APPLIED STRESS ANALYSIS OF PLASTICS

A Mechanical Engineering Approach

APPLIED STRESS ANALYSIS OF PLASTICS

A Mechanical Engineering Approach

S.I. Krishnamachari

L.J. Broutman & Associates, Ltd.
Chicago, IL

VNR SPRINGER SCIENCE+BUSINESS MEDIA, LLC

To my mother.

Originally published by Van Nostrand Reinhold in 1993
Softcover reprint of the hardcover 1st edition 1993
Library of Congress Catalog Card Number 92-27825
ISBN 978-0-442-23907-7

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Krishnamachari, S. I. (Sadagopa I.), 1944-
Applied stress analysis of plastics: a mechanical engineering approach / S. I. Krishnamachari
p. cm.
Includes bibliographical references and index..
ISBN 978-0-442-23907-7 ISBN 978-1-4615-3110-4 (eBook)
DOI 10.1007/978-1-4615-3110-4
1. Plastics—Testing. 2. Stresses and strains. I. Title.
TA455.P5K7 1992
620.1' 9233' 0287—dc20 92-27825
CIP

Contents

Preface

This book is a product of the understanding I developed of stress analysis applied to plastics, while at work at L. J. Broutman and Associates (LJBA) and as a lecturer in the seminars on this topic co-sponsored by LJBA and Society of Plastics Engineers. I believe that by its extent and level of treatment, this book would serve as an easy-to-read desktop reference for professionals, as well as a text book at the junior or senior level in undergraduate programs.

The main theme of this book is what to do with computed stress. To approach the theme effectively, I have taken the "stress category approach" to stress analysis. Such an approach is being successfully used in the nuclear power field. In plastics, this approach helps in the prediction of long term behavior of structures. To maintain interest I have limited derivations and proofs to a minimum, and provided them, if at all, as flow charts. In this way, I believe that one can see better the connection between the variables, assumptions, and mathematics.

I intend this book as a guide for the mechanical engineer working in plastics product design. Therefore, the use, rather than the description of mechanical behavior is treated preferentially. A working knowledge of the strength of materials, differential calculus, and ordinary differential equations should be adequate for most of the text, except that some knowledge of Laplace transforms may be helpful for Chapter 5. A cursory review of this topic is provided in Appendix 3. Wherever appropriate, I have provided interpretive comments, and have explained the use of existing material test practices based on the mechanical behavior of the materials. Examples in this book perform two major tasks. The first one is to illustrate a certain principle, and the second is to provide commentaries about the differences between theory and practice. It is my hope that the student engineer will find these commentaries valuable.

Chapter 1 deals with the overall structure of the theory of elasticity, and in particular, with the fact that stresses caused by loads are basically different from stresses caused by displacements. Understanding this difference is fundamental to understanding plastics. It also introduces the stress category concept. Chapter 2 is an overview of how much can be done in plastics design by using existing techniques in metallics. The techniques used in this chapter range from simple press-fits to matrix structural analysis (using an example in piping flexibility). I should admit that in this chapter, the progression of complexity is rather fast. However, I was able to discuss a wider range of practical problems more compactly. Chapter 3 is basically about incipience of plastic flow. No flow rules are discussed. Chapter 4 returns to the stress category, and its relation to the failure modes known to occur in plastics. The concept of factor of safety is also discussed, as are the facts that it is a number having more details to it than meets the eye, and that rational product quality specifications decide what to look for in an analysis. Chapter 5 is a discussion of the application of viscoelasticity to static problems. I have presented a view that the so-called "pseudoelasticity" is a consequence of the correspondence principle. The examples in Laplace transforms are for illustration of the correspondence principle. If one were to assume that the Poisson's ratio remains constant with time, and express all elastic properties in terms of E and ν only, the Laplace transform approach will give results identical to those of pseudoelasticity. Thus, the Laplace transform has been used in this book as a pointer to pseudoelasticity technique. A proposal for ranking plastics is also included in this chapter. Chapter 6 concerns linear elastic fracture mechanics and applications. The basic four approaches to crack stability are discussed, but the application to the stress intensity approach is dealt with in detail because it permits computation. Calculation of the fatigue life of plastics is presented as a problem in the progressive increase of K_I. The crazing mechanism is explained using the background of stress intensity at crack tip. Chapter 7 discusses the micro- and macro-mechanics of fiber-reinforced plastics. A variety of results have been compiled in a manner that is suitable for computer coding. This chapter, with its exercises, may be suitable for a three-credit course.

Chapters 8 and 9 deal with finite elements. What do finite elements have to do with plastics? Finite elements are replacing classical methods of analysis in the same way that calculators replaced addition and multiplication tables. The design engineer invariably is a user of some finite element software. Covering an extensive topic such as this in one or even two chapters is presumptuous. Only the elementary ideas are discussed and I hope the reader will gain enough confidence to refer to more detailed books on the subject. Chapter 8 discusses the steps involved in the finite element analysis, by taking a linear triangular element as the basic entity. Extensions to higher order elements, or more nodes per element are just indicated. A few exercises stand in for detailed discussion of the topic. Chapter 9 contains cautionary advice to any user of finite elements.

I have used a casual style in algebraic manipulations. At several places, I have used dots such as $(\cdots)$ to mean an exact repetition of the quantity in the previous step. This is not formal, but the reader who wants to get to the bottom line quickly will find this notation agreeable. In Chapter 5, I have used E' and E'' with subscripts σ and ϵ, to denote the manner in which the test data were obtained. This once again is nonstandard. I have used such shortcuts consciously with the hurried student in mind, the kind of student who might pick a formula from the text without pausing to look for the applicable restrictions. In Chapter 7, for example, the Tsai-Halpin formulas are summarized by the use of an unreadable symbol $(\bullet)$, a symbolism which, I believe, communicates the generality of the formulas.

Some curves in this text are reproductions taken from other texts, trade brochures or company manuals. I gratefully acknowledge the permissions from the organizations to reproduce them.

Acknowledgments

The origins of this book are in the seminars I worked on with Dr. L. J. Broutman who co-sponsored them with the Society of Plastics Engineers. I gratefully acknowledge the support, resources, and encouragement I received from him, without which this book would not have been possible. Thanks are due to Prof. S. Kalpakjian and Dr. S. Nair, both of Illinois Institute of Technology, Chicago, and to my colleague Dr. Paul K. So, whose counsel and technical discussions were valuable to me all along the writing. I sincerely appreciate the advice on the style and grammar I received from my colleagues Mr. Ken E. Hofer, and Mr. Michael R. Roop. I thank the editors of Van Nostrand Reinhold, a little suggestion from whom sparked off this project. My wife Lalitha and sons Sriram and Parashar gave me loving support, cooperation, and understanding for the last three years of writing.