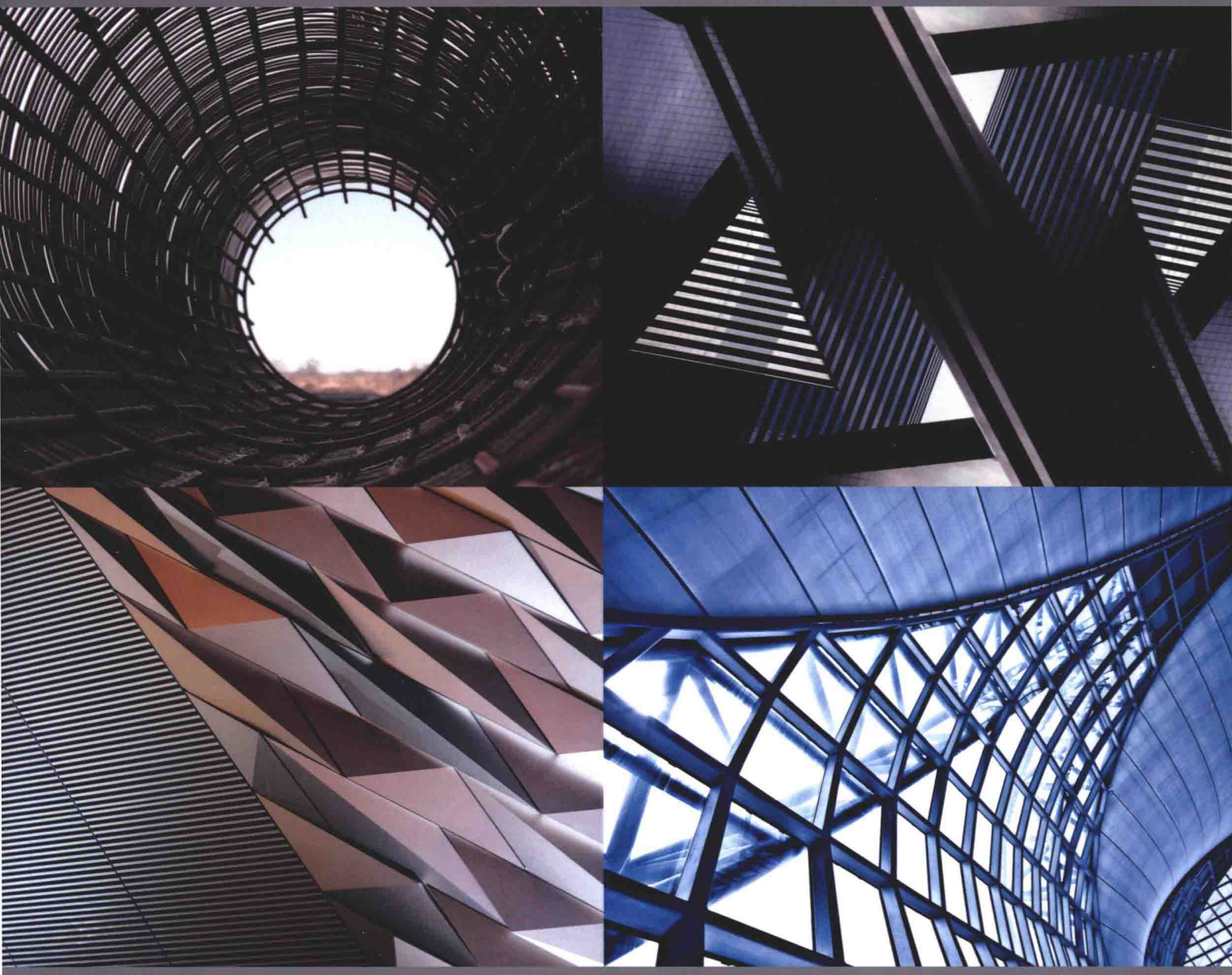
Composite Structures

Design, Mechanics, Analysis, Manufacturing, and Testing



Manoj Kumar Buragohain

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To my parents...

Author's parents
Late Bijoy Krishna Buragohain and Smt Tilottama Buragohain

Preface

The composites industry has grown multifold in recent times; it continues to grow and further growth is expected in the future as well. Composite materials and products are now regularly used in a wide range of applications across various industrial sectors. Naturally, there has been an increased demand for trained personnel in the field of composites. The subject of composites, which used to be taught only at a few select universities and institutes a couple of decades ago, is offered today by many other universities and institutes both at the undergraduate as well as the postgraduate levels. It is also offered as short-term courses as a part of continuing education program by certain institutes. Also, there are a large number of practicing professionals who do self-study.

