Microstructural Characterization of Thermal Barrier Coatings Glazed by a High Power Laser

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Abstract

Thermal barrier coatings have been widely used in in both energy and propulsion systems. Lasers have been used for modification of materials surface. In this paper, plasma-sprayed thermal barrier coatings were laser-glazed by a high power laser in order to modify the structures. The microstructure of laser-glazed TBCs is investigated. The result indicates that a smooth and dense glazed surface with craters and a network of microcracks is obtained after laser-glazing. The laser-glazed region consists of a columnar microstructure. There are segmentation microcracks in the laser-glazed coatings, which don't run through the coatings along thickness. Surface roughness has been reduced significantly for the laser treated ceramic coatings.

Keywords: Surface laser-glazing; Thermal barrier coatings; Plasma Spray; Microstructure

Introduction

The requirements for thermal barrier coatings (TBCs) in gas turbines are stringent due to extreme high temperatures and constant thermal cycling, which demands a material with excellent thermal shock resistance and thermal insulation properties. Plasma-sprayed TBCs have relatively high interconnected porosity and lamina structure with splat boundaries and microcracks parallel to the interface, which are beneficial for low thermal conductivity. However, those microstructural features bring out a low bond strength of plasma-sprayed TBCs, lead to a short thermal cycling life [1-2]. Lasers have been used for modification of materials surface since lasers can deliver very high energy density to a localized surface area without significantly heating up the whole body [3-4]. In this paper, plasma-sprayed thermal barrier coatings were investigated by laser-glazing with a high power laser in order to modify the structures. A study with focus on the microstructure of the laser-glazed TBCs is reported.

Experimental Procedure

Materials. 8wt. % Yttria partially stabilized zirconia (YPSZ) powders (HHYPSZ, CAAMS, Beijing, China) with particle sizes from 38.5 to 63 μm, were selected for the ceramic coatings. YPSZ coatings with thickness of about 0.3 mm were deposited on mild steel substrates by a plasma spray system (DH80, CAAMS, Beijing, China). The spraying parameters are listed in Table 1.

Table 1: The spraying parameters for the TBCs

	Current [A]	Voltage [V]	Primary gas Ar [l·min^{-1}]	Primary gas N_2 [l·min^{-1}]	Secondary gas H_2 [l·min^{-1}]	Powder feeding rate [g·min^{-1}]	Stand off distance [mm]
NiCrAlY	480	65	37	-	5	50	100
YPSZ	480	75	-	37	3-5	15	60

Laser processing. The Laser-glazing process was carried out on the plasma-sprayed TBC surface by using an industrial high power (maximum output power of 15 kW) CO_2 continuous wave laser (TLF15000, Trumph Lasercell, Germany) at a power of 3,500 W, as shown in figure 1. The laser system characteristics and processing parameters are listed in table 2.

Fig. 1 The industrial CO_2 continuous wave laser

Wave type:	Continuous
Wave length (μm)	10.6
Raw beam size (mm):	25
Focal length (mm):	357
Focal point diameter (mm):	0.7
Defocus distance (mm):	120
Glazing beam diameter (mm):	8.4
Power (W):	3,500
Scanning speed (mm/min):	10000

Table 2 Laser characteristics and processing parameters

Microstructural Characterization. Surface morphologies and coating microstructure were observed by using a field emission scanning electron microscope (FESEM, Model FEI Sirion 200, USA). Fractured and polished cross sections of the laser-glazed ceramic coatings, which were perpendicular to the laser beam travel, were prepared to determine morphological and microstructural modifications along the coating thickness. The arithmetic mean roughnesses (Rα) of the ceramic coating surfaces with and without laser-glazing were determined by a mechanical profilometer (TR100, Time Inc., Beijing, China). The measurement is performed along two orthogonal directions on the coating surfaces. 10 measurements were taken for each sample, and the average value of all measurements was used as the arithmetic mean roughness (Rα) of the ceramic coating surfaces.

