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The homogenizing of carbon nanotube dispersion in aluminium matrix nanocomposite using flake powder metallurgy and ball milling methods

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ABSTRACT

In the present work, the flake powder metallurgy as a slurry based method and the ultrasound-assisted then ball milling as a semi-wet based route were applied to modify the carbon nanotube dispersion within the aluminium powder. For this purpose, two types of long and short fiber CNTs-COOH were selected as reinforcement to strengthen the matrix of Al powders with particle sizes of <45 and <20 μm. The effects of morphological changes in composite constituents and the variables of each procedure such as time and rotation speed of ball milling, chemical modification of Al powder by a hydrophilic Polyvinyl alcohol, production of nano-flake Al powders and the carboxyl agent on the wall of CNTs were investigated in this research. The Al (20) and Al (45) with 1.5wt. %CNTs well-dispersed nanocomposites were produced in semi-wet based process after medium energy level ball milling at 200 rpm in duration of 2 and 4 h, respectively. Also, the flaky shape morphologies of pure Al powders with large aspect ratio of 50 and 125 were obtained after the 2 h ball milling of <45 and <20 μm powders, respectively.

In slurry based method, by forming the hydrogen bonding between the –OH groups of PVA and –COOH groups of multi walled CNTs, the suitable dispersion was resulted for both types of CNTs in Al flake powders with large specific surface area. The final products were studied through field emission scanning electron microscopy (FE-SEM).

1. Introduction

The carbon nanotubes reinforced aluminium matrix composites have aroused much attention during recent years. This is resulted from their good mechanical and thermal properties [1]. However, some problems related to the dispersion of CNTs in Al matrix can lead to difference between the expected and actual results. This initial step can be imagined as a more important level of Al/CNT manufacturing procedure. To overcome these problems, many of processing routes have been applied such as powder metallurgy (PM), casting, melt infiltration, friction stir, thermal spraying and the other novel techniques [2–7]. The powder metallurgy based methods have shown much research interest to achieve a uniform dispersion of CNTs within Al powder due to the lower temperature of process and better control of interface reactions between the matrix and reinforcement [8–17].

Some important procedures are involved in the category of powder metallurgy which can be generally divided into three separate groups. Firstly, single step process like ball milling has been used as a dry process and the mixing is totally performed in a batch state [18–23]. The second group has been employed by the continuous multistep procedure like ultrasonic-assisted then ball milling and nano-scale dispersion (NSD) methods which can be introduced as a semi-wet based process. In this group the unique properties of both dry and slurry based routes are considered to achieve the desired products [24–27]. The last one is more complicated process comprising the wet-based methods which are applied by the fluid dispersive environment and chemical reactions to make the demanded products like flake powder metallurgy and in-situ chemical vapor deposition (CVD) methods [28–31]. The more initial preparation is needed for materials in the third group of PM processing methods.

There are many important factors such as purity and refluxing of CNTs, functionalizing the carbon nanotubes with different chemical agents, metallization of CNTs, chemical modification of metal powder and changing the morphology of composite constituents which affect the CNTs dispersion in the first step [32–38]. Consequently, the complete achievement to homogenized distribution of high volume fraction of CNTs within Al powder has not been feasible yet.

In the present research, the effects of morphological changes of CNTs and Al powders were investigated using ultrasound-assisted then ball milling and flake powder metallurgy to compare both of semi-wet and slurry based methods, respectively.

The novel approach of this investigation is related to homogenize the dispersion of different shapes of CNTs within Al powders with

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Table 1
Physical and chemical characteristics of initial carbon nanotubes.

Type/Property	Specified Surface Area (m^2/g)	Length (μm)	ID (nm)	OD (nm)	COOH Content (wt. %)	Purity (%)	Processing Method
Long CNT-COOH	110<	10–30	5–10	20–30	1.23	95<	CVD
Short CNT-COOH	60<	0.5–2	5–12	30–50	1.73	95<	CVD

variable particle size to identify the effects of specific surface area on processing of Al/CNT nanocomposites.

Finally, the parameters of ball milling time and rotation speed, chemical modification of the surface of Al powder, chemical agents on the wall of CNTs and the aspect ratio of the constituents were investigated and discussed in this paper.

2. Experimental procedure

2.1. Materials

Two types of multiwall carbon nanotubes functionalized with carboxyl (-COOH) were supplied by Neutrino Corporation. The physical and chemical characteristics of CNTs are shown in Table 1. To remove the impurities and to increase the carboxyl content of CNTs, the nanotubes were refluxed in concentrated nitric acid at 120 °C for 6 h. Afterwards, the CNTs were completely rinsed with distilled water to achieve PH = 7 and finally dried in an oven at 120 °C [32,34]. Fig. 1 demonstrates the microstructure of long and short MWCNTs-COOH after refluxing treatment.

