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Processing copper–carbon nanotube composite powders by high energy milling

A.K. Shukla[a], Niraj Nayan[a,*], S.V.S.N. Murty[a], K. Mondal[b], S.C. Sharma[a], Koshy M. George[c], Srinivasa Rao Bakshi[c]

[a]Vikram Sarabhai Space Centre, Trivandrum, India
[b]Indian Institute of Technology, Kanpur, India
[c]Indian Institute of Technology Madras, Chennai 600036, India

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ABSTRACT

Carbon nanotube reinforced copper composites are expected to have superior mechanical and thermal properties. Consolidation of copper–carbon nanotube composite powder is the commonly used technique but uniform distribution of carbon nanotubes in copper matrix remains a challenge. In this study, copper–carbon nanotube composites reinforced with 0.2, 5 and 10 vol.% single walled carbon nanotubes and 5 and 10 vol.% multi-walled carbon nanotubes were processed by high energy milling of pure copper powder with carbon nanotubes. Constituent powders were milled in Attritor mill for 20 h and powder samples were collected after every 5 hour intervals. The composite powders had flake like morphology after prolonged milling. The SEM micrographs of the cross-section of powders revealed layered structure. The particle size distribution showed an increase in the average particle size with increasing milling time for all composite powders except for copper–10 vol.% single wall carbon nanotube. The cold welding and fracturing phenomena of copper–carbon nanotube powders during milling are influenced by the quantity and type of carbon nanotubes. The higher volume fraction of single walled carbon nanotubes has suppressed the cold welding and enhanced the fracturing of copper–carbon nanotube composite powders.

1. Introduction

Carbon nanotubes (CNTs) have been suggested as an ideal reinforcement to improve the mechanical performance of monolithic materials due to their high elastic modulus, strength and aspect ratio [1]. Due to unique mechanical, thermal and electrical properties, efforts have been made to develop novel composites by incorporating CNTs with polymer, ceramic and metal matrices via various routes to realize composites with outstanding properties over conventional engineering composite materials [2–7]. A large portion of the research on CNT based composites has been focused on polymer-matrix composites (PMCs) in order to improve their electrical conductivity along with the enhancement of mechanical properties [8–10]. However, work on metal matrix composites has been scarce primarily due to difficulties in achieving homogeneous dispersion of CNTs within metal matrices with minimal interfacial reaction [11–14] and lack of suitable synthesis techniques.

In order to obtain excellent mechanical and physical properties, several fabrication routes namely thermal spraying [15], hot-pressing [16–22], hot extrusion [23], spark plasma sintering [24–28], thermal spraying [29–32] and electro-less deposition [33] have been used to synthesize metal–CNT composites. Mechanical alloying and molecular mixing [34] as

* *Corresponding author*. Tel.: +91 471 256 3582; fax: +91 471 270 5048.
E-mail address: metnayan@gmail.com (N. Nayan).

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Table 1 – Experimental details of powders and sample collection interval.

Experiment no.	Type of CNTs	Volume fraction	Sample collection (h of milling)
E1	SWCNT	0.2	5, 10, 15, 20
E2	SWCNT	5	5, 10, 15, 20
E3	SWCNT	10	5, 10, 15, 20
E4	MWCNT	5	1, 2, 5, 10, 15, 20
E5	MWCNT	10	5, 10, 15, 20

mechanical dispersion techniques have received the maximum attention and have been proven to be a promising technique for dispersing CNTs in the metal-matrices [35–37].

Copper has always been the most suited candidate material for applications involving high thermal and electrical conductivity. Many of these applications (e.g. rocket engines and nuclear reactors) demand superior mechanical properties at elevated temperatures. Hence, copper is alloyed or dispersed with reinforcements to enhance the mechanical properties. However, the use of alloying elements or dispersoids invariably leads to poor thermal conductivity, the sole property for which copper is selected. The use of CNTs, due to its high thermal conductivity [38] and strength, promises to be an ideal reinforcement in copper. Even though, the mechanical alloying has been used commonly for distributing CNTs in copper matrix, there is no detailed study regarding mechanical alloying of CNTs with copper (Cu). Authors have carried out mechanical alloying [39,40] of Cu with CNTs before consolidation but the dispersion characteristics and the powder morphology evolution during milling is absent.

