EFFECT OF CNT CONTENT ON THE SYNTHESIS AND CHARACTERIZATION OF COPPER-CNT COMPOSITES FABRICATED BY BALL MILLING TECHNIQUE

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ABSTRACT

Copper matrix composites reinforced with carbon nanotube (CNT) particles were produced by powder metallurgy method, including ball-milling process. The effect of CNT content (0.5-5 wt%) on the microstructure, physical and mechanical properties of Copper/CNT composites was comprehensively investigated. CNT particles are embedded on the copper matrix powders during the ball milling process. The dispersion of CNTs in the Copper matrix was observed by a scanning electron microscopy. It was observed that density, electrical conductivity, and hardness change with chancing CNT content. The lowest density was 6.73 g/cm3 for sintered Cu-5wt% CNT nanocomposites, while the highest density value was 8.57 g/cm3 for sintered Cu-0.5wt% CNT nanocomposites. The measured conductivity values were 74.56 IACs for 0.5wt% CNT- reinforced sintered samples and decreased up to 5.3 IACs for 5wt% CNT-reinforced sintered samples.

Key Words: *Nanocomposite, powder metallurgy, Carbon nanotube, electrical conductivity*

1. INTRODUCTION

Metal matrix composites accepted as advanced engineering materials is widely used in many applications because of outstanding physical and mechanical strength as well as wear and conductivity properties. Copper and copper matrix composites have advantages like low cost, good formability, excellent conductivity, good toughness and corrosion resistance. However, Copper and copper matrix composites have some disadvantages such as low hardness and poor wear resistance in the tribology applications. Especially, copper and its composites cannot provide suitable wear resistance for heavy loads or high sliding speed. Therefore, it is needed to improve wear performance of copper and its composites in the tribological application [1-3]. Carbon nanotubes (CNTs) are considered ideal reinforcements for composites because of their high specific strength and stiffness. Specifically, CNT reinforced metal (Al, Cu, and Mg) matrix composites have much attention in recent decades because of the increasing demand from the fields of the electronic and military devices, bearing and automotive materials and high-speed transportation [4-5]. The objective of the study was to produce Copper-CNT composites with different CNT contents using flake powder metallurgy. The effect of CNT particle content on the microstructure, physical and mechanical properties of Cu matrix composites were also investigated in this study.

2. MATERIAL AND METHOD

As-received Cu powders of 99% purity with an average particle size of 58.5µm and multi-walled carbon nanotubes (MWCNTs) with an average diameter of 9.5 nm and an average length of 1.5µm were used in this study. A high-resolution scanning electron microscope (Zeiss Evo LS 10) was used to study the particle morphology of this powder. Flake Cu-CNT nanocomposite powders were synthesized by 5h of ball milling. The Cu powders were reinforced with 0.5, 1, 3 and 5wt% of multi-walled carbon nanotubes using a planetary mill (Retsch PM 200) for 5h with rotation speed of 300 rpm; the ball-to-powder ratio was 5:1. Samples were taken out from the vial at the end of milling process and were subjected to morphological investigation (SEM), particle size examination (Malvern, model 'Mastersizer Hydro 2000e') and X-ray diffraction (XRD) analysis. The powder compact was warm-pressed at 500MPa for 1h at 500 ◦C. After compacting, the green billets were sintered in a tube furnace at 950 ◦C for 2 h under argon atmosphere. The theoretical densities used in calculating the overall nanocomposite density were 8.94 g/cm3 (Cu) and 2.1g/cm3 (MWCNTs). Electrical conductivity of produced composites was measured using Sigmascope SMP10 HF electrical conductivity measurement device and reported in the

International Annealed Copper Standard (IACS). The hardness test was carried out using a Brinell hardness tester with a load of 60 kgf for 10 s.

3. RESULTS AND DISCUSSION

3.1. Morphology and Particle Size

The morphological images of 5 h milled Cu-CNT nanocomposite powders are shown in Fig. 1. The morphology of Cu matrix powders changed from a spherical morphology to flake morphology by ball collisions, as can be seen in Fig. 1. SEM images of Cu–CNT nanocomposite powders for different CNT contents (0.5, 1, 1.5, 2, 2.5, 3 and 5wt.%) showed the initial stage or deformation stage of ball-milling process. According to the results (Fig. 1), it can be said that the particle deformation has a dominant process among the particles during milling of unreinforced Cu particles and Cu-CNT nanocomposite powders. The amount of deformed particles decreased with increasing CNT content (Fig. 1). This can be attributed to the lubrication effect of CNT particles in the ball-milling process.

