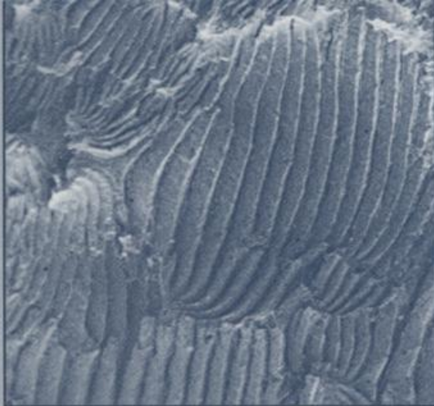

FATIGUE and FRACTURE MECHANICS

27th Volume

Robert S. Piascik
James C. Newman, Jr.
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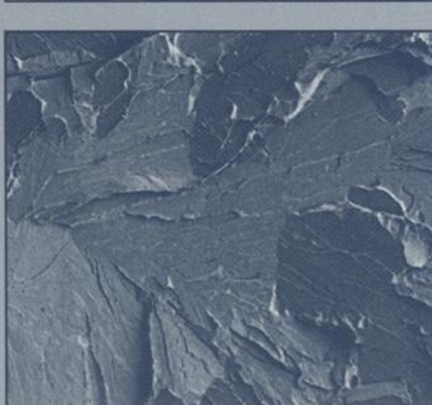
EDITORS



ASTM STP 1296

STP 1296

Fatigue and Fracture Mechanics: 27th Volume

Robert S. Piascik, James C. Newman, Jr., and Norman E. Dowling, Editors

ASTM Publication Code Number (PCN):
04-012960-30

ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

Printed in the U.S.A.

ISBN: 0-8031-2412-0
PCN: 04-012960-30
ISSN: 1040-3094

Peer Review Policy

Each paper published in this volume was evaluated by two peer reviewers and at least one editor. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of the peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Printed in Ann Arbor, MI
April 1997

Foreword

The Twenty-Seventh International Symposium on Fatigue and Fracture Mechanics was held in Williamsburg, Virginia on 26–29 June 1995. The sponsor of the event was ASTM Committee E-08 on Fatigue and Fracture.

The symposium chairman was Robert S. Piascik, NASA Langley Research Center, Hampton, VA. Symposium co-chairmen were J. C. Newman, Jr., NASA Langley Research Center, Hampton, VA; R. P. Gangloff, University of Virginia, Charlottesville, Virginia; and Norman E. Dowling, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

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Overview

With the formation of ASTM Committee E-8 on fatigue and fracture, the Twenty-Seventh National Symposium was expanded and hence forth will represent both the Fatigue and Fracture Mechanics communities at the annual "National Symposium on Fatigue and Fracture Mechanics." With this new charter, the symposium chairmen (R. S. Piascik and J. C. Newman, Jr. of the NASA Langley Research Center, R. P. Gangloff of the University of Virginia, and N. E. Dowling of the Virginia Polytechnic Institute and State University) formed a symposium organizing committee that represented both technical communities. The organizing committee consisted of the symposium chairmen, A. Saxena of the Georgia Institute of Technology, R. C. McClung of the Southwest Research Institute, M. R. Mitchell of the Rockwell International Company, and R. H. Dodds, Jr. of the University of Illinois.

During the two and one-half day symposium held in Williamsburg, VA in June of 1995, an international group of experts from the United States, Canada, the United Kingdom, The Netherlands, Sweden, Germany, Austria, Japan, France, the Peoples Republic of China, India, and Korea presented their research findings concerning issues relating to fatigue and fracture mechanics. Published herein are papers grouped in four technical categories relating to elastic-plastic fracture, fatigue, advanced materials and applications, and analytical methods. Papers relating to a fifth category on elevated temperature effects have been published as *Elevated Temperature Effects on Fatigue and Fracture*, ASTM STP 1297, edited by R. S. Piascik of the NASA Langley Research Center, R. P. Gangloff of the University of Virginia, and A. Saxena of the Georgia Institute of Technology.

