Studies on the Mechanical and Oxidation Resistance Properties of CoNiCrAlY/Al_2O_3/YSZ Compositionally Graded Thermal Barrier Coating Developed by Air Plasma Spraying

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Abstract

The service life of thermal barrier coating (TBC) is determined by it's mechanical properties like Young's modulus and toughness and high temperature oxidation resistance (under isothermal condition). Conventionally, TBC is composed of Yttria stabilized Zirconia (YSZ) top coating applied on MCrAlY bond coat. Alumina is also a promising diffusion barrier coating which has improved performance against high temperature oxidation and hot corrosion. However, large probability to sintering, high Young's modulus and low coefficient of thermal expansion are the drawbacks associated with application of alumina as the thermal barrier coating. The present study concerns development of a compositionally graded CoNiCrAlY/Al_2O_3/YSZ thermal barrier coating by thermal spray deposition route and a detailed investigation of mechanical (Young's modulus, hardness and fracture toughness) and high temperature oxidation resistance properties (under isothermal condition) of the compositionally graded TBC and its comparison with conventional CoNiCrAlY/YSZ duplex TBC. The properties achieved in the graded coating are analyzed and compared with the duplex coating.

1 Introduction

Ceramic insulating materials are applied as thermal barrier coating, on to the surface of metallic components which operates in high temperature environment to limit the heat transfer towards the substrate [1]. The dominant failure mechanisms usually observed in conventional duplex TBCs are due to the stress generated because of (a) thermal expansion mismatch between the ceramic top coat and metallic bond coat and (b) growth of TGO during oxidation of bond coat [1]. The oxidation of bond coat occurs by the diffusion of oxygen through the ceramic top coat and the growth rate of TGO is influenced by the partial pressure of O_2 (P_{O2}) available at the bond coat and top coat interface. Hence, application of oxygen diffusion barrier coating between the top coat and bond coat has been helpful in lowering the TGO growth rate [2]. In the present study, a detailed investigation of isothermal oxidation behavior of compositionally graded CoNiCrAlY/Al_2O_3/YSZ TBC has been undertaken (kinetics and mechanism) and compared with conventional duplex TBC of CoNiCrAlY/YSZ.

2 Experimental

In the present study, Ni-based superalloy (Inconel 718) of 20 mm × 20 mm × 5 mm dimensions are used as substrate. CoNiCrAlY bond coat is deposited on sand blasted Inconel 718 superalloy substrate using high velocity oxy-fuel spray (HVOF) technique. The details of parameters used for the developemnt of duplex and compositionally graded TBC have been reported elsewhere [3]. The composition of the compositionally graded CoNiCrAlY/Al_2O_3/YSZ TBC consists of the mixture of CoNiCrAlY and Al_2O_3 in the ratio of 70:30, 50:50, 30:70, and 0:100 applied onto the surface of 100% CoNiCrAlY followed by a coating mixture of Al_2O_3 and YSZ in the ratio of 70:30, 50:50, and 30:70 on top of already developed 100% Al_2O_3. Isothermal oxidation studies of the coated samples are undertaken by holding the samples isothermally in air at temperatures ranging from 900 °C to 1000 °C and subsequently, measuring the weight change at regular interval from 1 hour to 96 hours. Microstructural analysis of the coating is carried out by field emission scanning electron microscope. Phase and residual stress are measured by x-ray diffraction technique. Indentation fracture toughness is measured by indenting at the bond coat and top coat interface with Vickers indenter at 5 Kgf and 10 Kgf load and holding at the maximum load for 10 s. The indentation fracture toughness (K_{IC}) of the interface is obtained using the following equation [4]:

$$K_{IC} = 0.016\left(\frac{E}{H}\right)^{1/2}\frac{P}{c^{3/2}}$$

Where, P is the applied load in Kgf, c is the crack length in μm, E is the Young's modulus in GPa and H is the hardness in GPa.

3 Results & Discussion

3.1 Microstructural Characterization

The cross-sectional microstructure of (a) CoNiCrAlY/YSZ duplex and (b) CoNiCrAlY/Al_2O_3/YSZ compositionally graded TBC deposited by plasma spraying technique is shown in **Fig. 1**. Heterogeneous distribution of microstructural defects (globular porosities/voids, intralamellar cracks, and interlamellar pores) is evident from **Fig. 1**. Improper melting of the powder particle, entrapment of carrier gases, and poor intersplat bonding between the splats cause the formation of these defects [5]. Though, these defects act as paths for the diffusion of oxygen, however, the presence of the defects increases the strain tolerance capacity of the TBC system as well as reduces thermal conductivity effectively by acting as phonon scattering centers [6].

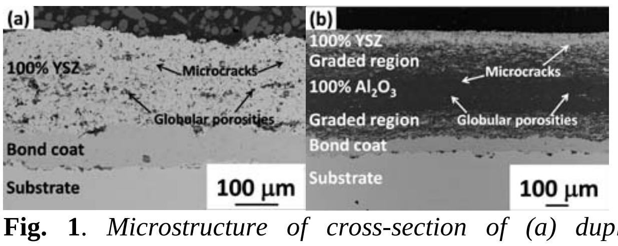

Fig. 1. *Microstructure of cross-section of (a) duplex CoNiCrAlY/YSZ TBC and (b) compositionally graded CoNiCrAlY/Al_2O_3/YSZ TBC.*

3.2 Isothermal Oxidation

Isothermal oxidation results are shown in **Fig. 2**. The mass gain per unit area in compositionally graded TBC is higher than that in duplex TBC both at 900 °C and 1000 °C. In the case of oxidation carried out at 950 °C, no significant difference between the mass gain curves for duplex and graded TBC is observed, initially, up to 24 hour of oxidation beyond which the mass gain in graded TBC shows a decreasing trend with increase in oxidation temperature. At 1000 °C, the severity of oxidation in graded TBC is more severe. The higher mass gain in graded TBC as compared to duplex TBC is attributed to the rapid oxidation of metallic elements present in the graded regions due to the spallation of coating.

