In the combustion zone of industrial- and aero- gas turbines, thermomechanical fatigue (TMF) is the dominant damage mechanism. Thermomechanical fatigue is a coupling of independent creep, fatigue, and oxidation damage mechanisms that interact and accelerate microstructural degradation. A mixture of intergranular cracking due to creep, transgranular cracking due to fatigue, and surface embrittlement due to oxidation is often observed in gas turbine components removed from service. The current maintenance scheme for gas turbines is to remove components from service when any criteria (elongation, stress-rupture, crack length, etc.) exceed the designed maximum allowable. Experimental, theoretical, and numerical analyses are performed to determine the state of the component as it relates to each criterion (a time consuming process). While calculating these metrics individually has been successful in the past, a better approach would be to develop a unified mechanical modeling that incorporates the constitutive response, microstructural degradation, and rupture of the subject material via a damage variable used to predict the cumulative “damage state” within a component. This would allow for a priori predictions of microstructural degradation, crack propagation/arrest, and component-level lifing. In this study, a unified mechanical model for creep-fatigue (deformation, cracking, and rupture) is proposed. It is hypothesized that damage quantification techniques can be used to develop accurate creep, fatigue, and plastic/ductile cumulative- nonlinear- damage laws within the continuum damage mechanics principle. These damage laws when coupled with appropriate constitutive equations and a degrading stiffness tensor can be used to predict the mechanical state of a component. A series of monotonic, creep, fatigue, and tensile-hold creep-fatigue tests are obtained from literature for 304 stainless steel at 600°C (1112°F) in an air. Cumulative- nonlinear- creep, fatigue, and a coupled creep-fatigue damage laws are developed. The individual damage variables are incorporated as an internal state variable within a novel unified viscoplasticity constitutive model (zero yield surface) and degrading stiffness tensor. These equations are implemented as a custom material model within a custom FORTRAN one-dimensional finite element code. The radial return mapping technique is used with the updated stress vector solved by Newton-Raphson iteration. A consistent tangent stiffness matrix is derived based on the inelastic strain increment. All available experimental data is compared to finite element results to determine the ability of the unified mechanical model to predict deformation, damage evolution, crack growth, and rupture under a creep-fatigue environment.

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The public is welcome to attend.