PLASTICS TECHNOLOGY HANDBOOK

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SECOND EDITION, REVISED AND EXPANDED

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Preface to the Second Edition

The impetus to produce a second edition of *Plastics Technology Handbook* less than five years after publication of the first edition came from two main sources. One was the encouraging reader response and the other was the need to document recent developments in the field of plastics. This new edition, moreover, provided an opportunity to add several important topics and to revise each chapter, bringing the information up-to-date. In preparing the present edition the structure of the book has not been altered, and the straightforward style of presentation and lucidity of treatment that characterized the earlier edition have also been retained.

The significance of stabilizing agents and other additives in making plastics useful in many applications cannot be overemphasized. Discussion of this subject has therefore been greatly expanded and updated to include recent developments. Because the science and technology of processing elastomeric products differ significantly from those of plastics and fibers, a new, elaborate section has been added to Chapter 2 to deal with the compounding and processing of rubber products. A review of prepregging technology, which has gained much popularity in composite processing, is included in Chapter 2 as well. Recently, much attention has been paid to polymer blending as a simple tool to produce new products with tailored properties. This is done by blending common polymers, hence eliminating the need to add to existing inventories. A discussion of polyblending can be found in Chapter 2.

With plastics now found in every aspect of life and newer innovative plastic products constantly entering the market, a curious user must often wonder what polymer a product is made of. Polymer identification can often be performed using simple tests. This is highlighted in Chapter 3's extensive section on identification of plastics.

Most commercial demand for plastics is met by a small number of large-volume common polymers such as PE, PP, PS, and PVC and a few so-called engineering polymers possessing superior mechanical properties for engineering applications. There are, however, many polymers that have been developed to meet critical needs of specialized applications. Although their tonnage rating is very low, the importance of their use in modern technology cannot be overemphasized. Examples of such special-use polymers include conductive polymers, photoconductive polymers, piezoelectric polymers, photoresist polymers, polymeric ion-exchangers, and polymeric catalysts. Chapter 5 is a comprehensive discussion on polymers in special uses. In addition, Chapter 4 has been augmented with additional information.

With the diverse fields of technology undergoing rapid change both qualitatively and quantitatively, novel applications of both common polymers and specialty polymers are coming to light. New uses of polymers in such diverse areas as automotive, aerospace, packaging, agriculture, horticulture, domestic appliances, office equipment, communication, electronics and electrical applications are reviewed in Chapter 6.

It has been our pleasure since the publication of the first edition to receive from readers appreciative comments as well as suggestions for improvement, most of which have been implemented in this edition. Although it is not possible to thank everyone individually, we record our special gratitude to Professor G. L. Rempel, Chairman of the Department of Chemical Engineering, University of Waterloo, Waterloo, Ontario, Canada for his continuing assistance and support and to Dr. Stephan Jaenicke, Department of Chemistry, National University of Singapore, Singapore, who read the book critically and made extensive comments and suggestions for improvement. Finally, we acknowledge the tolerance shown by our wives, Mridula and Snigdha, and our daughters, Amrita and Rarita, who allowed us, though not ungrudgingly, to engage in this work so soon after the labor of love for the first edition.

Manas Chanda
Salil K. Roy

Preface to the First Edition

The title of the book requires that a definition of plastics be given, although it is very difficult and probably of little value to try to produce an accurate definition of the word *plastics*. Plastics are defined in the *Modern Plastics Encyclopedia* (1962) as a "large and varied group of materials which consist of or contain as an essential ingredient, a substance of high molecular weight which while solid in the unfinished state, at some stage in its manufacture is soft enough to be formed into various shapes, usually through the application, either singly *or* together, of heat and pressure." A more concise definition but one which requires clarification is "plastics materials are processable compositions based on macromolecules." With ever widening application of polymeric materials, the term *plastics*, however, has gained usage much beyond the original concept which classifies polymers into elastomers, plastics, and fibers, with plastics being less amorphous than the former and less crystalline and oriented than the latter. In view of this it is perhaps more appropriate to define plastics simply as "those materials which are considered to be plastics materials by common acceptance."

Plastics thus include by common usage all of the many thousands of grades of commercial materials, ranging in application from squeeze bottles, bread wrappers, baby pants, shoes, fabrics, paints, adhesives, rubbers, wire insulators, foams, greases, oils, and films to automobile and aircraft components, and missile and spacecraft bodies. In most cases (certainly with all synthetic materials) the macromolecules used in them are polymers, which are large molecules made by the joining together of many smaller ones.

Chapter 1 of this book provides a brief account of the molecular make-up and structural characteristics of these macromolecules and a short summary of the general methods of their preparation. It continues by showing how polymer properties are related to chemical structure and physical states of aggregation. A knowledge of this structure-property relation is essential for a fuller appreciation of the application potential of different polymers. This also leads to realization that the scope of application of polymers can be greatly extended since polymers can be modified and structural changes can be effected in a variety of ways, which is responsible, in a large measure, for the versatility and popularity of plastics.

Polymers are converted to a myriad of useful objects. Molding is one of the critical steps in this process. Molding processes vary depending on the type of plastics to be processed and also on the end products to be made. An outline of the more important of these molding processes is presented in Chapter 2.

Plastics materials differ very greatly from metals in respect of mechanical and other properties. These differences can be attributed to the molecular structural characteristics of the polymer base materials forming the plastics. The characteristic properties of plastics materials are responsible for their applications in many areas in preference to metals. Moreover, their unique properties make them the indispensable choice in many instances. The characteristic properties of polymeric materials are highlighted in Chapter 3, with broad classification into mechanical, electrical, optical, and thermal properties.

