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ARAŞTIRMA MAKALESİ /**RESEARCH ARTICLE**

THE EFFECT OF LASER GLAZING PROCESS ON MICROSTRUCTURE OF PLASMA SPRAYED THERMAL BARRIER COATINGS

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ABSTRACT

Thermal barrier coatings (TBCs) are widely used by aero and land based gas turbines to protect hot section parts from oxidation and reducing component temperature thereby increase life. TBCs are generally a combination of multiple layers of coating (usually two) with each layer having a specific function [Aktaa et al., 2005]. In this study air plasma sprayed TBCs were deposited on 304 stainless steel substrates then ceramic surfaces were glazed using Nd-YAG laser. Both glazed and as-coated samples were subjected to metallographic examination to investigate microstructural changes in glazed ceramic layer. Laser glazing provides a remelting and subsequent solidification of the surface, resulting on new top layer microstructure.

Keywords: Thermal barrier coatings, Laser glazing, Plasma spray.

LAZER SIRLAMA PROSESİNİN PLAZMA SPREY TERMAL BARİYER KAPLAMALARIN MİKROYAPISI ÜZERİNDEKİ ETKİSİ

ÖZ

Termal bariyer kaplamalar (TBK), havacılık ve enerji üretiminde kullanılan gaz türbinlerinin sıcak kısım parçalarını oksidasyondan korumak, bu parçaların çalışma sıcaklığını düşürmek ve böylelikle ömürlerini uzatmak amacıyla yaygın bir şekilde kullanılmaktadır. TBK'lar genellikle, her biri özel bir fonksiyonu üstlenmiş birden fazla kaplama katmanının (genellikle iki) kombinasyonu şeklinde üretilirler [Aktaa ve ark., 2005]. Bu çalışmada, hava plazma sprey tekniğiyle TBK 304 paslanmaz çelik malzeme üzerine kaplanmış ve daha sonra kaplama seramik yüzeyi Nd-YAG lazer kullanılarak sırlanmıştır. Sırlama işlemi uygulanmış ve uygulanmamış numuneler, sırlanmış seramik yüzeydeki mikroyapısal değişikliklerin değerlendirilmesi için metalografik olarak incelenmiştir. Lazer sırlama, yüzeyin tekrar ergimesi ve katılaşmasına yol açarak yeni bir üst katman mikroyapısı oluşmasına yol açmıştır.

Anahtar Kelimeler: Termal bariyer kaplamalar, Lazer sırlama, Plazma sprey.

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1. INTRODUCTION

Thermal barrier coatings (TBCs) are widely used by aero and land based gas turbines to protect hot section parts from oxidation and thermal loads and allow hot gas temperature to increase and therefore the efficiency of the engine [Aktaa et al., 2005; Biu et al., 2000; Portinha et al., 2005]. These coatings generally consist of multiple layers of coating (usually two) with each layer having a specific function. The ceramic top layer provides thermal insulation made by zirconium oxide (ZrO_2) known as zirconia, usually partially stabilized (YSZ) with about 6 to 8 wt.% yttrium oxide (Y_2O_3) [Batitsta et al., 2006; Vaßen et al., 2001]. The metallic bond coat has higher oxidation and hot corrosion resistance than substrate and placed between substrate and ceramic top layer. Bond coat usually MCrAlY (where M stands for Nickel, Cobalt or a combination of these) has also a function that reduces the thermal stress caused by thermal expansion mismatch between metallic substrate and ceramic top coat [Wolfe et al., 2005; Diltemiz, 2010; Rabiei 2000]. TBCs are generally deposited with air plasma spray (APS) or electron beam physical vapor deposition (EB-PVD) techniques.

Typical plasma sprayed zirconia layer microstructure contains; interlayer splat boundaries, horizontal and transverse cracks, unmelted particles and porosities. These features are formed during the depositing particles are flattened by the force of impact and solidify to form splats. The deposited particles exhibit very high residual stress arising from the differential thermal contraction of zirconia relative to the underlying metallic substrate and extremely high cooling rate ~ 10^6 K/s [Bose, 2007].

During the ceramic coating deposition, a thermally grown oxide (TGO), predominantly Al_2O_3, forms on the bond coat surface at the ceramic-bond coat interface. In effect, the TGO binds the ceramic layer to the bond coat. As the TBCs continue exposure in oxidizing thermal environment during use, the TGO thickness increases and cause top coat failure by spalling. The growth generally occurs at the TGO-bond coat interface. [Aktaa et al., 2005]. Two mechanisms have been proposed for transferring oxygen through plasma sprayed zirconia coatings: ionic diffusion from the crystalline structure of ZrO_2 and gas penetration through porosities and micro cracks, which the latter plays a major role [Saremi et al., 2008].

