N87-11218

LIFE PREDICTION AND CONSTITUTIVE MODELS FOR ENGINE HOT SECTION ANISOTROPIC MATERIALS

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INTRODUCTION

The development of directionally solidified and single crystal alloys is perhaps the most important recent advancement in hot section materials technology. By reducing or eliminating grain boundaries in superalloys, the high temperature strengths have been substantially improved. Metallurgists have developed the alloy chemistries and casting processes so that they are now in practical use. However, the life limits of gas turbine parts, under complex loading conditions, are still not well known or understood. The objective of this program is to develop that knowledge to enable the designer to improve anisotropic gas turbine parts to their full potential.

Program Overview

The base program, which is followed by two options (fig. 1), will concentrate on coated turbine blade airfoil conditions. The coating, which is added to turbine airfoils to improve their oxidation and corrosion life, plays a major role in fatigue initiation. For this reason coated specimens are used extensively in this program. The materials have been selected, specimen fabrication is underway, the literature search is completed and Task III testing has begun. Table I shows the task breakdown of the base program.

Material Selection

The two single crystal alloys selected are PWA 1480 and Alloy 185. Table II lists the composition of these alloys. PWA 1480 was selected because it is the single crystal alloy most widely used today in gas turbine engines. Furthermore, it is representative of other practical single crystal alloys. Alloy 185 was selected because of differences between it and PWA 1480. These differences include a high volume fraction of γ' due to the higher aluminum content, a large γ/γ' misfit due to the high molybdenum content, and a higher level of creep anisotropy at higher temperatures. Contrast between the two alloys will provide a good test of the generality of any life prediction and constitutive models developed in this program.

The coatings selected are an overlay coating, PWA 286, and an aluminide diffusion coating, PWA 273. Coating chemistries are listed in Table III. These widely used coatings represent two basic classes.

Test Specimens

The constitutive specimens are solid and cylindrical; the fatigue specimens are hollow and cylindrical. The latter geometry is particularly applicable to thermomechanical fatigue (TMF) specimens. The thin wall facilitates thermal transient responses at reasonably fast rates. In addition, compressive stresses can be achieved

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with minimum risk of buckling. The crystallographic orientation of the specimens for both the constitutive and life prediction program will include <100>, <110>, <111>, and <123>. Under tensile loading, the first two orientations produce slip along the orthogonal planes; the third along cuboidal planes, and the forth a mixture of the two.

Test specimens for the coatings' tensile, constitutive, and life properties required special preparation. The plasma-sprayed specimens were fabricated by two methods; some were machined from HIPed bulk powder. The others were sprayed with a 1.5 mm (0.060 in.) layer of coating on a metal substrate which was subsequently removed by machining. On turbine blades the plasma-sprayed coating is about 0.4 mm (0.015 in.) thick and finished with shot peen. Metallographically the two specimens bracket the actual porosity of airfoil coating (see fig. 2).

Diffusion coating properties are impossible to measure directly. The strategy in this program will be to utilize two thicknesses of substrate. Specimens of both thicknesses will be coated and then tested for tensile, creep and fatigue properties. The results will then be plotted versus substrate thickness and extrapolated to zero thickness to obtain the values for the coating alone.

Models to be Evaluated

An extensive literature search has been completed for both the constitutive and life prediction models. The bulk of the past work has been done on isotropic materials. This research will be adapted to anisotropic materials whenever possible. For example, the life prediction models may use maximum resolved shear strain ranges on the active slip planes in place of principle strain ranges. The constitutive models to be considered will include macroscopic continuum theories of Hill (ref. 1), and Lee and Zaverl (ref. 2 and 3), or a unified visco-plastic formulation such as that of Walker and Cassenti (ref. 4 and 5). The unified theory is currently being extended by Walker to recognize specific slip systems of nickel-based single crystal alloys. Stouffer, in a parallel program (ref. 6), is also developing a constitutive model for single crystal alloys. All of these models will be evaluated utilizing the test data generated in this program.

Life prediction models under consideration include a number of isotropic models: linear time-cycle fraction (ref. 7), ductility exhaustion (ref. 8 and 9), frequency modified life (ref. 10, 11 and 12), frequency separation (ref. 13 and 14), Ostergren's method (ref. 15), strain range partitioning (ref. 16), damage mechanics, (ref. 17 and 18), continuous damage (ref. 19 and 20), and cumulative damage approach (ref 21). All of these models will be evaluated utilizing resolved shear stress and/or strain on active slip planes. A model to study the interaction of the coating and substrate is being developed.

Test Results

Because the test program is in its early stages evaluation of the results would be premature. One interesting preliminary result, however, is a comparison of the fracture surfaces of tensile specimens of PWA 1480 pulled in the <001> direction shown in figure 3. Note that the faceting at 760°C (1400°F) is pronounced and that the number of active slip planes is small. However, as the test temperature is increased to 1093°C (2000°F), the number of faceting planes becomes more numerous and the fracture surface appears more normal to the tensile load.

