



# Nonlinear viscoelastic solids

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## Abstract

An overview of constitutive equations and models for fracture and strength of nonlinear viscoelastic solids is given. Recent work is emphasized. Research needs are listed in the concluding section. © 1999 Elsevier Science Ltd. All rights reserved.

## 1. Introduction

Many materials of engineering importance exhibit significant nonlinear viscoelastic behavior in physical environments and under mechanical loading of practical interest. Plastics and rubber, with and without reinforcement (Lai and Bakker, 1995; Tuttle et al., 1995; Ha and Schapery, 1998), asphalt concrete (Uzan, 1996), polycrystalline ice (Schapery, 1997b) and biological materials (Fung, 1993) are examples. Viscoelastic behavior manifests itself in various ways, including creep under constant load, stress relaxation under constant deformation, time-dependent recovery of deformation following load removal, time-dependent creep rupture and frequency-dependence of fatigue strength. If, following load removal, a measurable portion of the deformation does not vanish after a long period of time, and this residual deformation is affected by the time under prior loading, then this deformation is commonly called viscoplastic. Viscoelastic solids, as discussed here, may or may not exhibit viscoplasticity.

Our attention here is mostly on mechanical behavior of monolithic and composite materials, and not on behavior of engineering structures made of these materials. There are two main sections in this paper: the first is on constitutive equations and second is on fracture and strength models. The emphasis is on nonlinearities, rather than linear effects. These nonlinearities may be due to intrinsic, locally nonlinear stress-strain behavior that exists practically down to the atomic or molecular scale, or may be due to the combined effect on macro-stress-strain equations of many defects that are large enough to be modeled using local continuum mechanics such as distributed microcracks or dislocations. Procedures

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# Nonlinear Viscoelastic Solids

**Pouria Hajikarimi, Alireza Sadat  
Hosseini**



## **Nonlinear Viscoelastic Solids:**

**Nonlinear Viscoelastic Solids** F. J. Lockett, 1972      Creep and Relaxation of Nonlinear Viscoelastic Materials William N. Findley, Francis A. Davis, 2013-01-15 This pioneering book presents the basic theory experimental methods experimental results and solution of boundary value problems in a readable useful way to designers as well as research workers and students The mathematical background required has been kept to a minimum and supplemented by explanations where it has been necessary to introduce specialized mathematics Also appendices have been included to provide sufficient background in Laplace transforms and in step functions Chapters 1 and 2 contain an introduction and historic review of creep As an aid to the reader a background on stress strain and stress analysis is provided in Chapters 3 and 4 an introduction to linear viscoelasticity is found in Chapter 5 and linear viscoelastic stress analysis in Chapter 6 In the next six chapters the multiple integral representation of nonlinear creep and relaxation and simplifications to single integral forms and incompressibility are examined at length After a consideration of other representations general relations are derived then expanded to components of stress or strain for special cases Both constant stress or strain and variable states are described together with methods of determining material constants Conversion from creep to relaxation effects of temperature and stress analysis problems in nonlinear materials are also treated here Finally Chapter 13 discusses experimental methods for creep and stress relaxation under combined stress This chapter considers especially those experimental problems which must be solved properly when reliable experimental results of high precision are required Six appendices present the necessary mathematical background conversion tables and more rigorous derivations than employed in the text An extensive updated bibliography completes the book      **Nonlinear Viscoelastic Solids [By] F. J. Lockett** F. J. Lockett, 1972      **Creep and Relaxation of Nonlinear Viscoelastic Materials** William Nichols Findley, James S. Lai, Kasif Onaran, 1976 Pioneering book presents basic theory experimental methods and results solution of boundary value problems Topics include creep stress and strain deformation analyses multiple integral representation of nonlinear creep and relaxation much more Appendices Bibliography      Viscoelastic Solids (1998) Roderic S. Lakes, 2017-11-22 Viscoelastic Solids covers the mathematical theory of viscoelasticity and physical insights causal mechanisms and practical applications The book presents a development of the theory addressing both transient and dynamic aspects as well as emphasizing linear viscoelasticity synthesizes the structure of the theory with the aim of developing physical insight illustrates the methods for the solution of stress analysis problems in viscoelastic objects explores experimental methods for the characterization of viscoelastic materials describes the phenomenology of viscoelasticity in a variety of materials including polymers metals high damping alloys rock piezoelectric materials cellular solids dense composite materials and biological materials analyzes high damping and extremely low damping provides the theory of viscoelastic composite materials including examples of various types of structure and the relationships between structure and mechanical properties contains examples on the use of

