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Influence of solution-precursor plasma spray (SPPS) processing parameters on the mechanical and thermodynamic properties of 8 YSZ

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ABSTRACT

8 mol% yttria stabilized zirconia (8YSZ) coatings are prepared by solution precursor plasma spray (SPPS) technique under different spray conditions. Phase analysis is performed using X-ray diffraction (XRD) and Electron back scattered diffraction (EBSD) techniques. Irrespective of the processing conditions and the heat treatment temperatures, all samples displayed cubic and tetragonal zirconia phases. Vertical and horizontal cracks appeared in the microstructural analysis of the coatings. Coating prepared under spray conditions having 40 mm distance between the spray gun and the sample exhibit high hardness, both at 0 h and 10 h heat treatment holding time. To explore the suitability of the coatings for the heat insulating applications, the thermal diffusivity and thermal conductivity are calculated. The coating with 42 mm distance between the spray gun and the sample displayed lowest thermal conductivity from 400 to 1200 °C.

1. Introduction

To insulate the metallic gas turbine engine components from the hot gas stream, numerous materials are utilized. The current state of art material is the thermal barrier coatings (TBC) that are widely used to protect the metallic components of engine from high temperature. Furthermore, it is useful for increasing the life time and operating temperature of the engine [1–5]. Low thermal conductivity and good strain tolerance are basic prerequisite for the thermal barrier coatings. TBC mainly consists of four layers; metal substrate, bond coat, ceramic top coat, and thermally grown oxide (TGO) layer between the top and bond coat [6,7].

Among the different materials, zirconia (ZrO_2) is considered to be a suitable material for the top coat of TBC. The selection of ZrO_2 is due to its excellent properties like low coefficient of thermal expansion, high thermal stability, low thermal conductivity and high erosion resistance. Fracture toughness and fracture strength of ZrO_2 could be improved by tetragonal to monoclinic phase transformation [5,8]. The reducing grain growth and stability of zirconia is improved by doping yttria (Y_2O_3) in ZrO_2. The 8 mol% Y_2O_3-ZrO_2 (represented as 8YSZ) is reported to be an ideal material due to its low thermal conductivity (below 2 W m^{-1} K^{-1}) and high durability at elevated temperatures (~ 1400 °C) [9,10].

Electron beam physical vapor deposition (EB-PVD) and atmospheric plasma spray (APS) are the common ways for ceramic layer deposition. EB-PVD produce strain tolerant TBC with enhanced thermal lifetime compared to APS. However, the high thermal conductivity and high cost limits the use of EB-PVD in most practical applications [11,12]. Solution precursor plasma spray (SPPS) method is considered to be a suitable alternate for producing TBC with improved thermal cycling and low thermal conductivity at low cost. The microstructural features obtained from SPPS TBC are responsible for its improved insulating capabilities [13,14].

In a typical SPPS process, chemical precursor (in aqueous form) feedstock is inoculated into the plasma jet and thereby chemical and physical reactions takes place. SPPS process is similar to the APS techniques, however in SPPS technique, atomized precursor is utilized as a feedstock instead of the solid particles in APS. The experimental setup and spraying parameters strongly affect the final coatings. The 8YSZ is a suitable material for thermal barrier coatings applications due to its low thermal conductivity and high durability [15–18]. It would be interesting to investigate the effect of spray parameters on the me-

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Table 1
Solution-precursor plasma spray processing parameters for the different samples.

	8YSZ-1	8YSZ-2	8YSZ-3
Power (KW)	43.8	43.8	43.8
Distance (Gun to the sample) (mm)	38	40	42

chanical, microstructural and thermal properties of 8YSZ prepared by SPPS technique.

In this manuscript, three samples of 8YSZ are prepared by SPPS technique with variable distances between the sample and the spray gun. The prepared coatings are characterized and the mechanical, microstructural and thermal properties are evaluated.

2. Experiments

Mainly three samples of 8 mol% yttria stabilized zirconia were prepared and it was heat treated at different temperatures. In these samples, the distance between the sample and the spray gun is varied. Table 1 shows the specification of each sample involved. The coatings with variable distances between the sample and the spray gun are named as 8YSZ-1, 8YSZ-2 and 8YSZ-3.

Each of the prepared samples was heat treated with different holding time. The samples were heat treated at 1000 °C for 4 h and 10 h. The sample 8YSZ-2 is further investigated and four different samples of 8YSZ-2 are obtained by heat treating the 8YSZ-2 at 450, 500, 550, and 600 °C, represented as 8YSZ-2a, 8YSZ-2b, 8YSZ-2c and 8YSZ-2d, respectively.

