Available online at www.sciencedirect.com
ScienceDirect
Vacuum 80 (2006) 1336–1340
VACUUM
SURFACE ENGINEERING, SURFACE INSTRUMENTATION & VACUUM TECHNOLOGY
www.elsevier.com/locate/vacuum

Microstructural characterization and properties of ZrO_2/Al_2O_3 thermal barrier coatings by gas tunnel-type plasma spraying

Gurusamy Shanmugavelayutham, Shoji Yano, Akira Kobayashi*

Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Abstract

Spraying condition plays an important role in the plasma-sprayed coating process and affects the final properties of the coatings. Zirconia, alumina and zirconia/alumina composite coatings were prepared on a stainless-steel substrate (SUS304) by the gas tunnel-type plasma spraying. Effects of different alumina mixing ratios on the coating properties were investigated. The results indicated that the mixing ratio of powders and the traverse number of substrate had an influence on the hardness, porosity and wear weight loss of composite coatings. The hardness increased while the porosity decreased with the increase in alumina mixing ratio. The porosity that was less than 10% and a hardness about $Hv = 1400$ was obtained for the alumina coating. The adhesive strength and wear weight loss of the composite coatings were also clarified at different alumina mixing ratios.

Keywords: Gas tunnel-type plasma spray; Zirconia/alumina composite coating; Adhesive strength; Hardness; Wear weight loss; XRD

1. Introduction

Thermal spraying is a highly complex deposition process with a large number of inter-related variables [1–3]. Due to the high velocity and the temperature gradients in the plume, even small changes in the controllable or uncontrollable parameters can result in significant changes in the particle properties and, in result, the microstructure of the coatings [4]. The coating microstructure is characterized by a heterogeneous-phase configuration with porosity content due to the voids left by the stacking process. In order to achieve consistent high-quality coatings to meet the more demanding performance requirements of today's applications, there is a need to put more effort into improvement of the plasma spray process. The control of the ceramic in-service properties and especially the wear behaviour is sensitive to the large number of the processing parameters and their interdependencies. Such control is obviously difficult to establish, and most models nowadays consider only a fewer number of control factors which have direct correlations with the processing parameters.

Gas tunnel-type plasma spraying has been developed [5–7] to produce new thermal barrier coatings that have superior properties as compared to the conventional plasma spray method. High-hardness ceramic coatings were investigated under the development of multilayered zirconia/alumina coatings with better structures. Multilayered graded surface treatment that offers optimized performance and novel coating processing technologies is being used to manufacture numerous coating systems that embody smart concepts [8].

In this study, zirconia/alumina composite coatings were deposited by using the gas tunnel-type plasma spraying with different spraying conditions such as mixing ratio of powders and substrate traverse time. Structure of the composite coating was also investigated by the X-ray diffraction (XRD) pattern.

2. Experimental details

Commercially available alumina and zirconia powders were used to deposit 100 wt% ZrO_2, 80 wt% ZrO_2–20 wt% Al_2O_3, 50 wt% ZrO_2–50 wt% Al_2O_3, 20 wt% ZrO_2–80 wt% Al_2O_3 and 100 wt% Al_2O_3 coatings onto grit-blasted stainless-steel substrates using a gas tunnel-type plasma

*Corresponding author. Tel./fax: +81 6 6879 8694.
E-mail address: kobayasi@jwri.osaka-u.ac.jp (A. Kobayashi).

0042-207X/$ - see front matter
doi:10.1016/j.vacuum.2006.01.056

spray system under atmospheric conditions. Fig. 1 shows a schematic diagram of the gas tunnel-type plasma torch. Operating conditions are listed in Table 1.

All the coated samples were prepared by adjusting the plasma torch power levels at 21 kW. The plasma jet is generated with the aid of argon gas whose flow rate was set as 180 l/min. The torch was maintained at a spray distance of 40 mm from the substrate plane. The feedstock powders were externally injected into the torch and directed parallel to the plasma flow and parallel to the torch trajectory. The maximum feed rate was 45 g/min. The spray system consists of a combination of a rotating sample holder and a permanently fixed torch. The substrate traverse numbers optimized were 4, 10 and 20 times. To avoid adhesion problems due to the mismatch of thermal expansion coefficients between the coating and the substrate and to reduce the stress level, nitrogen gas was added to the spray configuration to lower the coating temperature during deposition.

Experiments were conducted with four processing parameters: arc current, gas flow rate, powder carrier gas flow rate and injection distance. The first two parameters are known to significantly influence the plasma jet properties (enthalpy, velocity, etc.) and the last two influence the particle trajectories in the plasma jet. Microscopic observation of the coatings was performed using an optical microscope (NIKON, Japan) and porosity was also measured by image analysis software with a CCD camera (FCD-10, IKEGAMI, Japan). Vickers microhardness was measured by using a microhardness tester (MATSUZAWA-MXT50) with a 0.5 N load and indentation parameters were set as 20 s loading time. Wear weight loss was calculated by using the abrasive wear loss method (10×10 mm sample holder and 400 mm SiC emery paper). The relationship between bond strength and wear resistance was investigated.

