Variational approach to viscoelastic fracture: comparison of a phase-field and a lip-field approach

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Abstract Fracture of viscoelastic materials is considered to be a complex phenomenon due to their highly rate sensitive behavior. In this context, we are interested in the quasi-static response of a viscoelastic solid subjected to damage. This paper outlines a new incremental variational based approach and its computational implementation to model damage in viscoelastic solids. The variational formalism allows us to embed the local constitutive equations into a global incremental potential, the minimization of which provides the solution to the mechanical problem. Softening damage models in their local form are known to result in spurious mesh-sensitive results, and hence, non-locality (or regularization) has to be introduced to preserve the mathematical relevance of the problem. In the present paper, we consider two different regularization techniques for the viscoelastic damage model: a particular phase-field and a lip-field approach. The model parameters are calibrated to obtain some equivalence between both these approaches. Numerical results are then presented for the bidimensional case and both these approaches compare well. Numerical results also demonstrate the ability of the model to qualitatively represent the typical rate-dependent behaviour of the viscoelastic materials. Besides, the novelty of the present work also lies in the use of lip-field approach for the first time in a viscoelastic context.

Keywords Damage · Viscoelasticity · Lip-field · Phase-field · Variational approach

1 Introduction

Viscoelastic materials like asphalt, biological tissues, wood and polymers have numerous applications in engineering. The properties of these materials are highly rate and temperature dependent, therefore, greatly affecting their failure behavior (Lakes and Wineman 2006; D'Amico et al. 2013). Designing for the mitigation of fractures in viscoelastic materials is an important problem, for example, in the case of asphalt and pavement construction (Pirmohammad and Ayatollahi 2020).

Fracture mechanics commenced with the earlier work of Griffith (Dugdale 1921). Based on this theory, the stress at the crack tip becomes infinite. Fracture mechanics is used to characterise the loads on crack using a single parameter. A number of different parameters have been developed and used. When the non-

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Hussin A.Rothana

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The Variational Approach to Fracture Blaise Bourdin,Gilles A. Francfort,Jean-Jacques Marigo,2008-04-19 Presenting original results from both theoretical and numerical viewpoints this text offers a detailed discussion of the variational approach to brittle fracture This approach views crack growth as the result of a competition between bulk and surface energy treating crack evolution from its initiation all the way to the failure of a sample The authors model crack initiation crack path and crack extension for arbitrary geometries and loads **Variational Approach to Fracture Mechanics with Plasticity** Roberto Alessi,2013 **Applications of the Variational Approach to Fracture Mechanics** Ataollah Mesgarnejad,2014 *A Variational Approach to Fracture and Other Inelastic Phenomena* Gianpietro Del Piero,2013-08-30 This book exposes a number of mathematical models for fracture of growing difficulty All models are treated in a unified way based on incremental energy minimization They differ from each other by the assumptions made on the inelastic part of the total energy here called the cohesive energy Each model describes a specific aspect of material response and particular care is devoted to underline the correspondence of each model to the experiments The content of the book is a re elaboration of the lectures delivered at the First Sperlonga Summer School on Mechanics and Engineering Sciences in September 2011 In the year and a half elapsed after the course the material has been revised and enriched with new and partially unpublished results Significant additions have been introduced in the occasion of the course The variational approach to fracture and other inelastic phenomena delivered at SISSA Trieste in March 2013 The Notes reflect a research line carried on by the writer over the years addressed to a comprehensive description of the many aspects of the phenomenon of fracture and to its relations with other phenomena such as the formation of microstructure and the changes in the material s strength induced by plasticity and damage Reprinted from the Journal of Elasticity volume 112 issue 1 2013 Development of a Work-controlled Algorithm for the Variational Approach to Fracture Mechanics and Its Application to Sandstone Burst Experiments Ataollah Mesgarnejad,2014 *Discrete Volume Method : a Variational Approach for Brittle Fracture* Víctor Eduardo Cardoso Nungaray,2018 This thesis presents a proposal to simulate mechanics and dynamics of brittle fracture A variational formulation is used to describe Lagrangian mechanics by minimizing the difference between potential and kinetic energy of the system obtaining a pair of partial differential equations the solution of these equations corresponds to the displacement field and damage phase field respectively Such an equations are coupled in the sense that the damage field is used in the first equation and the displacement field is used in the second one In this work we propose a numerical method based on control volumes to solve the differential equations extending the formulation to support the separation of control volumes processing these volumes as discrete entities This treatment results in accurate calculations of stress field and the nucleation of new internal fractures that can be propagated through domain creating multiple bifurcations To integrate equations inside control volumes we introduce a family of polynomial splines that we refer as homeostatic splines since its