One of the primary objectives of composites education is to equip the student with adequate know-how in the area of development of composite products. Composites, in general, and composite product development, in particular, are interdisciplinary subjects that draw resources from a number of subfields, namely, material science, mechanics, analysis, design, tooling, manufacturing, and testing. These topics have been extensively covered in a number of excellent books. Depending on the content, the books on composites can be broadly placed in three categories. The first category includes several excellent texts on mechanics of composites. In the second category, composites are treated as a part of material science. The third category includes the literature on manufacturing methods and shop floor and lab activities in composites.

The topics in composites mentioned above, however, cannot be considered in isolation and an integrated approach is essential for successful execution of a composite product development program. This book is a humble effort to present the concepts in composites in an integrated manner.

The contents of this book are organized in two parts. Part I is devoted to the topics related to mechanics, analytical methods in composites, and basic finite element procedure. An introductory discussion on the characteristic features of composites is given first. Basic concepts of solid mechanics are reviewed and it is followed up by discussions on the concepts of micromechanics and macromechanics. Analytical methods are excellent tools in understanding the behavior of composite structural elements. Some of these methods in the simple cases of beams and plates are presented next. Finite element method is the most popular tool for analysis; understanding of the underlying concepts and the basic procedure is essential for effective use of this method and a brief presentation on the same is given to complete the discussions in Part I.

Part II of this book is devoted to the topics on materials, manufacturing processes, testing, and design. These are the aspects in composites that the shop floor man is directly concerned with. The author is of the firm belief that composites design is not a closed door activity and a general understanding of the concepts of mechanics, analysis tools, available materials, manufacturing processes, tooling, and destructive and nondestructive test methods is essential for doing an efficient design. With this in mind, a discussion on composites design is given in the end.

The primary objective of this book is to expose the reader to the complete cycle of development of a composite product. I sincerely hope that this book will be an excellent guide to a student who wants to make a career in composites. I also expect that it will be an excellent companion to a practicing professional in the field of composites.

Finally, I take this opportunity to place on record my sincerest gratitude to all my teachers who molded me—right from my early school days to my doctoral study at IIT Madras; all that I present in this book belongs to them.

This book would not have seen the light of day without very professional guidance and support from CRC Press; my sincere thanks to Dr. Gagandeep Singh (Commissioning Editor), Mouli Sharma, Hector Mojena, Renee Nakash, Rachael Panthier, and Shashikumar Veeran, all of whom have been directly associated with the editing and production of this book.

I would like to place on record my sincere gratitude to Dr. Tessy Thomas, Outstanding Scientist and Director, Advanced Systems Laboratory, Hyderabad, for her encouragement and support in publishing this book. My sincerest thanks are also due to my colleagues with whom I have had long hours of invaluable interactions developing composite products.

I take this opportunity to express my gratitude to my parents, who brought me up in a small sleepy town yet taught me to be ambitious. I thank all my family members and near and dear ones for their support in this humble endeavor. Life is a long journey and the past six to seven years, were special and tough too; I spent long hours working on the manuscript of this book; my wife Ainu managed family affairs and son Beli grew up silently. I would like to express my love and gratitude to my loving family for their sacrifice and support and for standing patiently by my side in the hours of need. I indeed remain indebted to them.

Manoj Kumar Buragohain
Hyderabad

Author

Dr. Manoj Kumar Buragohain is a scientist at the Advanced Systems Laboratory, Hyderabad of Defense Research and Development Organization, India. He earned his BSc Engg from the Regional Engineering College Rourkela; MTech and PhD from the Indian Institute of Technology Madras; and PGDFA from The Institute of Chartered Financial Analysts of India, Hyderabad.

Dr. Buragohain has well over two decades of hands-on experience in the design and development of composite products. His primary research interests are in the fields of geodesic and nongeodesic filament winding, tape winding, rosette lay-up, and contact lay-up. Some of his major contributions have been in large size composite pressure vessels, grid-stiffened composite structures, tubular structures, ablative liners, and composite rotor blade. He has several journal and conference publications to his credit and is a life member of the Indian Society for Advancement of Materials and Process Engineering (ISAMPE) and Aeronautical Society of India (AeSI). His contributions to the field of composites have been well recognized and he was awarded the Laboratory Scientist of the Year Award, National Science Day Commendation Certificate & Silicon Medal, DRDO Award for Performance Excellence as a team member, and Agni Award for Excellence in Self-reliance as a team leader.

