FINAL REPORT

LIFE PREDICTION OF ADVANCED MATERIALS FOR GAS TURBINE APPLICATOIN:

THE EFFECT OF THERMOMECHANICAL STRAIN/TEMPERATURE CYCLING ON FATIGUE LIFE AND CRACK GROWTH OF COATED IN-738LC MATERIAL

AGTSR Subcontract No.: 93-01-SR012D

Principal Investigator :Professor Sam Y. Zamrik*
Co-Investigators :Professor Donald A. Koss**
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June 16, 1997

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EXECUTIVE SUMMARY

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Project Title: Life Prediction of Advanced Materials for Gas Turbine Application

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Principal Investigator : Professor Sam Y. Zamrik
Co-Investigator : Professor Donald A. Koss
Ph.D. Candidates : Mark L. Renauld
: Ravindra Annigeri

Objectives:

The main objective of the ATS research program is directed towards life prediction modeling of coated advanced gas turbine materials due to thermomechanical strain cycling. Emphasis is placed on life characterization on the basis of low cycle fatigue (LCF) under isothermal conditions and also on thermomechanical fatigue (TMF). In addition, the material deformation response to TMF is to be analyzed in terms of fracture mechanisms, microstructure changes and environmental effect. IN-738LC was chosen as a basic substrate material with overlay and aluminide coatings.

General Remarks:

Thermomechanical fatigue (TMF) is a unique type of fatigue in which material is simultaneously subjected to fluctuating loads and temperatures. Isothermal life prediction techniques are often not applicable to TMF conditions since mechanical properties are typically temperature dependent and because different damage mechanisms can arise. Many service conditions may be simulated using simple relationships between the thermal and mechanical strains. In-phase (IP) TMF occurs when the maximum strain and peak cycle temperature coincide whereas the maximum strain and lowest cycle temperature coincide during out-of-phase (OP) TMF. “OP TMF” cycles represent the TMF damage which occurs on the leading edge of a gas turbine blade from repeated turbine starts and stops. Turbine blades are routinely coated with either an aluminide, overlay or thermal-barrier coating to either inhibit oxidation or hot corrosion or to reduce substrate temperature. It is imperative that the coating maintain adherence to the blade without cracking or spalling to ensure maximum substrate protection. However, properties such as Young’s moduli, thermal expansions and inelastic deformation behavior of the coatings are highly dependent upon temperature and often differ from the respective substrate properties, thereby complicating TMF life prediction. Accurate TMF life estimates of coated turbine blades should account for these temperature-dependent properties of both the coating and substrate.

Accomplishments:

The project was completed with the development of a new life prediction model to account for thermomechanical strain cycling effect on fatigue. The model has two components:

- A viscoplastic component which accounts for the stain/temperature cycling response of the substrate and coatings in terms of hysteresis loops. These loops characterize the evolution of stress/strain/cycle up to mid-life cycle where the mid-life cycle represents the average cyclic deformation of the material. The outcome of this approach is to predict the maximum stress and strain range at the mid-life cycle where stress and strain are saturated.

- A tensile energy component to assess the damage incurred in the material as a result of TMF. The damage process incorporates creep effect due to dwell-time in terms of cycles to failure.

In addition, **a TMF crack growth model** has been developed which shows the acceleration and retardation of cracks due to the types of coatings applied to the substrate.

Interaction with Industrial Partners:

In development of the ATS life prediction program, close cooperation was established between the PI and co-workers with Westinghouse, Power Division in Orlando, FL, through Mr. John Junkin who provided us with the over lay coatings and data on their materials used in their gas turbine applications. Also, a close cooperation with the engine division of Allied Signal Aerospace Co. in Phoenix, AZ, through Drs. Graham Webb and Tom Strangman who provided the aluminide coatings and data on IN-738LC mechanical properties. Throughout the entire period, continuous contact was established between us and our industrial partners. In addition, we have received advice and technical information from Dr. David Nissley of United Technologies.

Students Support and Status:

Two Ph.D. candidates have successfully completed their doctorate degrees through this program. Dr. Mark Renauld, a strong contributor to the success of this research effort has joined United Technologies (Pratt& Whittney Aircraft Co.) in East Hartford, CT, and Dr. Ravi Annigeri has joined General Electric Co. in Schenectady, NY. In addition, through the Penn State CURO minority program, Mr. Jason Williams, an undergraduate engineering student from Tuskegee University, did his summer intern at our laboratory working with Mark Renauld on the ATS research program.