Module

3

Selection of Manufacturing Processes

Lecture

7

Design for Polymer Processing

Instructional objectives

By the end of this lecture, the student will get a basic introduction to polymer structure and various routes of processing of polymers, and the factors to be considered during design for polymer processing.

Introduction

Polymers are natural or synthetic resins or their compound which can be molded, extended, cast or used as films or coatings. Naturally occurring polymers – those derived from plants and animals – are in use for many centuries; these materials include wood, rubber, cotton, wool, leather, and silk. Modern scientific research tools facilitated the determination of the molecular structures of this group of materials, and the development of numerous polymers, which could be synthesized from small organic molecules. The synthetics can be produced inexpensively, and their properties may be managed to the degree that many are superior to their natural counterparts. In many applications, metal and wood parts are replaced by plastics, which have satisfactory properties, longer durability and can be produced at a lower cost.

Classification

Polymers are most commonly classified as (a) *thermoplastics* and (b) *thermosetting polymer*.

Thermoplastic Materials

The polymeric materials which soften on the application of heat with or without pressure, but require cooling to set them to shape are called *Thermoplastic Materials.* These can be heated and cooled any number of times, but should not be heated above the decomposition temperature. These polymers primarily include long chain straight molecule and the chains are held close to each other by secondary weak forces. Upon heating, these secondary forces are reduced and sliding can occur easily thereby allowing visco-plastic flow and ease in molding. These polymers are characterized with low melting temperature and lesser strength compared to the thermo setting plastic. Some important thermoplastic materials are *Polythene, Polyvinyl chloride, Polystyrene* etc.

Thermosetting Materials

Polymers which require heat and pressure to mold them into shape and become permanently hard during shaping are called *Thermosetting Materials.* These materials cannot be resoftened once they are set and hardened. *Thermosetting polymers* typically include cross-linked molecular chains and hence, are ideal for making components which require rigidity, strength and resistance to heat. Due to cross linking, *thermosetting polymers* are hard, tough, non-swelling and brittle, and cannot be softened and remolded as thermoplastic materials. Some important thermoplastic materials are Phenol Formaldehyde, Epoxy Resins, and Polyesters etc.

Molecular Structure

The physical characteristics of a polymer depend not only on its molecular weight and shape but also on differences in the structure of the molecular chains. Several types of molecular structure are possible and can be controlled over various structural possibilities.

Linear polymers [*Figure 3.7.1* (*a*)]

The *linear polymers* are those in which repetitive molecular units are joined together end to end in single chains. These long chains are flexible with extensive van der Waals and hydrogen bonding between the chains. Some of the common polymers that form with linear structures are polyethylene, polystyrene, nylon, and the fluorocarbons.

Branched Polymers [*Figure 3.7.1*(*b*)]

These polymers are characterized by side-branch chains that are connected to the main ones, as indicated schematically in *Figure 3.7.1*(*b*). The branches may result from side reactions that occur during the synthesis of the polymer. The chain packing efficiency is reduced with the formation of side branches, which results in a lowering of the polymer density.

Crosslinked Polymers [*Figure 3.7.1*(*c*)]

These polymers are characterized with adjacent linear chains that are joined one to another at various positions by covalent bonds, as represented in *Figure 3.7.1*(*c*). Cross linking is done during synthesis or by a non-reversible chemical reaction. Often, this crosslinking is accomplished by additive atoms or molecules that are covalently bonded to the chains.

Network Polymers [*Figure 3.7.1*(*d*)]

These polymers are formed when multifunctional monomers forming three or more active covalent bonds, make three-dimensional networks. A polymer that is highly cross linked may also be classified as a network polymer. These materials have distinctive mechanical and thermal properties. The epoxies, polyurethanes and phenol-formaldehyde belong to this group of polymers

