

Fabrication Process and Properties of Carbon Nanotube/Cu Nanocomposites

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Abstract

Carbon nanotubes (CNTs) have attracted remarkable attention as reinforcement for composites owing to their outstanding mechanical properties. The CNT/Cu nanocomposite is fabricated by a novel fabrication process named molecular level process. The novel process for fabricating CNT/Cu composite powders involves suspending CNTs in a solvent by surface functionalization, mixing Cu ions with CNT suspension, drying, calcination and reduction. The molecular level process produces CNT/Cu composite powders whereby the CNTs are homogeneously implanted within Cu powders. The mechanical properties of CNT/Cu nanocomposite, consolidated by spark plasma sintering of CNT/Cu composite powders, shows about 3 times higher strength and 2 times higher Young's modulus than those of Cu matrix.

Keywords : Carbon Nanotube, Cu, Nanocomposites, Spark Plasma Sintering, Composite Powders

1. Introduction

Several researchers have attempted to fabricate CNT reinforced metal or ceramic matrix composite materials by means of traditional powder metallurgy process [1, 2], which consists of mixing CNTs with matrix powders followed by sintering or hot pressing. However, these attempts have failed to fabricate CNT/metal or CNT/ceramic composites with homogeneously dispersed CNTs in the matrix. This is mainly due to strong agglomeration of CNTs in powder forms. At the same time, the most important processing issue is the interfacial strength between carbon nanotubes and the matrix. In the case of CNT/polymer nanocomposites, the interfacial strength between the CNTs and the polymer matrix is strong because they interact at molecular level [3]. In the case of CNT/metal or CNT/ceramic nanocomposites, however, the interfacial strength cannot be expected to be strong because the CNTs and the matrix are merely blended [1].

In this study, novel fabrication process for CNT/Cu nanocomposites, named as molecular level mixing process, was proposed and the mechanical properties of CNT/Cu nanocomposites were characterized.

2. Experimental and Results

Multi-wall carbon nanotubes, with diameter of 10~40nm, fabricated by thermal chemical vapor deposition were purified and functionalized by acid treatment using HF, H₂SO₄ and HNO₃. The purified CNTs was dispersed within ethanol by sonication for 2 hours to form a stable suspension.

Cu(CH₃COO)₂·H₂O (Aldrich 21,755-7) was added to the CNT suspension and sonicated again for 2 hours. The solution was vaporized with magnetic stirring at 100°C, and the dried powders were calcinated at 300°C in air. The calcinated powders were reduced at 250°C for 3 hours under hydrogen atmosphere. The CNT/Cu composite powders were pre-compacted in a graphite mold with 15mm in diameter under a pressure of 10MPa. The pre-compacted powders were consolidated by spark plasma sintering at 550 °C for 1 minute in a vacuum of 10⁻³ torr with an applied pressure of 50 MPa. The final size of spark plasma sintered CNT/Cu nanocomposite was 15mm in diameter and 5mm in thickness.

The CNTs are homogeneously dispersed within Cu powders fabricated by molecular level mixing process as shown in Fig. 1. The most important feature of this process is that CNTs and Cu ions are mixed each other at molecular level. That is, the CNTs are located within the powders rather than on the powder surfaces. The morphologies of the CNT/Cu powders show an ideal composite microstructure, which displays spherical morphologies with CNTs implanted in the powders as shown in Fig. 1(a). The implanted CNTs in CNT/CuO composite powders can be seen more clearly in TEM observation as shown in Fig. 1(b).

The CNT/Cu composite powders fabricated by the above-explained molecular level mixing process were consolidated into bulk CNT/Cu nanocomposite with full densification by spark plasma sintering, which can produce a high heating rate of 100°C/min and rapid consolidation through high joule heating and spark plasma generated between powders. The consolidated CNT/Cu nanocomposite shows homogeneous distribution of carbon nanotubes within

the Cu matrix, which had not been obtained until now for CNT/metal or CNT/ceramic nanocomposites. Particularly, the TEM micrograph in Fig. 2(a) shows that the carbon nanotubes form a network within the Cu grains. Moreover, the Cu grains show very low dislocation density when they are reinforced by carbon nanotubes.

