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Original Research

High temperature oxidation behavior of aluminide on a Ni-based single crystal superalloy in different surface orientations

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Abstract

An investigation on oxidation behavior of coated Ni-based single crystal superalloy in different surface orientations has been carried out at 1100 °C. It has been found that the {100} surface shows a better oxidation resistance than the {110} one, which is attributed that the {110} surface had a slightly higher oxidation rate when compared to the {100} surface. The experimental results also indicated that the anisotropic oxidation behavior took place even with a very small difference in the oxidation rates that was found between the two surfaces. The differences of the topologically close packed phase amount and its penetration depth between the two surfaces, including the ratio of α-Al_2O_3 after 500 h oxidation, were responsible for the oxidation anisotropy.

Keywords: Ni-based superalloy; Oxidation behavior; Microstructure; Aluminide coating; Crystallographic orientation

1. Introduction

Ni-based single crystal superalloys have been widely used in the industrial gas turbines and jet engines. The materials with superior properties such as mechanical strength and oxidation resistance are required for high temperature applications [1–3]. Recently, the surface operating temperatures of gas-turbine blades could reach 1200 °C or even higher. It has been reported [4,5] that high operating temperature motivates the degradation of superalloys during service with respect to oxidation or corrosion. More importantly, the oxidation behavior of materials becomes one of the predominant life-limiting factors for high temperature applications.

Aluminide coatings have been applied on the surface of Ni-based superalloys by the pack aluminizing process [6]. Many investigators have reported [6–11] that there are two types of aluminizing treatments, known as (1) high-temperature low-activity (HTLA) [6–9] and (2) low-temperature high-activity (LTHA) [6,7,10,11] processes. The difference between the two types depends upon the temperature of aluminizing and the activity of the pack used. However, the interdiffusion of elements between the superalloy substrate and the coating layer takes place when coated specimens are thermally exposed at high temperatures, resulting in a change in the microstructure of the substrates such as the formation of topologically close packed (TCP) [12]. Furthermore, the crystallographic orientation effect is one of the interesting subjects in Ni-based single crystal superalloys. It is well known that the mechanical properties of Ni-based single crystal superalloys are influenced by the crystallographic orientation of the surface of the specimen [13]. To date, the investigators have not paid much attention to the effect of crystal orientation on the oxidation behavior of alloys. From this point of view, the objective of the present work was to investigate the oxidation

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behavior characteristics of a coated Ni-based single crystal superalloy at high temperature with different surface orientations by using a variety of orientation and characterization tools such as the Laue technique, isothermal oxidation kinetics, optical and scanning electron microscopy (SEM).

2. Experimental procedures

A Ni-based single crystal superalloy, CM186LC was employed as an experimental material for the present study. The chemical composition of the superalloy in mass% was 5.74 Al, 0.73 Ti, 6.0 Cr, 9.3 Co, 0.5 Mo, 1.4 Hf, 3.4 Ta, 2.9 Re, 8.3 W, 0.07 C and balance Ni. A cylindrical rod of CM186LC was directionally solidified in the [001]-direction. The rod was solution heat-treated at 1274 °C for 8 h followed by gas fan cooling. A two-step aging treatment was then carried out at 1080 °C for 4 h and at 871 °C for 20 h before finally cooled down by an air cooling. The principal oxidation surfaces of single-crystal samples were identified to be within 4° of the desired orientations using the Laue technique. The specimens were cut from the rod along the {100} and {110} surfaces with the dimension of 10 mm in length, 5 mm in width and 3.5 mm in thickness using an electrodischarge machine (EDM). Prior to aluminizing treatment, the specimens were mechanically polished down to 1200-grit SiC paper, degreased in alcohol, ultrasonically cleaned in alcohol and finally dried in air.

In the present study, the specimens were coated by the pack aluminizing process. The HTLA process was used in preparing the aluminide coating. The specimens were then embedded in an Al_2O_3 retort containing a mixture of 24.5 Al, 24.5 Cr, 49.0 Al_2O_3 and 2.0 NH_4Cl powders (all in mass%) and heated at 1000 °C for 5 h in argon atmosphere. All the coated specimens were subjected to isothermal oxidation in air at 1100 °C for 500 h. The specimens were then detached and weighed after varied oxidizing periods of 25, 50, 100, 200 and 500 h. The oxidation kinetics was determined through the relationship between mass gain and oxidation time. The mass gains were measured using an electrobalance that had a precision of 0.1 mg after the specimens were air cooled to room temperature.

