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Plasma spray deposition and characterization of strontium zirconate coatings

A. Pragatheeswaran[a], P.V. Ananthapadmanabhan[b,*], Y. Chakravarthy[b], Subhakar Bhandari[b], T.K. Thiyagarajan[b], Nirupuma Tiwari[b], T.K. Saha[b], K. Ramachandran[c]

[a]Department of Physics, Karunaya University, Coimbatore 641114, India
[b]Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai 400085, India
[c]Department of Physics, Bharathiar University, Coimbatore 641046, India

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Abstract

Strontium zirconate has been deposited on stainless steel substrates by atmospheric plasma spray technique. In-flight temperature and velocity of strontium zirconate particles were measured by the 'spraywatch' particle diagnostics system. The coatings have been characterized by x-ray powder diffraction and scanning electron microscope. Results indicated that the coating microstructure, porosity and deposition efficiency could be correlated with torch input power and spray distance in terms of the particle temperature and velocity. Adherent coatings with low porosity could be obtained at 24 kW power and 80 mm standoff distance.

Keywords: Atmospheric plasma spraying; Deposition efficiency; In-flight particle temperature and velocity

1. Introduction

Atmospheric plasma spraying (APS) technique is generally used for depositing ceramic materials due to the high enthalpy and temperature available in the plasma jet. Depending on the process parameters, the temperature at the core of plasma jet can be as high as 10,000–15,000 K and any metal or ceramic powder injected into the plasma jet can be melted and spray coated [1–6]. The injected spray grade powder particles are rapidly melted, accelerated and propelled at high velocity to the substrate surface. Quality of the deposit is determined by many parameters including plasma input power and torch nozzle to substrate distance, which are the most important parameters controlling the coating microstructure [7–14].

By virtue of its low thermal conductivity [15], high melting point [16,17] $SrZrO_3$ ceramic has potential applications for thermal barrier coatings (TBC). The thermal expansion coefficient of $SrZrO_3$ is larger by about 4% [15] than that of Yttria stabilized zirconia in the temperature range 200–1200 °C. This can reduce the stress at the interface of the ceramic layer and bond coat. The value of Young's modulus of $SrZrO_3$ is lower than that of YSZ, which would lead to lower stress level for coatings. The only undesirable feature of $SrZrO_3$ for TBC applications is the temperature induced phase transitions. However, the volume change accompanying the phase transition is very small, only about 0.14% [18] and can be tolerated. Based on their studies on thermal cycling lifetime of plasma spray deposited $SrZrO_3$–YSZ double layer coatings, Wen et al. [15] have suggested the possible use of $SrZrO_3$ as a high temperature alternative to YSZ coatings.

In this study, strontium zirconate was coated by atmospheric plasma spraying technique on stainless steel (SS304) substrates at different power levels and standoff distances. The spraywatch-2i diagnostics system was used to measure the in-flight particles temperature and velocity during plasma spray deposition. The coatings were characterized for phase and microstructure using x-ray diffraction and electron microscopy techniques respectively. Influence of in-flight particle temperature and velocity on microstructure, deposition efficiency, porosity of coatings and micro-hardness of the deposit are also discussed.

*Corresponding author. Tel.: +91 22 25595107.
E-mail address: pvapadmanabhan@gmail.com
(P.V. Ananthapadmanabhan).

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2. Experimental procedure

Plasma spray grade strontium zirconate powder supplied by Cerac Incorporated, Wisconsin was sieved and collected in a narrow size range of 63–75 μm that was used as feedstock powder for all the experiments. Plasma spray deposition of $SrZrO_3$ was carried out on sand blasted stainless steel (SS) coupons (30 × 25 × 2 mm). Plasma deposition was carried out using a 40-kW atmospheric plasma spray system developed at the Laser & Plasma Technology Division, BARC. The powder was stored in a powder feeder and injected into the plasma jet through a side port located 3 mm inside the plasma torch nozzle exit. A mixture of argon and nitrogen was used as the plasma gas. The coatings on coupons were carried out at 16, 20, 22 and 24 kW plasma power. Spray deposition was carried out at 60 mm, 80 mm and 100 mm at each power level. The experimental parameters are given in Table 1.