Professor Robert P. Wei of Lehigh University, the Twenty-Seventh National Symposium J. L. Swedlow Memorial Lecturer, set the stage for the symposium by addressing important fatigue and fracture issues relating to life prediction. Professor Wei's lecture, entitled "Life Prediction: A Case for Multidisciplinary Research," illustrated the need for multi-disciplinary research by presenting examples based on his research directed at the development of environmentally assisted crack growth models.

The collection of papers published in this volume describes the current research in the following technical areas.

Elastic-Plastic Fracture

R. H. Dodds, Jr. and W. G. Reuter chaired several sessions on elastic-plastic fracture. Several papers presented recent work on the study of constraint, in particular the J integral and the constraint parameter Q. A J-Q model for predicting failure in the ductile-brittle fracture transition region for steels was presented with experimental verification. The J-Q theory was also applied to large surface-cracked tension plates and other standard laboratory fracture specimens (compact, three-point bend, and single-edge-notched tension) to study crack initiation and growth under monotonic loading. Ductile crack growth initiation is well characterized by J alone and appears to be insensitive to constraint effects in both the transition region and the upper shelf region. But ductile crack growth is clearly sensitive to constraint effects, and the J_R-curve is lower for higher Q values. The constraint effects on brittle fracture (specimen size and geometry effects) were studied with a constraint parameter based on the second term in the normal stress field expansion at a crack tip. The theory was then applied to the prediction of fracture toughness values for a brittle material.

Several papers presented results on other crack-tip parameters, such as crack-tip-opening displacement (CTOD), crack-tip-opening angle (CTOA), the T^*-integral, and the energy dissipation rate (D). Large-strain, three-dimensional finite element analyses were performed for a variety of crack geometries to study local crack-front stress-strain fields. The results showed that the deformations at the crack front are highly constrained with nearly plane-strain behavior in the mid-region and plane stress on the free surface, even in relatively thin specimens of finite size. An evaluation of J- and T^*-integrals on stabile tearing cracks in a thin aluminum alloy showed large differences between far-field and near-field J values for small amounts of stable crack growth. But the CTOA computed by the near-field J was in reasonable agreement with the measured CTOA values during crack extension. In another study, a two-dimensional, elastic-plastic finite element analysis was used with a critical CTOA to predict stable tearing in aluminum alloy plates. The analyses showed good correlation with the measured load-against-crack-opening displacement data. Stable tearing experiments under mixed-mode (Modes I and II) loading indicated that the critical CTOD measured at 1 mm behind the crack tip was nearly constant after a small amount of stable tearing. In a study of mixed mode (Modes I and III) loading on a surface-crack specimen, a micromechanical model was developed to account for the effects of crack-face friction on fracture toughness. The model predictions on fracture toughness agreed well with test results from the literature.

The application of elastic and elastic-plastic fracture mechanics concepts to structural components was demonstrated in papers on reactor pressure vessels to determine warm-prestress effects on fracture toughness and on stable tearing in welded structural I-beams. The more advanced methods of analysis, such as the finite-element method, gave predicted results in better agreement with the measured load-deformation curves of the cracked members.

Fatigue

The technical session on fatigue chaired by R. C. McClung and T. H. Topper covered a variety of topics. Research was presented on improved understanding of fatigue endurance limits. Here, three proposed mechanisms are correlated with fatigue crack growth thresholds and fatigue limits, i.e., (1) dislocation morphology, (2) material texture, and (3) stress-state. Further understanding of fatigue crack growth in terms of interaction with microstructure and loss of similitude was presented. Microstructure was found to influence the kinetics of the growth process, but not the growth processes. It was also concluded that similitude concepts should extend to microstructure and response of the material to cyclic loading. An engineering methodology for elastic-plastic fatigue crack growth (EPFCG) for life and instability assessment was presented. Experimental verification of the ΔJ-based predictions of EPFCG was shown. The effect of hydrogen on near-threshold fatigue crack growth was also discussed. The damaging effect of hydrogen was correlated to microstructural effects, including dislocation transport of hydrogen and trapping at interfaces. A method for performing stress-strain analysis of notched components subjected to multi-axial loading was compared to strain-gaged 2-D and 3-D notched bodies subjected to fatigue loading and also compared to finite element analysis of notches. The new method was shown to be useful for analysis of notches where numerical solutions become time consuming and impractical.

