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Effect of coating repair on microstructure and mechanical properties of Ni₃Al based alloy IC6^①

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[Abstract] The effect of coating repair on microstructure and mechanical properties of a directionally solidified nickel base alloy IC6 was studied. The experimental results show that after coating repair treatment, the substrate/coating interface keeps well, and the combination of coating and substrate is very good, as well as very slight mutual diffusion of alloying elements between substrate and coating occurred. Although coating repair treatment make diffusion time double, only a little amount of Mo diffused into coating, and the elements Cr and Co of NiCoCrAlYHf coating only exist in a thin layer of influence region of the substrate, which has no obvious effect on the microstructure of alloy IC6. Tensile tests at room temperature and stress rupture tests under 1 100 °C, 90 MPa of the coating-repaired sample were conducted. The results show that the coating repair has no evident effect on mechanical properties. Therefore, it may be considered that when the coating is unexpectedly destroyed, it can be repaired.

[Key words] nickel aluminides; coatings; aero-engine components

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1 INTRODUCTION

Ni₃Al based alloy IC6, which is a directionally solidified high temperature structural material, has been recently developed by Beijing Institute of Aeronautical materials^[1~3]. Alloy IC6 has some advantages, such as high yield strength, fairly good ductility from room temperature to 1 200 °C, high creep resistance up to 1 100 °C, low density (7.90 g/cm³) and higher melting point ($t_m = 1\,310 \sim 1\,320$ °C) than most of the advanced nickel base cast superalloys, as well as lower production cost due to the absence of expensive alloying elements^[4]. However the resistances to oxidation and hot corrosion of this alloy is not very good due to its high content of Mo and lack of oxidation and corrosion resistant elements, such as Cr and Ta. It has been found that a small addition of RE element can improve oxidation resistance of the alloy obviously; but have no effect on the hot corrosion resistance^[5, 6]. Therefore, similar to most commercial nickel base superalloys, suitable coatings must be developed for alloy IC6. Three kinds of coatings including diffusion coatings, overlay coatings and thermal barrier coatings are usually applied for superalloy components in gas turbine engines^[7]. Among them the diffusion and overlay coatings are usually used to resist attack from the environment. Compared with Al-Si diffusion coating, the MCrAlY overlay coating has better oxidation and corrosion resistance and hardly affects mechanical properties of substrate.

Therefore, a NiCoCrAlYHf coating was designed to applied to alloy IC6. Many factors can make effects on the service life of the coating, such as composition of the coating, coating process, composition of the substrate, operation conditions. The purpose of this paper is to study the effect of coating repair treatment on microstructure and mechanical properties of alloy IC6.

2 EXPERIMENTAL

The columnar samples of alloy IC6 with the chemical composition of Ni (7.5~8.5) Al (13.0~15.0) Mo (0.02~0.10) B (mass fraction, %) were produced by rapid solidification technique in a commercial directionally solidified (DS) vacuum induction furnace, and then were homogenized at 1 260 °C for 10 h followed with oil-quenching. The size of the specimens for tensile and stress rupture tests was 5 mm in diameter and 25 mm in gauge length. NiCoCrAlYHf overlay coating with the chemical composition of Ni (11.0~13.0) Co (18.0~21.0) Cr (10.0~12.0) Al (0.3~1.0) Y (0.3~1.0) Hf (mass fraction, %) was deposited on the samples by arc physical vapor deposition (PVD) method. The coatings were deleted with local and complete wiping off before and after 950 °C, 2 h vacuum diffusion annealing in order to simulate the damage during coating process. The coatings were then deposited, and vacuum diffusion treated once again and this process is so called coating repair. Tensile properties at room tem-

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perature and stress rupture properties under 1 100 °C, 90 MPa of the coating-repaired sample were tested. The microstructures and composition of the specimens were examined and analyzed by JEOL JSM-5600LV scanning electron microscopy and JXA 8600 electron probe micro-analyzer. The phase analysis was carried out by X-ray diffraction tests in the BD-86 model instrument.

3 RESULTS AND DISCUSSION

3.1 Microstructure of NiCoCrAlYHf overlay coating after diffusion annealing

The microstructure of the specimen in cross-section of NiCoCrAlYHf overlay coating after diffusion annealing at 950 °C for 2 h is shown in Fig. 1. It can be found that the coating is consisted of three parts: deposition layer, diffusion layer and influence layer. The deposition layer is about 30 μm , the diffusion layer is about 5 μm and the influence layer is about 3 μm . The X-ray diffraction patterns illustrated in Fig. 2 show that the outer layer or deposition layer is mainly composed of γ -(Ni, Mo), γ' -Ni₃Al, β -NiAl and α -Cr. The chemical compositions of the coating is listed in Table 1. The results show that the diffusion of Mo, Co and Cr between the substrate and the coating occurred during annealing.

