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Properties of alumina matrix composites reinforced with SiC whisker and carbon nanotubes

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Abstract

The microstructure and mechanical properties of Al_2O_3 containing 0, 0.1, 0.5 or 1.0 wt% multi-walled carbon nanotubes (MWCNTs) were examined with/without the addition of 25 wt% SiC whisker (SiCw) for cutting tool applications. Eight types of composites with different compositions and a density >99% could be manufactured by optimizing the hot-pressing conditions. The addition of MWCNTs had negligible effects on the mechanical properties of the resulting Al_2O_3–MWCNTs composites due to agglomeration and the retardation of sintering. On the other hand, the incorporation of SiCw to Al_2O_3 enhanced the mechanical properties significantly, which enabled the cutting of Inconel 718 super-alloy. Both K_{1C} and the flexural strength of Al_2O_3–SiCw–MWCNTs were improved by >60% compared to those of the Al_2O_3–MWCNTs composites. Moreover, it was proposed that the MWCNTs in the Al_2O_3–SiCw reduced the wear of the cutting tool by lubrication when the high composite density was ensured.

Keywords: B. Composites; B. Whiskers; C. Mechanical properties; E. Cutting tools

1. Introduction

Although Al_2O_3 is a popular ceramic used in many applications, such as cutting tools, electrical insulators, refractory materials and wear-resistance components, owing to its good mechanical and chemical properties, it is brittle and suffers from a drastic decrease in strength at high temperatures [1]. Therefore, the application of Al_2O_3 as a cutting tool has been restricted only to the cutting of cast iron which is much milder than high-strength steel or super-alloy [2]. Because metal cutting accompanies a rapid temperature change up to several hundreds of degrees Celsius, the thermal shock resistance, fracture toughness and reasonable strength at high temperatures are essential considerations [3]. SiC whisker (SiCw)-reinforced Al_2O_3 has been proposed to enhance the fracture toughness and strength. Whisker reinforcement can minimize the catastrophic brittle failure of Al_2O_3 via a range of toughening mechanisms, such as crack deflection, whisker pullout and bridging [4–6]. Regarding the effects of whisker properties on the mechanical characteristics of Al_2O_3–SiCw composites, several factors are known to be important, including the whisker/matrix interface, whisker morphology and internal stresses originated from the thermal expansion mismatches [7–9]. Garnier et al. [7] reported that the presence of oxygen on the SiCw surface deteriorated the mechanical properties by the degradation of SiC and the formation of strong interface between Al_2O_3 and SiO_2. Li and Bradt [8] also explained that the geometry of whisker as well as the thermo-elastic differences between the matrix and whisker could be significant on the internal stresses of the composites. Furthermore, Homeny and Vaughn [9] have demonstrated that the fracture toughness could vary significantly by the whisker morphology.

Carbon nanotubes (CNTs) have also been considered a promising reinforcing material for Al_2O_3 owing to their outstanding mechanical properties [10,11], such as a high elastic modulus of ~1 TPa and tensile strength of >10 GPa as well as good chemical stability [12]. The main issue associated with the reinforcement of Al_2O_3 by CNTs, however,

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is the uniform dispersion of CNTs because they become entangled with each owing to their high aspect ratio and strong van der Waals forces. Therefore, considerable effort has been made to achieve a uniform dispersion of CNTs through surface treatments or mechanical milling [13,14]. Although reinforcement with CNTs has been reported to enhance the toughness of Al_2O_3 [11,12], the results revealed large variations in terms of reproducibility and the testing method used. Moreover, the addition of CNTs was reported to cause a decrease in both the grain size and sintered density of Al_2O_3 [15], while highly dense microstructure is essential for practical application. Regarding the other effects of CNTs addition, it was recently reported that the addition of multi-walled carbon nanotubes (MWCNTs) increased the wear resistance of Al_2O_3 by decreasing the coefficient of friction [16,17], which is quite desirable for cutting tool applications of Al_2O_3–MWCNTs composites.

Although the effects of each SiCw or CNTs addition to Al_2O_3 have been reported, there are no reports on the properties of Al_2O_3-based composites containing both SiCw and MWCNTs. Therefore, in this study, the physical and mechanical properties of Al_2O_3–SiCw–MWCNTs composites were examined by varying the quantity of CNTs in the composites. The sintered density, microstructural evolution and mechanical properties along with the cutting test results for Inconel 718 super-alloy were examined systematically.

