Chapter 1

Overview

There are many potential definitions of polymer processing. One of my favorites is that given by Tadmor and Gogos[1] in their classic textbook: polymer processing concerns "operations carried out on polymeric materials or systems to increase their utility." Personally, I prefer the use of the word "value" in place of "utility." The goal of polymer processing is to increase the value of the polymer or formulation. Polymer processing is a tool to achieve the desired shape, properties, and performance for a polymer article. It has broad applicability from packaging to aerospace.

It is the *performance* of a material which generates value. Thus, for each particular application, one should ask:

- "What are the critical performance requirements for this application?"
- "How can this performance be achieved by a combination of the material and the process?"

Let's take a particular example, the body and wings of the F-117A stealth fighter/bomber. What are the critical performance requirements for this application? A few of them are listed in Table 1.1:

How are these characteristics achieved? The body and wings of these stealth aircraft are constructed primarily of an epoxy/carbon fiber composite which is shaped and manufactured using a process called hand lay-up. For example, the starting material may be preforms in the shape of flat sheets which consist of uniaxial carbon fibers impregnated with a low or medium molecular weight epoxy. These sheets are stacked and formed in the desired shape of the wings and/or body and then cured to polymerize the epoxy.

Both the materials used and the processing operation are critical for achievement of the desired performance.

There is one key characteristic which we have not yet discussed.

The MOST important property of *ANY* material is its PRICE.
The MOST important property of *ANY* process is its COST.

In this sense the stealth aircraft is an unusual example. High performance epoxy/carbon composites are very expensive. In addition, the hand lay-up process is very expensive because it requires a large amount of highly skilled labor. In this case, high costs are justified, due to the concurrent high costs of the engines and electronics on the aircraft. In addition, consider the military and political costs of having a pilot shot down behind enemy lines.

1.0.1 An Example: Poly(ethylene terephthalate)

Poly(ethylene terephthalate)(PET) is a polymer which is widely used in packaging, fiber, and engineering applications. This polymer may be synthesized by a variety of means, including the reaction of ethylene glycol with dimethyl terephthalate, as illustrated in Figure 1.1.

The molecular weight is built by reaction in the melt state until the polymer has an inherent viscosity of approximately 0.5. It is then extruded and pelletized. The material at this molecular weight may be used directly in fiber or textile applications. For most packaging and engineering applications the molecular weight is further increased through polymerization in the solid state.

The shaping of the polymer through a variety of potential processing operations: fiber spinning, blow molding, thermoforming, injection molding, etc.; is where classical polymer processing starts.

Performance Requirement	Comments
High strength/weight ratio	Strong and light materials for aerospace
Small radar signature	Must be a "stealthy" aircraft
Temperature resistance	Hot engines and exhaust gases
Chemical resistance	Intermittent contact with rain, jet fuel, etc.

Table 1.1: Key performance requirements for the body and wings of a stealth fighter.

Performance Characteristic	Material Contribution	Process Contribution
High strength/weight ratio	The composite incorporates high strength carbon fibers in a matrix of low density (compared to metals) epoxy.	The hand lay-up process allows for detailed control of fiber orientation at different locations on the part. The fiber orientation can be optimized in order to support the loads which are expected to be generated during flight.
Small radar signature	The materials have low radar reflection compared to metals, which can be further improved by the use of additives.	The hand lay-up process is extremely flexible, allowing for the design and manufacture of shapes with low radar reflectance.
Temperature resistance	Since the epoxy is crosslinked, it has very high dimensional stability. In fact, this material will thermally degrade before it begins to soften and flow.	Shaping the part prior to crosslinking (curing) allows forming of a part which is eventually highly crosslinked.
Chemical resistance	Since the epoxy is crosslinked, it is very resistant to chemical penetration. It is difficult to swell and cannot be dissolved.	Shaping of the part prior to crosslinking (curing) allows forming of a part which eventually is highly crosslinked.

Table 1.2: Methods for achievement of the key performance criteria.

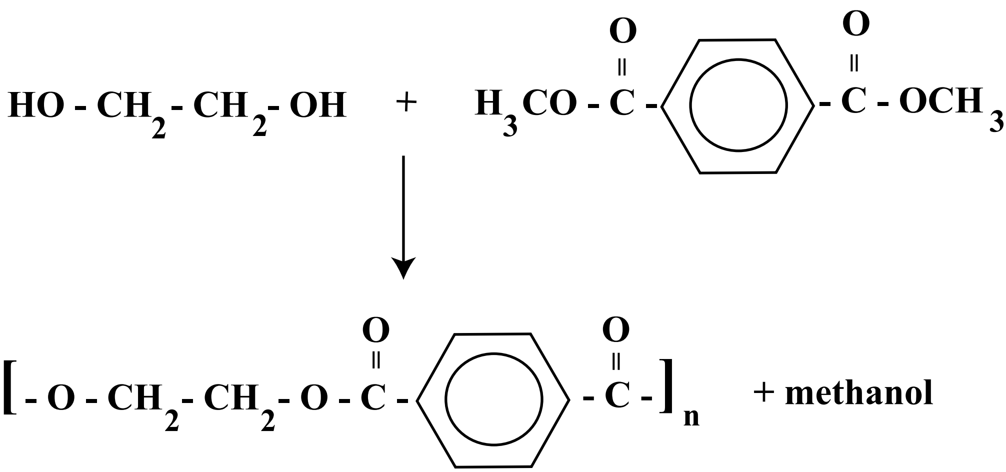

Figure 1.1: One route for the synthesis of PET.

The mechanical properties of a polymer are generally not purely a material function, but instead depend on the manner in which it was processed. Semicrystalline polymers such as PET are excellent examples of materials which are sensitive to processing conditions.

The same poly(ethylene terephthalate) was injection molded under slightly different conditions of melt temperature and mold temperature. The part produced is a standard rectangular shape, 6 inches long, 1/2 inch wide, and 1/8 inch thick. The influence of these changes on the mechanical properties are summarized in Table 1.3.

Melt Temperature	Mold Temperature	Part Appearance	UnNotched Izod Impact Strength	Heat Deflection Temperature
300^0C	40^0C	opaque	1.5 ft-lb/in (brittle)	200^0C
280^0C	25^0C	clear	12.0 ft-lb/in (tough)	60^0C

Table 1.3: Properties of poly(ethylene terephthalate) as a function of the process parameters for a particular injection molding operation.

How is it possible that such seemingly minor changes in the process conditions resulted in large changes in the material properties? In what specific ways does the processing control the polymer microstructure in this particular case? This is an excellent example of why it is important to understand polymer processing and its interaction with the material.

1.0.2 Problems

1. **Manufacture of a polymeric item.**
   (a) Select a polymeric item; describe it briefly. Provide a sketch.
   (b) What polymer do you believe it is composed of?
   (c) Outline the process which you believe was used to make it.
   (d) What are the critical performance requirements for this item?
   (e) How do the materials and process used address the critical performance requirements for this particular application?

Bibliography

[1] Z. Tadmor and C.G. Gogos, **Principles of Polymer Processing**, John Wiley and Sons (1979).