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Influence the Carbon Nanotubes on the Structure and Mechanical Properties of Aluminum-based Metal Matrix Composites

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Abstract. It is known that metal matrix composites reinforced with non-metallic inclusions are of great interest in various fields of technology owing to a good combination strength to weight ratio. Carbon nanotubes (CNTs) are expected to be ideal reinforcements for composite materials due to their high modulus and low density. In this paper metal matrix composites were obtained through hot pressing of powder mixtures Al-1% and 5% carbon nanotubes at different isothermal time. Hardness and density of materials went up with an increase in the isothermal holding time. However, the hardness of composites decreases with an increase the nanotubes content in the material.

INTRODUCTION

The replacement of steel by ultra-lightweight metal matrix composites (MMC) reduces the weight of a construction and improves fuel efficiency. One of the most promising composite materials to solve the problem of reducing the weight of constructions while retaining their high strength is a reinforced MMC. Aluminum, magnesium and their alloys are widely used as materials for such a matrix; and particles of aluminum oxide (Al_2O_3), silicon carbide (SiC) and others, as reinforcement [1-4]. Using multi-walled carbon nanotubes (MWCNT) as the strengthening phase is promising for composite production, since such nanotubes have high mechanical properties (elastic modulus up to 1.5 GPa), which, in turn, affects the mechanical properties of the resulting composite materials [5, 6].

Synthesis of aluminum-based nanotube-reinforced composites makes a wide use of powder metallurgy [5, 7]. The greatest challenge when producing composite materials using these methods is known to be the formation of aluminum carbide (Al_4C_3) [8, 9] at the Al/MWCNT interface, which transforms nanotubes in the metal matrix and, consequently, prevents achieving high mechanical properties. When producing such materials, one can use a hot-pressing technique, which enables the production of dense materials in the solid state without melt formation and hence, preserve the carbon nanotubes.

The aim of the work is to investigate the microstructure, crystal structure and phase composition of hot-pressed aluminum-based MMC reinforced with carbon nanotubes.

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EXPERIMENTAL PART

Materials and methods of experiment

As research materials, we used aluminum powder (ASD6) and multi-walled carbon nanotubes produced by chemical vapor deposition (CVD) [10]. Powder mixture is prepared using a ball milling during 24 hours.

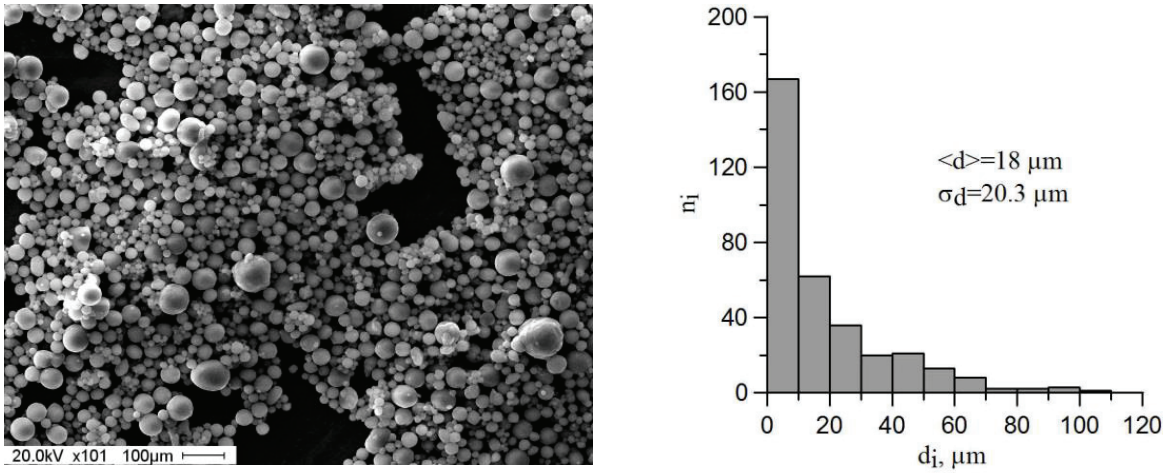
We produced composite materials from the powders under study by hot pressing of powder mixtures in graphite molds in an argon environment at a temperature of 600°C and under a pressure of 30 MPa. Isothermal times for the mixtures under pressure were 5 and 20 minutes. The share of carbon nanotubes in the powder mixture to be hot-pressed was 1 and 5 wt%.