Book Road Map

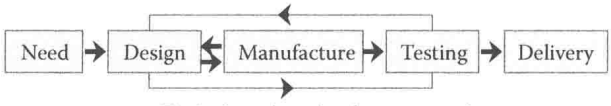
The topics for this book have been chosen keeping in mind the primary objective of the book, that is, to expose the reader to the complete cycle of development of a composite product—from design to manufacturing to testing and evaluation. The chapters, as depicted pictorially in the figure given below, are organized into two parts and placed by and large in a chronological order of reading.

PART I

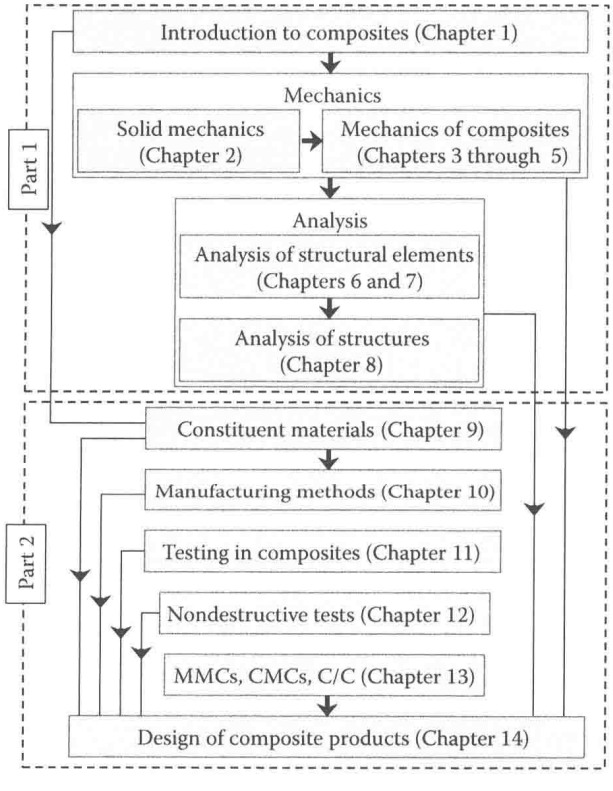
Part I is devoted to the introductory concepts and the topics on mechanics, analytical methods, and analysis; these topics are primarily computational in nature.

The objective of Chapter 1 is to introduce the subject of composite materials and structures. Toward this, we shall begin our journey with a discussion on the characteristic features that define a composite material, their advantages and disadvantages, and their typical applications.

The mechanics of composite materials is an important subject; a good understanding of the concepts of mechanics is essential for understanding the analytical methods and analysis tools, which in turn are essential for the efficient design of a composite product. Chapters 2 through 5 present discussions on basic solid mechanics and mechanics of composites. Composites are anisotropic in nature and, as a result, the



Typical product development cycle



Structure of this book

mechanics of composite material is more involved than that for conventional metallic materials. The concepts of solid mechanics provide the foundation on which the subject of mechanics of composite materials is built. A detailed review of the basic solid mechanics concepts is presented in Chapter 2. A composite structure is built with composite laminates. A laminate is made by combining several laminae and a lamina consists of reinforcements and matrix. The laminae are the building blocks and we shall address them in Chapters 3 and 4. Chapter 3 presents the micromechanics of a lamina; the interaction of the individual constituents and their effect on the behavior of the lamina are discussed in this chapter. The macromechanics of a lamina, that is, the study of the gross behavior of a lamina without making a distinction between the constituents, is presented in Chapter 4. The macromechanics of a laminate is discussed next in Chapter 5.

Analytical methods and analysis tools play an important role in the design process by providing estimates of the response of a structure to applied loads; these topics are presented in Chapters 6 through 8. Analytical methods are available for the solution of simple structural elements under simple loading; we shall discuss such analytical tools for composite beams and plates in Chapters 6 and 7, respectively. These methods, however, are not suitable for most real-life situations, where a structure as well as the applied loads are rather complex. In such cases, numerical methods such as the finite element method are invariably used. The finite element method is the most popular tool used for the analysis of structures. Several general-purpose finite element software are commercially available. A basic understanding of the method is essential for the proper use of these software. We shall wind up Part I of this book with a brief discussion on the basic concepts and general procedure in the finite element method in Chapter 8.

