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Effect of Laser Treatment on the Surface Roughness of Multilayer Plasma Sprayed Thermal Barrier Coating System

Mais A. Habeeb[a]*, Mohammed J. Kadhim[b], Fadhil A. Hashim [c], Maryam A. bash [d]

[a] Materials Engineering Department, University of Technology, Baghdad, Iraq, maiskareem90@gmail.com

[b] Production Engineering and Metallurgy Department, University of Technology, Baghdad, Iraq

[c] Materials Engineering Department, University of Technology, Baghdad, Iraq, 11142@uotechnology.edu.iq

[d] Production Engineering and metallurgy Department, University of Technology, Baghdad, Iraq, 70016@uotechnologyedu.iq

*Corresponding author.

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K E Y W O R D S

CSZ/YSZ TBCs, Plasma sprayed coating, Laser sealing, Roughness, Taguchi design.

A B S T R A C T

Thermal barrier coatings (TBCs) are used in advanced engines working at higher temperatures. Higher efficiency and performance of gas turbine engines will require careful selection of TBCs. In this study, Ni22Cr10Al1.0Y (Amdry 9625) bond coat and two types of top coat including ceria stabilized zirconia (CSZ) ZrO_2-24CeO_2-2.5Y_2O_3) and yttria stabilized zirconia (YSZ) ZrO_2-8Y_2O_3 were deposited on IN 625 by air plasma spraying (APS). The thickness of the duplex ceramic coat based on zirconia was in the range between 350 to 400 µm. The effect of high power Yb:YAG solid state laser at different laser parameters on feature, microstructure and roughness of plasma sprayed and laser sealed coating of multilayer ceria stabilized zirconia/ yttria stabilized zirconia was investigated. Surface roughness has been reduced significantly after laser sealing. The effect of laser process parameters carried out using Taguchi's L_{16} orthogonal array design. Minimum roughness can be obtained at moderate power density and longer interaction time with sufficient specific energy to produce complete melting of coating. Characterization and analysis of results was achieved by employing scanning electron microscopy (SEM) , (EDS) and image J analysis. It was found from the results, there were significant improvements in the performance of plasma sprayed coatings after laser sealing due to the reduction of surface coating defects.

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1. INTRODUCTION

The hot metallic sections used in the turbine industries, power generation, marine and aerospace applications are often coated with thermal barrier coating to protect them from aggressive environment [1]. Typically, TBCs comprise of three layers: a ceramic top coat, a metallic bond coat and Ni- base super alloy substrate [2, 3]. The intermetallic bond coat typically consist of MCrAlY (M =Ni, Co or NiCo) alloy which improve the adhesion strength between ceramic top coat and the substrate [4]. Zirconia- based ceramic coatings are commonly used as top coat because of low thermal conductivity, high temperature stability and high thermal expansion coefficient which matches with that of the substrate [5, 6]. Between the top coat and metallic coat, there is a thermally grown oxide layer (TGO) formed as a result of the bond coat oxidation [7].

However, the presence of voids and segmented cracks at the top surface of plasma sprayed coating, lead to decrease the life time of the coating [8, 9]. Surface defects act as the path for penetration of oxygen and contaminates from the low grade fuel to attack the TBCs system [10]. Tremendous techniques were used to improve the performance of TBCs [11, 12]. Laser processing of plasma sprayed coating considered the most acceptable tool was used to seal the top surface of ceramic coating [13]. Laser sealing providing a dense layer and modified microstructure, resulting in reduction of surface roughness considerably. It also produce surface free from porosity and form continuous network of crack perpendicular to the surface which improve the strain accommodation [14]. Batista et al. reported that laser glazing led to reduction in the coating roughness while the decrease in voids and micro cracks led to increase thermal conductivity and decrease thermal insulation [15]. Jasim stated that laser sealing of ternary TBCs ZrO_2-Y_2O_3-Al_2O_3 significantly improved the microstructure, microhardness, fracture toughness and phases [16].

