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Interfacial strength and oxidation resistance of the NiCrAlYSi coating with a diffusion barrier and/or buffer layer on DSM11 deposited by continuous arc ion plating

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ABSTRACT

The NiCrAlYSi coating with a diffusion barrier (DB) and/or buffer layer (BL) on DSM11 substrates was deposited by continuous arc ion plating (AIP) method. The interfacial strength, oxidation resistance and diffusion-barrier effectiveness were investigated. The tensile adhesion test result showed that the interfacial adhesive strength was stronger than that in the coating system with a diffusion barrier deposited by the conventional two-step AIP. The pre-deposition of the buffer layer into the DB/DSM11 interface could improve the interfacial strength further. The oxidation test results indicated that the multilayer could provide more effective protection for the DSM11 substrate than the single coating system. During thermal exposure, continuous and adhered Al_2O_3 scales were presented to the coating surface and the interdiffusion of alloying elements between the overlayer and the substrate was suppressed markedly. After thermal exposure or thermal cycle, the diffusion barrier was stable and kept efficient.

1. Introduction

MCrAlY (M = Ni and/or Co) coatings, with the good balance between oxidation resistance and mechanical properties, have been widely used for the protection for the gas turbine components [1,2]. However, after a long-term exposure to high temperature atmosphere in service, the coatings are rapidly degraded. The main reason is ascribed to the intensive element interdiffusion between the coatings and the substrates [3,4]. To solve this problem, a diffusion barrier should be included into the coating system [1]. With the addition of diffusion barrier, the question that must be taken into account is that how about the interfacial strength of the multilayer system will be, and whether the oxidation resistance is improved.

Many investigations have been made of the interfacial strength of multilayer systems. It is considered that the interfacial strength is related to the mechanical properties of layer materials and the cleanness of interfaces [5–7]. Smaller the property discrepancy and less the interfacial contaminants, stronger is the interfacial bonding. In our previous work [8–11], it was found that the interfacial strength was markedly weakened with the introduction of a CrON diffusion barrier into the MCrAlY/DSM11 interface. Two reasons were ascribed: one was the presence of high interfacial residual stress, which was formed during the coating deposition or thermal cycle due to a low CTE in the brittle diffusion barrier and a high CTE in the ductile overlayer or substrate. The other was the contaminants which originated from discontinuous deposition process. During the two-step deposition, the contaminants including C, water vapor, etc., were adsorbed into the diffusion barrier when the specimens were exposed to ambient atmosphere at deposition interval. The presence of the contaminants and residual stress markedly impaired the interfacial adhesion of the multilayer system [5,6]. To continuously deposit the diffusion barrier and the overlayer with the same alloy target can result in the diffusion barrier with a close composition to the overlayer and can effectively eliminate the interfacial contaminants. This way, it is believed that the interfacial strength will be enhanced. And the interfaces are strengthened further with the pre-deposition of a buffer layer into the diffusion barrier/substrate interface due to a roughening surface of the buffer layer deposited by AIP technology [7]. To the best of the authors' knowledge, no attempts have been made to deposit the multilayer system with a diffusion barrier and/or buffer layer by continuous AIP method.

The oxidation resistance of the MCrAlY coatings mainly depends on the formation of continuous, dense and adherent Al_2O_3 or Cr_2O_3

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Table 1
Composition (wt%) of DSM11 substrate and NiCrAlYSi target.

Alloy	Ni	Cr	Co	Al	Ti	W	Mo	Ta	Y	Si
DSM11	Bal	14	9.5	3.0	4.9	3.8	1.5	2.8	–	–
NiCrAlYSi	Bal	20	–	14	–	–	–	–	0.7	1.3

Table 2
Deposition parameters.

Coating	O_2 (sccm)	N_2 (sccm)	Ar (sccm)	Bias voltage	Arc current	Target	Time (min)
BL	0	0	70	−240	65–75	NiCrAlYSi	60
DB	100	110	0	−240	65–75	NiCrAlYSi	40
Overlayer	0	0	70	−240	65–75	NiCrAlYSi	360

scales on the coating surface [1]. However, the integrity of the scales is strongly affected by element interdiffusion [3]. It was reported that Ti and W elements, rapidly diffusing through the overlayer, resulted in the formation of a high stress in the scales and accelerated the scales spalling off [10–13]. Otherwise, inward-diffusion of Al and Cr accelerated their depletion and decreased the regeneration of protective scales. Thus, the coating was degraded. The introduction of a diffusion barrier as an interlayer is to suppress the element interdiffusion so as to improve the oxidation resistance of the coating system.

In the present paper, the overlayer, diffusion barrier and/or buffer layer were continuously deposited on superalloy DSM11 with the same NiCrAlYSi alloy target by arc ion plating. The interfacial strength and oxidation resistance of the multilayer system and the diffusion-barrier effectiveness were investigated.