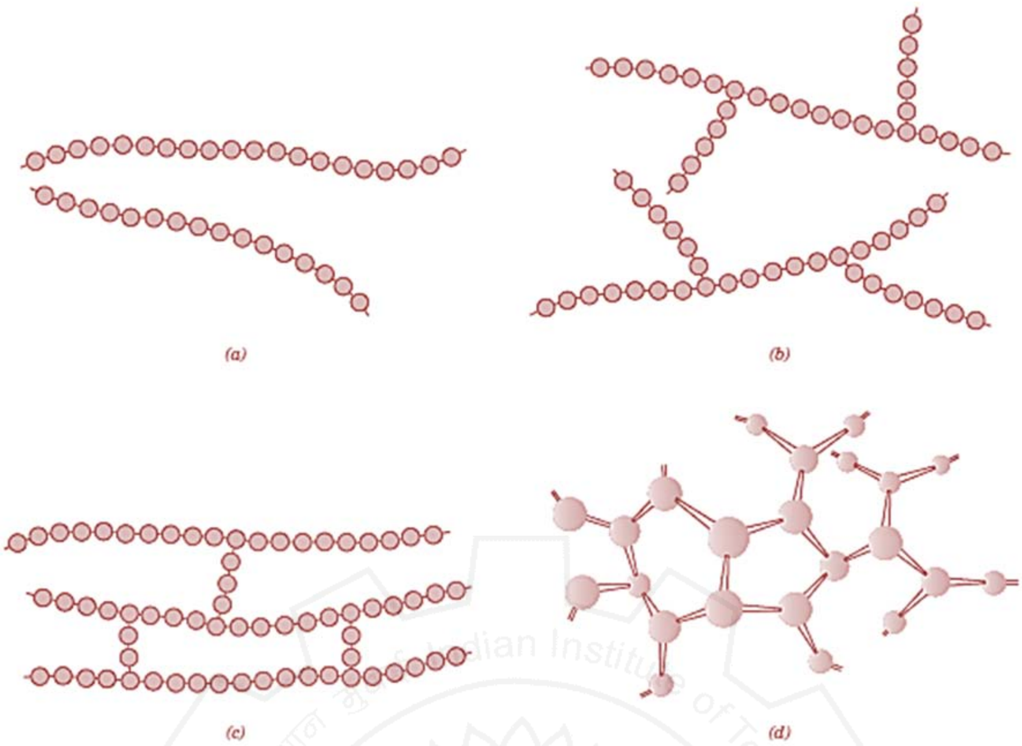

Figure 3.7.1 Schematic representations of (a) linear, (b) branched, (c) cross linked, and (d) network (three-dimensional) molecular structures [3]

Processing methods of Polymers and Design Guidelines

Manufacturing process used with polymers take advantage of the unique visco-plastic flow properties of polymers. Compared with the metals, the flow stress is much lower and highly strain rate dependent, the viscosity is much higher, and formability is much greater. Some of the common manufacturing processes of polymers The common production process is given below.

Injection Molding

In this process, plastic granules are heated and forced under pressure into a die cavity of desired shape. This process is well suited for producing true three-dimensional shapes such as bottles, toys etc, which require fine details like holes, snaps and surface details. *Figure 3.7.2* schematically presents an Injection Molding set-up for polymer processing.

- Design for gating and feed system for the die is crucial to ensure complete die fill. It is important to design the molding so that solidification does not prevent complete mold filling. The design and location of the gates for entry of polymer is a crucial design details. For large part more than one gate may be required for proper flow of material.

- Mold must be designed in such a way that the solid part can be ejected without distortion. By considering proper orientation at the beginning, in may be possible to avoid expensive mold cost. If possible, design the part so that it can be ejected in the direction of mold closure.
- To minimize the shrinkage fillers like glass fiber, wood flour, are added during molding. With some part geometries, post mold shrinkage can lead to generation of high residual stress.

