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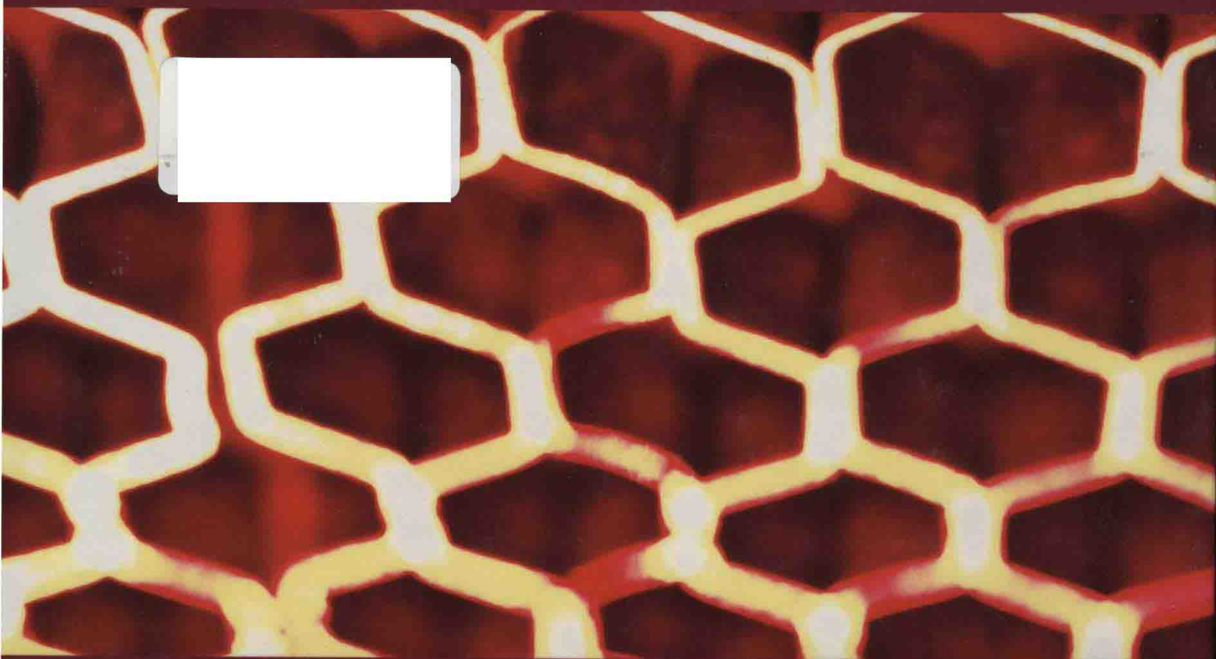

Heat Transfer in Polymer Composite Materials

Forming Processes

Edited by
Nicolas Boyard

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Heat Transfer in Polymer Composite Materials

Preface

This book is a recapitulation of the CNRS Summer School organized in June 2013 dedicated to heat transfer in organic matrix composite materials and their forming processes. The industry of composites has grown steadily in recent years due to the numerous advantages of these materials, such as their lightness and interesting mechanical properties, compared to aluminum and other metal-based alloys. To remain competitive, especially in a very strong international economic context, the quality of the produced parts must be fully controlled. This control requires an accurate knowledge of physical phenomena occurring during the various steps of their manufacturing process and in a context where the strong activity and the needs led to the emergence of new processes and increasingly fast production rates. The forming of composite materials has thus become a major topic of research in terms of experimentation, modeling and simulation, where several scientific disciplines must come together in order to achieve the control of manufactured parts and properties. We can notice that heat transfer is one of the main levers to control the forming processes and induced properties of the composite part. They have to be carefully analyzed during the manufacturing of these materials that also require a multidisciplinary approach. Thus, thermal sciences have to be coupled to other scientific fields such as mechanics and physical chemistry.

The first goal of this summer school was to bring together academic and industrial researchers from different disciplines within thermal sciences with transverse themes common to their activities. A second aim was also to provide the basis on heat transfer during polymer and composite processing as well as the latest methods and techniques from experimental, numerical and modeling points of view, useful to help in the solving of many issues. Therefore, the book takes this and gives theoretical and practical information to understand, measure and describe, in a relevant way, heat transfer during forming processes (in the tool as well as in the composite part) and introducing the required couplings. For this purpose, we relied on the experience of recognized French researchers.

