

APPLYING THE STRAIN ENERGY DENSITY CRITERION TO FATIGUE AND FRACTURE PROBLEMS IN THE TRANSPORTATION INDUSTRY

David Y. Jeong

ABSTRACT

Today fracture mechanics is an independent discipline that deals with structures containing detectable or visible sharp cracks. The basic concepts of fracture mechanics are well established due to the contributions of researchers such as G. C. Sih. This paper focuses on one of his many contributions: specifically, the strain energy density criterion for fatigue and fracture problems involving mixed mode loading. Moreover, this paper reviews examples of original research in the transportation industry in which the strain energy density criterion was applied. In particular, these examples come from the aircraft and railroad industries. Both industries now use fatigue and fracture control programs, developed from damage tolerance or fracture mechanics principles, to minimize the risks associated with structural failures.

Key Words:

1. INTRODUCTION

Historically, the problems associated with fatigue and fracture have been brought to the forefront of research after the occurrence of a structural failure. For example, brittle fractures were observed in about twenty-five percent of the fleet of welded Liberty ships constructed in the United States in the 1940s. Investigations revealed that the maximum bending moments at the time of failure were one-half of the bending moments allowed for in the design. Subsequently much of the early work on fracture mechanics in the United States was conducted at the Naval Research Laboratories. In 1954, the Comet I aircraft, the first jet-propelled passenger airplane, disintegrated in the air at approximately 9,140 meters (30,000 feet) and crashed into the Mediterranean Sea near Elba. Investigation of this crash concluded that the accident was caused by fatigue failure of the pressurized cabin. In 1988, an explosive decompression occurred in a commercial transport aircraft when approximately 5.5 meters (18 feet) of the upper crown

skin and structure separated from the fuselage while in flight at about 7,320 meters (24,000 feet) near Maui, Hawaii. The failure was caused by the formation, growth, and linkup of multiple fatigue cracks. The phenomenon of multiple site fatigue cracking in aging airplanes is now referred to as "widespread fatigue damage."

Today the principles of fracture mechanics are applied during the design process to control, mitigate, or prevent structural failures due to fatigue and fracture. Moreover, the basic concepts of fracture mechanics are now well known and established due to the contributions of researchers such as G. C. Sih. One among his many contributions is the development of the strain energy density criterion for fatigue and fracture problems involving mixed mode loading (Sih, 1974).

This paper reviews four examples in the transportation industry in which the strain energy density criterion was applied to examine the fatigue and fracture process. These examples originate from previous research studies. Two examples are presented from the aircraft industry, and are specifically related to the phenomenon of widespread fatigue damage. The other two examples come from the railroad industry, which now is evolving its fatigue and fracture control programs to emulate the damage

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George C. Sih, S. E. Hsu



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Fracture Problems and Solutions in the Energy Industry Leonard A. Simpson, 1982 **Predictive Corrosion and Failure Control in Process Operations** P. F. Timmins, 1996-01-01 Intended for inspectors and engineers in the refining petrochemical and process industries Includes material such as methods for inspecting process operations equipment a diagrammatic cross reference between processes and corrosion a philosophy on metals selection for the construction of equipment *Strength of Metals and Alloys (ICSMA 6)* R C Gifkins, 2013-10-02 Strength of Metals and Alloys ICSMA 6 Volume 1 contains the proceedings of the 6th International Conference on the Strength of Metals and Alloys held in Melbourne Australia on August 16 20 1982 The conference provided a forum for reviewing advances that have been made with regards to the strength of metals and alloys and tackled topics ranging from cross slip and work hardening to alloy design for strength High strain and high strain rate processes are also discussed Comprised of 88 chapters this volume begins with an introduction to the fundamentals of strengthening mechanisms such as the temperature and strain rate dependence of the flow stress of fatigued niobium single crystals and the mechanism of slip transfer across high angle grain boundaries Subsequent chapters focus on the behavior of dislocations near a free surface the strength of polycrystals void damage in dual phase steels during plastic deformation and the dynamic strain aging of cast iron Shear band deformation process in metallic glasses is also examined This book will be of interest to engineers metallurgists and materials scientists

