IMPROVEMENT OF HOT CORROSION RESISTANCE OF Ti_3Al INTERMETALLIC COMPOUND BY SPUTTERED NiCrAlY COATING①

Zeng, Chaoliu Zhang, Jianqing Wu, Weitao Zhu, Shenglong
Corrosion Science Laboratory, Institute of Corrosion and Protection of Metals, Academia Sinica, Shenyang 110015

ABSTRACT The effects of sputtered NiCrAlY coating on hot corrosion resistance of Ti_3Al intermetallics in the presence of $(Na, K)_2SO_4$ salts film at 950 ℃ in air were studied. It was shown that Ti_3Al suffered from severe corrosion, forming a poor adhesive scale with an outer TiO_2-enriched and inner Al_2O_3 enriched layer. The electrochemical mechanism was responsible for the corrosion process. The sputtered NiCrAlY coating can greatly improve corrosion resistance of Ti_3Al by the the formation of a good adhesive Al_2O_3 enriched scale. But a-three-layer diffusion zone formed between coating and substrate alloy.

Key words: intermetallic compounds Ti_3Al NiCrAlY coating hot corrosion

Ti_3Al based intermetallic compounds have received increasing attention for its good high temperature properties but faces low room temperature ductility, and poor oxidation and hot corrosion resistances. Improving oxidation and hot corrosion resistances of Ti_3Al are important for its high temperature applications. Here, effects of sputter deposited NiCrAlY coating on hot corrosion resistance of Ti_3Al are studied.

1 EXPERIMENTAL

The chemical composition of the ingot Ti_3Al in atomic percent is Al 24 and Nb 11 with the balance being Ti. The specimens of 15 mm × 10 mm × 2 mm were cut from the ingot, followed by surface polishing and cleaning. The NiCrAlY coating of 40 μm thick on Ti_3Al was prepared by magnetron sputtering technique. The chemical composition of alloy for sputtering in weight percent is Ni-40Cr-10Al-1Y. A$(0.9Na, 0.1K)_2SO_4$ salt film of 2.8 mg/cm^2 was applied to the specimens surface after the specimens were heated to 300 ℃. The samples in an Al_2O_3 crucible were put into furnace. After some time testing, the crucibles were removed out and weighted when being cooled down to room temperature. The test temperatre was 950 ℃.

X-ray diffraction, EPMA and SEM techniques were employed to analyse the corrosion products.

2 EXPERIMENTAL RESULTS AND DISCUSSION

2.1 *Hot Corrosion Kinetics*

Hot corrosion kinetics of Ti_3Al and NiCrAlY coated Ti_3Al in the presence of $(Na, K)_2SO_4$ film at 950 ℃ are shown in Fig. 1. Ti_3Al has a rapid corrosion with the average mass gain of 0.27 mg/cm^2·h in the 40 h testing. On the contrary, the mass gain rate for NiCrAlY coating is much slower than Ti_3Al. The average mass gain is 0.04 mg/cm^2·h in

① Supported by National Natural Science Foundation of China and "863" Advanced Technology Committee of China; received Feb 15, 1994

the 40 h testing. Obviously, the sputtered NiCrAlY coating can greatly improve corrosion resistance of Ti_3Al.

2. 2 *Corrosion Products*

XRD analysis revealed that TiO_2 is the primary oxide phase with some Al_2O_3 and Nb_2O_5 for Ti_3Al and Al_2O_3 is the main oxides with some Cr_2O_3 and little TiO_2 for NiCrAlY coated Ti_3Al. The examination of the cross section of the corroded samples indicated that the corrosion products for Ti_3Al is porous and multilayered with an outer TiO_2 enriched and inner Al_2O_3 enriched layer, as shown in Fig. 2. The Al_2O_3 doesn't form a continuous, protective layer. Some sulfides form along scale/substrate boundary. Fig. 3 gives the cross-sectional morphology and elements distribution of NiCrAlY coated Ti_3Al after corrosion at 950 ℃ for 60 h. It is shown that a protective Al and Cr oxides layer enriching in Al_2O_3 forms on the coating surface. Little TiO_2 also forms by the outer diffusion of Ti in the substrate alloy. Some Al oxide and sulfide form along the pores across the coating. A-three-layer diffusion zone forms between coating and substrate with an outer Ti enriched, middle Ni enriched and inner complex Ti, Ni, Cr, Al and Nb-contained layer.

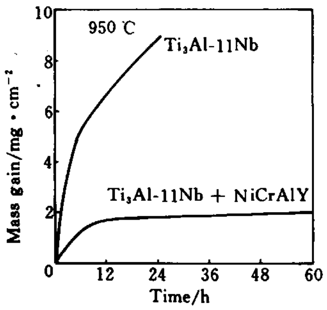

Fig. 1 Kinetics of hot corrosion at 950 ℃ for Ti_3Al based compound and the compound with NiCrAlY coating