viscoelastic materials in preventing and alleviating human suffering Viscoelastic Solids also demonstrates the use of viscoelasticity for diverse applications such as earplugs gaskets computer disks satellite stability medical diagnosis injury prevention vibration abatement tire performance sports spacecraft explosions and music      **Theory of Viscoelasticity** R. M. Christensen, 2013-04-26 Integration of theoretical developments offers complete description of linear theory of viscoelastic behavior of materials with theoretical formulations derived from continuum mechanics viewpoint and discussions of problem solving 1982 edition      **Mechanics of Viscoelastic Solids** Aleksey D. Drozdov, 1998-03-06 This book focuses on the mechanical response in viscoelastic media under isothermal and nonisothermal conditions The viscoelastic response covered in this book is observed in a wide variety of common materials polymers and plastics metals and alloys at elevated temperatures concrete soils road construction and building materials biological tissues and foodstuffs Emphasizing the mechanical behavior of solid polymers subjected to physical aging the book analyzes constitutive equations in thermoviscoelasticity and compares the results of numerical simulation with experimental data After covering linear viscoelastic media at small strains a clear approach to nonlinear constitutive equations in viscoelasticity at small strains and at finite strains is developed The book concludes with coverage of constitutive relations in thermoviscoelasticity which account for thermally induced changes both in elastic moduli and relaxation spectra Written for specialists in mechanical and chemical engineering in the fields of manufacturing polymer and polymer composite articles this book will also appeal to specialists in applied and industrial mathematics mechanics of continua and polymer physics who study the response of solid polymers to thermomechanical stimuli      **Constitutive Modelling of Solid Continua** José Merodio, Raymond Ogden, 2019-11-14 This volume consists of a collection of chapters by recognized experts to provide a comprehensive fundamental theoretical continuum treatment of constitutive laws used for modelling the mechanical and coupled field properties of various types of solid materials It covers the main types of solid material behaviour including isotropic and anisotropic nonlinear elasticity implicit theories viscoelasticity plasticity electro and magneto mechanical interactions growth damage thermomechanics poroelasticity composites and homogenization The volume provides a general framework for research in a wide range of applications involving the deformation of solid materials It will be of considerable benefit to both established and early career researchers concerned with fundamental theory in solid mechanics and its applications by collecting diverse material in a single volume The readership ranges from beginning graduate students to senior researchers in academia and industry      Continuum Mechanics of Single-Substance Bodies A. Cemal Eringen, 2013-10-22 Continuum Physics Volume II Continuum Mechanics of Single Substance Bodies discusses the continuum mechanics of bodies constituted by a single substance providing a thorough and precise presentation of exact theories that have evolved during the past years This book consists of three parts basic principles constitutive equations for simple materials and methods of solution Part I of this publication is devoted to a discussion of basic principles irrespective of material geometry and

constitution that are valid for all kinds of substances including composites The geometrical notions kinematics balance laws and thermodynamics of continua are also deliberated Part II focuses on materials consisting of a single substance followed by a general theory of constitutive equations and special types of bodies The thermoelastic solids thermoviscous fluids and memory dependent materials are likewise considered Part III is devoted to a discussion of a variety of nonlinear and linear problems as well as nonlinear deformations of elastic solids viscometric fluids singular surfaces and waves and complex function technique This volume is a good source for researchers and students conducting work on the continuum mechanics of single substance bodies

**Computational Modeling, Optimization and Manufacturing Simulation of Advanced Engineering Materials** Pablo Andrés Muñoz-Rojas, 2016-06-20 This volume presents recent research work focused in the development of adequate theoretical and numerical formulations to describe the behavior of advanced engineering materials Particular emphasis is devoted to applications in the fields of biological tissues phase changing and porous materials polymers and to micro nano scale modeling Sensitivity analysis gradient and non gradient based optimization procedures are involved in many of the chapters aiming at the solution of constitutive inverse problems and parameter identification All these relevant topics are exposed by experienced international and inter institutional research teams resulting in a high level compilation The book is a valuable research reference for scientists senior undergraduate and graduate students as well as for engineers acting in the area of computational material modeling