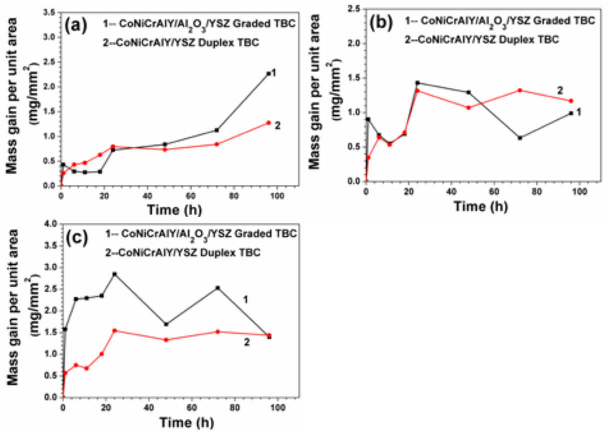

Fig. 2. *Kinetics of isothermal oxidation in compositionally graded (plot 1) and duplex (plot 2) TBC at (a)900 °C, (b) 950 °C, and (c)1000 °C.*

3.3 Post-oxidation Analysis

The post oxidation microstructural analysis of graded TBC and duplex TBC after oxidation at 900 °C up to 96 hour is shown in **Fig. 3**. Formation of TGO at the interface between top coat and bond coat is evident from **Fig. 3a**. The formation TGO is the result of oxidation metallic elements present in the bond coat to that of atmospheric oxygen. The graded TBC shows complete spallation after thermal exposure for 96 hour as observed from **Fig. 3b**. The spallation is observed at the interface between 100% Al_2O_3 and 70% Al_2O_3 + 30% CoNiCrAlY coating layers. The spallation in the graded TBC is observed during cooling period which indicates that the failure in graded TBC is attributed to the developemnt of large residual thermal stress.

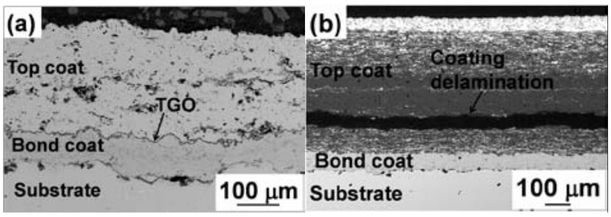

Fig. 3. *Microstructure of cross-section of (a) duplex CoNiCrAlY/YSZ TBC and (b) compositionally graded CoNiCrAlY/Al_2O_3/YSZ TBC after isothermal oxidation at 900 °C for 96 hour.*

3.4 Indentation Fracture Toughness

Indentations are made at the interface between 100% Al_2O_3 and 70% Al_2O_3 + 30% CoNiCrAlY layers and 30% Al_2O_3 + 70% CoNiCrAlY and 100% CoNiCrAlY layers as shown in **Fig. 4**. The fracture toughness at the interface between 100% Al_2O_3 and 70% Al_2O_3 + 30% CoNiCrAlY layers and 30% Al_2O_3 + 70% CoNiCrAlY and 100% CoNiCrAlY layers are measured to be 0.42 MPa.$m^{-1/2}$ and 8.2 MPa.$m^{-1/2}$, respectively. The maximum crack length of 644 μm is observed at the interface between 100% Al_2O_3 and 70% Al_2O_3 + 30% CoNiCrAlY layers with an applied load of 5 Kgf, whereas a crack length of 234 μm is obtained at the interface between 30% Al_2O_3 + 70% CoNiCrAlY and 100% CoNiCrAlY coating with an applied load of 10 Kgf. From the results, it is observed that the at the interface with 100% Al_2O_3, the fracture toughness is inferior which resulted in spllation of the coating.

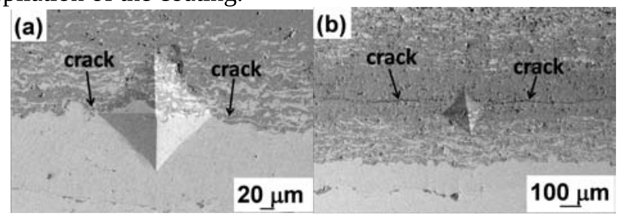

Fig. 4. *Microstructure of cross-section showing indentataion at the interface between (a) 70% CoNiCrAlY and 100% CoNiCrAlY layers and (b) 100% Al_2O_3 and 70% Al_2O_3 + 30% CoNiCrAlY layers.*

4 Conclusions

The following conclusions may be drawn from the present study:

1. The graded CoNiCrAlY/Al_2O_3/YSZ TBC shows inferior oxidation resistance as compared to duplex TBC. Complete spallation of the graded coating is observed at the early stage of oxidation.
2. The fracture toughness of the interface close to Al_2O_3 layer shows the lowest value which is the main reason for the complete spallation of graded TBC.

5 References

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