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Effect of electron beam remelting treatments on the performances of plasma sprayed zirconia coatings

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ABSTRACT

In this study, zirconia coatings were deposited on stainless steel using air plasma spraying (APS), and electron beam remelting treatments (EBRTs) were used to improve the performances of the plasma sprayed coatings. The properties of the zirconia coatings such as porosity, microhardness, surface roughness, phase transformation and wear behaviors were characterized and measured. The experimental results showed that electron beam treatments of the plasma sprayed coatings generated a compact remelted layer on top of the surface composed of columnar structure. EBRTs significantly reduced the porosity and surface roughness. The surface microhardness had also nearly doubled after EBRTs. Compared with the as-sprayed zirconia coating, wear behaviors of the electron beam treated coatings had considerably improved.

1. Introduction

Zirconia (ZrO^2) has high melting point (2680 °C), low thermal conductivity, and low thermal expansion. Due to these advantages, it has been widely used for thermal barrier coatings (TBCs) to protect gas turbines and diesel engines and to enhance engine efficiency [1–3]. Nowadays, TBCs are usually prepared by air plasma spraying (APS) due to high deposition efficiency, and this technology is cost-effective [4–7]. However, there are still many issues to be addressed in relation to plasma sprayed coatings applications. One of the most important issues is high porosity, which could reduce the erosion and corrosion resistance [8–12]. In the course of service, besides high temperature corrosion, the impact of a large amount of high-speed particles on the coatings surface contributes to failure of TBCs more effective [12–21]. Thus, it is required for zirconia TBCs to reduce porosity and improve their wear behaviors. In order to solve these problems, post-treatments with high-energy beam welding have been developed. In terms of zirconia as-sprayed coatings, most reported studies have focused on laser remelting technology [6,11,18,22], but studies on the electron beam remelting treatments (EBRTs) are very rare. EBRTs have higher efficiency, simplicity and reliability as compared with laser and ion beams [23–26]. In this study, the effects of EBRTs on the performances of ZrO^2 coatings including porosity, microstructure, surface roughness and microhardness were investigated systematically. The wear behaviors of ZrO^2 coatings, before and after EBRTs, were also examined. This work could open new opportunities for using the EBRTs to functionalize the TBCs with better performance, not only to enhance their mechanical properties and the engine efficiency, but also to improve their service life.

2. Experimental procedures

Commercial ZrO^2~7 wt.%Y^2O^3 powders (PRAXAIR, USA) sized between 45 and 106 μm were used to fabricate ZrO^2 coatings with an average thickness of ~300 μm on stainless steel. The plasma spray parameters are listed in Table 1. The air plasma spraying system (PRAXAIR, USA) was performed under air atmosphere using argon as both primary and carrier gas. Hydrogen was used as secondary gas to enhance the enthalpy. The arc power was 20 kW and the spray distance was 80 mm. During the spraying process, the substrates were cooled by water cooling system to ensure a great adhesion between the coating and the substrate.

Then the plasma sprayed samples surfaces were post-treated by raster scanning electron beam system (SEB-100A, China) as follows: the samples were placed on the x-y table under vacuum

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Table 1
Atmospheric plasma spray parameters for the zirconia powder.

Power	Voltage	Current	Primary gas (Ar)	Secondary gas (H2)	Carrier gas (Ar)	Spray distance	Traverse speed	Powder feed rate
20 kW	45 V	444 A	56.5 L/min	3.5 L/min	17.5 L/min	80 mm	200 mm/s	3.5 g/min

environment, after setting the parameters, electron beam was carried out to scan the specimen's surface automatically for 200 ms with electron gun power of 10 kW and spot diameter of 5 mm. The vacuum chamber was opened after the coatings were cooled down enough to prevent oxidation between the coatings and the substrates. The raster scanning electron beam processing is shown in Fig. 1 (a) and the parameters employed are shown in Table 2.