*Mechanical Characterization of Nonlinear Viscoelastic Solids for Iterative Solution of Boundary Value Problems* Richard G. Dong, Karl S. Pister, Robert S. Dunham, CALIFORNIA UNIV BERKELEY STRUCTURAL ENGINEERING LAB., University of California, Berkeley. Structural Engineering Laboratory, 1968 A boundary value problem of quasi static deformation of physically nonlinear viscoelastic solids is discussed in the context of providing a scheme for characterization of material response in a manner compatible with an algorithm for numerical solution of boundary value problems An illustrative example involving axial deformation of a statistically indeterminate nonlinear viscoelastic rod is included Author

*Computational Viscoelasticity* Severino P. C. Marques, Guillermo J. Creus, 2012-01-03 This text is a guide how to solve problems in which viscoelasticity is present using existing commercial computational codes The book gives information on codes structure and use data preparation and output interpretation and verification The first part of the book introduces the reader to the subject and to provide the models equations and notation to be used in the computational applications The second part shows the most important Computational techniques Finite elements formulation Boundary elements formulation and presents the solutions of Viscoelastic problems with Abaqus

**Constructional Viscoelastic Composite Materials** Pouria Hajikarimi, Alireza Sadat Hosseini, 2023-06-01 Viscoelasticity is a complicated theorem that is generally used in several aspects of material characterization and modeling of polymers resins fiber reinforced composites bituminous composites etc On the other hand the heterogeneous nature of composites like asphalt concrete and fiber reinforced polymers has motivated lots of researchers

to investigate the mechanical and rheological properties of these materials This book mainly consists of the theory and application of viscoelastic materials used for construction It starts with a comprehensible presentation of the theory of linear and nonlinear viscoelasticity Wherein the application of viscoelastic equations and principles on constructional viscoelastic composite materials considering time temperature loading rate dependency and heterogeneity of composite substances is highlighted The principles and equations of the viscoelasticity theorem are presented in several books but here it is tried to present them more understandable and straightforwardly This helps in solving real problems of heterogeneous composite materials especially those which are used in construction Moreover the fundamental experiments for characterizing the elastic and viscoelastic properties of fibrous and bituminous composites are introduced and summarized Then after some analytical and empirical formulations for deriving the material properties of composites from the properties of the basic constituents are presented These are followed by numerical simulation techniques using the finite element method to simulate composite materials

*Research in Mathematics of Materials Science* Malena I. Español, Marta Lewicka, Lucia Scardia, Anja Schlömerkemper, 2022-09-27 This volume highlights contributions of women mathematicians in the study of complex materials and includes both original research papers and reviews The featured topics and methods draw on the fields of Calculus of Variations Partial Differential Equations Functional Analysis Differential Geometry and Topology as well as Numerical Analysis and Mathematical Modelling Areas of applications include foams fluid solid interactions liquid crystals shape memory alloys magnetic suspensions failure in solids plasticity viscoelasticity homogenization crystallization grain growth and phase field models

**Dilation Enhanced Stress Relaxation Effects in the Nonlinear Viscoelastic Solid Polymeric Structures** Je-Hong Min, 1995 **Continuum Mechanics - Volume II** José Merodio, Giuseppe

Saccomandi, 2011-11-30 The main objective of continuum mechanics is to predict the response of a body that is under the action of external and or internal influences i e to capture and describe different mechanisms associated with the motion of a body that is under the action of loading A body in continuum mechanics is considered to be matter continuously distributed in space Hence no attention is given to the microscopic atomic structure of real materials although non classical generalized theories of continuum mechanics are able to deal with the mesoscopic structure of matter i e defects cracks dispersive lengths Matter occupies space in time and the response of a body in continuum mechanics is restricted to the Newtonian space time of classical mechanics in this volume Einstein s theory of relativity is not considered In the classical sense loading is considered as any action that changes the motion of the body This includes for instance a change in temperature or a force applied By introducing the concept of configurational forces a load may also be considered as a force that drives a change in the material space for example the opening of a crack Continuum mechanics refers to field descriptions of phenomena that are usually modeled by partial differential equations and from a mathematical point of view require non standard knowledge of non simple technicalities One purpose in this volume has been to present the different subjects in a self contained way for