Advanced Materials and Applications

M. R. Mitchell chaired the session on advanced materials and applications. A number of papers presented were related to the fracture of nuclear reactor components. A finite element analysis to quantify the fracture toughness for shallow cracks contained in pressure vessels was presented. The model appears to be effective in adjusting test data to account for in-plane loss of constraint for uniaxially tested beams. The "local approach to cleavage fracture" method for evaluating the probability of cleavage failure of reactor pressure vessel components subjected to mechanical and thermal loading was also discussed. Details of the Weibull-based model are discussed and related to the probability of failure. The result of a study to confirm decreased ductile tearing resistance of nuclear pipe steels due to fully reversed loading was presented. Experiments showed that as the stress ratio was decreased, i.e., the amount of compressive plasticity increased and the ductile tearing resistance of the material decreased. Crack tip sharpening and void flattening were observed, which could be the mechanism contributing to cyclic degradation. A finite element code for predicting overload pull-out failures in resistance spot-welded joints was presented. The elements of this code will lead to a spot weld impact failure criterion for an advanced crashworthiness code. The results of an experimental investigation of mismatched weld performance show that the effect of mismatch in welds is minimized in more highly constrained configurations. Therefore, fracture toughness measurement and constraint indexing procedures are applicable with little modification to the homogeneous methodology for many typical weld joints. The results of tests conducted to investigate the effect of multiple site damage (MSD) in large-scale thin sheet panels were presented. The data are analyzed by a plastic zone model and *R*-curve analysis to predict the affect of MSD on residual strength. The fatigue and tensile properties of an advanced perforated titanium component for laminar flow control applications were studied. A detailed description of the fatigue failure response of the perforated sheet material is presented. A model for fatigue damage in elastomeric materials was presented. The model of fatigue life and damage is given versus parameters and temperature (-50 to 80°C).

Analytical Methods

The technical session on analytical methods chaired by J. C. Newman, Jr. and M. A. Sutton covered a variety of different methods to determine stress-intensity factors (SIF) and strain-energy release rates for linear-elastic cracked bodies. For two-dimensional cracked bodies, a boundary-element/dislocation density method, called FADD, was presented as an easy and convenient method to perform stress analyses of bodies with or without cracks, and the finite-element method was used to determine the SIFs for a single-edge-notched "shear" beam and for through cracks growing from pin-loaded, interference fit, lug joints. The strain-energy release rates (G) were calculated for delamination cracks in adhesively bonded joints using both two- and three-dimensional finite-element analyses with special adhesive element models. For three-dimensional cracks, the finite-element method with a new quasi-compatible element and equation solver was used to analyze the interaction between two semi-elliptical surface cracks. An evaluation of a three-dimensional weight-function method (3D-WFM) for surface and corner cracks in plates or at holes was made, and the results compared well with the accepted solutions for these crack configurations. The 3D-WFM provides an inexpensive method to obtain SIFs.

Acknowledgments

The symposium chairmen wish to thank Dr. J. P. Gallagher, ASTM Committee E-8 Chairman, Dr. J. Goode, and the ASTM staff for their advice and guidance. And finally, prior to the J L. Swedlow Award, Professor J. Landes of the University of Tennessee (Professor Wei's first Ph.D. student) performed a spirited introduction of his advisor. A special thanks to John Landes for roasting Professor Wei in a way that neither he nor the banquet attendees will ever forget.

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ISBN 0-8031-2412-0