Air Plasma Sprayed Bond Coat Oxidation Behavior and its Resistance to Isothermal and Thermal Shock Loading

E. Poursaeidi*, K. Torkashvand, M. Mohammadi

Mechanical Engineering Department, Faculty of Engineering, University of Zanjan, Zanjan, Iran

PAPER INFO

ABSTRACT

An experimental investigation was conducted to find the effect of spraying method of coating of Thermal Barrier Coatings (TBCs) on their oxidation behaviour and resistance to various thermal loading. Isothermal and thermal shock tests were performed in order to study oxidation behaviour of air plasma sprayed Bond Coat (BC) and assess its effect on TBCs lifetime under the stated loadings. Specimens, after loading were investigated using Field Emission Scanning Electron Microscopy (FE-SEM). Results showed in spite of forming various oxide layers within the BC its oxidation in Bond Coat/Top Coat interface behave the same as samples coated by other methods and no failure was observed at substrate/BC interface or within the BC.


1. INTRODUCTION

In order to increase the efficiency of gas turbines, the input temperature is requird to be increased. On the other hand, increasing temperature can reduce the life of components due to the emergence of phenomena such as creep, hot corrosion, changes in material properties and oxidation at high temperatures [1, 2]. Nowadays, thermal barrier coatings (TBCs) is used as a thermal insulator for components exposed to temperatures higher than their limit of materials' capabilities [3-5]. TBCs consist of two main layers top coat (TC) and bond coat (BC). There are several methods of spraying TC layer such as plasma spray (PS), high-velocity oxygen fuel (HVOF), flame spraying, cold spraying etc. Among these air plasma spray method is well known for its cost-efficiency and high productivity [6, 7]. BC layer plays a crucial role in a TBC system by providing a strong adhesion of TC to the substrate. Several methods have been applied to deposit the bond coat, like air plasma spray (APS), low-pressure plasma spray (LPPS), vacuum plasma spraying (VPS) and HVOF spray [8-11]. LPPS provides a dense bond coat without oxide formation during spraying [12]. The porosity percentage and internal oxidation of BC deposited by HVOF almost resemble LPPS, higher than APS but higher than VPS. Hence this method is one of the most common techniques for applying bond coats [13, 14]. Among all these methods APS has the lowest cost. However, due to forming several oxide layers within the BC during the process, this method does not tend to be used for applying BC. But the question is how much these oxide layers contribute to the durability of TBCs and TC/BC interface adhesion.

In this study, the interface and internal oxidation of BC were investigated and the durability of BC coated using APS under various thermal loading including isothermal and thermal shock was studied.

2. EXPERIMENTAL METHODS

2.1. Coating the Samples

NiCrAlY powder with the particle size of 60-90 micron was deposited by APS method by the process parameters. According to Table 1, the thickness of this layer is considered to be 100±20 microns. A layer with a thickness of 450±50 microns ZrO2 - 8wt% Y2O3 was applied as TC using this method as well.

*Corresponding Author Email: epaeidi@znu.ac.ir (E. Poursaeidi)
2. 2. Experiment Tests In order to assess the durability of plasma-sprayed bond coat under various thermal loading, two experiments were performed as follows.

2. 2. 1. Isothermal For studying the effect of being exposed to high temperature on bond coat oxidation, the heat treatment was conducted using a furnace for 24, 72, 120 and 192 hours with its temperature increased to 1070 °C.

2. 2. 2. Thermal Shock In this test, first, in order to oxides within the BC expand and TGO layer at BC/TC interface forms, the samples experienced isothermal loading for various time exposure (0, 24, 72 and 120h) and then, thermal shock test was performed. In this test, the temperature of sample went from room temperature to 1000 °C in 3 minutes and cooled down in 45 seconds using water quenching method, a detailed explanation of this method can be seen in literature [15].

3. RESULTS AND DISCUSSION

3. 1. Isothermal Test Figure 1(a) shows a region within the BC area which is oxidized during the APS process. Figures 1(b) and 1(c) show the EDS analysis of regions A and B, respectively. As it can be seen during the process, TGO and mixed oxides of Cr and Y are formed.