3.2 Effect of coating repair on microstructure of NiCoCrAlYHf coated alloy IC6

The experimental results show that compared with initial NiCoCrAlYHf coated alloy, the microstructure of coating repaired specimen has no significant difference, which is also composed of deposition layer, diffusion layer and influence layer, and the combination between the coating and the substrate is still very well. Since the coating was not wiped off completely, there was a clear interface in the deposition layer, as shown in Fig. 3. The chemical composition of the coating repaired specimen after diffusion treatment is listed in Table 2, indicating that the diffusion of alloying elements occurred during annealing at 950 °C for another 2 h. It can be seen from Table 2 that the content of Cr and Co in the diffusion layer of coating repaired sample is higher than that in the initial coated sample as the diffusion time is doubled. However the content of Mo only has a little change, and the reason may be that the diffusion coefficient of Mo is smaller than that of Cr and Co.

3.3 Effect of coating repair on mechanical properties of NiCoCrAlYHf coated alloy IC6

The yield strength, ultimate tensile strength and elongation at room temperature of uncoated, NiCoCrAlYHf coated and coating repaired specimens of alloy IC6 were tested, and the results were illustrated in Fig. 4 (State 1—Uncoated; State 2—Coated

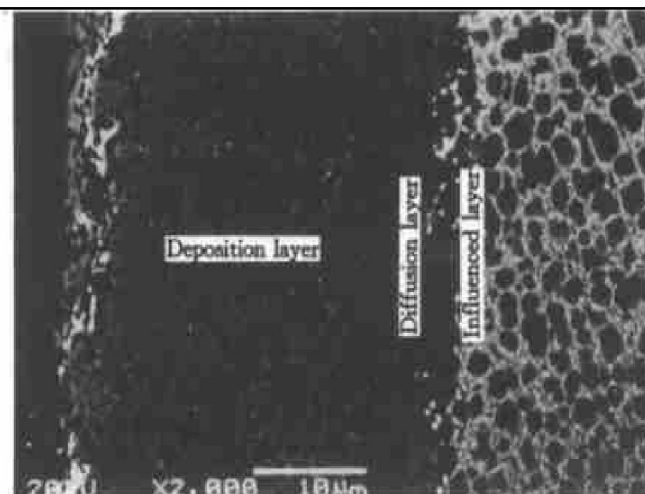


Fig. 1 Microstructure of NiCoCrAlYHf overlay coating after diffusion annealing at 950 °C for 2 h

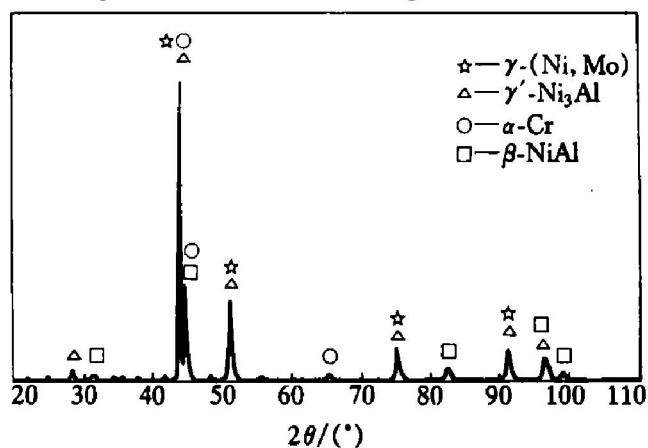


Fig. 2 X-ray diffraction patterns of deposited coating in outer layer

Table 1 Chemical composition in NiCoCrAlYHf coated IC6 sample

Position	w (Ni) / %	w (Co) / %	w (Mo) / %	w (Cr) / %	w (Al) / %
Deposition layer	58.210	13.680	0.590	20.640	6.690
Diffusion layer	72.858	7.541	3.173	7.479	8.950
Influence layer	77.201	0.561	14.016	0.887	7.133

Table 2 Chemical composition in coating repaired specimen after diffusion treatment

Position	w (Ni) / %	w (Co) / %	w (Mo) / %	w (Cr) / %	w (Al) / %
Outer of deposition layer	53.97	14.39	0	22.55	9.09
Inner of deposition layer	55.77	13.64	0.69	21.48	8.42
Diffusion layer	56.02	12.95	2.60	21.37	7.06
Influence layer	71.16	4.69	9.59	5.30	9.26

