



Multiaxial High Cycle Fatigue Criteria Based on Fracture Plane Identification: Applicability to Metallic Materials

Marcos V. Pereira, Fathi A. Darwish, Maria C. Teixeira , and Roberta A. Gonçalves

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Two multiaxial high cycle fatigue criteria pertaining to the critical plane-based approach are reviewed. The models were proposed by Carpinteri and Spagnoli (C&S) and Liu and Mahadevan (L&M), and unlike other models based on the same approach, they have the critical plane directly correlated with the fatigue fracture plane. As the aim of this study is mainly to compare their capability to predict fatigue failure, the two models were applied to a number of published experimental fatigue tests, involving synchronous sinusoidal in-phase and out-of-phase bending and torsion. The results indicate that both models possess good predictive capability under fully reversed stresses, with the L&M model being on the average slightly more conservative. Applying, to the same loading conditions, a mesoscopic scale-based approach proposed by Papadopoulos, one can verify that its predictive capability is as good as those corresponding to the C&S and L&M criteria. However, in the presence of superimposed mean stresses, the capability of these two models to predict fatigue behavior is seen to be considerably lower than that detected for Papadopoulos'.

Keywords: C&S criterion, critical plane, error index, fatigue limit state, fracture plane, L&M criterion, principal stresses.

1. Introduction

Historically, the evaluation of the fatigue behavior of metallic materials was based on the determination of uniaxial fatigue test parameters for life prediction. However, many mechanical components, such as railroad wheels, crankshafts, axles and turbine blades, are expected to experience time-varying multiaxial stresses during their in-service lifetime. Accordingly, the need has been arising, over many decades, to introduce multiaxial fatigue damage criteria capable of predicting fatigue failure under such loading conditions. These criteria can be divided into three groups: stress-based, strain-based and energy-based models (Ref 1). Since the main focus in the present work is multiaxial high cycle fatigue, where most mechanical components are expected to operate under elastic stress levels, only stress-based models are considered.

Generalization of the fatigue limit concept, so as to englobe multiaxial loading conditions within the domain of stress-based models, is seen to be compatible with the notion of dividing the whole stress space in two parts, namely safe and unsafe. The safe part, containing the origin, is to be bounded by a closed surface, and the fatigue criterion can thus be expressed in terms of an inequality whose satisfaction signifies that the stress state

induced by the external cyclic loading remains within the safe part of the stress space.

The stress-based approach, which is popularly used in high cycle fatigue analysis, englobes a large number of models that can be divided into four groups based on empirical equivalent stress, stress invariants, average stress and critical plane stress (Ref 1). Several reviews of multiaxial fatigue damage criteria, including stress-based models, can be found in the literature (Ref 2-6). In the present study, two stress-based high cycle fatigue models, namely Liu and Mahadevan (L&M) (Ref 1) and Carpinteri and Spagnoli (C&S) (Ref 6-9), both belonging to the critical plane approach, are reviewed with the underlying purpose of comparing their applicability to predicting high cycle fatigue behavior of metallic materials. Both models are, in fact, applicable to a wide spectrum of materials ranging from very ductile to extremely hard metallic alloys (Ref 1, 6). Accordingly, the comparison can be made by applying the two models to a number of experimental constant amplitude cyclic loading conditions available in the literature (Ref 10-12). These involve synchronous sinusoidal in-phase and out-of-phase bending and torsion applied to a variety of metallic materials with different fatigue behaviors. At this point, it needs to be mentioned that all of the selected loading conditions correspond to the fatigue limit state above which fatigue failure occurs and below which fatigue life extends over a very high number of cycles, in analogy with the fatigue limit state for uniaxial loading of smooth (unnotched) specimens. However, one may also point out that the C&S criterion, which has been used for fatigue assessment of both smooth and notched structural components, has also been extended to assess the fatigue behavior of welded joints under in-phase and out-of-phase loadings and more recently to evaluate fatigue life under multiaxial random loading conditions (Ref 9, 13-15).

