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Influence of dispersion/mixture time on mechanical properties of Al–CNTs nanocomposites

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ABSTRACT

The influence of dispersion/mixture time on microstructural evolution and mechanical properties of aluminum matrix nanocomposites reinforced by carbon nanotubes (Al–CNTs) were investigated in this study. The nanocomposites were produced by conventional powder metallurgy routes. The microstructure was characterized by scanning electron microscopy (SEM), electron backscattered diffraction (EBSD) and high-resolution transmission electron microscopy (HRTEM). Microstructural analysis shows clusters of carbon nanotubes (CNTs) mainly at the grain junctions, but also CNTs well dispersed and embedded in the aluminum matrix. A strong strengthening effect of the CNTs on the aluminum matrix was measured for the nanocomposites produced with 15 min of dispersion/mixture time. For shorter times than 15 min, it is not possible to obtain a dispersion, which can lead to a reinforcement of the aluminum matrix, while longer dispersion/mixture times cause a decrease in mechanical strength due to the damage caused by the increase in the number of defects and junctions of CNTs.

1. Introduction

The number of studies related to metal matrixes reinforced with carbon nanotubes (CNTs) has increased, in recent years, from 40 in 2003 to 324 in 2013. This is mainly due not only to the attractive properties of these nanocomposites but also to the potential reinforcement provided by CNTs [1–3]. However, further development of techniques for CNT dispersion in the metal matrix is needed.

While many processes are effective in dispersing the CNTs, these do not address the need for obtaining a stable dispersion. It is essential to find a compromise between these two factors. The techniques described in the literature, which confer the best results of CNT dispersion, are comprise of mechanical processes [4,5] and the chemical and physical modifications of the CNTs (CNT functionalization) [6].

The functionalization processes cause major damage to the CNT structure. Due to the changes in the CNT structure, this process allows stabilization of the dispersion but is not very effective in dispersing very tangled CNTs. For this reason, mechanical processes or the combination of both processes are the best option for dispersing CNTs [7,8]. In the production of metal matrix nanocomposites reinforced with CNT, the dispersion is usually mechanical, such as ball milling or sonication.

In the ball milling method, a large amount of energy is involved, since the dispersion is achieved by collisions of dense and rigid balls with the CNT. Due to this high-energy milling, CNTs suffer damage causing a degradation of its properties. This method can be used when the objective is the reduction of the length of the nanotubes and can be performed with lower energy and in shorter times [9].

The ultrasonication methods involve the dispersion of the CNTs in a liquid by ultrasound energy. It is a very efficient method for obtaining untangled CNTs dispersed in liquids, such as water, acetone, ethanol or acids. The efficiency of this dispersion technique depends on the liquid, ultrasound energy, time and type of CNTs, an important factor being the time required for dispersion, since a very long time leads to their damage.

To obtain the expected mechanical strength of the CNT-reinforced nanocomposites, it is essential to combine a good dispersion of carbon nanotubes with a manufacturing process which promotes uniform distribution of carbon nanotubes in the matrix. This process should ensure the dispersion of nanotubes without damaging them, and the formation of a strong bond with the metallic matrix to achieve an effective load transfer to it, so that the maximum reinforcement effect of CNTs will be accomplished.

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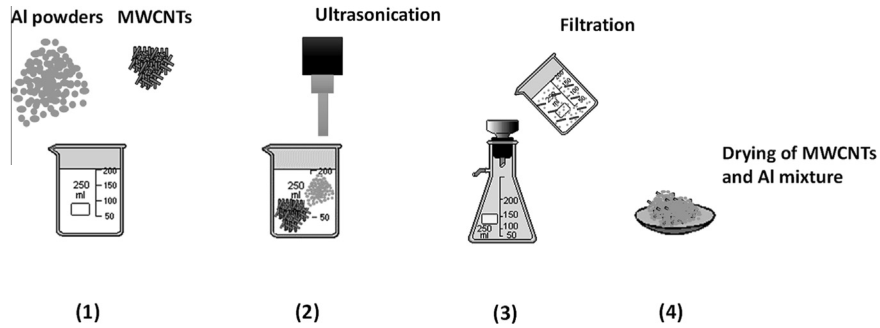

Fig. 1. Schematic illustration of the dispersion/mixture process: (1) addition of Al powders and MWCNTs to isopropanol, (2) dispersion and mixture by ultrasonication of the Al powders and MWCNT, (3) filtration and (4) drying of the mixture.

