Polymer Blends

Volume 1: Formulation

Edited by

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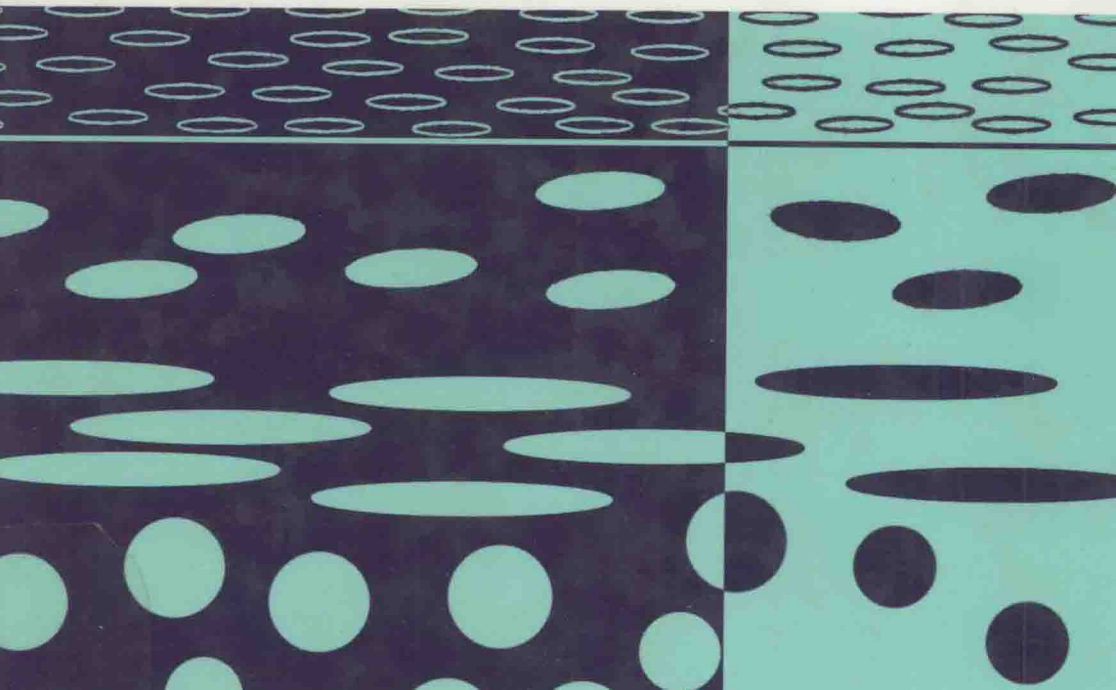
C. B. Bucknall



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A WILEY-INTERSCIENCE PUBLICATION

JOHN WILEY & SONS, INC.

New York / Chichester / Weinheim / Brisbane / Singapore / Toronto

This book is printed on acid-free paper. ♾

Published simultaneously in Canada.

Library of Congress Cataloging-in-Publication Data:

Polymer blends / D. R. Paul and C. B. Bucknall, editors.
p. cm.
Includes index.
Contents: 1. Formulation –
ISBN 0-471-24825-8 (set : alk. paper). — ISBN 0-471-35279-9 (v. 1). – ISBN 0-471-35280-2 (v. 2)
1. Polymers. 2. Plastics. I. Paul, Donald R. II. Bucknall, C. B.

TP1087.P64 1999 99–36533
668.9–dc21 CIP

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

POLYMER BLENDS: FORMULATION

Preface

The field of polymer blends, or alloys, has experienced enormous growth in size and sophistication over the past two decades in terms of both the scientific base and technological and commercial development. It has become clear to us that an appropriate summary of this progress is needed to educate and to guide professionals working in this area into the twenty-first century. This two-volume set is a multiauthored treatise that might be viewed as an updated version of the analogous set edited by Paul and Newman and published in 1978. (See the reading list at the end of Chapter 1.) The book is intended to be a coherent entity rather than a collection of separate chapters, and a great deal of effort has been devoted to coordinating the content and style of the chapters. The editors intended each chapter to be far more than an encyclopedic summary of the literature or a review focusing only on the most recent advances in research. The authors were asked (a) to provide enough background in each chapter to enable beginners to work in the field by reading this book; (b) to sift critically through the literature and present only the most important issues (not every reference deserves mention); and (c) to write clearly but concisely, using carefully selected graphics, in order to make the important conceptual points and capture the attention of the browser.

It is the goal of these two volumes to be the authoritative source that professionals of the next decades will seek out to learn about this important field and use to set directions for future research and product development. The two volumes are roughly equal in length. Volume 1 is subtitled *Formulation* and is largely about the physics, chemistry, and processing issues associated with the formation of polymer blends and the evaluation and control of their structure. Volume 2 is subtitled *Performance* and is primarily concerned with how blends perform in practical situations. Naturally, there is a heavy emphasis on mechanical performance, but several chapters deal with a range of other properties as well. At some risk of oversimplification, it can be said that Volume 1 is about *structure*, while Volume 2 is about *properties*. Thus, the two-volume set provides a broad view of the *structure–property* relationships for polymer blends as seen by experts from around the world.

The editors have been friends and colleagues for many years. Their professional interests have been somewhat different over their careers, but there are many points of intersection. These differences and similarities have been helpful during the course of planning, which started in early 1994, and development of this book. A common view was needed in order to foster agreement on the scope, content, and choice of

authors. The differences in expertise led Don Paul to have primary responsibility for Volume 1 and Clive Bucknall to oversee Volume 2.

We are thankful to many colleagues and friends who have encouraged us and given us advice on many issues.