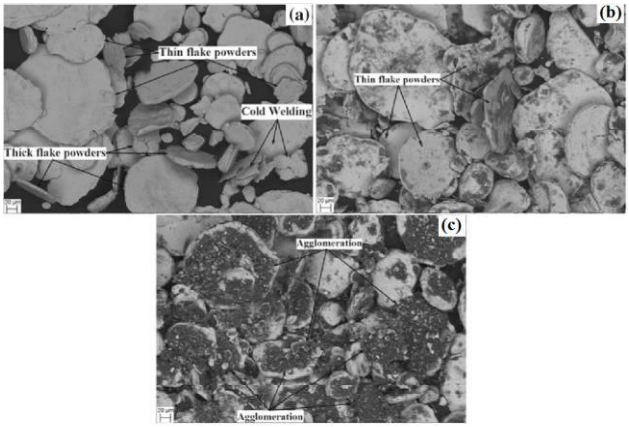


Figure 1: The morphology of Cu-CNT composite powders at the end of 5h of milling: (a) 0.5, (b) 2, (c) 5wt% CNT

The smallest size of Cu-CNT nanocomposite powders obtained with 5wt% CNT content after 5h of milling was found to be 49.652 µm (D50), while the biggest size of Cu-CNT nanocomposite powders obtained with 0.5wt% CNT content after 5h of milling was determined to be 103.81µm (D50) (Fig. 2). The average particle size of Cu-CNT nanocomposite powders at the end of 5h of milling is very high compared with as-received Cu powders. This can be attributed to flake morphology of Cu matrix powders obtained after 5h of milling. As it seen in Fig. 2, the average particle size of Cu-CNT nanocomposite powders decreased with increasing CNT content. This can be attributed to the number of nanoparticles in the composite powder mixture.

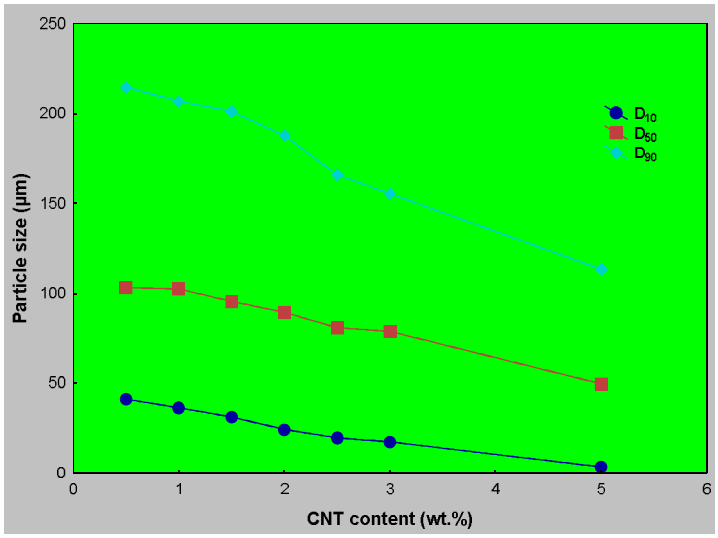


Figure 2: The change in particle size with increasing CNT content (wt%)

3.2. Microstructure

The sintered microstructures of the Cu-CNT nanocomposites showed the CNT particles distributed to the particle boundaries rather than embedding process (Fig. 3). This can be attributed to the effect of volume diffusion during the sintering process. The Cu-CNT nanocomposite reinforced with lower CNT particle content (0.5 and 2wt%) exhibited significantly a lower agglomeration content, while the Cu-CNT nanocomposite reinforced with higher CNT particle content (5 wt%) showed a higher agglomeration content. It should be noted that the reinforcement particles can agglomerate very easily in the matrix when the reinforcement size is smaller than the matrix size. Figure 6 also showed that as the CNT content increased, the porosity content and size increased and the sintering ability of the Cu CNT nanocomposite decreased.

