MICROSTRUCTURE OF NiCoCrAlY COMPONENT IN PLASMA SPRAYED ZrO_2/NiCoCrAlY GRADED COATING①

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ABSTRACT NiCoCrAlY alloy component in ZrO_2/NiCoCrAlY graded coating forms heterogeneous microstructure after plasma spraying, which consists of γ(Ni) matrix phase and some εCo phase, as well as a little γ′(Ni_3Al) phase. Moreover, owing to the impaction of molten NiCoCrAlY droplets on the substrate at high speed, the alloy particles experience severe deformation at a high strain rate, producing a lot of dislocations. During rapid solidification, NiCoCrAlY alloy reacts with oxygen in air, and some NiO, Cr_2O_3, Al_2O_3 form in the alloy.

Key words plasma spraying graded coating NiCoCrAlY microstructure

1 INTRODUCTION

Ceramics/metal graded coating is a new type of thermal barrier coatings (TBCs)[1, 2], whose compositions distribute gradually from metal bond layer to ceramics surface layer, so as to eliminate the macroscopic ceramics/metal interface in traditional TBCs. Therefore, the thermal stress induced by the mismatchs of thermal expansion coefficient and elastic modulus between ceramics coating and metal substrate can be relaxed in high temperature application, and the thermalshock property can be largely improved.

MCrAlY(M= Ni, Co, Fe, etc.) is a special kind of superalloy, whose compositions are designed more simpler comparing with the common superalloy. Because of the higher content of Cr and Al, MCrAlY alloy displays excellent antioxidation property at high temperature, and has become the most used metal component in TBCs[3]. Since plasma spraying process has the characteristics of rapid solidifying and cooling, the microstructure of MCrAlY alloy in the coating is very complicated[4] which needs to be deeply investigated, but this investigation is insufficient up to date because people are usually more interesting in the utility of TBCs[5, 6]. In this paper, the microstructure of NiCoCrAlY alloy component in ZrO_2/NiCoCrAlY graded coating was discussed preliminarily.

2 EXPERIMENTAL PROCEDURE

The substrate material was TC4(Ti-6Al-4V), which was grit-blasted prior to plasma spraying. The spraying powders were 8% Y_2O_3 partially stabilized ZrO_2(PSZ) and Ni-4.5Co-20Cr-4Al-1Y alloy, which were premixed together in various volume ratios according to the predesigned compositional distribution, then carried into the plasma stream. So the ZrO_2/NiCoCrAlY graded coating was fabricated by adjusting the plasma spraying parameters.

Coating samples were cut across section, then ground and polished. The microstructural distribution and phase composition were investigated with optical microscopy(OPM), electron probe microanalyzer(EPMA) and X-ray diffrac-

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tion(XRD). Substructure of NiCoCrAlY alloy was explored by Phlips CM-12 transimission electron microscopy(TEM). TEM samples were mechanically milled to 0.05 mm thickness, and followed by ion thinning to transparency.

3 RESULTS AND DISCUSSION

3.1 Microstructure distribution in graded coating

Fig. 1 is the cross-sectional microstructure of ZrO_2/NiCoCrAlY graded coating, in which the left side is TC4 substrate and the other is the graded coating. In the coating, the white phase is NiCoCrAlY alloy and the gray one is ZrO_2. From substrate to coating surface, the amount of ZrO_2 increases gradually, but that of NiCoCrAlY changes oppositely. During plasma spraying the melted NiCoCrAlY particles impacted onto the substrate surface at high speed, and then flew and deformed along the substrate surface. Finally the coating was formed by the deformed particles which heaped up layer by layer, and displays typical laminar structure[7].

3.2 Phase composition of NiCoCrAlY alloy

The bonding layer of the graded coating is pure NiCoCrAlY alloy, whose phase composition and distribution were investigated by EPMA (shown in Fig. 2). Fig. 2(a) and Fig. 2(b) are composition image and morphology image, respectively. Fig. 2(c) ~ 2(f) are the area distribution images including Ni, Co, Cr, Al elements. It could be found that NiCoCrAlY alloy contains Ni-rich matrix phase, some Co-rich phase and Al-rich phase, as well as a little Cr-rich phase. Owing to the severe flow and deformation of NiCoCrAlY particles at high strain rate during plasma spraying, the microstructure is composed of heteromogeneous and irregular multi-phases.

