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Interface microstructure and diffusion of vacuum annealed ceramic coating on superalloy GH202

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Abstract: In order to improve the wear resistance and high-temperature oxidation resistance of superalloy GH202, the ultrafine-grain ceramic coating containing nano-size nickel particles was obtained by flow coat method on the surface of GH202. The interface microstructure between ceramic coating and superalloy GH202 substrate during vacuum diffusion was studied. It is shown that Al_2O_3 oxide layer and (Ti, N) compound exist in the alloy substrate close to interface. During long time diffusion, nano-size nickel powders gradually congregate and grow up, and the confluent interface appears, which shows that the nano-size nickel powders have the effect of restraining the coating from failure.

Key words: GH202 superalloy; nano-size nickel powder; ceramic coating; vacuum annealing; microstructure

1 Introduction

For applications in the first generation turbine blades, nickel-based superalloys in various wrought and cast forms, augmented by coatings since 1960s, have been successful material systems[1−4]. Protective coatings are applied for prolonging component life[5−9]. Ceramics, as coating materials, in contrast to metals, are often more resistant to oxidation, corrosion and wear, as well as have better thermal stability. During the past decade, extensive research efforts have been devoted to the development and manufacture of thermal barrier coatings(TBCs) on turbine part[10−14]. However, the inherent low ductility of the ceramic coatings and the lack of stability at high temperature are great concerns in restricting their applications.

Nano-composition coatings have wide application prospects in modifying the surface of turbine materials for their characteristics of high strength, ductility and hardness. POMEROY[15] has reported the Pt-modified aluminide coatings on single-crystalline CMSX-4 and CMSX-10 superalloy substrates, showing that Al diffuses into the bulk of the alloy via γ matrix channels and Ni diffuses outward along the same route. These inter-diffusional processes influence the long term stability of both coating and substrate. KITAYAMA and PASK[16] studied the agglomeration phenomenon of the high purity nano-size alumina powder and the results showed that it has positive effect on dispersion of the nano ceramic slurry.

In this work, a ceramic coating was developed by adding nano-size nickel particles into ultra-fine ceramic slurry, which combined both the ductility of the metallic elements and the stability of the ceramics at high temperature. Furthermore, as the failure of the coatings is mainly influenced by the interface microstructure between the coating and substrate, the interfacial inter-diffusion behavior of as-produced ceramic coating on superalloy GH202 after vacuum annealing was also investigated.

2 Experimental

The ultra-fine ceramic coating used in this experiment was prepared using the mixture of oxide powders according to optimized proportion (SiO_2 52.6%, CaO 17.0%, MgO 1.8%, Al_2O_3 9.3%, TiO_2 3.5%, BaO 8.8%, and B_2O_3 7.0%, mass fraction) followed by sintering, water quenching and grinding.

The aqueous ceramic slurry containing 50% (mass fraction) solids was prepared, of which more than 80% particles were less than 1.0 μm. The average particle diameter of nano-size nickel particles was about 80 nm (see Fig.1). The viscosity of the coating was adjusted using distilled and deionized water. In order to enhance

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the toughness and wear-resistance, the coatings were prepared by adding 10% (mass fraction) nano-size nickel particles followed by mixing and dispersion[17−19]. The substrate used was Ni-based alloy GH202, which had been ground by a 400-grit diamond sand paper. Then, the ground surface of the GH202 was treated by acid and alkali in turn. Flow coating method was applied to preparing the specimens, which were dried in air, kept in thermo-stated container at 50 ℃ for 1 h prior to further treatment. All the samples were sintered at 1 050 ℃ for 5 min in a high-temperature furnace. The interface reaction was investigated by means of interface diffusion annealing experiments in vacuum. Coated specimens were used for diffusion annealing experiments in a high temperature vacuum diffusing furnace. The diffusion temperature was 900 ℃ and holding time was 0, 50, 100, 200, 300 and 500 h, respectively. The composition and microstructure of the specimens were analyzed by scanning electron microscope (SEM, JSM−5600LV) equipped with energy-dispersion analytical X-ray spectroscope (EDS).

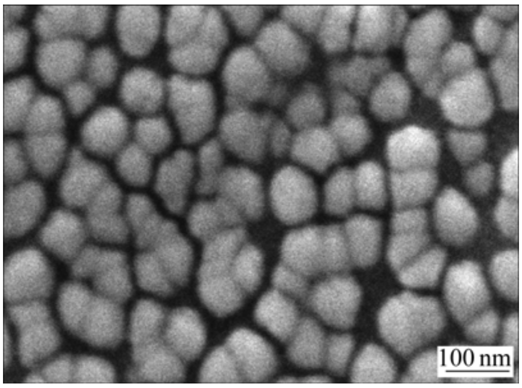

Fig.1 SEM image of nano-size nickel powders

3 Results and discussion

The interface microstructures of the coated specimens after diffusion annealing are shown in Fig.2, and the annealing time is 0, 50, 100, 200, 300 and 500 h in turn from Fig.2(a) to Fig.2(f).