In recent studies, many investigation has been conducted on laser sealing of YSZ TBCs using continuous CO_2 or Nd:YAG lasers. Present work concentrate on using high power solid state laser type Yb:YAG for sealing multilayer of TBCs consist of CSZ then YSZ as ceramic coat. And study the effect of laser treatment on the surface roughness of plasma sprayed thermal barrier coating. As well as study the alteration of laser processing parameters on the obtained roughness using design of experiment by Taguchi methods.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

A Ni-base superalloy (Inconel 625) was used as substrate material. The starting powder of thermal barrier coating consisting of ZrO_2- 8% Y_2O_3 (204NS: sulzer metco, USA, -125+11 µm) and ZrO_2-24%CeO_2 -2.5% Y_2O_3 (205NS: sulzer metco, USA, -125+11 µm) as top ceramic coat. The XRD pattern of the top ceramic coat was demonstrated in Figure 1. The bond coat powder was NiCrAlY (AMDRY9625,Sulzer MetcoInc.,USA,-74+45µm) with nominal composition of Ni–22Cr–10Al–1.0Y (wt%). Both bond coat and ceramic coat was plasma sprayed using 3MB gun manufactured by Metco INC, Westbury, L.I.N.Y. A Yb:YAG laser type YFL600 was used in this investigation. There are three factors (parameters) affecting laser sealing presented in Table I: power (p), laser beam diameter (d) and scan speed (v). As there are four levels for each parameter, therefore the orthogonal arrays 34 (L16) was used by taguchi design.

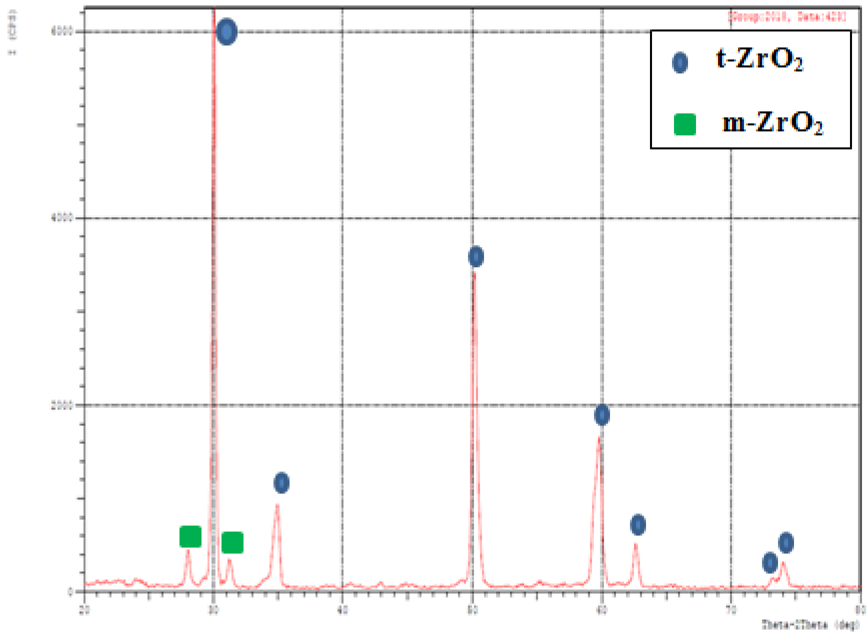


Figure 1: Illustrates the XRD patterns of powder YSZ, this powder contains tetragonal phase (t) with small amounts of monoclinic (m) phase.

TABLE I: The factors and levels of laser sealing process for plasma sprayed coating.

FACTORS	LEVELS			
	1	2	3	4
Power (W)	100	200	350	500
Beam diameter (mm)	1	2.5	3.5	5
Scan speed (mm/s)	3	25	150	200

The as-sprayed coatings and laser sealed coatings were evaluated using scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectroscopy (EDS). Roughness measurement was assessed using portable surface roughness tester, TR-200. The roughness measurements were quantified in terms of average for five readings of both plasma sprayed and laser sealed coatings.

3. RESULTS AND DISCUSSION

The surface morphology of plasma sprayed thermal barrier coating is sign (a and b) of in Figure 2 at low and high magnification. Relatively, different features such as voids, microcracks and protrusions, which is typical phenomenon for air plasma sprayed TBCs. These features formed in the ceramic top coatings due to thermal stresses induced during rapid cooling rate generated after coating process. The EDS analysis reveals the elemental composition of the top ceramic coat in Figure 3 which composed of zirconium, yttrium and oxygen. The surface roughness of plasma sprayed coating was ≈ 7.5 µm due to the heterogeneous microstructure.

