Available online at www.sciencedirect.com

SCIENCE DIRECT®

Thin Solid Films 506–507 (2006) 136 – 139

thin solid films

www.elsevier.com/locate/tsf

Segmented thermal barrier coatings produced by atmospheric plasma spraying hollow powders

H.B. Guo [a,b,*], S. Kuroda [b], H. Murakami [a,b]

[a] *Department of Materials Engineering, School of Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-Ku, Tokyo, 113-8656, Japan*
[b] *Thermal Spray Group, Materials Engineering Laboratory, National Institute for Materials Science, 1-2-1, Sengen, Tsukuba Science City, Ibaraki, 305-0047, Japan*

Available online 9 September 2005

Abstract

Segmented thermal barrier coatings were produced by plasma spraying hollow and solid ZrO_2–8 wt.% Y_2O_3 powders. The solid powder (SP) had greater capability of producing segmentation cracks in coating compared with the hollow powder (HP). High substrate temperature (T_s) gave rise to an increased segmentation crack density (D_s). The segmentation crack network was still stable even after sintering at 1300 °C for 15 h. The microcracks that are mainly attributed to delaminations between splats had a negative effect on the origin and propagation of segmentation cracks.

Keywords: Plasma spraying; Thermal barrier coatings; Segmentation cracks

1. Introduction

Plasma sprayed thermal barrier coatings (TBCs) are extensively used in critical hot section components of gas turbines. The use of TBCs (usually 100 to 500 μm in thickness), along with internal cooling of the underlying superalloy component, provides a reduction of 100–300 °C in the surface temperature of the superalloy [1]. This enables the gas turbines to operate at gas temperatures above the melting temperature of the superalloy, thereby improving the efficiency and performance of engines. Recent demands on engine performance, however, have required the implementation of even thicker coatings for increased thermal protection [2]. TBCs with a thickness of more than 1 mm are being developed to fulfill the demand, but present new problems unseen with traditional thinner TBCs. A major problem concerning the thick coating is a low thermal shock resistance when the coating is subjected to thermal shock loads [3].

Microstructure modifications have been done to improve the thermal shock resistance of thick TBCs [3–5]. A certain degree of porosity and microcracks is favorable in achieving a high level of thermal shock resistance [6]. Segmentation cracks enable TBCs to tolerate greater strains, thereby improving thermal shock behaviors of TBCs. A segmentation crack network was developed when “hot-spraying” was conducted (without cooling during spraying) and moreover, an increased surface temperature produced a denser network of segmentation cracks [7].

Powder feedstock characteristics (such as particle density, size and shape) have considerable effects on sprayed coating microstructures. The present work investigates influence of two kinds of powders and spray conditions on coating microstructures aiming at developing TBCs with high segmentation crack density.

2. Experimental

2.1. Materials and spray details

YSZ coatings have been produced in an atmospheric plasma spraying facility using an SG100 Gun (Praxair,

* Corresponding author. Thermal Spray Group, Materials Engineering Laboratory, National Institute for Materials Science, 1-2-1, Sengen, Tsukuba Science City, Ibaraki, 305-0047, Japan. Tel.: +81 29 859 2449; fax: +81 29 859 2401.

E-mail address: guo.hongbo@nims.go.jp (H.B. Guo).

0040-6090/$ - see front matter
doi:10.1016/j.tsf.2005.08.142

Table 1
Spray parameters used for the preparation of YSZ top coatings

No.	Current (A)	Voltage (V)	D (mm)	Ar (slpm)/He (slpm)	F (g/min)	S (mm/s)	T_s (°C)
1	800	40	80	50/27	40	200	700
2	800	40	100	50/27	20	200	500
3	1000	30	70	40/13	20	200	650
4	1200	32	60	35/13	20	150	800

D: spray distance; F: powder feed rate; S: plasma gun traverse speed; T_s: substrate temperature.

