INFLUENCE OF A COATING ON THE FATIGUE DAMAGE OF THE <001> AM1 SINGLE CRYSTAL SUPERALLOY AT 950°C

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In this study, the fatigue damage at high temperature of the coated AM1 single crystal superalloy has been assessed. In particular, comparisons were made with the fatigue damage of the uncoated material. SEM observations revealed a great influence of the coating upon cracking. A beneficial or detrimental effect of the coating upon lifetime has been observed depending on the mechanical conditions of testing. Furthermore, the influence of oxidation has also been studied. Fatigue tests performed under vacuum revealed complex damage phenomena due to oxidation in air.

INTRODUCTION

The improvement of aero turbo engine thermodynamic efficiency has been made possible by the development of superalloys which exhibit high mechanical behaviours at high temperature. The high pressure turbine blades are directly concerned by the increase of the turbine inlet temperature. Several causes explain their degradation, among them : creep, thermal fatigue cracking, oxidation, hot corrosion and exposure to overtemperature, (Koul et al. (1)). Among the Ni-base superalloys, single crystals present the best resistance capabilities according to these damages, (Erickson (2)). In order to increase oxidation and corrosion resistance, turbine blades are coated. The coating can be seen as an aluminium-chromium reservoir that provides elements to form specific oxides (Al_2O_3, Cr_2O_3). In this way, the substrate does not have to provide such elements and its oxidation and

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corrosion resistance is enhanced. But the efficiency of the coating is always balanced by its low strength resistance and its tendency to initiate cracks, (Stringer (3)).

The aim of this paper is to present the role of a Ni-Al-Cr coating(C1A treatment) in the cracking processes of the coated AM1 Ni-base single crystal superalloy used for the manufacturing of the M88 SNECMA engine turbine blades. A special attention has been paid to the influence of oxidation on crack initiation processes. For that, isothermal Low Cycle Fatigue tests were performed in air and vacuum on C1A-coated and uncoated specimens.

EXPERIMENTAL DETAILS

Cylindrical fatigue specimens of AM1 with a diameter of 4.4 mm and a gauge length of 13 mm were used to investigate the fatigue damage processes. Those specimens have been machined from <001> directionally solidified bars provided by SNECMA. After machining, they were mechanically polished down to 1 µm. Some of them were coated by SNECMA. The C1A coating process consists in an aluminisation modified by chromium. The deposit is then made of two layers : a rich chromium inner columnar layer and a Ni-Al outer layer. The entire deposit is about 50 µm thick.

The uncoated specimens have undergone the thermal treatment advised by SNECMA so that both coated and uncoated samples have the same microstructure in the bulk before fatigue tests (equivalent sizes of γ' precipitates).

Fatigue tests were performed at 950°C in the laboratory air under stress control with a stress ratio of $R = 0$ or $R = -1$ and a frequency of 0.5 Hz using a triangular signal. Some other tests have been performed under vacuum (pressure $< 10^{-3}$ Pa) in the same thermal and mechanical conditions so as to establish the influence of oxidation on cracking processes.

The analysis and quantification of damage features were made through SEM observations performed on gauge lengths and along lengthwise sections of air and vacuum tested specimens.

ROLE OF THE COATING ON CRACK INITIATION

Crack initiation occurs at the free surface of the specimen gauge length whatever the sample. From micropores located at or near the surface in the case of the uncoated material, and from the coating in the case of the coated one. In this case, casting defects seem not have a great influence on crack initiation.

The influence of the coating depends on the stress ratio value. For tension-compression tests, the coating seems to play no role on fatigue life (figure 1). But for tension-tension tests, a detrimental effect of the coating upon lifetime has been noticed (figure 2). SEM observations allowed to understand these results.

For fatigue tests performed at stress ratio R=-1, a big reduction of the number of cracks that penetrate into the substrate has been recorded on the coated material compared to the uncoated one. In fact, cracks initiated from the outer layer of the coating and deflected at the substrate-coating interface and thus crack penetration into the substrate is delayed. In this way, higher lifetimes could have been expected for the coated material. But for this type of test (R=-1) and the stress levels investigated here, the crack initiation stages were very short compared to the total fatigue lives for both materials. Then, differences on crack initiation were too weak to lead to significant differences in lifetime at R=-1. However, it is expected that at lower stress levels crack penetration into the coated-substrate will be delayed enough to reveal lifetime improvements.

For fatigue tests performed at a null stress ratio, a large part of lifetime is spent on the main crack initiation stage for the both materials. In fact, for these mechanical conditions the coating still rapidly initiates cracks that penetrate into the substrate at low stress amplitudes whereas crack initiation is strongly delayed or even suppressed in the uncoated material. By this way, it means that the coating can lead to early failure in isothermal fatigue testing conditions even if tests are performed at a temperature above the brittle-to-ductile transition temperature, (Chataîgner (4)).