Critical plane-based models depend for their application on the prior identification of the critical plane, where fatigue damage can occur leading to crack nucleation. One can therefore proceed to calculate the normal and shear stress amplitudes as well as the mean stresses acting on the critical plane, and fatigue failure assessment can thus be presented in

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Multiaxial Fatigue And Fracture

Xiangqiao Yan



Multiaxial Fatigue And Fracture:

Biaxial/Multiaxial Fatigue and Fracture Andrea Carpinteri, Manuel De Freitas, Andrea Spagnoli, 2003-03-19 The European Structural Integrity Society ESIS Technical Committee on Fatigue of Engineering Materials and Structures TC3 decided to compile a Special Technical Publication ESIS STP based on the 115 papers presented at the 6th International Conference on Biaxial Multiaxial Fatigue and Fracture The 25 papers included in the STP have been extended and revised by the authors The conference was held in Lisbon Portugal on 25-28 June 2001 and was chaired by Manuel De Freitas Instituto Superior Tecnico Lisbon The meeting organised by the Instituto Superior Tecnico and sponsored by the Portuguese Ministerio da Ciencia e da Tecnologia and by the European Structural Integrity Society was attended by 151 delegates from 20 countries The papers in the present book deal with the theoretical numerical and experimental aspects of the Multiaxial fatigue and fracture of engineering materials and structures They are divided into the following six sections Multiaxial Fatigue of Welded Structures High cycle Multiaxial fatigue Non proportional and Variable Amplitude loading Defects Notches Crack Growth Low Cycle Multiaxial Fatigue Applications and Testing Methods As is well known most engineering components and structures in the mechanical aerospace power generation and other industries are subjected to multiaxial loading during their service life One of the most difficult tasks in design against fatigue and fracture is to translate the information gathered from uniaxial fatigue and fracture tests on engineering materials into applications involving complex states of cyclic stress strain conditions This book is the result of co operation between many researchers from different laboratories universities and industries in a number of countries **Multiaxial Fatigue and Fracture** E. Macha, W. Bedkowski, T.

Lagoda, 1999-09-06 This volume contains 18 papers selected from 90 presented at the Fifth International Conference on Biaxial Multiaxial Fatigue and Fracture held in Cracow Poland 8-12 September 1997 The papers in this book deal with theoretical computational and experimental aspects of the multiaxial fatigue and fracture of engineering materials and structures The papers are divided into the following four categories 1 Proportional cyclic loading 2 Non proportional cyclic loading 3 Variable amplitude and random loading 4 Crack growth Most papers in this publication talk about the behaviour of constructional materials and elements of machines under non proportional loading and under variable amplitude and random loading which are more realistic load histories met in industrial practice Variable amplitude loading under cyclic load with basic frequency and random loading under load with a continuous band of frequency is classified here This book gives a review of the latest world success and directions of investigations on multiaxial fatigue and fracture More and more often publications are results of the co operation of researchers from different laboratories and countries Seven out of eighteen papers included here were worked out by international authors teams This is a symptom of the times when science and investigations know no borders *Multiaxial Fatigue* Darrell Socie, Gary Marquis, 1999-12-15 This book provides practicing engineers researchers and students with a working knowledge of the fatigue design process and models under multiaxial

states of stress and strain Readers are introduced to the important considerations of multiaxial fatigue that differentiate it from uniaxial fatigue Advances in Multiaxial Fatigue David L. McDowell, Rod Ellis, 1993 Papers presented at the ASTM Symposium on Multiaxial Fatigue held in San Diego November 1991 to communicate the most recent international advances in multiaxial cyclic deformation and fatigue research as well as applications to component analysis and design The 24 papers are grouped into five categories **Biaxial/Multiaxial Fatigue and Fracture** L. P Pook, Ky Dang Van, Cetin Morris Sonsino, 2003

