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Laser sealing and thermal shock resistance of 6.5 wt% yttria Partially stabilized zirconia plasma sprayed layers

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Abstract

Laser sealing of zirconia-6.5 wt% yttria partially stabilized zirconia (YPSZ) plasma sprayed layers were examined for both plan views and transverse sections. Scanning electron microscopy (SEM) has been used extensively to characterize the general features and microstructure of the layers under optimum laser processing conditions. The laser beam is shown to be effective in modified the plasma sprayed layers by sealing the porosity and decrease the roughness. Thermal shock resistance test reveals that sealed layers have been an excellent resistance to cracks formation parallel to the surface.

غلق المسامية والصدمة الحرارية لطبقات الرش بالبلازما من الزركونيا الحاوية على 6.5% ياتريا

الخلاصة

تم فحص الأسطح الخارجية والمقاطع العمودية لطبقات الرش بالبلازما ذات الأساس من الزركونيا واليتريا المعاملة بالليزر. استخدم المجر الالكتروني الماسح بصورة فاعلة لتقييم الملامح العامة والبنية المهجرية وعند الظروف المثلى لمتغيرات الليزر. وجد أن حزمة الليزر فعالة لتعديل طبقات الرش بالبلازما من خلال غلق المسامية وتقليل الخشونة. أوضح اختبار الصدمة الحرارية بان طبقات الرش المعاملة بالليزر تمتاز بمقاومة عالية لتقدم الشقوق الموازية للسطح.

Introduction

The availability of high power lasers in recent years has led to a range of applications in materials processing such as cutting, welding, drilling and surface engineering, which includes melting, glazing, alloying and cladding. Since the discovery of the laser much research has been done on the laser processing of alloys. In comparison there is a dearth of information on laser processing of ceramics and plasma sprayed coatings [1-3]. Plasma spraying is one of the important processes currently used to produce thermal barrier coating systems (TBCs) for a wide range of substrates for different applications [4-6]. Thermal spraying techniques has been used over the last thirty years or so with success to coating the inside surface of the high temperature engines. Thermal barrier coating systems (TBCs) may be defined as insulative and oxidation resistance materials used in hot sections in the engines (utility, diesel and turbine) and consist of ceramic/alloy layers [4]. The ceramic layers are used effectively to improve the thermal properties and decrease the temperature of the substrate by ≈ 50 to 200 ^{o}C which allows higher temperature inside the engine [6]. The intermediate layers are used to improve the mechanical properties such as adhesion.

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Insulative layers of TBC produced from 6.5 to 8.5 wt% yttria partially stabilized zirconia system (YPSZ's) offer a range of unique properties for components. They have a low thermal conductivity, a high thermal expansion coefficient, close to the super alloy substrate and bond layer, high fracture toughness and very good oxidation resistance [6]. However, several problems can arise during service due to penetration of species in the fuel through the porosity in the ceramic layer; this can affect the life of the component. Because of this and other problems, advanced surfacing techniques should be used to eliminate or remove the porosity.

Materials and Experimental Procedure

The Laser used was " 2 kW continuous wave, fast axial, shock stabilized, gas discharge laser" model BOC 901 which was designed by British Oxygen Company and manufactured by Control Laser Ltd. The main laser beam is reflected by curved copper mirror, gold coated. The beam is deflected vertically through the laser head and is focused by a 150 KCI lens. The substrate samples of medium carbon steel used for plasma spraying in the form of disc of thickness 5.6 mm and 25.4 mm diameter were SiC shot blasted before spraying. The powder used for the sprayed of bond layer is Co-32Ni-21Cr-8Al-0.5Y (wt%) (AMDRY 935). The ceramic powder of average particle size of ~ 100 μm (Fig.1) used for outer ceramic layer was yttria partially stabilized zirconia (YPSZ) with 6.5 wt% Y_2O_3 (Table 1). In laser sealing, the plasma sprayed discs were fixed into a jig, which was clamped to the x-y table. Table 2 summarizes the laser processing variables studies for 6.5 wt% yttria partially stabilized zirconia.