a general audience The organization of the volume is as follows Mathematically to predict the response of a body it is necessary to formulate boundary value problems governed by balance laws The theme of the volume that is an overview of the subject has been written with this idea in mind for beginners in the topic Chapter 1 is an introduction to continuum mechanics based on a one dimensional framework in which simultaneously a more detailed organization of the chapters of this volume is given A one dimensional approach to continuum mechanics in some aspects maybe misleading since the analysis is oversimplified Nevertheless it allows us to introduce the subject through the early basic steps of the continuum analysis for a general audience Chapters 3 4 and 5 are devoted to the mathematical setting of continuum analysis kinematics balance laws and thermodynamics respectively Chapters 6 and 7 are devoted to constitutive equations Chapters 8 and 9 deal with different issues in the context of linear elastostatics and linear elastodynamics and waves respectively for solids Linear Elasticity is a classical and central theory of continuum mechanics Chapter 10 deals with fluids while chapter 11 analyzes the coupled theory of thermoelasticity Chapter 12 deals with nonlinear elasticity and its role in the continuum framework Chapters 13 and 14 are dedicated to different applications of solid and fluid mechanics respectively The rest of the chapters involve some advanced topics Chapter 15 is dedicated to turbulence one of the main challenges in fluid mechanics Chapter 16 deals with electro magneto active materials a coupled theory Chapter 17 deals with specific ideas of soft matter and chapter 18 deals with configurational forces In chapter 19 constitutive equations are introduced in a general implicit form Well posedness existence time of existence uniqueness continuity of the equations of the mechanics of continua is an important topic which involves sophisticated mathematical machinery Chapter 20 presents different analyses related to these topics Continuum Mechanics is an interdisciplinary subject that attracts the attention of engineers mathematicians physicists etc working in many different disciplines from a purely scientific environment to industrial applications including biology materials science engineering and many other subjects

### **Mechanics and Chemistry of Solid Propellants** A. C.

Eringen,H. Liebowitz,S. L. Koh,2014-06-28 Mechanics and Chemistry of Solid Propellants is a collection of papers presented at the Fourth Symposium on Naval Structural Mechanics held in Purdue University Lafayette Indiana on April 19 21 1965 under the joint sponsorship of the Office of Naval Research and Purdue University The contributors consider the development and utilization of solid propellants This book is composed of 22 chapters that cover the many branches of studies that touch upon the science and technology of solid propellants Some chapters present the mathematical and physical theories underlying the behavior of solid propellants such as nonlinear and linear theories of viscoelasticity Other chapters are devoted to advances in solid propellant binder chemistry combustion and its effects on the structural integrity of the solid propellant grain and design and other engineering problems This book will be of value to scientists engineers and researchers who are interested in the diverse applications of solid propellants Research in Progress ,1964 Non-Linear Viscoelasticity of Rubber Composites and Nanocomposites Deepalekshmi Ponnammam,Sabu Thomas,2014-11-20 Advances in

Polymer Science enjoys a longstanding tradition and good reputation in its community. Each volume is dedicated to a current topic and each review critically surveys one aspect of that topic to place it within the context of the volume. The volumes typically summarize the significant developments of the last 5 to 10 years and discuss them critically, presenting selected examples explaining and illustrating the important principles and bringing together many important references of primary literature. On that basis, future research directions in the area can be discussed. Advances in Polymer Science volumes thus are important references for every polymer scientist as well as for other scientists interested in polymer science as an introduction to a neighboring field or as a compilation of detailed information for the specialist.

**Springer Handbook of Experimental Solid Mechanics** William N. Sharpe, Jr., William N. Sharpe, 2008-12-04

The Springer Handbook of Experimental Solid Mechanics documents both the traditional techniques as well as the new methods for experimental studies of materials, components and structures. The emergence of new materials and new disciplines together with the escalating use of on and off line computers for rapid data processing and the combined use of experimental and numerical techniques have greatly expanded the capabilities of experimental mechanics. New exciting topics are included on biological materials, MEMS and NEMS, nanoindentation, digital photomechanics, photoacoustic characterization and atomic force microscopy in experimental solid mechanics. Presenting complete instructions to various areas of experimental solid mechanics, guidance to detailed expositions in important references and a description of state of the art applications in important technical areas, this thoroughly revised and updated edition is an excellent reference to a widespread academic, industrial and professional engineering audience.



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