G Model
JECS-10707; No. of Pages 7
ARTICLE IN PRESS
Journal of the European Ceramic Society xxx (2016) xxx–xxx
Contents lists available at www.sciencedirect.com
Journal of the European Ceramic Society
journal homepage: www.elsevier.com/locate/jeurceramsoc

In-situ fabrication of amorphous/eutectic Al_2O_3–YAG ceramic composite coating via atmospheric plasma spraying

Kai Yang[a,*], Jian Rong[a], Jingwei Feng[a,b], Yin Zhuang[a], Shunyan Tao[a], Chuanxian Ding[a]

[a] Key Laboratory of Inorganic Coating Materials CAS, Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai 201899, PR China
[b] Inorganic Materials Analysis and Testing Center, Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai 200050, PR China

ARTICLE INFO

Article history:
Received 3 February 2016
Received in revised form 31 May 2016
Accepted 5 June 2016
Available online xxx

Keywords:
Plasma spraying
Amorphous oxides
Coatings
Eutectic phase transformation
Al_2O_3–$Y_3Al_5O_{12}$ (YAG)

ABSTRACT

The microstructure and property of plasma-sprayed Al_2O_3–$Y_3Al_5O_{12}$ (YAG) composite coatings were investigated. The sprayable feedstock was composed of Al_2O_3/Y_2O_3 granules obtained from the spray drying. As-sprayed Al_2O_3–YAG composite coating showed obvious amorphous characteristics. Post-heat treatment facilitated the complete crystallization of the Al_2O_3–YAG composite coating. The heat-treated Al_2O_3–YAG ceramic coating possessed the deposition microstructure comprising three-dimensional interpenetrating network of α-Al_2O_3/YAG eutectic phases, which is very similar to the directional solidification microstructure of Al_2O_3/YAG eutectic bulk ceramics. This eutectic coating microstructure does not correspond to a traditional eutectic microstructure. Al_2O_3–YAG ceramic coating with eutectic composition is obtained from the crystallization of an amorphous solid ceramic instead of the solidification of the liquid. Furthermore, the plasma-sprayed Al_2O_3–YAG eutectic ceramic coating with the heat treatment exhibits excellent microstructure and performance stabilities under high temperature.

1. Introduction

Oxide ceramics show high strength, high hardness and anti-wear performance, as well as high temperature and good oxidation resistances [1–3]. The corresponding coatings are expected to supply effective surface protection for the various workpieces against the severe working conditions of high temperature, high load capacity, serious oxidation and strong thermal shock. The Al_2O_3 coatings are considered to be the typical representative of oxide ceramic coatings [4]. The previous studies were focused on the strength-toughness enhancement of the Al_2O_3 coatings, including porosity control [5], metal phase addition [6], other oxide solution [7–9], structure nano-crystallization [10], component or structure gradient [11] and post processing [12]. However, some problems exist in the above-mentioned property improvement methods: (1) limited effects of porosity change; (2) obviously decreased hardness and strength of the coating due to the metal phase addition; (3) lower thermal conductivity for Al_2O_3–ZrO_2 coatings and worse mechanical behavior under high temperature for Al_2O_3–TiO_2 coatings; (4) poor high temperature microstructure stability caused by the nano crystalline growth and heat-conducting performance reduction caused by the increased phonon scattering in the nano-sized Al_2O_3 coatings; (5) aggravated layering effects in the gradient coatings; (6) laser-remelting easily resulting in high level residual stress, superheating damage and matrix oxidization in the coating system. Accordingly, it is necessary to seek new method to enhance microstructure stability, mechanical property, thermal conduction, density and interface cohesion of the Al_2O_3 coatings, which would be conducive to endure the drastic thermal-mechanical coupling actions (high temperature/high velocity/high load/thermal shock).

