Effect of supersonic fine particles bombarding bond coat on oxidation resistance of thermal barrier coating

DONG Yun[1], LIU Chun-yang[1], LIN Xiao-ping[1], WANG Tie-bao[1], ZHANG Li-juan[1], WANG Zhi-ping[2]

(1. School of Material Science and Engineering, Hebei University of Technology, Tianjin 300130, China;

2. College of Science, Civil Aviation University of China, Tianjin 300300, China)

Abstract: Thermal barrier coating (TBC) obtained on GH99 high-temperature alloy by APS, NiCoCrAlY bond coat was treated by supersonic fine particles bombarding. The microstructure and oxidation behavior of TBC were characterized by transmission electron microscope, scanning electron microscope equipped with energy dispersive spectroscopy (EDS). As shown in the results: After disposed on bond coat by supersonic fine particles bombarding, plastic deformation and large quantities of dislocation obtained on the top of bond coat. The dislocations accelerate the diffusion of atoms to the BC/TC interface. A continuous Al_2O_3 layer forms on the interface quickly. High temperature oxidation resistance of TBC could be improved.

Key words: thermal barrier coating; supersonic fine particles bombarding; high temperature oxidation resistance

1. Introduction

In thermal barrier coating (TBC) systems, metallic bond coat (BC), usually MCrAlY, where M = Ni and/or Co, is an important constituent. In addition to improving the adhesion of ceramic top coat (TC) to nickel-based superalloy substrate, bond coat also provides protection against high temperature oxidation and hot corrosion. Oxidation of bond coat results in the formation of a TGO layer at the top coat/bond coat interface. If TGO was composed of a continuous scale of Al_2O_3, it would act as a barrier to suppress the formation of other detrimental oxides[1-4]. However, with thermal exposure in service, some other bulk oxides such as chromia $(Cr, Al)_2O_3$, spinels $Ni(Cr, Al)_2O_4$ and nickel oxide NiO also formed in the TGO layer. These mixed oxides are detrimental to the durability of TBC systems because of the rapid local volume increase that generate stress[5-6]. Spallation usually occurs in the porous mixed oxide layer or above the TGO/YSZ interface in APS TBCs.

Supersonic Fine Particles Bombarding[7-9], that is, using supersonic air as a carrier, making the fine particles bombard bond coat in high velocity. The roughness changes on the top of bond coat, and a plastic deformation layer forms in the superficial area of bond coat. The dislocation density may increase in this area. Dislocations provide diffusion channels for the atoms of bond coat. A continuous Al_2O_3 layer could form rapidly at the ceramic/bond coat interface in the APS TBCs under high temperature exposure, which could suppress the formation of detrimental oxides during later thermal exposure in service. The oxidation resistance of TBC could be improved.

2. Experiment

TBC samples consist of a NiCoCrAlY bond coat and a ZrO_2–8 Y_2O_3 (wt%) topcoat. The bond coat was deposited to a thickness of 150 μm by the air plasma spray (APS) technique (PRAXAIR 3710, USA), with powders of Ni–20.8Co–17.3Cr–11.5Al–0.6Y (wt%) onto 20 mm×10 mm inconel 625 disks. Some as-sprayed samples were treated by supersonic fine particles bombarding. On parts of these samples, topcoats were deposited to a thickness of 200 μm by the APS technique, employing the same plasma spray

Corresponding author: LIU Chun-yang (1982-), male, professor, master; research field: surface engineering. E-mail: liucy826@gmail.com.

torch, with powders of ZrO_2-8 wt% Y_2O_3. The initial state of superficial bond coat was analyzed by SRT-2 surface roughness tester and Philips Tacnai F200 transmission electron microscope (TEM). For the coating samples (BC, without TC), the substrates were mechanically removed by grinding, and then the coatings were dimpled and ion-milled to a desired thickness for the TEM studies. TBC samples were then subjected to thermal exposure in high temperature furnace at a constant temperature of 1050℃ in air atmosphere. The specimens were analyzed after 3, 6, 48, 96, 200, 300 h of thermal exposure at 1050℃. Cross-section samples of TBC were examined using a Philips LEO1530 scanning electron microscope (SEM) with an energy-dispersive spectrometer (EDS), to analyze the oxides microstructures and chemical composition.

