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Composite Materials Series, 4

FATIGUE OF COMPOSITE MATERIALS

edited by

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Fatigue of Composite Materials
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Preface

This book deals with the long-term behavior of composite materials and structures subjected to time-variable influences. In deference to traditional associations, we will group our discussions under the title "Fatigue of Composite Materials", with a quick reminder that we will not be constrained by the classical boundaries of the subject of fatigue. In general, fatigue is concerned with the loss of properties and performance caused by internal processes driven by the continued application and variation of external influences such as mechanical loading, thermal loading, and chemical environments.

A rational description of the fatigue process based on first principles has not yet been achieved. Available descriptions rely heavily on engineering experience, which is reflected in empirical and phenomenological descriptions aided by subdisciplines such as fracture mechanics and micro-mechanical formulations. This lack of rigor in our understanding and descriptions, which makes it difficult to predict the behavior of homogeneous materials, is further aggravated by the complexity of composite materials and by the fact that we have considerably less experience with composite material systems. However, the use of these materials is rapidly expanding, especially in high-performance structures such as power systems, electronic devices, medical appliances, aircraft, and other vehicles. In fact, applications for which composite materials are most clearly superior are precisely those situations in which the degradation of strength and life by fatigue processes is most likely and most severe. It is critical that this problem be addressed. Failure of composite structures under long-term service must be avoided; but nothing can be reliably avoided which cannot be reliably predicted. If we are to predict such behavior, we must achieve a thorough understanding of fatigue processes, and establish quantitative representations which include the controlling factors and mechanisms.

The book which follows represents an attempt to provide a few first stones in the foundation of a rational structure for the development of an understanding and philosophy of the fatigue of composite materials as a discipline, and for the development of the associated rigor. To that end, the book presents a strongly interdisciplinary treatment of the subject, beginning with micro-mechanisms and processes, continuing with an association of these micro-details and macro-behavior, and culminating with the prediction of behavior based on quantitative representations. The book begins by addressing the fatigue process itself, with a discussion of damage development, damage characterization, and damage mechanics. The physical details of the

damage development process in various composite systems (especially those aspects judged to be generic), as well as various representations of damage, and the use of those representations to predict remaining stiffness, strength and life, are emphasized. On that basis, the phenomenon of fatigue behavior at the global level is introduced. The characterization of the fatigue behavior of various composite systems, including short- and long-fiber composites, polymer and metal matrix composite materials, and highly oriented as well as randomly oriented fiber-reinforced materials, is described and the nature of that response is thoroughly analyzed. The topic of delamination, one of the most widely discussed and perhaps one of the most thoroughly understood damage modes in composite laminates, is examined in a separate chapter.

Several special topics then receive focused attention. The viscoelastic behavior of laminated composite materials is recognized as an essential part of this topic and discussed in detail, especially in the context of long-term behavior and the degradation of properties and performance. The problem of moisture sorption in composites and its relationship to damage, of special importance to the behavior of polymer matrix materials, is investigated from an experimental standpoint and rigorously represented by a continuum formulation. Modeling of global-level behavior in the presence of cumulative damage development receives special attention, and brings the discussion to a review of statistical considerations, a subtopic of ubiquitous importance to the general subject of fatigue.

This book is most certainly not complete: partly because of the incomplete development of the subject at the time of writing, and additionally because of the limited scope of the book required by expediency. However, a special attempt has been made to include discussions of what are thought to be the fundamental subtopics and issues which are important to a complete discussion of the subject of fatigue of composite materials, from the micro-events to the macro-behavior that we wish to describe and predict. Moreover, the book is designed to suggest an interdisciplinary approach to the subject, that combines a thorough and precise understanding of the physical mechanisms that play an active role in these processes and a rigorous representation of the mechanics associated with their collective action. Hence, investigators and students of the subject should find some guidance and considerable food for thought in the following pages. However, the applied community was also strongly considered in the coverage of material, especially in the presentation of numerous collections of data and characterizations of behavior, the discussion of test techniques and methods of analysis, and the presentation of various predictive modeling methods and approaches.

Throughout the preparation of this book, it has been my very good fortune to work with a group of chapter authors whose excellence and diligence made possible a development of this subject that exceeds initial expectations. There is an unusual amount of new and original material in the present volume. This is a special tribute to the activity of the authors in this field, and a reminder that this subject area is developing very rapidly. Beyond this primary set of contributors, a great number of other individuals and circumstances made contributions to this volume. Supporting agencies and individuals are noted in various chapters. Special thanks go to Barbara Wengert for inestimable assistance in preparation of the manuscript and assembly of

the book. Finally, special appreciation is extended to faculty and students in the Materials Response Group at Virginia Tech who have provided the academic environment and inspiration that has guided me in my pursuit of this subject over nearly 18 years of academic excitement and discovery.

K. L. Reifsnider

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Chapter 1

Introduction

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Contents

Abstract

The essential details of the subject of fatigue of composite materials are thoroughly presented in the chapters which follow. The purpose of this Introduction is to define the subject at the general level and to provide a context of technical issues, perspectives, and relationships that form the superstructure to which the various components of the subject are attached. Our introductory discussion will be brief and divided into the topics listed above.

The reader is reminded that, owing to the infancy of this subject, these writings should be regarded as interim statements of reality that reflect current enlightenment as well as current shortcomings in our understanding and perceptions. However, even at this stage of development, the subject is richly rigorous and presents a remarkable challenge and opportunity for scientific and technical advancement.

1. Fatigue – the subject

Few things last forever. It would appear that most material things that respond to their environment (including our own species) change their form or function with time. With the inspiration of Einstein and the labor and insight of others, the technical community has admitted time as a dimension, and has learned to account for it in the