

Two-Phase Polymer Systems

L. A. Utracki (Editor)

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FOREWORD

The term "polymer processing" encompasses the whole spectrum of polymer science and engineering domains, from polymerization, compounding, forming, decorating, and assembling to properties. The polymers in question can be either natural or man-made, elastomeric, thermoset or thermoplastic. Formation method may be by extrusion (including profiles, films or fibers), molding in solid or molten state, casting, etc.

In polymer processing there is an uneasy balance between the technology and science. Most frequently the technology has led the way in opening new areas, such as in development of rubbers or thermosets, in extrusion or molding. In this case the science followed, providing understanding and tools for optimization. However, in the area of thermoplastics frequently the reverse was true; here the scientific curiosity and directed research led to synthesis of these market dominating polymers. Nowadays development of new materials or products first and foremost requires solid understanding of basic principles, followed by good engineering design of the forming process and sound knowledge of the market. The successful polymer process researcher or engineer must have a broad knowledge of fundamental principles and engineering solutions.

There are several polymer engineering societies, based on the national membership, promoting interests of the industry and disseminating pertinent technological information. There are also chemical and physical societies with polymer divisions taking a more basic approach to polymer science. However, searching for information to solve a specific polymer processing problem still leads to difficulties. There are hundreds of thousands of articles published annually. They provide a fragmented body of information requiring, to start with, either familiarity within the narrow domain or an encyclopedic knowledge of the field. On the other hand, with the exponential expansion of information the preparation of monographic single-authored books is a tedious and frustrating task, particularly when trying to catch up with recent and most pertinent developments.

There is also another element - the globalization of science and technology. As the development of polymer blend technology demonstrates, the center of activity within a domain may rapidly shift from one country to another, from one continent to the next. The recognition of these globalization tendencies led to the formation in 1985 of the Polymer Processing Society, PPS, the first fully international professional organization dedicated to the promotion, growth and development of scientific understanding, and innovation in polymer processing. It provides a forum for the world-wide community of engineers and scientists and publishes the Society journal, *International Polymer Processing*, as well as the book series, *Progress in Polymer Processing*.

Progress in Polymer Processing was initiated by PPS in 1986 and formally established in 1988. Its aim is to provide complete, in-depth, up to date information on various aspects of polymer science and engineering. The Series Editor, with the internationally based Advisory Board, is responsible for selecting the volume topics and Volume Editor(s), as well as for general supervision of content, quality, and form of the publication.

The series aims to provide multi authored monographic books on the subject of current interest to the international polymer processing community. Depending on the breadth of the selected topic, the volume may have the character of either an exhaustive monograph, providing an actual, complete picture of the selected field, or of an in-depth progress report of its dominant aspects. As time progresses we hope to shift more and more toward the former character. Using the multi authored format we expect on the one hand to provide a more complete picture of the

selected topic viewed from different perspectives, and on the other to shorten the production time, keeping the published information up to date. We expect to produce two to three volumes a year. Current list of titles has a dozen positions.

To accomplish these goals, we shall need the help and cooperation of the international community, as well as serious effort by everyone involved in the process, the authors, editors, members of the Advisory Board, and the publisher. It is hoped that in time we will become more accustomed to our tasks and hence more efficient, always guided by the needs of our colleagues within the polymer processing community.

L.A. Utracki
Series Editor

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PREFACE

This second volume in the *Progress in Polymer Processing* series took nearly three years to prepare. During this period, the publication procedure of the series was established, necessitating some modification of the texts. However, the long preparation time was caused primarily by expansion of the chapters in terms of depth of subject treatment and length.

