Overview

Background

Thermo-mechanical fatigue (TMF) problems are encountered in many applications, such as high-temperature engines, structural components used in high-speed transport, contact problems involving friction, and interfaces in computer technology. Thermo-mechanical fatigue provides a challenge to an analyst as well as to an experimentalist. The analyst is faced with describing the constitutive representation of the material under TMF, which is compounded by complex internal stresses, aging effects, microstructural coarsening, and so forth. The evolution of microstructure and micromechanisms of degradation differ from that encountered in monotonic deformation or in isothermal fatigue. Experimentalists conducting TMF tests need to ensure simultaneous control of temperature and strain waveforms, and minimization of temperature gradients to enable uniform stress and strain fields. Failure to meet these requirements may result in fortuitous results.

This symposium was organized to provide a means of disseminating new research findings in thermo-mechanical fatigue behavior of materials. The need for the symposium grew naturally from the activities of the E9.01.01 Task Group on Thermomechanical Fatigue. There have been numerous developments in understanding thermo-mechanical damage mechanisms over the last decade. The last ASTM symposium on TMF was held in 1975, and since then, the role of oxidation damage is now better recognized, the asymmetry of creep damage is well accepted, and microstructural evolution is established as a contributor to stress-strain response and to damage behavior. Moreover, the experimental techniques to study TMF evolved significantly over the last decade. Computer control of strain and temperature waveforms, high-temperature strain, and temperature measurement techniques were refined considerably. Researchers are gaining a better understanding of damage at the micro-level with sophisticated microscopy tools probing to ever lower size scales. At the same time, with refined numerical models and improved computer power, it is possible to conduct more realistic simulations of material behavior. The last decade has seen increased emphasis on composite materials designed to withstand high operating temperatures and severe TMF environments. Both the experiments and their interpretation are difficult on these highly anisotropic materials with complex internal stress and strain fields.

The purpose of thermomechanical fatigue studies is twofold. First, to gain a deeper understanding of defect initiation and growth as influenced by the underlying microstructure or discrete phases, and second, to obtain useful engineering relationships and mathematical models for macroscopic behavior, allowing the design and evaluation of engineering systems. The first goal is sought by materials scientists and mechanicians conducting basic research, while the second goal is pursued by engineers and designers who are integrating this basic information and experimental data to develop structural models. It is desirable that basic research in this field be guided by the needs and requirements set by designers in their search for better performance.

The papers presented in this special technical publication (STP) have the aim of addressing both the basic research and the design issues in thermomechanical fatigue. The authors have been active researchers in high-temperature fatigue and have all made notable contributions in their specific areas of interest. In addition to U.S. researchers, the contributions from overseas researchers are noteworthy and encouraging.

Summary of the Papers

It is now widely accepted that a materials' TMF behavior be studied under the in-phase case (where maximum temperature and maximum strain coincides) and the out-of-phase case (where maximum temperature and minimum strain coincide). These two loading types represent strain-temperature histories that often produce different damage mechanisms. The reader will find these terms used repeatedly in this publication. A mini-summary of the 14 papers included in this STP follows.

Dr. Remy and colleagues have elucidated the dramatic contribution of oxidation on fatigue crack growth in thermomechanical fatigue by comparing preoxidized and virgin samples. Mr. Zauter and colleagues demonstrated dynamic strain aging and dynamic recovery effects in austenitic stainless steels under thermomechanical fatigue. Similar behavior was seen in Hastelloy X studied by Castelli et al. who proposed a constitutive equation to describe the aging phenomena. Kadioglu and Sehitoglu studied the MarM247 alloy and calculated internal stresses caused by oxide spikes and refined an early model proposed by the senior author. Miller et al. proposed microcrack propagation laws suitable for TMF loadings incorporating creep, fatigue and oxidation effects. Thermomechanical fatigue of In-738 was considered by Bernstein et al. who proposed a life model incorporating time, temperature, and strain effects. Single crystal and directionally solidified nickel alloy was considered by Guedou and Honnorat who also examined coated alloys. Kalluri and Halford studied the Haynes 188 under various TMF cycle shapes demonstrating creep and oxidation damages. Halford et al. discussed the thermomechanical fatigue damage mechanisms in several unidirectional metal-matrix composites. Analysis of local stresses and strains for same class of materials has been achieved in the work of Coker et al. Experiments demonstrating deviations from linear summation of creep and fatigue damages in TMF have been conducted by McGaw. Characterization of crack growth through temperature and stress gradients has been considered by Sakon et al. The shear stress-strain behavior of solder materials in TMF has been studied as a function of cycle time in Hacke et al.

Future Needs

Advanced monolitic materials and their composites will provide challenges to experimentalists and analysts working on thermomechanical fatigue. Beyond the need for TMF resistance in applications listed earlier, studies of thermomechanical fatigue and fracture in the electronics industry and in manufacturing operations involving thermomechanical processing are other areas likely to attract attention in the future.

I would like to express my gratitude to all authors, reviewers, and ASTM staff for their contribution to the publication of this STP. A follow up symposium is planned in two years, which will highlight new developments in this field.

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