Members of the Polymer Family

Polymers can be separated into two different groups depending on their behavior when heated. Polymers with linear molecules are likely to be **thermoplastic**. These are substances that soften upon heating and can be remolded and recycled. They can be semi-crystalline or amorphous. The other group of polymers is known as **thermosets**. These are substances that do not soften under heat and pressure and cannot be remolded or recycled. They must be remachined, used as **fillers**, or incinerated to remove them from the environment.

Thermoplastics

Thermoplastics are generally carbon containing polymers synthesized by addition or condensation polymerization. This process forms strong covalent bonds within the chains and weaker secondary **van der Waals** bonds between the chains. Usually, these secondary forces can be easily overcome by thermal energy, making thermoplastics moldable at high temperatures. Thermoplastics will also retain their newly reformed shape after cooling. A few common applications of thermoplastics include: parts for common household appliances, bottles, cable insulators, tape, blender and mixer bowls, medical syringes, mugs, textiles, packaging, and insulation.

Thermosets

Thermosets have the same van der Waals bonds that thermoplastics do. However, they have a stronger linkage to other chains. Strong covalent bonds chemically hold different chains together in a thermoset material. The chains may be directly bonded to each other or be bonded through other molecules. This "cross-linking" between the chains allows the material to resist softening upon heating. Thus, thermosets must be machined into a new shape if they are to be reused or they can serve as powdered fillers. Although thermosets are difficult to reform, they have many distinct advantages in engineering design applications including:

1. High thermal stability and insulating properties.
2. High rigidity and dimensional stability.
3. Resistance to **creep** and deformation under load.
4. Light-weight.

A few common applications for thermosets include epoxies (glues), automobile body parts, adhesives for plywood and particle board, and as a matrix for composites in boat hulls and tanks.

Polymer Processing

There are five basic processes to form polymer products or parts. These include; injection molding, compression molding, transfer molding, blow molding, and **extrusion**. Compression molding and transfer molding are used mainly for thermosetting plastics. Injection molding, extrusion and blow molding are used primarily with thermoplastics.

Injection Molding

Injection molding is a very common process for forming plastics, which involves four steps:

1. Powder or pelletized polymer is heated to the liquid state.
2. Under pressure, the liquid polymer is forced into a mold through an opening, called a sprue. Gates control the flow of material.
3. The pressurized material is held in the mold until it solidifies.
4. The mold is opened and the part removed by ejector pins.

Advantages of injection molding include rapid processing, little waste, and easy automation.

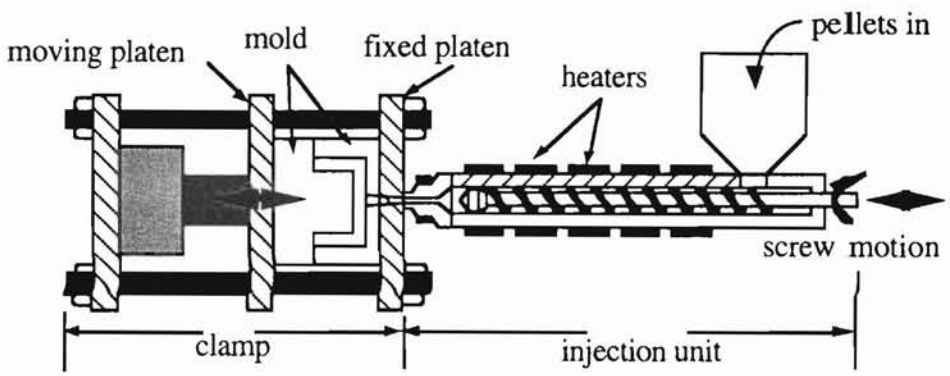


Figure 3: *Diagram of injection molding.*

Compression Molding

Compression molding was among the first methods used to form plastics. It involves four steps:

1. Pre-formed blanks, powders or pellets are placed in the bottom section of a heated mold or die.
2. The other half of the mold is lowered and pressure is applied.
3. The material softens under heat and pressure, flowing to fill the mold. Excess is squeezed from the mold. If it is a thermoset, cross-linking occurs in the mold.
4. The mold is opened and the part is removed.