Roughness measurements were taken in the sealed tracks as well as for the plasmna sprayed regions. The roughness was given in the term of a centre-line-average (CLA). Scanning electron microscopy equipped with energy dispersive analysis was used to evaluate the structure and chemical composition.

X-ray analysis was conducted using a step scanning technique with 2 theta of 0.01 degree interval and a counting of 1 sec/step. The ranges of scanning are 27.5-32 and 72-75.5 degrees.

Results and Discussion

The main objectives of this paper were to show the effect of optimum laser parameter to seal the porosity of ceramic plasma sprayed layers and improve the performance of sealed layers and enhance thermal shock resistance. Fig.2 shows typical plan views giving the general appearance of the plasma sprayed coating; there is a non-uniform distribution of porosity together with primary and secondary cracks. The roughness of the plan view was determined to be 6.5 ± 0.3 μm. A typical transverse section of the plasma sprayed coatings, together with the CoNiCrAlY bond layer; is shown in Fig.3. The volume fraction of the porosity was determined to be 12 ± 2%. The material contains a high proportion of interconnected and closed porosity as shown from the transverse section (Fig.4). A typical low magnification plan view of as-sealed layer is shown in Fig.5 with a corresponding SEM of a transverse section (Fig.6). No cracking was observed at the interface between sealed and plasma sprayed ceramic layers when sealing was carried out under acceptable laser conditions. A smooth outer surface is also evidenced with shallow surface cracks and small depressions. The presence of network cracks and depression are very shallow and did not penetrate through the sealed region. Surface topography of the laser sealed and as-sprayed coating is shown in Fig.7. It is clearly shown that the sealed layer has a lower roughness compared with as-sprayed layer. Generally, the microstructure of as-sealed layers under optimum conditions is consisted of cellular structure (Fig.8). Detailed X-ray analysis showed that the dominant phase in plasma sprayed and sealed layers is t' due to rapid solidification.

The plasma sprayed and quenching in water after annealing for 24 hrs from 1100 ^{o}C thermally shocked sealed layers. These tests showed that the sealed layers have a good resistance to crack propagation, while the plasma sprayed region showed severe crack formation (Fig.9). Transverse section examined by SEM showed the good resistance of the sealed layer to thermal shock, where as cracks parallel to the surface are produced in the plasma sprayed layer. Final failure started from the bond layer near the substrate attributed to severe oxidation of the mild steel substrate and from bond layer. SEM and EDS analysis showed local damage and the presence of iron oxides and aluminum oxide with small amount of nickel and chromium oxides in the plasma sprayed regions.

Conclusions

1- It is possible to weld the porosity for plasma sprayed layers of yttria partially stabilized zirconia by using CW CO_2 laser.
2- Complete remelting and resolidification characterize the sealed layers with a cell structure under optimum laser condition.
3- Thermal shock resistance test showed that the sealed layers have superior properties compared with plasma sprayed layers.

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Table 1 Chemical analysis of yttria partially stabilized zirconia powder (wt%).

Ceramic	wt%
Yttria	6.2
Hafnia	1.4
Titina	0.15
Soda	0.1
Other oxides	0.3
Zirconia	91.5

Table 2 Laser sealing parameters used.

Power, kW	0.8 – 2
Traverse speed, mm/s	5 - 370
Beam diameter, mm	5
Specific energy, J/mm^2	0.43-80