3. Results and discussion

3.1 Morphology and microstructure of bond coat

Fig. 1(a) and Fig. 1(b) show the morphological differences of NiCoCrAlY between as-sprayed and after supersonic fine particles bombarding process, respectively. Matrix phase of samples were all γ′-Ni_3Al. The superficial morphology of as-sprayed bond coat was conventional, there was no distinct micro-defect (Fig. 1(a)). However, after supersonic fine particles bombarding, a lot of dislocation networks were observed in the superficial bond coat (Fig. 1(b)). The formation of dislocation networks during bombarding was considered to be a consequence of plastic deformation.

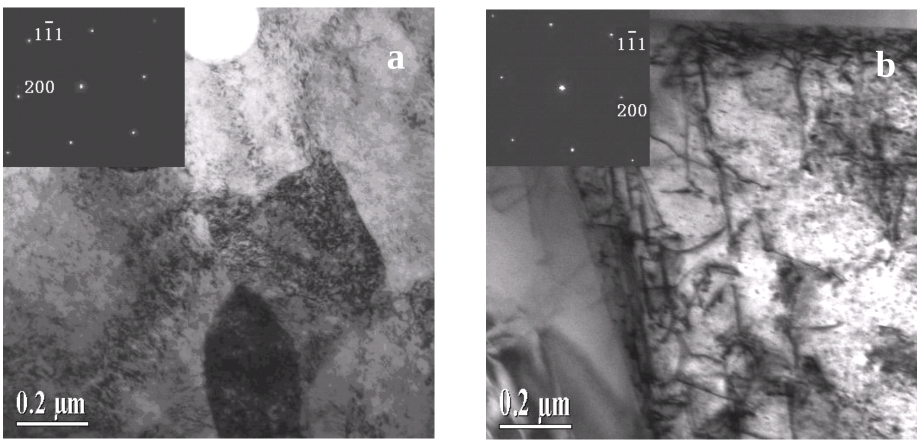

Fig. 1 TEM images of (a) as-sprayed bond coat and (b) supersonic fine particles bombarding bond coat

3.2 Oxidation behavior of APS thermal sprayed coatings

Fig. 2 shows the cross-section SEM images of as-sprayed samples at different thermal exposure hours. The marked phases based on analyzing XRD, EDS and related documents[10-12]. The microstructure of as-sprayed TBC was shown in Fig. 2(a). As a result of oxidation during spraying, some Al_2O_3 flakes were distributed in the bond coats, as well as along the ceramic/bond coat interface, there were also a few mixed other oxides. It is believed as a result of unselective oxidation in bond coat. After 6 h exposure at 1050℃, a thin layer of Al_2O_3 was observed at the ceramic/bond coat interface, in addition, some clusters of oxide products were also observed, indicated by the arrows in Fig. 2(b). These oxide clusters contained 20-45 at% nickel, 12-33 at% cobalt, 7-26 at% chromium and 3-32 at% aluminum. They are close to a mixture of chromia ($(Cr, Al)_2O_3$), spinels ($Ni(Cr, Al)_2O_4$), and nickel oxide (NiO) in chemical composition, The mixed oxide products have been reported by other researchers. After 200 h exposure at

1050℃ (Fig. 2(c)), TGO change into two layers, the Al_2O_3 layer was still observed at the ceramic/bond coat interface, and the clusters of oxide products became larger in the ceramic/Al_2O_3 region. This phenomenon is more obvious in Fig. 2(d), TGO had been composed of the clusters of oxide products in some TGO areas. Large amount of voids formed in CSN layer. The average thickness of TGO is more than 5 μm.

