CONSTITUTIVE MODEL DEVELOPMENT FOR ISOTROPIC MATERIALS

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Abstract

The trend toward increased performance for aircraft gas turbine engines has resulted in higher turbine blade tip speeds and higher inlet gas temperatures and pressures. These more severe operating conditions have reduced the durability of hot section components and have demonstrated the need to improve upon the current analytical methods used in the design of these components.

Under a recently instituted contract effort undertaken as part of the HOST program, crack initiation life prediction methods will be developed for hot section components fabricated from isotropic materials. To apply these methods it is first necessary to determine the component structural response, specifically the stress-strain history at the critical cracking location. The structural analysis method must be capable of accounting for cyclic thermomechanical loading, plastic flow during thermal transients, creep and stress relaxation during steady-state operation and inelastic strain ratchetting and reversal due to repeated flight cycles.

In recent years, nonlinear finite element computer codes such as ANSYS and MARC have become available for cyclic analysis of components involving inelastic strains. These codes are based on classical plasticity theory and use uncoupled creep constitutive models. The classical methods utilize simplifying assumptions for computational convenience. Among these assumptions are (1) the definition of a specific yield surface with associated flow rules and hardening models, (2) the partitioning of inelastic strains into time-independent (plastic) and time-dependent (creep) strains and (3) the uncoupling of time-independent and time-dependent inelastic strain effects. That these classical methods and their assumptions do not realistically represent superalloy material behavior under cyclic loading have been demonstrated in two pre-HOST programs (the turbine blade durability study reported in NASA CR-165268 and the combustor liner durability study reported in NASA CR-165250).

The objective of this program is to develop a unified constitutive model for finite-element structural analysis of turbine engine hot section components. This effort constitutes a different approach for nonlinear finite-element computer codes which have heretofore been based on classical inelastic methods. A unified constitutive theory will avoid the simplifying assumptions of classical theory and should more accurately represent the behavior of superalloy materials under cyclic loading conditions and high temperature environments. Model development will be directed toward isotropic, cast nickel-base alloys used for aircooled turbine blades and vanes. The Contractor will select a Base Material for model development and an Alternate Material for verification purposes from a list of three alloys specified by NASA. The candidate alloys represent a cross-section of turbine blade and vane materials of interest to both large and small size engine manufacturers. Material stock for the Base and Alternate Materials will be supplied to the Contractor by the Government.

The contractual effort will be conducted in two phases, a Basic Program of two years duration and an optional follow-on program also of two years duration. In

the Basic Program, a unified constitutive model will be developed for the prediction of the structural response of isotropic materials for the temperatures and strain ranges characteristic of cooled turbine vanes in advanced gas turbine engines. A data base of uniaxial and multiaxial material properties required for the constitutive model will be obtained for the Base Material. The constitutive model will be incorporated into a finite-element computer code. An evaluation will be made of the capability of the analytical method to predict structural response for multiaxial stress states and nonisothermal conditions by conducting thermomechanical loading and benchmark notch verification experiments and analyses. As a final evaluation of the analytical methods, a structural analysis will be performed for a hot section component fabricated of the Base Material for simulated engine operating conditions. In the optional program entitled Option 1, further development will be undertaken to consider thermal history effects and to correct any deficiencies indicated in the constitutive model or in the computational algorithms in the code. The material property test procedure will be developed to minimize the amount of testing required, estimate the model material constants from conventional property data, and account for coating effects. In addition, the constitutive model development will be verified for an alternate material.

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OBJECTIVE:

TO DEVELOP A UNIFIED CONSTITUTIVE MODEL FOR REPRESENTING CYCLIC INELASTIC BEHAVIOR OF ISOTROPIC CAST NICKEL-BASE ALLOYS USED FOR AIRCOOLED GAS TURBINE BLADES AND VANES.

BASIC PROGRAM

SCREENING OF CANDIDATE CONSTITUTIVE MODELS

SPECIMEN FABRICATION AND TESTING

UNIAXIAL EVALUATION OF CONSTITUTIVE MODELS

BASIC PROGRAM

IMPLEMENTATION OF MODELS IN F. E. CODE

MULTIAXIAL EVALUATION OF CONSTITUTIVE MODELS

BENCHMARK NOTCH EXPERIMENTS

BASIC PROGRAM

COMPONENT DEMONSTRATION PROBLEM

DELIVERY OF COMPUTER CODE TO NASA

OPTION 1

DEVELOPMENT OF MAT. PROP. TEST PROCEDURE

FINAL DEVELOPMENT OF CONSTITUTIVE MODEL

MODEL VERIFICATION FOR ALTERNATE MATERIAL