The microstructure of the coatings was characterized by scanning electron microscopy (SEM; U70, Hitachi, Japan). The porosity was measured by automatic mercury porosimeter (AutoPore IV, micromeritics, USA). Before testing, samples were dried in drying oven at 100 °C for 4 h. Then penetrometers of 5 cc was loaded at 1.83 g to perform pressure analysis of the zirconia samples. The phase transformation of the zirconia coatings was measured by X-ray diffraction (XRD; TD-3000, China). The XRD patterns from 20° to 90° were characterized at ambient temperature using Cu Kα radiation ($\lambda = 0.154056$ nm) with a tube voltage of 30 kV and a tube current of 20 mA. The Vickers microhardness was tested on both surface and cross-section of the coating by a microhardness testing machine (DURASCAN G5-20, Austria). Samples were ground and polished before tests to ensure smoothness of the surface required for testing. Three test points were selected for each sample. Then the indenter was applied with a load of 2 N for 15 s. The distance between each point was three times greater than the indentation diagonal length. The roughness of the surface was determined using profilometer (Bruker Dektak XT) with a load of 3 mg, and stylus tip radius of 2 μm. The distance traveled by the probe on the surface was 1 mm, with a scan duration of 20 s. Sandblasting machine (AMS 7090C) was used to examine wear behaviors of the surface comparing the as-sprayed coatings with the remelted treated coatings. The pressure value is 0.4 MPa, and alumina particles with a size of 40–60 μm are used as the sandblasting media during the wear testing. Before wear testing, the substrates on both sides of the coatings were cut off to ensure that the mass loss are entirely from the coatings themselves. The wear behaviors of the coatings were tested at ambient temperature, 400 °C, 500 °C, 600 °C, respectively. The thermal conductivity of the coatings were tested by thermal conductivity tester (KY-DRX-RW,China).

3. Results and discussion

3.1. Coatings characterization before and after EBRTs

Fig. 1 (b) and (c) show the morphology of the zirconia coatings before and after remelting treatments respectively. After remelting treatments, the surface of the as-sprayed coatings turned black. However, after heating at 700 °C for 20 min in air, the surface gradually turned white again. In previous studies [27,28], similar experiments with laser treated zirconia ceramic were conducted and a similar experimental phenomenon of the surface color was observed. Yoshioka et a1 proposed that these results were caused by the reduction in oxygen content during instantaneously high energy irradiation. To explore the cause, mass changes and oxygen content were measured by electronic scale and energy dispersive X-ray spectroscopy (EDS) respectively. After remelting treatments, the mass of the coating was lost about 0.02 g, which was partly attributed to the zirconia evaporation. Then heated the sample in air, mass was increased about 0.01 g with the surface turning white once again. These results suggested that about 0.01 g of mass loss was attributed to the reduction in oxygen content during remelting process. This phenomenon could be explained by the EDS tests as following results: after remelting treatments, the content of oxygen atom was reduced from 65.6% to 52.3%. Then heated in air, the content of oxygen atom was returned to 63.9%. According to the results above, it was concluded that the color change of the surface was indeed related to the levels of oxygen content. However, the effect of oxygen content on zirconia performances is not yet comprehensively investigated.

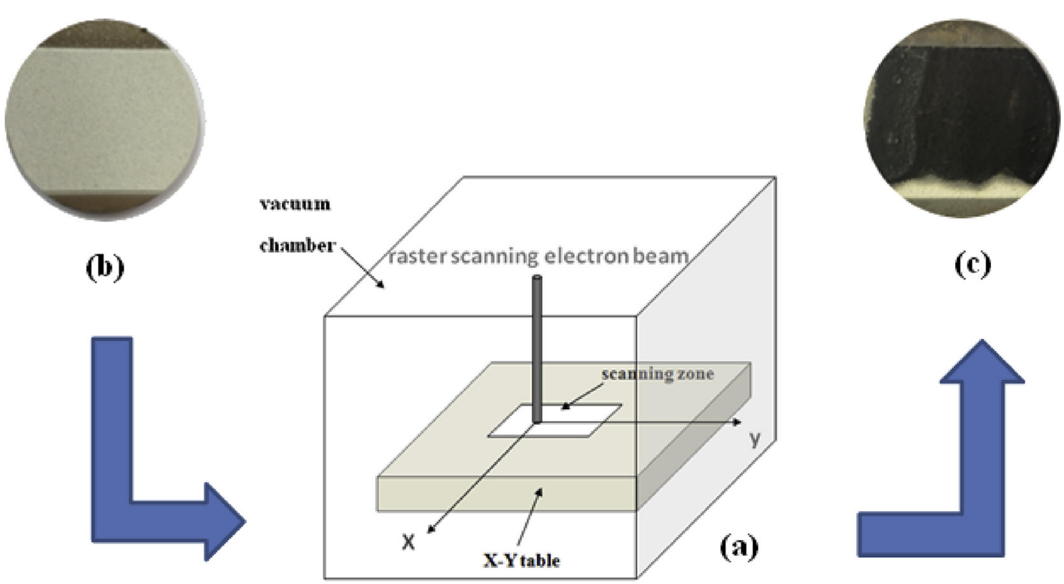

Fig. 1. Electron beam remelting treatments (EBRTs) for zirconia coatings. (a) Schematic illustration of scanning EBRTs, (b) One morphology of the zirconia coating before remelting treatments, (c) One morphology of the zirconia coating after remelting treatments.