Plans

By October 1985, we plan to complete the Task III tests and to have a preliminary evaluation of the constitutive and life prediction models.

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TABLE I

BASE PROGRAM TASKS

I	Material/Coating Selection and Acquisition
II	Selection of Candidate Life Prediction and Constitutive Models
III	Level 1 Experiments
IV	Correlation of Models With Level 1 Single Crystal Experiments
V	Level 2 Single Crystal Experiments
VI	Final Selection of Life Prediction and Constitutive Models
VII	Subcomponent Verification For Primary Single Crystal Material
VIII	Alternate Single Crystal Material Characterization For Airfoil Applications
IX	Model Verification On Alternate Single Crystal Material
X	Delivery of Computer Code to NASA

TABLE II

SINGLE CRYSTAL ALLOY COMPOSITION

(Weight Percent)

Alloy	Ni	Cr	Co	Ti	Al	Ta	W	Mo	Nb	C	B	Zr	Hf	Y
PWA 1480	Bal*	10.0	5.0	1.5	5.0	12.0	4.0	--	--	--	--	--	--	--
Alloy 185	Bal	--	--	--	6.8	--	6.0	14.0	--	0.04	--	--	--	--

* Balance

TABLE III

COATING MATERIALS

Coating	Composition	Deposition Process
Overlay PWA 286	NiCoCrAlY + Si+Hf	Vacuum Plasma Spray
Diffusion PWA 273	Aluminide/ Outward Diffusion	Gas Phase

PROGRAM OUTLINE

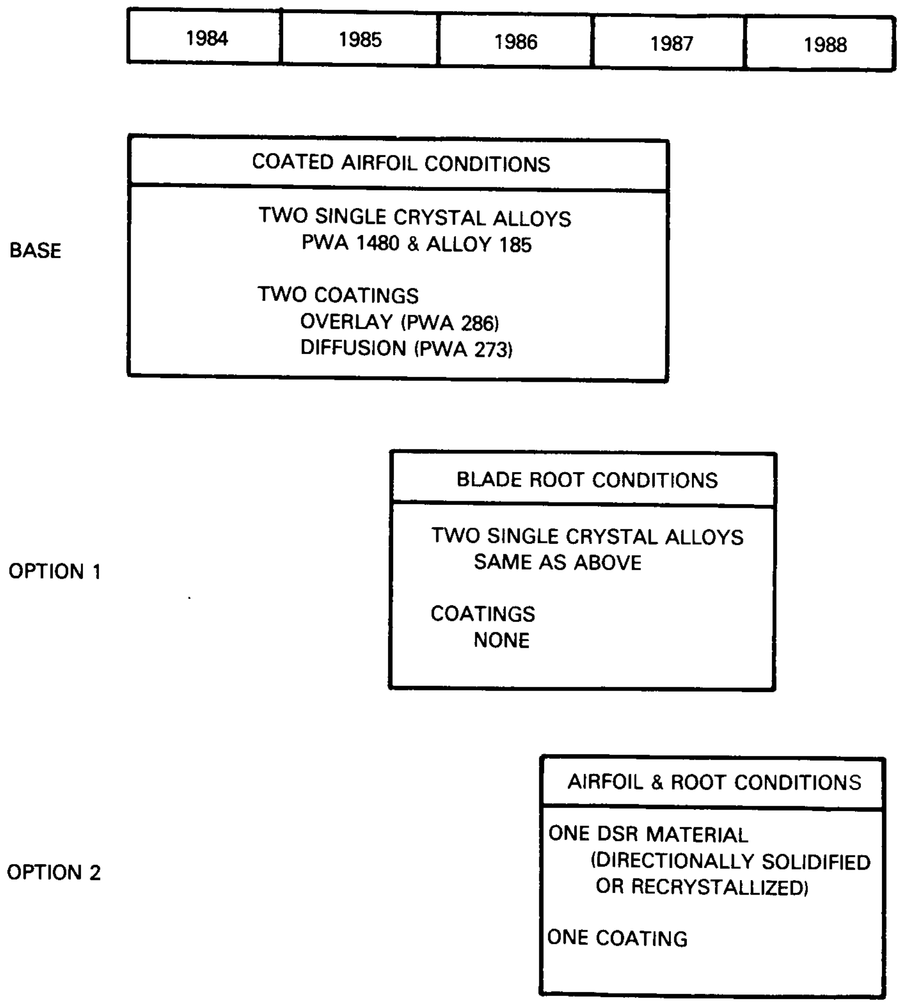
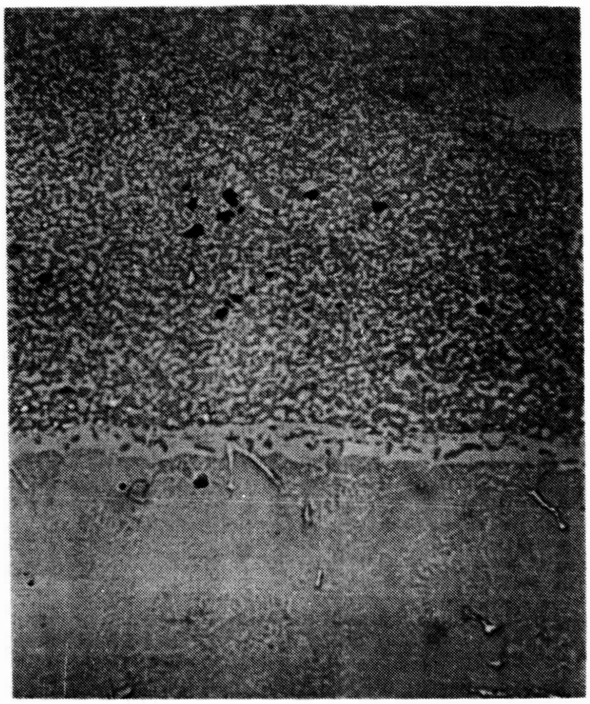
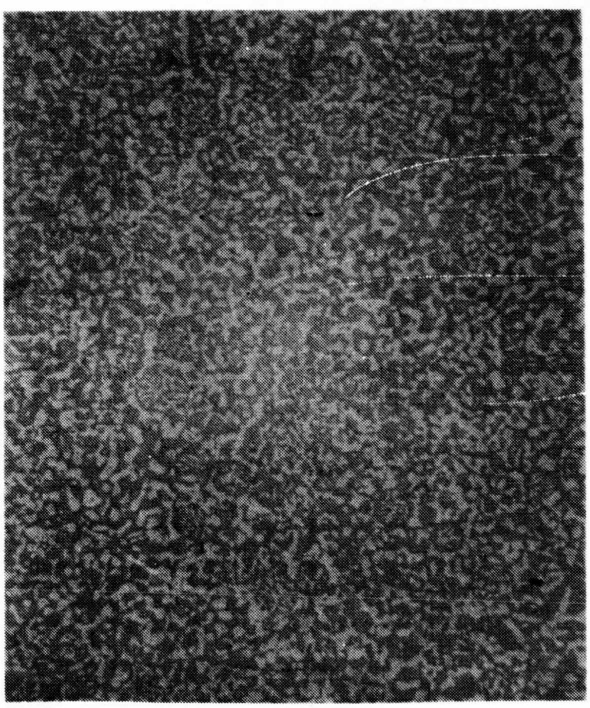


