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Effect of TBC on oxidation behaviour of γ-TiAl based alloy

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Materials

ABSTRACT

Purpose: The purpose of the research was identification of the influence of TBC coating system on oxidation resistance of TiAl based alloy during oxidation at temperature of 900°C and 950°C for 500h and 200h respectively.
Design/methodology/approach: The APS technique was used to modify and improvement of oxidation resistance of TiAl intermetallic alloy. As a bond coat the NiCrAlY overlay coating was applied. The bond-coat provided a good bonding strength between matrix and ceramic top coat. The research allowed the identification of microstructural changes that take place between top coat and bond coat and bond coat and substarte. The examinations were conducted on specimens after 200h and 500h of exposition at 950°C and 900°C.
Findings: It was found that the surface conditions of basic alloy is electively protected by used type of ceramic coating. The basic alloy exhibited poor oxidation resistance at this range of temperature due to formation of mixed Al_2O_3 + TiO_2 scale which is easily spalled off. A ceramic top coat together with bond coat can be effectively coated on the surface of TiAl basic alloy by APS method. Oxidation test both at 900°C and 950°C showed that oxidation resistance of APS coated 48-2-2 alloy was improved.
Research limitations/implications: Application of TBC remarkably improve the oxidation resistance of TiAl basic alloy due to lowering temperature of the substrate surface and due to formation of dense alumina sublayer (TGO) on the top surface of bond coat which can prevent diffusion processes of titanium and oxygen.
Practical implications: The results obtained allow the determination of the degree of life-time lost of the TBC system used as protection for titanium aluminides alloys.
Originality/value: The results obtained are valuable contribution to the development of new typ of TBC for TiAl alloys. They enable the identification of the degradation mechanisms in YSZ / MCrAlY / substrate system.
Keywords: Metallic alloys; Thin & thick coatings; TBC; Degradation; Oxidation

1. Introduction

At present, oxidation resistance constitutes a major problem restricting the application of Ti-Al alloys. This problem is particularly acute in the elements designed for work conditions requiring prolonged exploitation at cyclically fluctuating temperature circa 700°C, and undergoing mechanical stress for periods ranging from 500 to 5000 hours. The given times correspond to the periods of work of aircraft engines, civil and military respectively. The heat resistance of γ -TiAl based alloys is higher than titanium alloys; they cannot, nevertheless, compete with nickel superalloys or NiAl phase-based alloys [1, 2]. The possible solution to this problem is the development of protective coatings characterized by sufficient plasticity and adherence as well as good oxidation and corrosion resistance [3-5]. During the last decade, research efforts have been devoted to the development and manufacturing of ceramic TBCs on turbine parts because the traditional turbine materials have reached the limits of their temperature capabilities. Thermal barrier coatings (TBCs) are used to sustain the highest temperature on the surface of high temperature superalloy substrates. TBCs have been widely used in hot-section metal components in gas turbines either to increase the inlet temperature with a consequent improvement to the

efficiency or to reduce the requirements for the cooling air. Ni-based superalloys have usually been used with thermal barrier coating (TBC) for vanes and blades in gas turbines and jet engines [6-9]. Recently TBC system has been applied to the hollow high pressure turbine blades in advanced gas-turbine engines to decrease the average metal temperature. Typically, this kind of protective coating is a two-layered system, consisting of a ceramic top coat and an underlying metallic bond coat. For top coat material, lower thermal conductivity and relatively higher thermal expansion coefficients are required. On the other side, for bond coat material, good oxidation resistance, slower growing and adherent thermally grown oxide (TGO), thermal expansion coefficient and stability adequate to the substrate are required [10-14].

2. Description of experiments methodology and materials

Substrate samples were prepared by cutting cast γ-TiAl (48-2-2) into oupons of 10×7×2mm. The surface of specimens were snad-blasted and ultrasonically cleaned with acetone. TBC coatings were assessed on basic alloy by APS method. M204 NS - ZrO_2×8%Y_2O_3 powder was used for the outer top layer. A962 (Ni22Cr10AlY) VPS-sprayed powder was employed as the interlayer. Isothermal oxidation tests were performed in static air at temperature 900°C and 950°C for 500h and 200h of exposure respectively.

3. Description of achieved results of own researches

X-ray diffraction investigation of as-sprayed ceramic top layer detected the presents of primarily of a tetragonal ZrO_2 phase, with minor amounts of cubic and monoclinic phases (Fig.1).