Fig. 3 is the XRD pattern of NiCoCrAlY bond layer. The result shows that NiCoCrAlY alloy includes a lot of γ(Ni) phase, and a little NiO, Cr_2O_3, Al_2O_3 etc. According to EPMA, it could be identified preliminarily that Ni-rich matrix phase is Ni-base solid solution γ-Ni, which contains some Cr, Co and Al. Cr-rich phase mainly is Cr_2O_3 and Al-rich phase is Al_2O_3. Because the content of Co-rich phase is very low, it is difficult to identify the phase structure of Co-rich phase according to XRD.

3.3 TEM observation of NiCoCrAlY alloy

The TEM observations reveal the phase structure of NiCoCrAlY alloy more clearly (shown in Figs. 4~ 6). Fig. 4(a) is the bright field image of γ(Ni) phase, whose electron diffraction pattern from [001] direction is shown in Fig. 4(b). It could be found that a lot of dislocations exist in γ(Ni) phase, which twine each other and form net structure inside the grain, and squeeze to form dislocation walls at the boundary(shown by the arrow). The comp-

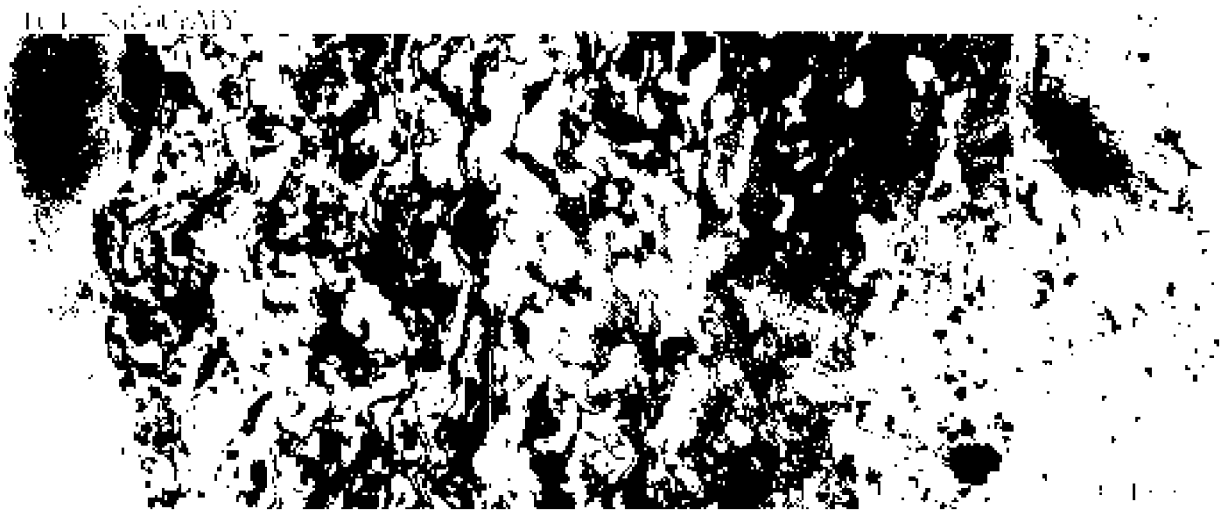

Fig. 1 Optical microstructure of ZrO_2/NiCoCrAlY graded coating

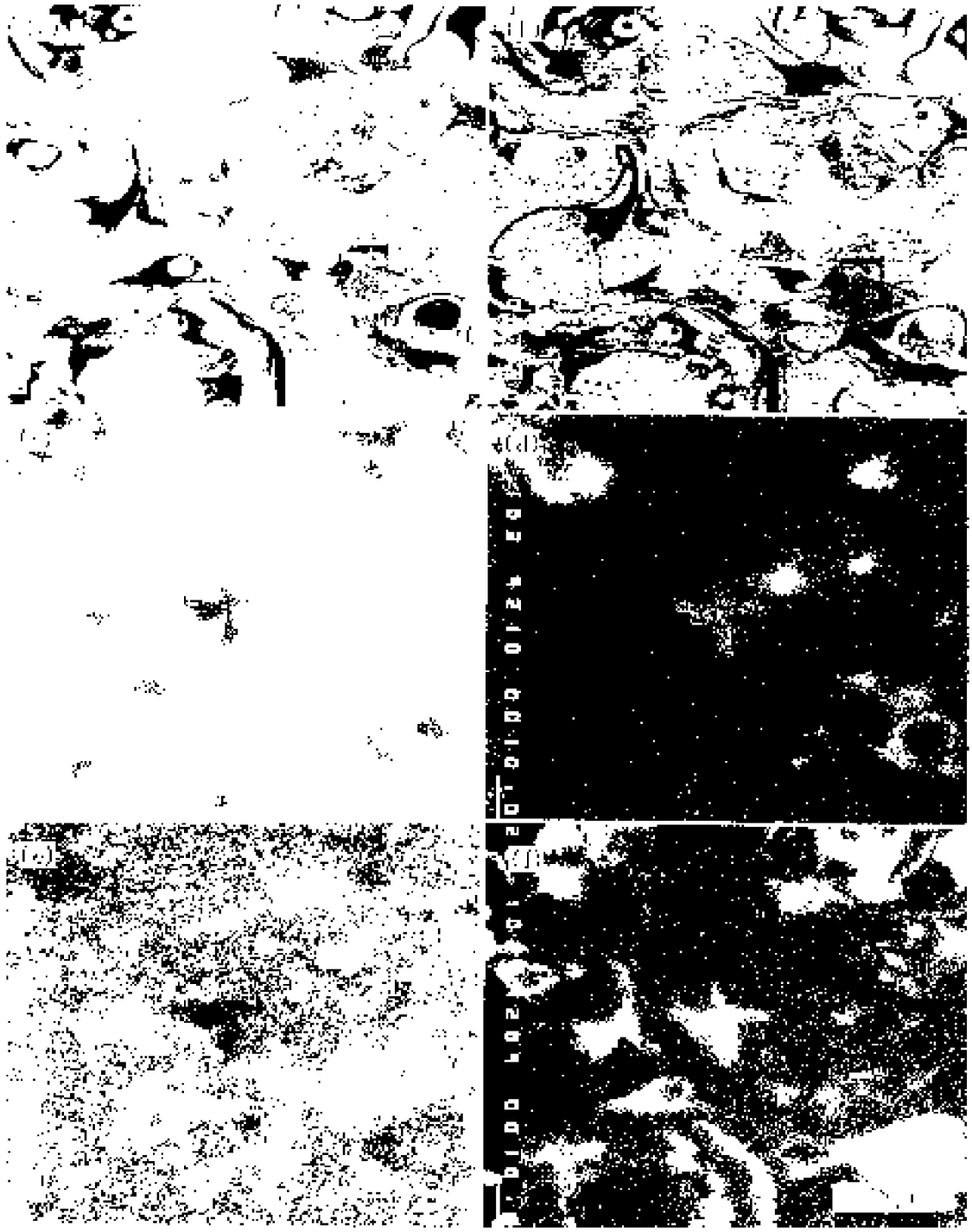

Fig. 2 EPMA of plasma sprayed NiCoCrAlY alloy

(a) —composition image; (b) —morphology image;
(c) ~ (f) —area distributing images of Ni, Co, Cr, Al respectively

osition of γ(Ni) phase identified by TEM EDS is

Co, 2.05%; Cr, 17.7%; Al, 1.12%; Y, 0.25% and Ni others. Comparing with the common Ni-base superalloy, the content of elements solved in γ(Ni) phase is very low[8].

Fig. 5(a) is the bright image of Co-rich phase, whose electron diffraction pattern is shown in Fig. 5(b). The indexed result shows that Co-rich phase has *hcp* structure, and the direction of electron beam in Fig. 5(b) is $[0\bar{1}10]$. The EDS analysis shows that the Co-rich phase is nearly pure Co, which indicates that the element Co unsolubilized in γ(Ni) phase transformed from *fcc* to *hcp* structure during cooling, and formed ε-Co phase.