Several techniques have been suggested as suitable for production of these nanocomposites, such as conventional sintering [10,11], hot pressing [12,13], deformation processing [14], thermal spraying [15,16] and spark plasma sintering [17]. However, sintering followed by deformation processes appears to be the most promising technique [18–20]. The main disadvantage of these processing technologies is that they require a high temperature, which may damage the CNTs, or can lead to a reaction between them and the matrix. The stresses imposed by some processes can also damage the CNTs, or may even align them in the matrix (leading to a heterogeneous distribution and strong anisotropic behavior).

Conventional powder metallurgy can be a good production route, if the challenge to achieve uniform dispersion of CNTs in the matrix is successfully met. In a previous work [21], the authors have proposed a new dispersion approach for the production of aluminum matrix nanocomposites reinforced by CNTs. These nanocomposites were produced via a classical powder metallurgy route and the dispersion and mixture of the Al powders and CNTs were performed in one step by ultrasonication in isopropanol for 15 min. This process has proved to be effective, as the nanocomposites produced with 0.75% of CNT at 640 °C exhibit an increase of 200% in yield strength (compared to pure aluminum). This value is slightly higher than the values reported for other Al–CNTs nanocomposites produced, for example, by hot extrusion [14]. However, the potential for strengthening the CNTs is even greater [22], so that it is necessary to further improve the mechanical properties of these nanocomposites by optimizing the conditions of this new dispersion treatment. One possibility to

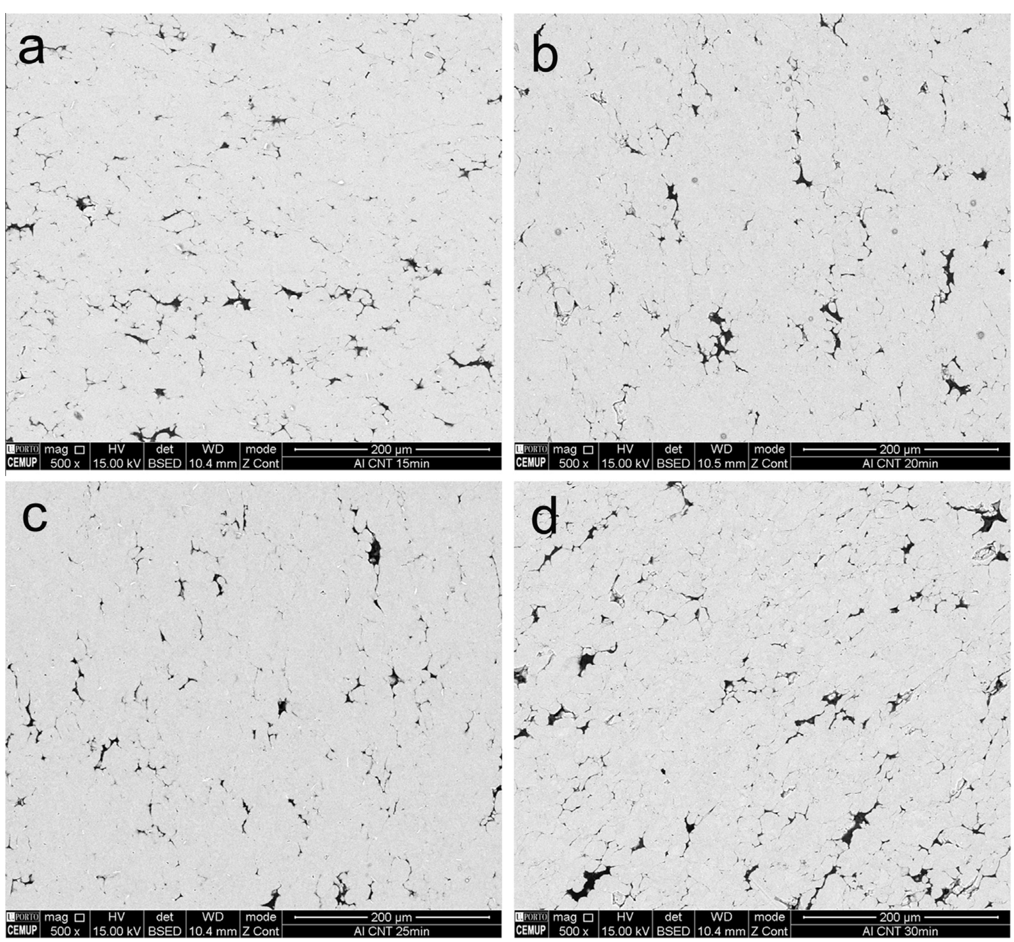

Fig. 2. SEM images of Al–CNTs nanocomposites produced with dispersion/mixture times of (a) 15, (b) 20, (c) 25 and (d) 30 min.