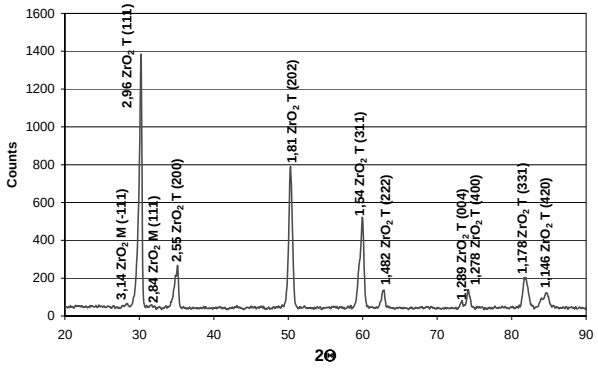


Fig. 1. X-ray diffraction analysis of powder Metco 204B-NS as-spray condition

The TBC microphotography in as-spray condition are shown in (Fig. 2). Figure 2 presents an air plasma sprayed coating with layered structure of ceramic top coat and inner bond coat. The thickness of ceramic layer was ca. 450 μm and was very similar on the all surface of the specimen. The thickness of bond coat was ca. 75 μm. The typical microstructure of the plasma sprayed YSZ could be seen with pores (total porosity ca. 5,5%), lamellae boundaries and micro-cracks. The metallography of the as-sprayed NiCrAlY bond revealed a dense, non-homogeneous coating structure containing visible splat boundaries and very small interlamellar porosity, isolated spherical internal porosity, and non-uniform dispersion of Y_2O_3 and Al_2O_3.

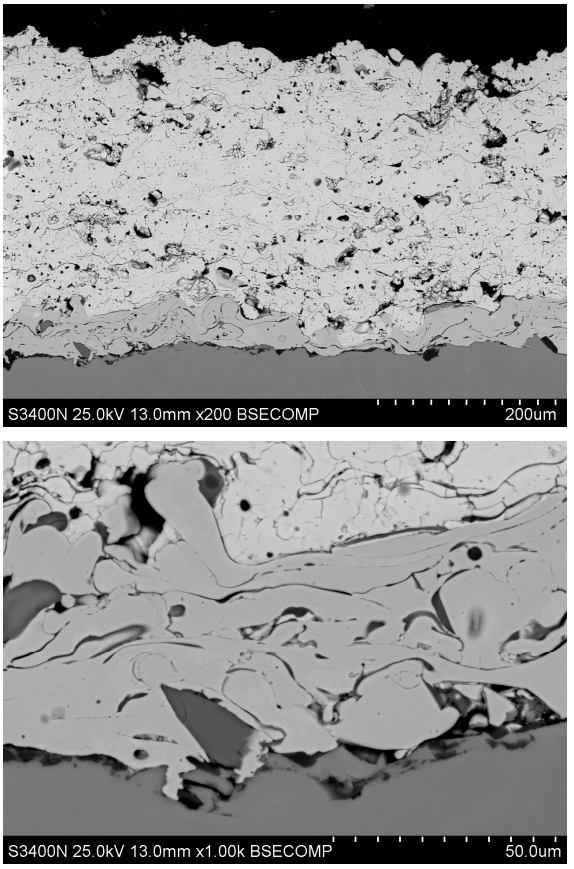
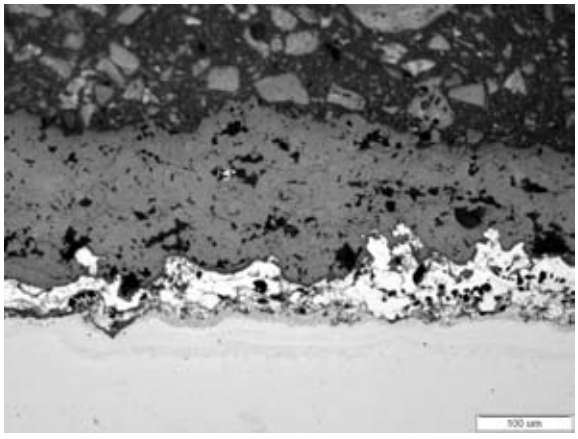
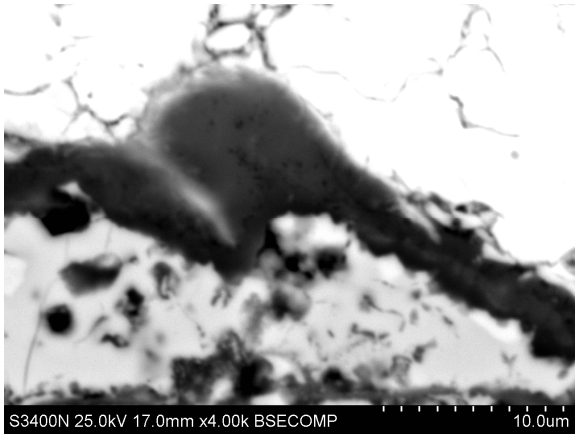