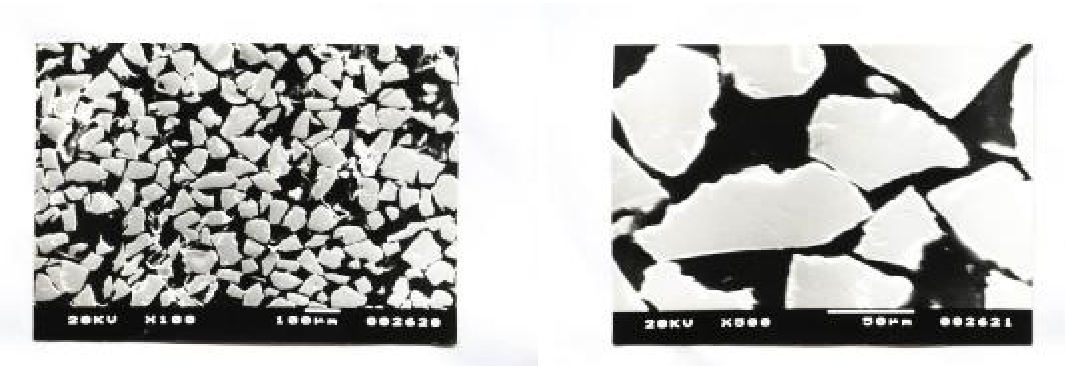

Figure (1) SEM of the yttria partially stabilized zirconia powder studied.

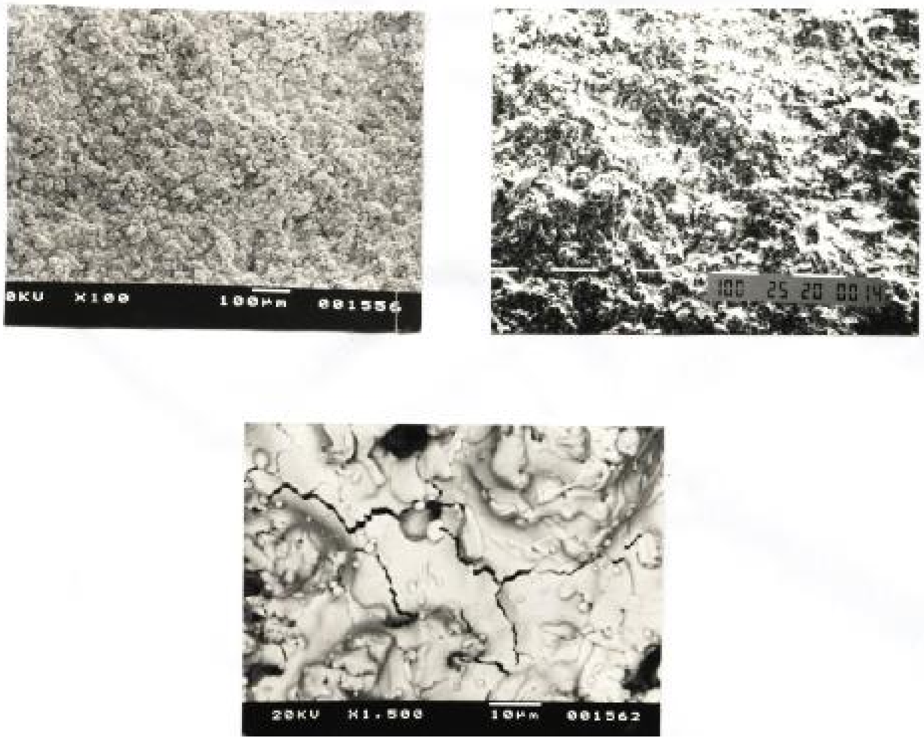

Figure. 2 SEM micrographs of the plan views of as-sprayed YPSZ layers.

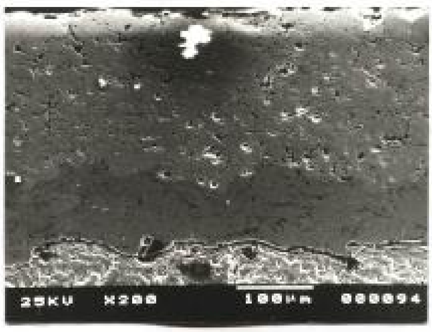

Figure 3 SEM micrograph of transverse section showing the different layers.

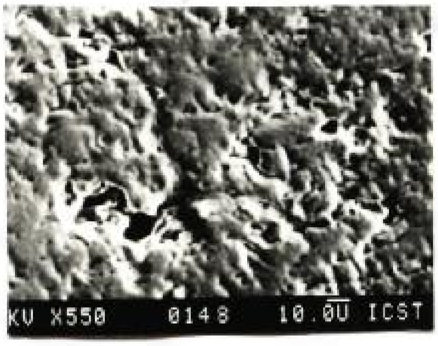

Figure 4 Higher magnification SEM micrograph of transverse section showing the internal porosity.