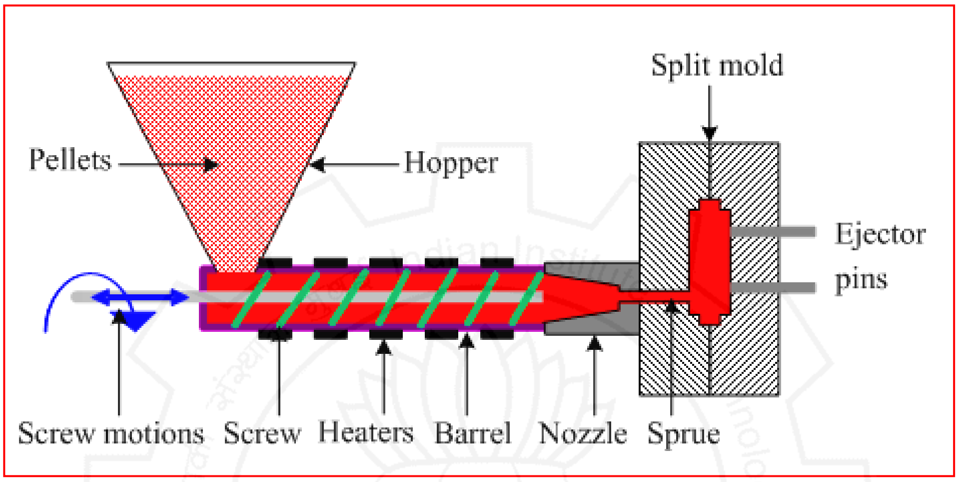

Figure 3.7.2 Schematic set-up of Injection Molding [4]

Extrusion

Extrusion is one of the few continuous plastic processes, which is used to produce sheet, film, long length with a profiled cross section and fiber. The chief concern with *extrusion of polymers* is the die swell and the orientation. In die swell, the extrudate swells to a size greater than the die from which it just exited. Thus the design must compensate for the swell. Polymer molecules become highly oriented in one or two directions as a result of the strongly oriented flow inherent in the extrusion process. Control of orientation can improve the property of the material. *Figure 3.7.3* depicts a typical set-up of polymer extrusion process.

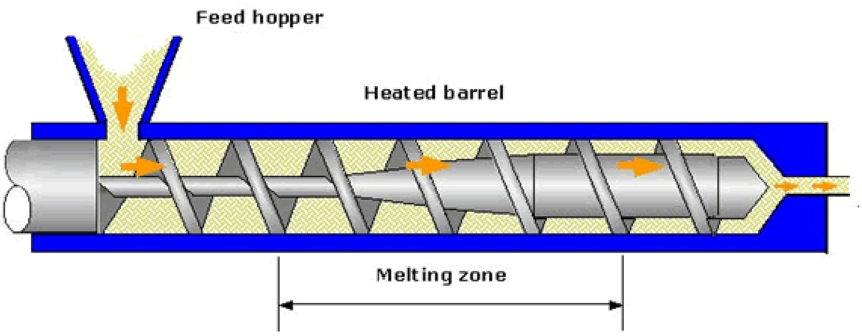

Figure 3.7.3 Schematic set-up of Polymer Extrusion [5]

Blow Molding

In blow molding, a hot tube of plastic material is placed between two halves of the mold. The mold is then closed and air or inert gas is blown at a pressure of 20 – 40 MPa which expands the hot tube outward to fill the mold cavity (as shown in *figure 3.7.4*). The part cools, hardened and is ejected from mold. The process produces a part that is dimensionally defined on its external dimension. The process does not lend itself to incorporate design details such as holes, corners, narrow ribs, etc. The *blow molding process* is very fast and can produce part very economically. The process can be accomplished manually or by semi-automatic or automatic machines.