ROLE OF THE ENVIRONMENT

SEM observations revealed two opposite effects of oxidation on coated material cracking :

On the one hand, oxidation favours crack initiation at the surface of the deposit and thus it weakens its fatigue resistance. This is confirmed by crack density quantifications made on lenghtwise sections of both air and vacuum tested coated-samples.

On the other hand, oxidation favours crack deflection at the substrate-deposit interface whereas cracks penetrate straightly in the substrate when specimens are tested under vacuum (figure 3). By this way oxidation delays crack penetration into the substrate.

CONCLUSIONS

The fatigue resistance of the coated AM1 single crystal superalloy clearly depends on the cracking conditions of the coating. A beneficial or detrimental effect of the coating on fatigue life is observed depending on the mechanical conditions of testing. Moreover, oxidation has not necessarily a negative effect on the first crack growth stages. Even if it accelerates crack initiation it also favours crack deflection at the substrate-coating interface. Further specific tests will allow to determine the crack growth kinetics on these cylindrical specimens and will participate to a better understanding of the cracking processes.

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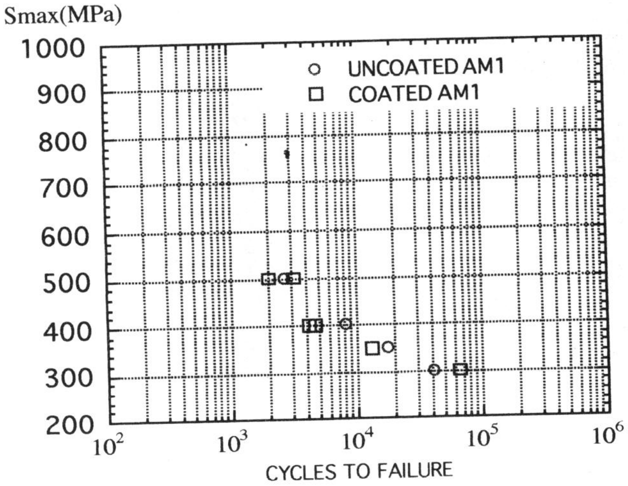

figure 1 : lifetime vs maximum stress level, fatigue tests performed at $R\sigma = -1$, 0.5 Hz, 950°C in air.

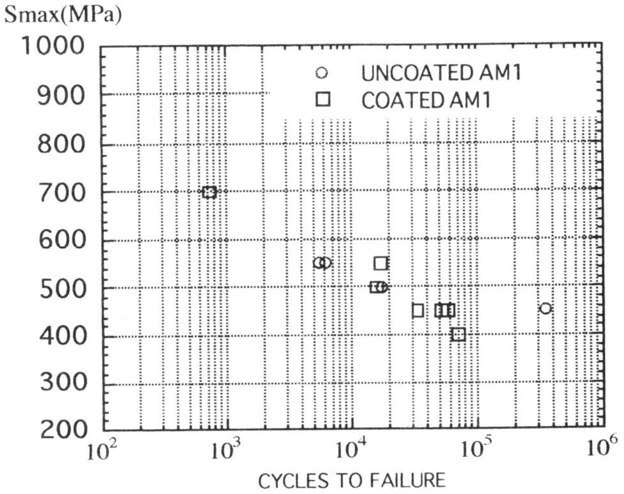

figure 2 : lifetime vs maximum stress level, fatigue tests performed at $R\sigma = 0$, 0.5 Hz, 950°C in air.

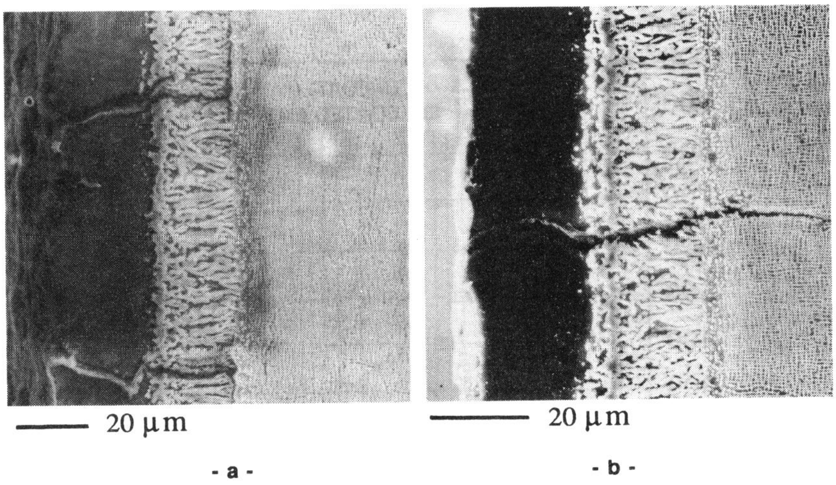

figure 3 : crack paths differences due to the environmental : a) crack deflection at the substrate-coating interface in air ; b) no deflection in vacuum