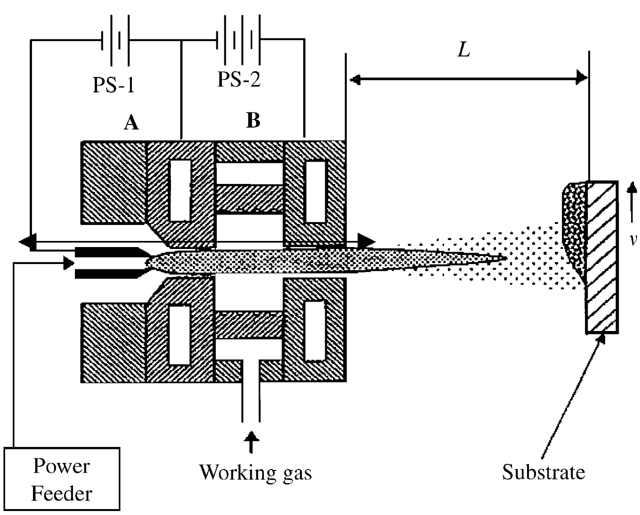

Fig. 1. Schematic diagram of the gas tunnel-type plasma-spraying torch system.

Table 1
Experimental conditions

Powder	$ZrO_2 + Al_2O_3$ mixture
Traverse number, N	4, 10 and 20
Power input, P (kW)	17–21
Working gas flow rate, Q (l/min)	180
Powder feed gas, Q_{feed} (l/min)	10
Spraying distance, L (mm)	40
Traverse speed, v (cm/min)	50 and 100
Powder feed rate, w (g/min)	25–45
Gas divertor nozzle diameter, d (mm)	20

3. Results and discussion

3.1. Microstructure of the coatings

Fig. 2 shows a typical microstructure of the dense plasma-sprayed ZrO_2 coating with homogeneously dispersed porosity. It was evident that no macrocracking was found. Pores were shown as black areas in the micrograph. It has been reported that pore content changes with surface roughness of the substrate, spray distance, substrate temperature and coating thickness [9]. It can be seen that

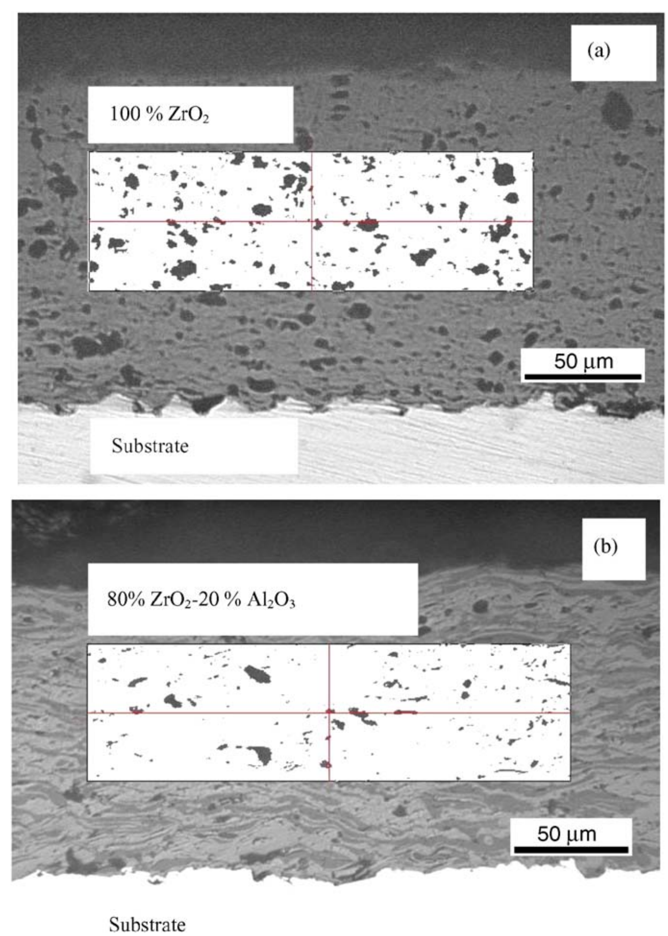

Fig. 2. Optical micrographs of the microstructure and porosity on the cross section of zirconia/alumina composite coatings. (a) 100% ZrO_2 and (b) 80% ZrO_2–20% Al_2O_3 composite coatings after image processing.