Hot corrosion of plasma sprayed and laser sealed coatings of yttria partially stabilized zirconia thermal barrier coatings with molten eutectic vanadate-sulfate Salt

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Abstract

Yttria partially stabilized zirconia thermal barrier coatings are frequently promising ceramic coatings used in many hot sections of turbine engines and isolation unit of fuel in oil refineries. Many surface sealing treatments have been employed to improve service lifetimes of these coatings by improving chemical and thermo-mechanical resistance. This work aimed to study the effect of hot corrosion molten salt of eutectic V_2O_5 + 45 wt% Na_2SO_4 on the performance of as-sprayed and as-sealed zirconia-8 wt% yttria coatings. Hot corrosion was done by exposing the samples to an isothermal air furnace testing at 900 °C for different exposure times of 1, 40, and 80 hours . Upper surface plan views of the coatings were examined using scanning electron microscopy to observe the morphological and microstructural changes. Element analysis and phases identification of the corrosion products were determined using energy dispersive spectroscopy (EDS), electron probe microanalysis (EPMA) and X-ray diffraction (XRD). The results indicate the higher resistance of as-sealed coatings compared with as-sprayed coatings to the hot corrosion. Degradation due to the presence of eutectic harsh salt attack was occurred by destabilization of yttria from the zirconia yttria coatings. This will lead to disrupt transformation from metastable tetragonal phase (t') to monoclinic phase (m). The formation of m phase having lower yttria content is taken place due to the formation of YVO_4 by leaching process. This introduces additional stresses which may lead to final degradation of coatings. The low leaching rate of yttria for the sealed coatings is related to the absence of pockets of open porosity eliminated after laser sealing of porous plasma sprayed coating.

Introduction

Thermal barrier coatings (TBCs) are frequently used in hot sections such as blades and vanes of gas turbine engines and isolation unit of fuel in oil refineries. Its increase the operating temperature and enhance the engine efficiency subsequently. TBC systems are composed of a zirconia based ceramic top coat, over a metallic bond coat. The top coat acts as a thermal insulation layer, while the bond coat provides corrosion and oxidation protection for the substrate and improves the adhesion of the ceramic top coat to the metallic substrate. The ceramic top most commonly made of yttria partially stabilized zirconia (YPSZ). High quality coatings of TBCs produced from YPSZ offer a range of unique properties to improve the overall performance of components. Much commercial techniques now widely used for the deposition of thermal barrier coatings, Atmospheric plasma spraying (APS) is one of the important plasma spraying techniques. However, it has been proposed that some problems encountered with plasma sprayed coatings, segmented cracks and interconnected porosity due to volume shrinkage and residual stresses in the topcoat.

These features are considered to be the path for molten salts such as Na, S and V, and corrosive gases to attack the TBC system, especially in applications where low-purity fuels at high working temperatures, Where the TBCs prone to hot corrosion. could be reduced and the performance enhanced if the upper surface of these coatings could be sealed by applying laser heat treatments. Laser sealing or sealing acts to prevent salt penetration into the TBC. sealing the top coat by laser beam is advanced approach to seal TBCs surface. The laser beam has the advantage of forming a dense thin layer composed of micro-grains. Laser sealing provides a re-melting and succeeding solidification of the surface, resulting in a dense to player with a new microstructure. It also leads to reducing the surface roughness considerably. Free from porosity, it forms a network of continuous cracks perpendicular to the surface. Although several studies have been done on the laser sealing and some of studies conducted the effect of sealing on hot corrosion resistance of TBCs. Laser treatment has been proved to be a highly promising method to improve the coating quality of the plasma-sprayed coatings by eliminating open pores within the coating surface and generating a controlled segmented crack network. Hot-corrosion tests in the presence of V2O5 indicated that the lifetimes of the plasma-sprayed 6.1YSZ, 7.3YSZ, 12YSZ and 19.5YSZ (numbers denote wt.% of Y2O3) coatings were largely increased after laser sealing.19,20. In view of this, a study has been under taken to investigate the effects of laser sealing process on hot corrosion of TBCs.

Methods

A Stainless Steel 316L plate with 3.2 thickness, 24 mm width and 15 mm length, was used as the substrate material. An Ni-22Cr-10Al-1.0Y (wt.%) type metallic powder (AMDRY 962, Sulzer Metco Inc., USA) was used as the bond coat layer. The ZrO_2-7 wt.% Y_2O_3 (Amperit 827.007) ceramics powders used for the top coat .