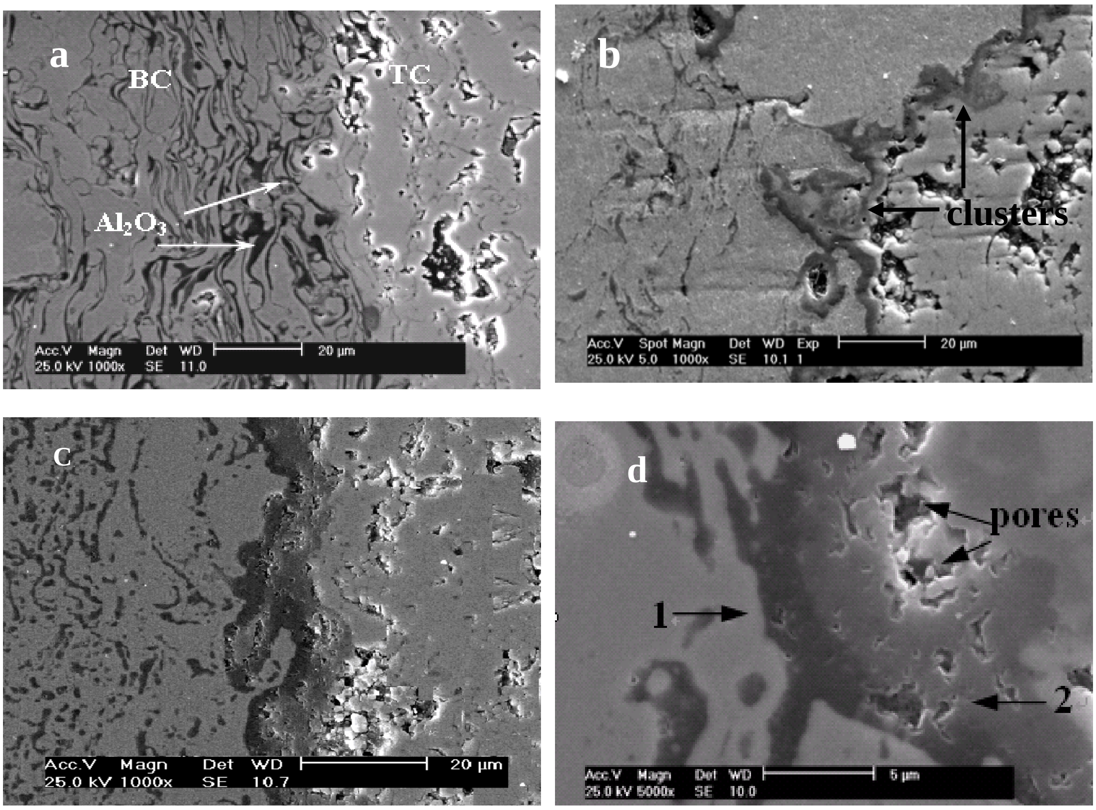

Fig. 2 Cross-sectional morphologies of as-sprayed TBC after oxidation

Notes: (a) No oxidation; (b) 1050℃×6 h; (c), (d) 1050℃×200 h.

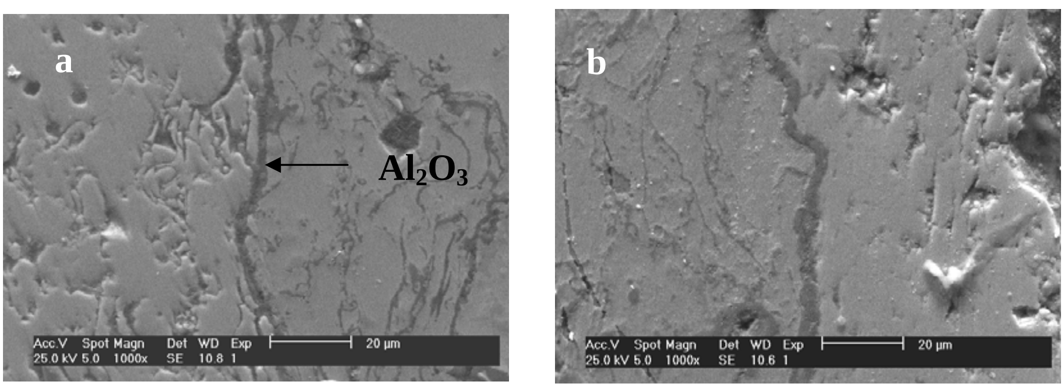

Fig. 3 Cross sectional morphologies of supersonic fine particles bombarding TBC after oxidation

Notes: (a) 1050℃×3 h; (b) 1050℃×300 h.