derivatives are null at vertices with a smooth function variation between adjacent volumes Furthermore we propose a shape function with trigonometric components for dynamic analysis allowing bigger time steps that with traditional approaches Finally we perform ten numerical experiments to show the effectiveness of the method and to compare our results with those published by other authors   Proceedings of the 2nd International Conference on Structural Damage Modelling and Assessment Magd Abdel Wahab,2021-12-04 This book comprises the select proceedings from the 2nd International Conference on Structural Damage Modelling and Assessment SDMA 2021 held in the city of Ghent Belgium on 4 5 August 2021 It discusses the recent advances in fields related to damage modelling damage detection and assessment non destructive testing and evaluation structure integrity and structural health monitoring The conference covers all research topics and applications relevant to structural damage modelling and assessment using theoretical numerical and experimental techniques This book is useful to scientists and engineers in academia and industry who are interested in the field of structural damage and integrity for disaster risk reduction   **Advances in Computational Plasticity** Eugenio Oñate,Djordje Peric,Eduardo de Souza Neto,Michele Chiumenti,2017-09-09 This book brings together some 20 chapters on state of the art research in the broad field of computational plasticity with applications in civil and mechanical engineering metal forming processes geomechanics nonlinear structural analysis composites biomechanics and multi scale analysis of materials among others The chapters are written by world leaders in the different fields of computational plasticity   **The Variational Approach to Brittle Fracture in Materials with Anisotropic Surface Energy and in Thin Sheets** Bin Li,2016 Fracture mechanics of brittle materials has focused on bulk materials with isotropic surface energy In this situation different physical principles for crack path selection are very similar or even equivalent The situation is radically different when considering crack propagation in brittle materials with anisotropic surface energy Such materials are important in applications involving single crystals extruded polymers or geological and organic materials When this anisotropy is strong the phenomenology of crack propagation becomes very rich with forbidden crack propagation directions or complex sawtooth crack patterns Thus this situation interrogates fundamental issues in fracture mechanics including the principles behind the selection of crack direction Similarly tearing of brittle thin elastic sheets ubiquitous in nature technology and daily life challenges our understanding of fracture Since tearing typically involves large geometric nonlinearity it is not clear whether the stress intensity factors are meaningful or if and how they determine crack propagation Geometry together with the interplay between stretching and bending deformation leads to complex behaviors restricting analytical approximate solutions to very simplified settings and specific parameter regimes In both situations a rich and nontrivial experimental record has been successfully understood in terms of simple energetic models However general modeling approaches to either fracture in the presence of strong surface energy anisotropy or to tearing capable of exploring new physics have been lacking The success of energetic simple models suggests that variational theories of brittle fracture may provide a unifying

and general framework capable of dealing with the more general situations considered here To address fracture in materials with strongly anisotropic surface energy we propose a variational phase field model resorting to the extended Cahn Hilliard framework proposed in the context of crystal growth Previous phase field models for anisotropic fracture were formulated in a framework only allowing for weak anisotropy We implement numerically our higher order phase field model with smooth local maximum entropy approximants in a direct Galerkin method The numerical results exhibit all the features of strongly anisotropic fracture and reproduce strikingly well recent experimental observations To explore tearing of thin films we develop a geometrically exact model and a computational framework coupling elasticity stretching and bending fracture and adhesion to a substrate We numerically implement the model with subdivision surface finite elements Our simulations qualitatively and quantitatively reproduced the crack patterns observed in tearing experiments Finally we examine how shell geometry affects fracture As suggested by previous results and our own phase field simulations shell shape dramatically affects crack evolution and the effective toughness of the shell structure To gain insight and eventually develop new concepts for optimizing the design of thin shell structures we derive the configurational force conjugate to crack extension for Koiter s linear thin shell theory We identify the conservative contribution to this force through an Eshelby tensor as well as non conservative contributions arising from curvature *Modeling in Engineering Using Innovative Numerical Methods for Solids and Fluids* Laura De Lorenzis,Alexander Düster,2020-02-08 The book examines innovative numerical methods for computational solid and fluid mechanics that can be used to model complex problems in engineering It also presents innovative and promising simulation methods including the fundamentals of these methods as well as advanced topics and complex applications Further the book explores how numerical simulations can significantly reduce the number of time consuming and expensive experiments required and can support engineering decisions by providing data that would be very difficult if not impossible to obtain experimentally It also includes chapters covering topics such as particle methods addressing particle based materials and numerical methods that are based on discrete element formulations fictitious domain methods phase field models computational fluid dynamics based on modern finite volume schemes hybridizable discontinuous Galerkin methods and non intrusive coupling methods for structural models **Mechanical and Aerospace Engineering, ICMAE2012** Amanda Wu,2012-11-29 Selected peer reviewed papers from the 2012 3rd International Conference on Mechanical and Aerospace Engineering ICMAE 2012 July 7 8 2012 Paris France **Mechanics of Advanced Materials** Vadim V. Silberschmidt,Valery P. Matveenko,2015-04-09 The book presents interesting examples of recent developments in this area Among the studied materials are bulk metallic glasses metamaterials special composites piezoelectric smart structures nonwovens etc The last decades have seen a large extension of types of materials employed in various applications In many cases these materials demonstrate mechanical properties and performance that vary significantly from those of their traditional counterparts Such uniqueness is sought or even specially manufactured to meet increased requirements on

