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Combined centrifugal-slip casting method used for preparation the Al_2O_3-Ni functionally graded composites

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ABSTRACT

The centrifugal-slip casting method was used for producing the Al2O3-Ni composites with a gradient distribution of the Ni phase. The final products had the shape of hollow cylinders. The casting slurries were water-based and contained alumina and nickel powders with two different particle sizes. The cast samples were then subjected to sintering at a temperature of 1400 °C in an N2/H2 reducing atmosphere with heating and cooling rates of 1 °C/min, and the dwell time - 4 h.

The rheological properties of the water-based slurries were examined. It appeared that the presence of the Ni particles strongly affected the slurry properties which was probably associated with the strong interactions between the Ni and α-Al_2O_3 particles.

The Al_2O_3-Ni composites with a gradient distribution of the Ni particles were examined using the X-ray diffraction method. No new phases such as the nickel aluminate spinel were identified in the sintered composites.

The microstructure of the samples was analyzed using Scanning Electron Microscopy (SEM). The observations revealed that the samples were composed of three zones with different distributions of the Ni particles on their cross-section. Finally, the Ni particle distribution in the functionally graded materials was described quantitatively.

1. Introduction

Ceramic matrix composites reinforced with metal particles are materials with a potentially wide application range. There is a possibility of a significant increase of their fracture toughness (compared with that of monolithic ceramics) so as to take full advantage of the excellent strength, and the chemical and thermal resistance of the ceramic matrix [1–3]. In ceramic-matrix composites, the main parameters on which the increase of the fracture toughness depends are the distribution of the metal phase and the distance between the particles [4]. Taking into account that irrespective of the load type (bending, twisting), the highest stress is induced on the surface of the sample, a good solution seems to be a gradient distribution of the metal particles in the sample, thus, the preparation of a functionally graded material (FGM) [5–8]. The use of graded materials can reduce the costs of raw materials as well as the costs of the servicing and maintenance of structural components. The prediction of the properties of composites with a gradient microstructure is a complicated issue. For this group of materials with a complex structure, the use of analytical models is very useful. Dorduncu studied in his work [9] wave propagation in functionally graded alumina-nickel cylinder subjected to dynamic load. In their research Apuzzo and his team investigated the elastostatic problem of functionally graded plate under constant distributions of transverse loads per unit area [10]. A separate, an interesting subject is also research on contributions on analytical modeling of functionally graded composites which were conducted by Barrett and his team [11–14].

The current state of knowledge indicates that graded materials can be prepared by a variety of fundamentally differing methods. One of the most economical methods of producing FGM composites is centrifugal casting [15]. In the recent years much attention has been paid to the application of this method for producing the FGM metal matrix composites with a ceramic phase particles added to the liquid metal which is then subjected to casting conducted under the action of a centrifugal force [16,17].

The present studies were focused on the use of the centrifugal-slip

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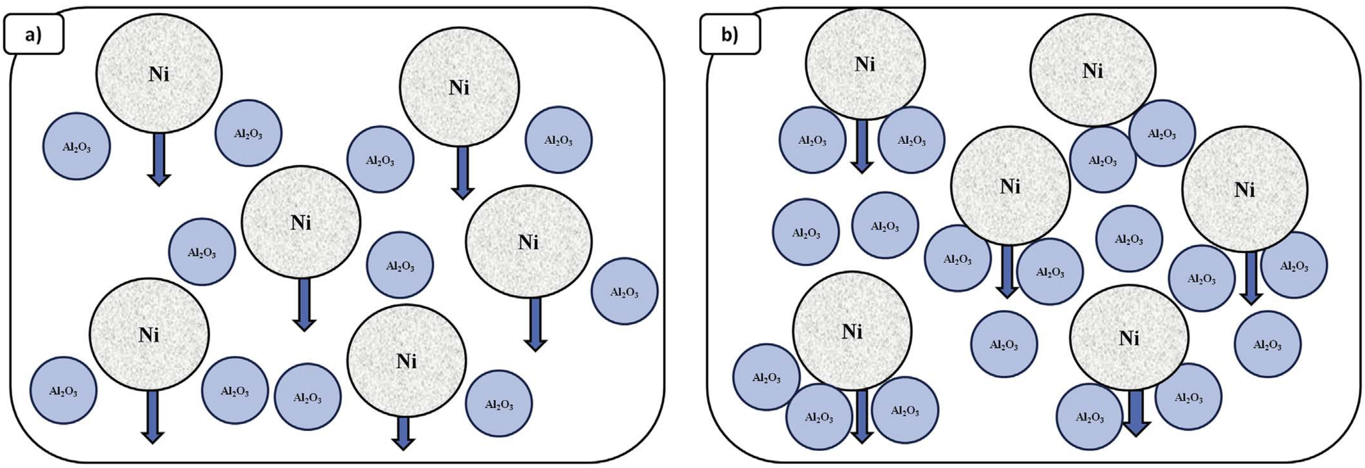

Fig. 1. Schematic representation of the sedimentation process in the Al_2O_3-Ni suspension: a) size of Ni particles is smaller than the distance between the ceramic particles - the Ni particles flow down b) size of the Ni particles is equal or higher than the distance between the ceramic particles - Ni particles are trapped by the ceramic particles.

