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Isothermal LCF behavior in aluminide diffusion coated René 80 near the DBTT

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ABSTRACT

Ni-base superalloys such as René 80 are widely used for aircraft turbine blades manufacture, due to possesses suitable mechanical, oxidation and hot corrosion properties. It is usually coated in order to increase its wear, oxidation, erosion and hot corrosion properties against environmental degradation. One the most important properties of coatings is its DBTT. In this paper the behavior of uncoated and coated (CODEP-B) René 80 has been studied near the DBTT (871 °C), $R = (\varepsilon_{min}/\varepsilon_{max}) = 0$ and strain rate of about $2 \times 10^{-3}\ s^{-1}$. Experimental results show that in coated specimens while the total cyclic strain is lower than 1%, coating leaves longer fatigue life, at this condition the nucleation of the cracks occurs merely in substrate, but in strains more than 1% as a result of nucleation of cracks in the coating surface, diffusion layer and substrate simultaneously, fatigue life time of the coated specimens is lower than that of uncoated specimens.

1. Introduction

High strength Ni-base superalloys have been used in turbine blades for many years because of their superior performance at high temperature. In such condition environments superalloys have limited oxidation and hot corrosion resistance and to solve this problem, protective coating are deposited on the surface. Overlay (Ni,CoCrAlY) and diffusion (low activity aluminide) coatings are recommended for oxidation, hot corrosion and erosion protection of aircraft turbine blades. In the aforesaid coatings the Cr and Al elements form protective oxide layers, i.e., Cr_2O_3 and Al_2O_3.

Ideally coatings should not have any effect on mechanical properties of the superalloy. One of the most important factors affecting the fatigue life of the coated blades is the magnitude of the applied tensile strain which must be lower than the fracture strain of the coating to observe the useful effect of presence of the coating. The fracture strain of the coatings could be obtained from temperature verses fracture strain graphs and interrupted tensile test results. At temperatures lower than the ductile to brittle transition temperature.

(DBTT) coating, as a result of differences in mechanical, chemical and physical properties of the substrate and that of coating, the presence of coat on the alloy may have an adverse effect on its mechanical properties. The DBTT of aluminide coatings lies in the range of 700–900 °C. As aluminum content, surface roughness and thickness of the coating decrease, the DBTT drops and thus the negative effects of the coating on the mechanical properties of the alloy diminishes [1–10]. The effect of composition on DBTT of aluminides is very clear from the work of Goward and Metals [10], who determined that the DBTT of aluminide coating is reduced by more d than 100 °C when aluminum content is lowered from 32 to 25%. DBTT also depends somewhat on the substrate on which the coating is deposited. Coating thickness is also known to have an effect on the measured DBTT [11]. It is noticeable that the DBTT of aluminide coating drop with increasing the service time as a result of oxidation of aluminum to form α-Al_2O_3 and also diffusing of aluminum in to the substrate which is in deed lowering the aluminum content in the coating, therefore fatigue failure often can come earlier than damage due to oxidation and the coating looses the protection function and subsequent crack propagation leads to accelerated corrosion of substrate.

The service life of aircraft turbine coated blades is based upon deterministic life of LCF. Some investigators have shown that, the coating decrease the fatigue life. Other reports no detrimental coating effects, or even fatigue life impotents. From the summary of test results reported in Ref. [8] it is concluded that no negative effect due to a coating on the LCF properties of Ni and Co-based superalloys can be found in cases where the coating can deform easily, i.e., above the DBTT and below a maximum coating thickness. The studies carried out by Totemeier and King [9], show that deposition of a high activity aluminide coating on the Ni-based single crystals would increase LCF life of the substrate at 800 °C, $R = -1$, strain rate $= 3.5 \times 10^{-3}\ s^{-1}$ and in strain lower than 1.2%.

René 80 is a Ni-base superalloy containing Ti, Al acting as the γ' precipitation hardening elements and Co, Cr, Mo added for solution

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strengthening of substrate. In the γ phase substrate there is high volume of primary and secondary precipitated γ′ phase which increases the strength of the alloy. Superalloy René 80 is used in the temperature range of 760–982 °C [12,13]. Aluminide coating with lower aluminum activity (outward diffusion) has lower DBTT in comparison to that of aluminide with higher aluminum activity. For this reason the coatings with lower aluminum activity such as CODEP-B is used for aircraft engine blades more frequently than other aluminide coatings [10]. A number of studies on the mechanical properties of René 80 have been performed [14–20]. In the field of influence of aluminide diffusion coating on the mechanical properties of this alloy there are few references. In this paper the behavior of uncoated and coated (CODEP-B) René 80 has been studied near the DBTT.

