HIGH TEMPERATURE FRACTURE MECHANISMS OF A COATED NICKEL BASE SUPERALLOY: INFLUENCE OF THE TESTING MODE.

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NiCoCrAlYTa coatings are commonly used to protect turbine blades and nozzle vanes in gas turbines engines against high temperature degradation by oxidation, corrosion and erosion. Monocrystalline, [001] oriented, samples of the AM-3 superalloy coated with a Low Pressure Plasma Spray (LPPS) NiCoCrAlYTa coating were submitted to two different loading modes until fracture: a) high temperature thermomechanical fatigue (TMF) tests and b) creep test at 1323 K (1050°C) and 140 MPa.. The selected TMF strain controlled cycle have four slopes and a duration of 180 seconds. The temperature range extended from 923 K (650°C) to 1373 K (1100°C). Two strain ranges of $\Delta\varepsilon_{max}$ / 2= 0.5 % and $\Delta\varepsilon_{max}$ / 2= 0.25 % were chosen for this study Scanning Electron Microscopy (SEM) analysis were performed to establish the microstructural evolution correlating it to the fracture mechanism and it's dependence on the loading mode.

INTRODUCTION

The requirement of having an elevated Turbine Inlet Temperature (TIT) to increase the efficiency of the turbine engines has led to protect the components in the high temperature gas path in order to protect them from corrosion, oxidation and erosion. The NiCoCrAlYTa coatings have been conceived to fulfil this goal and are currently applied by Low Pressure Plasma Spray (LPPS). Creep is generally assumed to be the limiting strain phenomena for uncooled blades used in small turbines engines and thermomechanical fatigue determines the design limits for convection air cooled blades which are associated with bigger engines.(1-5).

The present paper reports the effects of the loading history on the fracture mechanisms of AM-3 superalloy single-crystals, whether coated with a NiCoCrAlYTa protective coating or not.

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EXPERIMENTAL PROCEDURE

Monocrystalline, [001] oriented, samples of the AM-3 superalloy, with a γ ' cube size of 0.7 μm, coated with a Low Pressure Plasma Spray (LPPS) NiCoCrAlYTa coating, (70-100 μm thick). were submitted to creep and thermomechanical fatigue tests (TMF). The measured compositions of the superalloy and the coating are presented in Table 1.

TABLE 1 Measured chemical composition in weight percent of the substrate and the LPPS coating.

	Chemical element								
	Ni	**Co**	**Cr**	**Al**	**Ta**	**Y**	**W**	**Ti**	**Mo**
AM-3	67.95	5.61	8.04	5.86	3.43		4.91	2	2.2
NiCoCrAlYTa	44.1	23	20	8.5	4	0.4			

Creep test were carried out at 1323 K (1050 °C) and 140 MPa until fracture. The high temperature thermomechanical fatigue tests were strain controlled with two strain ranges $\Delta\varepsilon_{max}$ / 2= 0.5 % or $\Delta\varepsilon_{max}$ / 2= 0.25 % with a four slopes cycle of 180 seconds. This cycle schematically reproduces the strain evolution of the leading edge (blade's critical element) in a civil turbine engine under normal working conditions. The temperature range extended from 923 K (650 °C) to 1373 K (1100 °C). Table 2 shows the main characteristics of the thermomechanical cycle. Scanning electron microscopy analysis were performed at each condition to establish microstructural evolution and the fracture mechanisms, correlating them to the existence or not of a NiCoCrAlYTa protective coating.

TABLE 2 Main features of the thermomechanical cycle.

Time (s)	Temperature (° C)	strain (%)	T/T_m
0	650	0	0.56
60	950	$-\varepsilon_{max}$	0.75
90	1100	0	0.84
160	750	$+\varepsilon_{max}$	0.62
180	650	0	0.56

RESULTS AND DISCUSSION

Table 3 shows the observed life times for the different loading modes. The coated samples last longer under thermomechanical fatigue conditions and the bare samples last longer when submitted to creep. The thermomechanical fatigue test results are not in agreement with the results obtained by Bresser et al. (4 and 6) or by Kraft et al. (8) but the different coatings deposition techniques (LPPS and PVD processes) and the different chemical compositions (NiCoCrAlYTa and NiAl) give rise to different mechanical responses at high temperature. The fact the LPPS coating is superplastic above 973 K (700 °C) as established by Veys (3) could explain the differences observed between the results of this study and those from (4,6 and 8) that used a basically brittle coating. Another consequence of testing the samples under creep conditions above the Ductile-Brittle Transition Temperature (DBTT) is that the coating do not present any crack or damage. The TMF cycle was conceived in order to have important strain below the DBTT, thus the coating presents cracks but this cracks are not able to propagate inside the coating as observed in the NiAl coatings.

