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Improving the hot corrosion resistance of plasma sprayed ceria–yttria stabilized zirconia thermal barrier coatings by laser surface treatment

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ABSTRACT

Ceria–yttria stabilized zirconia (CYSZ) thermal barrier coatings (TBCs) were deposited by air plasma spraying on NiCoCrAlY-coated Inconel 738LC substrates. After that, the surface of plasma sprayed CYSZ TBCs were glazed using a pulsed Nd:YAG laser. The effects of laser glazing on hot corrosion resistance of the coatings were evaluated in presence of 45 wt%Na_2SO_4 + 55 wt%V_2O_5 corrosive molten salt at 1000 °C. The results revealed that the hot corrosion resistance of plasma sprayed CYSZ TBCs were enhanced more than twofold by laser surface glazing due to reducing specific reactive area of the dense glazed surface layer and consequently, decreasing the reaction between molten salt and zirconia stabilizers.

1. Introduction

Thermal barrier coatings (TBCs) are widely applied to hot sections of the gas turbine engines in order to increase the operating temperature and enhance the engine efficiency subsequently [1,2]. TBC systems are composed of a zirconia based ceramic top coat, over a metallic bond coat [3–5]. The top coat acts as a thermal insulation layer [6,7], while the bond coat provides corrosion and oxidation protection for the substrate [7,8] and improves the adhesion of the ceramic top coat to the metallic substrate [9]. The ceramic top coat may be electron beam physical vapor deposited with a columnar structure or air plasma sprayed with a splat structure [10]. The ceramic top coat of TBCs is most commonly and typically made of yttria stabilized zirconia (YSZ) [11,12]. However, YSZ is prone to hot corrosion caused by molten salts, such as Na, S and V, which are contained in low-quality fuels at high working temperatures [13,14]. Thermal barrier coatings have been developed for military land or sea engines, which are usually operated with low quality fuel and corrosive environments [15,16]. Various approaches have been taken toward developing TBCs that tolerate hot corrosion: (i) use a different material than zirconia, (ii) substitute Y_2O_3 with more acidic stabilizer elements for zirconia such as CeO_2, In_2O_3 and Sc_2O_3, and (iii) provide laser glazing or seal coats to prevent salt penetration into the TBC [17].

Previous results [18,19] demonstrated that when applied in a more demanding environment, such as higher temperatures, the CYSZ coating appeared to be promising, as corrosion and stress were scrutinized. It has been indicated that the CYSZ coating was superior to the YSZ coating due to its phase stability at high temperature [20], improved thermal insulation [21], higher CTE [19], good corrosion resistance and thermal shock resistance [18].

Laser treatment is currently recognized as a promising technique for the improvement of plasma sprayed TBCs performance and extension of their lifetime [21–23]. However, despite the high potential of laser technology, a few studies have examined the use of laser modification technique in the improvement of plasma sprayed TBCs properties. On the other hand, in this field, up to now, most researches have been conducted on the laser glazing of YSZ coatings.

The use of CYSZ coatings and their laser surface modification is a promising approach for increasing the hot corrosion resistance of thermal barrier coatings that have received less attention. In addition, the performance evaluation of CYSZ coatings after laser glazing has not been investigated. Therefore, in this paper, a study with a particular focus on hot corrosion response of laser glazed CYSZ coatings, in the presence of Na_2SO_4 + V_2O_5 molten salt, is reported and the resistance of plasma sprayed and laser glazed coatings is compared.

2. Experimental procedures

2.1. TBCs preparation

The substrates were cut into coupons with a dimension 16 mm × 16 mm × 10 mm from a cast bar of Inconel 738LC superalloy. These coupons were grit blasted with alumina powder in

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order to increase adherence between the bond coat and the substrate and then degreased and cleaned with acetone and preheated with plasma gun prior to spraying. The NiCoCrAlY (22 SN 6883, S.N.M.I.-Avignon, 38–75 μm) and the ZrO_2–25 wt%CeO_2–2.5 wt%Y_2O_3 (205NS, Sulzer-Metco, 16–90 μm) powders were deposited onto the surface of the substrates by air plasma spraying. Plasma spraying was carried out with a Plasma Technik AG; F4-MB gun (Sulzer-Metco, Switzerland) in air. The parameters for air plasma spraying of the powders have been reported in authors' previous study [24]. The average bonding strength of CYSZ/NiCoCrAlY plasma sprayed coatings (measured according to the ASTM: C-633-01) obtained in this study was about 31 MPa.

2.2. Laser surface treatment

The coated samples were laser treated by a pulsed Nd:YAG laser, with mean power of 400 W and standard square shaped pulses. Optimum parameters for laser surface modification of plasma sprayed CYSZ thermal barrier coatings by pulsed Nd:YAG laser were obtained in our previous research [25]. The samples were placed on the *x*–*y* table and the laser beam was scanned over the specimen surfaces, generating multiple parallel tracks of controlled overlapping to treat the whole surface area of the coatings.

