Raju S. Davé / Alfred C. Loos

Processing of Composites

Polymer Processing Society

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Processing of Composites

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Hanser Publishers, Munich

Hanser/Gardner Publications, Inc., Cincinnati

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Distributed in the USA and in Canada by
Hanser/Gardner Publications, Inc.
6915 Valley Avenue, Cincinnati, Ohio 45244-3029, USA
Fax: (513) 527-8950
Phone: (513) 527-8977 or 1-800-950-8977
Internet: http://www.hansergardner.com

Distributed in all other countries by
Carl Hanser Verlag
Postfach 86 04 20, 81631 München, Germany
Fax: +49 (89) 98 12 64

Library of Congress Cataloging-in-Publication Data
Processing of composites / Raju S. Davé, Alfred C. Loos, editors :
with contributions from F. Abrams . . . [et al.].
p. cm. – (Progress in polymer processing)
Includes bibliographical references and index.
ISBN 1-56990-226-7 (hc.)
1. Plastics. 2. Polymeric composites. I. Davé, Raju S.
II. Loos, Alfred C. III. Series.
TP1120.P76 1999
668.4—dc21 99-27337

Die Deutsche Bibliothek – CIP-Einheitsaufnahme
Processing of composites / Raju S. Davé/Alfred C. Loos (ed.). With
contributions from F. Abrams . . . – Munich : Hanser ; Cincinnati :
Hanser/Gardner, 1999
(Progress in polymer processing)
ISBN 3–446-18044-3

Typeset in England by Techset Composition Ltd., Salisbury
Printed and bound in Germany by Kösel, Kempten

PROGRESS IN POLYMER PROCESSING SERIES

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Foreword

Since World War II, the industry based on polymeric materials has developed rapidly and spread widely. The polymerization of new polymeric species advanced rapidly during the 1960s and 1970s, providing a wide range of properties. A plethora of specialty polymers have followed as well, many with particularly unique characteristics. This evolution has been invigorated by the implementation of metallocene catalyst technology. The end use of these materials has depended on the development of new techniques and methods for forming, depositing, and locating these materials in advantageous ways, which are usually quite different from those used by the metal or glass fabricating industries. The importance of this activity, "polymer processing," is frequently underestimated when reflecting on the growth and success of the industry.

Polymer processes, such as extrusion, injection molding, thermoforming, and casting provide parts and products with specific shapes and sizes. Furthermore, they must control, beneficially, many of the unusual and complex properties of these unique materials. Because polymers have high molecular weights and, in may cases, tend to crystallize, polymer processes are called to control the nature and extent of orientation and crystallization, which, in turn, have a substantial influence on the final performance of the products made. In some cases, these processes involve synthesizing polymers during the polymer processing operation, such as continuous fiber composites processing, which is the topic of this book. Autoclave processing, pultrusion, and filament winding each synthesize the polymer and form a finished part in one step or a sequence of steps, evidence of the increasing complexity of the industry. For these reasons, successful polymer process researchers and engineers must have a broad knowledge of fundamental principles and engineering solutions.

Some polymer processes have flourished in large indutrial units, such as synthetic fiber spinning. However the bulk of the processes are rooted in small- and medium-sized entrepreneurial enterprises in both developed and new developing countries. Their energy and ingenuity have sustained growth to this point, but clearly the future will belong to those who progressively adapt new scientific knowledge and engineering principles to the industry. Mathematical modeling, online process control and product monitoring, and characterization based on the latest scientific techniques will be important tools in keeping these organizations competitive in the future

The Polymer Processing Society was started in Akron, Ohio, in 1985 with the aim of focusing on an international scale on the development, discussion, and dissemination of new and improved polymer processing technology. The society facilitates this by sponsoring several conferences annually and by publishing the journal, *International Polymer Processing*, and this book series, *Progress in Polymer Processing*. This series of texts is dedicated to the goal of bringing together the expertise of accomplished academic and industrial professionals. The volumes have a multiauthored format, which provides a broad picture of the volume topic viewed from the perspective of contributors from around the world. To accomplish these goals, we need the thoughtful insight and effort of our authors and book editors, the critical overview of our Editorial Board, and the efficient production of our publisher.

The book deals with the underlying process fundamentals and manufacturing processes for preparing polymer composites reinforced with continuous fibers. These processes have developed into what is arguably the single largest producer of complex engineered parts, finding significant application in the aerospace industry, for example. The resulting products represent the most significant incursion by polymeric materials into those areas, where high performance traditional materials, such as metals and ceramics, have been used. These achievements are dependent on the complex interplay of chemical kinetics, rheology, and morphology development in a multiphase environment, which leads to the required anisotropic properties. Quite new continuous fiber composite processes have been developed during the last decade, and the complexity and fundamental steps involved signal further imaginative developments in the future. This book includes numerous contributions, industrial and institutional, from America as well as Europe and Asia and, as such, forms a valuable contribution to the field.

Brampton, Ontario, Canada

Warren E. Baker
Series Editor

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Part I Theory

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Preface

Composite materials have been acclaimed as the "Materials of the Future." A key question is whether composite materials will always remain the materials of the future or if the future is here. Advanced polymer composites, once destined for stealth military aircraft or aerospace uses, are beginning to be used in down-to-earth structures, such as bridges, buildings, and highways. However, there are still considerable impediments to wider use, and composite manufacturers need to make great strides in the development and manufacturing of composite materials.

What makes the fabrication of composite materials so complex is that it involves simultaneous heat, mass, and momentum transfer, along with chemical reactions in a multiphase system with time-dependent material properties and boundary conditions. Composite manufacturing requires knowledge of chemistry, polymer and material science, rheology, kinetics, transport phenomena, mechanics, and control systems. Therefore, at first, composite manufacturing was somewhat of a mystery because very diverse knowledge was required of its practitioners. We now better understand the different fundamental aspects of composite processing so that this book could be written with contributions from many composite practitioners.

This book provides a quick overview of the fundamental principles underlying composite processing and summarizes a few important processes for composite manufacturing. This book is intended for those who want to understand the fundamentals of composite processing. In particular, this book would be especially valuable for students as a graduate level textbook and practitioners who struggle to optimize these processes.

We thank all the chapter authors for their heroic efforts in writting their chapters. Without their contributions this book would be incomplete. In addition, we thank Lloyd Goettler of Monsanto, who is past president of the Polymer Processing Society, for suggesting that we edit this book. Other friends and mentors who had a major influence on our work include Robert L. Kruse, Kishore Udipi, and Allen Padwa, all of Monsanto, and Professor John L. Kardos of Washington University. Professor Warren Baker, Series Editor, has been very helpful in overseeing this project.

Certainly, we may have overlooked others who have helped us on our way to completing this book over a period of four years. Our sincere apologies to them, and we hope they will reflect on their positive contributions when they read this book. Last, but not least, we thank our families who endured through this process. Criticism and comments from readers are most welcome.

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