Fig. 3 shows the cross-section SEM images of samples which have been treated by supersonic fine particles bombarding. After 3 h exposure at 1050℃, an uniform Al_2O_3 layer at TC/BC interface was produced, as shown in Fig. 3(a). The roughness of bond coat reduced from R_a=13.92 μm to R_a=9.36 μm after supersonic fine particles bombarding, inducing the appearance of TGO was regular during oxide exposure process. Proper reducing roughness could avoid excessive oxidation in different areas[13-18]. After 300 h exposure at 1050℃, TGO still grew in steady-state growth stage. No visible other oxides observed in TGO scale (Fig. 3(b)).

3.3 Discussion

The oxidation of bond coat occurs throughout the thermal exposure period. It is noticeable that supersonic fine particles bombarding treatment improves the oxidation resistance of TBC. In the early oxidation stage of bond coat, because of exposed at high oxygen pressure, non-selective oxidation occurred in the TC/BC interface. Fig. 4 shows the SEM images for a as-sprayed specimen after 6 h exposure at 1050℃ with the corresponding EDS analysis, which indicated that, there were Ni, Cr, Al-rich oxides existed in TGO layer. The tendency to form a continue Al_2O_3 layer was unobvious. That meant, the formation of Al_2O_3 was accompanied with other detrimental oxides growing. When TBC experienced the stage of selective oxidation to form Al_2O_3, large quantity of Al had been depleted in forming detrimental oxides, such as $NiAl_2O_4$, $CoAl_2O_4$, etc. Nevertheless, when the bond coat experienced a severe Al depletion, detrimental oxides would grow rapidly, which was detrimental for the TBC, promoting top coat cracking.

There was a plastic deformation layer after supersonic fine particles bombarding. Large quantities of dislocation obtained on the top of bond coat, which provided accelerated diffusion channels for bond coat atoms in thermal exposure period. The diffusion channels made the initial oxidation reaction intensively. In the initial thermal exposure period, TGO consisted of more than 90% Al_2O_3. This phenomenon can probably be attributed to the existing of diffusion channels and selective oxidation of Al. TGO has been in steady-state growth stage after 3h thermal exposure. Fig. 5 shows the SEM images for supersonic fine particles bombarding TBC specimens after 3 h exposure at 1050℃ with the corresponding line scanning analysis. Uphill diffusion of Al was observed near the surface area of bond coat. The aluminum concentration of bond coat was found to be ≥15 at% along TGO/bond coat interface region. The enrichment of Al can extend the steady-state growth stage of TGO. After 300 h thermal exposure, TGO was still in the steady-state growth stage (Fig. 3(b)).

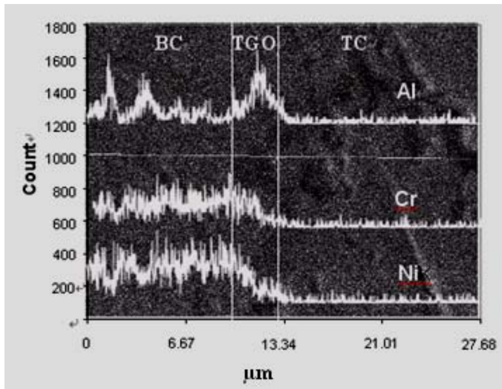

Fig. 4 Cross-sectional morphology of as-sprayed TBC and corresponding line scanning at 1050℃ for 6 h

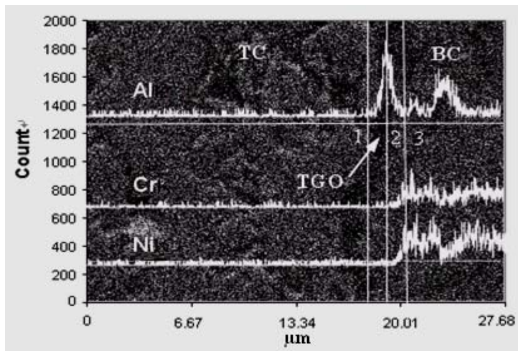

Fig. 5 Cross-sectional morphology of supersonic fine particles bombarding TBC and corresponding line scanning at 1050℃ for 3 h

4. Conclusions

The treatment of supersonic fine particles bombarding promoted the formation of a continuous Al_2O_3 layer at the ceramic/bond coat interface in the

APS TBCs under high temperature exposure, and suppressed the formation of detrimental oxides. After 300h thermal exposure, TGO was still in the steady-state growth stage, the oxidation resistance of APS TBC under high temperature exposure improved.

