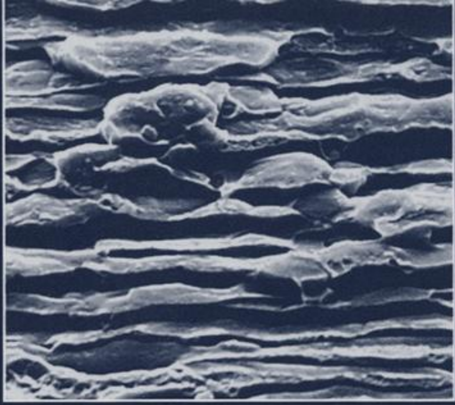
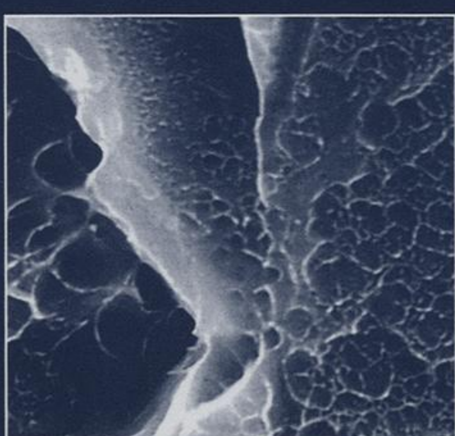


Elevated Temperature Effects on FATIGUE and FRACTURE



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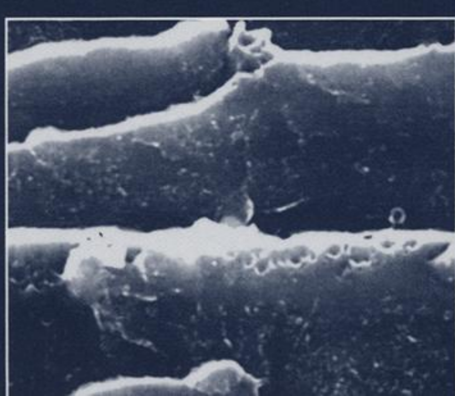

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Robert S. Piascik, Richard P. Gangloff, and Ashok Saxena, editors

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Each paper published in this volume was evaluated by two peer reviewers and at least one of the editors. 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 these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution to time and effort on behalf of ASTM.

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Foreword

The Twenty-Seventh National 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-8 on Fatigue and Fracture. The symposium chairman was R. S. Piascik, NASA Langley Research Center. Symposium co-chairmen were: J. C. Newman, Jr., NASA Langley Research Center; R. P. Gangloff, University of Virginia; and N. E. Dowling, Virginia Polytechnic Institute and State University. This special technical publication highlights a topical subset of the meeting: research on the critical effect of temperature on the fatigue and fracture of structural materials. The editors of this publication were R. S. Piascik, R. P. Gangloff, and A. Saxena.

Contents

FRACTURE

Overview

The 27th National Symposium on Fatigue and Fracture Mechanics, held in Williamsburg, Virginia in June of 1995, was organized with the goal of providing an international forum for the integration of research on fatigue and fracture mechanics. The intent of this meeting was to reinforce the recent merger of ASTM Committees E09 on Fatigue and E24 on Fracture Mechanics, forming Committee E08 on Fatigue and Fracture. This special technical publication highlights a topical subset of the meeting, that is, research on the critical effect of temperature on the fatigue and fracture of structural materials.

While elevated temperature effects on mechanical behavior have been studied for over 100 years, uncertainties continue to hinder prediction of the long-life performance of flawed aging structures in the aggressive thermal environment, as well as the development of damage-tolerant alloys. The organizing committee aimed to examine the extent to which recent developments in fatigue and fracture mechanics have been exploited to further quantitative understanding of this field. Papers were sought that highlighted:

- Integration of damage evolution, from the distributed form to that focused at a crack tip.
- High-resolution experimental probes of fatigue and fracture processes.
- Measurement and modeling of the important role of time in microstructural degradation, damage evolution, and crack growth.
- Models that provide quantitative predictions and are tested by high-quality experimentation.
- Performance of next-generation structural metals and composites, characterized within a framework useful in component life prediction.

