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Influence of preheating processes on the microstructure of laser glazed YSZ coatings

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ABSTRACT

Laser glazing is considered to be a promising surface sealing technique for thermal barrier coating. The dense top layer with reduced surface roughness and the segment cracks perpendicular to the surface are considered to be suitable for improving the thermal cycling and hot corrosion resistance of these kind of coatings. In present study, yttria stabilized zirconia ceramic coatings were manufactured by atmospheric plasma spraying and then subjected to a Nd-YAG pulsed laser source. During the laser glazing process, coatings were preheated to 600 °C and 800 °C in order to obtain different microstructure of the laser glazed coatings. The surface morphologies and cross-sections of the coatings were examined by scanning electron microscopy and microhardness measurements of coatings were carried out. The results indicate that preheating process induces a reduction of the grain size of laser glazed coatings in conjunction with an increasing of microhardness and toughness. In addition, preheating also decreases the substrate-coating interface tensile stress which leads to a reduction of crack surface density.

1. Introduction

Yttria stabilized zirconia ceramic coatings are typically used as thermal barrier coatings (TBCs) that have significantly improved the efficiency of gas turbines by protecting them from hot corrosion and oxidation [1–4]. A TBC generally consists of two layers: top ceramic (mostly yttria stabilized zirconia) layer, and a superalloy bond coating (typically MCrAlY). Top YSZ coatings provide thermal insulation because of their low thermal conductivity (1.5–2.05 $Wm^{-1} K^{-1}$) [5,6] at high service temperature. The bond coating is usually applied to the substrate by vacuum plasma spraying (VPS) or high velocity oxy-fuel flame (HVOF) as an oxidation resistant layer. At the evaluated service temperature, TBCs' failure is related to a series of factors such as creep, oxidation, sintering and thermal mismatch stresses [7–11]. Investigations have demonstrated that defects, such as pores and cracks induced by thermal spraying could provide passage for oxygen under high temperature service environment. These conditions lead to formation and thickening of the thermally gown oxide and the spallation of the ceramic layer [12–16].

Laser glazing is recognized as a promising surface sealing treatment for YSZ coatings. For the reason that it can provide a dense glazed layer with a refined microstructure along with reduced roughness and a pore-free surface [17–19]. Meanwhile, it induces cracks networks perpendicular to surface [20], which are regarded to be beneficial for accommodating the strain during the thermal cycling [21]. Raheleh [22] has found out that thermal shock resistance of plasma sprayed YSZ coatings are improved almost fourfold by laser glazing post treatment due to the formation of segment cracks perpendicular to surface. Studies [23–26] confirmed that the cyclic life time of plasma sprayed TBCs can be prolongated by laser glazing.

In addition, laser glazing is also an approach to improve hot corrosion resistance of TBCs. With respect to gas turbines, corrosive species, such as sodium and vanadium found in low-quality fuels, diffuse into coating and react with metallic components resulting in the failure of TBCs [27–29]. Laser glazing is considered as a useful technique for reducing the penetration of molten salts in coated surfaces as a consequence of decrease of roughness and porosity [30]. More specifically, Tsai [31] proposed that laser glazing improved the hot corrosion resistance of thermal barrier coatings since the dense laser glazed layer reduced the penetration of molten V_2O_5. Studies

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Table 1
Chemical composition of substrate.

Elements	C	Si	Mn	Cr	Ni	Fe
wt%	0.05	1.60	1.35	19.30	11.40	bal.

conducted by Batista [32] also reported that hot corrosion resistance of laser glazed coating is improved because the specific active area between molten salts and glazed layer is reduced as a consequence of the decrease of surface roughness.

In most of these works, the authors confirmed the possibility to improve the performance of YSZ coating by laser glazing and roughly investigate the laser glazing parameters on the microstructure of resultant coatings. It has been demonstrated that properties of the glazed coating are determined by the microstructure characters, especially the cracking patterns [33,34]. Actually, the final cracking pattern strongly depends on the accumulated residual stress level which is very sensitive to the cooling rate of the coating. Except for the laser glazing parameters, preheat is also a possible approach to control the cooling rate of the coating and thus adjust the cracking pattern and thereby properties. Therefore, in the present work, the coating was preheated to 600 °C and 800 °C respectively and comparably investigated with un-preheated coating to explore one more approach to tailor the microstructure.

