Evaluation of Thermo-Mechanical Properties of Transferred Arc Plasma (TAP) Melted $La_2Zr_2O_7$ Ceramics for Thermal Barrier Coatings

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Abstract

Yttria stabilized zirconia based thermal barrier coating (TBCs) is widely used in turbine engines to protect hot-section metallic components from corrosion and oxidation. However, it has limitations for long-term application at temperatures above 1200 ^{0}C due to sintering and phase instability of coating. So it is important to develop new TBCs materials with a lower thermal conductivity and higher sintering resistance than 8YSZ. Recent studies reveals that the rare earth zirconates has excellent thermal stability, low sintering rate and low thermal conductivity. There are many industrial methods available to produce free flowing powders of ceramics and metals. Some of the major processing methods used to produce free flowing powders are atomization, fusing or sintering, spray drying, cladding and plasma processing. Among these methods, plasma processed powders are free from internal porosity and have excellent flow ability. The present paper reports plasma spray deposition of thermal spray grade Lanthanum Zirconate (LZ) powder prepared by TAP (Transferred Arc Plasma) melting technique followed by characterization for its suitability for TBC applications. Experimental results show that the synthesized $La_2Zr_2O_7$ powder and coatings keeps the pyrochlore structure. The measurements for thermal expansion coefficient and tensile bond strength of the coatings shows encouraging results for TBC applications.

Keywords: Plasma melting, Lanthanum zirconate, plasma spray coating, Thermal expansion coefficient, tensile bond strength.

Introduction

Thermal barrier coatings (TBCs) are widely applied on the surface of the metallic components to increase the reliability, durability of hot section metal components in advanced jet engines and to enhance engine performance. Presently, 6–8 wt% yttria stabilized zirconia (YSZ) is widely used for thermal barrier coatings [1,2]. In the next generation of advanced gas turbine engines, the use of low thermal conductivity and higher sintering resistance ceramic materials are envisaged. Increased research have been focused on the preparation of $A_2Zr_2O_7$. Several promising zirconates, such as $Sm_2Zr_2O_7$, $Gd_2Zr_2O_7$, $Nd_2Zr_2O_7$ and $La_2Zr_2O_7$ were investigated. Among these, $La_2Zr_2O_7$ (LZ) has low thermal conductivity, higher sintering resistance, outstanding thermal stability, chemical resistance, and become a very hopeful candidate material for novel TBCs [3,4]. The microstructure of plasma-sprayed coatings control the thermo-mechanical properties of TBCs, and this coating microstructure may be controlled by adjusting the plasma spray process parameters. In this study, an attempt has been made to evaluate the coatings thermal expansion coefficient at different spraying conditions and tensile bond strength for TBC applications. A comparison also made between the laboratory developed LZ powder and plasma spray coatings.

Expeimental

Lanthanum zirconate (LZ) powder with the desired composition was prepared by Transferred Arc Plasma (TAP) melting [5] technique with La_2O_3 and ZrO_2 as the starting materials. TAP melted powders were crushed manually , ball milled for 24 h and sieved to the sprayable powder size range of -106 + 10 µm. The thermal expansion behavior of free standing LZ coatings over a temperature range of 20 ^{0}C to 1200 ^{0}C. The procedures prescribed in ASTM- C633 standard [6] was used to evaluate for adhesion bond strength of as sprayed coatings. The schematic diagram of tensile bond strength specimen is shown in Fig. 1. The coated samples were loaded with a loading rate of 1mm/min using a universal tensile testing machine (Model: UNITEK-94100; Make: FIE Blue Star, India) until fracture and the corresponding fracture stress was recorded for analysis. The Experimental parameters used in this investigation are shown in Table 1.

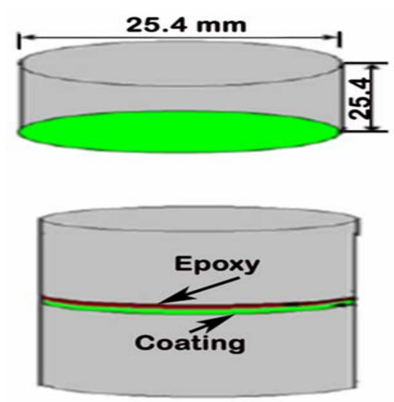

Figure 1 Schematic diagram of tensile bond testing as per ASTM C-633-01

Table 1 Important plasma spray parameters and their levels

No	Factors	Units	Levels A	Levels B	Levels C
1	Power (P)	kW	21	24	26
2	Standoff distance (D)	mm	106	115	124
3	Powder Feed Rate (F)	g/min	22	28	34

Results and discussion

Figure 2 reveals the microstructure of the coating cross section, deposited using plasma spray conditions listed under 'C' that shows pores and cracks within the coating. From the Fig. 2, it is learnt that the coating microstructure is strongly dependent on spray parameters conditions. When an adequately melted, molten particle impinges over the substrate, the molten particle experiences sudden deceleration, resulted in a pressure build-up at the particle-substrate interface. The high pressure inside the particle forces the melted material to flow laterally to deform the molten particle and thus splat form [7].