Samples for the electron back scattered diffraction (EBSD) analysis are prepared by mechanical polishing. Moreover, it was followed by three consecutive ion beam polishing steps using a Leica EM TIC 3× for 3 h. Using FEI Magellan 400 field-emission scanning electron microscope (SEM) equipped with a Channel 5 EBSD system (Oxford Instruments) and a Nordly-S EBSD detector, the EBSD data was collected. Hardness is calculated using Vickers hardness test by Vickers (TUKON-2100B). The hardness of all samples is calculated at 1000 °C with different holding time. To observe the morphology and cracks in the samples, the samples were examined using Scanning Electron Microscope (SEM) (SU8220, Japan). For the thermodynamic properties investigation, the thermal diffusivity and thermal conductivity are calculated.

3. Results and discussion

Phase analysis of the samples by X-Ray diffraction (XRD) technique is shown in Fig. 1. Due to the similarities between cubic and tetragonal zirconia phases [19], the prepared coatings are composed of tetragonal and/or cubic phases. Processing parameters have no considerable influence on the phase of the coatings and all coatings displayed nearly the same pattern. Coating 8YSZ-2 was further investigated and the XRD patterns of 8YSZ-2 with different heat treatment temperatures are shown in Fig. 1(b). It is interesting to note, that with the increasing heat treatment temperature, no news peaks are detected in the XRD pattern. It means that these phases are quite stable in the range 450–600 °C. Our results are found in agreement with the reported data [3,19,20].

Phase of the coating is also analyzed using EBSD and the results are depicted in Fig. 2. The major phases found in the coatings are $Zr_{0.86}Y_{0.14}O_{1.93}$, $(ZrO_2)_{0.88}(Y_2O_3)_0$ and Baddeleyite represented by green, red, and yellow color, respectively. The coating 8YSZ-1 contain 58.8% of

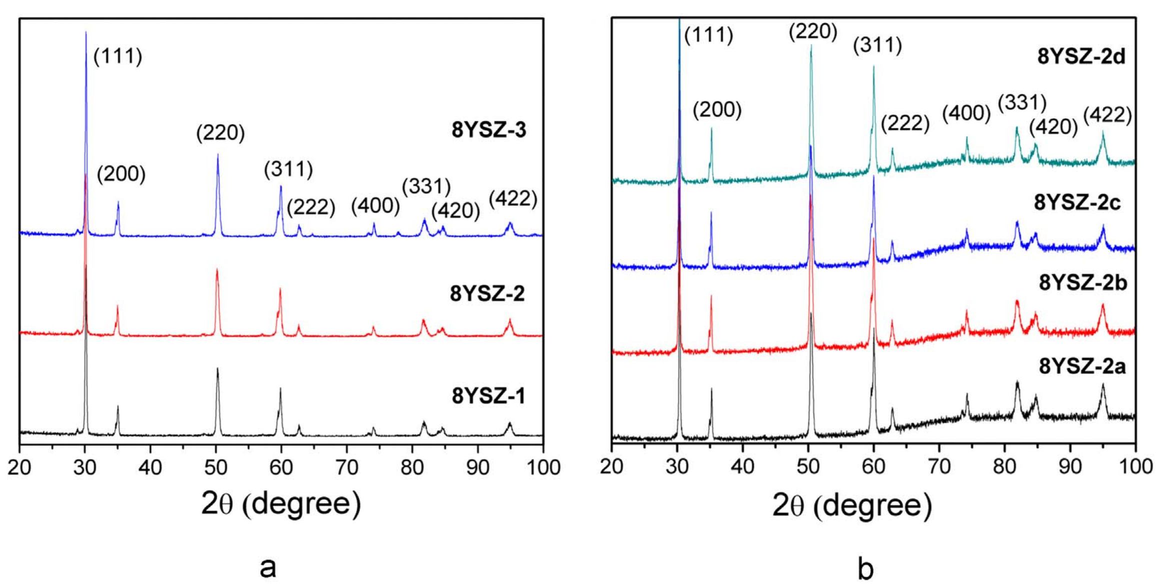

Fig. 1. X-Ray diffraction pattern of: (a) prepared three coatings, (b) sample 8YSZ-2 with different heat treatment temperatures.