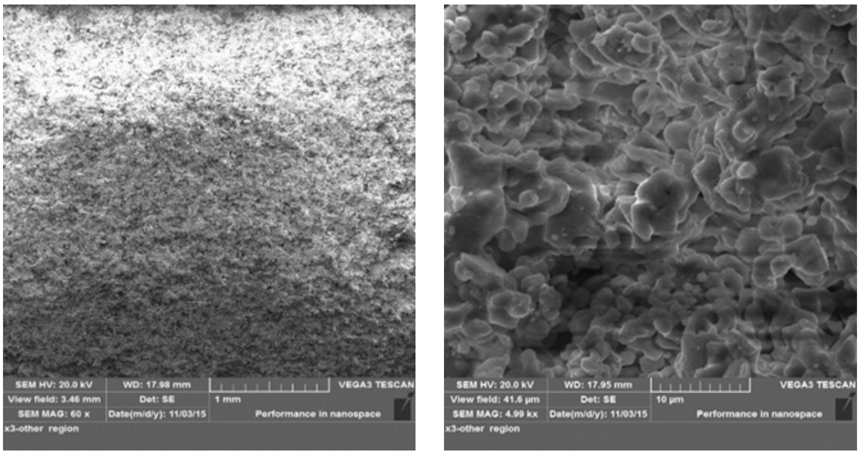


Figure 2: Plan view SEM micrograph of plasma sprayed CSZ /YSZ, 400μm at low and high magnification

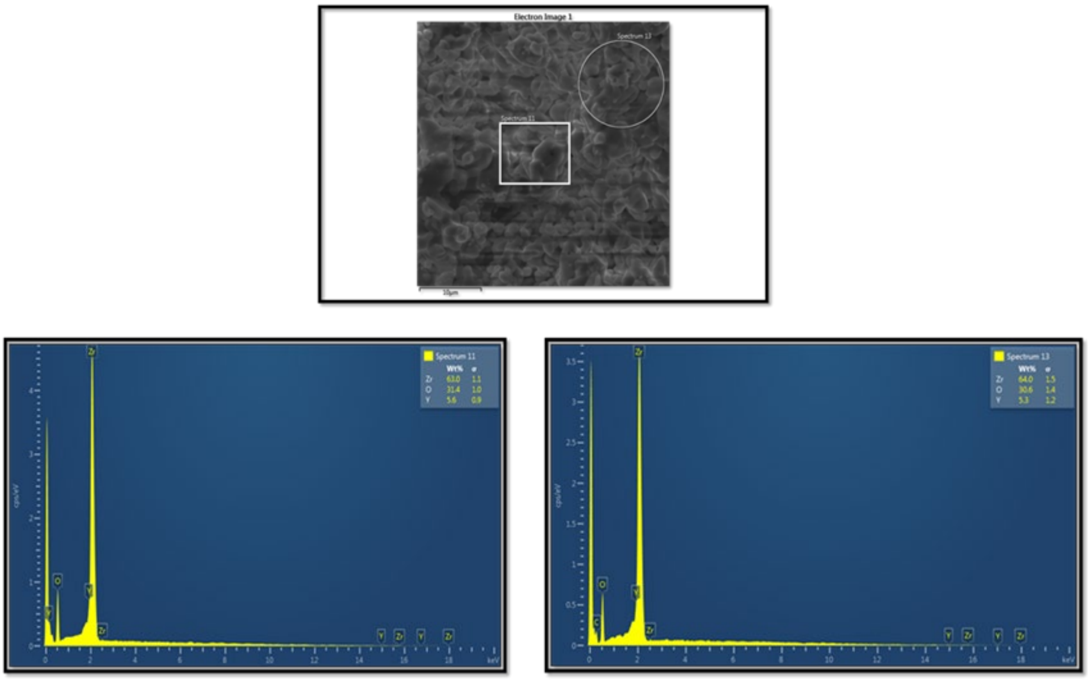


Figure 3: EDS analysis showing the elements inside the coating from the upper surface

The SEM of polished cross-section of the as-sprayed coating is shown in Figure 4. In this figure, its demonstrate the lamellar structure and different layers of TBC including NiCrAlY bond coat and duplex CSZ/YSZ top coat can be observed. As well as it consist of closed porosity, that which increase the thermal insulation during services.

