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Full Length Article

Oxidation behavior of NiCoCrAlY coatings deposited by double-Glow plasma alloying

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ABSTRACT

The NiCoCrAlY coatings were deposited on the Inconel 718 alloy substrates by a novel method called double-glow plasma alloying (DG). The phases and microstructure of the coatings were investigated by X-ray diffraction analysis while their chemical composition was analyzed using scanning electron microscopy. The morphology of the NiCoCrAlY coatings was typical of coatings formed by DG, with their structure consisting of uniform submicron-sized grains. Further, the coatings showed high adhesion strength (critical load >46 N). In addition, the oxidation characteristics of the coatings and the substrate were examined at three different temperatures (850, 950, and 1050 °C) using a muffle furnace. The coatings showed a lower oxidation rate, which was approximately one-tenth of that of the substrate. Even after oxidation for 100 h, the Al_2O_3 phase was the primary phase in the surface coating (850 °C), with the thickness of the oxide film increasing to 0.65 μm at 950 °C. When the temperature was increased beyond 1050 °C, the elemental Al and Ni were consumed in the formation of the oxide scale, which underwent spallation at several locations. The oxidation products of Cr, which were produced in large amounts and had a prism-like structure, controlled the subsequent oxidation behavior at the surface.

1. Introduction

Ni-based superalloys are widely used in hot-section components such as jet engines and gas turbines due to their excellent mechanical properties. [1] So far, to improve the oxidation and corrosion resistance of superalloys, four types of high-temperature protective coatings have been employed: aluminum diffusion coatings, platinum aluminum diffusion coatings, MCrAlY (M = Ni, Co, and/or Fe) coatings, and thermal barrier coatings (TBCs). [2,3] Of these, MCrAlY coatings have attracted the most attention from the scientific community owing to their good ductility, high plasticity, and excellent oxidation resistance. They are used as the conventional protective coatings for gas turbines operated at temperature lower than 900 °C and are also employed as the bonding coating in TBCs. [4–6] However, significant efforts are being made to further improve the performance of these coatings. Several methods can be used for depositing MCrAlY coatings, including plasma spraying, electron beam physical vapor deposition, and magnetron sputtering. [7–9] However, despite the flexibility of these methods, the coatings formed using them exhibit high porosity and low adhesion strength. Hence, it has become essential to develop novel methods for depositing MCrAlY coatings, in order to improve their surface quality. [10,11]

A new technique called double-glow plasma alloying (DG) shows promise in this regard. It has been used successfully to prepare various kinds of coatings, such as those of Nb, Cr, and Fe-Al-Cr-Nb. The DG process employs low-temperature plasma produced by glow discharges to form an alloying layer on the surface. This results in low power consumption and good environmental safety. Further, the process can be used with large surface areas. [12–15] Coatings synthesized by the DG technique exhibit surface structures consisting of submicron-sized grains. In addition, the adhesion between the coating and the substrate is high because of the formation of an interdiffusion layer. [9] Although a wide range of high-performance composite coatings have been fabricated by the DG process, the technique has not been used widely for forming high-temperature coatings. Using this technique could effectively decrease the number of microholes and cracks formed in the coatings as well as the amount of detrimental oxides formed during the deposition process.

The present study aimed to elucidate the oxidation behavior of NiCoCrAlY coatings deposited by the DG technique. The phase evolution and antioxidation mechanism of the coatings were also analyzed.

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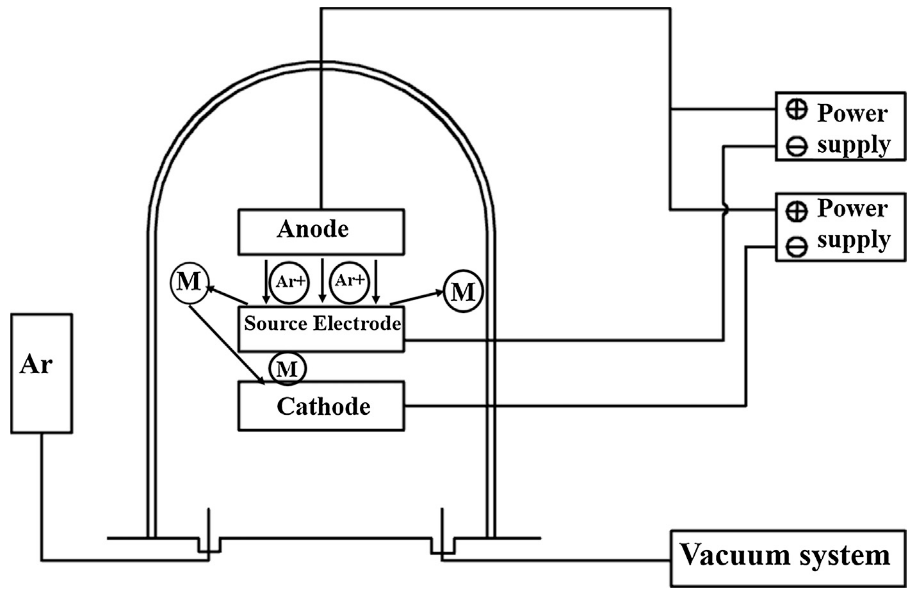