PART II

There are several aspects in the overall cycle of a composite product development, where the engineer is primarily involved with shop-floor-related activities. Part II of this book is devoted to these topics. These topics are materials, manufacturing methods, testing of composites and their constituents, and nondestructive evaluation. In addition to these, other major classes of composites, viz. metal matrix composites (MMCs), ceramic matrix composites (CMCs), and carbon/carbon composites (C/C composites) are included in this part. Also, a discussion on the design of composite products is given in the end.

The major raw materials used in the polymer matrix composites industry are presented in Chapter 9. Raw materials play a key role in any product development exercise. Two primary categories of raw materials needed to make a composite product are the reinforcements and the matrix. The general characteristics and the mechanical and physical properties of common fibers and resins are presented. We shall also briefly present the principles of manufacturing methods for these materials. It is expected that this chapter will be able to guide the designer in selecting the appropriate reinforcement and matrix materials for specific applications.

Composites technology is process-intensive and a good knowledge of manufacturing processes is essential for anyone in this field. Similar to materials selection, the manufacturing process selection is a critical decision to be made in the design of a composite product. With a view to getting solutions to such issues, we shall address manufacturing methods in polymer composites in Chapter 10. Several manufacturing processes are regularly employed in the composites industry; they can be categorized into open mold, closed mold, and continuous molding processes. The basic processing

steps, some of the popular manufacturing processes, and the manufacturing process selection are presented in this chapter.

Another major aspect of composites technology is testing, various aspects of which are addressed in Chapter 11. We will see there that testing is an inseparable part in any composite product development program. It is done with either one or more of the following as objectives—design data generation, quality control, and development of new materials. Testing in composites is unique and typically a building-block approach is adopted. Tests are done at various levels—constituent raw materials testing to full-scale component testing. These tests are destructive in nature and the specimen gets consumed/damaged during testing. In contrast to destructive testing, nondestructive testing neither destroys nor causes any damage to the part, and the utility of the part remains intact. We shall briefly review some of the common nondestructive evaluation techniques in Chapter 12.

MMCs, CMCs, and C/C composites complement polymer matrix composites in the overall composites industry. The scope of this book is limited to mainly polymer matrix composites. However, familiarity with these sister composite materials helps a polymer matrix composite professional immensely in the design and development of a product. The introductory concepts covering general characteristics, raw materials, and manufacturing methods with regard to MMCs, CMCs, and C/C composites are presented in Chapter 13.

Finally, we shall acquaint ourselves with various aspects of design in Chapter 14. Design is a common term, yet very often misunderstood. It is an art, yet certain set patterns and key features can be associated with it. The concept of design as a solution to meet certain requirements using available resources within certain constrains is introduced in this chapter. The fundamental features of composites structural design process, laminate design, joint design, and some important design issues are presented. Design examples are provided to help in the assimilation of the concepts. It is a phase that comes fairly early in the overall product development program. However, it is a subject that demands a reasonable level of insight into various other aspects of composites technology; inputs from mechanics, analysis estimates, materials data, manufacturing, testing, and evaluation are required in the design process. Accordingly, we shall deliberate on it in the end.

SUGGESTED PLAN FOR READING

There are 14 chapters in this book and they can be read in a sequential manner. However, it will be difficult to cover the entire book in the time frame of a single semester. From the points of view of (i) organizing the contents in one-semester courses and (ii) effective self-study, the following study plans are suggested:

First, a basic course on the mechanics of composites can be planned based on the sequence: Chapter 1 → Chapter 2 → Chapter 3 → Chapter 4 → Chapter 5. Some selected sections from Chapters 6 through 8 can be added.

Second, an advanced course on the mechanics and analysis of composites can be planned based on the sequence: Chapter 1 → Chapter 4 → Chapter 5 → Chapter 6 → Chapter 7. Some selected sections from Chapters 2, 3, and 8 can be added.

Third, a course on manufacturing and testing of composites can be planned based on the sequence: Chapter 1 → Chapter 9 → Chapter 10 → Chapter 12 → Chapter 13. Some selected sections from Chapters 3 through 5 and 11 can be added.

Fourth, a generalized course on the design of composite products can be planned based on the sequence: Chapter 1 → Chapter 4 → Chapter 5 → Chapter 9 → Chapter 10 → Chapter 14. Some selected sections from Chapters 2, 3, 6 through 8, and 11 through 13 can be added.

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