Fig. 2. General view of the TBC system before the oxidation test

Cross-sectional investigations after oxidation at 900°C for 500h (Fig.3) showed any important effect of cracks nucleation and delamination processes in area of ceramic top coat, but very significant changes in region of substarte-bond coat. The dark layer of TGO between ceramic layer and bond coat is dense with small amount of gray areas (with small pores) of oxides attached to the YSZ.

After 500h of exposition the thickness of oxides in TGO is ca. 5μm. The same observation was mead in the case of TBC system oxidized at 950°C for 200h. Quality of zirconia top coat is still very good, without any effects of cracking and delamination. The thickness of TGO layer is ca. 3μm. But at higher temperature bigger value of gray oxide areas is observrd in TGO sub-layer. There was observed effects of cracking in TGO as well. The microanalysis of chemical composition of oxides areas in TGO showed that dense dark areas are rich in Al (the main component is Al_2O_3, but in the gray oxides EDS showed presents of Al, Cr, and Ni. In this area exist probably mixed oxides such as Al_2O_3, Cr_2O_3 and probably spinel (Ni,Cr)Al_2O_4. Results of EDS analysis of oxide layer for are presented in Fig.4.





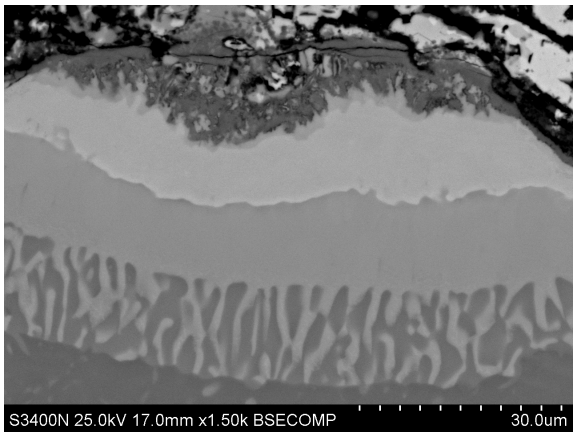
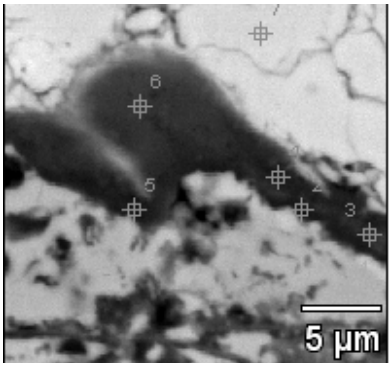


Fig. 3. General view of the TBC system after the oxidation test at 900°C

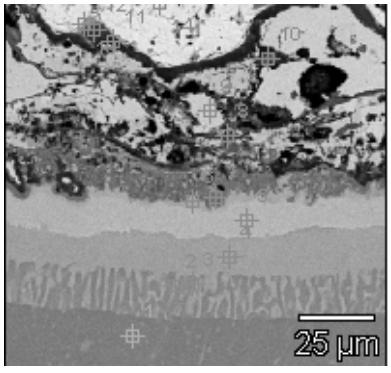
Much significant changes was detected below bond coat sub-layer. There was found 5 sub-layers with different chemical composition. The specific orange colour of firs sub-layer suggested presence of titanium nitride. First of them consist small gray particles rich in Ni (ca.18wt%) in matrix alloy. Each next 3 sub-layer consist much more Ni (to 53wt.%) and less concentration of Ti (from 38 to 12 wt.%). This area is probably build from ternary intermetallic phases from system Ti-Al-Ni.