Fig. 1. A schematic of the double-glow plasma alloying machine.

Table 1
The deposition parameters of the double-glow plasma alloying.

Parameter	Values
Voltage of the source electrode (V)	950
Voltage of the cathode (V)	450
Working pressure (Pa)	35
Distance between the source electrode and cathode (mm)	15
Treatment time (h)	4
Argon flow rate (sccm)	60

Table 2
The technology parameters of the scratch test.

Parameters	Settings
Initial load (N)	0.5
Final load (N)	100
Loading rate (N/min)	20
Scratch speed (mm/min)	10

2. Experiment procedure

2.1. Coating preparation

In this study, NiCoCrAlY coatings were deposited on Inconel 718 alloy substrates by the DG method. The DG system used consisted of three electrodes (Fig. 1): the device chamber (anode), the metal target (source electrode), and the workpiece (cathode). When the power supply is switched on, both the metal target and the workpiece are covered by the glow discharge, which transfers heat and results in the sputtering of the source elements on the workpiece because the active plasma ions (Ar^+) continuously hit the target with sufficient energy. [14] The processing parameters used are listed in Table 1. The source target was a Ni-21.5Co-22Cr-12Al-0.35Y (wt.%) disc (diameter of 100 mm and thickness of 3 mm) with a purity of 99.99% and was produced using powder metallurgy techniques. Inconel 718 alloy substrates with dimensions of 15 mm × 15 mm × 5 mm were used as the base materials. Before the deposition process, the substrates and the target were polished and cleaned ultrasonically in an ethanol bath.

2.2. Coating characterization and oxidation test

The adhesion strength of the NiCoCrAlY coatings on the substrates was examined by the scratch test (WS-2005, Lanzhou Institute of Chemical Physics, China). A progressively increasing load was applied on the coating surface to evaluate the adhesion strength. The loading rate was 20 N/min, and the results were obtained in the form of an acoustic emission (AE) signal. [10] The parameters used for the test are listed in Table 2. Morphologies and corresponding chemical compositions were observed by a scanning electron microscope (JSM-6360LV, JEOL, Japan) equipped with an energy-dispersive spectroscope (XMS60S,EDAXInc.,USA). The crystalline phases were detected by X-ray diffraction (APD1700, Philips, The Netherlands) using a Cu Kα radiation over the range from 20° to 90°. To determine the phase composition of the interdiffusion layer, the top coating of the test specimen was polished till the coating thickness was less than 5 μm. Then, X-ray diffraction (XRD) analysis was performed on the interdiffusion layer.

To study the oxidation behavior of the coatings, substrates with and without the coating were subjected to isothermal oxidation in a muffle furnace at 850, 950, and 1050 °C for 100 h. This was because Inconel 718 alloy exhibits the best performance at temperatures lower than 700 °C and does not show long-term stability at higher temperatures (> 1100 °C). To ensure the accuracy of the results, the specimens were weighed in the crucible using an electronic balance (BSA224S-CW, Satorious, Germany) with a sensitivity of 0.01 mg every 10 h and then placed back into the furnace for the remaining of the oxidation process.

3. Results and discussion

3.1. Microstructure and adhesion strength

Images showing the surface and cross-sectional morphologies and porosities of the as-deposited NiCoCrAlY coatings are given in Fig. 2. The surface consists of compact submicron-sized grains arranged in a stacked structure (Fig. 2a). These submicron-sized grains of NiCoCrAlY (approximately 500 nm in size), which are a typical feature of the DG process. Fig. 2c shows the porosity of the coating (approximately 0.37%) as determined based on a digital image capture and analysis system. Although a densewas formed, gaps existed between the deposited particles, resulting in oxygen diffusion. [10,16,17] The thicknesses of the as-deposited coating and the interdiffusion layer were 15 and 1.5 μm, respec-