A little γ′(Ni_3Al) phase is found in NiCoCrAlY alloy(shown in Fig. 6). Fig. 6(a) displays that γ′ phase has typical cellular structure, and γ phase distributes along the interface between γ′ phase grains, which indicate that the reaction of Ni and Al occurred during plasma spraying, and form Ni_3Al phase. Fig. 6(b) is the electron diffraction pattern from [$\bar{1}$11] direction of γ′ phase, in which regular superlattices spots exists due to the *fcc* lattice-ordered structure in γ′ phase.

The microstructure of plasma sprayed NiCoCrAlY alloy is very complicated, and is different from the common Ni-base superalloy. This results from the complex forming process of the microstructure of plasma sprayed coating. On the one hand, the melted NiCoCrAlY particles impacted onto the substrate at high speed, and deformed severely; meanwhile, the alloy particles went through rapid solidification and cooling, so high mechanical stress and thermal stress formed in the coating[9], and

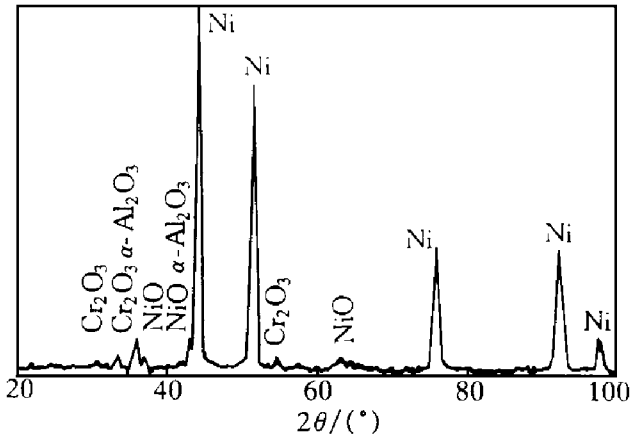

Fig. 3 XRD pattern of NiCoCrAlY bond layer

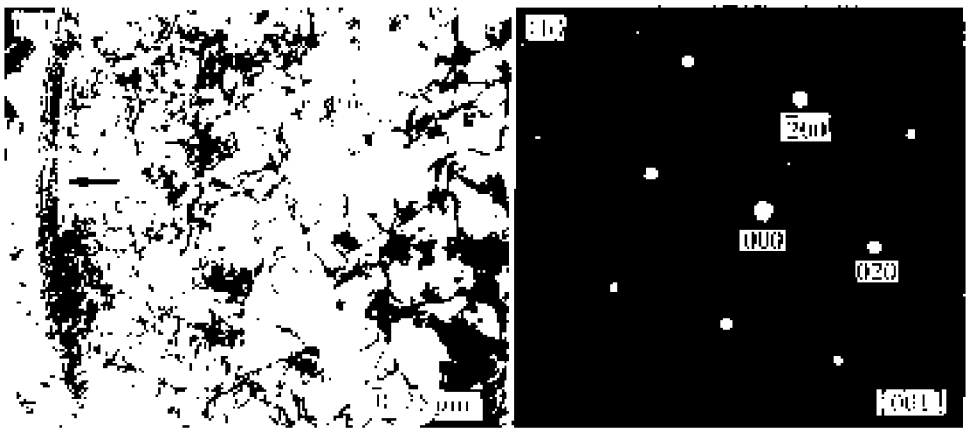

Fig. 4 TEM micrographs of γ(Ni) phase in NiCoCrAlY alloy
(a) —morphology; (b) —EDP