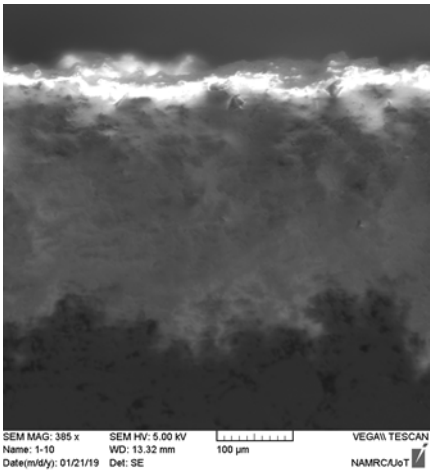
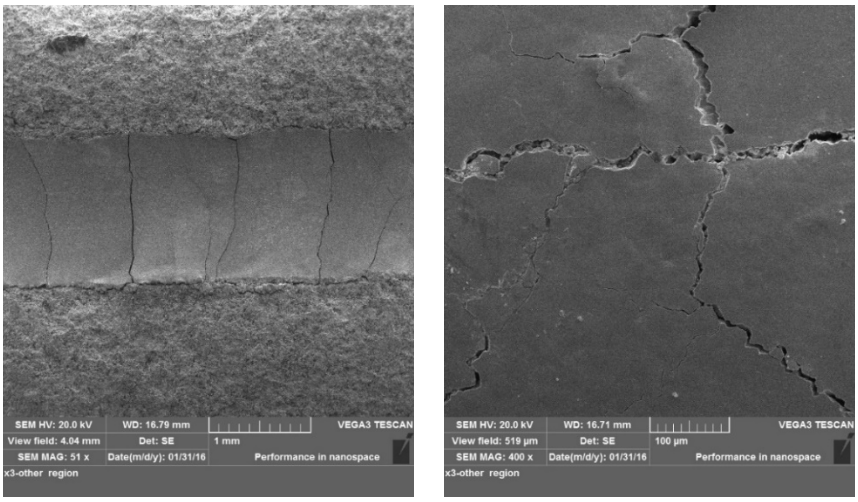


Figure 4: SEM photographs of transverse sections of plasma sprayed CSZ/YSZ

Characteristic microstructure of the laser sealed coatings was presented in the Figure 5. The upper surface of laser-treated coatings becomes smoother than as-sprayed coatings and the microstructure reveal the presence of fine cells and dendrites. Meanwhile, porosity, microcracks and other defects in the plasma sprayed coatings were eliminated. It is interesting that all surface of laser sealed zones exhibits segmented cracks due to high localized temperature gradient after laser treatment. The advantage of cracks formation represented in volume shrinkage and relaxation of residual stresses during servicing.

As seen from the cross –sectional SEM micrographs Figure 6, the sealed layer had a complete dense microstructure. That's mean reduction in volume fraction of heterogeneous distributions of general defects specially closed porosity. There is significant reduction of surface roughness due to laser sealing of plasma sprayed coatings Table II. Decrease in roughness values plays a great role in increasing the efficiency of thermal barrier performance. Because, it decrease the total area of contact at the surface.



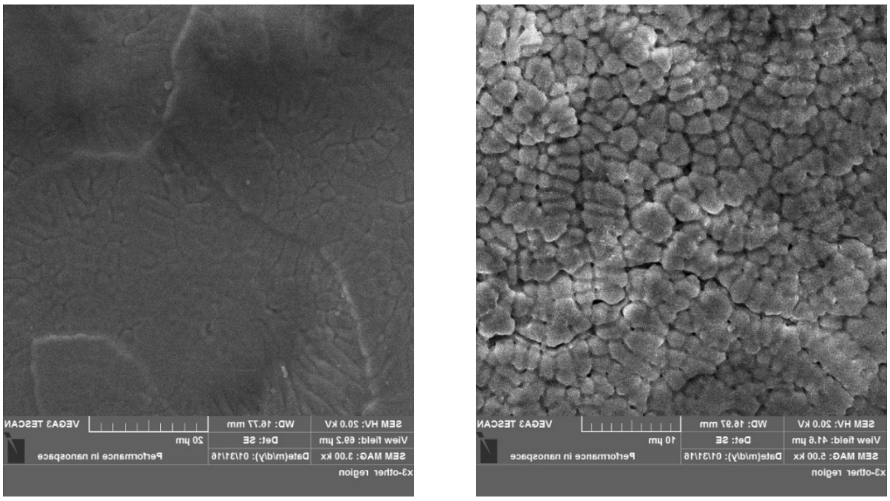


Figure 5: SEM micrographs for various features of laser sealed plasma sprayed TBCs.