Therefore, the life of the TBCs are generally limited by oxidation of the bond coat and thermal mismatch stress [Tsai et al., 2007; Thomas et al., 1997]. Transverse and longitudinal cracks form at the surface and near the top coat / bond coat interface in the ceramic layer due to thermal stresses which eventually will leads to top coat failure by partial or complete spalling. Their local failure results in hot spots with severe impacts on the structural integrity of the engine and has to be prevented during operation [Diltemiz, 2010].

Several attempts have been made to improve TBCs life and one of them is laser glazing. Recent experimental studies show that laser glazing process improve both oxidation and thermal shock resistance of TBCs [Batista et al., 2006; Park et al., 2008; Antou et al., 2006]. Laser glazing provides a remelting and subsequent solidification of the surface, resulting on new top layer microstructure, which needs to be characterized for better understanding of these improvements.

2. METHODS

2.1 Coating Preparation

SAE 304 stainless steel plates with 30 x 25 x 4 mm^3 were used as substrates. These plates were grit blasted with alumina particles to improve coating adhesion and obtain clean surfaces just before the coating application. Both bond and top coating layers were deposited with air plasma spray using Metco 9MB system. Spraying deposition parameters were shown in Table 1. Two types of commercially available powder were selected: Amdry 962 as the bond coat, Metco 204 NS as top coat. Powder properties are given in Table 2.

2.2 Laser Glazing

The laser-glazing process was carried out using Nd-YAG (Huffman HP-8S8) pulsed industrial laser. The coated samples were placed and fixed on the laser table and the laser beam was scanned over the zirconia top coat surface generating parallel overlapped tracks that cover whole surface area. Real focus distance of laser beam was changed to larger value intentionally to obtain proper melting practice. Otherwise, laser beam temperature is approximately 15000 ^oC in exact focus distance and this value is too high for zirconia coated surface. Laser operating parameters are listed in Table 3.

Table 1. Parameters of plasma spraying

Parameter	*NiCrAlY - Bond Coat*	*YSZ – Top coat*
Current (A)	500	400
Spray distance (mm)	125	90
Powder feed rate (g/min)	30	40
Primary gas, Ar (l/min)	40	40
Secondary gas, H_2 (l/min)	7	10

Table 2. Powder characteristics

	Composition (wt.%)	*Powder size (µm)*
Bond coat-Amdry 962	Ni-22Cr-10Al-1Y	-106+52
Top coat-Metco 204 NS	ZrO_2-8Y_2O_3	-106+11

Table 3. Parameters of laser glazing

Working power (W)	240
Wavelength (µm)	1,06
Spot size (mm)	4,1
Beam angle (^{o})	90
Track shift (mm)	2
Scanning speed (mm/min)	120
Pulse frequency (Hz)	10
Coverage ratio (%)	205

2.3 Metallographic Sample Preparation

Metallographic examinations were applied to both glazed and as-coated samples to investigate microstructural changes in glazed ceramic layer. The metallographic samples were cut with precise cutting machine using thin alumina disk then mounted with cold epoxy under vacuum. Vacuum epoxy cold mounting gives best result to fill and protect all open voids and cracks. The rest of the metallographic sample surface preparation steps were performed automatically with grinding and polishing machine and are given in Table 4.

3. RESULTS

The average thickness of the bond coat, top coat, and glazed surface layers were measured on prepared cross sections using optic microscope and image analyzer according to the ASTM B487 standard. Average bond and top coat thicknesses were measured as 118 µm and 141 µm respectively. The glazed surface layer thickness was measured as about 24 µm that takes roughly 17 percent of total ceramic top coat thickness. As-coated and laser-glazed sample micrographs with main microstructural components are given in figure 1.

These micrographs also revealed that, laser-glazing process altered the microstructure dramatically, glazed layer was locally remelted and cracked in the perpendicular direction to the surface which are called “inverse cracks”. Sintered layer provides a local remelting and subsequent solidification of the surface, resulting on a dense top layer with a new microstructure with reduced surface roughness and porosity. This layer also contain less inter layer splat boundaries and horizontal cracks but with formation of surface cracks perpendicular to the coating plane. The initial and glazed layer top coat porosity were measured using micrographs and image analyzer and found to be about 13,1 percent and 4.6 percent respectively.

Zirconia surface SEM examination was also performed to reveal topological changes as a result of glazing process and is given in Figure 2. In this figure, reduced surface roughness and inverse cracks can be seen. Inverse cracks are seen as “network cracks” with varied width values in glazed area from this angle of the view. Broken and partially melted zirconia particles can also be seen in as-coated SEM image.