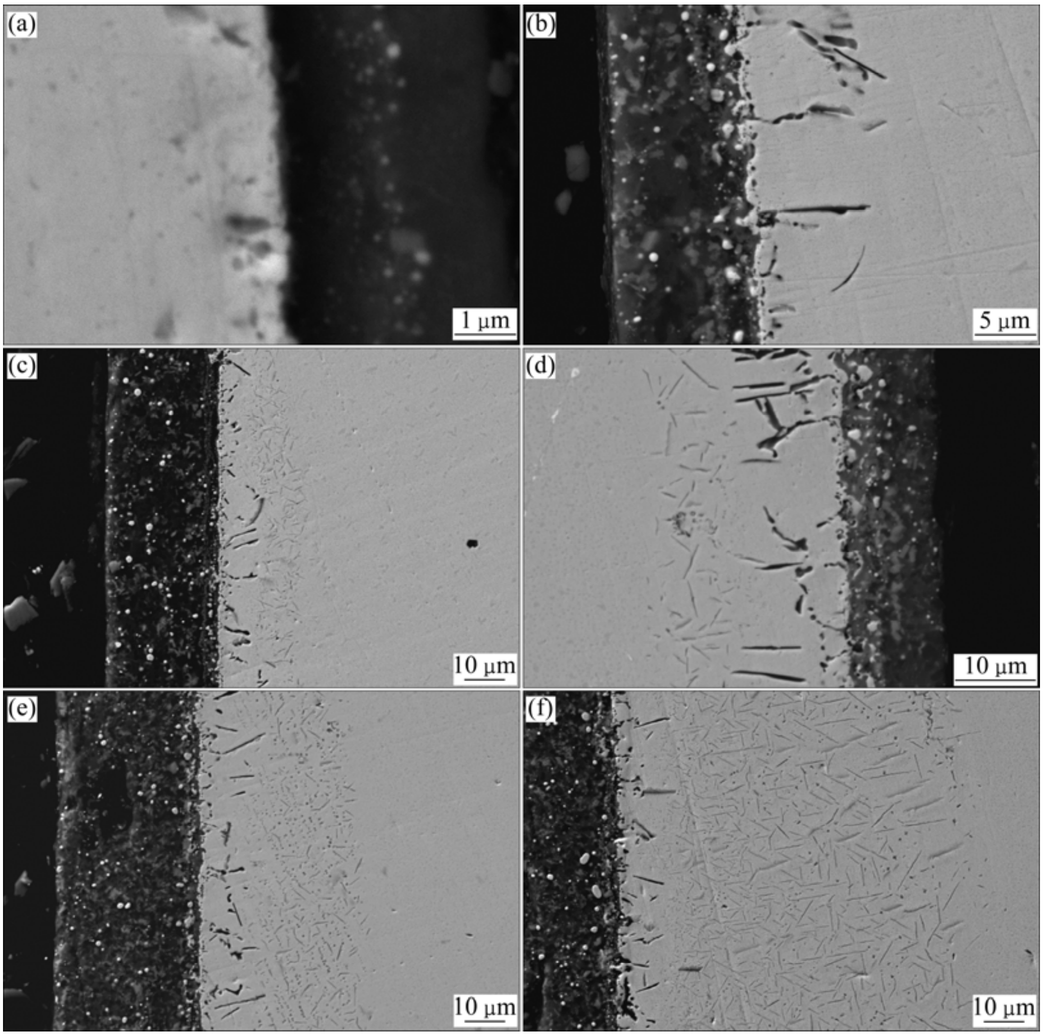

Fig.2 SEM images of interface between coating and substrate of sample annealed at 900 ℃ in vacuum for different time (without erosion): (a) 0 h; (b) 50 h; (c)100 h; (d)200 h; (e) 300 h; (f) 500 h

Fig.2 shows that nickel particles are dispersed homogeneously in the coating with no apparent aggregation. The nano-size nickel particles are mainly distributed along the coating/substrate interface as a “transition layer” (see Fig.2(a)) before annealing. However, this distribution has changed after diffusion annealing at 900 ℃ for 500 h. There are some white particles in the coating with the size of about 1 μm, and the result of linear scanning of element Ni in the coating shows that the white particles are nickel particles formatting through the aggregation of nano-size nickel particles during annealing (see Fig.3). The amorphous phases in the coating crystallize and network mica is precipitated with the increase of diffusion time (see Figs.2(b)−(f)).

