

Fracture of Solids Based on Deformation Wave Dynamics

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Abstract. Fracture of solids is considered from the viewpoint of wave dynamics derived from a field theory. Based on the principle known as the symmetry of physical laws, the present field theory describes deformation and fracture on the same theoretical basis. From experimental observations, fracture is classified into two types; the first type characterized by decaying displacement waves that initially travel and eventually become stationary, and the second type characterized by shear bands that are initially dynamic and eventually become stationary. The field theory interprets that the decaying displacement wave represents elasto-plastic deformation dynamics and that the shear band indicates solitary wave dynamics associated with strain concentration. In either case, the theory explains that the termination of wave propagation causes infinite volume expansion that generates material discontinuity. From the wave dynamical viewpoint, fracture is a self-driving phenomenon where the decrease in the elastic constant in a late stage of deformation induces instability in oscillatory dynamics which leads to exponential increase in the volume expansion with time. The theory indicates that in this mechanism fast pulling rate enhances the instability. Simple numerical analysis with finite element modeling supports this argument of instability and its association with the pulling rate.

INTRODUCTION

Conventionally, elastic deformation, plastic deformation and fracture of solids are treated as separate phenomena. Consequently, fundamentally different approaches are applied to the respective regimes. In the elastic regime, continuum mechanics [1, 2] is used to describe reversible deformation based on the linear constitutive relation. Various theories [3, 4, 5, 6, 7, 8] are available for the plastic regime, and these theories can be generally classified into two groups. The theories classified in the first group [3, 4, 5, 6] are based on certain physical processes such as dislocation dynamics and thermodynamic processes. Those classified as the second group [7, 8] describe deformation based on nonlinear constitutive relations that are empirically known or mathematically modeled. In the regime of fracture, a number of theories [9, 10] have been developed as well. They mostly describe crack propagation based on various underlying physics such as energy argument near the crack tip to evaluate the crack resistance of the material under given conditions.

Although these are established theories and work well in the respective regimes, there are limitations in the use of them for some areas of engineering for two main reasons. The first reason is that in reality elastic and plastic deformations are not separate events but they coexist. Metal specimens freshly taken out from an annealing oven always have a number of dislocations. The existence of dislocations and other defects makes the elastic theory less accurate when the object is in the micro or nano-scale level. The second reason is that often the analysis of the transition from one regime to another is important in engineering. For instance, fracture mechanics cannot describe when a fatigued metal fractures. On the other hand, a deformation theory cannot describe crack generation or propagation. The use of a deformation and fracture theory separately is not practical to predict fracture accurately.

In this study, we discuss a physics-based approach to describe deformation and fracture of solids on the same theoretical basis. The present approach is based on a fundamental physical principle known as the symmetry in physics [11], which in short, states that the laws of physics are independent of the choice of the coordinate system. In other words, the physical laws do not change where, when and how (still or in motion, or in which orientation in space) you make the experiment, although the obtained data are completely different depending on the way the experiment is conducted. In the present case, we request the symmetry in Hooke's law in local regions of the object under plastic deformation. The request of this local symmetry requires the introduction of a compensation (gauge) field. We can

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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 [Mechanics and Physics of Fracture](#) Laurent Ponson, 2023-03-31 The volume provides a comprehensive understanding of the macroscopic failure behavior of solids from the description of the microscopic failure processes and their coupling with the microstructure Several fundamental questions were addressed the relation between the microstructural features of materials and their fracture properties and crack trajectories the role of damage mechanisms and non linear deformations near the crack tip on the failure behavior of solids and finally the role of dynamic inertial effects during fast fracture was more briefly evoked The chapters provide a pedagogical overview of recently developed concepts and tools that permit to perform the transition from small scales to large ones in fracture problems thus introducing basic rules for the rational design of tough solids *High-Pressure Shock Compression of Solids II* Lee Davison, Dennis E. Grady, Mohsen Shahinpoor, 2012-12-06 This volume concerns the fracture and fragmentation of solid materials that occurs when they are subjected to extremes of stress applied at the highest possible rates The plan for the volume is to address experimental theoretical and computational aspects of high rate dynamic fracture and fragmentation with emphasis on recent work We begin with several chapters in which the emphasis falls on experimental methods and observations These chapters address both macroscopic responses and the microscopic cause of these responses This is followed by several chapters emphasizing modeling the physical explanation and mathematical representation of the observations Some of the models are deterministic while others focus on the stochastic aspects of the observations Often the overall objective of investigation of dynamic fracture and fragmentation phenomena is provision of a means for predicting the entire course of an event that begins with a stimulus such as an impact and proceeds through a complicated deformation and fracture process that results in disintegration of the body and formation of a rapidly expanding cloud of debris fragments Analysis of this event usually involves development of a continuum theory and computer code that captures the experimental observations by incorporating models of the important phenomena into a comprehensive description of the deformation and

fracture process It is to this task that the work of the last few chapters is devoted *Applied Mechanics Reviews*, 1992