TABLE II: Values of roughness for all experiments

Exp. No.	Control factors P	d	V	Mean of Roughness	SNs
1	100	1	3	1.079	-0.6604
2	100	2.5	25	1.969	-5.8849
3	100	3.5	150	7.8	-17.8419
4	100	5	200	7.56	-17.5704
5	200	1	25	2.545	-8.1138
6	200	2.5	3	0.94	0.5374
7	200	3.5	200	7.2	-17.1466
8	200	5	150	7.12	-17.0496
9	350	1	150	0.289	10.7820
10	350	2.5	200	0.609	4.3077
11	350	3.5	3	1.391	-2.8665
12	350	5	25	2.906	-9.2659
13	500	1	200	1.033	-0.2820
14	500	2.5	150	2.669	-8.5270
15	500	3.5	25	1.804	-5.1247
16	500	5	3	1.050	-0.4238

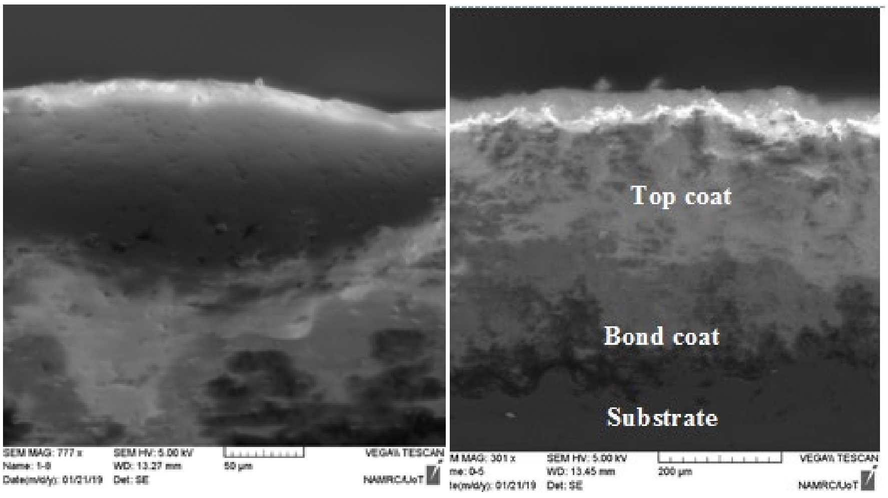


Figure 6: SEM micrographs of transverse sections of as laser sealed plasma sprayed coatings.

It's important to mention, there is aphenomenon appeared near the interface between plasma and laser sealed called marangoni effect resulting from thermal gradients and surface tension of the melted zone during solidification towards the interface. Figure 7 shows different coarse and fine rippling at high specific energy 42 J/mm^2. These ripples were composed of very fine striated ripples structure mostly nucleated perpendicular to the traverse speed [16]. Figure 8 demonstrate the clear difference of roughness between laser sealed coating and only plasma sprayed coating.

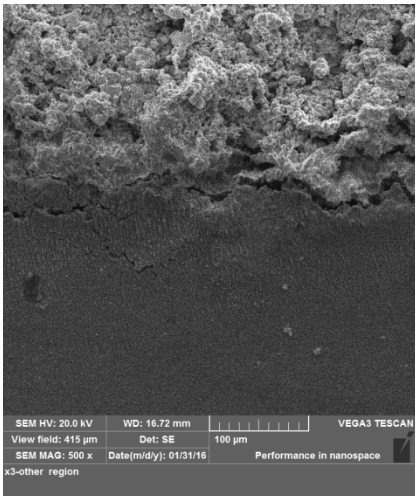


Figure 7: Marangoni effect at high specific energy and moderate power density.

