Plastics Fabrication and Recycling

Plastics Engineering Series

Manas Chanda
Salil K. Roy

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Preface

What makes plastics the most versatile of all materials is the ease with which they can be given any desired shape and form. Molding and fabrication processes, however, vary depending on the type of polymers to be processed and the shape and form of the end products to be made. Tooling for plastics processing defines the shape of the end product. A *mold* forms a complete three-dimensional part and is used in a number of fabrications processes, such as compression molding, injection molding, blow molding, thermoforming, and reaction injection molding (RIM), whereas a *die* is used to form two of the three dimensions of a plastic part—the third dimension, usually thickness or length, being controlled by other process variables—and is used in fabrication processes such as extrusion, pultrusion, and thermoforming. (Many plastics processes, however, do not differentiate between the terms *mold* and *die*.) Considering their critical importance in shaping the plastic products, Chapter 1 on fabrication processes begins with a discussion of different types of molds and dies.

Traditionally, plastics are divided into two broad categories, namely, *thermoplastic* and *thermosetting*. Thermoplastic resins, usually obtained as a granular polymer, can be repeatedly melted or solidified by heating or cooling—heat softens or melts the material so that it can be formed, and subsequent cooling then hardens or solidifies the material in the given shape. Thermoplastic resins are, therefore, usually molded by extrusion, injection, blow molding, and calendering processes as well as by thermoforming. On the other hand, thermosetting resins, which are usually supplied as a partially polymerized molding compound and are cross-linked or "cured" during the fabrication process, are usually shaped by compression molding and RIM. However, with the progress of technology, the demarcation between thermoplastic and thermoset processing has become less distinct so much so that thermoset processes have been developed which make use of the processing characteristics of thermoplastics, and modified machinery and molding compositions are made available to extend the economics of thermoplastic processing to thermosetting materials. All these molding processes are described in detail in the first part of Chapter 1.

Fiber-forming thermoplastic polymers are processed by spinning into filaments, which in turn are made into yarn, tow, roving, staple, and cord. The three principal types of spinning processes, namely, melt spinning, dry spinning, and wet spinning are also discussed in Chapter 1, with a focus on the physico-chemical factors of the respective processes and their effects on end–product qualities.

Besides the main fabrication processes cited above, there are many other processes that have been developed to serve specific needs, such as casting processes and reinforcing processes. Both thermosets and thermoplastics can be cast, for which the commonly used resins are acrylics, polystyrene, polyesters, poly(vinyl chloride), phenolics, and epoxies. Two basic types of casting are used in the plastics industry—simple casting and plastisol casting, while there are three variations of the latter, namely, dip casting, slush casting, and rotational casting. Reinforced plastics (RPs), in which a resin—thermosetting or thermoplastic—is combined with a reinforcing agent that can be fibrous, powdered, spherical, crystalline, or whisker and made of organic, metallic, or ceramic material, occupy a special place in the industry. A host of molding methods can be used for RPs, such as hand layup or contact molding, spray-up, matched metal molding, vacuum-bag molding, pressure-bag molding, continuous pultrusion, filament winding, pre-preg molding, RIM, structural RIM, and resin transfer molding. All these methods have been given due consideration in Chapter 1. Various types of fibrous reinforcements used for these RPs and their methods of manufacture are also discussed.

Foamed plastics, also referred to as cellular or expanded plastics, are widely used in making insulation frames, core materials for load-bearing structures, packaging materials, and cushioning materials. In view of their importance and wide diversity of forms and applications, a relative large space has been given to discussion of foaming processes, foaming agents, and other materials used in foamed polymers. Different types of cellular polymers, e.g., low-density, high-density, single-component, multicomponent, fiber-reinforced, and syntactic foams, are compared from structural point of view. Details of common industrial foams with focus on manufacturing processes are presented. These include polystyrene foams, polyolefin foams, polyurethane foams, foamed rubbers, foamed epoxies, urea-formaldehyde foams, silicone foams, phenolic foams, PVC foams, and syntactic foams.

The technology used for rubber processing and making rubber goods is quite different from that used for conventional thermoplastic and thermosetting resins. A separate section is therefore provided to present a fairly detailed account of rubber compounding and processing technology as practiced in the industry, including also the use of reclaimed rubber. The manufacturing technology of major rubber products is included.

Besides the main fabrication processes mentioned above, a wide variety of other techniques have been developed to diversify the use of polymers and to find many new uses. The more important of these methods and processes are described in the last part of Chapter 1. These include coating processes (e.g., fluidized bed coating, spray coating, and electrostatic coating), powder molding techniques (e.g., static molding, rotational molding, and centrifugal casting), adhesive bonding of plastics (e.g., solvent cementing, adhesive bonding, and plastics-specific miscellaneous methods), and plastics welding (e.g., hot-gas welding, fusion welding, friction welding, high-frequency welding, and ultrasonic welding).

