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Original Research Paper

Effect of cup and ball types on alumina–tungsten carbide nanocomposite powder synthesized by mechanical alloying

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ABSTRACT

Alumina-based nanocomposite powders with tungsten carbides particulates were synthesized by ball milling WO_3, Al and graphite powders. X-ray Diffraction (XRD) was used to characterize the milled and annealed powders. Microstructures of milled powders were studied by Transmission Electron Microscopy (TEM). Results showed that Al_2O_3–W_2C composite formed after 5 h of milling with major amount of un-reacted W in stainless steel cup. The remained W was decreased to minor amount by increasing carbon content up to 10 wt.%. When milled with ZrO_2 cup and balls, Al_2O_3–W_2C composite was completely synthesized after 20 h of milling with the major impurity of ZrO_2. In the case of stainless steel cup and balls with 10 wt.% carbon, Fe impurity after 5 h of milling (maximum 0.09 wt.%) was removed from the powder by leaching in $3HCl{\cdot}HNO_3$ solution. The mean grain size of the powder milled for 5 h was less than 60 nm. The powder preserved its nanocrystalline nature after annealing at 800 °C.

1. Introduction

Alumina is one of the most employed engineering ceramics having great potentials in many special fields where low density, high stiffness, high hardness, chemical inertness and good high-temperature properties are required [1,2]. However, its poor mechanical properties, especially fracture toughness, make it difficult to withstand severe conditions applied, for example, in the field of high-speed cutting tools. From the viewpoint of multiphase ceramics, the flexural strength and fracture toughness of the matrix materials can be enhanced by incorporating second phase particles [3,4]. Tungsten carbide, as one of common hard alloy powders, is extensively employed in machine tools and protective coatings owing to its high hardness, chemical stability and high abrasion resistance [5]. Therefore, it sounds reasonable to improve the mechanical properties of alumina matrix ceramics by adding tungsten carbide particles as a secondary phase. Another possible mechanism is to prepare these materials in nano-structure form. Alumina–tungsten carbide nanocomposite powder can be obtained easily by direct mixing of nano alumina and tungsten carbide [6,7]. However, the heterogeneity of resulting microstructure and high cost of the starting materials are two important setbacks of this method. Alternatively, nano-metric Al_2O_3–WC powders can be obtained through high-energy reactive milling of mixtures of WO_3, Al and C powders.

Mechanical alloying (MA) has proved to be a powerful technique for synthesizing metal–metalloid compounds and fabricating homogeneously distributed nanocrystalline composites at ambient temperature [8,9]. El-Eskandarani obtained Al_2O_3–WC nano composite from WO_3, Al and graphite mixture after 100 h of milling and consolidation at 1963 K for 300 s under pressure and vacuum conditions. Also Pallone et al. conducted the same experiment, but they obtained very different results [10,11].

As an investigation, we also re-performed the above-mentioned study, devoting more emphasis on the various conditions of the cup and balls type, milling time and annealing temperature. The subsidiary objective of this work is to obtain alumina–tungsten carbide composite powder by ball reactive milling of WO_3, Al and graphite in the best conditions of milling and annealing.

2. Materials and methods

Mechanical alloying was performed in a planetary ball-mill at nominal room temperature with a vial rotational speed (cup speed) of 500 rpm. Pure Al (Fluka Co, 99.9%, <200 μm), graphite (MERCK, 99.9%, <50 μm) and WO_3 (BDH, 99.9%, <100 μm) powders were mixed according to the following reaction:

$$WO_3 + 2Al + C \rightarrow Al_2O_3 + WC \quad \Delta G^{\circ}_{298} = -1327.8\,kJ/mole \qquad (1)$$

Two kinds of cup and ball (namely, stainless steel and ZrO_2) were used in this study. The ball to powder weight ratio (BPR) was 10:1. The mixture of the powders and balls was charged into both of the vials (250 ml) in argon atmosphere. The mixtures were

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