Mechanical Behavior of Engineering Materials Y.M. Haddad, 2000-08-31 This monograph consists of two volumes and provides a unified comprehensive presentation of the important topics pertaining to the understanding and determination of the mechanical behaviour of engineering materials under different regimes of loading The large subject area is separated into eighteen chapters and four appendices all self contained which give a complete picture and allow a thorough understanding of the current status and future direction of individual topics Volume I contains eight chapters and three appendices and concerns itself with the basic concepts pertaining to the entire monograph together with the response behaviour of engineering materials under static and quasi static loading Thus Volume I is dedicated to the introduction the basic concepts and principles of the mechanical response of engineering materials together with the relevant analysis of elastic elastic plastic and viscoelastic behaviour Volume II consists of ten chapters and one appendix and concerns itself with the mechanical behaviour of various classes of materials under dynamic loading together with the effects of local and microstructural phenomena on the response behaviour of the material Volume II also contains selected topics concerning intelligent material systems and pattern recognition and classification methodology for the characterization of material response states The monograph contains a large number of illustrations numerical examples and solved problems The majority of chapters also contain a large number of review problems to challenge the reader The monograph can be used as a textbook in science and engineering for third and fourth undergraduate levels as well as for the graduate levels It is also a

definitive reference work for scientists and engineers involved in the production processing and applications of engineering materials as well as for other professionals who are involved in the engineering design process Advanced Composite Materials and Structures George C. Sih, S. E. Hsu, 1987-12 Through interviews with people in the jobs we learn what their job involves What types of food outlets what qualities are needed in different jobs Jobs looked at include cook chef waitress waiter counter attendant short order cook hostess etc Advanced Multilayered and Fibre-Reinforced Composites Y.M. Haddad, 2012-12-06 I express my sincere gratitude to NATO Science Committee for granting me the financial award to organize and direct the Advanced Research Workshop on MULTILAYERED and FIBRE REINFORCED COMPOSITES PROBLEMS AND PROSPECTS that was held in Kiev Ukraine during the period of June 2 6 1997 in collaboration with Professor S A Firstov of the Frantsevich Institute for Problems of Materials Science National Academy of Sciences Kiev Ukraine In this context I wish to convey special thanks to Dr J A Raussell Colom NATO Programme Director for Priority Area on High Technology for his kind efforts and continuous guidance in the course of organizing the Workshop I appreciate sincerely the opportunity of working closely with Professor Firstov and acknowledge with deep gratitude his outstanding contribution in co directing the Workshop I wish to express my special thanks to Dr N Orlovskaya of the Frantsevich Institute for her outstanding contribution towards both the organization and conduct of the Workshop I wish to convey my sincere thanks to Professor V V Skorohod Deputy Director of the Frantsevich Institute on behalf of the same Institute for hosting the Workshop and welcoming the participants to Kiev The very kind efforts of the members of the Scientific Advisory Committee the Local Organizing Committee and the Staff of the Frantsevich Institute towards the organization and conduct of the Workshop are gratefully appreciated I convey my full indebtedness to all researchers who participated in the Workshop

Techniques of Tomographic Isodyne Stress Analysis A. Pindera, 2001-11-30 It is true that Nothing is more practical than theory as Boltzmann said Provided however that the assumptions on which The theory is founded are well understood But indeed engineering costly experience shows that Nothing can be more disastrous than a theory when applied To a real task outside of practical limits of the assumptions made Because of an homonymous identity with the considered problem J T P The growing interest in Isodyne Stress Analysis and the related experience of the author show that the major monograph and reference book on the subject Isodyne Stress Analysis by Jerzy T Pindera and Marek Jerzy Pindera 27 does not contain sufficiently detailed data on the theories and techniques experimentation The purpose of this work is to close this gap Thus this work is an extension of Isodyne Stress Analysis and complementary to it Consequently only a short outline of the theory of isodynes is given in Chapter 2 Only the basic concepts and relations are presented to provide the link between the underlying analytical and optical theories and the experimental techniques One of the major purposes of a preface is to formulate and explain the chosen frame of reference in a condensed form even when some components of it are discussed in the text A main issue of the underlying frame of reference pertains to the roles of the abstract thinking and of the observation

in cognition of reality *Isodyne Stress Analysis* M.J. Pindera, 2012-12-06 It is true that Nothing is more practical than a theory Provided however That the assumptions on which the theory is founded Are well understood But indeed engineering experience shows that Nothing can be more disastrous than a theory When applied to a real problem Outside of the practical limits of the assumptions made Because of an homonymous identity With the problem under consideration J T P The primary objective of this work is to present the theories of analytical and optical isodynes and the related measurement procedures in a manner compatible with the modern scientific methodology and with the requirements of modern technology pertaining to the usefulness of the stress analysis procedures The selected examples illustrate some major theses of this work and demonstrate the particular efficiency of the isodyne methods in solving the technologically important problems in fracture mechanics and mechanics of composite structures including new materials To satisfy this objective it was necessary to depart from the common practice of presenting theories and techniques of experimental methods as a compatible system of equations and procedures without mentioning the tacitly accepted assumptions and their influence on the theoretical admissibility of analytical expressions and the reliability of the experimental or analytical results It was necessary to design a more general frame of reference which could allow to assess the scientific correctness of isodyne methods and the reliability of experimental results **Structural Integrity Assessment** Raghu V. Prakash, R. Suresh Kumar, Atikukke

