

PRINCIPLES OF COMPOSITE MATERIAL MECHANICS

THIRD EDITION

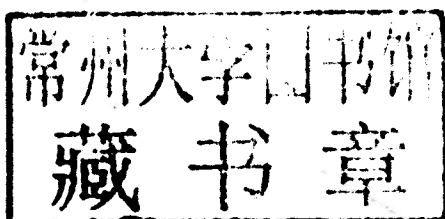
Ronald F. Gibson



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*To my wonderful family, Maryanne, Tracy, Tola, Sophie, and
Aidan, and the memory of my parents,*

Jim and Lora Gibson

Preface

The goals for the third edition are to continue to present a unique blended coverage of classical and state-of-the-art mechanics of composites technologies, while striving to incorporate the most worked-out example problems and homework problems of any available textbook on mechanics of composite materials. A high priority has been placed on writing a textbook that is easily understood by students. Pedagogical improvements include a total of 81 worked-out example problems (25 of which are new for the third edition); 177 homework problems (25 of which are new); 388 figures (46 of which are new); a new appendix on matrix concepts and operations; new coverage of particle composites, nanocomposites, nanoenhancement of conventional fiber composites, hybrid multiscale composites; and additional coverage of finite element modeling and test methods. Although the book is written first as a textbook covering classical methods, frequent references to current state-of-the-art composites technology and research findings are included. Extensive references are provided, including many current journal articles along with classic and historical publications.

I continue to be indebted to my colleagues, graduate students, and sponsors for their encouragement and support over the years. Most recently, my professional affiliations with Wayne State University (WSU) and the University of Nevada, Reno (UNR) have provided the necessary positive environments for teaching and research that made the development of this new edition possible. I have been particularly motivated by the interactions with students in my composites classes at WSU and UNR. As with the earlier editions of this book, my wife and best friend, Maryanne, continues to be my most enthusiastic supporter, and there is no way that I could have completed this project without her.

Ronald F. Gibson

Preface to the Second Edition

There have been many developments in mechanics of composite materials since the first edition of this book was published. Accordingly, the second edition has new sections on recent applications of composite mechanics to nanocomposites, composite grid structures, and composite sandwich structures. In order to strengthen the emphasis on the basic principles of mechanics, I have added a review of the basic mechanics of materials equations in the Introduction, and appendices covering the derivations of stress equilibrium equations and strain–displacement relations from elasticity theory. Coverage of micromechanics in Chapter 3 has been revised to include more detailed discussions of elasticity and finite element models. Chapter 4 on strength analysis has been updated to include results from the World Wide Failure Exercise. Chapter 8 has been improved by adding a phenomenological approach to understanding linear viscoelastic behavior of composites. Chapter 9 on fracture has been updated to include coverage of the finite element implementation of the virtual crack closure technique. Chapter 10 on testing of composites and their constituents has been extensively updated to include coverage of both new and revised ASTM standard test methods. Finally, more example problems and homework problems have been added to most chapters, and new references have been cited throughout.

As with the first edition, I am indebted to many colleagues, graduate students, and sponsors. I am grateful to Wayne State University for providing a nurturing environment for my teaching and research, and for granting me sabbatical leave, which were essential to the completion of this project. My graduate students have been particularly helpful in identifying the inevitable errors in the first edition, and their thesis research findings have enabled me to add important new dimensions in the second edition. And as with the first edition, my wife and best friend, Maryanne, has continued to be my strongest supporter, and I will be forever grateful for her love, encouragement, patience, and understanding.

Ronald F. Gibson

Preface to the First Edition

Composite materials is truly an interdisciplinary subject, and the number of students taking courses in this area is steadily increasing. Books on the subject tend to emphasize either the mechanics or the materials science aspects of composites. *Principles of Composite Material Mechanics* is mechanics oriented. Composite materials technology is new enough for many working engineers who have had no training in this area, and so a textbook in composite material mechanics should be useful not only for the education of new engineers, but also for the continuing education of practicing engineers and for reference. The high level of interest in composite materials, the interdisciplinary nature of the subject, the need to reeducate practicing engineers, and the need for a new composite mechanics textbook at the introductory level all led to my decision to write this book.