2. 3 *Discussion*

Just as oxidation behaviour[1], a protective Al_2O_3 scale cann't form on the salts-coated Ti_3Al alloy surface, which may be ascribed to that the activity of Al obviously deviates from its solubility in Ti_3Al system[1]. Furthermore, Ti oxides have relatively high grown rates[2]. Just as mentioned above, Ti_3Al has a relatively more rapid corrosion, especially in the initial stage (the average mass gain rate is 2. 35 $mg/cm^2 \cdot h$ in the initial 2 h testing). But, the mass gain for oxidation in air is only 1. 92 mg/cm^2 after testing at 950 ℃ for 20 h. It can be concluded that the $(Na, K)_2SO_4$ deposites can accelerate corrosion of Ti_3Al. Hot corrosion mechanisms mainly include sulfidation, fluxing and electrochemistry models, which have been excellently discussed in reference [3]. The sulfidation and fluxing mechanisms cann't responsible for the corosion behaviour of Ti_3Al. Firstly, the oxides scale on Ti_3Al is formed by direct growth, not by fluxing and reprecipitation. Secondly, oxygen solubility in molten salts is rather small, and its diffusion rate is very slow, which cann't account for the rapid mass gain of Ti_3Al. Hot corrosion of Ti_3Al is an electrochemical process, which mainly includes anodic oxidation, cathodic reduction and ions diffusion. Reduction reaction is mainly the reduction of O_2^{2-}, produced by the chemical solution of oxygen in molten salts ($O^{2-} + 1/2O_2 = O_2^{2-}$). O_2^{2-} in strong-electroly-

Fig. 2 Microstructure of Ti_3Al after hot corrosion at 900 ℃ for 20 h

te molten salts has a relatively fast diffusion rate, and may diffuse to alloy surface and be reduced (O_2^{2} + 2e = $2O^{2-}$). The formed O^{2-} may react with anodic oxidation products, mainly Ti^{4+}, and contribute to the growth of oxides. The formation of TiO_2 may cause the enrichment of Al and the formation of Al_2O_3 enriched layer, produced by the reaction of Al^{3+} with O^{2-}. So, an outer TiO_2 enriched and inner Al_2O_3 enriched scale can keep growing. The formed Al_2O_3 may dissolve, reprecipitate in the TiO_2 layer, and cann't provide protection[4]. The existance of TiO_2 in the inner Al_2O_3 enriched layer may increase the vacancy number of Al or interstitial number of O^{2-}, which can cause the Al_2O_3 enriched layer to lose its protection function[5]. On the other hand, the rapid outerward diffusion of Ti^{4+} to the alloy surface may produce a strong reduction condition, and cause the reduction of SO_4^{2} (SO_4^{2} + 2e = SO_2 + $2O^{2-}$). SO_2 or SO_4^{2} may diffuse inward, and cause the formation of sulfides. Sulfides may provide rapid diffusion way for the anodic ions, and accelerate

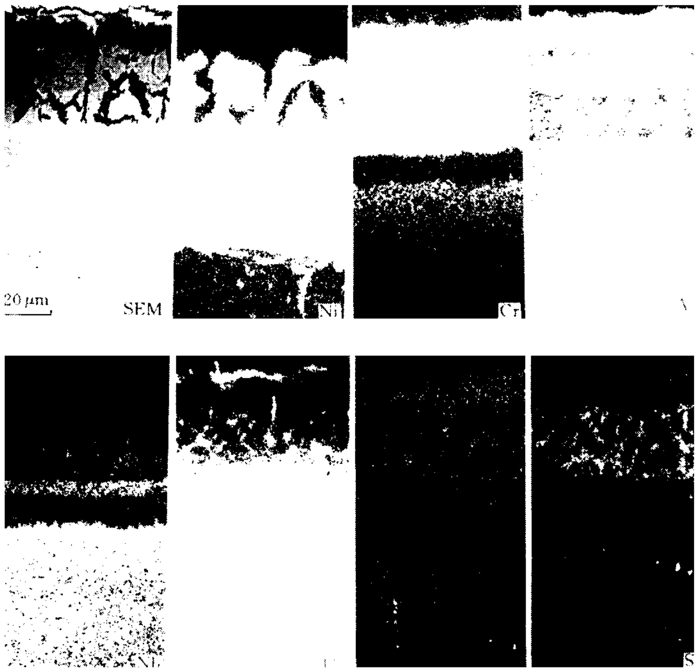

Fig. 3 Microstructure and X-ray mapping of Ti_3Al with NiCrAlY coating after hot corrosion at 950 ℃ for 60 h

corrosion of Ti_3Al.

The sputtered NiCrAlY coating can provide good corrosion resistance for Ti_3Al by the preferential formation of a protective Al_2O_3scale. The outerward diffusion of Al in the substrate alloy can also keep the growing and rehealing of Al_2O_3 scale, which is superior to the aluminides coating. Of course, the NiCrAlY coating still cann't inhibit the outerward diffusion of Ti. More study should be done to know how to inhibit the diffusion of Ti.

3 CONCLUSIONS

Ti_3Al intermetallic compound in the presence of $(Na, K)_2SO_4$ salts film at 950 ℃ suffers from severe hot corrosion. A protective Al_2O_3 scale doesn't form, but a TiO_2 enriched complex scale of Ti, Al and Nb oxides be formed. Some sulfides form across the scale, especially along scale/substrate alloy boundary. The corrosion is an electrochemical process. The sputtered NiCrAlY coating may greatly improve corrosion resistance of Ti_3Al by the formation of a protective Al_2O_3 scale. A-three-layer diffusion zone forms between the coating and substrate alloy.

REFERENCE

1 Luthra, K L. Oxi Met, 1991, 36: 475.
2 Kofstad, P. High Temperature Corrosion, Elsevier, 1988, 295.
3 Zhang, Yunshu. J of Chiness Society of Corrosion and Protection, 1992, 12:1.
4 Becker, S; Rahmel, A; Schorr, M; Schutz, M. Oxi Met, 1992, 38(5/6): 425.
5 Huntz, A; Boumaza, A; Moulin, G; Lebrun, J. In: Proceedings of 10th International Congress on Metallic Corrosion, New Delhi, 1987, 4: 3565.