Nagesha, Gomathy Sasikala, Arun Kumar Bhaduri, 2019-07-31 This volume contains selected papers from the Second Quadrennial International Conference on Structural Integrity ICONS 2018 The papers cover important topics related to structural integrity of critical installations such as power plants aircrafts spacecrafts defense and civilian components The focus is on assuring safety of operations with high levels of reliability and structural integrity This volume will be of interest to plant operators working with safety critical equipment engineering solution providers software professionals working on engineering analysis as well as academics working in the area **Rock Mechanics in Civil and Environmental**

Engineering Jian Zhao, Vincent Labiouse, Jean-Paul Dudt, Jean-Francois Mathier, 2010-05-19 During the last two decades rock mechanics in Europe has been undergoing some major transformation The reduction of mining activities in Europe affects heavily on rock mechanics teaching and research at universities and institutes At the same time new emerging activities notably underground infrastructure construction geothermal energy develop *Fracture Problems and Solutions in the*

Energy Industry Leonard A. Simpson, 1982 **Photoelasticity** Kozo Kawata, Masataka Nisida, 2012-12-06 Thirty five papers were presented at the International Symposium on Photoelasticity Tokyo 1986 representing fifty five authors Eighteen of these papers were presented by Japanese photoelasticians and seventeen by leading foreign authorities from eleven countries Austria Canada Czechoslovakia F R of Germany France Greece India Switzerland UK USA and USSR This is the first symposium on photoelasticity of international scope held in Japan The primary objectives of this symposium are to help bridge the gap between photoelastic researchers around the world to promote mutual understanding and communications

and to facilitate exchange of newly acquired knowledge in theories and techniques In addition it is important that these valuable results are communicated effectively to engineers who can apply them in practice in industry The papers presented at this symposium cover all branches of photo elasticity in a broad sense including in addition to long established photoelasticity newly developed moire interferometric and holographic photoelasticity caustics and speckle Therefore from an optical stress analysis perspective this volume is the latest comprehensive collection of photoelastic expertises Trends in Structural Mechanics J. Roorda,N.K. Srivastava,2012-12-06 The desire to understand the mechanics of elastic and plastic solids new materials and the stability reliability and dynamic behaviour of structures and their components under extreme environmental conditions has dominated research in structural engineering for many decades Advances in these areas have revolutionized design methods codes of practice and the teaching of structural engineers In this volume an international body of leading authorities presents some forty papers on current research directions in the specific areas of solid mechanics structural computation modern materials and their application buckling and instability design of structural systems and components reliability seismic analysis and engineering education They were presented at a symposium held July 10 12 1994 at the University of Waterloo Canada to honour Professor Archibald Norbert Sherbourne who recently retired from a long and active career of teaching research and academic administration at this University The themes of the work contained within this volume reflect Professor Sherbourne's own research interests and will be of interest to both academics and practicing structural engineers

Welding for Challenging Environments Sam Stuart,2014-06-28 Welding for Challenging Environments documents the proceedings of the International Conference on Welding for Challenging Environments held in Ontario Canada on October 15 17 1985 This compilation provides a unique reference to the state of technological development research and application of welded fabrications in challenging environments This book discusses the developments in pulsed gas metal arc welding pulsed FM GMA welding and narrow gap welding of pressure vessels The fracture toughness considerations for offshore structures microcomputer method for predicting preheat temperatures and submerged arc welding of high yield strength steel are also elaborated This text likewise covers the influence of nitrogen content on deposited weld metal notch toughness gas metal slag interactions of binary fluxes containing CaF_2 and evaluation of susceptibility of welds made with a stable austenitic welding wire to hot cracking This publication is a good source for welders and metallurgists as well as students interested in welded fabrications in challenging environments

