Materials Science & Engineering A 639 (2015) 575–584

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Effect of Pt–aluminide bond coat on tensile and creep behavior of a nickel-base single crystal superalloy

Chandrakant Parlikar*, D.V.V. Satyanarayana, D. Chatterjee, N. Hazari, Dipak K. Das

Defence Metallurgical Research Laboratory, P.O.-Kanchanbagh, Hyderabad 500058, India

ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form
15 May 2015
Accepted 15 May 2015
Available online 22 May 2015

Keywords:
Pt–aluminide coating
Single crystal alloy
Pack aluminizing
Tensile and creep properties

ABSTRACT

The effect of Pt–aluminide bond coat on the mechanical properties, namely tensile and creep, of a Ni-base single crystal superalloy has been investigated. Tensile properties of both uncoated and bond coated specimens were evaluated in the temperature range of room temperature (RT)-1100 °C. Creep testing was carried out using four combinations of temperature and stress, viz. 850 °C/500 MPa, 982 °C/240 MPa, 1038 °C/138 MPa and 1100 °C/90 MPa. By and large, the presence of bond coat reduced the tensile strength of the superalloy at all temperatures. However, the coated alloy exhibited a higher ductility than the uncoated alloy in the above temperature range. The lowering of strength in the coated alloy can be explained in terms of the significantly lower strength of the coating as compared to that of the substrate, which caused a decrease in the strength of the coating-substrate composite structure. The higher ductility of the coated alloy, especially at elevated temperatures, can be attributed to the surface protection provided by the oxidation resistant bond coat to the substrate. The creep properties (strain-to-fracture and creep life) of the coated alloy were somewhat inferior to those of the uncoated alloy at all test temperatures. This can be ascribed to the low strength of the bond coat at high temperatures and also to the microstructural changes that took place in and near the coating during the creep test.

1. Introduction

Superalloy components operating in hot sections of aviation gas turbine engines are exposed to oxidizing environments. In order to combat high temperature oxidation damage, these components are provided with protective coatings. Platinum-modified diffusion aluminide coatings (also called as Pt–aluminide coatings) provide excellent oxidation resistance to nickel-base superalloy components such as blades and nozzle guide vanes that operate in high temperature sections of advanced gas turbine engines [1,2]. The oxidation resistance of Pt–aluminide (Pt–Al) coatings is derived from the formation of an adherent and protective alumina scale on coating surface during high temperature exposure [3–5]. The improved scale adherence achieved because of the presence of Pt [3,4,6] reduces the incidence of scale spallation under cyclic heating and cooling conditions, typically encountered in gas turbine environments [7,8]. As a result, the effectiveness of these coatings against high temperature oxidation exposure is greatly enhanced.

Notwithstanding their excellent oxidation resistance, Pt–Al coatings are reported to degrade the mechanical properties of substrate superalloys [9–17]. Such degradation is caused by the brittle β-NiAl phase which is the primary constituent phase of the coating and has a high ductile-to-brittle transition temperature (DBTT) typically above 650 °C [12]. Effect of aluminide coating on various mechanical properties such as tensile [9–11,13], creep [9,11,14], high cycle fatigue [15] and thermo-mechanical fatigue [16,17] of various superalloys has been reported. For example, Veys and Mervel [11] have reported that the application of a diffusion aluminide bond coat did not appreciably affect the strength of the single crystal alloy CMSX-2 up to about 1050 °C. However, it led to a drastic reduction in the room temperature (RT) ductility of the alloy, although at higher temperatures (> 850 °C), the coated alloy exhibited very good ductility values [12]. Alam et al. [13] have reported the tensile properties of Pt–Al coated directionally solidified (DS) CM-247LC superalloy, evaluated at a test temperature of 870 °C. They evaluated the properties in as-coated condition as well as after subjecting the samples to cyclic oxidation in air at 1100 °C. In as-coated condition, the presence of bond coat was found to cause about 8–10% drop in the strength of the substrate alloy, although it did not appreciably affect the ductility [13]. The coated alloy exhibited a significantly higher ductility as compared to the uncoated alloy after a cyclic oxidation exposure of 750 h at 1100 °C [13]. There have been limited studies where the effect of aluminide coatings on the creep and stress rupture behavior of superalloys has been examined [9]. Most of these studies conclude

* Corresponding author.
E-mail address: cparlikar@yahoo.co.in (C. Parlikar).

http://dx.doi.org/10.1016/j.msea.2015.05.051
0921-5093/

that the rupture life of the substrate is not appreciably affected by the presence of the diffusion aluminide coating provided that the test is carried out above the DBTT of the coating [9]. In a recent study by Alam et al., nearly 45% drop in the creep rupture life of Ni-base superalloy CM-247LC was observed when it was applied with a Pt–Al bond coat [18]. Degradation in the thermo-mechanical fatigue life of superalloys in presence of Pt–Al bond coat has also been reported [17].

Despite several reported studies on the mechanical properties of diffusion aluminide coated superalloys, as mentioned above, the effect of Pt–Al bond coat on the tensile and creep behavior of substrate superalloys has not been examined in a systematic manner. In the present study, the effect of a high activity Pt–Al bond coat on the tensile and creep properties of a single crystal superalloy alloy has been investigated. Detailed microstructural and factography examination of the tested samples has been carried out to understand the tensile and creep behavior of the above superalloy in both uncoated and bond coated conditions.