Thermal barrier coatings were fabricated by air plasma spray system using Sulzer-Metco 3-MB plasma gun (Sulzer Metco AG, Switzerland). the substrate surface was grit-blasted in a sand-blasting box using the alumina abrasive of 24 meshes, under a pressure of 5 bars and a distance of 15 cm. spraying parameters are summarized in table 1. Laser surface treatment of YSZ coatings were done by using a 2.5kW continuous wave, fiber-coupled lamp-pumped Yb^{+3}:YAG laser and standard circular shaped pulses. Laser sealing processing parameters are listed in table 2.

Table 1 : spraying parameters

Spray parameter	Bond layer	Ceramic layer
Primary gas	Ar	Ar
Pressure, psi	100	100
Flow, SCFH*	80	70
Secondary gas	H_2	H_2
Pressure, psi	50	50
Flow, SCFH	15	15
Current, A	450	500
Voltage, volt	50	55
Spray distance, cm	12	8
Angle,%	90	90
Carrier	Ar	Ar
Flow, SCFH*	28	37
Spray rate , 1b/h	10	10

Table 2 laser sealing parameters

Parameters	Value
Average working power (W)	550
Beam diameter (mm)	4
Scanning speed (mm/s)	26.3
Overlap (mm)	0.2
Distance (mm)	10
Specific Energy (J/mm^2)	5.2
Power density (W/mm^2)	43

Hot corrosion resistance of the as-sprayed and laser sealing coatings were done at 900 ^{o}C for different times are 1, 40 and 80 hours. Coatings were exposed to the mixture of 45 wt.% Na2SO4+ 55 wt.% V2O5 to simulate the deposits and the temperature present in a diesel engine combustion chamber. The features and Morphology and microstructure of coating as-sprayed and laser sealed YSZ coating after and before hot corrosion test were determined by Visual examination and of the optical microscopy and SEM.

X-ray diffraction was used in phase identification phase analysis and EDS was used as a complement of XRD for local element analysis and detection of corrosion products.

Results

The surface morphology of as-sprayed coating Indicate the two kinds of microstructure. One referred to the partially melted particles, which had a porous microstructure. The other is the molten parts bonded with each other to form a dense structure It can be seen that the melted zone of top coat surface contained microcracks due to rapid solidification Fig 1.

The surface roughness (Ra) of as-sprayed coating was about 7.50 µm. It was very rough due to the existence of microcracks and partially molten particles involved in the lover deformation impact of the surface as compared to the fully molten particles.

total porosity of the coatings calculation by using a computer-based image-J analysis system is 13%. (% area.).

Fig. 2 shows the surface morphology of laser-seald coating. Laser treatment or remelted process melted a surface region of the top coat and induced vertical cracks. Cracking was due to shrinkage and thermal stresses produced during rapid solidification. All the principal characteristics in the plasma-sprayed TBCs such as voids, porosity, crack, and partially and non-melted particles were vanished after laser sealing. These remelting and resolidification phenomena resulted in the reduction of surface roughness.

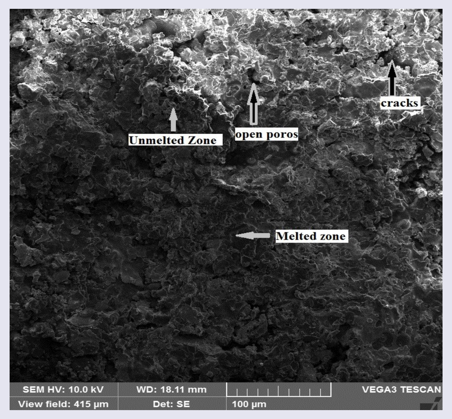


Figure 1

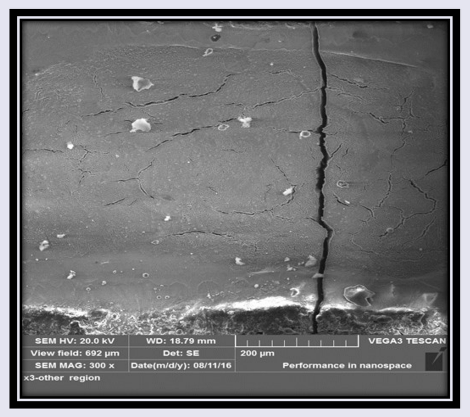


Figure 2

Figs. 3&4 illustrates the XRD patterns of as spray and the sealed coating. It demonstrates that the phase composition of as-sealed coatings was the non- transformable tetragonal phase (T$^{'}$) with small amount of monoclinic phase, while the sealed coating have (T$^{'}$) phase only. This phenomenon resulted from the rapid solidification during the process of laser sealing.

