of techniques such as vacuum forming, thermoforming and machining.

Thermosets

Epoxy (EP)

Used for the majority of aerospace bonding applications and for high performance polymer matrix composites. Epoxy provides excellent adhesive strengths and toughness and on curing only a small amount of shrinkage is experienced. Epoxy is resistant to most chemicals. Epoxy-based paints are available for coating steel and other materials that need protecting from weather, chemicals and corrosion.

Furan

It has good strength properties in high temperature applications. It is very rigid with poor resistance to shock loading. It provides good resistance to most chemicals. It is used as a bonding medium in furnaces for carbon and graphite tiles.

Melamine or Ure

Melamine is a hard polymer with good resistance to impact loading, abrasion and scratching. It exhibits moderate resistance to chemical attack.

Phenolic or Phenol Formaldehyde (PF)

This material was one of the first plastics to be manufactured and sold under the trade name of Bakelite. It can be filled with a variety of different materials depending on the application, for example mica for electrical components and glass fibre for strength. The resulting components can be brittle, although they exhibit good compression strengths.

Polyester (unsaturated)

Polyester is used for glass-reinforced composites. This polymer is tough at low temperatures and provides moderate load support capabilities.

Cast Elastomeric Polyurethane (EP)

Normally supplied in a liquid state, this can be cast into a wide variety of shapes with relative ease. Modifying the composition of the material before casting can provide a wide range of hardnesses and load bearing properties. The resulting components exhibit excellent elastic properties and are resistant to chemical attack and tearing. The material properties remain constant until the temperature reaches such a point that decomposition occurs.

Polyurethane is also available in expanded form as a foam and it is frequently used in furniture applications, here important performance characteristics are density, support and resilience. Other applications include foam insulating materials, where the foam materials are mixed and then sprayed onto walls, floors and ceilings.

Vinyl Ester

Vinyl Ester is used as matrix in a large number of polymer matrix composites, especially glass reinforced composites. It provides a good barrier against corrosion and adheres well to the surface of the glass fibres.

Thermoplastics

Acrylonitrile Butadiene Styrene (ABS)

This is a tough and rigid copolymer that exhibits good dimensional stability. The quality of the surface finish of ABS components can be very good. A large number of products use ABS moulded or vacuum formed parts to act as an external cover to the product, and they are also used to manufacture automotive bumpers. Variations on the composition provide grades suitable for medical components and flame resistant applications. ABS has fairly poor resistance to chemical attack.

Aramid or Aromatic Polyamide (PI)

This high tensile strength and high impact resistance polymer is normally produced in fibre form and used as the reinforcement in polymer matrix composites. It is a low-density material which provides an extremely low stiffness and strength to weight ratio. It maintains its performance over a wide range of temperatures. Its high cost restricts its use to aerospace

and other high performance applications. Aramids are part of the nylon family of polymers. Aramid will not dissolve in any chemicals.

Ethylene Vinyl Acetate (EVA)

This rubber-like material is very flexible, tough and has a high coefficient of friction. Commonly used for flexible tubing and teats on babies milk bottles. Other uses include low performance adhesives.

Polyacetal or Acetal or Polyoxymethylene (POM)

Used for bearing applications, due to self-lubrication properties and excellent resistance to wear. Provides good dimensionally stable components for use at temperatures below 90°C. Exhibits moderate resistance to chemical attack. Special grades are available that are glass filled or with added lubrication. Two types of acetal are available, the copolymer and the homopolymer. The homopolymer type is used for applications that require superior mechanical properties. The machining characteristics of the homopolymer are also superior to that of the copolymer. The water and chemical resistance of the copolymer are slightly higher.

Polyacrylonitrile (PAN)

Homopolymers of polyacrylonitrile are processed to make carbon fibres for reinforcing polymer matrix composite materials. Copolymers made containing polyacrylonitrile and other polymers are used in the manufacture of fibres for fabric applications such as outdoor clothing and tents.

Polyamides (Nylon)

Commonly used in bearing and gear applications due to toughness and good wear properties. Changes in size and performance can be significant as a result of water absorption on the low numbered nylons, 6 & 6-6. Higher numbered nylons, 11 & 12, do not absorb as much water and retain their properties.

Available in many forms, including reinforced, graphite filled and oil impregnated. Reasonable cost for performance characteristics. Most grades provide moderate resistance to chemical attack.

Polycarbonate (PC)

Providing excellent resistance to shock loading, rigid and available in transparent form, this polymer is used for ‘bullet-proof’ windows. Also used for compact discs, utilising its ability to be moulded to tight tolerances. External applications should consider its low weather and chemical resistance and provide the appropriate coatings.

Polyesters (Thermoplastic) (PET)

PET is used for the manufacture of bottles for the drinks industry, utilising its properties of good rigidity, high toughness, ease of manufacture (blow moulding), excellent barrier properties, chemical resistance and moderate strength.

Polyethylene (PE)

Available in a number of densities that are suitable for a wide variety of applications. The widespread use, ease of manufacture and availability of polyethylenes helps maintain their low overall cost.

Low Density Polyethylene (LDPE)

Applications of LDPE range from films for the manufacture of packaging and bags to electrical cable insulation sheathing. This material is very flexible, soft, and tough, but provides little load support capabilities. LDPE can provide very good fluid barrier properties.

Medium Density Polyethylene (MDPE)

This exhibits greater rigidity and strength. It is used as a water-piping medium and for low specification mouldings.

High Density Polyethylene (HDPE)

HDPE provides good toughness properties over a wide range of temperatures. Used for applications such as low specification fluid handling, household goods and toys.