There is no need to stress the importance of two-phase polymeric systems both to science and technology. Mixtures of polymer melts with gas (*foams*), with another molten polymer (*alloys* and *blends*) and with solid particles (*filled systems* and *composites*) constitute the majority of modern polymeric materials. This volume aims to stress the common denominators of these materials, methods of combining the ingredients (mixing or compounding), the need for care in structure development during processing as well as the effects of the two-phase nature on properties of finished products. Note that such a volume program resulted in the elimination of an important subclass of two-phase systems, the coprocessed materials, but it still left such a vast area of science and technology to be covered as to make a complete presentation of the topic impossible. For this reason, from the point of view of *Progress in Polymer Processing* goals this volume lies somewhere between the "progress on" and a monographic book.

The fourteen chapters were written by prominent, competent and internationally known experts in the field. With the Editor's intervention limited to rules on the mechanics of text preparation and a general outline of topics, the chapter development was left to each author's good judgment. An attempt has been made to preserve uniform nomenclature in the volume. However, in order to avoid any possibility of confusion, a list of symbols and abbreviations is provided after each chapter. The common subject index illustrates the generality of behavior of the two-phase systems.

The volume begins with an overview "On Processing Two-Phase Polymer Systems." This chapter attempts to provide a general outlook on the problems associated with mixing, extruding, and molding two-phase systems, as well as information on the most recent developments in the field. Chapter 2 by *Hold* and Chapter 3 by *Todd* deal with complementing aspects of mixing - a general introduction is provided by the first author followed by a treatise on the use of the ever popular twin-screw extruder prepared by the second.

The next two chapters, Chapter 4 by *Hornsby* and Chapter 5 by *Kim* and *Kim*, discuss processing and properties of rigid, structural polymeric foams. *Hornsby* provides a general overview on processing and properties of thermosets and thermoplastics based systems with and without reinforcement, while *Kim* and *Kim* concentrate on the flow behavior of polyvinylchloride during the chemical foaming process.

Chapters 6 to 10 deal with polymer blend science and technology. In Chapter 6, *Elmendorp* and *van der Vegt* discuss the fundamental aspects of microrheology during flow and processing. Since control of the blend structure is essential for optimization of performance, the chapter's importance exceeds the goals modestly stated by the authors. In Chapter 7, *Dumoulin* et al. review the flow behavior of polymer blends with special emphasis on the polyethylene/polypropylene two-phase mixtures. The crystallization of polymer blends is comprehensively examined in Chapter 8 by *Nadkarni* and *Jog*. The authors stress the diversity of effects observed upon blending as well as the importance of crystalline morphology on properties of finished products. A new use of blend technology for controlling birefringence in injection molded optical disks is discussed in Chapter 9 by *Kijima* et al. In Chapter 10, *Kyu* et al. provide an important insight into the blend fracture. The authors observed that two-phase morphology (generated via controlled spinodal decomposition) leads to enhancement of mechanical properties when compared to that of single-phase specimens having identical composition.

The remaining Chapters 11 to 14 concentrate on processing and process-related behavior of reinforced polymer composites. *Vincent and Agassant* in Chapter 11 discuss principles of flow orientation in the fiber-filled composites. The authors developed a predictive model and evaluated its validity by comparing it with experimental data on injection molded simple geometry specimens. The work by *Mutel and Kamai* on rheology of fiber-reinforced polymer melts is presented in Chapter 12. It complements the preceding chapter well. The authors provide insight into the orientational effect on flow behavior especially within the transient zone. It is well-known that properties of the fiber-filled systems greatly depend on the fiber length-to-diameter (aspect) ratio. Chapter 13, by *Hiscock and Bigg*, discusses new technology for manufacturing the long fiber composites in which the large aspect ratio is retained. Finally, in Chapter 14, *Xavier* reviews the crystallization phenomenon in polymer composites with particular attention to transcrystallinity and modification of performance it introduces.

Although the volume provides but a glimpse of the vast domain of two-phase polymeric materials, the selected topics illustrate their importance and congruency. The mixture of academic and technological approaches stems from our basic philosophy that progress in polymer processing depends on the integration of both. As Editor, I wish to thank all the authors for the efforts and cooperation.

L. A. Utracki
Montreal, 1990

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