Multiaxial Notch Fatigue Luca Susmel, 2009-03-20 Metal and composite components used in structural engineering not only contain geometrical features resulting in stress concentration phenomena but they are also subjected to in service multiaxial fatigue loading To address the problem structural engineers need reliable methodologies which allow for an adequate margin of safety The book summarises methods devised by the author to design real components against multiaxial fatigue by taking full advantage not only of nominal but also of local stress strain quantities The book begins by reviewing definitions suitable for calculating the stress strain quantities commonly used to perform fatigue assessment The Modified Wöhler Curve Method is then explained in detail by focusing attention on both the high and the medium cycle fatigue regime The existing links between the multiaxial fatigue criterion and physical properties are also discussed A procedure suitable for employing the method developed by the author to estimate fatigue damage both in notched and in welded components is explained The Modified Manson Coffin Curve method is investigated in depth by reviewing those concepts playing a fundamental role in the so called strain based approach Lastly the problem of performing the fatigue assessment of composite materials is addressed by considering design parameters influencing composite behaviour under complex cyclic loading paths and those criteria suitable for designing real components against multiaxial fatigue The book also contains two appendices summarising experimental data from the technical literature These appendices provide a unique and highly valuable resource for engineers The appendices summarise around 100 values of the material characteristic length L experimentally determined by testing specimens made of different engineering materials and about 4500 experimental fatigue results generated by testing plain notched and welded specimens under constant amplitude proportional and non proportional multiaxial fatigue loading are listed Summarises methods devised by the author to design real components against multiaxial fatigue Reviews definitions suitable for calculating the stress strain quantities commonly used to perform fatigue assessment Includes an in depth explanation of both the Modified Wöhler Curve and Modified Manson Coffin Curve Method *Multiaxial Fatigue and Fracture: A Literature Review*, 1984 Problems often arise when attempting to determine the fatigue behaviour of structural components from laboratory data A major reason for this lack of correlation is that most engineering components operate in stress environments significantly more complicated than uniaxial tension the stress state in which most research studies are conducted A review of the literature has shown that virtually all fatigue and fracture properties of metals and components are affected by multidirectional loading In particular variations in stress state

compared with uniaxial tension produce the following effects a decreases in the fatigue limit by up to approximately 50% b increases or decreases in low cycle fatigue life by factors of up to 20 depending on whether the stress in the second direction is tensile or compressive and is static or cyclic c out of phase loading also reduces the low cycle fatigue life by a factor of up to 4 compared with in phase loading and d acceleration and retardations of fatigue crack growth rates by factors of 3 to 4 depending on the nature of the transverse stress It is also evident that multiaxial criteria used for design purposes can be non conservative especially under out of phase loading and consequently can lead to unsafe estimates of the fatigue life of a component Originator supplied keywords include Multiaxial stress Low cycle fatigue Fracture properties Fatigue tests Crack propagation Metal fatigue **Multiaxial Fatigue** Keith John Miller,Michael W. Brown,1985 **Multiaxial Notch**

Fracture and Fatigue Xiangqiao Yan,2023-02-28 This book presents the unified fatigue life prediction equation for low medium high cycle fatigue of metallic materials relevant to plain materials and notched components The unified fatigue life prediction equation is the W hler equation in which the stress based intensity parameter is calculated based on the linear elastic analysis A local approach for the static fracture analysis for notched components is presented based on the notch linear elastic stress field In the local approach a stress intensity parameter is taken as a stress based intensity parameter Experimental verifications show that the local approach is also suited for the static fracture analysis for notched components made of ductile materials The book is also concerned with a material failure problem under the multiaxial stress states A concept of the material intensity parameter is introduced in this book It is a material property parameter that depends on both Mode I fracture toughness and Mode II or Mode III fracture toughness and the multiaxial parameter to characterize the variation of the material failure resistance notch fracture toughness with the multiaxial stresses states The failure condition to assess mixed mode fracture of notched or cracked components is stated as the stress based intensity parameter being equal to the material intensity parameter With respect to the traditional S N equation a similar S N equation is presented and verified to have high accuracy This book will be of interest to professionals in the field of fatigue and fracture for both brittle and ductile materials *Stochastic Modeling of Multiaxial Fatigue and Fracture* Yongming Liu,2006 **Biaxial/multiaxial**