Table 4. Metallographic sample preparation steps.

	Material	*Load (N)*	*Time (min)*
#220 grit grinding	Silicon carbide	18	2
#320 grit grinding	Silicon carbide	18	1
#500 grit grinding	Silicon carbide	18	1
#800 grit grinding	Silicon carbide	18	1
#1200 grit grinding	Silicon carbide	18	1
Coarse polishing	3 µm diamond	22	6
Fine polishing	1 µm diamond	20	3

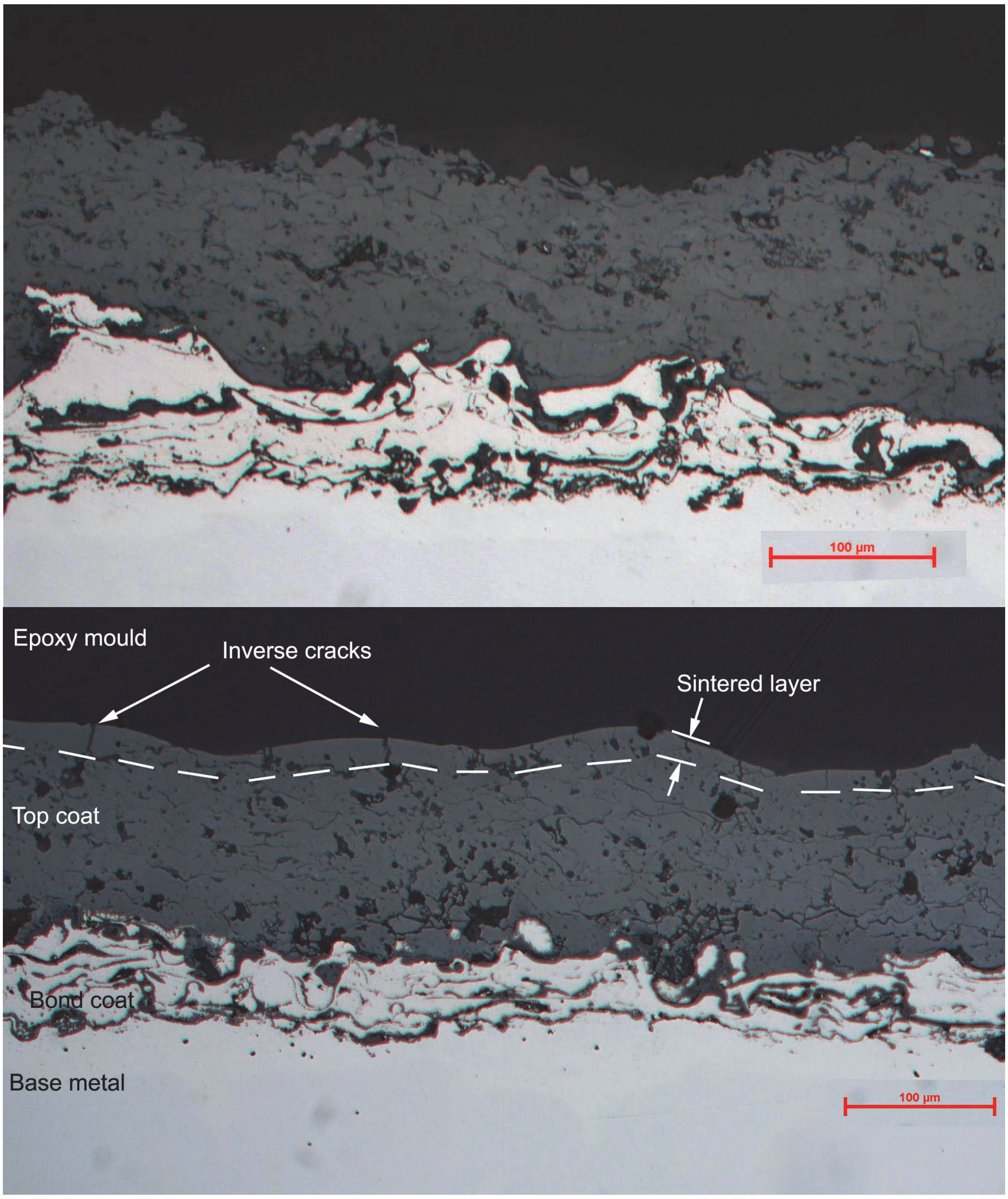

Figure 1. Cross section of as-coated (above) and laser-glazed (below) thermal barrier coatings.