In the present study, the authors have carried out mechanical alloying of Cu–CNT powders in an Attritor mill and analyzed the effect of type of CNT, volume fraction and milling time. The morphological evolution of mixed powders containing different volume fraction of CNTs after milling for different intervals of time was characterized using SEM. The change in particle size distribution of Cu–CNT composite powder was also studied. This study is important because it gives an insight into the parameters to be chosen for a given type of CNTs used.

2. Experimental Procedures

Copper (99.9% pure, −140 mesh) and CVD grown MWCNT (approximately 15 ± 5 nm in diameter, 5–20 μm in length and purity of more than 90% supplied by Nanolab Inc., USA) and CVD grown SWCNT (approximately less than 2 nm in diameter and a few microns in length supplied by Thomas Swan & Co. LTD., UK), were used in the present experimental study. No functionalization of the nanotubes was carried out prior to mixing. Measured amounts of CNTs to achieve a vol. percent of 0.2, 5 and 10 in the case of Cu–SWCNT and 5 and 10 in the case of Cu–MWCNT were mixed with copper powder in stainless steel mixing jar containing stainless steel balls of 10 mm diameter (with initial ball to powder ratio (BPR) = 5:1). The density of MWCNT used in this study was 1.8 g/cm^3 and that of SWCNT was 1.2 g/cm^3 as quoted by the suppliers. The jar was filled with argon and agitated using an Attritor mill (Szegvari, Union Process) at 200 rpm for milling times up to 20 h. The milled powder samples were collected at intervals of 5 h. Two samples after 1 h and 2 h were also collected for Cu–5 vol.% MWCNT to study the changes during initial stages of milling. The details of powders and sample collection are provided in Table 1. Raman spectroscopy was carried out to study the changes undergone by CNTs during the mechanical milling process. The

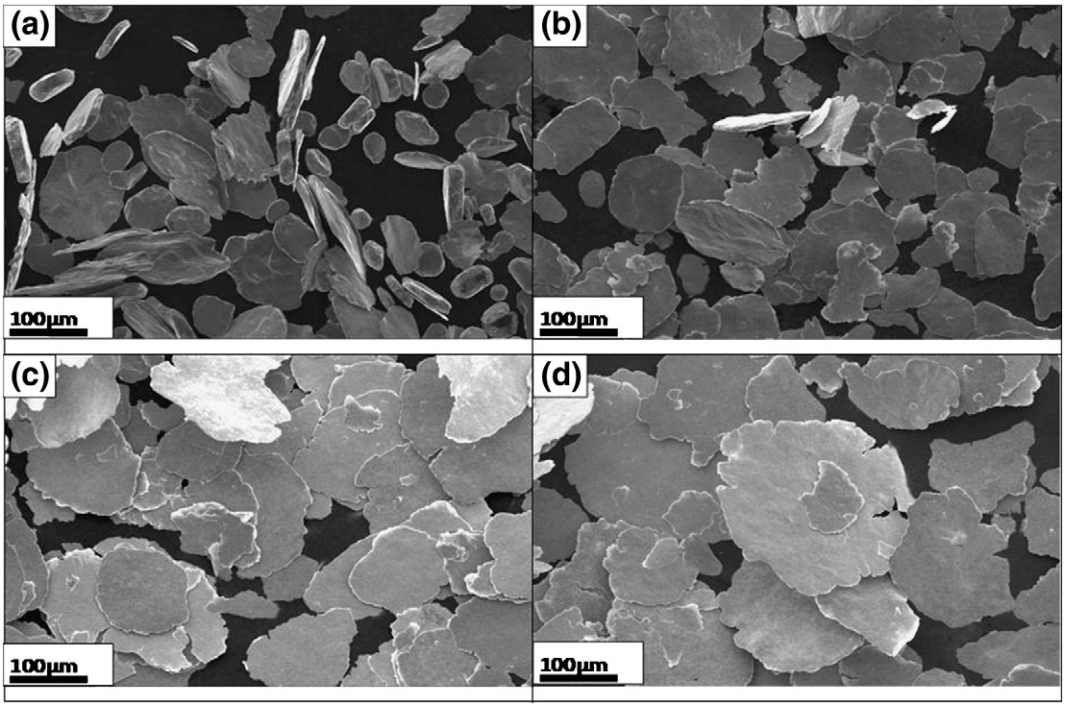

Fig. 1 – SEM micrographs of Cu–0.2 vol.% SWCNT powders after (a) 5 h, (b) 10 h, (c) 15 h & (d) 20 h of milling.