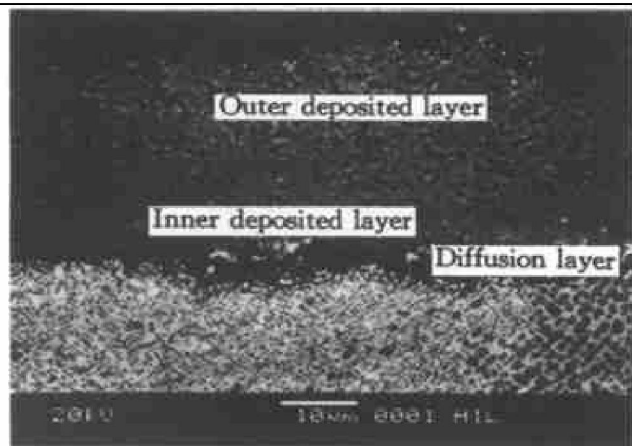


Fig. 3 Microstructure of coating repaired specimens after diffusion annealing at 950 °C for 2 h

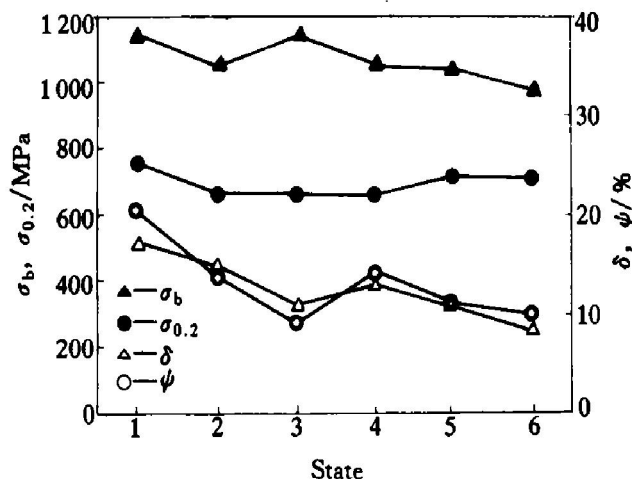


Fig. 4 Comparison of tensile properties between coated and uncoated alloy IC6 at room temperature

and annealed at 950 °C for 2 h; State 3—Coated again after local wipe off of annealed sample, and annealed again; State 4—Coated again after complete wipe off of annealed sample, and annealed again; State 5—Coated again after local wipe off of unannealed sample, and annealed again; State 6—Coated again after complete wipe off of the unannealed sample, and annealed again). Compared with uncoated alloy IC6, the yield strength and ultimate tensile strength of coated samples have no change, and only elongation decreased slightly. Compared with initial coated specimens, the coating repaired specimens have the similar change trend. Fig. 5 shows the results of high temperature stress rupture tests of Ni-CrAlYHf coated alloy IC6 before and after repairing as well as uncoated specimens, which indicates that coating repair has no obvious influence on stress rupture properties of the alloy. As these are cast specimens, the data are dispersed to a certain extent.

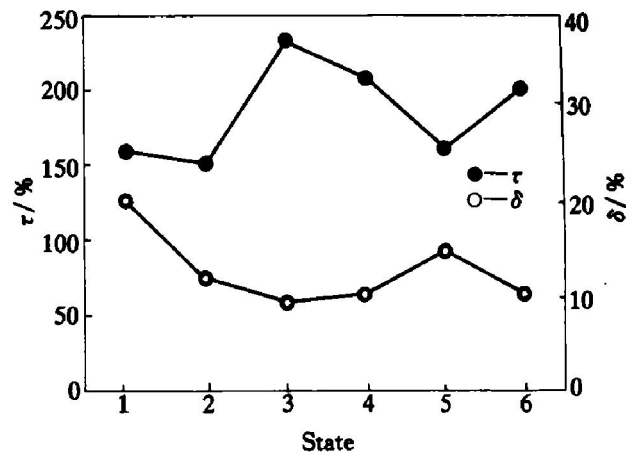


Fig. 5 Comparison of high temperature stress rupture properties between coated and uncoated alloy IC6

Compared with uncoated alloy IC6, the elongation of the coated specimens slightly decreased, but there is no obvious difference between coating repaired and unrepaired samples.

According to the experimental results, it may be concluded that the mechanical properties of alloy IC6 are not harmfully affected by coating repair. Therefore, when the coating is unexpectedly destroyed, it can be repaired.

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