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Structural and mechanical properties of graded composite Al_2O_3/Ni obtained from slurry of different solid content

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Abstract

In this work, an alumina-nickel graded hollow cylinders were prepared by the centrifugal slip casting. In the paper, the results for samples formed from slurries with different solid content: 45 vol.%, 40 vol.% and 35 vol.% are presented. The structure of the samples after sintering was examined by X-ray diffraction (XRD). The microstructure of the composite, especially the nickel particle size distributions were investigated by using scanning electron microscopy (SEM). An image analyzer has been used for the measurement of volume fraction of the nickel particles in the composites. The hardness was measured by using a Vickers hardness-testing. Based on hardness measurements K_{IC} value were determined. The XRD results confirmed only two phases: Ni and α-Al_2O_3 in all samples. The preliminary macroscopic observation as well as SEM showed, that the microstructure of the sample cross-section is not homogeneous. Microstructural characterization revealed the gradation of nickel content along the radial direction of hollow cylinder. Three zones were distinguished, from outer surface towards the inner side of the tube. The maximum of volume fraction of nickel particles was obtained at the middle zone of the composites. The results of hardness-testing revealed that the maximum hardness values were observed in region at the inner edge of the casting due to an absence of nickel particles.

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Keywords: Functionally graded materials (FGM), Ceramic-Metal Composites, Microstructure, Microhardness

1. Introduction

The demand for the Functionally Graded Materials (FGMs) have increased significantly in recent years due to their unique properties, which are not achieved by the conventional materials. FGM consisting of two or more phases, in

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which properties change at least in the one spatial direction (Miyamoto 1999; Ogawa 2006; Hirai 1996; Suresh 1998; Neubrand 1997; Tomsia 1998; Mortensen 1995). These materials have successfully been introduced in many applications field due to their unique physical and mechanical properties (Suresh et al. 1998).
Example of the FGMs are Al_2O_3-Ni composites with a gradient of Ni concentration obtained by the centrifugal slip casting (Zygmuntowicz et al. 2015). Own experiments and research showed that the tree zones with different Ni particles concentration can be distinguished (Zygmuntowicz et al. 2015). Depending on the content of the metal particle in the zone, the composites have a different microstructure, and hence different mechanical properties. The zones containing metal particles are characterized by increased fracture toughness compared to the zones with lower content of metal particles (Moya 2007; Konopka 2001; Konopka 2003; Diaz 2000; Sun 1996).

The metal particles in a ceramic matrix can disperse the energy of propagating cracks (Yeomans, 2008). In the case, when the metallic and ceramic phases are firmly connected together, important role in increasing the fracture toughness has mechanism of bridging an advancing cracks by the ductile particles (Konopka 2003; Yeomans 2008). The zones composed almost entirely of ceramic are characterized by higher brittleness as compared to areas containing the metal particles, although these zones have a higher hardness.

The width of each zone can be controlled through the selection of technological parameters such as: solids content, the amount of the metallic phase, speed of the mixing or the size of used powders (Zygmuntowicz et al. 2015).

The purpose of the present work is to prepare Al_2O_3-Ni functionally gradient materials from the slurry of different solid content (35 vol.%, 40 vol.%, 45 vol.%). The dependency between the microstructures and mechanical properties (the fracture toughness and hardness) of the composites are discussed.

2. Experimental procedure

Functionally gradient composites with 45 vol.%, 40 vol.% and 35 vol.% content of solid phase in an aqueous based slurries containing alumina and nickel powder (10 vol.% with respect to total volume) were tested. The following commercially available powders were used for this work: Al_2O_3 TM-DAR from Taimei Chemicals of an average particle size 133 nm and density 396000 kg/m^3, and Ni powder from Alfa Aesar of an average particle size 27 μm and density 89000 kg/m^3. Citric acid (≥ 99.5% Sigma-Aldrich) and diammonium hydrocitrate (puriss, POCh) were applied as dispersant in the composite slurries.

Composites were fabricated by centrifugal slip casting method. Fig. 1. and Fig. 2. show the schematic diagram of used vertical centrifugal casting equipment and the summarized processing route applied in this work for the fabrication of graded hollow cylinders. Ceramic suspensions were prepared by mixing of powders with deflocculates and water as a solvent in a planetary ball mill PM100 (Retsch) for 1 hours with a speed of 300 rpm. The slurry were poured in a gypsum mold with the inner diameter of 0.02 m. The cylindrical mold was centrifuged along the radial direction with a speed of 1000 rpm for 4 hours. After centrifugation, the sample together with a gypsum mold was removed from metal mold and the gypsum mold with sample was dried in vertical position inside vacuum chamber at room temperature for 24 hours. The dried and shrunk sample could be removed from the gypsum mold easily. The sample was sintered at 1400°C in an atmosphere of H_2/N_2 with H_2 of 20 vol. % and rest N_2. The heating and cooling rate was taken as 1°C/min through sintering process. The dimensions of the fabricated tubes after sintering were 0.04 m length and 0.020 m outer radius with a wall thickness falling between 0.016 and 0.018 m. The sintered functionally graded hollow cylinder composites are show in the Fig. 3.