modern components and structures related to their specific use As a result mechanical behaviors of these materials under different loading and environmental conditions are outside the boundaries of traditional mechanics of materials presupposing development of new characterization techniques theoretical descriptions and numerical tools The book presents interesting examples of recent developments in this area Among the studied materials are bulk metallic glasses metamaterials special composites piezoelectric smart structures nonwovens etc   *Innovations in the Analysis and Design of Marine Structures* Yordan Garbatov,C. Guedes Soares,2025-05-09 Innovations in the Analysis and Design of Marine Structures is a collection of papers presented at MARSTRUCT 2025 the 10th International Conference on Marine Structures MARSTRUCT 2025 Lisbon Portugal 20 22 May 2025 The contributions cover a wide range of topics including Loads and load effects Strength assessment Experimental analysis of structures Materials and fabrication of structures Structural design and optimization Structural reliability and safety Innovations in the Analysis and Design of Marine Structures is essential reading for academics engineers and professionals involved in the design of marine and offshore structures The Proceedings in Marine Technology and Ocean Engineering series is devoted to the publication of proceedings of peer reviewed international conferences dealing with various aspects of Marine Technology and Ocean Engineering The Series includes the proceedings of the following conferences the Marine Structures MARSTRUCT Conferences the Maritime Technology MARTECH Conferences the Renewable Energies Offshore RENEW Conferences the Collision and Grounding of Ships and Offshore Structures ICCGS Conferences and the International Maritime Association of the Mediterranean IMAM Conferences The Marine Technology and Ocean Engineering series is also open to new conferences that cover topics on the sustainable exploration and exploitation of marine resources in various fields such as maritime transport and ports usage of the ocean including coastal areas nautical activities the exploration and exploitation of mineral resources the protection of the marine environment and its resources and risk analysis safety and reliability The aim of the series is to stimulate advanced education and training through the wide dissemination of the results of scientific research   Applied Mechanics Reviews ,1998

Statistical Rock Physics Gabor Korvin,2024-04-06 The book is the first systematic and comprehensive treatise of stochastic models and computational tools that have emerged in rock physics in the last 20 years The field of statistical rock physics is a part of rock physics Petrophysics Its concepts methods and techniques are borrowed from stochastic geometry and statistical physics This discipline describes the interior geometry of rocks derives their effective physical properties based on their random composition and the random arrangement of their constituents and builds models to simulate the past geological processes that had formed the rock The aim of the book is to help the readers to understand the claims techniques and published results of this new field and most importantly to teach them in order to creatively apply stochastic geometry and statistical physics in their own research tasks For this purpose the underlying mathematics will be discussed in all sections of the book numerical solutions will be highlighted a full set of references will be provided and theory will go hand in

hand with practical applications to hydraulic permeability electric conduction rock failure NMR mechanics of random grain packings as well as the compaction of shale **Paper** ,1991 *On Fracture of Thin Films* Andrés A. Leòn Baldelli,2013 We study the problem of mechanical failure of thin films on a rigid substrate This is a problem of technological interest as thin films of various kinds play a critical role in electronic devices and as protective coatings In addition it raises a fundamental interest in the mechanical modeling analytic treatment and numerical experimentation In all these systems a change in temperature moisture or other environmental condition results in unequal spontaneous deformation of the film and substrate This leads to mechanical stress and failure in the form of film fracture debonding film buckling grooving etc This thesis considers situations where the film is subjected to tensile stress so that the first two mechanisms of failure are active in the context of a variational model for fracture The thesis begins with a broad overview of the issues involved in the problem a survey of the literature and a summary of the theoretical framework that is used It then provides a detailed analysis of a idealized problem in one dimension using a phenomenological model This analysis is carefully conducted and provides important insights into the critical issues Then the phenomenological model is rigorously justified with an asymptotic approach It is performed rigorously in the scalar setting and heuristically in the physically relevant vector setting The final chapter is dedicated to numerical studies of the problem using a regularized model **Journal of Electronic Packaging** ,1992 **SPE Production Engineering** ,1991 **Winter Annual Meeting** American Society of Mechanical Engineers,

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