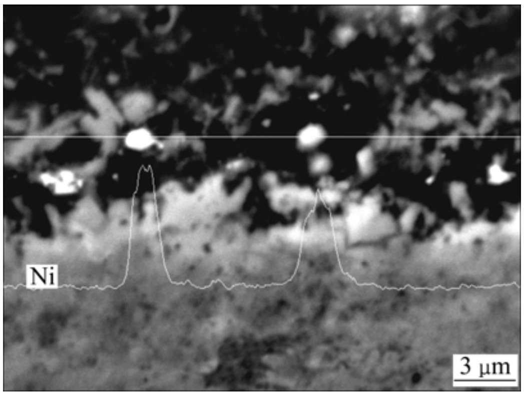

Fig.3 Linear scanning result of element Ni in coating

The enlarged cross-sectional SEM image of the specimens after vacuum annealing at 900 ℃ for 500 h is shown in Fig.4. It can be seen that the nano-size nickel particles diffuse not only to the interior of the coating but also to the substrate during the vacuum annealing, and even fuse with the substrate at the interface, which cause the interface to be metallurgically bonded. It is also shown that the nano-size nickel particles are advantage to increasing the bonding strength of the coating and the substrates.

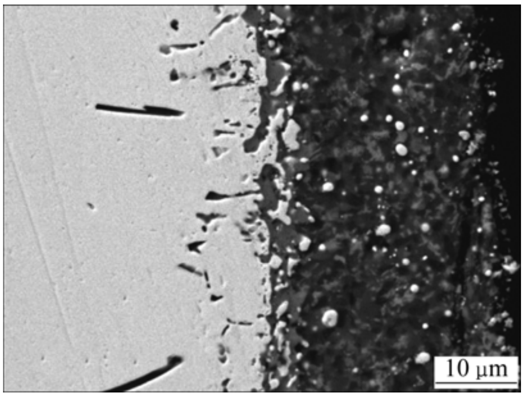

Fig.4 Metallurgical bonding of interface between coating and substrate

From Fig.2 it can also be seen that some black phases are found to extend to the substrate near the interface in the coated sample after vacuum annealing at 900 ℃. The element linear scanning of the black phases indicates that they are mainly Al_2O_3 intergranular oxides (see Fig.5). The same phenomenon has also been found by CHEN[20]. Furthermore, some needle-shaped precipitates emerge near the Al_2O_3 intergranular oxides in the substrate, and the educts layer becomes thick with the annealing time prolonging. The educts have length of about 3−10 μm and width of about 300 nm. Because the educts are fine and their quantity is small, they can hardly be identified by XRD technique. So, the planar distribution of main elements was used to qualitatively analyze the educts, and the results of the planar distributions of main elements are shown in Fig.6.

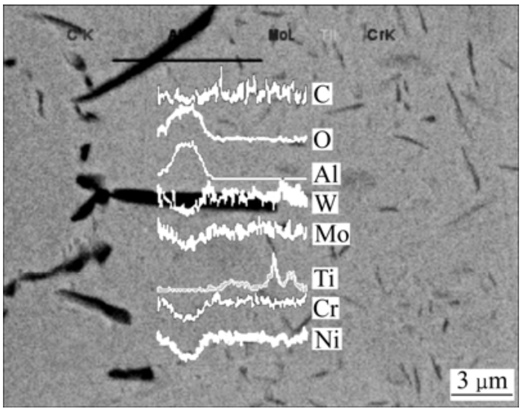

Fig.5 SEM images and element linear scanning result of black phases appearing after vacuum annealing at 900 ℃

Fig.6(a) shows the needle-shaped precipitates in the substrate. Figs.6(b)−(e) show the planar distributions of element Ti, N, O and Ni, respectively. It is observed that the elements of Ti and N are rich but O and Ni are absent in the educts, which can predicate that the educts may be (Ti, N) compounds.

All the analyses show that the Al_2O_3 intergranular oxides layer and (Ti, N) educts layer form in the substrate near the interface during vacuum annealing at 900 ℃. The potential reasons for this phenomenon may be as follows. Elements N and O diffuse from coating to substrate during annealing, and because the activity of Al is higher than that of element Ti, then element Al in the alloy reacts with O and N to form Al_2O_3 and AlN. Then, the AlN is further oxidized and element N is released. Furthermore, the released N diffuses to the inner of the alloy and reacts with Ti to form (Ti, N) compounds, so the Al_2O_3 layer and (Ti, N) compound layer emerge in the substrate close to the interface.