Chapters 1 through 7 form the basis of a one-semester senior/graduate-level course in mechanical engineering, which I have taught for the last 15 years. Chapters 8 through 10, along with selected papers from technical journals and student research projects/presentations, form the basis of a second one-semester course, which is taken only by graduate students, and which I have taught for the last 4 years. The book could also be the basis for a two-quarter sequence by omitting some topics. Prerequisites for the course are knowledge of mechanics of materials, introduction to materials engineering, and ordinary differential equations, and previous exposure to linear algebra is highly desirable. For some of the graduate-level material, earlier courses in advanced mechanics of materials, elasticity, and partial differential equations are recommended, but not required.

Some of the basic elements of composite mechanics covered in this book have not changed since the first books on the subject were published in the 1960s and 1970s, and, where possible, I have tried to use the accepted terminology and nomenclature. For example, the coverage of stress-strain relationships and transformation of properties for anisotropic materials in Chapter 2 and the classical lamination theory in Chapter 7 is consistent with that of previous textbooks such as the *Primer on Composite Materials* by Ashton, Halpin, and Petit, and *Mechanics of Composite Materials* by Jones. However, rather than beginning the study of laminates by jumping directly into classical lamination theory, I have concluded that a better pedagogical approach is to introduce first basic laminate concepts by using the simpler theory of laminated beams in pure flexure. Also, I believe that the concept of an effective modulus of an equivalent homogeneous material, which had previously been covered only in advanced books such as *Mechanics of Composite Materials* by Christensen, is essential for the proper development of heterogeneous composite micromechanics. Thus, effective modulus

concepts are emphasized from their introduction in Chapter 2 to their use in the analysis of viscoelastic and dynamic behavior in Chapter 8.

Although many basic concepts have been presented in earlier textbooks, numerous new developments in composite mechanics over the last two decades have made it increasingly necessary to supplement these books with my own notes. Thus, I have added coverage of such important topics as hygrothermal effects in Chapter 5, discontinuous fiber composites in Chapter 6, viscoelastic behavior and dynamic behavior in Chapter 8, fracture in Chapter 9, and mechanical testing in Chapter 10. The coverage of experimental mechanics of composites has been expanded to include summaries of the most important ASTM standard test methods, many of which did not exist when the early mechanics of composites books were published. A variety of example problems and homework problems, a number of them related to practical composite structures, are also included.

The contents of this book represent the cumulative effects of more than 25 years of interactions with colleagues and students, and I would be remiss if I did not mention at least some of them. My fascination with composites began in 1965 with my first engineering position in what is now part of Oak Ridge National Laboratory in Tennessee, where I was involved in the design and development of high-speed rotating equipment. At that time I realized that the advantages of using composites in rotating equipment are numerous, as is the case in many other applications. My experiences working with Dean Waters and other colleagues in the mechanical development group in Oak Ridge have had a strong influence on my later career decision to emphasize composites research and education. My doctoral research on vibration damping characteristics of composites with Robert Plunkett at the University of Minnesota further cemented my desire to continue working in the composites area and ultimately led to my career in university teaching and research.

After beginning my academic career at Iowa State University in 1975, I began a long and productive association with C.T. Sun, and later had the pleasure of spending a one-year leave working with C.T. and his colleagues Robert Sierakowski and Shive Chaturvedi at the University of Florida. I owe much of my understanding of composite mechanics to interactions with them. The notes leading to this book were developed by teaching composite mechanics courses at Iowa State University, the University of Idaho, the University of Florida, Michigan State University, and Wayne State University, and I am indebted to the students who took my classes and helped me to "debug" these notes over the years. Most recently, my students at Wayne State University have been particularly effective at finding the inevitable errors in my notes. Interaction with my graduate students over the years has contributed immeasurably to my understanding of composite mechanics, and the work of several of those students has been referred to in this book. I am particularly indebted to Stalin Suarez, Lyle Deobald, Raju Mantena, and Jimmy Hwang, all former graduate students at the University of Idaho.

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