Results and Discussion

Microstructural Analyses. Figure 2 depicts the surface morphology of the as-sprayed ceramic coating and the contrast of surface morphology in a region containing both laser treated and untreated areas. Thermal-sprayed coatings typically have a rough surface because they are formed by successive impingements and inter-bonding materials among splats, solidified individual molten particles. The surfaces of laser-glazed ceramic coatings have been changed, which become much smoother, as shown in Fig 2b.

a) b)

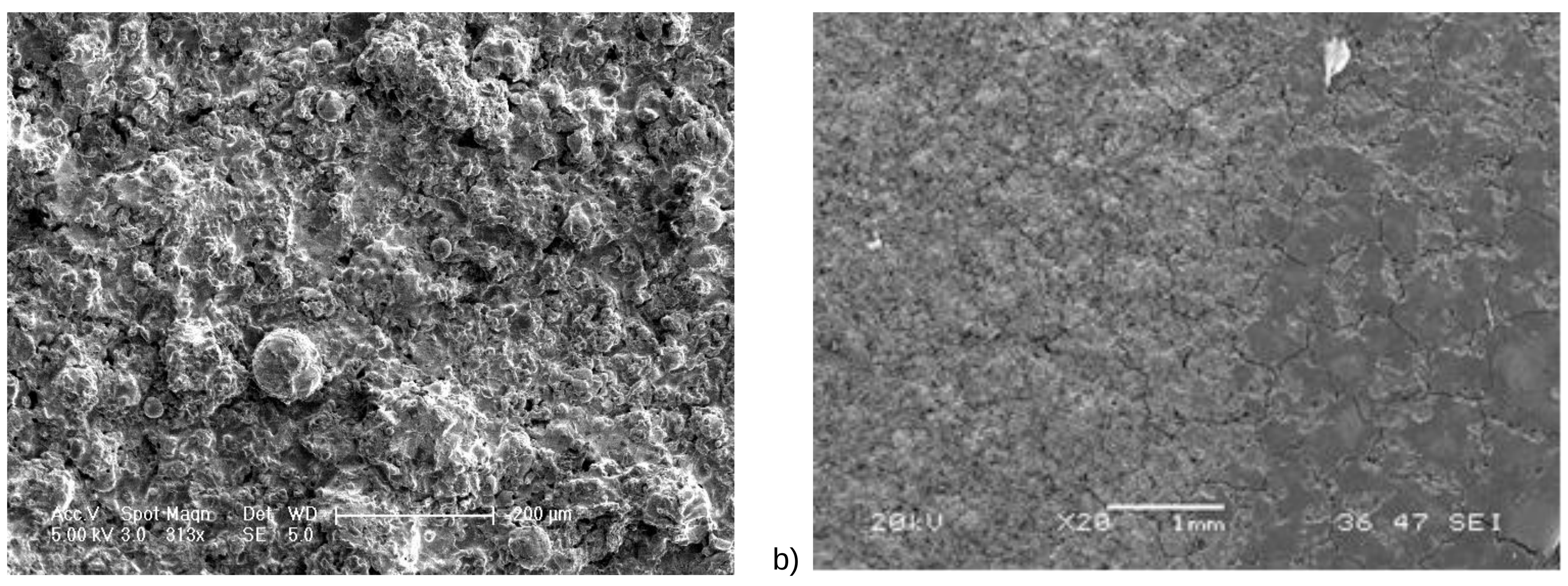

Fig. 2 SEM images of a) the top surface of the as-sprayed ceramic coating and b) the contrast of surface morphology in a region containing both laser treated (right) and untreated (left) areas.

Results and Discussion - Continued

SEM observation in figure 3a shows that a network of microcracks, perpendicular to the densified surface, has been formed throughout the glazed surface of the ceramic coating. The microcracks are generated due mainly to thermal shock, shrinkage and thermal stresses induced by the fast cooling rate during the laser treatment. Fig. 3b presents the polished cross-section of laser-glazed TBCs. Segmentation microcracks along the densified layers have been observed in the ceramic coatings. None of the segmentation microcracks goes through the coatings along thickness, just end in the ceramic coatings.