TABLE 3 Observed life times for the different loading modes.

Test	Life time (hours)	
	Coated	Bare
Creep	220	300
TMF $\Delta\varepsilon_{max}$ / 2= 0.25 %	510.05 (10201 cycles)	356.55 (7131 cycles)
TMF $\Delta\varepsilon_{max}$ / 2= 0.5 %	63.80 (1276 cycles)	40.40 (808 cycles)

After Bressers et al. (7) under TMF conditions in which $\Delta\varepsilon_{max}$ > 0.8 % the dislocation movements is restraint to the (111) planes. This fact leads to fracture surfaces parallel to this planes family. This heterogeneous strain mode leads to the shearing of the gama prime precipitates that lead to dislocation dissociation and pile-up defaults. The bare samples showed this type of fracture planes, even for $\Delta\varepsilon_{max}$ = 0.5 %, and the fracture surfaces show a highly crystallographic morphology with a type I crack propagation mode (Figure 1). The coated samples have fracture surfaces showing the 'beach-trays' characteristic of the mode II propagation mode (Figure 2).However, while testing samples under TMF at $\Delta\varepsilon_{max}$ / 2= 0.5 %, a control-loop error lead to a suddent overloading at cycle's intermediate temperature and the fracture surfaces show the crystallographic features observed in the bare samples (Figure 3)

The heterogeneous strain mode contrast with the homogeneous strain a fracture surfaces observed under creep in which there is a void coalescence that leads to the formation of several macrovoids and cracks (Figure 4).

CONCLUSIONS

1- Samples with a LPPS NiCoCrAlYTa coating seems to last longer under TMF conditions and less under creep.

2- The heterogeneous strain mode proposed by Bressers et al. (7) seems to be confirmed for the uncoated samples under TMF.

3- Creep failure mode consist on voids coalescence and is independent of any crystallographic direction.

4- In all the cases fracture started at the superalloy substrate ; thus damaging processes in the coating do not induce the failure of the sample.

SYMBOLS USED

ε = mechanical strain

T_m = melting temperature

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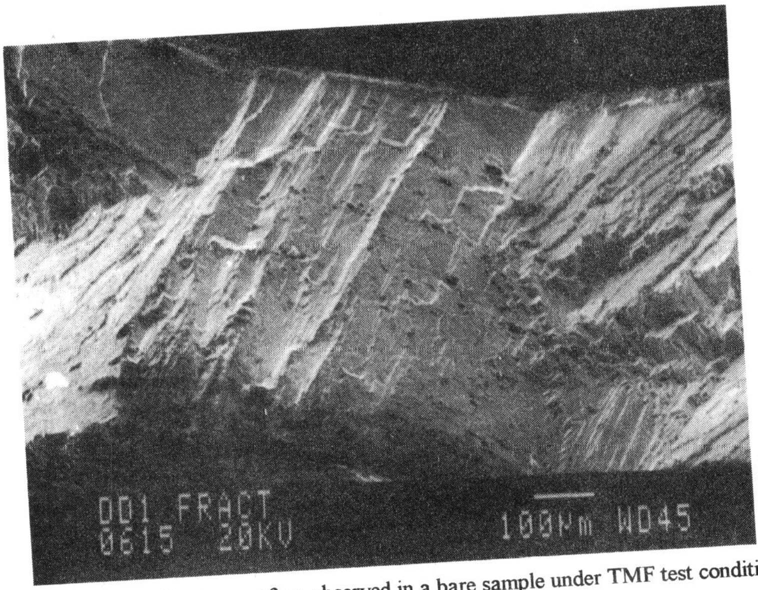

Figure 1 Type I fracture surface observed in a bare sample under TMF test conditions

