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Manufacturing Wear-Resistant 10Ce-TZP/Al_2O_3 Nanoparticle Aluminum Composite by Powder Metallurgy Processing

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Aluminum matrix composites (AMCs) are candidate materials for total joint arthroplasty, dental prostheses, cutting tools, and biomedical gadgets owing to their strength, machinability, dimension accuracy, and wear resistance. A novel method for manufacturing new generation of AMCs by addition of 10Ce-TZP(tetragonal zirconia polycrystal)/Al_2O_3 nanoparticles to aluminum via powder metallurgy is devised. Aqueous combustion synthesis is used for dispersoid production and milling–compaction–sintering for AMC fabrication. Effects of 10Ce-TZP/Al_2O_3 content on hardness, erosion, and wear resistance are investigated. Scanning electron microscopy, energy dispersive x-ray spectroscopy, x-ray diffraction, and pin-on-disk analyses are used to explore worn interface, morphology, mechanism of abrasion, and resistance to wear. By addition of 7 wt% dispersoid, considerable increase in hardness and resistance to wear are achieved.

Keywords Aluminum; Intermetallics; Lightweight; Matrix; Nanocomposite; Nanomaterials; Nanoparticle; Nanotribology; Wear.

Introduction

A lightweight, strong, stable, and wear-resistant material is desirable for automotive and structural applications [1–6]. Considerable attention has been devoted in recent years to the aluminum matrix composites (AMCs) reinforced with ceramic particles [7–9]. Although significant improvements have been achieved [5, 10–13], challenging issues like homogeneity, wettability, wear, and agglomeration have remained for investigation [13–16].

Ceramic–ceramic nanocomposites are new materials of interesting features [13–16]. They have benefits of both ceramics and dispersoids. Neutrality, strength, and stability are desirable properties of these materials [17–19]. Zirconia–alumina composites have been used to make bearing components [20]. Uniform distribution of alumina and ceria into the TZP (tetragonal zirconia polycrystal) matrix results in: (a) improvement of flexibility and (b) hindrance of tetragonal–monoclinic transformation required for better mechanical specifications [21–23].

Powder metallurgy (PM) is an effective way of sample preparation [24, 25]. Combustion synthesis facilitates production of objects from highly reactive substances [26]. Dispersoids homogeneity not only improves micro-properties, but also nano-properties [27–30]. Although zirconia reinforced castings have been used before, PM has not been considered significantly [31]. Contamination, segregation, undesirable inclusions, high cost, and poor control are some shortcomings of the former [32]; while PM seems less expensive and simpler [31, 33].

Many investigators have focused on the effects of SiC, TiC, TiB, B_4C, and Mg_2Si reinforcements on wear resistance of Al [34–39]. No report has, however, been found in the literature on improvement of wear properties of Al with 10Ce-TZP/Al_2O_3; while sliding tests have shown some surface improvements [40, 41].

Provision of a deeper insight into the wear resistance and mechanical property enhancement by dispersing ceria-stabilized ZrO_2/Al_2O_3 into Al is a novel aim of this investigation. Quantitative studies of the effect of dispersoid size and distribution on the wear resistance of AMCs demonstrates main advantage in production and use of 10Ce-TZP/Al_2O_3 nanoparticles (NPs) for strengthening, hardening, and wear improvement of the Al pieces. Suitable specifications for maximum wear resistance are given.

Experimental procedure

Analytical grade initial reagents for experiments obtained from Merck (Germany) were employed as starting materials. Table 1 summarizes the raw materials utilized for production of 10Ce-TZP/Al_2O_3 nanocomposite. Desirable amounts of these reagents were added to distilled water and stirred. The solution was then evaporated, burned at 400°C, heated up to 1150°C, and retained for 8 h. The following reaction led to the formation of Ce-TZP/Al_2O_3:

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