Comprehensive Structural Integrity Ian Milne, R. O. Ritchie, B.L. Karihaloo, 2003-07-25 The aim of this major reference work is to provide a first point of entry to the literature for the researchers in any field relating to structural integrity in the form of a definitive research reference tool which links the various sub disciplines that comprise the whole of structural integrity Special emphasis will be given to the interaction between mechanics and materials and structural integrity applications Because of the interdisciplinary and applied nature of the work it will be of interest to mechanical engineers and materials scientists from both academic and industrial backgrounds including bioengineering interface engineering and nanotechnology The scope of this work encompasses but is not restricted to fracture mechanics fatigue creep materials dynamics environmental degradation numerical methods failure mechanisms and damage mechanics interfacial fracture and nano technology structural analysis surface behaviour and heart valves The structures under consideration include pressure vessels and piping off shore structures gas installations and pipelines chemical plants aircraft railways bridges plates and shells electronic circuits interfaces nanotechnology artificial organs biomaterial prostheses cast structures mining and more Case studies will form an integral part of the work *Fracture Mechanics* Huy Duong Bui, 2007-01-03 This book is an outgrowth of my involvement in two groups of research in solid mechanics created in 1960 for the French nuclear energy program At this time it was decided that France as a no oil reservoir country must be powered by nuclear energy which represents today 80% of the total tional energy supply Long before the construction of the first nuclear plant at Fessenheim in 1973 Electricit de France EdF created its first solid mechanics laboratory appointed researchers and sent them to the universities or abroad in order to learn about theories and new methods of assessment of the safety of structures Working at EdF I was training in Professor Jean Mandel s laboratory at Ecole Polytechnique LMS Paris My friend Ren Labbens working at Framatome the builder of nuclear plants was training at the Lehigh University under the guidance of professors G R Irwin and G C Sih We had to work hard both academically at the u versities laboratories and performing engineering tasks for our employer This dual position was a great chance for many of us since we discovered that real industrial problems are the source of new subjects and research problems to be solved by theoreticians in the universities and conversely we immediately knew if our theoretical work was good or not for appli tions as revealed in our daily works conducted for our industrial employer **Duality, Symmetry and Symmetry Lost in Solid Mechanics** Huy Duong Bui, Alain Ehrlicher, Xanthippi Markenscoff, 2011 Solid Mechanics Research Trends and Opportunities, 1985 **Mechanics of Solids**, 1987 **Solid Mechanics Research Trends and Oppotunities**, 1985 **Proceedings of the ASME Applied Mechanics Division**, 2007 *Eight Non-Classical Problems of Fracture Mechanics* Aleksander N. Guz, 2021-08-08 This book presents an analysis of eight non classical problems of fracture and failure mechanics mainly obtained by research in the department of dynamics and stability of continuum of the S P Timoshenko Institute of Mechanics of the National Academy

of Sciences of Ukraine NAS of Ukraine It focusses on the application of the 3D three dimensional theories of stability dynamics and statics of solid mechanics to the investigation of non classical problems of fracture and failure mechanics

Applied Solid Mechanics A.R.S. Ponter, A.C.F. Cocks, 1991-11-30 **Research Trends in Solid Mechanics** U.S. National Committee on Theoretical and Applied Mechanics, 1999 Hardbound Solid mechanics is a basic scientific discipline which provides the theoretical foundation experimental support solution methodology and computational tools for analysis design construction manufacture and behavior prediction in service of many devices machines materials structures and large complex systems that are essential to the existence and progress of an advanced civilization It is concerned with both manmade natural and living solid objects and with all aspects of their physical behavior that affect their function integrity or service life expectancy The contents of this volume offer examples of some of the activities that are currently at the forefront of solid mechanics research and also illustrate the vast reach of the discipline and of its interactions with other science and engineering endeavors

Inverse Problems in Mechanics of Materials H. D. Bui, 1994-06-23 Inverse Problems in the Mechanics of Materials concentrates on two timely subjects Ill posed inverse problems related to defect identification and the mechanics of homogeneous and heterogeneous media including such topics as cracked bodies solids with interfaces or inclusions and materials rendered inhomogeneous by irreversible deformation due to their thermomechanical history These intriguing subjects are not found together in previous publications Written in a unique easy to read format Inverse Problems in the Mechanics of Materials provides quick access to current information It includes up to date references and many recent results particularly in such classical subjects as elasticity plasticity and fracture mechanics The reader discovers numerous recipes for solving inverse problems and reviews of available methods provide applications to real life problems in industry

Recent Advances in Fracture Mechanics Wolfgang Knauss, R.A. Schapery, 1999-09-30 The papers in this volume represent a considerable cross section of the field of fracture mechanics a testimony to the breadth of interest that Mel and Max Williams friends share with them Several are expanded versions of papers that were given in special sessions honoring them at the 1997 Ninth International Conference on Fracture Mechanics in Sydney Australia The subjects treated in this volume can be classified as follows dynamic fracture problems as viewed primarily from a classical continuum point of view analysis of relatively general crack geometrics fracture problems of polymers and other relatively ductile materials scaling rules that allow extension of results obtained at one size to be translated into behavior at different size scales problems dealing with interactions that produce complex stress fields fracture problems directly appropriate to composite materials analysis of stress concentrations in anisotropic elastic solids and the problem of cracks in thin plates bending This volume will be of interest to engineers and scientists working on all aspects of the physics and mechanics of fracture

Engineering, 1905 *Dynamic Fracture* K. Ravi-Chandar, 2004-10-16 Dynamic fracture in solids has attracted much attention for over a century from engineers as well as physicists due both to its technological interest and to inherent

scientific curiosity Rapidly applied loads are encountered in a number of technical applications In some cases such loads might be applied deliberately as for example in problems of blasting mining and comminution or fragmentation in other cases such dynamic loads might arise from accidental conditions Regardless of the origin of the rapid loading it is necessary to understand the mechanisms and mechanics of fracture under dynamic loading conditions in order to design suitable procedures for assessing the susceptibility to fracture Quite apart from its repercussions in the area of structural integrity fundamental scientific curiosity has continued to play a large role in engendering interest in dynamic fracture problems In depth coverage of the mechanics experimental methods practical applications Summary of material response of different materials Discussion of unresolved issues in dynamic fracture *U.S. Government Research & Development Reports* ,1970
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