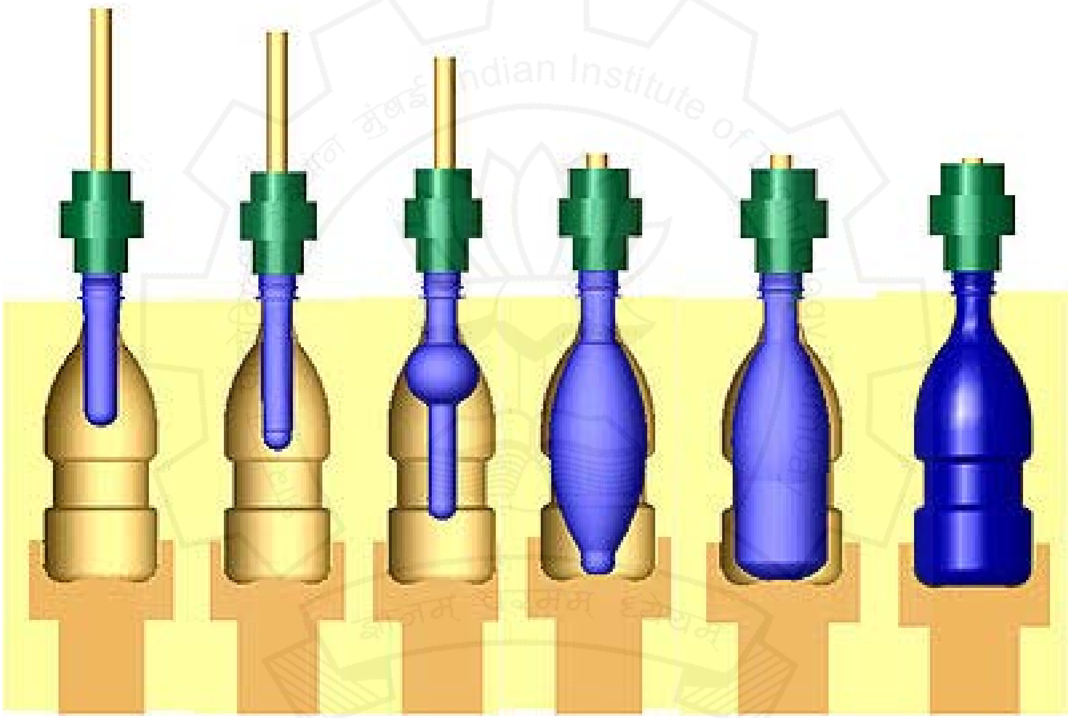

Figure 3.7.4 Schematic set-up for Blow Molding of Polymer [5]

Compression Molding

In this technique, a preform of a typical polymer is placed in a heated mold cavity and a plunger applies pressure to force the polymer to fill the mold cavity. The material is then allowed to cure and ejected from the mold. As the amount of flow is much lesser than the same used in injection molding, the level of residual stress in the part is low. Parts made in this way would have sprues and runners which must be trimmed. *Figure 3.7.5* depicts a schematic set-up of *compression molding* for polymers.

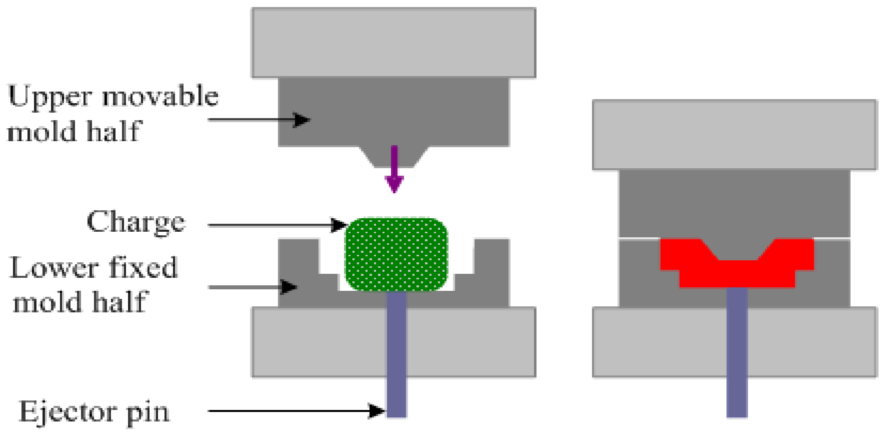

Figure 3.7.5 Schematic set-up of Compression Molding of polymers [6]

Thermoforming

Thermoforming refers to heating a sheet of plastic material until it becomes soft and flexible and then forming it either by vacuum, by air pressure or between matching mold halves. Following are the typical sequences used in *thermoforming* of polymers.

- A sheet of thermoplastic material is placed over a die and heated until it becomes soft.
- A vacuum is then created inside the die cavity which draws down the heated plastic sheet into the shape of the die.
- The material is then cooled, the vacuum is released and the final product is taken out.

Figure 3.7.6 depicts typical sequences in thermoforming schematically. Traditionally, thermoforming is done with only a single mold, but for more precise control of dimension two matching mold halves are used.

Design Issues in Polymer Processing

Following are some of the significant design issues that should be considered during polymer processing.

(1) The minimum wall thickness is the most important design feature of any plastic part. The wall thickness should not vary greatly. The nominal wall thickness will vary from about 0.4 – 4.0 mm. The rate of change of section thickness should be gradual to ensure proper mold filling.