The phase composition and structural parameters of the initial powders and composite materials produced on their basis were investigated using an X-ray diffraction (XRD) with filtered CuK_α radiation. The study was carried out in two ranges along the points with a step of 0.1°. To determine the dimensions of coherent scattering regions (CSR) by the broadening of X-ray profiles (111) at small diffraction angles, the range was $20°<2\theta<80°$. To calculate microdistortions of a crystal lattice using the broadening of reflections at far diffraction angles (422), the range was $130°<2\theta<140°$. The lattice constant was calculated by extrapolating the parameters to an angle of 90° using the approximating function $\cos^2\Theta$.

The structure of the composite materials was examined in a scanning electron microscope Philips SEM 515. The microhardness of Al-MWCNT was measured in a microhardness Nano Indenter G200 tester with an indentation load of 200 g.

RESULTS AND DISCUSSION

Figure 1 a shows a SEM image of the initial aluminum powder. We can see that it consists of particles of a regular spherical shape; moreover, the particle size distribution (Fig. 1b) shows that their average size is 18 μm.



(a) (b)

FIGURE 1. SEM image of aluminum powder (a) and particle size distribution (b)

The analysis of aluminum powder diffractograms only shows the reflections of aluminum on the pattern with no signs of aluminum oxide. According to XRD analysis data, the size of CSR in the powder is 110 nm with the value of microdistortion of the crystal lattice $<\varepsilon>=2.9*10^{-3}$. The calculation of the aluminum lattice parameter shows an insignificant difference from the known data (a=0.40479 nm vs. a=0.4049 nm).

Carbon nanotubes used in this work had the same morphology as those in Ref. [11].

XRD patterns of hot-pressed samples show that they have only reflections of aluminum. Apparently, due to small amount of MWNT in the composite reflections of aluminum carbide have been observed on the patterns. Relatively low temperature of the materials synthesis must have enabled us to prevent the chemical reaction between aluminum and carbon nanotubes. XRD analysis shows that the size of the CSR of aluminum for a 5-minute exposure

time is 100±10 nm, which corresponds to the size of CSR in initial powder; however, longer hot pressing time (20 minutes) leads to a drop in the size of CSR down to 55±5 nm. Nevertheless, the microdistortion of aluminum crystal lattice changes negligibly and amounts to $2.5\text{-}2.8*10^{-3}$.

Fig. 2 shows SEM images of acid-etched cross section of hot-pressed MMC Al-1% MWCNT (a) and Al-5% MWCNT (b) for an isothermal time of 20 minutes. From Fig. 2 (a) one can see, that hot pressing leads to the formation of a structure consisting of grains with an average size of 21 μm, which is close to the average particle size in an aluminum powder. At the same time, Fig. 2 (b) demonstrates that an increase in the content of carbon nanotubes in a metal matrix leads to plastic deformation of aluminum crystal grains associated with not significant interfacial reaction. They change their shape from equiaxed (Fig. 2a) to fiber - like with the major axis perpendicular to the pressing axis with dimensions of 3 μm parallel to the pressing axis and 25 μm normal to it. Moreover, the large agglomerations in the structure composite were not found.