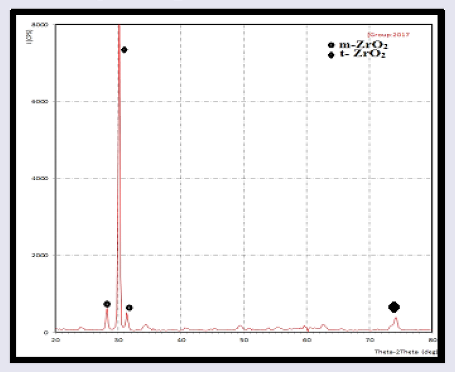


Fig 3

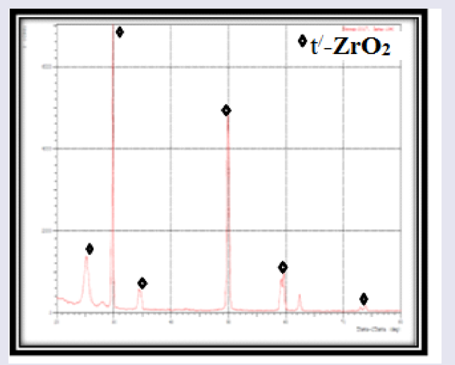
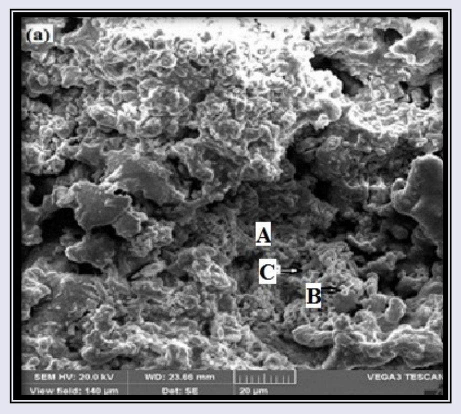
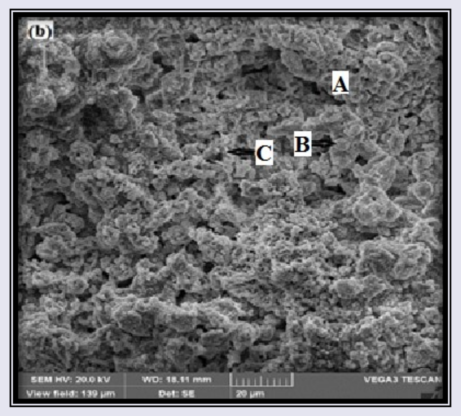


Fig 4

Figures 5 and 6 shows the SEM image of top surface of coatings after 1, 40, and 80 hours hot corrosion for as-sprayed and laser-sealed coating, respectively. As-sprayed and laser-sealed coatings revealed a porous surface and glossy surface with many rod-like crystals on the surface, respectively. As clearly shown in this figure, the semi-cubic (B) and rod-type crystals (C) have been formed on the coating surface (A) in As-sprayed coating. In the laser-sealed coating, these crystals were fewer and smaller than as-sprayed coating in terms of quantity and size.