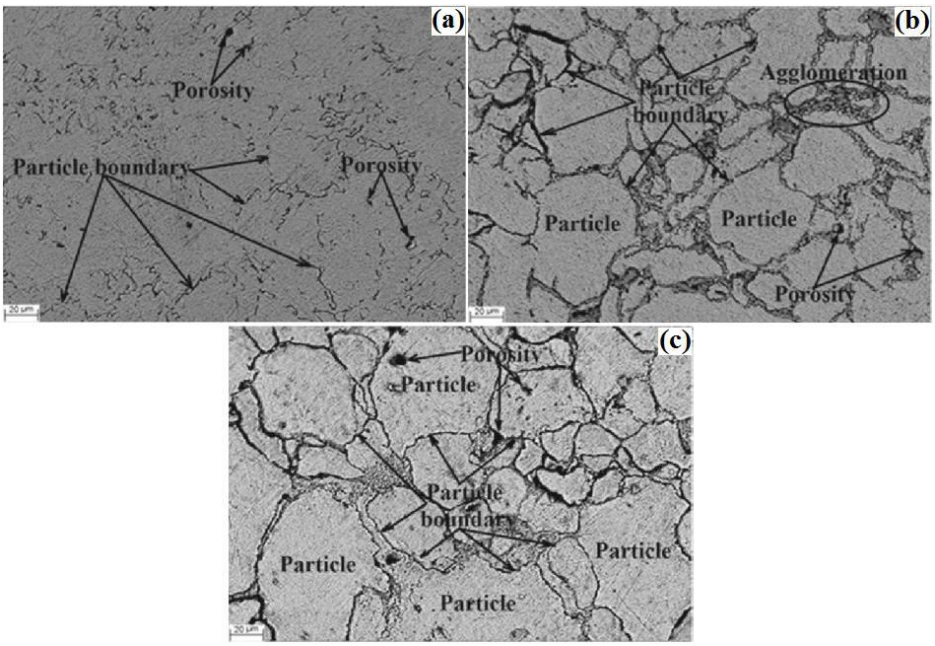


Figure 3: Sintered microstructure images of Cu–CNT nanocomposites: (**a**) Cu–0.5wt% CNT nanocomposites, (**b**) Cu-2wt% CNT nanocomposites, (**c**) Cu–5wt% CNT nanocomposites

3.3. Density and Hardness

A decrease in theoretical density of Cu–CNT nanocomposites with increasing in the weight percentage of CNT particle was found (Fig. 4a). This was because the density of Cu matrix powders (8.94 g/cm3) was higher than that of CNT particles (2.25 g/cm3). The lowest density was 6.3 and 6.73 g/cm3 for green and sintered Cu-5wt% CNT nanocomposites, respectively, while the highest density value was 8 and 8.57 g/cm3 for green and sintered Cu-0.5wt% CNT nanocomposites, respectively. The green density of the Cu-CNT nanocomposites was lower than the sintered density of the Cu–CNT nanocomposites for all CNT contents (Fig. 4a). As shown in Fig. 4b, the hardness of Cu-CNT nanocomposites decreased with the addition of CNT particles. The hardness decreased slightly up to 2 wt.% of CNT content and after that decreased rapidly because the porosity and agglomeration content increased with increasing CNT content.

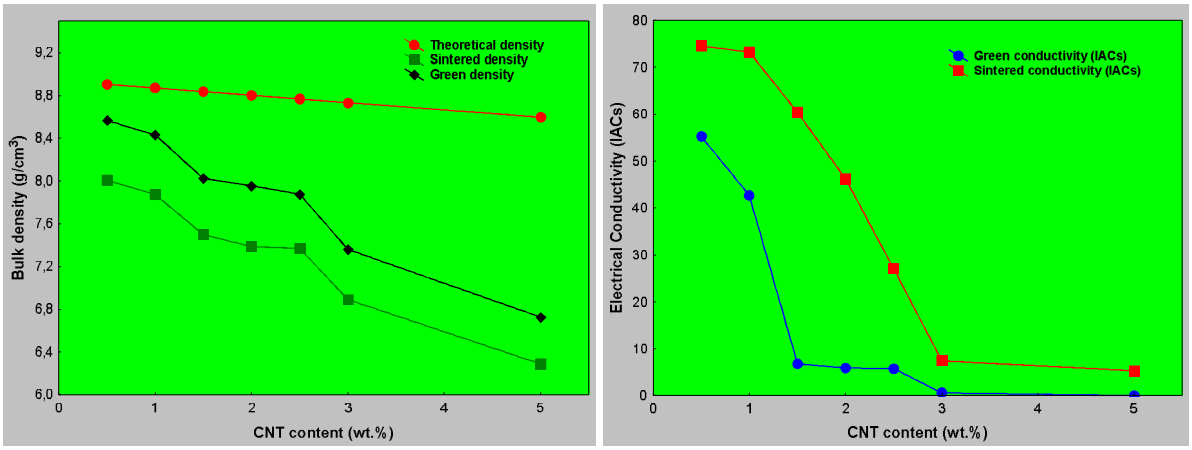


Figure 4 (a) Density, (b) Hardness values

3.4. Electrical Conductivity

The electrical conductivity of green Cu samples increased from 84 IACs to 93 IACs after sintering process. There was a remarkable increase in the electrical conductivity of the sintered Cu-CNT nanocomposites compared to the green Cu-CNT nanocomposites. The electrical conductivity of the green Cu-2wt.% CNT nanocomposites was 6 IACs while that of sintered Cu-2wt.% CNT nanocomposites was 46 IACs (Fig. 5). This can be attributed to microstructural change. Moreover, the agglomeration content increased with increasing CNT content and the agglomeration regions caused electron scattering within the grain boundaries.

