# Foreword

Although it was understood very early that fatigue was a matter of creating and propagating a crack to the point of ultimate failure of a specimen or structural component, indeed long before "crystallization" theories of fatigue eventually died from natural causes, no significant measurements of crack propagation kinetics existed before the early 1960's. Theories of crack growth existed before then, of course, highly speculative and based on unrealistic models. Only after appropriate fracture mechanics parameters were developed to allow the driving forces for crack growth to be expressed for a wide variety of component geometries did predictive capability greatly improve for fatigue design purposes. The traditional approach of designing against fatigue, known as the "total-life" approach, worked adequately on the whole before the arrival of linear elastic fracture mechanics, mainly because it was backed by extensive (and expensive) experimentation. It also has undergone improvements, for examples in counting cycles during variable load cycling and in strain (rather than stress)-based predictions, and continues in wide use today, even in certain aerospace applications where usually fracture mechanics considerations now dominate. The total-life approach can be valid in situations where inspections for cracks are difficult or are economically prohibitive. The success of fracture mechanics in applications to aircraft probably arises from the necessity to use high stresses in aircraft and where relatively infrequent very high stress cycles promote early crack initiation, even in the absence of significant manufacturing defects, on which some fracture mechanicians rely to justify the approach.

Like most books on fatigue, the aim of Dr. Krupp's book is to help to make better fatigue life predictions. Although the title of his book implies an emphasis on fracture mechanics, and does focus on fracture mechanics (and almost exclusively on metals), it contains an elaborate chapter on crack initiation, and it also deals with the underlying physics of fatigue mechanisms. It is a well-balanced book in other respects as well, in the referencing between early and recent publications, between fundamental aspects such as dislocation considerations and modeling, and particularly in the balance between mechanics and materials considerations. It covers the range from elementary dislocation behavior to recent advances in modeling. It is thus suited to a wide range of students from different backgrounds and developmental stages; veterans of fatigue studies will find it interesting. In

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that it contains detailed treatments of microstructural effects on short crack growth behavior, the book goes far to bridge gaps of understanding between material scientists and mechanical engineers. Thus, Dr Krupp's worthy book represents another important step in the evolutionary development of books dealing with fatigue.

It is a pleasure to acknowledge a highly productive collaboration with Dr. Krupp during his sabbatical visit to the University of Pennsylvania. His Penn colleagues gained much from his industry and insights, of which his book is an excellent example.

November 2006

Campbell Laird
Stockbridge, Michigan

# Preface

As long as machines are moving we have to care about fatigue and fatigue-crack propagation. What we don't know about fatigue damage mechanisms is hidden in safety factors. However, in terms of light-weight design and economic engineering design safety factors need to be chosen as small as possible, i.e., it has to be accepted that technical materials exhibit microstructural changes and crack propagation during service life. This book outlines shortly the present state in fatigue-life prediction paying particular attention to fracture mechanics concepts. Today we know that interactions between a growing fatigue crack with local features of the material's microstructure are most relevant for understanding and modeling fatigue damage in the fatigue-limit range under high-cycle fatigue (HCF) and very-high-cycle fatigue (VHCF) conditions. It is hoped that this book gives students in advanced courses in materials engineering and researchers in industry and academia a picture of the sum of implications of short-crack propagation in fatigue life, helping them to interpret failure cases and to identify strategies for mechanism-based service-life prediction and the design of fatigue-damage-resistant material concepts.

Beside a literature review this book contains the results of research work the author carried out at the University of Siegen, Germany, and the University of Pennsylvania, Philadelphia, USA. The complete work was encouraged and strongly supported by Prof. Dr. Hans-Jürgen Christ, holder of the chair of materials science and testing at the University of Siegen. Working with such an outstanding scientist and teacher was most enjoyable and I am greatly indebted not only for his great effort in supporting my scientific career but also for his friendship. I was lucky also to have the chance to closely collaborate with the Institute of Mechanics, Prof. Dr. Claus-Peter Fritzen. This collaboration, which is greatly acknowledged, allowed me to combine the experimental work with complex modeling concepts.

A very strong impact on the research presented in this book was the chance to work together and to discuss the results with Prof. Dr. Charles J. McMahon, Jr. and Prof. Dr. Campbell Laird at the University of Pennsylvania. Thanks to their hospitality and friendship my family and me spent a great and unforgettable time in Philadelphia and for that I wish to express my gratitude.

Of course, this book was only possible by the huge amount of work carried out by my former colleagues and PhD students at the University of Siegen, Dr. Wil-

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helm Floer, Dr. Alexander Schick, Dr. Olaf Düber, Dr. Boris Künkler, Helge Knobbe, Philipp Köster, and Arne Ohrndorf and the great support by my colleagues at the University of Pennsylvania, Dr. William M. Kane and Dr. Alex Radin. Beside their invaluable scientific contribution to this book it was and is their friendship, which made work really enjoyable and for which I am very thankful.

My special thanks goes to Prof. Dr. Hans-Jürgen Christ, Prof. Dr. Campbell Laird, Prof. Dr. Charles J. McMahon, Jr., and Dr. Boris Künkler for critically reading parts of the manuscript and to Wiley's editing and publishing team for their patience and support during the completion of this book.

However, without financial support successful research is hardly possible. I was lucky that I received several grants from the German research foundation, Deutsche Forschungsgemeinschaft, and a personal fellowship from the Alexander von Humboldt foundation allowing me to live and work in the United States. This support is gratefully acknowledged.

Finally I am deeply grateful to my family, especially my grandmother Johanna Schlaadt, my parents Hiltrud and Peter and my two children Lukas and Lorenz. Without their help and their love I never would have come so far and I wish to dedicate this book to them.