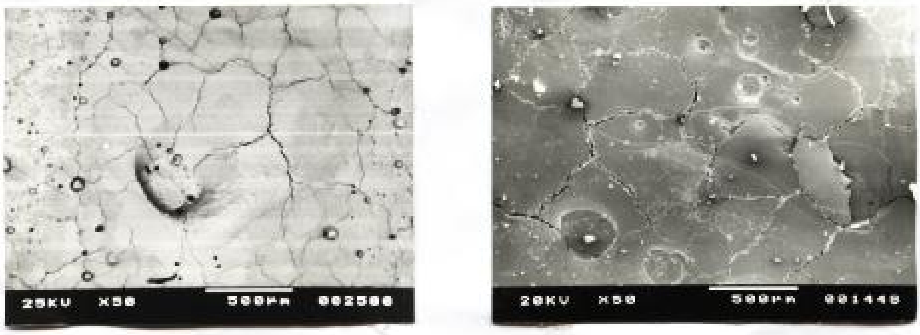

Figure 5 Low magnification SEM micrographs of sealed layers showing the net-work cracks and depressions.

Figure 6 Low magnifications SEM photograph showing the depth of sealing without any cracks.

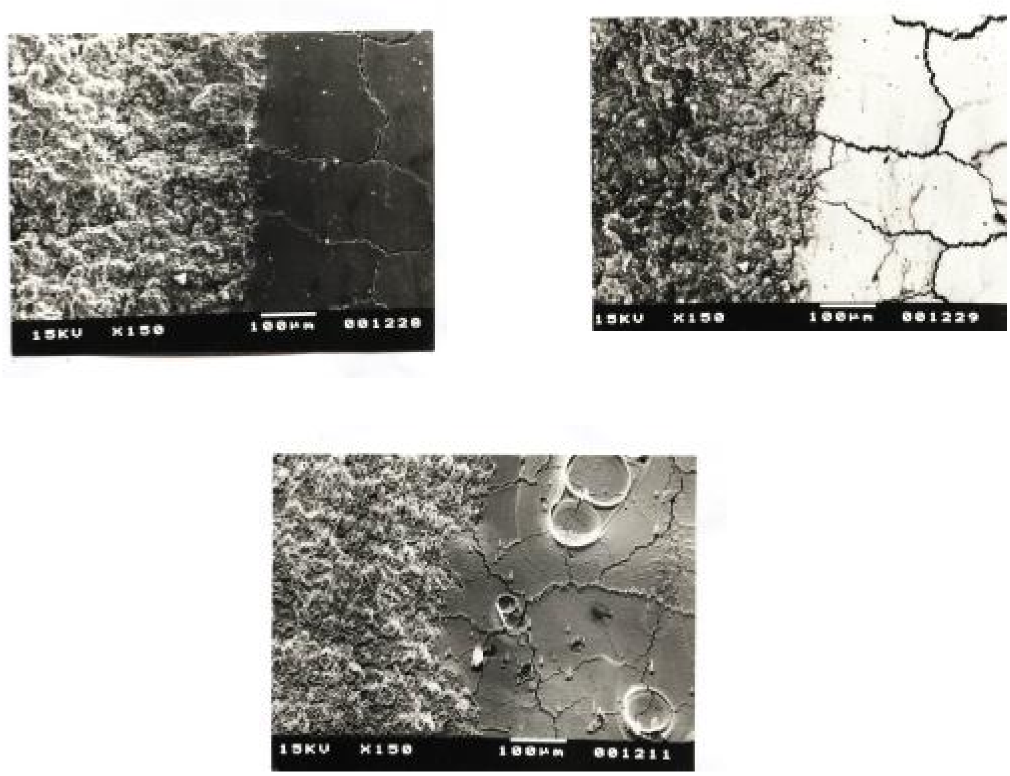

Figure7 SEM photographs showing the plan views of as-sprayed/as-sealed regions of YPSZ.

