CNT-ALUMINUM METAL MATRIX NANOCOMPOSITES

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Abstract
Carbon Nanotubes-Aluminum (CNT-Al) agglomerates were synthesized by DC arc discharge method under argon/acetone mixed atmosphere. Synthesis was performed by arc plasma on high pure graphite rod, filled by aluminum powder as anode and aluminum plate as cathode. Discharge conditions of 85 A and 20 V were used at a pressure range of 0.5 to 1 MPa. This new method allows obtaining nanotubes agglomerated with aluminum. Metal matrix composites were produced with this agglomerates dispersed in an aluminum matrix. Mixtures of CNT-Al agglomerates, 0.5 and 1.0 wt%, with Al powders were pressed and sintered at 625 ºC. A poor dispersion of the agglomerates in the metal matrix was obtained. For both compositions large clusters were observed at aluminum grain boundary junctions. Although the poor dispersion of CNT in the composite, a 40% increase in hardness is obtained in the 1.0 wt% CNT agglomerates composite.

1 Introduction
The metal matrix nanocomposites are excellent candidates for various applications due to high mechanical properties including high strength and specific stiffness, desirable coefficient of thermal expansion and good damping properties. Furthermore, the more resistant is the material, the lesser the amount required and the lighter the structure. Materials with low density and high strength are key requirements to make new components more energy efficient, particularly in components for transportation systems [1].
Carbon nanotubes (CNT) have unique mechanical and thermal properties such as high stiffness (970 GPa), high strength (63 GPa) and high thermal conductivity that combined with its low weight make them an ideal reinforcement material [2,3]. The CNT reinforced metal matrix composites have generated a great interest in recent years [5-17]. The growing concerns about energy consumption and environmental protection require the development of high performance structural alloys. Aluminum alloys are positioned to meet these demands because of their resistance to corrosion, low density and high specific strength.
The objective of this study is to strengthen aluminum alloys with carbon nanotubes (CNT). Aiming to obtain materials with high mechanical properties. Some studies are reported on composite Al/CNT [4-14]. However, the difficulty to obtain a good CNT dispersion in the matrix compromises the properties of the composite. Several techniques for processing carbon nanotubes composites have been reported including powder metallurgy routes [6-8,11], melt processing [18], thermal spraying [19] and electrochemical routes [20]. Powder metallurgy is the most popular and feasible route for preparing bulk metal matrix/CNT composites. The

main challenge during processing MM/CNT nanocomposites is to obtain a homogeneous dispersion and good reinforcement of the matrix by CNT.
In this paper, the composites of aluminum reinforced by CNT were produced with CNT-Al agglomerates and aluminum powders. Firstly, the agglomerates were produced by DC arc discharge. Secondly, these agglomerates were mixed to aluminum powders and sintered.
The use of agglomerates of CNT-Al and aluminum powders, as an alternative to the traditional systems of powder and carbon nanotubes, is expected to improve the dispersion of the nanotubes in the aluminum matrix composite. With this methodology we explore the modification of the wetting properties of the nanotubes by aluminum.

2 Materials and testing methods

The agglomerates of CNTs/Al were synthesized by DC arc discharge in a self-made apparatus where an anode made of pure graphite rod (99.99%) with dimensions of Ø12 mm × 100 mm (length) was filled by Al powders with a purity of 99.94% wt, while an Al-plate with Ø30 mm × 15 mm (thickness) was used as cathode, with the same chemical composition of Al powders. Table 1 show the composition of the Al used in this work. The arc plasma was maintained constant at a voltage of 20 V and a current of 85 A, under mixed argon/acetone atmosphere under a pressure of 0.5 to 1 MPa.

Al	Si	Fe	Ga	Ni	Cu
99.94	0.028	0.024	0.010	0.002	0.001

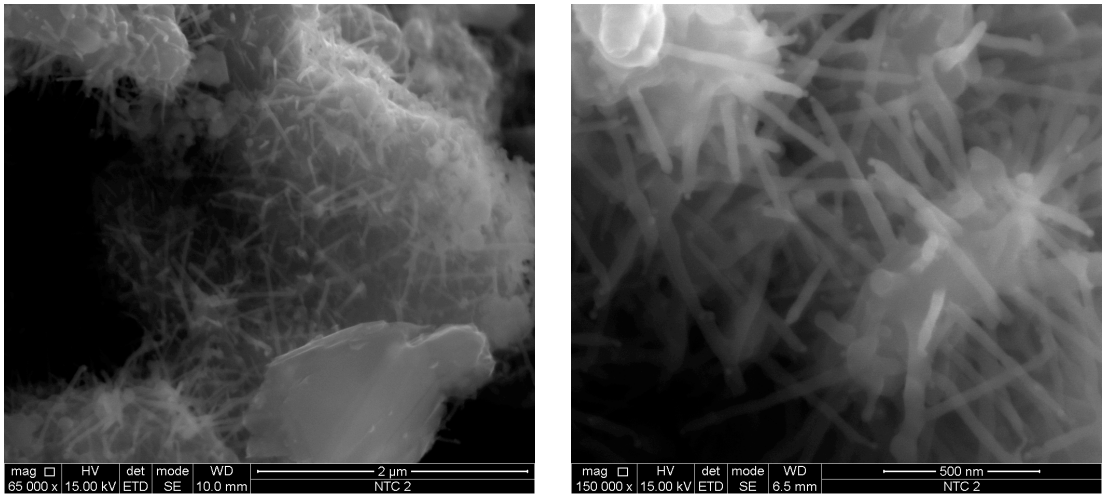
Table 1. Composition (wt%) of Al powders and plate.

