Mechanical Response of Polymers

The use of polymers has become so commonplace that it would be nearly impossible to pass a day without coming into contact with polymer-based products. For example, automobiles, household appliances, and electronic devices all make use of polymeric materials. As polymers are used increasingly in sophisticated industrial applications, it has become essential that mechanical engineers, who have traditionally focused on the behavior of metals, become as capable and adept with polymers.

This text provides a thorough introduction to the subject of polymers from a mechanical engineering perspective, treating stresses and deformations in structural components made of polymers. Three themes are developed. First, the authors discuss the time-dependent response of polymers and its implications for mechanical response. Secondly, descriptions of mechanical response are presented for both time-dependent and frequency-dependent material properties. Finally, the stress–strain–time relation is applied to determine stresses and deformations in structures.

With numerous examples and extensive illustrations, this book will help advanced undergraduate and graduate students, as well as practicing mechanical engineers, make optimal and effective use of polymeric materials.

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AN INTRODUCTION

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Preface

During the past several decades, the use of polymers has become so commonplace that it would be nearly impossible to pass a day without coming into contact with a polymer-based product. The automobile, aerospace, appliance, and electronics industries use more polymers, by weight, than all the metals put together. Despite the increased use of polymers in engineering products, the stresses and deformations that these polymers undergo are generally determined as if the behavior is that of a classical elastic material. This is in part due to the traditional mechanical engineering education that has emphasized the behavior of metals rather than polymers. Polymeric materials have been studied more within the context of understanding their material properties by chemists, chemical engineers, and material scientists, rather than with a view toward understanding the stresses and deformations in structural components. However, rapid changes are occurring in current engineering practices involving polymers from the perspective of mechanical engineering. Polymers are being considered for increasingly sophisticated industrial applications. The effective and efficient use of these materials requires an understanding of their time-dependent response and energy dissipation properties. Thus, it is essential that the mechanical engineering education be expanded so that students become as capable and adept with polymers as they are with metals in determining stresses and deformations.

The authors have spent many years teaching engineering students about stresses and deformations in metallic structural components, on the one hand, and carrying out research in the mechanical response of polymers, on the other. They have also taught graduate courses in the viscoelastic response of polymers. In recognition of the increasing need that mechanical engineers be educated in the mechanics of polymers, we have used our teaching and research expertise to develop a book which is intended to serve as both a textbook and an engineering reference.

This book was prepared with several purposes in mind. The first is to instill a solid grasp of the phenomena of stress relaxation and creep in polymers, and their consequences for mechanical response. This is achieved by developing the stress–strain–time relation for the response of polymers, and then using it to explore characteristic material and process times, energy dissipation, and the effects of fading memory. The second purpose has to do with the mechanical properties of polymers. An engineer should be familiar with descriptions of mechanical response in terms of both time-dependent and frequency-dependent material properties. Thus, we develop the background necessary for this purpose. In particular, we use the stress–strain–time relation to interpret the response in fundamental experiments, and then to develop relations between material properties in their creep, stress relaxation, time- and frequency-based forms.

Our third purpose is to show how the stress–strain–time relation is used to determine stresses and deformations in structures. We begin with a thorough treatment of polymeric beams and bars under torsion. Examples are presented which not only illustrate different aspects of the consequences of creep and stress relaxation, but also illustrate different methods for analyzing structural problems. In effect, given a textbook for an introductory solid mechanics course in the mechanical engineering curriculum, it is shown that each example can be defined for polymeric materials, and can be treated by the methods presented here. The same approach is then used to determine stresses and deformations in bodies with more complicated shapes and loadings. Instead of examples of beams and torsion bars, examples are drawn from the classical linear theory of elasticity.

To come to grips with viscoelasticity it is helpful to have a clear grasp of the response of elastic solids and viscous fluids. Here, we shall concentrate our efforts on describing the linear response of viscoelastic materials that stems from the material responding both as a linear elastic solid and a linear viscous fluid. While the linear viscous fluid is a proper model in its own right, the linear elastic solid model (linearized elastic solid to be more precise) is an approximation that has served as an indispensable model in virtue of its usefulness and applicability. The same can be said of the linear viscoelastic model; while it is not frame-invariant, its ease of use and the conformity of the predictions of the model with available experimental data have rendered it an essential tool to the practicing engineer.

It is our goal that the treatment of material modeling, formulation of the basic issues in mechanics, and methods for the calculation and solution of engineering problems presented here will enable the student or practicing engineer to make optimal and effective use of polymeric materials.

A word of caution to the reader about our notation: we follow the style of Timoshenko. While the equations are numbered sequentially during the development of the theory in each chapter, we assign equation numbers independently for the solution of the special problems that are treated in each chapter.

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