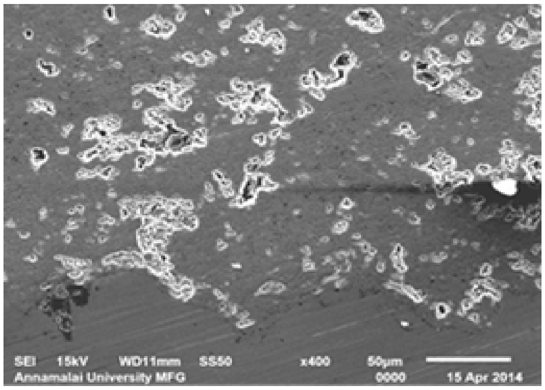

Figure. 2 SEM image of the coating deposited using spray condition 'C'

A higher degree of flattening corresponds to a decrease in splat thickness and a larger area of splat surface being in contact with the underlying material. The liquid spreads outward from the point of impact and forms a splat. This splat formation determines both microstructural and macroscopic characteristics of the coating. Similar microstructures were observed in A and B spray conditions, hence spray condition "C' only presented here.

Measurement of coefficient of thermal expansion

The thermal expansion data of LZ coatings prepared at various spraying conditions are compared (Fig. 3) The thermal expansion between room temperature and 1200 ^{0}C is almost equal for all the spraying conditions, However, increasing temperature increases thermal expansion co-efficient over 400 ^{0}C. The average value of thermal expansion coefficient (TEC) is determined for LZ coatings to be 8.5 - 9.5 X10^{-6} K^{-1}. From the results it is learnt that the thermal expansion coefficient was not influenced by the microstructure [8] and was not sensitive to the processing parameters for the sprayed coatings produced in these trials.

Evaluation of Tensile bond strength

The mechanical properties of plasma sprayed coatings, such as adhesion to substrate, can be affected by the spraying conditions. It is assumed that adhesion is substantially dependent on the microstructure aspects generated under process conditions. If the failure occurs at the substrate – ceramic coat interface, then the strength known to be coating adhesive strength. If the rupture is occurred within the ceramic coating, then it is referred as coating cohesive strength [9].

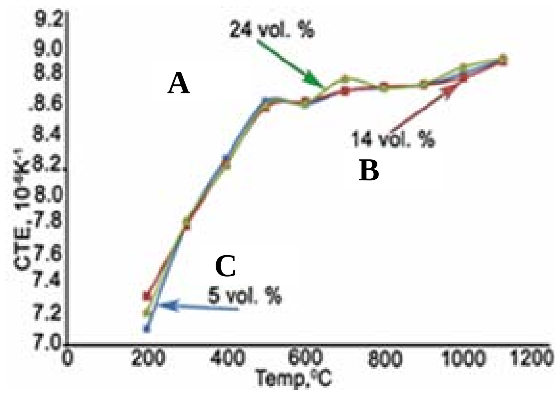

Figure 3 Effect of spray conditions on CTE values

Figure 4 Photograph of tensile bond tested specimens

From the Fig. 4, it is inferred that tensile bond tested specimens exhibits adhesive / cohesive failure for a value of 10 MPa, 14, 12 for conditions A, B and C respectively. The microstructure of plasma sprayed YSZ coatings may be altered with change in plasma spray conditions. It can be explained by changes in total porosity, shape/size of the intersplat pores and unmelted particles for the various spraying conditions.

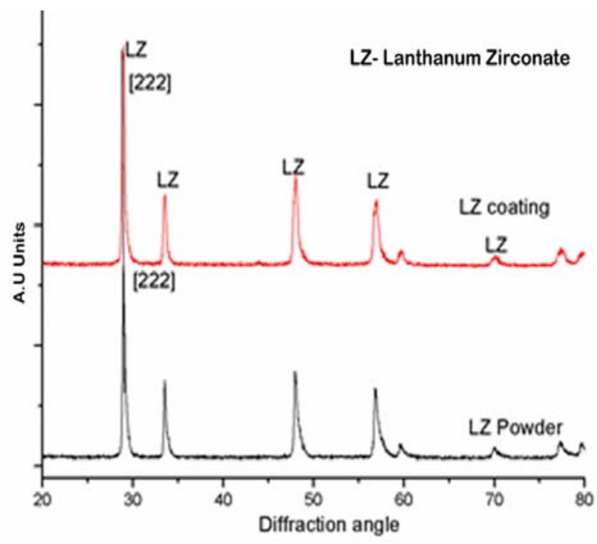

Figure 5 XRD comparison of LZ powder and coating

Phase analysis

Lanthanum zirconate powder developed by TAP melting route and its coatings sprayed by plasma XRD pattern are compared in Fig.5. From the Fig. it is observed that powder and coating shows similar pyrochlore peaks and there is no new peaks were observed. Hence, it is concluded that pyrochlore structure is retained both in coating and powder, this structure can accommodate large deviations [10] in stoichiometric and LZ coating can be used for TBC applications.

Conclusions

(i) Coatings produced under three different plasma spraying conditions shows pores and, cracks irrespective of the processing conditions.

(ii)Thermal expansion coefficient (CTE) of LZ coating is in the range of 8.5 - 9.5 X10^{-6} K^{-1} and CTE of coating was not influenced by the spraying conditions and coating microstructures.

(iii) The maximum tensile bond strength value of 14 MPa was obtained in “B” processing condition. However, all the LZ coatings failed in an adhesive/cohesive failure pattern under different spraying conditions. Tensile bond strength value is dependent on the microstructure of the coatings.

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