2. Experimental

Commercial α-Al_2O_3 (APA-0.5, Sasol, USA) with a mean particle size, specific surface area and purity of 0.3 μm, 8 m^2/g and >99.96%, respectively, was used as the matrix phase. β-SiC whiskers (Silar® SC-9M, Advanced Composite Materials, USA) with a mean diameter and length of 0.65 μm and 10 μm, respectively, were used as a reinforcing material. MWCNTs (CNT 97, Applied Carbon Nano Technology, Korea) with a mean diameter, length and purity of 15 nm, 10 μm and >97%, respectively, were also used as a reinforcement of Al_2O_3.

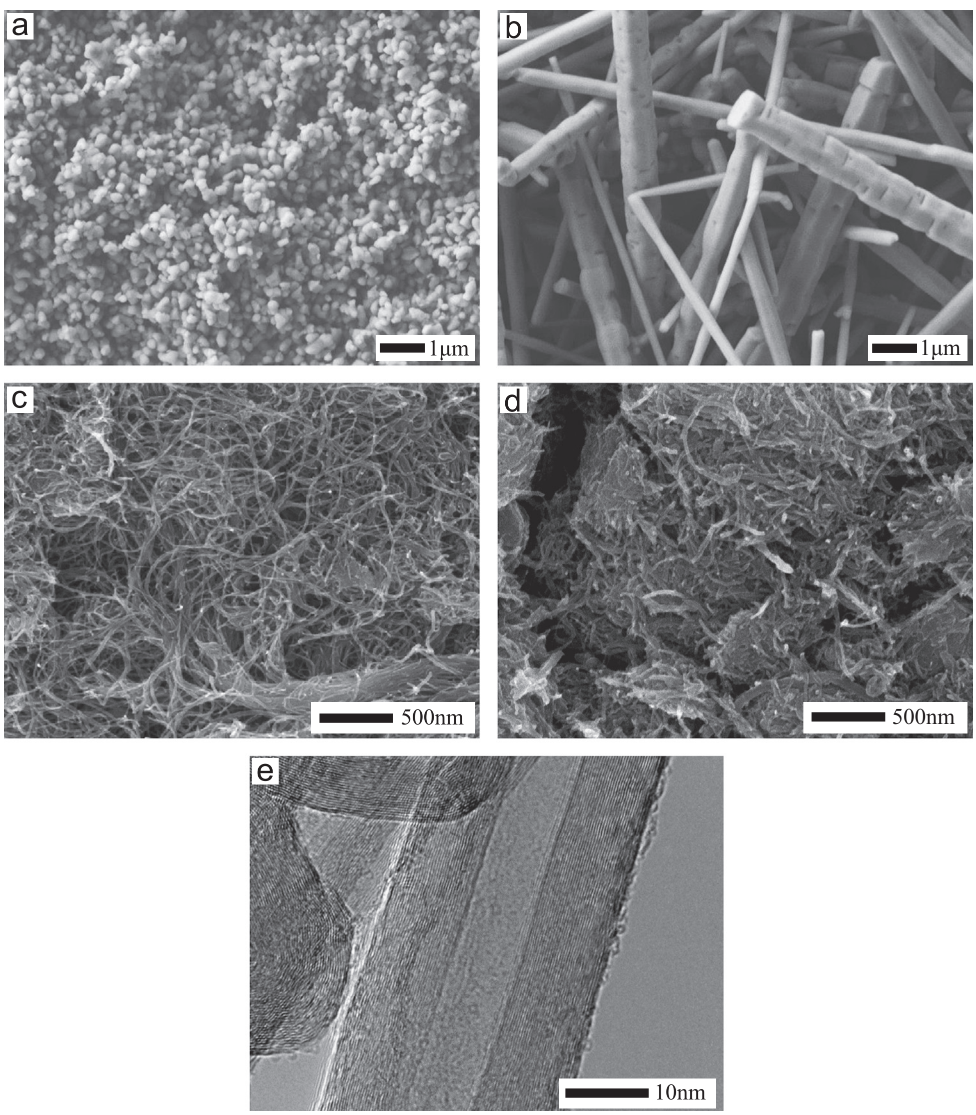

Fig. 1. SEM images of (a) Al_2O_3, (b) SiC whisker, (c) as-received and (d) chopped MWCNTs, and (e) TEM image of the chopped MWCNTs after 40 h of ball milling.