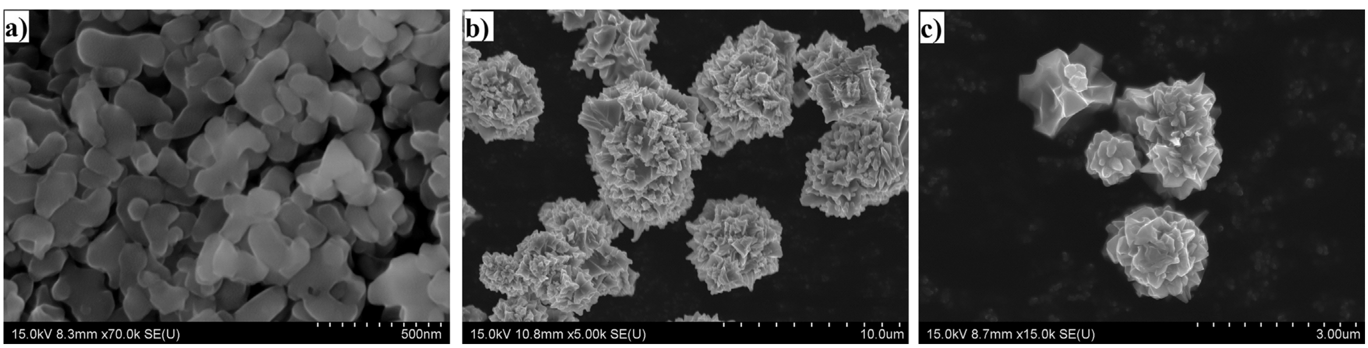

Fig. 2. Scanning electron microscopy images of the starting powders: a) α-Al_2O_3 b) nickel (D_{50} = 8.5 μm) c) nickel (D_{50} = 3 μm).

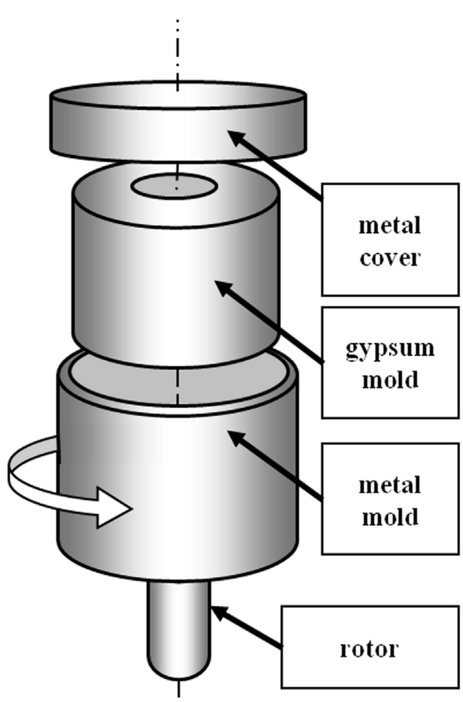

Fig. 3. Model of the apparatus used in the centrifugal-slip casting.

casting method for producing alumina-matrix composites with a gradient concentration of nickel particles. This method combines the classical colloidal process (slip casting) with the formation of the material under the action of a centrifugal force. According to the literature the method was successfully used in the case of ceramic materials such as Al_2O_3 [18], ceramic/ceramic Al_2O_3/ZrO_2 composites [19] and ceramic/metal mullite/Mo composites [20]. Under the action of the centrifugal force, the particles of differing densities will have different velocities, which will result in their gradient distribution. Therefore, the two nickel powders used in the present study differed by their particle sizes which will affect the microstructure of the composite.

2. Experimental

2.1. Materials and preparation of the samples

In order to produce functionally graded Al_2O_3-Ni composites with the use of a centrifugal-slip casting, the size of the ceramic and metal particles, the concentration of the solid phase, and the centrifugal acceleration should be optimally selected. One of the methods of generating the gradient distribution of the metal phase in the ceramic matrix is to control the sedimentation of the heavier metal particles in the ceramic-metal suspension. To induce the sedimentation of the metal particles which have higher density than alumina, the distance between the ceramic particles should be greater than the average particle size of the metal (Fig. 1a). On the other hand, when the size of the metal particles exceeds the distance between the ceramic particles, the metal sedimentation is practically impossible (Fig. 1b) since the particles of the metallic phase are locked between the ceramic particles. The proposed combination of slip casting with the action of a centrifugal force allows increasing the distance between the metallic and ceramic particles. It can therefore be seen that the concentration gradient of the metal particles depends on the particle size of both the ceramics and