2. Experimental

2.1. Coating preparation and laser glazing process

Commercial available zirconia established by 8 wt% yttria powder was deposited on 309 heat resisting stainless steel substrates with a Sulzer-Metco made F4 plasma gun by atmospheric plasma spraying. Chemical composition of the substrate is shown in Table 1. A Nd-YAG pulsed laser (Cheval, Pirey, France) with a maximum average power of 1100 W and a frequency of 10 Hz was employed to glaze the as-sprayed YSZ coatings. Prior to laser glazing, the as-sprayed coatings were preheated to 600 °C and 800 °C (Fig. 1) by an oxygen-acetylene flame. The diameter of the laser spot is 3 mm at an offset distance of 340 mm. Laser glazing was conducted under an average laser power of 287 W

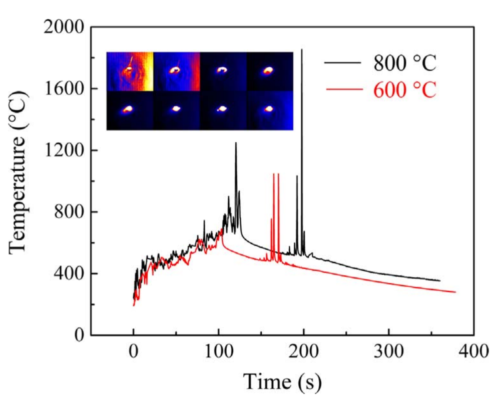

Fig. 1. Temperature evolution of YSZ coating during preheating process.

and a pulse duration of 5 ms with a scanning speed of 10 mm/s. Table 2 depicts the conditions of the laser treatment.

2.2. Characterizations

Cross-sections and surface morphologies of coatings were observed by scanning electron microscopy (SEM). Vickers microhardness was measured with a Leitz microhardness tester on the surface with a load of 300 g for a dwelling time of 15 s. Average microhardness values resulted for performing fifteen measurements for each sample. Fracture toughness was measured according to the following equation:

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

where E is Yong's modulus, H represents the Vickers hardness, P is the applied load and a denotes the radial crack length measured from the center of the indent. A calorimeter (Labmaster 4DOPTICAL USA) was used to measure the average power of the laser beam based on the following relationship:

$$P_a = P_p \tau \cdot F \tag{2}$$

where P_a is its average power (W), P_p is the peak power (W), F denotes the frequency and τ represents the pulse duration of firing (ms).

An infrared thermal imaging camera (SC 5210, FLIR) was employed to estimate the coating temperatures during pre-heating process. The size distribution of the grain was determined by image analysis (NIH Image J, Software, USA). Surface crack density measurements were also carried out employing the software *Image J* on magnified (X60) SEM images of the laser glazed layer surface. Images were firstly converted into a black and white mode to distinguish the cracks from the other parts of the coatings by setting a threshold value. Thus, the black pixels correspond to the cracks on the surface of the coatings while the white pixels are related to the dense part. Afterwards, the images were changed to binary and skeletonized so that the width of cracks was negligible (Fig. 2). Thus the total length of the cracks accorded with the numbers of black pixels. Subsequently, the ratio between the black pixels and total pixels was identified as the value of surface density of cracks.

3. Results and discussions

3.1. Microstructure of laser glazed coatings

Fig. 3 illustrates the cross-sectional and surface morphology of as-sprayed coating. The coating presents a porous microstructure with a porosity value of 9.17 ± 1.44% and a thickness of almost 570 µm. Cross-sections of laser glazed coatings are shown in Fig. 4. A dense top layer is induced on the top of coating by laser glazing process. Cracks

Table 2
Conditions of laser glazing YSZ coatings.

Parameters	Value
Duration of laser firing (ms)	5
Average power (W)	287
Scanning speed (mm/s)	10
Off-set distance (mm)	340
Diameter of laser spot (mm)	3