Ultra High Molecular Weight Polyethylene (UHMWPE)

UHMWPE is very hard and rigid. It has a low water absorption and a low coefficient of friction against most materials, although its moderate coefficient of thermal expansion requires due consideration. Commonly used as wear plates and change parts in packaging and materials handling machinery. The fibre form of UHMWPE is being used to replace Kevlar fibres in bullet-proof vests, due to its higher strength and energy absorbing capabilities. UHMWPE is used in marine docks in wear plates to protect the dock and vessel structures from impact and wear.

Polyimide (Thermoplastic)

A very expensive material, but it offers excellent performance at elevated and cryogenic temperatures. It is extremely strong, it exhibits a low coefficient of friction and it provides excellent resistance against chemical attack. Another property that polyimides exhibit that makes them extremely useful in applications exposed to the risk of fire, is that they produce a ‘char’ on the surface that is alight, which blocks the flames from the material itself, meaning that there is no fuel exposed to burn.

Polymethylmethacrylate (PMMA)

This material can be easily formed into complex shapes when heated and it provides near crystal clear transparent components. The weather resistance capabilities promote its use in external applications, such as bus shelters. Consideration must be given towards its impact strength, which is low, although impact grades can be specified where the impact strength can be increased by a factor of ten.

Polypropylene (PP)

This polymer is available in a wide variety of compositions, all of which display the following general properties across their range: good toughness, moderate rigidity, ease of manufacture, good fatigue resistance, and a 'live' hinge property. These properties ensure widespread use of PP across a wide range of products, although difficulty has been found in trying to mould PP to tight tolerances.

Polystyrene (PS)

The use of PS is widespread and there are a multitude of different grades, the most commonly used grades being general purpose, expanded and high impact.

General Purpose Polystyrene (GPPS)

GPPS is cheap, rigid, easy to manufacture and has a low density. This material can be supplied transparent and non-toxic; these two factors see its widespread use in food packaging.

Expanded Polystyrene (EPS)

EPS is used as a bulk or packing medium, to prevent damage to the contained product. It can be easily moulded to shape and it can absorb large amounts of energy from shock loads. It can also provide excellent thermal insulation properties. Other shock absorbing applications include cycle helmets and child car seat linings.

High Impact Polystyrene (HIPS)

A mixture of Polybutadiene and Polystyrene is formed so that when the component is hit with a shock load then the 'rubber like' polybutadiene absorbs the impact energy. The impact strength can be increased up to seven times that of general purpose polystyrene. The increased impact strength of this material leads to it being specified for items such as television and computer monitor casings.

Polytetrafluoroethelene (PTFE)

PTFE, sometimes referred to as a fluoroplastic or fluoropolymer, has an extremely low coefficient of friction against the majority of materials. It maintains its shape and size at high temperatures and displays good toughness properties at low temperatures. PTFE does not resist abrasion and penetration to the same extent as acetals and nylons, but provides excellent chemical resistance and good weathering properties. Applications of PTFE include 'non-stick' pans, bearings, pipe linings and thread sealing tape.

Polyvinyl Chloride (PVC)

PVC is a polymer that can be supplied in any state from soft and flexible to moderately hard and rigid. The latter is used to manufacture clean and waste water piping and window frames, whilst the soft and flexible PVC is used to manufacture shower curtains, raincoats, electrical insulation and modern tarpaulins. Both ends of the spectrum use the waterproof properties of PVC. Other properties include good resistance to impact loads and fire resistance. PVC does not retain these properties well at low or elevated temperatures.

Rubber

There are two different types of rubber, natural and synthetic. The synthetic rubbers have been developed to provide resistance to chemical and environmental attack, whilst natural rubbers are chosen for applications where extreme elasticity, resilience and fatigue properties are required.

Natural Rubber

Natural rubber is sometimes referred to as polyisoprene or latex. When selecting natural rubber, consideration must be given to its limited chemical and UV radiation resistance. Natural rubbers can perform over a temperature range from -50°C to 80°C. Cross-linking or vulcanisation adds sulphur to natural rubber which ties the polymer chains together. This cross-linked rubber provides a material that is more capable of returning to its original state when the loads are removed, and it is capable of performing over a wider range of temperatures, depending on the quantity of sulphur added.

Synthetic Rubber

Many different types of synthetic rubbers are available, including stryrene butadiene rubbers, butyl rubbers, nitrile rubbers, neoprene rubbers, polyurethane rubbers and fluorocarbon rubbers. These are generally less expensive than natural rubber and provide improved resistance to chemical attack over a wider range of temperatures, although they do not provide the mechanical properties of natural rubbers.

Thermoplastic Polyurethane (TPU)

This impermeable, wear resistant and flexible material is used for the manufacture of fluid piping media. Its elastic and shock absorbing properties promote its use in other applications such as running shoes. Thermoplastic polyurethane is available in compositions that allow it to be stretched to five times its original length.

Internet Resources

The British Plastics Federation is a trade association that represents the interests of all industries relating to plastics manufacture and provides information relating to plastic properties and processing.

RAPRA technology Ltd. Polymer and Rubber Selection Software and Consultancy. The Polymer Search on the internet is part of the RAPRA website.

British Plastics and Rubber Online is an on-line directory listing to UK companies that manufacture polymer-related products.

The Polymer Centre based at the University of Sheffield conducts research into polymer technologies and provides resources of expertise across every aspect of polymer manufacture and application.

The British Rubber Manufacturers Association (BRMA) promotes the use of rubber products across a wide range of industries and acts to protect the interests of its members.