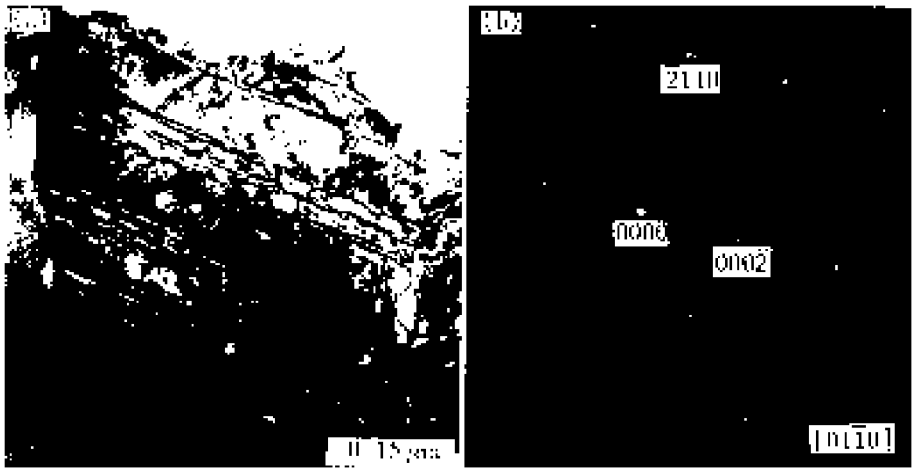

Fig. 5 TEM micrographs of ε-Co phase in NiCoCrAlY alloy
(a) —morphology; (b) —EDP

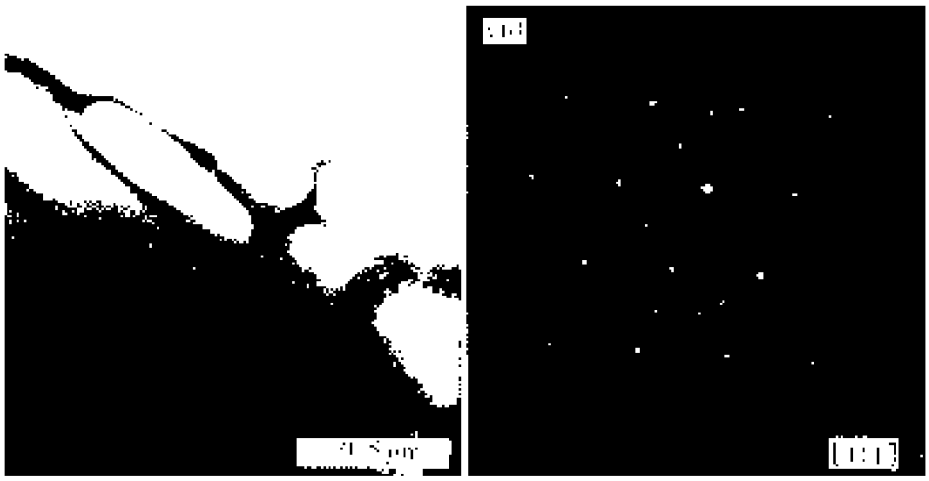

Fig. 6 TEM micrographs of γ′ (Ni_3Al) phase in NiCoCrAlY alloy

(a) —morphology; (b) —EDP

induced high density dislocation in NiCoCrAlY alloy, on the other hand, because of the rapid melting and solidifying process of NiCoCrAlY particles during plasma spraying, the solution of alloying elements such as Co, Cr, Al and Y into γ(Ni) phase is insufficient. So the content of elements in γ(Ni) phase is fairly lower, and some pure element phase such as εCo etc remained at room temperature. Moreover, the reaction between Ni and Al was incomplete, and only a little γ′ (Ni_3Al) phase was poduced in the alloy. Some oxidizing reaction occurred on the alloy particles surface during solidification, and a little NiO, Cr_2O_3, Al_2O_3 films formed.

Since the microstructure of NiCoCrAlY alloy is very complicated, further work must be done to investigate the microstructural characteristics and forming mechanism, as well as the influence of microstructure on thermal shock properties.

4 CONCLUSIONS

(1) NiCoCrAlY alloy component in ZrO_2/NiCoCrAlY graded coating exhibits complex multiphase microstructure after plasma spraying, which consists of a lot of γ(Ni) matrix phase, some εCo phase and a little γ′ (Ni_3Al) phase. During plasma spraying process, NiCoCrAlY alloy reacts with oxygen in air, and some NiO, Cr_2O_3, Al_2O_3 form in the alloy.

(2) Owing to the impaction of molten NiCoCrAlY droplets on the substrate at high speed, the alloy particles experience severe deformation at high strain rate, producing heterogenous and irregular microstructure as well as a lot of dislocations.

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