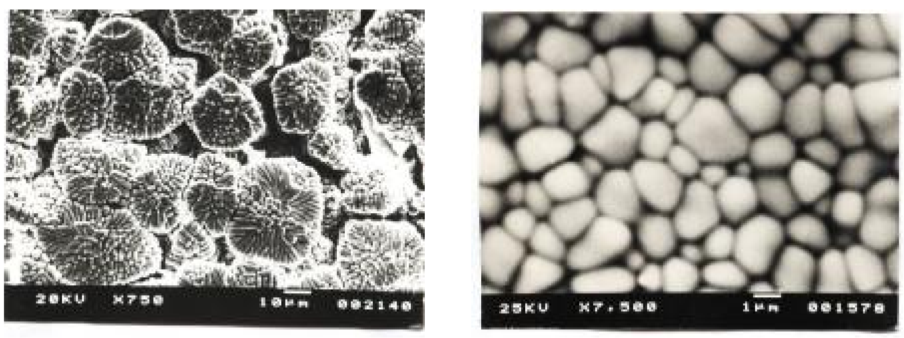

Figure 8 Higher magnification SEM micrographs showing the typical structure of sealed layers.

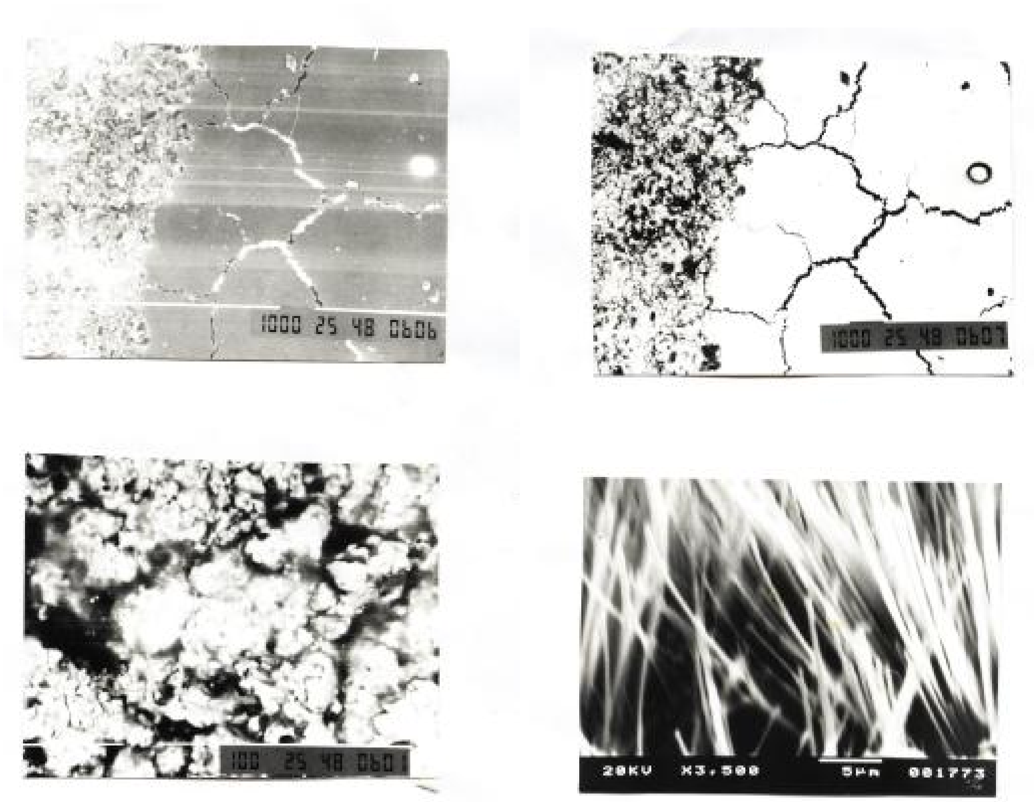

Figure 9 SEM micrographs of the sprayed and sealed regions after thermal shock showing the high performance of sealed layer compares with as-sprayed layer.