Damage and Wear Resistance of Al_2O_3-CNT Nanocomposites Fabricated by Spark Plasma Sintering

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Abstract

In this study, we prepare Al_2O_3-CNT (carbon nanotube) composites with different contents of CNT, 1~20vol% into the Al_2O_3 ceramics, for the purpose of improving damage and wear resistance. Al_2O_3-CNT composites are obtained by spark plasma sintering in conditions of 1400~1600°C in vacuum and 30MPa~80MPa. Hardness evaluated by Vickers indentation shows that the hardness of Al_2O_3-CNT composites can be enhanced when the CNT addition is less than 5vol%. Toughness evaluated by Vickers indentation indicates that the toughness of the composites is comparable with that of an Al_2O_3 monolith. Hertzian indentations using a spherical indenter indicate the hard and elastic behavior of the composites by the addition of CNT. The wear rate and friction coefficients of the composites evaluated by the ball-on-disk method show that the composites represent low friction and reduced wear loss under constant contact load. The results indicate that the damage and wear resistance of Al_2O_3 ceramics can be enhanced by the addition of carbon nanotubes in optimum conditions.

1. Introduction

CNT have attracted great interest because of their unique structural, electronic, physical, and thermal properties, such as high electrical conductivity, thermal conductivity, and elastic modulus[1,2]. It has been reported that CNT are 100 times stronger and 6 times lighter than steel. The electrical conductivity of CNT is better than that of copper (Cu), and the thermal conductivity of CNT is better than that of diamond. Therefore, CNT are added to metal, polymer, or ceramics to improve mechanical and thermal resistance or electrical conduction. Among these, CNT addition into engineering ceramics is expected to offer good damage and wear resistance, exhibited by the lower friction and damage absorption characteristics of carbon material.

The goal of the present study is to improve the damage and wear resistance of alumina ceramics by the addition of CNT, considering only the content of CNT in the composites. The load-displacement curves were influenced by the CNT content in the composites. The hardness and toughness of Al_2O_3-CNT nanocomposites were also affected by CNT contents, which, in turn, influenced the wear characteristics of the composites.

2. Experimental procedures

Commercial starting powders of multi-walled CNT and Al_2O_3 (AKP-50, Sumitomo Co.) were used for fabricating the composites. The additions of CNT in the Al_2O_3 matrix are 1, 3, 5, 10, and 20vol%. Mixed powders were prepared by ball milling using high-purity Al_2O_3 balls with a 5mm diameter in a polyethylene pot with an isopropyl alcohol solution for 24h. The assembly of the graphite mold and mixed powders was set into the spark plasma sintering (SPS) apparatus (Syntex, Inc., Japan). The sintering temperature was 1400~1600^oC in a vacuum of 10^{-2} Pa. Sintering was conducted for 20min at each sintering temperature under pressure of 30MPa, 60MPa, or 80MPa. After sintering, the samples were cooled to room temperature.

Hertzian indentations were carried out to induce contact damages on the polished Al_2O_3-CNT composites using a universal testing machine (Instron 5567, UK). The top surfaces of each sample were contacted with a WC (tungsten carbide) spherical indenter with a radius (r) of 3.18mm, and the load was increased to P = 3000N and then unloaded to P = 0N. Vickers indentations using a sharp indenter were also carried out to evaluate hardness and toughness of the Al_2O_3-CNT composites using a microhardness tester (HM-114, Akashi, Japan). The surfaces of the composites were polished, and the indenter was driven and held for 5sec under P = 9.8N then unloaded.

3. Results and discussion

Fig.1 shows typical micrographs of pristine CNT powders. Fig. 2 shows the representative mechanical behaviors of load-displacement curves for Al_2O_3-CNT composites containing different CNT contents under indentation loading by Hertzian indentation, using a WC ball with *r* = 3.18mm at maximum load *P* = 3000N. The composite was sintered at 1400°C under 60MPa. Indentation loadings cause fractures only in local areas and make it possible to predict the macroscopic mechanical properties.The load-displacement curve shows continuous curves during loading and unloading. It is noteworthy that the displacement after unloading is finished is smaller and that the slopes of the tangential curve increase as the CNT content increases in the composites. It is crack deflection and bridging to dominate the toughening in the composites as shown in Fig. 3. The fractured surfaces examined by SEM show many fractions of morphologies of CNT with high aspect ratio in the figure. Presumably, the crack propagates along the interface of the CNT, and crack bridging across the strong CNT occurs in the composites [3]. In addition, the pull out of CNT was observed in the Al_2O_3 matrix. Fig. 4 shows the comparison of average friction coefficients. The friction coefficients increase as the CNT content increases to 5vol%, then the coefficient is down to half one of 5vol% added one at 10vol% CNT content. The friction coefficient of 20vol% CNT-added composites is still lower than that of the Al_2O_3 sample. For all material cases, the composites containing 5vol% and 10vol% of CNT content sintered at 1500°C yielded lower friction [4].

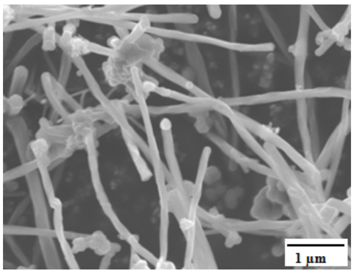

Fig.1. Micrographs of CNT.

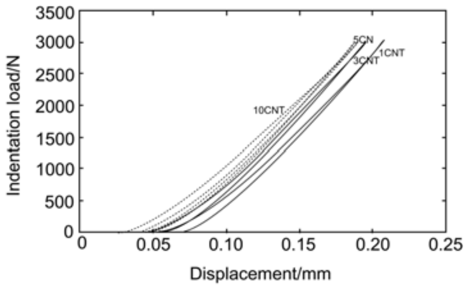

Fig.2. Plot of indentation load-displacement curves during Hertzian indentation.

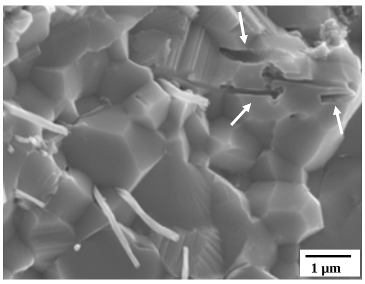

Fig.3. SEM showing fractured surface of Al_2O_3-2vol% CNT composites.

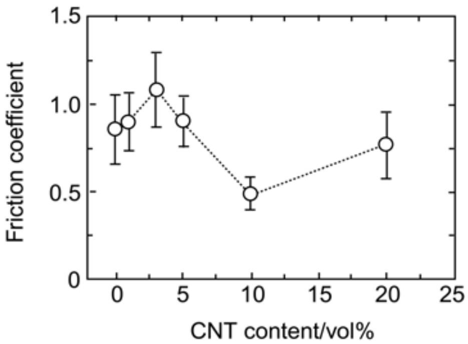

Fig.4. Friction coefficient changes of Al_2O_3-CNT composites as a function of CNT content in a wear test.

4. Summary

The hardness and toughness were improved from or comparable with those of Al_2O_3 ceramics when the CNT additions are less than 10vol% in the composites. The hardness could be particularly enhanced by addition of 5vol% CNT in the composites. The wear resistance of Al_2O_3 can be improved by the addition of CNT when the CNT content is optimized. The wear loss decreased due to CNT addition up to 10vol%. The Al_2O_3-10vol% CNT composites sintered at 1500°C showed the lowest friction coefficient in this study.

References

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