The following is an overview of the Symposium papers included in this topical volume. The selection process adhered to ASTM procedures for peer review by a committee of three experts. The review of each paper was overseen by one of the STP coeditors and a representative of the ASTM Committee on Publications. Authors provided mandatory revisions in response to this process and several papers were not published. This standard of review is equivalent in rigor to that practiced by the archival journals in our field.

The manuscripts are divided according to the topics of creep crack growth, fatigue, and fracture.

Creep Crack Growth

Gao, Chen, Chen, and Wei reported on research conducted to understand the rate controlling process and micromechanisms for environmentally enhanced intergranular creep crack growth in Inconel 718 at elevated temperatures. The effects of environmental oxygen pressure and alloy chemical composition on crack growth rate were elucidated. The role of niobium as an enhancer of creep crack growth rate was identified, providing a basis for alloy development. The approach embodied in this research follows the philosophy but forth by Professor Wei in his J. L. Swedlow lecture that keynoted this conference.

Sester, Mohrmann, and Riedel presented a constitutive model for creep and creep rupture of 12% Cr steel. The aim of this approach was to develop better understanding of the role of microstructure during creep crack growth. The model includes the Hutchinson damage parameter, the Rodin-Parks model for the effect of creep damage on macroscopic constitutive behavior, and an empirical evolutionary equation for estimating microcrack density. Model parameters are adjusted to a set of uniaxial creep data over a wide range of stress. Model predictions compare favorably with creep crack growth test results and are conservative, suggesting further work to refine the constitutive model.

Chell, Kuhlman, Millwater, and Riha considered creep crack growth in terms of C_t. This driving force was estimated for cracks with multiple degrees of freedom, such as an embedded elliptical flaw, using the reference stress to determine C^* and a probabilistic method. It was concluded that the reference stress approach provides a simple and versatile method for evaluating C^*, in addition to including the important effects of self-equilibrated secondary stresses and prior damage in the determination of C_t. The application of a probability analysis, based on fast probability integration techniques, enables decisions regarding inspection schedules for an operating plant and identifies the variables that govern the lifetime of the cracked component.

In a two-part contribution, Hamilton, Hall, Saxena, and McDowell investigated the creep deformation and creep crack growth characteristics of Aluminum Alloy 2519-T87 at 135°C. Experimental work in Part I demonstrated that, characteristic of a creep brittle material, crack growth rate effectively correlates with the applied stress intensity, but not with time-dependent C_t. Subcritical cracking was either distinctly intergranular or transgranular, with the transition between these fracture regions occurring at a critical K-level. The incubation time required for crack growth was correlated with K and related to an accumulation of a critical amount of damage ahead of the crack tip. In Part II a finite element model of AA2519 creep crack growth was used to gain insight into the relation of crack tip strain field fracture parameters to creep crack growth rate. Numerical results indicate an initial transient period of crack growth, followed by a quasi-steady-state cracking regime in which the crack tip fields change slowly with increasing crack length. Transition of crack growth to the quasi-stead-state regime, where similitude and small-scale creep conditions roughly exist, is given by a transition time (t_s) that depends on crack growth history and material properties. Creep crack growth rate is predicted to correlate with K for times in excess of t_s, as observed experimentally.

Fatigue

Ohtani, Kitamura, Tada, and Zhou modeled creep-fatigue damage in 304 stainless steel sheet at elevated temperature. The model predicts the evolution of both surface and internal cracking. For surface cracking, grain boundary facets were generated using an isotropic grain growth model, and cracks were simulated where facets intersect the surface. In the case of internal cracks, grain boundary facets were projected on a plane perpendicular to the stress axis. A random-number description of the intrinsic fracture resistance of each grain facet represented the stochastic nature of crack initiation and propagation. To describe damage evolution, the fracture resistance of each facet was reduced by the magnitude of the driving force after every cycle. Here, the driving force depends on tensile and compressive strain rates, total strain range, and temperature. When the resistance becomes zero, a crack is assumed to initiate. Numerical simulations of surface and internal cracking exhibit similar morphologies compared to creep-fatigue cracking observed in 304 stainless steel sheet. The predicted number of cracks, the distribution of crack length, and the crack propagation rate agree quantitatively with experimental observations.