Figure 2 shows an SEM image of BC/TC interface of the sample which is being exposed to the temperature of 1070 °C for 120 hours. A semi-quantitative analysis of different regions is provided in Table 2.

It can be seen that a uniform thick layer of TGO is formed in region A. A mixed oxide clusters of Chromium (Cr, Al)2O3, Spinel Ni(Cr, Al)2O4 and Nickel oxide NiO (CSN) are formed in regions of B, C and D region, respectively. In order to assess the cohesiveness of BC/TC, four samples with a time exposure of 0, 24, 120 and 192h were studied.

Figure 3 shows the SEM images of samples with a time exposure of 0, 24, 120 and 192h, respectively. As it can be seen there is no sign of separation or crack formation in the as-sprayed sample (0 hours of time exposure) and sample with 24 hours of time exposure (Figures 3(a) and 3(b), respectively).
A partial and universal separation can be seen in Figure 3(c) (sample with a time exposure of 72 hours) and Figure 3(d) (sample with a time exposure of 120 hours), respectively. It can be concluded from Figure 3 that BC coated by APS method provides a strong bonding between ceramic layer and substrate in a way that separations almost occur within TC layer not at the substrate/BC interface or within the BC, during the isothermal loading just like the behaviour of the bond coat applied by other methods as reported in literature [11, 20, 21].

3. 2. Thermal Shock Test

After thermal shock test, all samples were observed using a scanning electron microscopy in order to identify any separation at the substrate/BC interface or within the bond coat. Figure 4(a) shows the sample after 50 cycles of thermal shock test. This sample experienced no isothermal heat treatment. Figure 4(b) shows a sample with 120 hours of heat treatment at 1070 °C and 98 thermal shock test. As it can be seen no sign of separation or crack initiation is observable within the bond coat layer or at the substrate/BC interface and like an isothermal test, separation starts at BC/TC or within the TC layer.

| TABLE 1. A semi-quantitative analysis of different regions |
|---------------------------------|-----------|----------|----------|----------|----------|
| Al (W%) | Ni (W%) | Cr (W%) | Zr (W%) | Y (W%) | O (W%) |
| A | 43.27 | 1.07 | 0.41 | 3.01 | 1.09 | 51.15 |
| B | 16.59 | 2.48 | 30.87 | 2.69 | 0.79 | 46.58 |
| C | 11.00 | 24.30 | 23.48 | 3.60 | 0.51 | 37.11 |
| D | 0.51 | 61.80 | 1.48 | 4.58 | 0.77 | 30.87 |

**Figure 3.** SEM images of samples after exposing at high temperature for (a) 0 hour (b) 24 hours (c) 120 hours (d) 192 hours

**Figure 4.** SEM image of samples after thermal shock test (a) after 50 cycles (b) after 98 cycles
4. CONCLUSION

Several experimental tests conducted in order to investigate the durability of bond coat layer applied using APS method under various thermal tests and oxidation behavior of bond coat during the coating process and after thermal loading. The results show that:

1. During the coating process, several layers of Al, Cr and Ni oxides form.
2. After thermal loading at 1070 °C for 120 hours several thick layers of TGO and CSN layers forms in the BC/TC interface.
3. Neither the oxides within the BC nor those at the BC/TC interface lead to no separation at substrate/BC or within the BC and the TBC system shows good durability under thermal shocks and isothermal loading.

Therefore, deposition of BC using APS method considering its durability and low economic costs can be a suitable method in applying bond coat layer of a TBC system.

5. REFERENCES

Air Plasma Sprayed Bond Coat Oxidation Behavior and its Resistance to Isothermal and Thermal Shock Loading

E. Poursaeidi, K. Torkashvand, M. Mohammadi

Mechanical Engineering Department, Faculty of Engineering, University of Zanjan, Zanjan, Iran

Paper history:
Received 23 June 2018
Received in revised form 28 April 2019
Accepted 03 May 2019

Keywords
Thermal barrier coating
Air plasma sprayed
Oxidation
Failure