

# 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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# Fracture Problems In The Transportation Industry

**G. N. Pande, J. Middleton**



## **Fracture Problems In The Transportation Industry:**

**Fracture Problems in the Transportation Industry** Pin Tong, Oscar Orringer, 1985      **Fracture Problems in the Transportation Industry** Pin Tong, Oscar Orringer, 1985      *Residual Stress in Rails* O. Orringer, J. Orkisz, Zdzislaw Swiderski, 1992-03-31 Rail integrity is a current application of engineering fracture mechanics at a practical level Although railroad rails have been manufactured and used for more than a century it is only in the last ten years that the effects of their crack propagation and fracture characteristics have been considered from a rational viewpoint The practical objectives are to develop damage tolerance limits for rail inspection and to improve the fracture resistance of new rail production Rail fatigue crack propagation rates and fracture resistance are strongly influenced by residual stresses which are introduced into the rail both during production and in service Therefore the rail residual stress field must be well understood before fracture mechanics can be usefully applied to the subject of rail integrity The three dimensional character of rail and its stress fields make it essential to apply both experimental and analytical methods in order to understand the effects of production and service variables on residual stress and the effects of the stress on fatigue crack propagation and fracture This volume brings together field observations and experimental stress analysis of railroad rails in the United States and Europe The ongoing search for an efficient and accurate technique is emphasized A companion volume brings together several analytical investigations based on advanced computational mechanics methods for correlation of the experimental data as well as evaluation of the effects of residual stress on rail integrity      **Numerical Techniques for Engineering Analysis and Design** G.N. Pande, J. Middleton, 2012-12-06 Numerical methods and related computer based algorithms form the logical solution for many complex problems encountered in science and engineering Although numerical techniques are now well established they have continued to expand and diversify particularly in the fields of engineering analysis and design Various engineering departments in the University College of Swansea in particular Civil Chemical Electrical and Computer Science have groups working in these areas It is from this mutual interest that the NUMETA conference series was conceived with the main objective of providing a link between engineers developing new numerical techniques and those applying them in practice Encouraged by the success of NUMETA 85 the second conference NUMETA 87 was held at Swansea 6-10 July 1987 Over two hundred and twenty abstracts were submitted for consideration together with a number of invited papers from experts in the field of numerical methods The final selection of contributed and invited papers were of a high quality and have culminated in the two volumes which form these proceedings This volume contains papers on the themes of Numerical Techniques for Engineering Analysis and Design and Developments in Engineering Software Many new developments on a wide variety of topics have been reported and these proceedings contain a wealth of information and references which we believe will be of great interest to theoreticians and practising engineers alike      **Rail Quality and Maintenance for Modern Railway Operation** J.J. Kalker, D.F. Cannon, O. Orringer, 2013-04-18 In April 1990 a conference was held at the Cracow Institute of

Technology Cracow Poland The title of that conference was Residual Stresses in Rails Effects on Rail Integrity and Railroad Economics and its themes were the measurement and prediction of residual stresses in rails but as the sub title suggests the intention was also to provide a link between research and its application to the practical railway world At the Cracow conference there were 40 participants with 5 railways and 5 rail makers being represented and 25 papers were given The Cracow conference was a success and by March 1991 its off spring The International Conference on Rail Quality and Maintenance for Modern Railway Operations was conceived and birth was ultimately given in June 1992 at the Technical University Delft It turned out to be some baby with 112 delegates from 24 countries taking part As with its predecessor the conference was to provide a forum for the exchange of ideas between research investigators rail makers and railway engineers A cursory examination of the list of participants suggests that about 57% were from the railway industry 34% from universities and other research institutions and 9% from the steel industry Bearing in mind that some of the railway industry participants were from their respective research and development organisations the balance of interests was about right

Crack Arrest Concepts for Failure Prevention and Life Extension Gyoujin Cho,1996-04-30 The proceedings of a seminar held at TWI in September 1995 focusing on crack arrest philosophy which acknowledges that a brittle crack is arrested when it emerges from the critical region Papers from prestigious researchers presented a critique and assessment of the theory and its application under Introduction to crack arrest concepts Recent trends in crack arrest research Application of crack arrest concepts Report ,1991 *Transactions of the American Society of Civil Engineers* American Society of Civil Engineers,1986 Vols 29 30 contain papers of the International Engineering Congress Chicago 1893 v 54 pts A F papers of the International Engineering Congress St Louis 1904 **The Economic Effects of Fracture in the United States: A report to NBS by Batelle Columbus Laboratories** Battelle Memorial Institute. Columbus Laboratories,1983 **Fundamental Issues and Applications of Shock-Wave and High-Strain-Rate Phenomena** K.P. Staudhammer,L.E. Murr,M.A. Meyers,2001-02-08 This book contains the proceedings of EXPLOMETTM 2000 International Conference on Fundamental Issues and Applications of Shock Wave and High Strain Rate Phenomena held in Albuquerque New Mexico 2000 the fifth in the EXPLOMETTM quinquennial series which began in Albuquerque in 1980 The book is divided into five major sections with a total of 85 chapters Section I deals with materials issues in shock and high strain rates while Section II covers shock consolidation reactions and synthesis Materials aspects of ballistic and hypervelocity impact are covered in Section III followed by modeling and simulation in Section IV and a range of novel applications of shock and high strain rate phenomena in Section V Like previous conference volumes published in 1980 1985 and 1995 the current volume includes contributions from fourteen countries outside the United States As a consequence it is hoped that this book will serve as a global summary of current issues involving shock and high strain rate phenomena as well as a general reference and teaching component for specialized curricula dealing with these features in a contemporary way Over the past twenty years the EXPLOMETTM

Conferences have created a family of participants who not only converse every five years but who have developed long standing interactions and professional relationships which continue to stimulate new concepts and applications particularly rooted in basic materials behavior

**Proceedings of the International Conference on Numerical Methods in Engineering--Theory and Applications, NUMETA '87, Swansea, 6-10 July 1987** G. N. Pande, J. Middleton, 1987

**Publications of the National Institute of Standards and Technology ... Catalog** National Institute of Standards and Technology (U.S.), 1983      **NBS Special Publication** , 1968      Crack Propagation Life of Detail Fractures in Rails , 1988

*In-depth Study Reports from the World Survey of Current Research and Development on Roads and Road Transport* International Road Federation, 1973      **Publications of the National Bureau of Standards** United States. National Bureau of Standards, 1982      *Directory of Published Proceedings* , 1996      *International Journal of Medicine and Surgery* , 1924      *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      **U.S. Department of Transportation Research and Development Plan** United States. Department of Transportation, 1999

## Unveiling the Power of Verbal Beauty: An Emotional Sojourn through **Fracture Problems In The Transportation Industry**

In a global inundated with screens and the cacophony of quick communication, the profound power and emotional resonance of verbal artistry often fade in to obscurity, eclipsed by the constant assault of sound and distractions. Yet, located within the musical pages of **Fracture Problems In The Transportation Industry**, a fascinating perform of literary elegance that impulses with raw emotions, lies an wonderful trip waiting to be embarked upon. Published by way of a virtuoso wordsmith, this exciting opus guides visitors on a mental odyssey, lightly exposing the latent potential and profound affect stuck within the complex internet of language. Within the heart-wrenching expanse of this evocative analysis, we will embark upon an introspective exploration of the book is main styles, dissect their fascinating publishing style, and immerse ourselves in the indelible effect it leaves upon the depths of readers souls.

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