USA). 316 L steel was used as substrate materials. Two kinds of zirconia stabilized with 8 wt.% Y_2O_3 powders, hollow spherical powder (Metco 204NS) and solid angular powder (Showa Denko, K-90) were chosen as spraying materials for the coatings. The hollow powder (HP) shows a broad particle size distribution that ranges from 20 μm to 120 μm, with a shell thickness of about 10 μm. The size for the solid powder (SP) is between 10 μm and 60 μm. Two sample holders made from a refractory brick (holder A) and steel (holder B) were employed to hold the substrate during spraying. In the case of holder B a faster cooling of coating was obtained during the deposition. The choice of spray parameters is based on a previous work [4]. The processing parameters for the spraying are listed in Table 1.

2.2. Microstructure characterization

The planar sections and cross-sections of the coatings were examined by optical microscopy (OM) and scanning electron microscopy (SEM). Segmentation cracks are defined as cracks running perpendicular to the coating surface and penetrating at least half the coating thickness. Segmentation crack density (D_s) was calculated by dividing the number of segmentation cracks in a cross-section with the length of the cross-section. Freestanding samples have been prepared by removing the substrate from the coating with a hydrochloric acid solution. The freestanding coatings have been heat-treated at 1300 °C in air furnace for 15 h. Pore size distribution of the coatings was determined using a mercury porosimeter. Total porosity was measured by Archimedes's technique.

3. Results and discussion

Fig. 1 shows the micrographs of YSZ coatings sprayed using holder A. A large number of segmentation cracks were distributed uniformly in the coating sprayed from the SP. However, there is no segmentation crack in the coating sprayed from the HP. In the case of holder B, the coatings sprayed from the HP contain some segmentation cracks, as shown in Fig. 2. The coating obtained at 800 °C shows an increased number of segmentation cracks compared with those obtained at 500 °C and 650 °C. Some delamination cracks and large pores are present in the coatings sprayed at the lower temperatures.

Fig. 3 shows dependence of the measured D_s on substrate temperature (T_s). All the coatings were produced using holder B. Basically, high temperature gave rise to increased D_s. For the coatings sprayed from the SP, a D_s was measured as high as 3.7 mm^{-1}. However, the coatings sprayed from the HP had lower D_s than those from the SP. It seems that the SP is much easier to produce segmentation cracks in coatings. The D_s for the heat-treated coatings were also examined in order to study the stability of segmentation crack network during sintering. The densities of the heat-treated coatings are slightly different from those of the as-sprayed coatings; however, the difference is not so significant considering the errors associated with the measurements. It can be concluded that segmentation cracks hardly initiated during high temperature sintering.

Fig. 4 shows the fracture surfaces of cross-sections of the coatings sprayed from the HP using holder B. For the coating sprayed at 650 °C, the interfaces between splats are obvious, which means a poor contact between the splats (see Fig. 4a). Compared to the above coating, the coating obtained at 800 °C seems to be denser, since there are only few cracks and pores in the coating (see Fig. 4b). Furthermore, the cohesion within the lamellae, compared to the structure in Fig. 4a, is apparently improved because of the lower amount of delaminations. Additionally, this

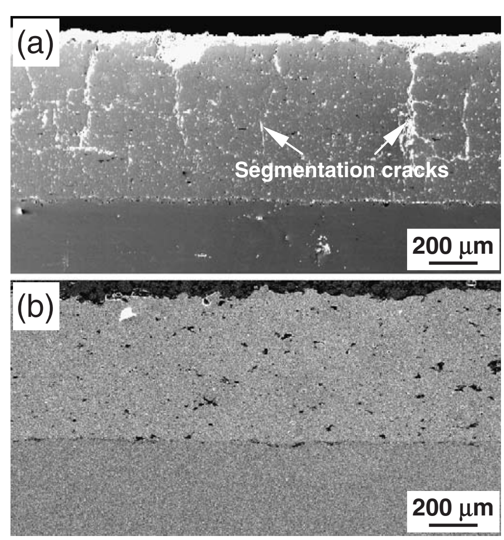

Fig. 1. SEM micrographs of YSZ coatings sprayed at 700 °C from solid powders (a) and at 850 °C from hollow powders (b). Holder A was used during the spraying.