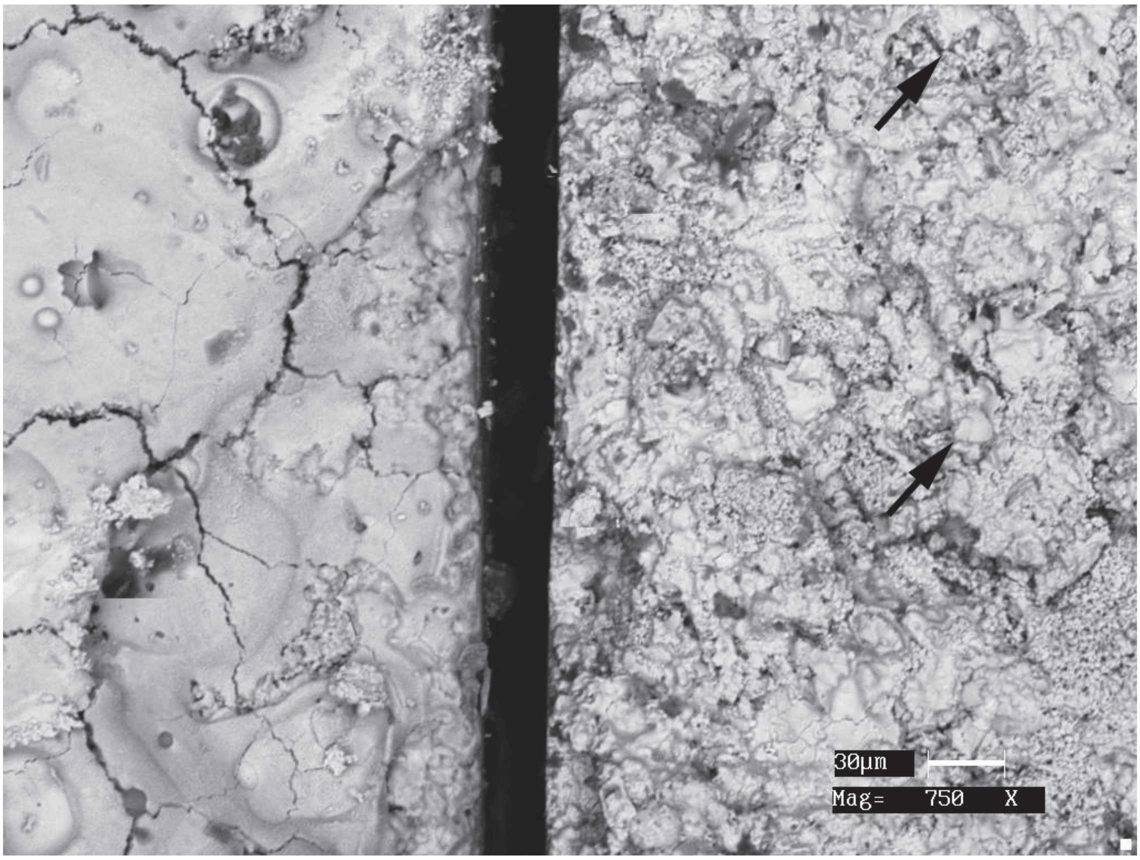

Figure 2. Surface topography of laser glazed (left) and as-coated samples, arrows indicate broken and unmelted powder particle pieces.

4. DISCUSSION

Thermal barrier coatings must stand in severe service conditions and their microstructural components are very critical to meet these conditions. In this study, as-sprayed and laser glazed thermal barrier coating samples are characterized in aspect of microstructural transformations.

Laser glazing process dramatically changed the microstructure, locally melted ceramic surface was sintered and inversely cracked. Inverse cracks were most probably formed due to thermal strain arising from local high heating and cooling rate while surrounding area remained relatively cold during glazing process. Sintered and changed layer thickness was approximately measured as one sixth of zirconia thickness. This value can be adjusted with changing laser parameters, voltage, scanning speed or frequency etc.

It can be expected that higher oxidation resistance will be reached by laser glazed plasma spray coated surfaces. This improvement would be attributed to sintering of zirconia layer, which act as oxygen barrier and formed with glazing process. Although inverse cracks allow oxygen pass easily, glazing layer with reduced porosity and closed inter-splat boundaries can still improve the high temperature oxidation performance.

It can be thought that inverse cracks permit better stresses accommodation therefore would play critical role in increasing thermal shock resistance which is another desired property. Normally, inverse cracks can be found in typical TBC top coat microstructure, but their sizes are proportional with splat thickness. These new inverse cracks formed along the sintered layer and therefore their sizes can be adjusted by changing the sintered layer thickness.

Reduced surface roughness can be considered another positive contribution to improve aerodynamic properties.

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