Polymers are ubiquitous, as they are used in a variety of forms including molded products such as radio cabinets, telephone sets, and thousands of other objects, wrapping, fibers, coatings, adhesives, and paints, and as components of composites. Instead of trying to know the different polymers used in this endless number of plastics products it is far easier to be acquainted with the various polymers and their characteristic features and properties so that their application areas can be self-evident. With this in view a large number of polymers have been reviewed in Chapter 4, highlighting their chemical nature, characteristic properties, and uses. The discussions in this chapter include industrial polymers of thermoplastic and thermosetting types, which are produced in substantial volumes and are more commonplace, as well as special polymers which can be described as tailor made macromolecules with specific properties to satisfy critical needs in more sophisticated areas of application.

While SI units are being increasingly used in all branches of engineering, other systems of units, that is, the cgs system and the British (or fps) system, are still in common use. This is particularly true of plastics. In the present book, cgs and fps units have therefore been used, and in most places equivalent values are given in SI units. A suitable conversion table is also provided as an appendix.

This should assist the reader in gradual transition from the present use of mixed units to full use of SI units.

In writing a book of this kind, one accumulates indebtedness to a wide range of people, not the least to the authors of earlier publications in the field. Our faculty colleagues, innumerable students, and academic associates in other universities and colleges have provided much welcome stimulation and direct help. We are much indebted to all of them. We also acknowledge with gratitude the painstaking work of Mr. S. Sundaresh in typing the manuscript and the enthusiastic help of Mr. M. J. Venugopal in preparing the large body of artwork which conveys much of the message of the book. We would not be doing justice in thanking our wives, Mridula and Snigdha, and our daughters, Amrita and Rarita, in the limited space available. We are grateful for their forbearance and sacrifice.

Manas Chanda
Salil K. Roy

Contents

1

Characteristics of Polymers

WHAT IS A POLYMER?

A molecule has a group of atoms which have strong bonds among themselves but relatively weak bonds to adjacent molecules. Examples of small molecules are water (H_2O), methanol (CH_3OH), carbon dioxide, and so on. *Polymers* contain thousands to millions of atoms in a molecule which is large; they are also called *macromolecules*. Polymers are prepared by joining a large number of small molecules called *monomers*. Polymers can be thought of as big buildings, and monomers as the bricks that go into them.

Monomers are generally simple organic molecules containing a double bond or a minimum of two active functional groups. The presence of the double bond or active functional groups act as the driving force to add one monomer molecule upon the other repeatedly to make a polymer molecule. This process of transformation of monomer molecules to a polymer molecule is known as *polymerization*. For example, ethylene, the prototype monomer molecule, is very reactive because it has a double bond. Under the influence of heat, light, or chemical agents this bond becomes so activated that a chain reaction of self addition of ethylene molecules is generated, resulting in the production of a high molecular weight material, almost identical in chemical composition to ethylene, known as *polyethylene*, the polymer of ethylene (Fig. 1.1).

The difference in behavior between ordinary organic compounds and polymeric materials is due mainly to the large size and shape of polymer molecules.

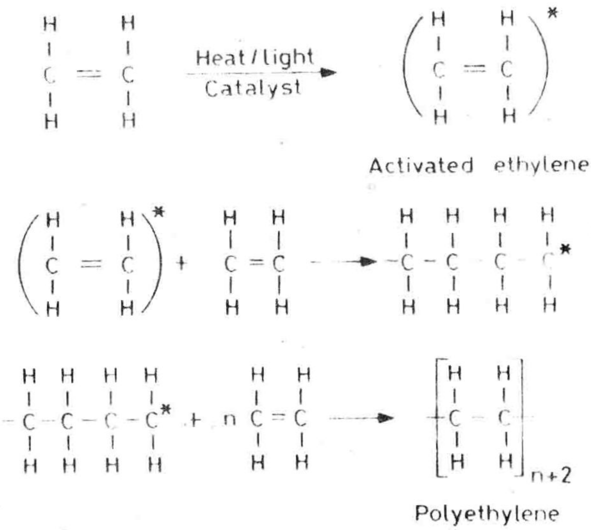

FIG. 1.1 Intermediate steps during formation of polyethylene.

Common organic materials such as alcohol, ether, chloroform, sugar, and so on, consist of small molecules having molecular weights usually less than 1000. The molecular weights of polymers, on the other hand, vary from 20,000 to hundreds of thousands.

The name *polymer* is derived from the Greek *poly* for many and *meros* for parts. A polymer molecule consists of a repetition of the unit called a *mer*. Mers are derived from *monomers*, which, as we have seen for ethylene, can link up or *polymerize* under certain conditions to form the polymer molecule. The number of mers, or more precisely the number of repetitions of the mer, in a polymer chain is called the *degree of polymerization* (DP). Since the minimum length or size of the molecule is not specified, a relatively small molecule composed of only, say, 3 mers might also be called a polymer. However, the term polymer is generally accepted to imply a molecule of large size (macromolecule). Accordingly, the lower molecular-weight products with low DP should preferably be called *oligomers* (*oligo* = few) to distinguish them from polymers. Often the term *high polymer* is also used to emphasize that the polymer under consideration is of very high molecular weight.

Because of their large molecular size, polymers possess unique chemical and physical properties. These properties begin to appear when the polymer chain is of sufficient length—i.e., when the molecular weight exceeds a *threshold value*—and becomes more prominent as the size of the molecule increases. The dependence of the softening temperature of polyethylene on the degree of polymerization is shown in Figure 1.2a. The dimer of ethylene is