In order to increase the yield of the method, the samples were calcined in a closed furnace at 575 °C for 60 min in air, temperature most favorable for the combustion of amorphous carbon [21]. Hereafter, samples were characterized by means of scanning electron microscopy (SEM - FEI Quanta 400 FEG) and analyzed by energy dispersive spectrometry (EDS) and transmission electron microscopy (TEM, JEM-2200 FS-200 kV).
For the production of the nanocomposites, the agglomerates of Al-CNT were mixed with Al powders (with the composition displayed in table 1) in a Turbula during 1h and then uniaxial pressed with 100 MPa. The compacts were produced with 0.5 and 1 wt% CNT agglomerates and sintered at 625 ºC during 1h under a vacuum better than 10^{-2} Pa. Microstructural characterization of aluminum metal matrix/ CNT composites was performed by SEM.
Mechanical properties of the composites were evaluated by Vickers microhardness tests using a 98 mN load; ten tests have been performed on each sample and also on an aluminum sample produced with the same powders and processing conditions for comparison.

3 Results and discussion

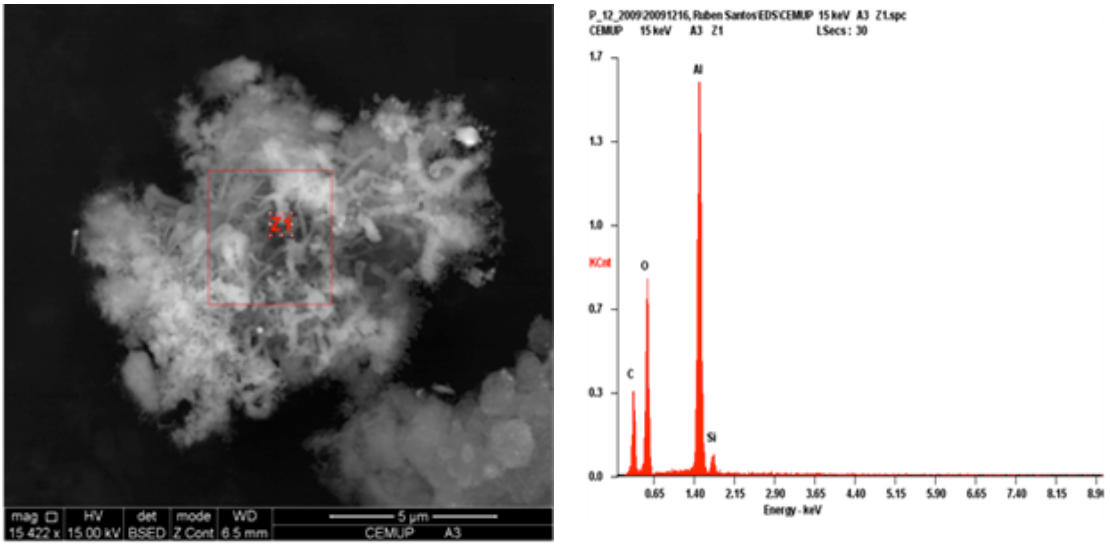
3.1 CNT-Al agglomerates

SEM images of Figure 1 show the morphology and distribution of the carbon nanotubes throughout the aluminum particles constituting the agglomerates. These images show that this synthesis technique was effective in the formation of CNT agglomerates. Figure 2 exhibit an agglomerate of CNT and aluminum particle, where the area analyzed by EDS is marked as zone 1 (Z1). This analysis indicates that the matrix show high concentration of aluminum used to nucleate the nanotubes; the silicon present as an impurity of aluminum is detected. It is also observed the presence of carbon and oxygen, the later being adsorbed during the synthesis process.



(a) (b)

Figure 1. SEM images of CNT-Al particles agglomerates (a) CNT dispersion around the aluminum particles and (b) higher magnification SEM image.