2. Experimental details

As mentioned earlier, the substrate material used in the present study was a first generation nickel base single crystal superalloy having a nominal chemical composition of (in wt%) Ni–6.5Co–7.8Cr–5.7 W–5.2Al–7.9Ta–1.1Ti–2.0Mo. This superalloy was available in the form of 12 mm diameter rods having the single crystal orientation of $<001>$ along the length of the rods. The single crystal orientation of the rods was determined by using a Laue XRD system (Make: Proto XRD, Canada) and the rods that were used for mechanical testing had the above $<001>$ orientation with a deviation not exceeding 10 degrees. All the rods were solutionized at 1300 °C for 3 h. Some of the solutionized rods were then given a two-step aging treatment, which consisted of 9 h at 1100 °C followed by 20 h at 870 °C, to achieve the required γ–γ' structure. Both the solutionizing and aging treatments were carried out in a vacuum furnace. The fully heat treated rods were used for preparation of uncoated tensile and creep specimens using a computerized CNC machine. Tensile and creep specimens were prepared as per ASTM standard. The remaining solutionised rods were used for preparation of coated specimens. To achieve this, tensile and creep specimens were machined from the solutionized rods. Subsequently, they were electroplated with an approximately 5 μm thick Pt layer. The Pt plated samples were given a diffusion treatment in vacuum at 1100 °C for 5 h. The specimens were then pack aluminized at 850 °C for 5 h in an argon atmosphere. Subsequently, the aluminized samples were given a post-aluminizing diffusion treatment at 1100 °C for 4 h in vacuum to complete the coating process. Finally, the coated samples were aged at 870 °C for 20 h in vacuum. It may be mentioned that the above mentioned coating treatments were selected in such a way that the substrate alloy simultaneously received the required two-step aging, as mentioned previously. Other details of Pt–Al coating formation can be found elsewhere [19].

Both uncoated and Pt–Al coated specimens were tensile tested at different temperatures, namely room temperature (RT), 870, 1000 and 1100 °C, using a Walter Bai universal testing machine. All testes were carried out at a cross head speed of 1 mm min^{-1}. At least two samples were tested under any given condition for ensuring consistency in the results. Tensile creep testing of uncoated and coated specimens was carried out in air under constant load conditions using four combinations of temperatures and stress, namely 850 °C/500 MPa, 982 °C/240 MPa, 1038 °C/138 MPa and 1100 °C/90 MPa. For measurement of creep strain, the extensometer was mounted on the specimen ridges and two linear variable differential transducers (LVDTs) were attached to the extensometer outside the hot zone of the furnace. The average of the strain values measured by the two transducers was used for plotting the creep curve. Creep data was collected at regular time intervals using a data acquisition system. All the creep tests were conducted till fracture of the specimens.

Detailed microstructural examination of the specimens and fractography studies were carried out using an optical microscope and a Leo 440I scanning electron microscope (SEM) operating at 20 kV. For metallographic observation of coating cross-section, the samples were first plated with a layer of Ni using sulfamate bath to prevent edge-rounding during polishing operation. Subsequently, the sample cross-sections were polished using standard metallography techniques. Hardness variation across the coating thickness was recorded by using a LEICA micro-hardness tester a load of 25 g. Hardness was taken on the polished cross-section of the coated alloy in as-coated condition.

3. Results

3.1. Microstructure

Fig. 1(a) is an optical micrograph of the single crystal superalloy in fully heat treated condition, showing the typical dendritic structure observed in cast nickel base superalloys [20]. Coarse eutectic γ' in the inter-dendritic regions which remained undissolved even after the solutionizing treatment can be seen in the magnified view shown in the inset (Fig. 1(a)). Apart from these coarse γ' precipitates, the alloy had the usual γ–γ' structure with the strengthening γ' precipitates having a cuboidal shape [20], as

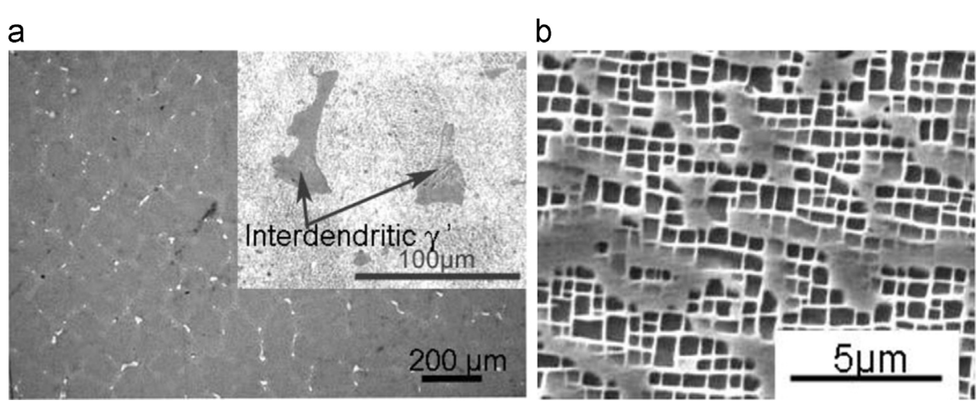

Fig. 1. Microstructure of the substrate alloy AM1: (a) optical micrograph showing the general dendritic structure with coarse interdendritic eutectic γ' phase shown in the inset, and (b) SEM BSE image showing the cuboidal γ' precipitates in γ matrix.