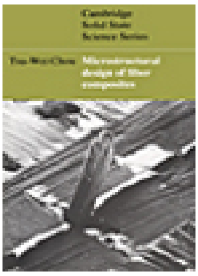

Microstructural Design of Fiber Composites

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Book DOI: http://dx.doi.org/10.1017/CBO9780511600272

Online ISBN: 9780511600272

Hardback ISBN: 9780521354820

Paperback ISBN: 9780521019651

Chapter

Preface pp. xvii-xx

Chapter DOI: http://dx.doi.org/10.1017/CBO9780511600272.001

Cambridge University Press

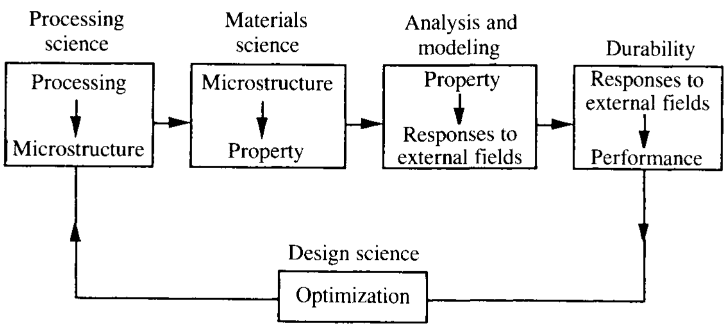
Preface

The science and technology of composite materials are based on a design concept which is fundamentally different from that of conventional structural materials. Metallic alloys, for instance, generally exhibit a uniform field of material properties; hence, they can be treated as homogeneous and isotropic. Fiber composites, on the other hand, show a high degree of spacial variation in their microstructures, resulting in non-uniform and anisotropic properties. Furthermore, metallic materials can be shaped into desired geometries through secondary work (e.g. rolling, extrusion, etc.); the macroscopic configuration and the microscopic structure of a metallic component are related through the processing route it undergoes. With fiber composites, the co-relationship between microstructure and macroscopic configuration and their dependence on processing technique are even stronger. As a result, composites technology offers tremendous potential to design materials for specific end uses at various levels of scale.

First, at the microscopic level, the internal structure of a component can be controlled through processing. A classical example is the molding of short-fiber composites, where fiber orientation, fiber length and fiber distribution may be controlled to yield the desired local properties. Other examples can be found in the filament winding of continuous fibers, hybridization of fibers, and textile structural forms based upon weaving, braiding, knitting, etc. In all these cases, the desired local stiffness, strength, toughness and other prespecified properties may be achieved by controlling the fiber type, orientation, and volume fraction throughout the structural component.

Second, the external geometrical shape of a structural component can also be designed. Advances in the technology of filament winding enable the automated production of components with complex contours. It is now also feasible to fabricate three-dimensional fiber preforms using advanced textile technology. As the ability to fabricate larger and more integrated structural components of net shape is further enhanced, the need to handle and join a large number of small parts, as is currently done with metallic materials, diminishes.

The integrated and system approach, ranging from microstructure to component net shape, offers almost unlimited opportunity in composites processing and manufacturing. The figure below depicts the interdependence of processing, microstructure, properties, responses to external fields (physical, chemical and mechanical), and performance of composites.



The purpose of this book is to address the issue of designing the microstructure of composites for optimum performance. This is achieved through the selection of fiber and matrix materials as well as the placement of both continuous and discontinuous fibers in matrix materials. Continuous fibers can assume straight or wavy shapes; they can also be hybridized or woven into textile preforms. The wide range of microstructures available offers tremendous versatility in the performance of composites; the ability to design microstructures enables performance to be optimized.

The book is intended as an intermediate-level textbook for students and a reference for research scientists and engineers. Readers need some background and preparation in materials science and applied mechanics. The first chapter examines the driving forces for advances in fiber composites, as well as the trends and opportunities of this rapidly developing field. Besides providing a concise summary of the linear elastic laminate theory, Chapter 2 examines some of the recent developments in the mechanics of laminated composites. Particular emphasis is given to thick laminates, hygrothermal effects and thermal transient effects. Chapter 3 treats the strength of continuous-fiber composites. Analyses of the local load redistribution due to fiber breakages are presented first. They are followed by a fairly comprehensive treatment of the statistical tensile strength theories which encompasses the behavior of individual fibers, fiber bundles, unidirectional fiber composites, cross-ply composites and laminates of multi-directional plies. Various modes of failure of laminated composites are examined. Section 3.4.6.2 is contributed by S. L. Phoenix, and Sections 3.4.7.4 and 3.4.8 are contributed by A. S. D. Wang. Chapter 4 deals with the elastic, physical and viscoelastic properties as well as the strength and fracture behavior of short-fiber composites. The effects of variations in fiber length and orientation are examined using a probabilistic approach. In Chapter 5, fiber hybridization serves as a vivid example of how the performance of composites can be controlled through the selection of material systems and their geometric distributions. The synergistic effects between the component phases with low elongation and high elongation fibers are of particular interest. Chapter 6 is devoted to two-dimensional textile structural composites based on woven, knitted and braided preforms. A comprehensive treatment of the techniques for analyzing and modeling the thermomechanical behavior of two-dimensional textile composites is presented. Chaper 7 introduces recent developments in the processing of three-dimensional textile preforms based on braiding, weaving, stitching and knitting. The processing–microstructure relationship is demonstrated by the establishment of 'processing windows' for a specific forming technique. Then the microstructure–property relationship is exemplified through the construction of 'performance maps'. Mechanical properties of polymer- and metal-based composites using three-dimensional textile preforms are reviewed. Chapters 8 and 9, in contrast to the earlier chapters, treat the topic of finite elastic deformation of flexible composites. The fundamental characteristics of flexible composites and the technique for analyzing them are presented in Chapter 8. A rigorous treatment of the constitutive relations of flexible composites is developed in Chapter 9 based upon both the Lagrangian and Eulerian descriptions of finite elastic deformation. Overall, the inter-relationship among processing, microstructure, property, responses to external fields, and performance of composites is emphasized throughout this text.

The contents of this book have evolved from my experience during two decades of teaching and research of composite materials at the University of Delaware. Stimulation from students and co-workers was indispensable to the preparation of this book. The contributions of the individuals with whom I had the privilege and pleasure to interact are too numerous to cite here. However, this book serves as a tribute to the intellectual achievements of them all. The generous support provided by the National Science Foundation, Department of Energy, Department of Transportation, Army Research Office, Office of Naval Research, Naval Research Laboratory, Air Force Office of Scientific Research, NASA, industrial companies and the Center for Composite Materials of the University of Delaware for conducting the research reported in this book is greatly appreciated. Ding-Guey Hwang, Shen-Yi Luo, Joon-Hyung Byun and Wen-Shyong Kuo read the manuscript and gave critical comments. Te-Pei Niu, Yih-Cherng Chiang, Mark Deshon and Alison Gier provided valuable assistance in the preparation of the manuscript.

Lastly, I should like to express my deep appreciation to the following persons. The late Prof. Alan S. Tetelman of Stanford University first pointed out to me the technological potential of fiber composites. As a colleague of mine at Delaware, Prof. R. Byron Pipes has greatly enriched my perspective on the subject matter. The scholarship and guidance of Prof. Anthony Kelly have always been a source of inspiration to me. Prof. Jerzy L. Nowinski encouraged me throughout the course of this endeavor.