On this transition layer there was found thick layer rich in Ti. The EDS analysis showed the presents of nitrogen as well.

This area is characterized by orange color on LM microphotography and consist probably TiN. The thickness of TiN layer is much bigger in the case of oxidation at 900°C for 500h than in 950°C. In the thick nitride layer many vertical crack was observed. The same constituent of transition layers was observed after oxidation at 900°C and 950°C.



Wt. %	*Al*	*Ti*	*Cr*	*Ni*	*Zr*
pt1	5.75	3.40	49.56	36.21	5.08
pt2	50.61	7.27	11.97	16.07	14.08
pt3	53.43	7.02	11.45	9.97	18.13
pt4	54.16	7.22	5.93	8.12	24.58
pt5	52.79	6.59	16.08	11.38	13.17
pt6	59.36	6.57	2.78	4.55	26.74
pt7	2.55	5.34	1.75	2.93	87.44



Wt %	*N*	*Al*	*Ti*	*Cr*	*Ni*	*Y*	*Zr*	*Nb*
pt1		31.18	60.13	2.42	1.81			4.45
pt2		25.45	48.41	4.48	17.62			4.05
pt3		22.25	66.90	2.08	4.60			4.17
pt4		26.51	38.33	4.99	27.05			3.12
pt5		16.69	25.78	1.19	51.53		2.25	2.57
pt6		29.42	12.24	2.07	53.81		2.46	
pt7	21.34	7.35	59.77	2.61	5.99			2.95
pt8		49.83	8.74	14.84	11.91	14.68		
pt9		6.38	3.96	23.54	62.28		3.85	
pt10		39.53	4.66	3.97	44.71		7.12	
pt11		54.23	7.49	4.97	7.29		26.03	
pt12		54.37	7.13	2.66	4.31		31.52	
pt13		26.86	5.27	1.72	4.75		61.39	
pt14		2.29	5.54	1.28	2.44		88.45	

Fig. 4. EDS results from TBC system after the oxidation test at 900°C

4. Conclusions

Investigated Ti48Al2Cr2Nb alloy can be described as insufficiently oxidation-resistant. This comparatively small oxidation resistance is connected to much higher kinetics of TiO_2 accretion as compared to the accretion rate of Al_2O_3. The microstructure of coated specimens showed that the thickness of the top-coat is about 450μm and the bond coat layer is about 75μm. The interfaces between matrix and bond-coat is slightly rough, however, the interface between bond-coat and top-coat is much rougher. No crack was observed on this interfaces. The APS coated 48-2-2 alloy was oxidized in air at 900°C and 950°C for different periods – 500h and 200h respectively. During oxidation at high temperature, oxygen penetrate trough the zirconia top-coat pores and in consequence react with the bond coat to form alumina and spinels such as $NiCr_2O_4$ or $NiAl_2O_4$ in form of TGO. At the same time on interface between bond-coat and basic alloys the processes of diffusion take place. The cross sectional investigation of oxidized specimens after 500h and 200h of exposure showed that diffusion layers formed between bond coat and titanium aluminides substrate. EDS analysis indicated that these layers resulted from Ni diffusing from NiCrAlY coating to substarte and are build from ternary intermetallics Ni-Al-Ti probably $AlNi_2Al$ and others. There was found, especially at 900°C of oxidation, orange in color sub layer rich in titanium. EDS analysis showed the presents of nitrogen as well. It is the most probably layer of TiN. The thickness of this areas was about 5μm after oxidation at 900°C and about 0,5μm at 950°C. This is the effect of decomposition of nitride to rutile at higher temperature. From the zirconia side the TGO was observed. The thicknes of this oxides after 500h of oxidation was about 5μm and 3 μm after oxidation for 3200h (950°C). EDS analysis showed that dominated phases in TGO are spinels $(Ni,Cr)Al_2O_4$.

- At 900°C and 950°C basic alloy Ti48Al2Cr2Nb exhibited poor oxidation resistance due to formation of mixed scale of alumina and titania.
- A YSZ as a top-coat with NiCrAlY as a bond coat can be effectively coated on the surface of basic alloys by APS method. Oxidation tests showed that oxidation resistance of APS coated specimens was improved.
- Due to inward diffusion of Ni to the substarte, Ni-Al-Ti diffusion layers formed between MCrAlY coating and TiAl alloys.

Acknowledgements

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