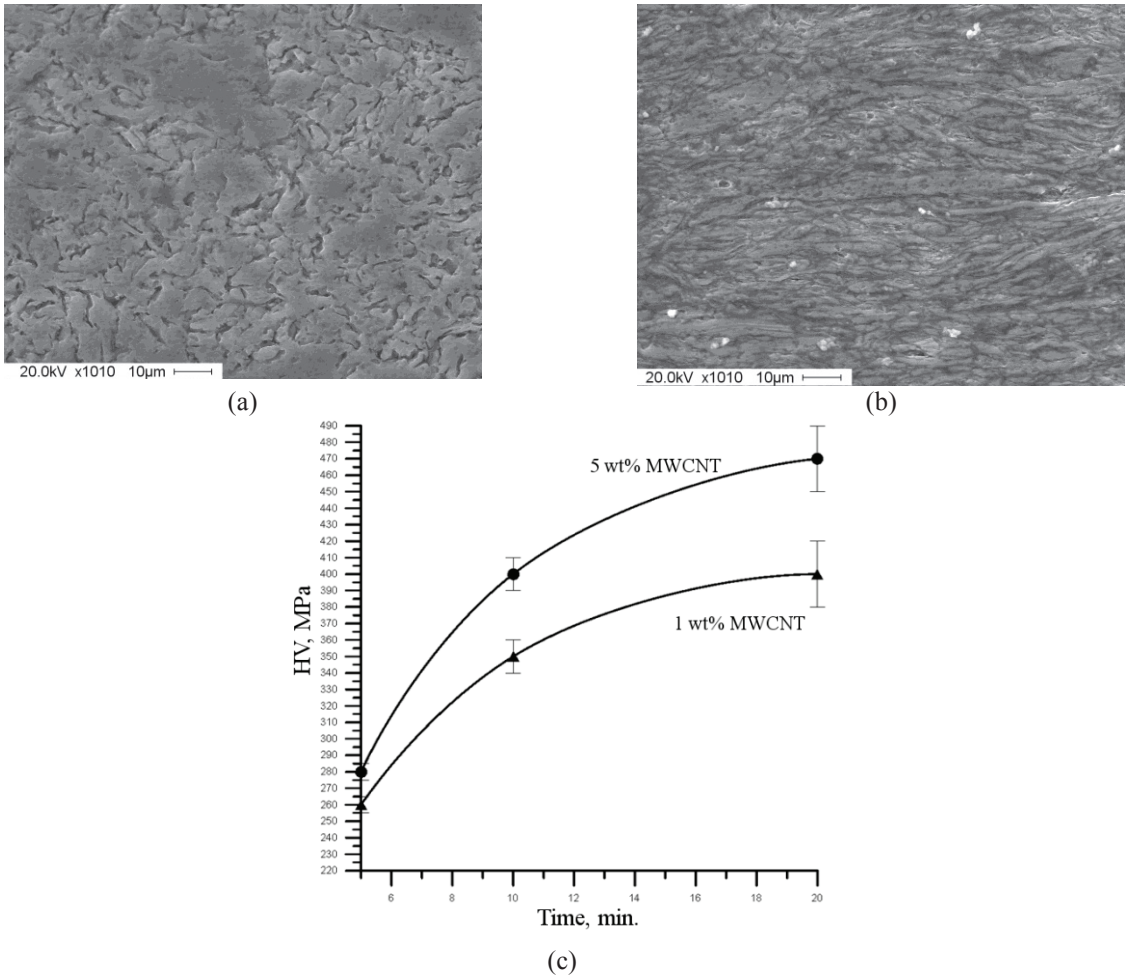


FIGURE 2. SEM images of the surface of hot-pressed Al-MWCNT MMC with the following MWCNT content: 1% (a) and 5% (b); hardness of materials depending on the time of hot pressing (c).

The density of the materials measured by hydrostatic weighing is ~2.4 g/cm^3 for an isothermal time of 5 minutes in all cases; a longer isothermal time of 20 minutes, however, increases the density of materials up to 2.69 g/cm^3, which is very close to the theoretical density of aluminum. It appears that plastic deformation of grains promotes the increase in the density of materials.

Measurements of Al-1%MWCNT hardness show that it goes up with increasing density of the samples. Five-minute holding time provides a hardness of 280 MPa, and 20 minutes, 470 MPa; however, the hardness of materials with the 5% content of MWCNT is somewhat lower and amounts to 260 and 400 MPa respectively. Decrease

hardness with increasing content particles, apparently due to the agglomeration of nanotubes in of intergranular area MMC.

Concluding remark

It is established that due to the low content of nanotubes in the MMC is no formation of aluminum carbide phase. It has been established that an increase in the content of carbon nanotubes in a metal matrix leads to plastic deformation of crystal grains that causes a higher density of materials. Hardness and density of materials go up with an increase in the isothermal holding time. A rise in the MWCNT content in a metal matrix leads to a slight decrease in hardness apparently due to the agglomeration of nanotubes in of intergranular area MMC.

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