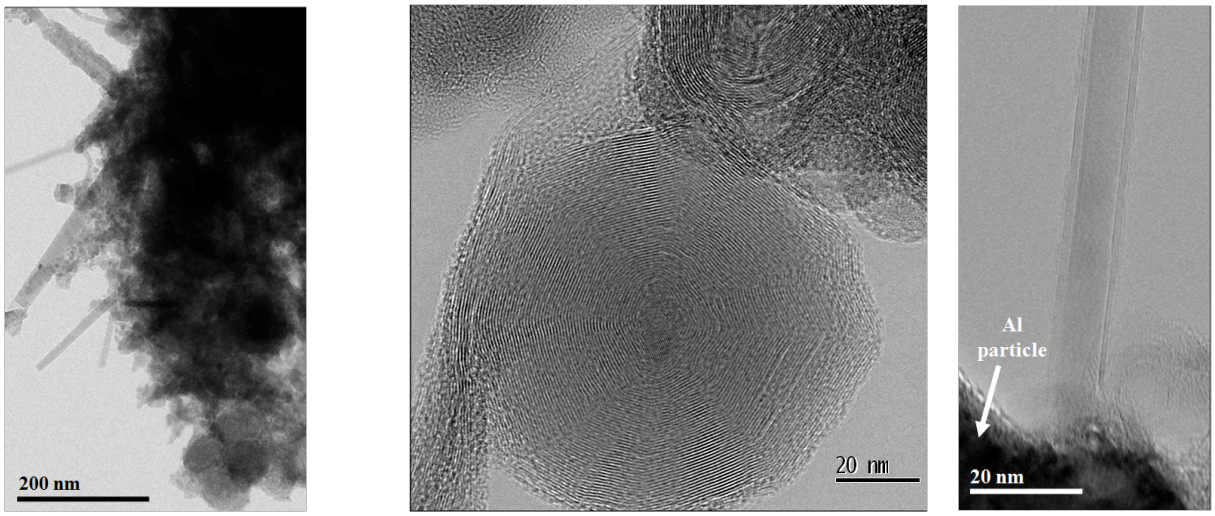
(a) (b)

Figure 2. (a) SEM image of CNT-Al particles agglomerates and (b) EDS spectrum of zone 1 marked in SEM image (a).

TEM image of CNT-Al agglomerates (figure 3) obtained before the thermal oxidation shows that metal particles are wrapped with MWCNT and other forms of carbon. Carbon round particles, designated as nano-onions, are clearly observed in figure 3b. A multiwall CNT nucleated at the surface of an aluminum particle, see figure 3c, and confirms the suitability of this method to produce MWCNT.