This book is written in a comprehensive way for an audience that is already aware of the world of composites and associated processes: graduate students, researchers and people involved in R&D activities in industrial sectors. Our aim is to provide a tool, useful for the readers to start a study on composite processing where heat transfers are involved. Each chapter describes the concepts, techniques and/or models related to the developed topic and several examples are given for illustration purposes. A list of selected references is also given at the end of each chapter for a deeper complement of its content, which is necessary for more complex analyses and developments. Unfortunately, all topics and issues related to heat transfer in composite parts and processes cannot be addressed in a single book and a selection was made to cover a broad range of subjects and associated issues.

The introductive chapter presents heat transfer analyses and issues in polymer and composite processing through illustrative examples mostly from injection molding. Preconceived ideas, difficulties and simplified approaches are well highlighted. One key to success in heat transfer modeling is the accurate knowledge of thermophysical properties, phase change kinetics and their associated models for both thermosets and thermoplastics. Conventional as well as new methods to experimentally determine these properties and reaction rate parameters as a function of temperature are detailed in Chapters 2 and 3. Scientific and technical issues are also included. A comprehensive review of the effects of thermoplastics process conditions (shear and/or elongation induced by the flow) and the addition of other components (nucleating agents, fibers, etc.) on the transformation kinetics of the polymers, their rheological behaviors and final microstructures is detailed.

From all these data, the simulation of residual stresses developed during the matrix transformation and the cooling is discussed. For this purpose, thermokinetic and mechanical couplings are introduced and the prediction of cure-dependent mechanical properties is presented. In Chapter 6, modeling of heat transfer in multi-scale porous media, which can be encountered during the filling step of Resin Transfer Molding (RTM) mold, is discussed following a homogenization approach. The relationship between the physics at local-scale and the macroscale description is explained, also including the determination of effective properties.

The improvement of the quality of parts can be achieved by optimizing process parameters. Among them, the thermal control of the part is of strong importance and depends on the thermal control of the mold. Thus, optimization approach has to consider heat transfer in the tool and couplings to include contact conditions and transformation kinetics. Context, definition and methods of optimization are covered in this book and are illustrated with two detailed examples. Process modeling is introduced in Chapters 8 and 9. First, we discuss the peculiar case of thermoplastic welding, where no adding materials is required for assembling. The importance of intimate contact and macromolecular diffusion is emphasized from theoretical and practical points of view, including the strong temperature dependence. A simulation of forming processes is also addressed in a more general way. Several examples are proposed to present multiscale, multiphysics and multidomain modeling, which are representative of the complexity of forming processes.

Another important part in heat transfer analysis concerns the instrumentation for the thermal characterization and the control of manufacturing processes. From these data, it is possible to obtain information about the process, thermophysical properties and/or the matrix transformation (for example, using inverse method algorithms). An overview of the existing instrumentation (contact and contactless methods) is given in this book. A specific chapter has been specifically dedicated to heat flux sensors, since they provide relevant information to quantify heat transfer between the part and the tool. It is thus an important complement to temperature measurement. Available heat flux sensor technologies and their main characteristics are also mentioned and are completed with practical examples.

Toward the final part of this book, radiative heat transfer in polymer and composite forming are detailed. The processes using infrared heating are in development and the complexity of heat transfer analysis leads to several scientific issues. After a presentation of the basics to define thermal radiative properties, measurements are presented for classical semi-crystalline polymers and associated composites. Finally, after a description of infrared emitters and the temperature measurement using infrared camera, modeling of radiative heat transfer is introduced and polymer processing applications are included.

I would like to thank all my French colleagues who have done me the honor of participating to the CNRS Summer School in 2013 and then of accepting to contribute to this book project with their high-quality work. Special recognition goes to Didier Delaunay, CNRS senior researcher, for his scientific involvement and significant contribution to research in heat transfer in composites and forming processes. I hope that all readers, working in the broad field of polymer and composite processing, may find this book an interesting and valuable resource.

Nicolas BOYARD
January 2016

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