The length to diameter ratio (L/D) was selected as an independent variable in dispersion mechanism. Pure air-atomized Al powders with different average particle sizes of <45 μm and <20 μm were used as the initial metal matrix. The morphology of irregular shaped Al powders is shown in Fig. 2. The other required materials consisting Sodium Dodecyl Sulfate (SDS), Stearic acid and Polyvinyl Alcohol (PVA), with a molecular weight of 72000 g/mol, were purchased through Merck Group.

2.2. Semi-wet based procedure

As a general view, the combined steps of dry and slurry based methods were applied in semi-wet based procedure. Firstly, 1.5 mg/ml long CNT-COOH was added into ethanol and then sonicated in an ultrasonic bath at a frequency of 40 KHz for 2 h. This treatment was performed to separate tangled CNTs in single wires. Secondly, the 45 μm Al powder was added to the MWCNTs-ethanol solution and the mixture was dispersed using electromagnetic stirrer and ultrasonic shaker for 2 h. Subsequently, the achieved mixed powders were dried in a rotary evaporator to remove the solvent at 50 °C under the vacuum pressure of 75 mbar. Finally, the ball milling

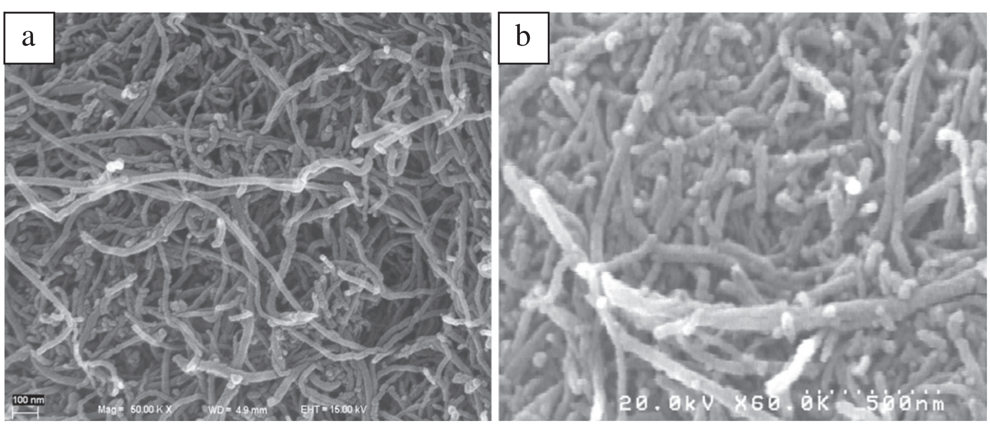

Fig. 1. FE-SEM images of carbon nanotubes: (a) Long CNT-COOH and (b) short CNT-COOH.

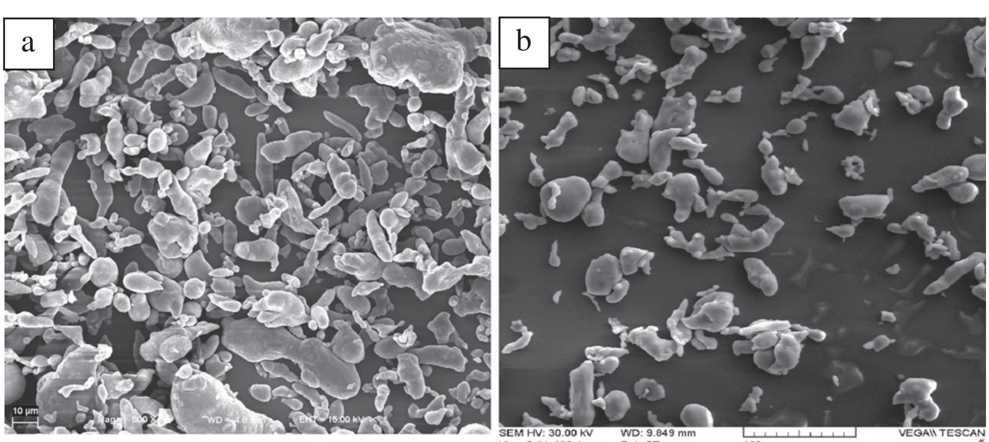

Fig. 2. SEM images of initial aluminium powders: (a) 45 μm and (b) 20 μm.