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a) b)

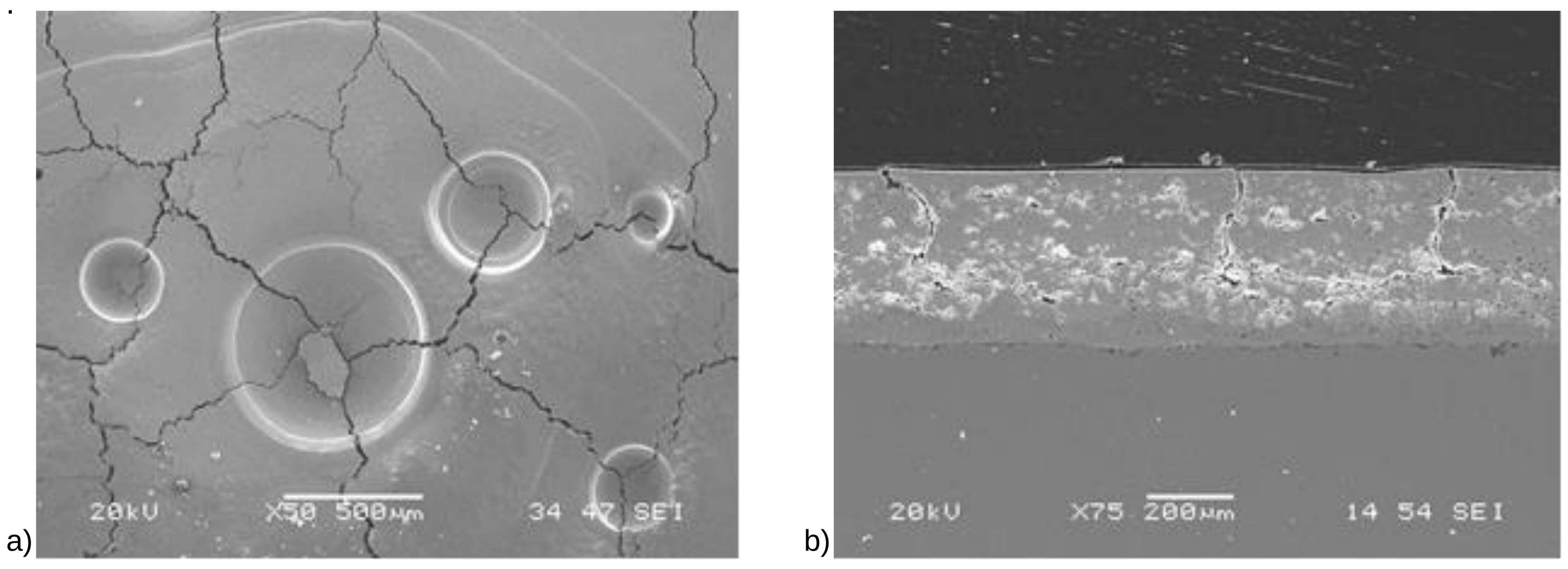

Fig. 3 a)The surface morphology and b) polished cross section of the laser-glazed TBCs

The microstructure of laser-glazed top surface is shown in Fig. 4a. It presents a fine polygonal cell structure with grain sizes varied from 2-8 microns. Fig. 4b shows the fractured cross section of coating. It reveals that the microstructure in the laser remelted regions is composed of columnar grains, which differe significantly from the lamina structure of plasma-sprayed coatings.

a) b)