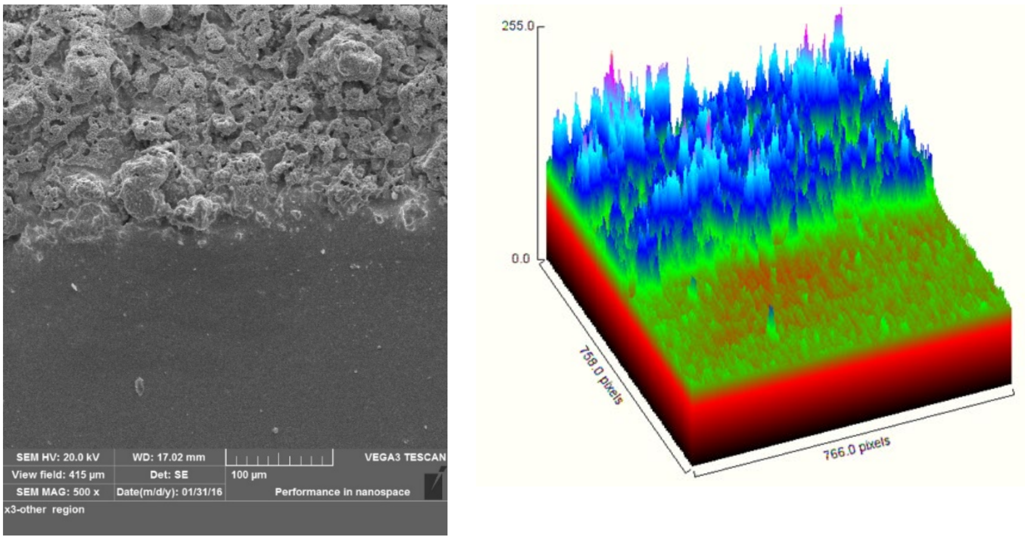


Figure 8: Difference of roughness at the interface between plasma sprayed and laser sealed coating for exp. 11.

During application of design of experiments, signal-to-noise (SNs) ratio was selected to be" smaller is better". The behavior of SNs for roughness at different levels for all variables is shown in Figure 9 represent clearly the different conductance of variables on the roughness. The dominant level value for each variable was listed in Table III which represents the best condition of laser processing of coating to produce roughness in the formula of smaller is better.

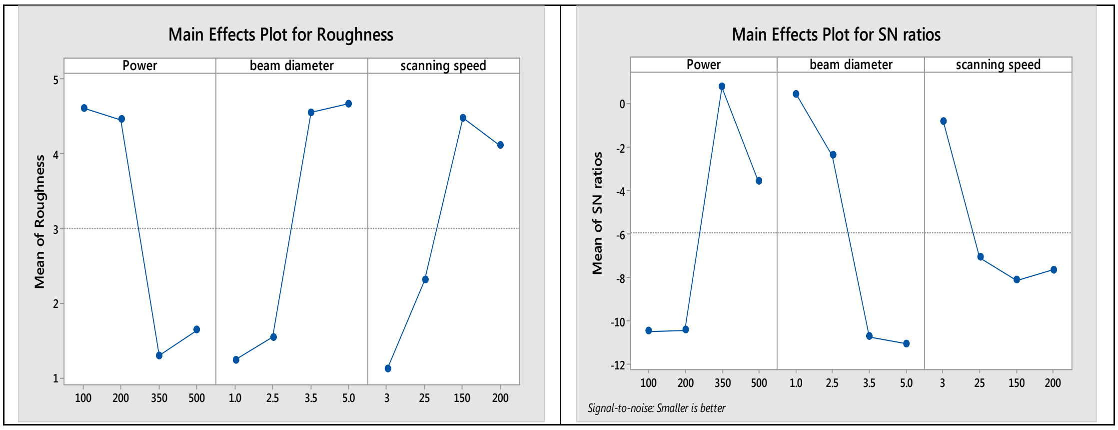


Figure 9: Mean and SNs plot for roughness of all parameters and levels

Table III: Best level of parameters for the roughness of laser sealed coating

The Factors	Value	level
Power	100	1
Beam diameter	5	4
Scanning speed	150	3

4. CONCLUSIONS

1- It is possible to produce multilayer thermal barrier coatings using plasma spraying processto improve the performance and the efficiency of gas turbines that exposed to high temperatures

2- It is possible to decrease the number of defects at the surface of coating using solid state laser type Yb-YAG.

3- Laser sealed coating has a lower roughness than as- plasma sprayed coating as a result of plasma coating defects reduction.

4- The roughness of laser sealed coating considered as a function to the dependent laser parameters: power density, interaction time and specific energy.

References

[1] A. A. Jabbar, A. K. RAI, P. R. Reedy and M. Dakhil , Design and analysis of gas turbine rotor blade using finite element method , Int. j. mech. prod. eng., 4 (2014) 73-94.