Bibliography on the Fatigue of Materials, Components and Structures J. Y. Mann,2013-10-22 Bibliography on the Fatigue of Materials Components and Structures Volume 3 addresses the problems associated with fatigue loadings as evident in branches of engineering and technology Such debilitating factor also affects the human skeletal system The book provides several references that show an increasing focus being given to the problem of fatigue in materials components and structures The journals and lists of references used in the book which discuss the subject of fatigue are chosen to give an

initial identification of citations These sources are accompanied by computer based documentation systems The bibliographical data for each citation are thoroughly reviewed by checking the original bases of publication The references in the book are arranged chronologically according to its year of publication Major use has been made of abbreviations for the titles of journals and publications The book can serve as a valuable tool for doctors therapists students and researchers in the field of medicine

Methods of Analysis and Solutions of Crack Problems George C. Sih, 1973-01-31 It is well known that the traditional failure criteria cannot adequately explain failures which occur at a nominal stress level considerably lower than the ultimate strength of the material The current procedure for predicting the safe loads or safe useful life of a structural member has been evolved around the discipline of linear fracture mechanics This approach introduces the concept of a crack extension force which can be used to rank materials in some order of fracture resistance The idea is to determine the largest crack that a material will tolerate without failure Laboratory methods for characterizing the fracture toughness of many engineering materials are now available While these test data are useful for providing some rough guidance in the choice of materials it is not clear how they could be used in the design of a structure The understanding of the relationship between laboratory tests and fracture design of structures is to say the least deficient Fracture mechanics is presently at a standstill until the basic problems of scaling from laboratory models to full size structures and mixed mode crack propagation are resolved The answers to these questions require some basic understanding of the theory and will not be found by testing more specimens The current theory of fracture is inadequate for many reasons First of all it can only treat idealized problems where the applied load must be directed normal to the crack plane

Numerical Mathematics and Advanced Applications ENUMATH 2023, Volume 2 Adélia Sequeira, Ana Silvestre, Svilen S. Valtchev, João Janela, 2025-04-27 This book gathers outstanding papers presented at the European Conference on Numerical Mathematics and Advanced Applications ENUMATH 2023 The conference was held in Lisbon Portugal in September 2023 Leading experts in the field presented the latest results and ideas regarding the design implementation and analysis of numerical algorithms as well as their applications to relevant societal problems ENUMATH is a series of conferences held every two years to provide a forum for discussing basic aspects and new trends in numerical mathematics and its scientific and industrial applications all examined at the highest level of international expertise The first ENUMATH was held in Paris in 1995 with successive installments at various sites across Europe including Heidelberg 1997 Jyväskylä 1999 Ischia Porto 2001 Prague 2003 Santiago de Compostela 2005 Graz 2007 Uppsala 2009 Leicester 2011 Lausanne 2013 Ankara 2015 Bergen 2017 and Egmond aan Zee 2019

Fracture Research in Retrospect H.P. Rossmanith, 1997-01-01 This book describes the historical development of the engineering discipline of fracture mechanics from early times to the scientific treatment of the subject in the 20th century Most papers do not require a mathematical background to understand them

Advances in Thermal Spraying Sam Stuart, 2013-10-22 Advances in Thermal Spraying contains the proceedings of the Eleventh

International Thermal Spraying Conference held in Montreal Canada on September 8 12 1986 The papers explore technological advances in thermal spraying and the related field of surfacing by welding This book is comprised of 97 chapters divided into 16 sections and begins with a discussion on the applications of thermal spraying in the power generation industry with emphasis on the use of thermal coatings to protect boilers against corrosion The following chapters focus on thermal spraying as applied to low pressure processes carbide coatings properties of coatings such as aluminum bronze coatings and control and automation of the thermal spraying process The reader is then introduced to ceramic powders and coatings used in thermal spraying quality assurance of plasma spray powders and applications of thermal sprayed coatings to protect against corrosion and wear The remaining sections consider arc spraying post deposition treatment of plasma sprayed coatings and miscellaneous applications of thermal spraying including insulation of diesel engine combustion chambers This monograph will be of value to materials scientists metallurgists mechanical engineers and those in fields ranging from physics to corrosion science and metallography

Smoothed Finite Element Methods G.R. Liu, Nguyen Trung, 2016-04-19 Generating a quality finite element mesh is difficult and often very time consuming Mesh free methods operations can also be complicated and quite costly in terms of computational effort and resources Developed by the authors and their colleagues the smoothed finite element method S FEM only requires a triangular tetrahedral mesh to achieve mo

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