Polymers: Properties, Processing and Applications

Thermoplastics and thermosetting polymers are types of plastic that undergo different production processes and yield a variety of properties depending on the constituent materials and production method.

The main physical difference is how they respond to high temperatures. When heated to their melting point, thermoplastics soften into a liquid form. Therefore, the curing process is reversible, which means that they can be remoulded and recycled. On the other hand, thermoset polymers form a cross-linked structure during the curing process, preventing them from being melted and remolded.

Think of Thermosets like concrete, once they have set you can never go back to the liquid form (irreversible process). While Thermoplastics are like water, they can transition between ice and water with the application or removal of heat (reversible process).

Properties of thermoplastics and thermosetting polymers

Thermoplastics generally provide high-strength, flexibility and are resistant to shrinkage, depending on the type of resin (the polymer in melted liquid form). They are versatile materials that can be used for anything from plastic carrier bags to high-stress bearings and precision mechanical parts.

Thermosetting polymers generally yield higher chemical and heat resistance, as well as a stronger structure that does not deform easily.

Property	Thermoplastics	Thermosetting Polymers
Molecular structure	Weak molecular bonds in a straight-chain formation	Strong chemical molecular bonds that are cross-linked
Melting point	Melting point lower than the degradation temperature	Melting point higher than the degradation temperature
Mechanical	Flexible and elastic. High resistance to impact (10x thermosets)	Inelastic and brittle.
Polymerisation	Repolymerized during manufacture (before processing)	Polymerized during processing
Microstructure	Comprised of hard crystalline and elastic amorphous regions in its solid state	Polymerized during processing
Recyclability	Recyclable and reusable	Non-recyclable

Chemical resistance	Highly chemical resistant	Heat and chemical resistant
Crack repair	Cracks can be repaired easily	Difficult to repair cracks

Processing of thermoplastics and thermosetting polymers

Thermoplastic processing

Thermoplastics can be processed in a variety of methods including extrusion moulding, injection moulding, thermoforming and vacuum forming.

Granular material is fed into the mould, usually in the form of spherical granules of approximately 3 mm diameter. These granules are then heated to melting point, which requires very high temperatures.

As thermoplastics are highly efficient thermal insulators, cooling during the curing process takes longer than other plastics. Therefore, rapid cooling is undertaken to achieve a high output rate, usually by spraying with cold water or plunging into water baths. To cool thermosplastic plastic films, cold air is blown onto the surface. The plastic shrinks upon cooling, varying between a shrinkage rate of 0.6% to 4% depending on the material. The rate of cooling and shrinkage has a distinct effect on the crystallisation of the material and internal structure, which is why the shrinkage rate is always specified for thermoplastics.

Thermosetting polymer processing

Thermosetting resins are processed in their liquid form under heat. The curing process involves adding curing agents, inhibitors, hardeners or plasticisers to the resin and reinforcement or fillers, depending on the required outcome.

The most commonly used thermosetting resins include:

- Epoxy
- Polyester
- Phenolic
- Silicone
- Polyurethane
- Polyamide

Thermosetting polymer composites processing

Thermosetting polymer composites are made using a laminating process, which binds together resins such as epoxy, silicone, melamine, etc. with reinforcement base materials such as glass, linen and graphite.

Prior to curing, the reinforcement substrate is dipped into the resin binder in its liquified form. Once bound, the sheets of material are passed through an oven to partially cure them. Several sheets are then piled to the required thickness, heated and pressed together to form a laminate. Alternatively, the sheets may be wrapped together and heated to create rods.

Materials and applications

Types of thermoplastics and their applications

Polyamide (nylon) – Tough and relatively hard material used for power tool casings , curtain rails, bearings, gear components and clothes.

Polymethyl Methacrylate (PMMA, acrylic) – Stiff, durable and hard plastic that polishes to a sheen, used for signage, aircraft fuselage, windows, bathroom sinks and bathtubs.

Polyvinyl Chloride (PVC) – Tough and durable material that is commonly used for pipes, flooring, cabinets, toys and general household and industrial fittings.

Polypropylene – Light, yet hard material that scratches fairly easily, with excellent chemical resistance, used for medical and laboratory equipment, string, rope and kitchen utensils.

Polystyrene (PS) – Light, stiff, hard, brittle, waterproof material used mainly for rigid packaging.

Polytetrafluoroethylene (PTFE, Teflon) – Very strong and flexible material used for non-stick cooking utensils, machine components, gears and gaskets.

Low-density Polythene (LDPE) – Tough, relatively soft, chemical resistant material used for packaging, toys, plastic bags and film wrap.

High-density Polythene (HDPE) – Stiff, hard, chemical resistant material used for plastic bottles and casing for household goods.

Types of thermosetting polymers and their applications

Epoxy resin – Hard material that is brittle without extra reinforcement. Used for adhesives and bonding of materials.

Melamine formaldehyde – Hard, stiff and strong, with decent chemical and water resistance, used for work surface laminates, tableware and electrical insulation.

Polyester resin – Hard, stiff and brittle when unlaminated. Used for encapsulation, bonding and casting.

Urea formaldehyde – Hard, stiff, strong and brittle used primarily in electrical devices due to its good electrical insulation properties.

Polyurethane – Hard, strong and durable material used in paint, insulating foam, shoes, car parts, adhesives and sealants.

Phenol formaldehyde resin (PF) – Strong, heat and electrical-resistant material used in electrical items, sockets and plugs, car parts, cookware and precision-made industrial parts.