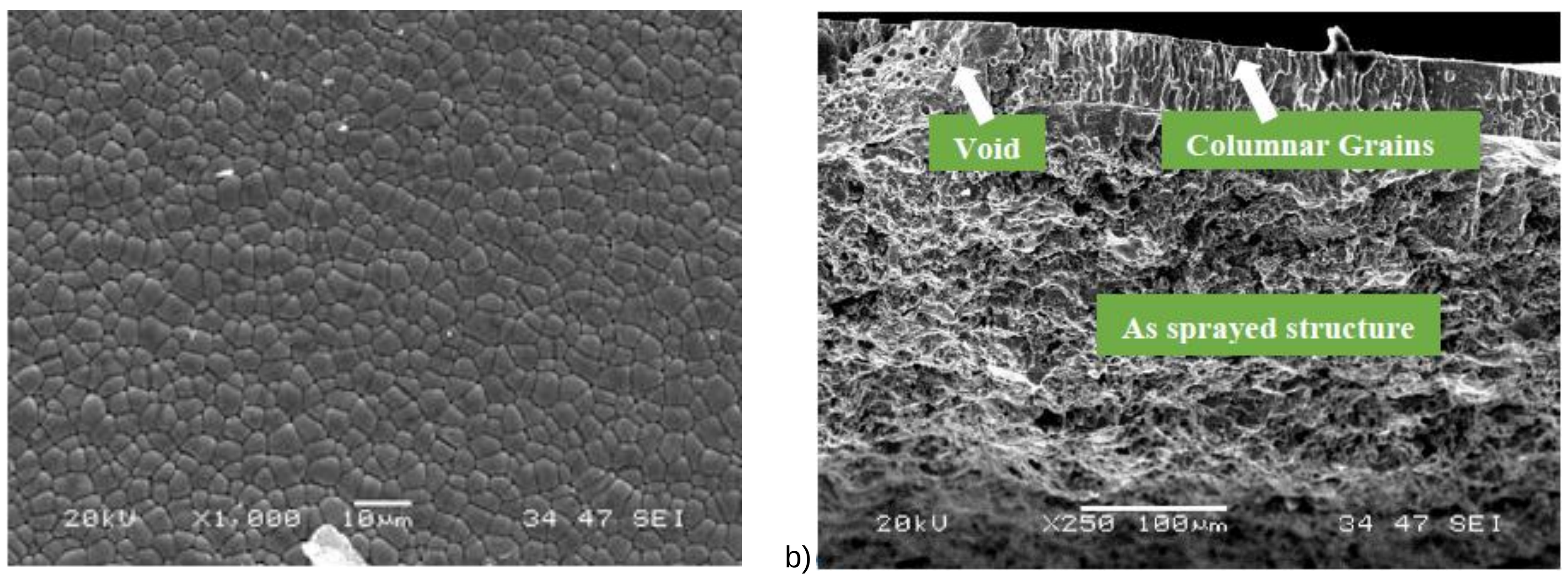

Fig. 4 SEM images of a) the top surface and b) the fractured cross-section of the laser-glazed coatings

Surface Roughness. Surface roughness (*Rα*) has been measured for the top ceramic coatings with and without laser-glazing. The surface roughness for as-sprayed coating is 9.3±0.8 μm, while that for the laser-glazed coating is reduced to 5.1±0.4 μm, as illustrated in Fig. 5. The result indicates an obvious reduction on surface roughness values after laser processing in spite of the forming of craters and microcrack networks on the surface, and thus generates a smoother surface.

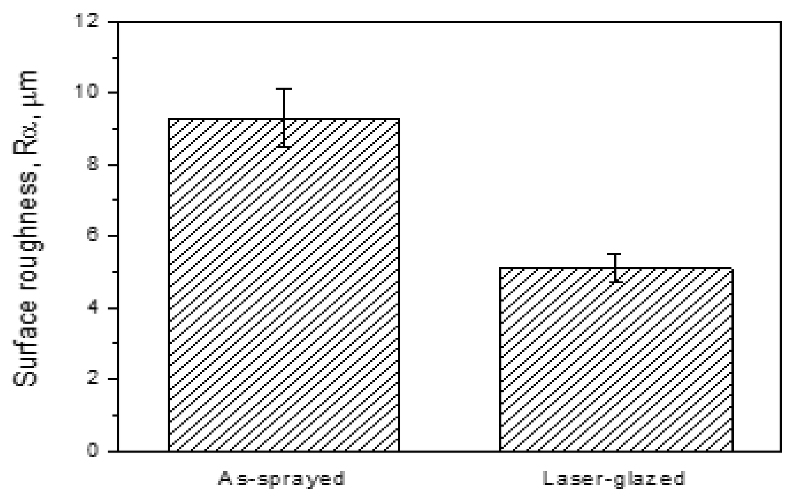

Fig. 5 Comparison of the surface roughness values (R_a) between the as-sprayed and the laser-glazed ceramic coatings

Conclusion

Plasma-sprayed TBCs deposited with high interconnected porosity and lamina structure will bring out a low bond strength, and lead to a short thermal cycling life. Laser treatment can modify materials properties because it provides a rapid remelting and subsequent solidification of the surface. Laser-glazing by a high power laser carried out on TBCs has resulted in a smooth and dense glazed surface with craters and a network of microcracks. The laser-glazed region consists of a columnar microstructure. The segmentation microcracks in the laser-glazed coatings have been observed, which don't run through the coatings along thickness. A significant change on surface roughness has been examined, and an obvious reduction on surface roughness is achieved after laser processing.

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