For thermoplastics, the mold is cooled before removal so the part will not lose its shape. Thermosets may be ejected while they are hot and after curing is complete. This process is slow, but the material moves only a short distance to the mold, and does not flow through gates or runners. Only one part is made from each mold.

Transfer Molding

Transfer Molding is a modified form of compression molding. It is used primarily to produce thermosetting plastics. It involves five steps:

1. A partially polymerized material is placed in a heated chamber.
2. A plunger forces the flowing material into molds.
3. The material flows through sprues, runners and gates.
4. The temperature and pressure inside the mold are higher than in the heated chamber, which induces cross-linking.
5. The plastic cures, is hardened, the mold opened, and the part removed.

Mold costs are expensive and much scrap material collects in the sprues and runners, but complex parts of varying thickness can be accurately produced.

Blow Molding

Blow molding involves three basic steps:

1. A softened plastic tube is extruded
2. The tube is clamped at one end and inflated to fill a mold.
3. Solid shell plastics are removed from the mold.

This process is rapid and relatively inexpensive.

Extrusion

Extrusion is ideally suited for parts of constant cross section like pipes and rods. It involves four steps:

1. Pellets of the polymer are mixed with coloring and additives.
2. The material is heated to its proper plasticity.
3. The material is forced through a die.
4. The material is cooled.

An extruder has a hopper to feed the polymer and additives, a barrel with a continuous feed screw, a heating element, and a die holder. • ••

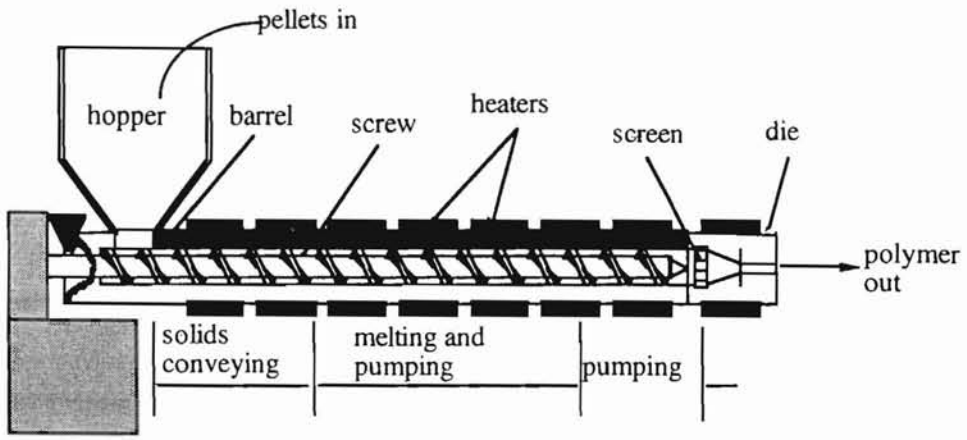


Figure 4: *Diagram of an extruder.*

•Molten ploymer, which is forced through the die, must be carefully cooled to avoid deformation (or slumping) upon exiting the die

••In addition, plastic bags and films can be formed by extrusion by fitting an adaptor at the end which blows air through an orifice into the hot polymers extruded through a ring die.

Table 1:
Comparison of polymer processing techniques for thermoplastics and thermosets.

Process	Thermoplastic (TP) or Thermoset (TS)	Advantages	Disadvantages
Injection Molding	TP, TS	It has the most precise control of shape and dimensions, is a highly automatic process ,has fast cycle time, and the widest choice of materials.	It has high capital cost, is only good for large numbers of parts, and has large pressures in mold (20,000 psi).
Compression Molding	TS	It has lower mold pressures (1000 psi), does minimum damage to reinforcing fibers (in composites), and large parts are possible.	It requires more labor, longer cycle than injection molding, has less shape flexibility than injection molding, and each charge is loaded by hand.
Transfer Molding	TS	It is good for encapsulating metal parts and electronic circuits.	There is some scrap with every part, and each charge is loaded by hand.
Blow Molding	TP	It can make hollow parts (especially bottles), stretching action improves mechanical properties, has a fast cycle, and is not labor intensive.	It has no direct control over wall thickness, cannot mold small details with high precision, and requires a polymer with high melt strength.
Extrusion	TP	It is used for films, wraps, or long continuous parts (ie. pipes).	It must be cooled below its glass transition temperature to maintain dimensional stability.