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1 Introduction

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I. PERSPECTIVE

There are many possible ways in which a book on polymer blends, or alloys, could be organized. For example, one might devote a chapter to each of the important blends (e.g., poly(2,6-dimethyl-1,4-phenylene oxide)/polystyrene, polycarbon-

Polymer Blends Volume 1: Formulation. Edited by D. R. Paul and C. B. Bucknall.
ISBN 0-471-35279-9.

ate/ABS, etc.) and discuss all fundamental issues of their formation, characterization, properties, and end uses. However, there is a great risk of duplication of content or omission of important concepts in this approach, and the chapters might become out of date rather quickly in some cases. An organization based on concepts and principles seems to provide a more thorough and enduring result, and that is the approach adopted here.

The paradigm that led to the organization and the subtitles of each of these two volumes is illustrated in Fig. 1.1. This flow diagram indicates the considerations that are typically involved in the development of a multiphase blend, particularly ones for which mechanical behavior of the product is of critical importance. The left side emphasizes the formulation of the blend, while the right side deals with the performance of the blend. Usually, the development of such a product is an iterative process in which one selects the components and a process, evaluates the performance, and then repeats the cycle until the performance matches the need. To understand the relationship between performance and formulation, the researcher usually evaluates the structure of the blend (its morphology) and perhaps assesses the adhesion between phases. These attributes are affected by the processing, thermodynamic interactions between the components, and any chemical reactions (interchange, grafting, etc.) that may occur inadvertently or by design. Obviously, the intrinsic properties of the components selected (e.g., rheological, chemical, mechanical, etc.) will have a significant influence on the properties of the resulting blend, or alloy. The mechanical behavior of the product (e.g., stiffness, toughness, etc.) may be related to the structure of

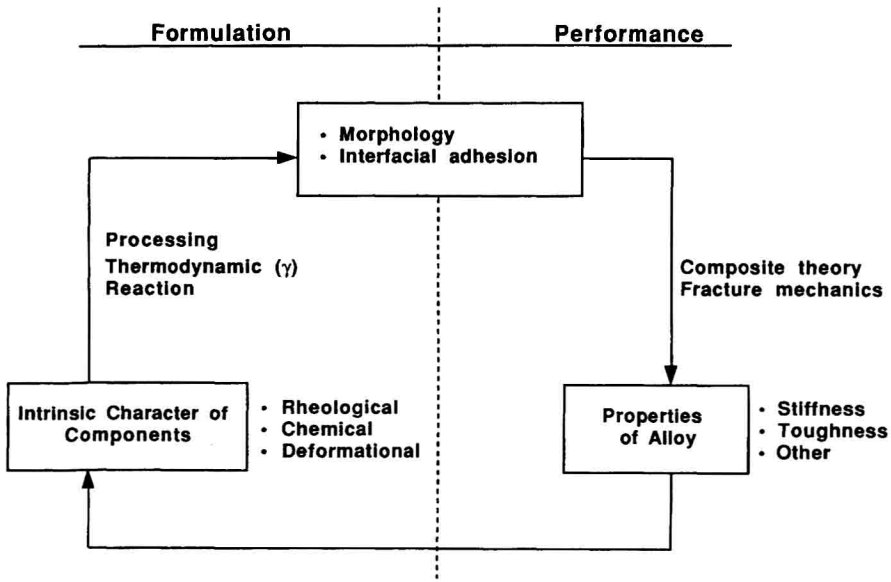

Figure 1.1 Schematic illustration of the cycle of the formulation and evaluation of performance involved in developing polymer blends, or alloys.

blend and the properties of the components via the concepts of composite theory or the techniques of fracture mechanics. A host of other attributes of the product might need to be considered as well.

The next two sections provide a brief review of the content of this two-volume set and an explanation of the organization of the chapters into various sections. Volume I deals primarily with *formulation* of blends, while Volume II deals primarily with their *performance*; however, to some degree, the two subjects are commingled throughout both volumes, since no absolutely clear division can be made along these lines, as the previous discussion suggests.

II. FORMULATION

The chapters of Volume I are organized into the following three sections:

A. Thermodynamics

Thermodynamics determines the equilibrium states that can be achieved for any given set of conditions when two polymers A and B are mixed together—i.e., the phase diagram and the nature of the interface when separate phases are formed. Because of the fundamental importance of thermodynamics in formulating polymer blends and the special issues that arise from the high molecular weight of the polymeric components, seven chapters are devoted to this topic.

Chapter 2 gives a very thorough and detailed review of the considerable advances in statistical thermodynamic theory and the simulations of polymer solutions and blends that have been made in recent years. An important feature of this chapter is an analysis of why the Flory–Huggins theory has endured so long as a basis for describing polymer solutions and blends, in spite of the availability of far more sophisticated theories. Application of the Flory–Huggins theory more than 50 years ago, along with some experimental evidence, led early researchers to conclude for polymer blends that immiscibility is the rule and miscibility is the exception. This rule of thumb is still essentially valid; however, over the past two decades, very many polymer pairs have been shown to be miscible, as a result of a better understanding of polymer–polymer interactions. In fact, the number of miscible pairs is so large that no attempt is made here to catalog them. Rather, the principles that have resulted from and/or made possible the discovery of so many miscible pairs are described in the next two chapters.

Chapter 3 summarizes a mean field analysis of polymer–polymer interactions using the simple ideas of a binary interaction model that has been used extensively with considerable success since the early 1980s for analyzing and predicting the phase behavior of blends based on copolymers. This chapter stresses the evaluation of interaction energies between important monomer unit pairs (in which the interactions are not very specific) in order to make predictions about phase behavior and the nature of the interface between polymer pairs that form separate phases. Chapter 4 describes the development of a different approach that has proved useful for under-