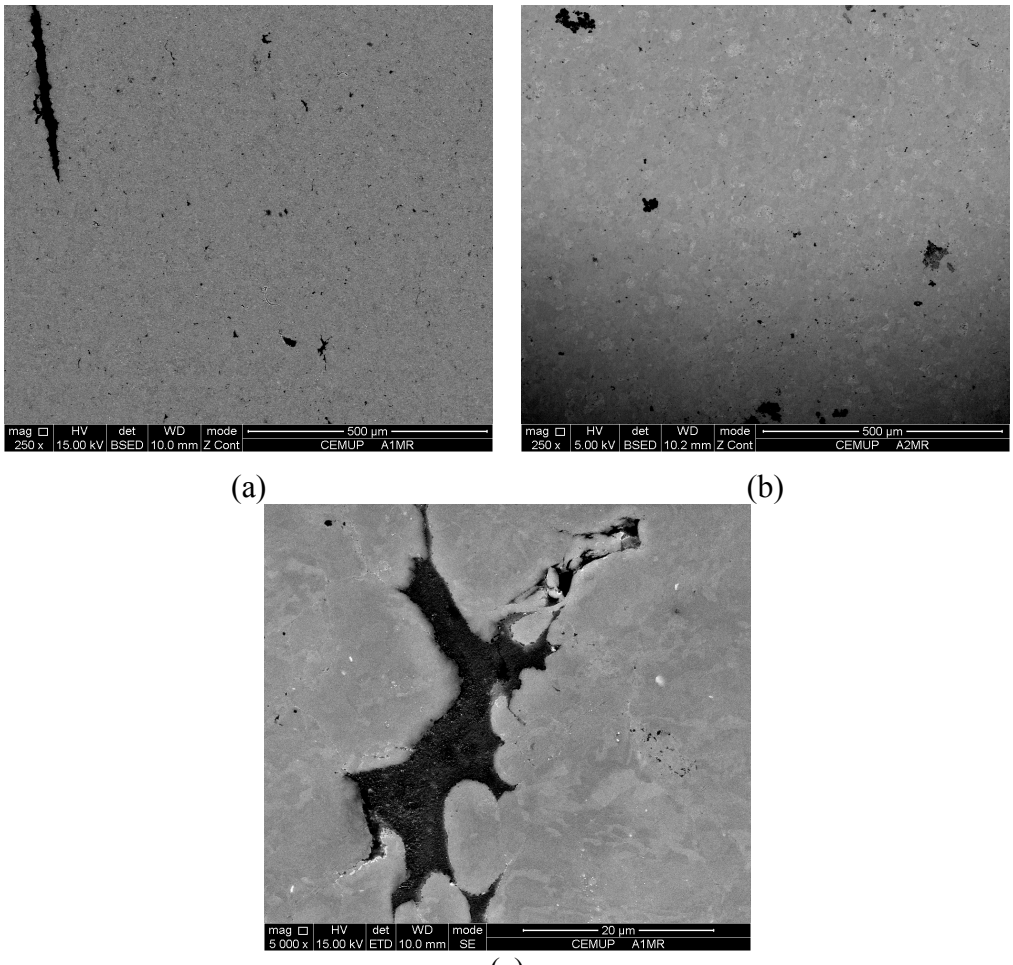
3.2 CNT-Al nanocomposites

Figure 4 shows SEM images of the CNT aluminum matrix composites with 0.5 and 1.0 wt% of CNT-Al agglomerates. As seen in these figure, the agglomerates are observed through the composite in clusters, mainly at grain boundary junctions (figure 4c). In some cases, these agglomerates are concentrated and aligned in large clusters as can be seen in figure 4a. The observed CNT-Al agglomerates dispersion in the composites is very poor for both concentrations; the clusters can reach sizes of approximately 400 μm.



(a) (b) (c)

Figure 3. TEM image showing a MWCNT /Al particles agglomerate with carbon round particles – nano-onions and amorphous carbon (a) detail of one of the nano-onions particles and (b) of a MWCNT nucleated in an aluminum particle.



(a) (b)

(c)

Figure 4. SEM images of CNT-Al composites (a) with 0.5 % of CNT, (b) with 1.0 % of CNT and (c) detail of the CNT in a grain boundary junction.

The strengthening of the composites by the CNT-Al agglomerates was evaluated by microhardness tests and is displayed in figure 5. The hardness of an aluminum sample (prepared and processed with the same conditions of the composites) was also measured. An increase in hardness with the CNT-Al agglomerate concentration was detected, from 30±2 to 42±4 HV0.098 for 0 and 1.0 wt%, respectively. The observed 40% increase in the composite hardness attests the strengthening effect of the CNT-Al agglomerates, despite its poor dispersion in the metal matrix.

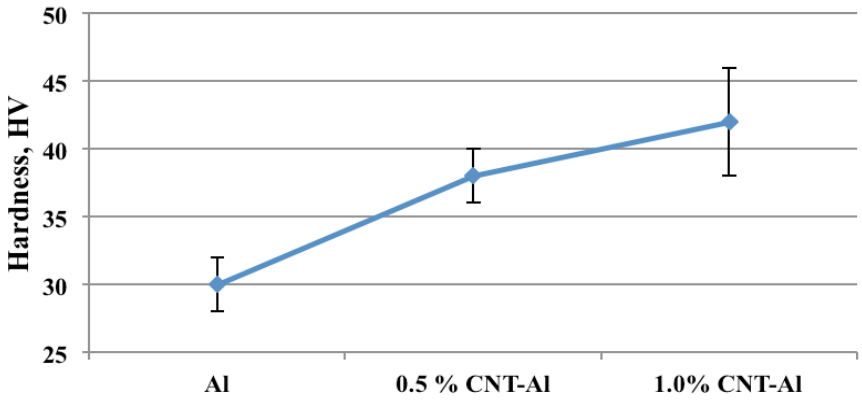


Figure 5. Hardness evolution of the aluminum matrix composites with CNT-Al agglomerates concentration. Average values and standard deviation errors (error bars) of ten tests were also represented.

Conclusions

The CNTs were successfully synthesized by DC arc discharge process under argon/acetone atmosphere, in the form of CNT-Al agglomerates with other forms of carbon.

Aluminum matrix composites reinforced by these CNT-Al agglomerates were produced by a classical powder metallurgy route.

The observed CNT-Al agglomerates dispersion in the composites is very poor for the two concentrations selected, 0.5 and 1.0 wt%; clusters of these agglomerates reach sizes of approximately 400 μm.

A strong strengthening effect of the CNT-Al agglomerates on the aluminum matrix was measured; the hardness raises 40% with the increase from 0 to 1.0 wt% in CNT-Al agglomerates concentration.

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