The effect of a gaseous environment on elevated temperature fatigue crack propagation kinetics was investigated by Sarrazin-Baudoux, Lesterlin, and Petit. Specifically, the crack growth behavior of Ti-6Al-4V and Ti-6Al-3Sn-4Zr-6Mo alloys was studied in purified nitrogen, with controlled additions of small partial pressure quantities of pure oxygen and water vapor. Comparisons with inert vacuum rates suggest that increased *da/dN* in water vapor is due to hydrogen embrittlement at 300°C. Above a critical temperature range (465 to 500°C), a time-dependent damage mechanism operated; fatigue crack growth rate increased as frequency decreased from 35 to 0.1 Hz. Here, oxygen was suspected of being the embrittling specie.

Albertson, Stephens, and Bayha provided data on the fatigue crack growth characteristics of two modern titanium alloys, Timetal-21S and Ti-6Al-2Sn-2Zr-2Mo-2Cr at 25 and 175°C. Differences in constant amplitude fatigue crack growth rate at various stress ratios ($R = 0.1, 0.5$, and -0.4) were rationalized in terms of crack tip closure mechanisms.

The research performed by Yoon, Beak, and Suh is directed towards turbine rotor life prediction. Here, waveform effects on the creep crack growth behavior of 1Cr-1Mo-0.25V rotor steel at 528°C are studied. Large scatter is observed in time-dependent crack growth, $(da/dt)_{avg}$, during hold times when correlated with estimated $(C_t)_{avg}$. A new estimation equation was proposed in which effects of load increasing rate are considered. The effectiveness of the proposed equation was discussed by showing that the scatter of the measured $(da/dt)_{avg}$ data was reduced when the new equation was adopted. The characteristics of the initial transient crack growth behavior are also shown to be dependent on an oxidation-dominated crack growth mechanism.

Fracture

Haynes, Somerday, Lach, and Gangloff predicted the temperature dependence of the initiation fracture toughness for a variety of advanced ingot and powder metallurgy aluminum alloys, utilizing a critical plastic strain-controlled micromechanical model of ductile microvoid fracture. This work showed that toughness is governed by the interplay of the temperature dependencies of the crack tip field and affected by material constitutive behavior and the intrinsic microvoid fracture resistance. A calculated critical distance parameter correlated with the nearest-neighbor spacing of void nucleating particles and with the extent of primary void growth determined fractographically. This work provides a broad confirming test of this crack tip process zone modeling approach and suggests a means to predict absolute values of fracture toughness.

The effect of long-term thermal exposure on the fracture properties of advanced aluminum alloys was studied by Reynolds and Crooks. Both lithium-based and non-lithium-containing alloys were exposed in moist air to temperatures ranging from 93 to 163°C for up to 7000 h, followed by tensile and *J*-integral fracture toughness testing. Detailed fractography revealed a predominantly transgranular microvoid fracture morphology prior to exposure, but both brittle and ductile grain boundary failure after exposure. A reduction in fracture resistance was correlated with boundary precipitation that occurred during long-term elevated temperature exposure. These results are pertinent to the use of light alloys in the next-generation supersonic aircraft.

Yang, Saxena, and Starr investigated the high-temperature (1000°C) fracture behavior of the unidirectional Nicalon fiber-reinforced reaction-bonded silicon nitride (RBSN) composite. Microstructural examinations demonstrated that high porosity and coarse open pores lead to oxidation above 800°C. Severe matrix oxidation leads to substantial expansion of the composite in the transverse direction. Fracture studies of the RBSN composite documented the effect of elevated temperature and oxidation on crack initiation and growth.

We wish to thank those who participated in this meeting and enabled this volume, including the session chairs, authors, reviewers, and ASTM staff. We hope that the collection of manuscripts in ASTM STP 1297 on *Elevated Temperature Effects on Fatigue and Fracture* will contribute to engineering solutions to life prediction problems, stimulate future research on the

critical issues represented here, and integrate work on fatigue and fracture mechanics as embodied in the new structure of ASTM Committee E08.

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