The mechanical properties of CNT/Cu nanocomposite were characterized using a compressive test. As shown in Fig. 2(b), the compressive yield strengths of CNT/Cu nanocomposites were much higher than that of Cu matrix, which is fabricated by the same process without adding CNTs. 5 volume percent CNT reinforced Cu matrix nanocomposite shows yield strength of 360MPa, which is 2.3 times higher than that of Cu. In the case of 10 volume percent CNT reinforced Cu, the yield strength is 485MPa, which is more than 3 times higher than that of Cu. Moreover, Young's modulus of CNT/Cu nanocomposite increases as the volume fraction of carbon nanotubes is increased.

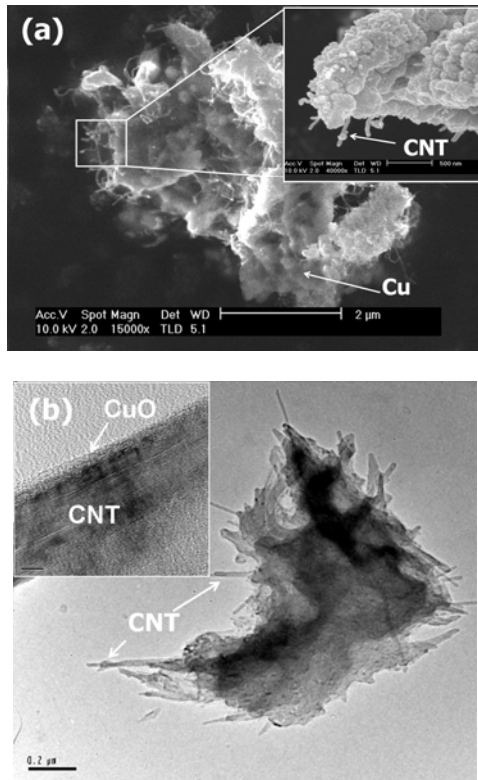


Fig. 1. (a) SEM micrographs of CNT/Cu composite powders, (b) TEM micrographs of CNT/CuO composite powders where CNTs are implanted within matrix with sound interface between CuO and CNT (inset).

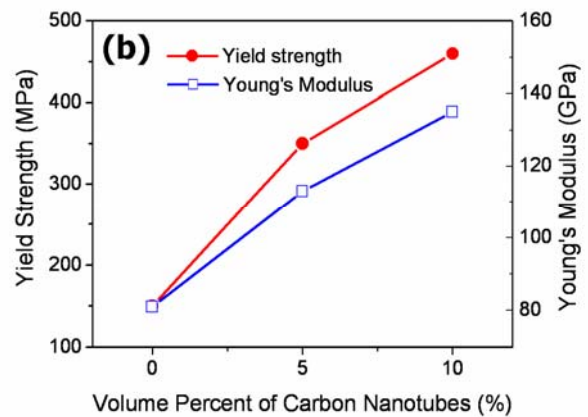
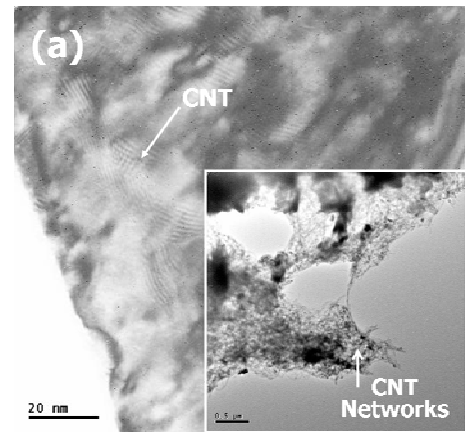


Fig. 2. (a) TEM micrographs showing a 3-dimensional network of CNTs in Cu grains and (b) yield strength and Young's modulus of CNT/Cu nanocomposites according to the volume percentage of CNTs.

3. Summary

CNT/Cu nanocomposites with homogeneously dispersed CNTs within the Cu matrix can be fabricated by means of the molecular level mixing process, which consists of mixing Cu ions with functionalized CNTs in solvent. The yield strength of CNT/Cu nanocomposite is shown to be 3 times higher than that of Cu.

4. References

1. G.-D. Zhan, J. D. Kuntz, J. Wan, A. K. Mukherjee, *Nat. Mater.*, **2**, 38 (2003)
2. E. Flahaut, A. Peigney, Ch. Laurent, Ch. Marliere, F. Chastel, A. Rousset, *Acta Mater.*, **48**, 3803 (2000)
3. A. A. Mamedov, N. A. Kotov, M. Prato, D. M. Guldi, J. P. Wicksted, A. Hirsch, *Nat. Mater.*, **1**, 190 (2002)