2.1. *Inflight particle diagnostics*

The surface temperature and velocity of in-flight particle was measured by Oseir's (Oseir Ltd., Tampere, Finland) 'Spray-watch 2i' diagnostics system. 'Spraywatch' measures the velocity and temperature of particles in a volume ensemble of 20 mm × 20 mm × 20 mm of the plasma jet emerging from the torch nozzle. In-flight particle temperature and velocity were measured at various axial locations of 50–70, 70–90 and 90–110 mm from the nozzle. The stream of particles crossing the measurement volume was imaged for a short duration of 5–10 μs using photodetectors, computer controlled CCD camera and dedicated image analysis software. The velocity was computed by the time-of-flight method and particle temperature was measured by two color pyrometer [19]. Particle diagnostics was not possible up to 40 mm distance from the nozzle, because of the intense plasma luminescence, which eclipsed the particles. The reported value is the average of 25 readings of the particle temperature and velocity measurements.

2.2. *Plasma spray coating characterization*

The phase composition of the feedstock powder and coated samples were carried out by x-ray diffraction using Philips X'pert diffractometer. Diffraction patterns were recorded in the two-theta range of 5° to 65° using copper K-α radiation of wavelength 1.5404 Å with a step size of 5°/min. Plasma sprayed coated samples were carefully cut by precision diamond abrasive wheel and the cross-sectioned samples were mounted by a cold setting epoxy resin and allowed to cure at room temperature for 24 hours. The mounted samples were polished using various emery papers of grit size from 400 to 2500 and final polishing was done with diamond paste grade of 3–0.25 μm size. These cross sectioned samples were used to analyze the coating microstructure of $SrZrO_3$.

The coating microstructure was studied by electron microscopy using Carl Zeiss model EVO40 scanning electron microscope (SEM). The samples were gold coated with thickness of about 7 nm before taking microstructure. In order to observe the porosity and other features, microstructures were taken at 1000 × . Plasma spray deposition efficiency was measured from the powder feed rate, coating time and the weight of powder deposited. The torch and substrate were fixed and spray deposition was carried out for one minute duration for deposition efficiency measurements on sand-blasted SS304 substrates of 50 × 50 × 4 mm dimensions. The micro-hardness of the coatings was measured by using Future-Tech micro-hardness tester under 50 gf load force and dwelling time of 10 s for all the samples.

Table 1
Operating parameters for the plasma spray torch and spraywatch.

Parameters	Value
Power (kW)	16, 20, 22, 24
Primary gas flow rate (SLPM)	30
Carrier gas flow rate (SLPM)	10–12
Powder feeding rate (g/min)	~10
Secondary gas flow N_2 (SLPM)	3–4
Coating standoff distance (mm)	60, 80, 100
Particle size range (μm)	63–75
Spraywatch standoff distance (mm)	50–70, 70–90, 90–110

3. Result and discussion

3.1. *In-flight particle characterization*

Particle temperature and velocity measured at different axial locations for various input power of the plasma are shown in Fig. 1(a) and (b). The dependence of particle temperature and velocity on plasma power is evident from the figures. The temperature and velocity at a given axial location is seen to increase with the input power. For a given input power, the particle temperature increases, reaching a maximum at about 80 mm from the nozzle and then starts decreasing. The average particle temperature at 16 kW and 60 mm distance was found to be 2530 °C. This value rises to 2560 °C at 80 mm from the nozzle and then falls. This trend is observed for all the power levels; however, the value of the temperature is higher at higher power. This finding is in agreement with the simulation results reported by Thiyagarajan et al. [20], who have studied the thermal behavior of yttrium oxide in a thermal plasma jet. It is seen that at 24 kW power, the average particle temperature, 80 mm down the nozzle, reaches 2800 °C, well above melting temperature of strontium zirconate. Simulation studies and experimental results of Ramachandran et al. [21] and Wan et al. [22] show that particle velocity also follows the trend similar to that of temperature. However, in our experiments velocity was found to decrease with standoff distance for all power levels. This may be because the measurement window was farther away from the axial location at which particle velocity was maximum.

3.2. *X-ray diffraction*

XRD patterns of the feedstock and plasma spray deposited $SrZrO_3$ are shown in Fig. 2. It is seen from the x-ray