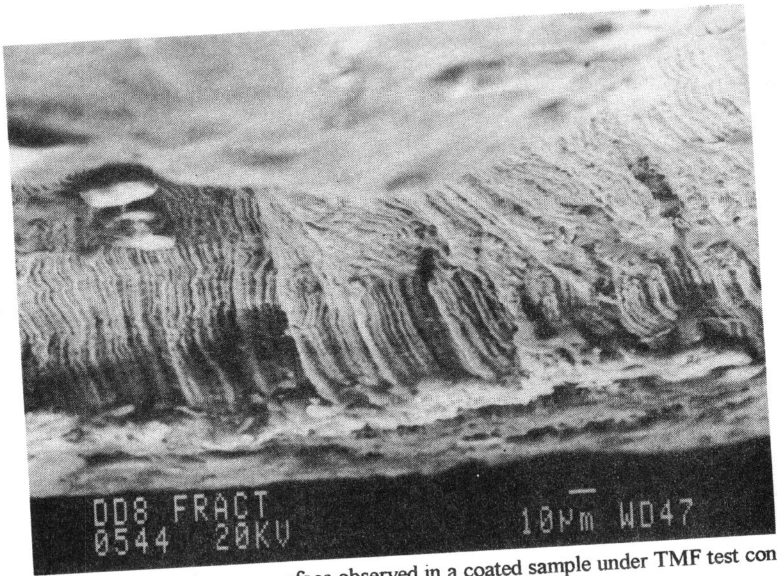

Figure 2 Type II fracture surface observed in a coated sample under TMF test conditions

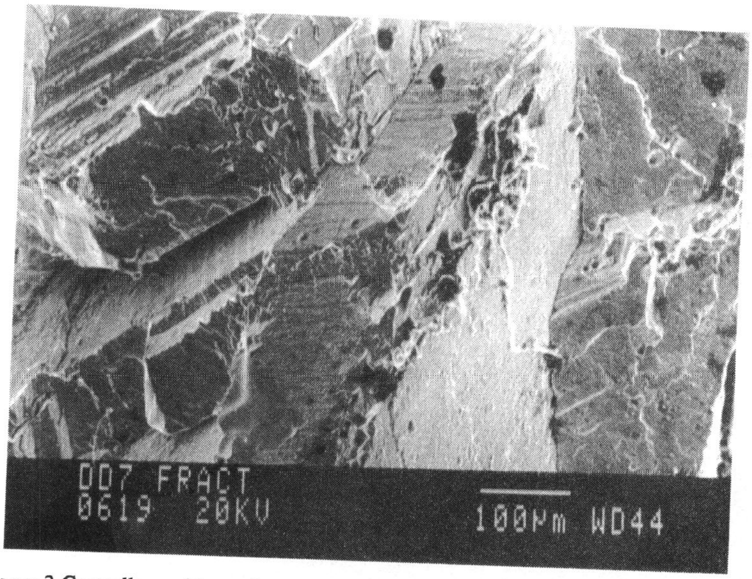

Figure 3 Crystallographic surface morphology in a coated sample after an overloading under TMF

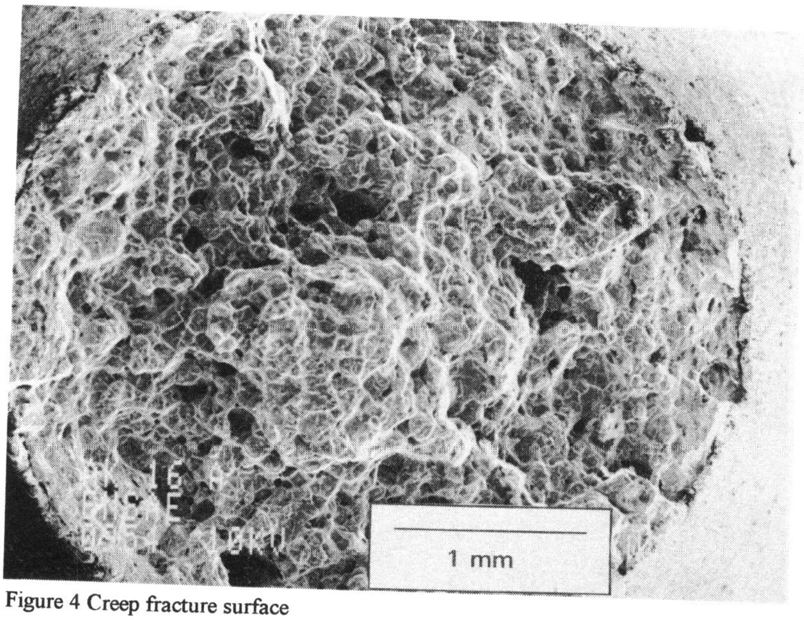

Figure 4 Creep fracture surface