Directionally solidified Al_2O_3-based eutectic ceramic in situ bulk composites with inherently high melting point, excellent microstructure stability, low defect, outstanding resistance to creep, corrosion and oxidization at an elevated temperature, have attracted great interest as promising candidate for high-temperature applications [13]. Binary and pseudo-binary eutectics, ternary eutectics and even some off-eutectic compositions of the ternary system Al_2O_3–ZrO_2–Y_2O_3 were explored in detail [14], including Al_2O_3–ZrO_2, Al_2O_3–YSZ (yttria-stabilized zirconia), Al_2O_3–$Y_3Al_5O_{12}$ (YAG), Al_2O_3–YAG–ZrO_2 and Al_2O_3–YAG–YSZ eutectic oxide ceramics. In particular, binary Al_2O_3–YAG eutectics have been reported to exhibit excellent mechanical performance, thermal conduction and creep resistance at high temperatures [15], which could be attributed to large area fraction of clean and strong interfaces without glassy phases and continuous interpenetrating networks formed by nano-scale or sub-micron eutectic phases [16].

* Corresponding author.
E-mail address: kaiyang@mail.sic.ac.cn (K. Yang).

http://dx.doi.org/10.1016/j.jeurceramsoc.2016.06.012
0955-2219/

Please cite this article in press as: K. Yang, et al., In-situ fabrication of amorphous/eutectic Al_2O_3–YAG ceramic composite coating via atmospheric plasma spraying, *J Eur Ceram Soc* (2016), http://dx.doi.org/10.1016/j.jeurceramsoc.2016.06.012

From the point of view of processing, the key to obtaining the homogeneous microstructure of Al_2O_3-based eutectic ceramics is to keep flat solid-liquid interfaces during growth at microscopic and macroscopic levels, and this requires large thermal gradient in the solidification direction. High-performance directionally solidified Al_2O_3-based bulk eutectics have been successfully produced in small cylindrical geometry by means of various techniques [17], such as the Bridgman, laser floating zone (LFZ), edge-defined film-fed growth (EFG), micro-pulling-down (μ-PD), laser engineered net shaping (LENS), and selective laser melting (SLM) methods. Based on the analysis of process conditions, there are three similarities existing in these eutectic ceramic preparation procedures: (1) high enthalpy; (2) steep temperature gradient; (3) rapid solidification. The three features may be critical to fabricate Al_2O_3-based eutectic ceramics. Furthermore, whether the distinct performance superiority of Al_2O_3-based eutectic bulk ceramics could be realized in the form of corresponding eutectic ceramic coatings?

Plasma spraying is a thermal spraying process used to produce high quality coatings by a combination of high temperature, high energy heat source, a relatively inert spraying medium, and high particle velocities. In plasma spraying devices, the arc is formed between two electrodes in plasma forming gas. Temperatures in the arc zone approach 20,000 K. Plasma sprayed coatings are made up of flattened particles, known as splats. The splats constitute layers in the coating and these layers in turn create the lamellar structure of the deposit. The high quench rate of the molten particles during plasma spraying is about 10^6 K s^{-1} [18]. The estimated temperature gradients in splats approach 10^4 K cm^{-1}. According to the above analysis, plasma spraying possesses three basic features, which may be consistent with the above-mentioned three critical factors of Al_2O_3-based eutectic bulk ceramic preparation. This indicates the corresponding eutectic ceramic coatings might be fabricated. In this paper, we proposed a bold hypothesis that Al_2O_3–YAG eutectic ceramic coating may be obtained via atmospheric plasma spraying. Interestingly, the amorphous phase is dominant in the as-sprayed Al_2O_3–YAG coating due to the greatly rapid cooling rate. Heat treatment facilitates the full crystallization of the coating, which shows the typical three-dimensional interpenetrating eutectic network structure consisting of α-Al_2O_3 and YAG phases. The coating microstructure here presented is not obtained from the traditional eutectic reaction (solidification of the liquid). The objectives of this work are to investigate the microstructure characterization of as-sprayed and heat-treated Al_2O_3–YAG composite coatings and to evaluate the microstructure and property stabilities of Al_2O_3–YAG eutectic coating.