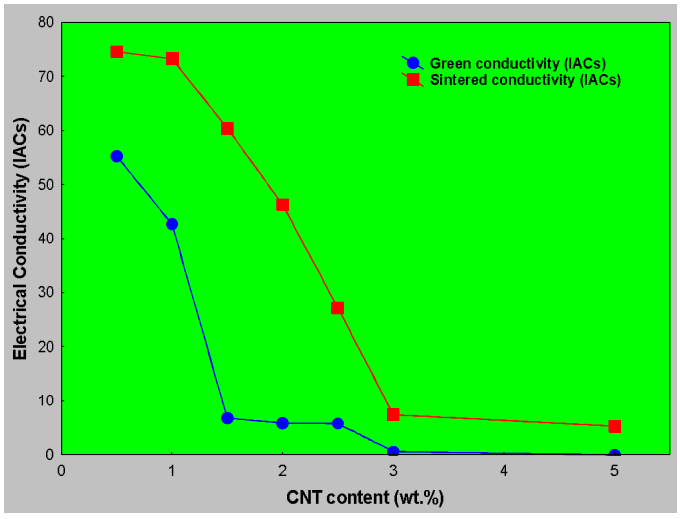


Figure 5: The change of electrical conductivity with increasing CNT content

4. CONCLUSİONS

The sintered density of the Cu-CNT nanocomposites was higher than the green density of the MLG/Copper nanocomposites for all Cu-CNT contents. The sintered density of 2 wt.% Cu-CNT nanocomposites found was 7.96 g/cm3 while the green density of 2 wt.% Cu-CNT nanocomposites was 7.39 g/cm3. Hardness of Cu-CNT nanocomposites decreased with increasing CNT particle content. The electrical conductivity of green 0.5 wt.% Cu-CNT nanocomposites was 55.3 IACs. The electrical conductivity of sintered 2 wt.% Cu-CNT nanocomposites was 46.26 IACs while that of green 2 wt.% Cu-CNT nanocomposites was 5.9 IACs.

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BIOGRAPHIES

Temel Varol was born in Trabzon (1980). He completed his primary, secondary and high school education in Trabzon. Temel Varol started the Mechanical Engineering education in the Atatürk University, Erzurum.
He worked on the production of metal matrix composites by powder metallurgy during master student and presented master thesis (The Production of AA2024 Matrix-B_4C Particle Reinforced Composites by Powder Metallurgy Method and Investigation of Their Properties) at 2012. His first article's name is "The effect of mechanical alloying on Al_2O_3distribution and properties of Al_2O_3particle reinforced Al-MMCs". He worked on the fabrication and characterization of nanoparticle reinforced electrical contact materials during PhD student and completed PhD thesis in January 2016. The last article's name is "The effect of type and ratio of reinforcement on the synthesis and characterization Cu-based nanocomposites by flake powder metallurgy". The current studies of Varol are related to powder metallurgy, mechanical alloying, composites/nanocomposites, functionally graded materials and biomaterials.
Dr. Temel Varol is the member of mechanical engineering association. He is also a professional beekeeper. He married and has two children.

Aykut Canakci was born in Trabzon (1971). He completed his primary and secondary education in Trabzon and received his high school education at Akçaabat. Aykut Canakci started the Mechanical Engineering education in the Karadeniz Technical University.
He worked on the production of metal matrix composite by stir casting during PhD student and presented PhD thesis at the 26 May 2006. His fist article's name is "The effect of brush spring pressure on the wear behavior of copper-graphite brushes with electrical current." The last article' name is "Effect of the B_4C content and the milling time on the synthesis, consolidation and mechanical properties of AlCuMg-B_4C nanocomposites synthesized by mechanical milling". The current studies of Canakci are related to powder metallurgy, mechanical alloying and metal matrix composites.
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Fatih Erdemir was born in Giresun (1984). He completed his primary, secondary and high school education in Giresun. Fatih Erdemir started the Metallurgical and Material Engineering education in the Eskisehir Osmangazi University.
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Dr. Fatih Erdemir is the member of metallurgical engineering association. He married and has one child.