The initial microstructure of the Ni-based single crystal superalloy was observed by optical microscopy (OM). The formed oxide phase on the surface of the superalloy after oxidation was identified by X-ray diffraction (XRD) using Cu Kα radiation. The outer surfaces and cross sections through the oxidized specimens were observed using SEM investigations. The chemical composition of the oxide scale-to-substrate regions after oxidation was determined by the energy-dispersive X-ray analyzer (EDX), which was attached to the SEM machine.

3. Results

3.1. Initial microstructure investigations

Fig. 1 shows (a) the optical (OM) and (b) SEM micrographs taken from the Ni-based single crystal superalloy surface before the aluminizing process. From Fig. 1a the γ/γ' two-phase structure can be easily observed, which has been usually found in the standard Ni-based single crystal superalloys. And Fig. 1b indicates that cuboidal γ' precipitates are regularly aligned along {001} during the aging treatment as a result of the elastic interaction between precipitates [14]. The SEM micrograph also confirms that the Ni-based single crystal superalloy contains about 70 vol% cuboidal γ' precipitates.

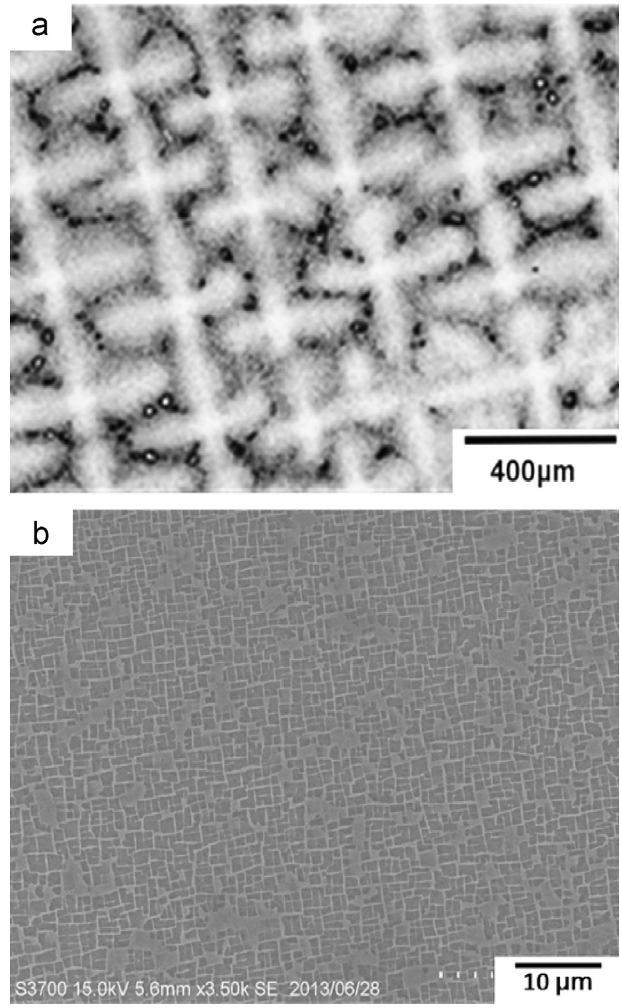

Fig. 1. Optical (a) and SEM (b) micrographs of Ni-based single crystal superalloy CM186LC.

3.2. Microstructures of as-coated specimens

The microstructure of the as-coated surface of (a) {100} and (b) {110} specimens are shown in Fig. 2. It can be seen from Fig. 2 that the as-aluminized specimens consisted of the coating layer, a diffusion zone which is called as "interdiffusion zone (IDZ)", and the substrate on both orientations. The formation of coating layer in a HTLA process is mainly due to the outward diffusion of Ni from the substrate and its reaction with aluminum available from the pack [15]. The formation of coating leads to the growth of a β-NiAl layer outward with regard to the initial substrate surface. Finally, the region under the initial surface of the substrate, which sustains the lack of Ni due to its outward diffusion, develops as the interdiffusion zone (IDZ) [10]. The IDZ thickness was circa 4.4 μm on {100} surface and about 4.7 μm on {110} surface.