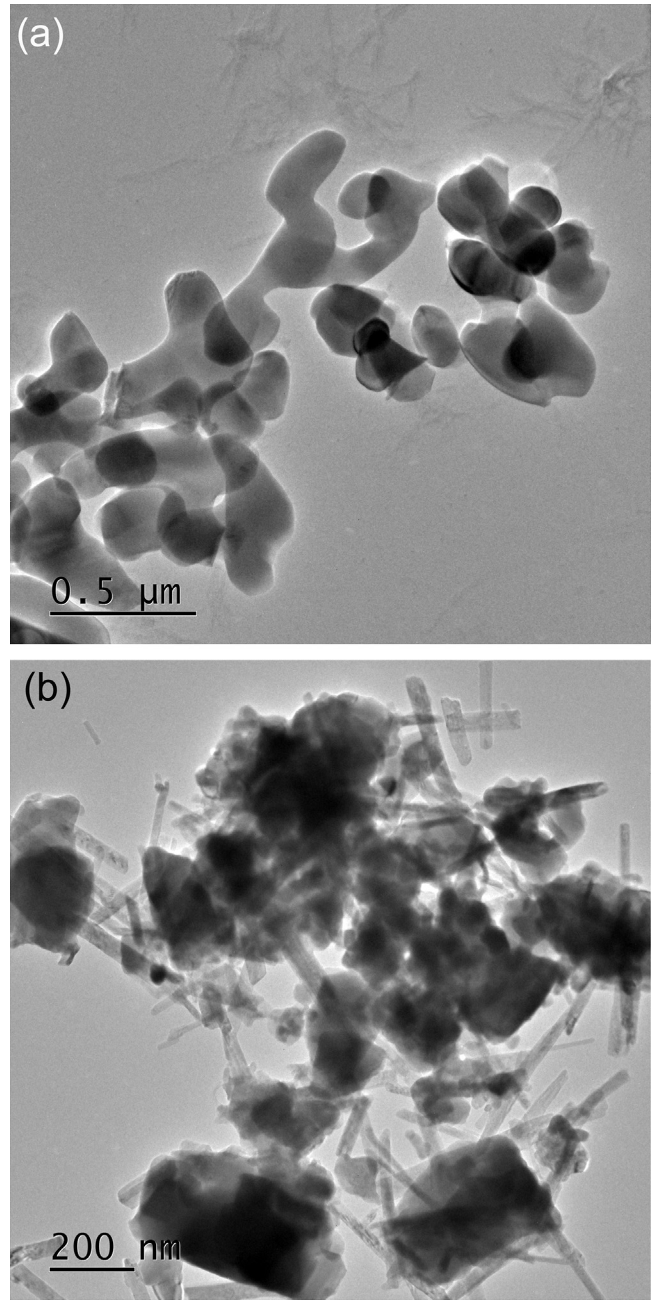

Fig. 1. TEM images of nano-sized powders: (a) Al_2O_3; (b) Y_2O_3.

2. Experimental procedure

2.1. Feedstock preparation

Commercially available nano-sized Al_2O_3 and Y_2O_3 powders (shown in Fig. 1) were used as feedstocks. The average sizes (D50) of Al_2O_3 and Y_2O_3 nanopowders are 76.4 nm and 74.2 nm, respectively. The nano-sized particles had to be granulated to micron-sized granules since they could not be used as sprayable feedstocks directly. The Al_2O_3 and Y_2O_3 nanopowders with the eutectic composition (82 mol% Al_2O_3, 18 mol% Y_2O_3) were put into the ball milling tank, which contained alumina based balls (the weight ratio of balls to powers was 4:1). After 10 h ball milling, as s typical mixture of the deionized water, binder, dispersant, and nanopowders were stirred homogenously for 4 h. When the corresponding slurry was prepared, the spray drying process was continued directly in order to avoid the precipitation of slurry. The main controlled operating parameters were the air temperature at the entry (220–240 °C), at the exit (120–130 °C), inside the chamber (170 °C), the rotation speed of atomizer (12,000 rpm), and slurry flow rates (1–1.2 kg/h). In order to increase the density of granules and eliminate all the organic additives, the granulated particles obtained from the spray drying process, were calcined. The sintering temperature (1000–1100 °C) was determined by the thermo gravimetric analysis (TGA) method. After that, small (<15 μm) and large particles (>65 μm) were removed by passing them through sieves to meet the demands of sprayable feedstocks. The corresponding morphology was presented in Fig. 2.

2.2. Coating deposition

The Multicoat atmospheric plasma spraying system equipped with a F4-MB plasma gun (Sulzer Metco AG, Switzerland) was applied to produce the coating. Prior to spraying, the rectangular stainless steel substrates with the dimensions of