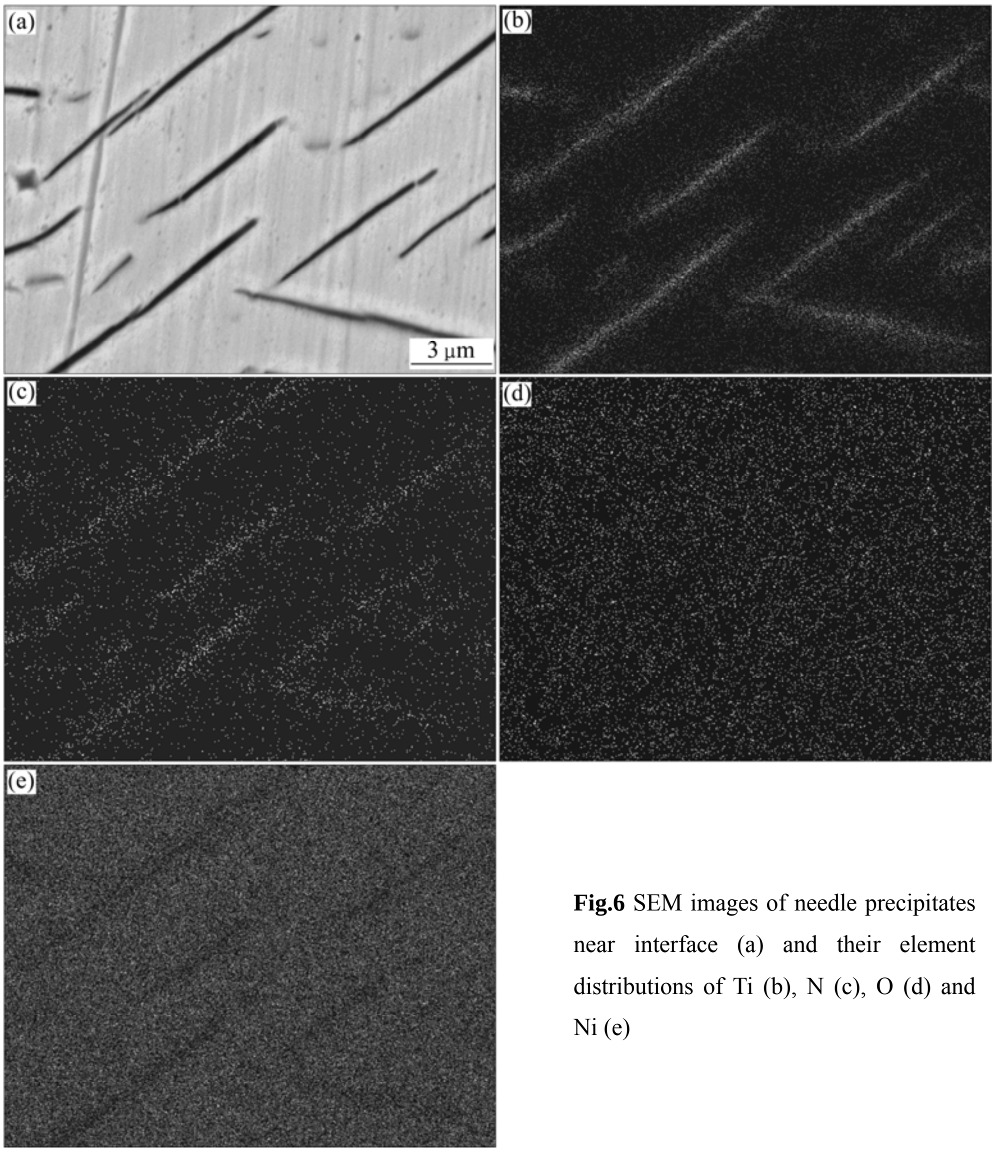

Fig.6 SEM images of needle precipitates near interface (a) and their element distributions of Ti (b), N (c), O (d) and Ni (e)

4 Conclusions

1) The nano-size nickel particles diffuse not only into the interior of the coating but also into the substrate during the vacuum annealing, and even fuse with the substrate at the interface, which causes the interface to be metallurgically bonded.

2) Al_2O_3 layer and (Ti, N) compound layer are formed in the substrate, and all the reaction layers become thicker and thicker with prolonging the annealing time.

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