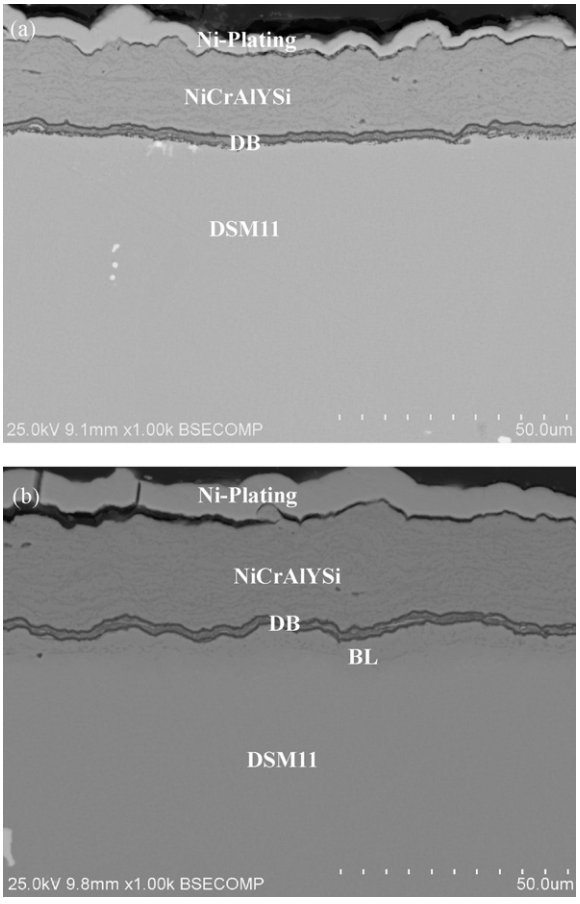

Fig. 1. Cross-section BSE images of the annealed samples. (a) NiCrAlYSi/DB/DSM11; (b) NiCrAlYSi/DB/BL/DSM11.

2. Experimental

The substrate material used is a Ni-based superalloy DSM11, whose composition is given in Table 1. The ingot was cut into coupons of size 15 mm × 10 mm × 2 mm. After being ground, grit-blasted and ultrasonically cleaned, the coupons were hanged in the chamber of arc ion plating equipment for the coating deposition.

The cathode target for the deposition of the buffer layer, diffusion barrier and overlayer is NiCrAlYSi alloy (Table 1). Before deposition, the AIP chamber was evacuated to a base vacuum of 6×10^{-3} Pa. Then bombardment cleaning of Ar^+ ion was carried out for 5 min with a negative bias of 800 V. The buffer layer was deposited in an Ar atmosphere of about 0.2 Pa (the gas flow rate was 70 sccm) for 60 min. Successively, the diffusion barrier and the overlayer were deposited. The oxygen and nitrogen gas flow rates were controlled at 100 sccm and 110 sccm, respectively, for the deposition of the diffusion barrier. The overlayer was deposited for 360 min with the same deposition parameter as that of the buffer layer. The detailed deposition parameters are shown in Table 2. Compared with the conventional AIP for the MCrAlY overlayer with a diffusion barrier on superalloy substrate [8–11], herein there were no deposition intervals and the target was the same NiCrAlYSi alloy during the continuous deposition. After deposition, the coated samples were annealed at 900 °C for 4 h in vacuum for the stress release and subsequently cooled down to room temperature. The heating rate was less than 7 °C/min.

The thermal exposure test was carried out at 1050 °C for 100 h in air to evaluate the oxidation resistance of the coating samples.

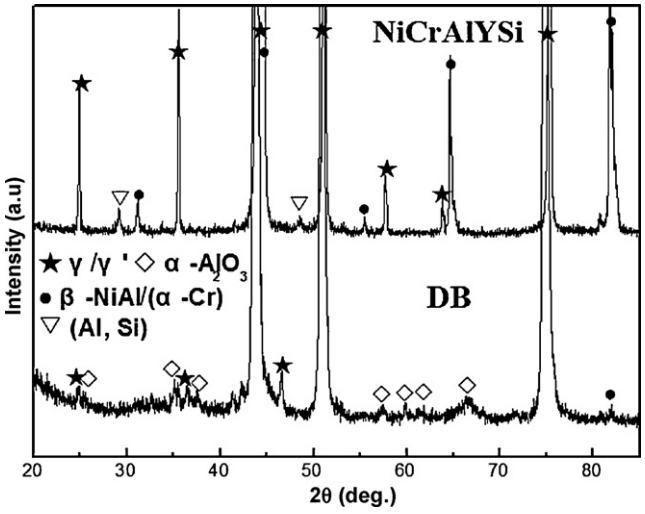

Fig. 2. XRD patterns of the overlayer and the diffusion barrier in the annealed NiCrAlYSi/DB/BL/DSM11 sample. The diffusion barrier was detected after the NiCrAlYSi overlayer was detached.