[2] F. Cernuschi, S. Ahmaniemi, P. Vuoristo and T. Mäntylä, Modelling of thermal conductivity of porous materials: application to thick thermal barrier coatings, J. Eur. Ceram. Soc., 24 (2004) 2657-2667. doi.org/10.1016/j.jeurceramsoc.2003.09.012

[3] R. Ghasemin, R. Shoja-Razavi, R. Mozafarinia and H. Jamali, Laser glazing of plasma-sprayed nanostructured yttria stabilized zirconia thermal barrier coatings , Ceram. Int., 39 (2013) 9483–9490. doi.org/10.1016/j.ceramint.2013.05.066

[4] A. G. Mora-Garcíaa,c, H. Ruiz-Lunab, M. Mosbacherc, R. Poppc, U. Schulzd, U. Glatzelc and J. Muñoz-Saldañaa, Microstructural analysis of Ta-containing NiCoCrAlY bond coats deposited by HVOF on different Ni-based superalloys , Surf. Coat. Technol., 354 (2018) 214–225 . doi.org/10.1016/j.surfcoat.2018.09.025

[5] X. Q. Cao, R. Vassen and D. Stoever, Ceramic materials for thermal barrier coatings , J. Eur. Ceram., 24 (2004) 1–10 . doi.org/10.1016/S0955-2219(03)00129-8

[6] E. Bakan and R. Vaßen, Ceramic top coats of plasma-sprayed thermal barrier coatings: materials, processes, and properties , J. Therm. Spray Tech., 26 (2017) 992–1010 .

[7] S. M. Zulkifli, M. A. Yajid, M. H. Idris, M. Daroonparvar and H. Hamdan, TGO formation with NiCoCrAlYTa bond coat deposition using APS and HVOF method, Adv Mat Res., 1125 (2015) 18-22. doi.org/10.4028/www.scientific.net/AMR.1125.18

[8] J. G . Odhiambo, W. G. Li, Y. Zhao and C. Li, Porosity and its significance in plasma-sprayed coatings , Coatings, 460 (2019) 1-19 . doi.org/10.3390/coatings9070460

[9] K. P. Jonnalagadda, Thermal barrier coatings: failure mechanisms and life prediction . Ph.D . Thesis , Linköping Studies in Science and Technology, Sweden, 2019. doi10.3384/diss.diva-154777

[10] H. Liu , J. Cai and J. Zhu, Hot corrosion behavior of BaLa2Ti3O10 thermal barrier ceramics in V_2O_5 and Na_2SO_4 + V_2O_5 molten salts , Coatings, 9 (2019) 1-9 . doi.org/10.3390/coatings9060351

[11] K. Kokini, Y.R.Takeuchi and B.D.Choules, Thermal crack initiation Mechanisms on the surface of functionally graded ceramic thermal barrier coatings , Ceram. Int., 22 (1996) 397–401. doi.org/10.1016/0272-8842(95)00122-0

[12] S. Ahmaniemi, J.Tuominen, M.Vippola, P.Vuoristo, T.Mäntylä, F. Cernuschi, C.Gualco, A.Bonadei and R. Di Maggio, Characterization of modified thick thermal barrier coatings , J. Therm. Spray Technol., 13 (2004) 361–370 .

[13] R. Ahmadi-Pidani, R.S. Razavi, R.Mozafarinia and H.Jamali, Improving the thermal shock resistance of plasma sprayed CYSZ thermal barrier coatings by laser surface modification , Opt Lasers Eng., 50 (2012) 780–786. doi.org/10.1016/j.optlaseng.2011.12.007

[14] C. J. Munez, J. Gomez-Garcia, F. Sevillano, P. Poza, and M. V. Utrilla, Improving thermal barrier coatings by laser remelting , J. Nanosci. Nanotechnol., 11(2011) 1–6 . doi.org/10.1166/jnn.2011.3457

[15] C. Batista , A. Portinha , R.M. Ribeiro , V. Teixeira , M.F. Costa and C.R. Oliveira, Surface laser-glazing of plasma-sprayed thermal barrier coatings , Appl. Surf. Sci., 247 (2005) 313–319 . doi.org/10.1016/j.apsusc.2005.01.047

[16] K. M. Jasim, Laser sealing of zirconia–yttria–alumina plasma sprayed coating , J. King Saud Univ. Eng. Sci., 25 (2013) 11–20. doi.org/10.1016/j.jksues.2011.10.004