(2) The typical projections from a molded wall are ribs, webs and bosses. These should be designed properly to endure proper mold filling.

(3) It is important to design as many feature, such as pilot holes, countersinks, snap fits, living hinges rather than adding them as secondary operations.

(4) Part design and process selection affect the residual stresses in the part. These stresses arise from inhomogeneous flow as polymer molecules flow through the passages of the mold. Lower stress leads to better dimensional stability.

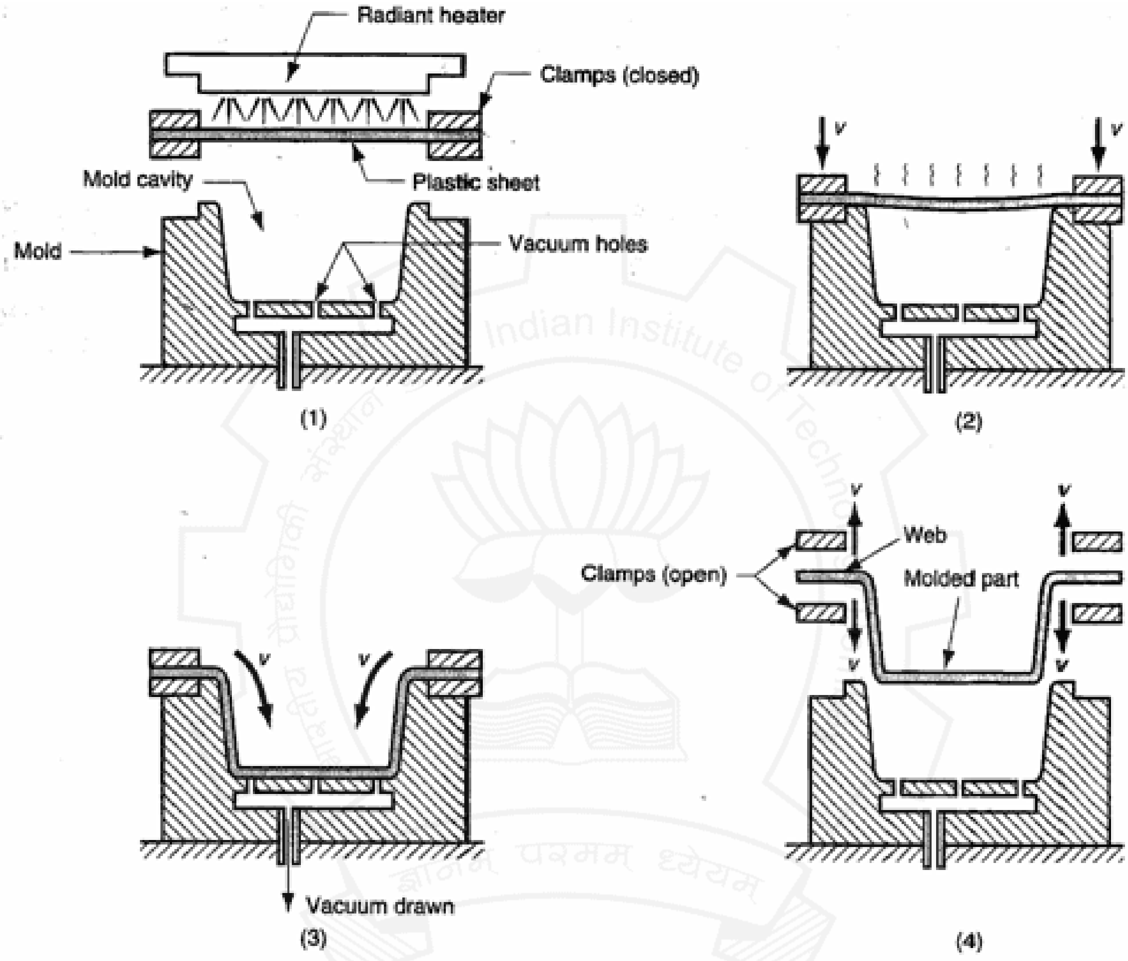

Figure 3.7.6 Schematic set-up of Thermoforming Process [1]

Exercise

1. The greatest quantities of plastic parts are made by ________ molding.
2. What are the characteristics of polymers?
3. Name three thermosetting polymers

References

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