Fatigue and Fracture L. P. Pook,International Conference on Biaxial, Multiaxial Fatigue and Fracture,2003

Mixed-mode Fracture in Ductile Materials and Low-cycle Multiaxial Fatigue Theory Yen kai Wang,1998 A Review of Multiaxial Fatigue and Fracture of Fibre-reinforced Composites (U) Paul William Beaver,AERONAUTICAL RESEARCH LABS MELBOURNE (Australia),1987 A review of the limited number of papers in the literature on multiaxial fatigue and fracture of fibre reinforced composites has shown that biaxial stress states can have a significant effect on both the fatigue and fracture properties of these materials In addition none of the presently available failure theories for composites agrees with the observed experimental results with sufficient accuracy to be confidently used for design purposes Keywords Multiaxial stress Fracture strength Fatigue life Fatigue limit Fibre reinforced composites Australia Multiaxial

Fatigue and Deformation Sreeramesh Kalluri, Peter J. Bonacuse, 2000 Contains papers from a May 1999 symposium describing state of the art multiaxial testing techniques and analytical methods for characterizing fatigue and deformation behaviors of engineering materials Papers are classified into sections on multiaxial strength of materials multiaxial deformation Mixed-mode Crack Behavior Keith John Miller, David L. McDowell, 1999 **International Conference on Biaxial, Multiaxial Fatigue and Fracture : ICBMF ; 3**, 1989 *6th ICB/MF&F*. Manuel de Freitas, 2001 **Fatigue of Materials and Structures** Claude Bathias, André Pineau, 2013-03-04 The design of mechanical structures with predictable and improved durability cannot be achieved without a thorough understanding of the mechanisms of fatigue damage and more specifically the relationships between the microstructure of materials and their fatigue properties Written by leading researchers in the field this book along with the complementary books *Fatigue of Materials and Structures Fundamentals and Application to Damage and Design* both also edited by Claude Bathias and Andr Pineau provides an authoritative comprehensive and unified treatment of the mechanics and micromechanisms of fatigue in metals polymers and composites Each chapter is devoted to one of the major classes of materials or to different types of fatigue damage thereby providing overall coverage of the field This book deals with multiaxial fatigue thermomechanical fatigue fretting fatigue influence of defects on fatigue life cumulative damage and damage tolerance and will be an important and much used reference for students practicing engineers and researchers studying fracture and fatigue in numerous areas of materials science and engineering mechanical nuclear and aerospace engineering **Fatigue of Materials and Structures** Qingyuan Wang, Shun-Peng Zhu, José Correia, Abílio De Jesus, Grzegorz Lesiuk, 2025-05-19 Fatigue failure of engineering materials and structures has long been a great challenge for structural integrity reliability and safety in mechanical civil and aerospace engineering These failure mechanisms and their modeling are critical concerns for managing aging structures and directly affect sustainability across society In this context the fundamental theories and methods of fatigue failure of engineering materials and structures are discussed in detail Fatigue damage accumulation crack initiation and crack growth analysis are presented from materials to structures deterministic to probabilistic fatigue physics to data science uniaxial to multiaxial fatigue and extremely low cycle fatigue to very high cycle fatigue The focus is on mechanical understanding and risk management for design maintenance and operation Some recent advancements include fatigue of additive manufactured AM metals and advanced materials which could potentially transform fatigue analysis and offer new perspectives on fatigue failure mechanisms and reliability design Both experimental supporting evidence and simulation benefits are demonstrated It integrates recent developments in artificial intelligence with fatigue in AM metals and advanced materials It provides case studies and future research challenges for the fusion of fatigue physics modeling with data analytics for graduate students and advanced practitioners *Proceedings of the Seventh International Conference on Biaxial/Multiaxial Fatigue and Fracture* ICBMFF, Deutscher Verband für Materialforschung und -prüfung, 2004

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