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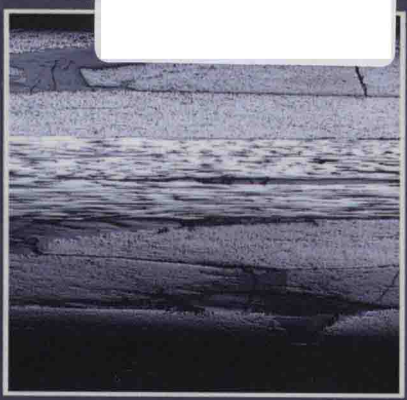

# Modeling Damage, Fatigue and Failure of Composite Materials

Edited by Ramesh Talreja and Janis Varna

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# Preface

In spite of their widespread applications in aerospace, automotive, wind turbine, and other industries where lightweight structures are advantageous, composite materials remain far from reaching their full potential. A main roadblock is lack of reliable models for damage, fatigue, and failure of composite materials. The subject of this book is exactly this, and with a collection of chapters from recognized experts, our aim is to help remove this roadblock.

The current state of designing composite structures in the aircraft industry is typified by the guidelines in the *Composite Materials Handbook* (MIL-17, 1999), which recommends the so-called "building-block approach," which requires extensive testing, beginning with fibers and matrix materials, and increasing in complexity as the size of test articles approach subcomponent and component levels. The number of tests conducted often reaches the thousands, with prohibitive cost and time needed to complete them. As one aircraft designer recently lamented, "engineers are forced to conduct tests at multiple scales because they do not really have a theory to connect the behavior across multiple scales." Multiscale analysis of damage and failure in composite materials is a central thrust of this book.

We have organized the book in four parts. Part One deals with damage development and has four chapters. Chapter 1 gives an overview of the constituent properties in a polymer matrix composite (PMC), and describes observations made over many years to reveal certain generic mechanisms of damage. Chapter 2 focuses on basic mechanisms of fatigue damage and discusses fatigue life diagrams as a means of conceptual interpretation of the roles of fibers, matrix, and laminate configuration in damage initiation and progression. Chapter 3 is devoted to damage in textile composites, and it highlights the specifics of damage mechanisms due to the woven fiber architecture. Chapter 4 focuses on systematic observations of damage mechanisms operating under combined loading and describes recent work conducted on tubular specimens under axial tension normal to fibers combined with torsion.

Part Two of the book has seven chapters devoted to modeling of the failure mechanisms at different levels in a composite laminate. Chapter 5 considers matrix and fiber–matrix interface failure, and reviews criteria for initiation of these mechanisms. Chapters 6 and 7 are focused on fiber–matrix debonding under loading in transverse and axial directions of the fibers, respectively. These chapters describe stress and fracture analyses of debond cracks in the two loading cases. Chapter 8 is on multiple cracking that occurs within plies of a laminate. While this subject is treated in several chapters of the book, this chapter is focused on evolution of multiple cracking. Chapter 9

considers fiber–matrix debonding initiating from a fiber break, and analyzes its growth along the fiber surface under quasi-static and cyclic tension. Failure in composites under compression is considered in Chapter 10. This chapter considers compressive strength of composite laminates with open holes or notches, and describes application of a cohesive zone model for predicting this property. Chapter 11 treats delamination as an interface crack between plies of a laminate. It reviews fracture mechanics approaches to testing, analysis, and design against failure from delamination. A particular feature of this chapter is J-integral-based bridging laws for interface cracks.

While Part Two of the book treats analyses of different failure mechanisms, Part Three shifts focus to relating these mechanisms to the materials response. Chapters 12 and 13 discuss microlevel approaches for describing the effective thermomechanical properties of laminates with multiple ply cracks. In Chapter 12, the approach consists of utilizing the surface displacements (opening and sliding) of ply cracks in analytical expressions for effective properties in terms of crack densities. Chapter 13, on the other hand, presents analytical approaches to effective properties of cross-ply laminates based on generalized plain strain and derives general interrelationships between damaged laminate elastic constants. Chapter 14 describes elastic response changes in multidirectional laminates with cracks in multiple orientations. The approach, called synergistic damage mechanics, utilizes ply level analysis of cracks into a continuum damage formulation.

Finally, Part Four of the book is concerned with failure analysis of laminates and joints. Chapter 15 here deals with a multiscale approach to predicting the load-carrying capacity of laminates. The focus in this chapter is on the stage of damage development, where localized failure events such as ply cracks interconnected by interlaminar cracks govern strength degradation. Next, Chapter 16 discusses developing failure criteria for fatigue damage in unidirectional composites under combined transverse and shear stresses. Manufacturing defects are an inherent feature of real composites. Chapter 17 treats approaches for incorporating such defects in composite failure analysis. Other practical aspects of failure in composite materials are treated in the last two chapters. Chapter 18 deals with failure initiating from sites where local stresses have gradients and are concentrated. Stress and failure analysis of bonded joints between composites is treated in Chapter 19.

From the synopsis of the book content just given, it is clear that the 19 chapters collectively present diverse treatments of various aspects of damage, fatigue, and failure in composite materials. Our intention is to give the reader an overview of the landscape of a vigorously developing field. Composite materials offer tremendous opportunities for innovative, high-performance structures, if the models to describe and predict their behavior under service environments are physically based and are firmly rooted in mechanics. This book will hopefully contribute toward advancing that purpose.

**Ramesh Talreja**
**Janis Varna**

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