References:

[1] Wellman R. G. and Nicholls J. R.. Erosion, corrosion and erosion–corrosion of EB PVD thermal barrier coatings. *Tribology International,* 2008, *41*: 657-662.

[2] Brandl W., Grabke H. J. and Toma D.. The oxidation behavior of sprayed MCrAlY coatings. *Surface and Coatings Technology,* 1996, *86*: 41-47.

[3] CHEN W. R., WU X., Marple B. R., et al. TGO growth behaviour in TBCs with APS and HVOF bond coats. *Surface and Coatings Technology*, 2008, *201*: 2677-2683.

[4] Teixeira V., Andritschky M. and Fischer W.. Analysis of residual stress in thermal barrier coatings. *Journal of Materials Processing Technology*, 1999, *92-93*: 209-216.

[5] ZHENG D. Y. Oxidation and hot corrosion behavior of a novel enamel-Al_2O_3 composite coating on K38G superalloy. *Surface and Coatings Technology*, 2006, *200*: 5931-5936.

[6] Tolpygo V. and Clarke D. R.. Morphological evolution of thermal barrier coatings induced by cyclic oxidation. *Surface and Coatings Technology,* 2003, *163*: 81-86.

[7] XIONG T. Y., LIU Z. W. and LI Z. C.. Supersonic fine particles bombarding: A novel surface nanocrystallization technology. *Mat-rev*, 2003, *17*: 69-72.

[8] GUO Hong-bo, XU Hui-bin, GONG Sheng-kai, et al. Effect of surface strengthening on high temperature oxidation and bonding strength of EB-PVD thermal barrier coating. *Rare Metal Materials and Engineering,* 2001, *30*: 314-317.

[9] SONG Hong-wei, LIU Zhi-bin, ZHANG Jun-bao, et al. Microstructure characteristics of surface nanocrystallized 40Cr steel. *Materials for Mechanical Engineering,* 2004, *28*(1): 35-37.

[10] Gil A., Shemet V. and Vassen R.. Effect of surface condition on the oxidation behavior of MCrAlY coatings. *Surface and Coatings Technology*, 2006, *201*: 3824-3828.

[11] WU F., Jordan E. H., MA X., et al. Thermally grown oxide growth behavior and spallation lives of solution precursor plasma spray thermal barrier coatings. *Surface and Coatings Technology*, 2008, *202*: 1628-1635.

[12] Miller, R. A.. *In Proceedings of the Thermal Barrier Coatings Workshop*, 1995: 17-34.

[13] Rätzer Scheibe H. J. and Schulz U.. The effects of heat treatment and gas atmosphere on the thermal conductivity of APS and EB-PVD PYSZ thermal barrier coatings. *Surface and Coatings Technology*, 2007, *201*: 7880-7888.

[14] Jang B. K. and Matsubara H.. Influence of porosity on thermophysical properties of nano-porous zirconia coatings grown by EB-PVD. *Scr. Mater*, 2006, *54*: 1665-1673.

[15] CHEN W. R, WU X., Patnaik P. C., et al. *Proceedings from the 1st International Surface Engineering Congress and the 13th IFHTSE Congress*, Columbus, Ohio, 2002: 535.

[16] CHEN W. R., WU X., Marple B. R., et al. The growth and influence of thermally grown oxide in a thermal barrier coating. *Surface and Coatings Technology*, 2006, *201*: 1074-1079.

[17] Giuliano G., John A. N. and David R. C.. Vibration damping of superalloys and thermal barrier coatings at high-temperatures. *Materials Science and Engineering*, 2007, *466*: 256-264.

[18] ZHOU Chun-gen and WANG Na. Comparison of thermal cycling behavior of plasma-sprayed nanostructured and traditional thermal barrier coatings. *Materials Science and Engineering,* 2007, *452*: 569-574.

(Edited by Donna and Edward)