Figure 1

PWA 286 OVERLAY COATING STRUCTURE: STAND-ALONE vs PRODUCTION



TYPICAL PRODUCTION COATING 500X
HEAT TREATED & PEENED

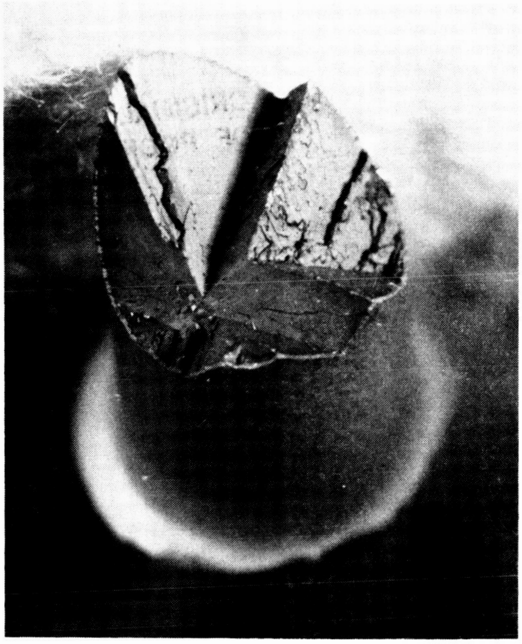


HIPed BULK POWDER 500X

THICK PLASMA SPRAY 500X
HEAT TREATED & PEENED

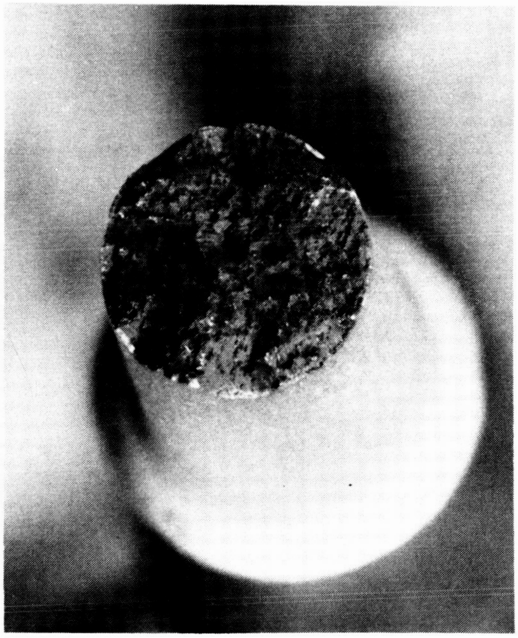
Figure 2

FRACTURE SURFACE OF PWA 1480 TENSILE SPECIMENS



760°C (1400°F)

871°C (1600°F)



982°C (1800°F)

1093°C (2000°F)

Figure 3