2. Experimental procedure

To produce the specimens, an investment casting method was used so that adequate amounts of polycrystalline round bars could be obtained. The chemical composition of the specimens is presented in Table 1. According to the heat treatment cycles presented in Fig. 1a, they were all homogenized and solution treated. After solution treatment they were machined and creep feed ground to bring them to the final shape as instructed in standards ASTM E-8 and ASTM E-606 as shown in Fig. 2. To make sure there are no defects, voids and cracks, all specimens were inspected by X-ray microfocus method. Following this inspection, the specimens were divided into sorts, i.e., the ones which were to be coated and the rest to be tested uncoated. Each sort was proceeded its own heat treatment cycle as shown in Figs. 1b and 1c.

The ones to be coated were immersed in a pack of powder mixture of 2 wt% of CODEP, 97 wt% of Al_2O_3 as filler and 1 wt% NH_4Cl as activator and put in H_2 atmosphere at 1052 °C for 4 h to form a suitable thickness, i.e., 30–40 μm of aluminide coating.

Tension and LCF tests were performed on both coated and uncoated tension test at temperatures of 22 °C, 760 °C, 871 °C, 982 °C and 871 °C respectively. The tensile tests were conducted with a constant strain rate of 0.007/min. All tensile tests have been done according to the standard ASTM – E21. In order to study the effect of elastic–plastic strain loading on the CODEP-B coating, the coated samples were axially strained up to 1% at 871 °C with the strain rate of 0.007/min.

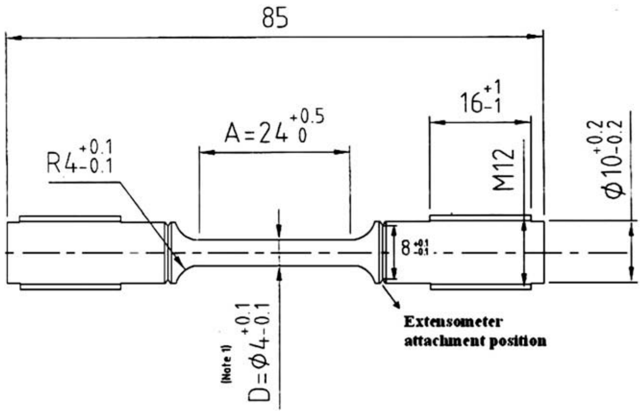


Fig. 2. Tensile and fatigue specimen dimensions (in mm) according to ASTM-E8 and ASTM-E606.

Both coated and uncoated specimens underwent the LCF conditions, i.e., triangular wave cyclic strain, $R = (\varepsilon_{\min}/\varepsilon_{\max}) = 0$, $\Delta\varepsilon_t = 0.8\%$ and strain rate = $2 \times 10^{-3}\ s^{-1}$. In order to minimize the effect of surface roughness on the LCF results, all the specimens were well polished according to ASTM E-606 and then gripped by threaded jaws to the modified Instron model 6027 electromechanical testing machine. To record the magnitudes and the variations of the cyclic strains applied on specimens; a linear variable differential transformer (LVDT) leg type extensometer was employed as illustrated in Fig. 2.

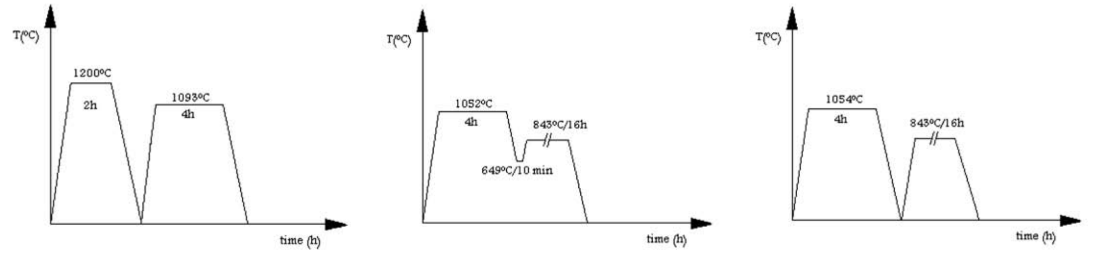
The microstructure and fracture surfaces of the specimens were studied by an optical microscope Olympus Model PMG3 and SEM Microscope Model Vega T Scan were employed.

3. Results and discussion

The microstructures of the coating and the substrate are shown in Fig. 3. Application of coating has no effect on the substrate microstructure as shown by comparing the microstructure of coated and uncoated substrate specimen. Studies have shown that the average size of γ′ phase is about 0.4 μm. Two layers were formed as a result of the coating process namely: outer and diffu-

Table 1
Chemical analysis of René 80, diffusion and outer layers of CODEP-B coating

	Ni	Cr	Co	Ti	Al	Mo	W	C	Zr	B
René 80	Bal.	14	9.3	5.05	2.94	3.75	3.75	0.16	0.02	0.016
Diffusion layer	65.22	6.83	7.84	6.47	5.86	3.11	4.66	–	–	–
Outer layer	62.3	2.93	6.8	2.86	25.11	–	–	–	–	–



(a) Homogenizing and solution treating cycle

(b) primary and secondary aging cycle for uncoated specimens

(c) Coating and aging cycle for coated specimens

Fig. 1. Heat treatment cycle for coated and uncoated René 80.