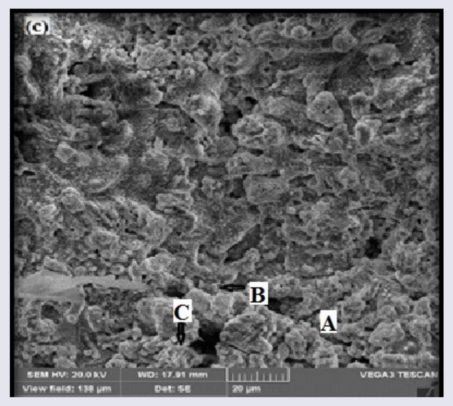


Fig 5

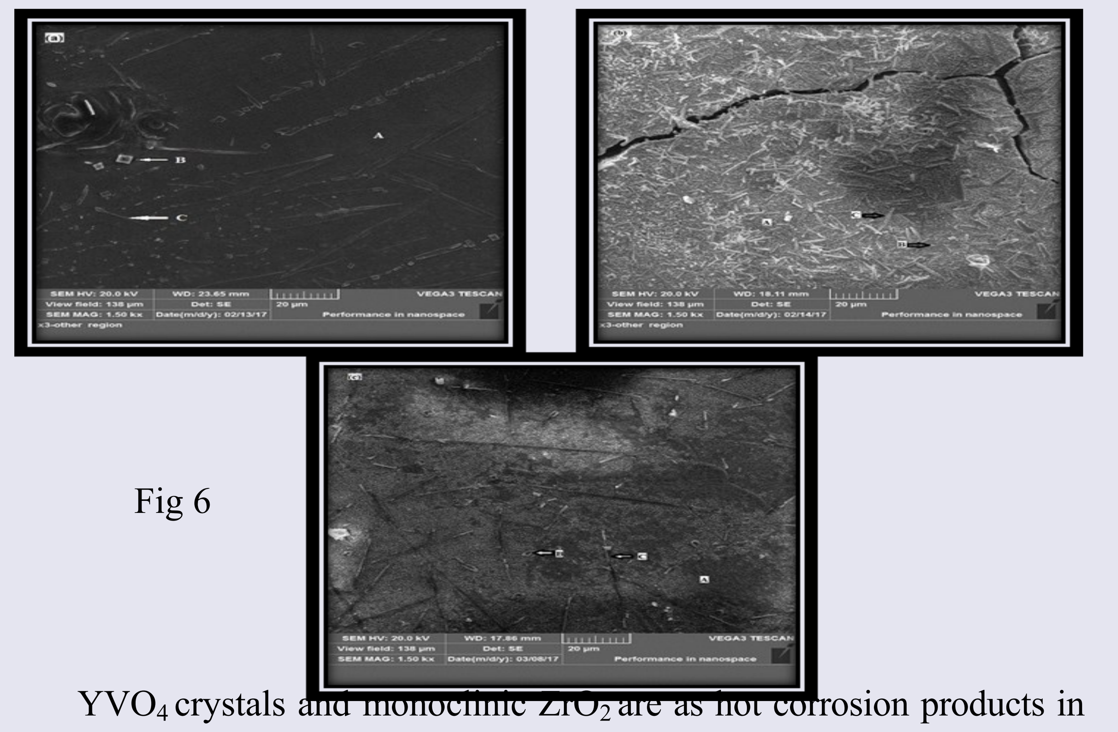
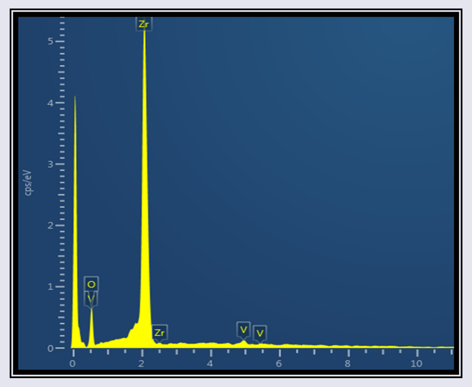


Fig 6

YVO_4 crystals and monoclinic ZrO_2 are as hot corrosion products in YSZ coating. The formation of YVO_4 led to the depletion of the Y_2O_3 stabilizer and transformation of the tetragonal phase to the monoclinic ZrO_2 phase. Transformation to the monoclinic phase during hot corrosion caused the destructive volume change and the consequent failure of coating.

The EDS analysis was performed at different regions of the coating surfaces to confirm the chemical compositions of the hot corrosions products. Fig. 7 shows the EDS analysis of points A, B and C . in Fig. 6 indicates porous and glossy areas (matrix). The matrix (B) contained zirconium, yttrium and oxygen, and the rod-like crystals "A and C" had vanadium, yttrium and oxygen.



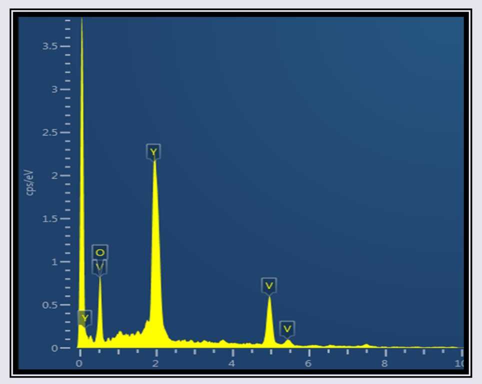


Fig 7

Conclusion

- The structured of as-sprayed coating possessed) and consisting of two kinds of microstructure are partially melted and full melted Particles with surface roughness (Ra 13) and Porosity percent is (13%), with some of defects such as voids and crack, while the laser-sealed process reduced the surface roughness, eliminated the porosity of surface and produced network cracks perpendicular to the surface, Cracking was due to shrinkage and thermal stresses produced during rapid solidification.
- The phase composition of laser sealing mainly consisted of non-transformable tetragonal phase (T′), while the plasma sprayed phase composition of (T′) with small amount of (m) phase.
- Hot corrosion of both as spray and laser sealing coting , due to the reaction of the molten salts (V_2O_5) with tetragonal stabilizer (Y_2O_3) in zirconia, led to the formation of YVO_4 and phase transformation of zirconia from tetragonal to monoclinic, which was accompanied by a large destructive volume expansion of the coating.
- Laser-sealed TBCs had a hot corrosion resistance higher than that of plasma-sprayed TBCs due to improvement in the surface roughness .
- Reducing the specific surface area of the dense glazed layer and improving the stress accommodation through network cracks produced by laser glazing were the main enhancement mechanisms accounting for TBC life extension.

References

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