Commercial techniques for decorating plastics are almost as varied as plastics themselves. Depending on end-use applications or market demands, virtually any desired effect or combination of effects, shading of tone, and degree of brightness can be imparted to flexible or rigid plastic products. The last section of Chapter 1 is dedicated to a discussion of *decoration of plastics*. The main topics chosen for discussion are various painting operations, printing processes (gravure printing, flexography, screen process printing, and pad printing), hot stamping, in-mold decorating, embossing, electroplating, and vacuum metallizing.

Beginning its journey from the womb of a mold or the face of a die, a plastic product, after its useful life, usually finds itself lodged in a landfill or discarded on the wayside. The property of high durability or permanence that is considered a valuable attribute of plastic in its applications becomes a distinct liability when the plastic is discarded. Plastics left lying around after use do not disappear from view and such post-consumer waste as foam cups, detergent bottles, and discarded film is a visual annoyance. All this is because plastics are not naturally biodegradable. However, to consider this as a detriment is a questionable argument. Rather, it may well be considered an advantage. This is borne out by the fact that recycling of plastics materials is now an important field in the plastics industry, not just an activity born under environmental pressure. The second chapter in the book presents an overview of several important aspects of plastics recycling and developments in the field. Some of the topics that are highlighted in this review are then elaborated in the subsequent sections of the chapter. In addition, waste recycling problems and possibilities relating to a number of common plastics are discussed.

This book was originally included in our well-known *Plastics Technology Handbook*. As this book deals only with fabrication processes and recycling methods, it will be found to be informative and useful by those who are more interested in learning about the fabrication processes used for polymers and the various methods presently available for polymer recycling. To a large extent, the book owes its origin to the efforts of Allison Shatkin, who first conceived the idea of bringing out spin-off plastics books for the benefit of different groups of readers and also took the initiative in realizing them. We greatly appreciate her efforts.

Manas Chanda
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Manas Chanda has been a professor and is presently an emeritus professor in the Department of Chemical Engineering, Indian Institute of Science, Bangalore, India. He also worked as a summer-term visiting professor at the University of Waterloo, Ontario, Canada with regular summer visits from 1980 to 2000. A five-time recipient of the International Scientific Exchange Award from the Natural Sciences and Engineering Research Council, Canada, Dr. Chanda is the author or coauthor of nearly 100 scientific papers, articles, and books, including *Introduction to Polymer Science and Chemistry* (CRC Press/Taylor & Francis). A fellow of the Indian National Academy of Engineers and a member of the Indian Plastics Institute, he received a BS (1959) and MSc (1962) from Calcutta University, and a PhD (1966) from the Indian Institute of Science, Bangalore, India.

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Appendices

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Fabrication Processes

1.1 Types of Processes

As indicated in Chapter 1 of *Plastics Fundamentals, Properties, and Testing*, the family of polymers is extraordinarily large and varied. There are, however, some fairly broad and basic approaches that can be followed when designing or fabricating a product out of polymers or, more commonly, polymers compounded with other ingredients. The type of fabrication process to be adopted depends on the properties and characteristics of the polymer and on the shape and form of the final product.

In the broad classification of plastics there are two generally accepted categories: thermoplastic resins and thermosetting resins.

Thermoplastic resins consist of long polymer molecules, each of which may or may not have side chains or groups. The side chains or groups, if present, are not linked to other polymer molecules (i.e., are not cross-linked). Thermoplastic resins, usually obtained as a granular polymer, can therefore be repeatedly melted or solidified by heating or cooling. Heat softens or melts the material so that it can be formed; subsequent cooling then hardens or solidifies the material in the given shape. No chemical change usually takes place during this shaping process.

In thermosetting resins the reactive groups of the molecules from cross-links between the molecules during the fabrication process. The cross-linked or "cured" material cannot be softened by heating. Thermoset materials are usually supplied as a partially polymerized molding compound or as a liquid monomer–polymer mixture. In this uncured condition they can be shaped with or without pressure and polymerized to the cured state with chemicals or heat.

With the progress of technology the demarcation between thermoplastic and thermoset processing has become less distinct. For thermosets processes have been developed which make use of the economic processing characteristics of thermoplastics. For example, cross-linked polyethylene wire coating is made by extruding the thermoplastic polyethylene, which is then cross-linked (either chemically or by irradiation) to form what is actually a thermoset material that cannot be melted again by heating. More recently, modified machinery and molding compositions have become available to provide the economics of thermoplastic processing to thermosetting materials. Injection molding of phenolics and other thermosetting materials are such examples. Nevertheless, it is still a widespread practice in industry to distinguish between thermoplastic and thermosetting resins.

Compression and transfer molding are the most common methods of processing thermosetting plastics. For thermoplastics, the more important processing techniques are extrusion, injection, blow molding, and calendaring; other processes are thermoforming, slush molding, and spinning.

1.2 Tooling for Plastics Processing

Tooling for plastics processing defines the shape of the part. It falls into two major categories, molds and *dies*. A mold is used to form a complete three-dimensional plastic part. The plastics processes that use