2.3. The hot corrosion experiment

For simulating an accelerated laboratory hot corrosion, a mixture of vanadium pentoxide (V_2O_5, Merck, Germany) and sodium sulfate (Na_2SO_4, Merck, Germany) corrosive powders with the ratio of 55:45 in wt% as a corrosive salt were spread over the surface of coatings in a 25 mg/cm^2 concentration leaving approximately 3 mm from the edge uncovered. The specimens were set in an electric furnace with air atmosphere at 1000 °C for 30 h and then, were left outside to let it cool down in the air. The specimens were inspected periodically every 6 h.

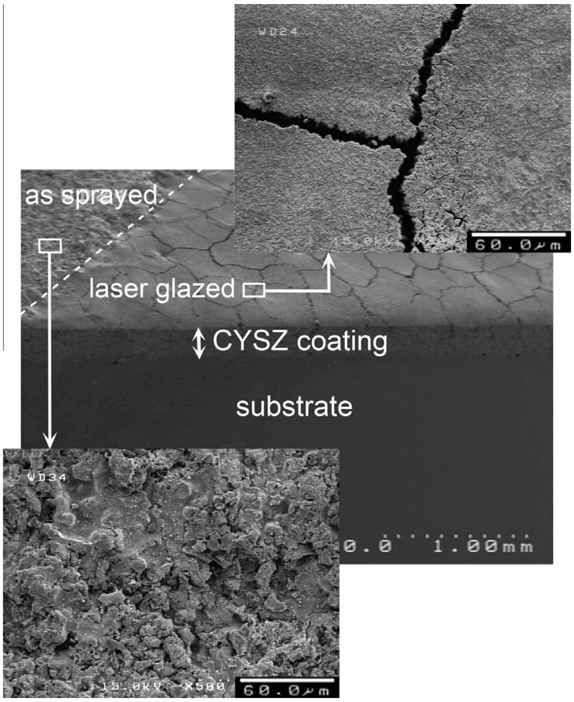

Fig. 1. FESEM micrographs of the top surface of as sprayed and the laser glazed CYSZ coating.

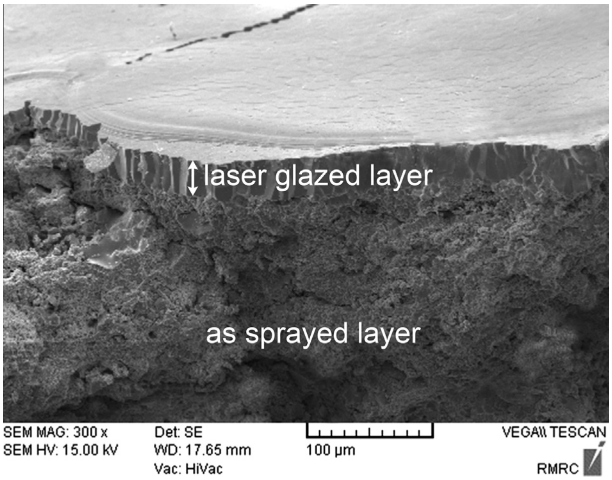

Fig. 2. SEM micrograph of fractured cross section of laser glazed CYSZ coating.

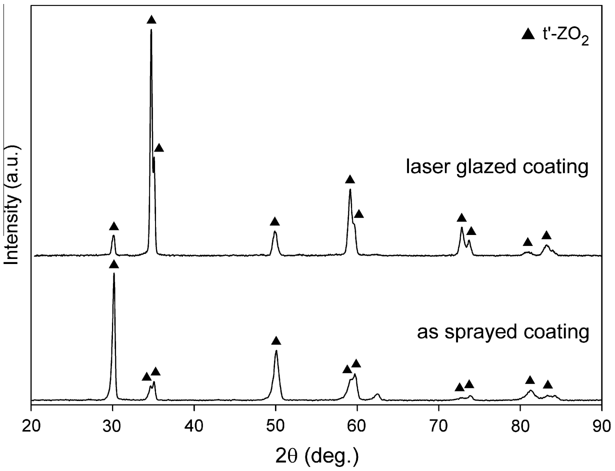

Fig. 3. XRD patterns of as sprayed and laser glazed CYSZ coatings.

2.4. Characterization

The microstructure of as sprayed and laser glazed coatings was observed using a field emission scanning electron microscope (FESEM; S-4160, Hitachi Ltd., Japan) and a scanning electron microscope (VEGA\\TESCAN, Czech). In order to cater for microstructural and elemental analysis of samples after hot corrosion test, a scanning electron microscope (Seron Technology-AIS-2000, Korea) supplied with energy dispersive spectroscopy (EDS; Sung Woo-550i, Korea) was used. The phases were analyzed using X-ray diffractometer (Bruker-D8 ADVANCE, Germany; 40 kV, 40 mA, Cu Kα radiation). The surface roughness (R_a) of as sprayed and laser glazed coatings was measured by a roughness tester (Mitutoyo SJ-201P, Japan). The roughness reported was the average of five values scanned from different areas on coating surface.

3. Results and discussion

3.1. Characterization of as sprayed and laser glazed coatings

Fig. 1 shows the surface of as sprayed and the laser glazed CYSZ coatings. Based on this figure, the top surface of as sprayed coating is very rough because it includes of splats (molten particles deformed on impact into a pancake shape) that deposited on