Vol. **135** (2019) *ACTA PHYSICA POLONICA A* No. 4

Special Issue of the 8th International Advances in Applied Physics and Materials Science Congress (APMAS 2018)

Effect of Carbon Nanotube Content on the Wear Behaviours of Cu–CNT Composites Produced by Powder Metallurgy Method

F. Taşdemir[a]*, D. Özyürek[a] and M. Yildirim[b]

[a]Karabük University, Department of Manufacturing Engineering, Karabuk, Turkey

[b]Karabük University, Department of Industrial Design Engineering, Karabuk, Turkey

In this study the effect of carbon nanotube content on the wear behaviours of Cu–carbon nanotube composites produced by powder metallurgy method was investigated. In the scope of the study five different amounts of carbon nanotube (0.5%, 1.0%, 1.5%, 2.0%, 2.5%) were added into pure Cu powders and mechanically milled for 360 min. The mechanically milled Cu–carbon nanotube powders were cold pressed under 600 MPa load and sintered in atmosphere-controlled furnace at 1000 °C for 1 h. Microstructure examinations, hardness measurements, and wear tests were carried out. In this study, the hardness values were found to have increased with increasing carbon nanotube content up to 1.5%. Then it decreased with increasing carbon nanotube content. Wear test results were compatible with hardness results. The lowest weight losses were measured with 1.5% carbon nanotube content.

DOI: 10.12693/APhysPolA.135.726

PACS/topics: carbon nanotube, Cu, hardness, wear behaviour, powder metallurgy

1. Introduction

Due to their electrical and thermal conductivity, Cu and Cu alloys are widely used in the industry. However, the low wear resistance of Cu and its alloys limits the use of these alloys [1, 2]. Cu matrix composites are produced by adding various reinforcement elements to increase the hardness and wear resistance of these alloys [3, 4]. In recent years, carbon nanotubes (CNT's) have begun to be used as reinforcing elements in composites due to their superior properties such as high strength, high modulus of elasticity, and electrical and thermal conductivity [5–7]. In previous studies, CNT's have been reported to be used as reinforcing elements in polymer matrix composites, but recently it has also been used in metal matrix composites as reinforcing elements [8, 9]. The most common problem with CNT-reinforced metal matrix composites is the low wettability. Furthermore, due to the agglomeration of nanomaterials, they cannot be homogeneously distributed in the matrix [10, 11]. The most widely used method in the production of CNT reinforced metal composites is mechanical alloying/mechanical milling (MA/MM) which is a powder metallurgy method. In this way, the reinforcement phase causes a more homogeneous distribution in the matrix structure, which also prevents unwanted reactions between the CNT's and the matrix [12]. When studies on CNT-reinforced metal matrix composites are examined, it is seen that mostly the pure Al and Al alloys were used as matrix materials and the use of Cu and its alloys as matrix materials seems to be very limited. For this reason, in this study, wear behaviors of the composites produced by adding CNT's in different amounts to Cu which is widely used in the industry by powder metallurgy method are examined.

2. Materials and equipments

In this study, commercially available pure copper (99%) powders were used as matrix material. Multi-walled carbon nanotubes with a size of 1.5 μm and a diameter of about 9.5 nm at 90% purity, obtained from Nanografi company, were used as reinforcements. Five different amounts of CNTs (0.5%, 1%, 1.5%, 2%, and 2.5%) were used. CNT was added into pure copper and milled in stainless steel chamber in MA/MM device. The MM operation was performed at 400 rpm for 360 min with 10:1 ball powder ratio and 1% stearic acid was used as a process control chemical. In order to prevent overheating during the MM operation, the milling was paused for 10 min after each 20 min milling. Milled composite powders were pre-formed in the mold with a force of 600 MPa to produce green compacts with diameter of 12 mm and height of 7 mm. Preformed composites were sintered at 1000 °C for 1 h in an atmosphere-controlled environment (argon). The sintered composites were etched with keller solution after metallographic processes and microstructural examinations were observed with scanning electron microscope. Hardness measurements were carried out a microhardness device (HMV 0.5). Wear tests were carried out on a pin-on disc type wear device at four different sliding distances (500 m, 1000 m, 1500 m, and 2000 m) and 30 N loads at a sliding speed of 1 m/s.

3. Results and discussion

Optical microscope images and results of EDS (mapping) of CNT-reinforced Cu-based composites are given in Fig. 1a–f and Fig. 2a–c. When the results of optical

---

*corresponding author; e-mail: fatihtasdemir@msn.com

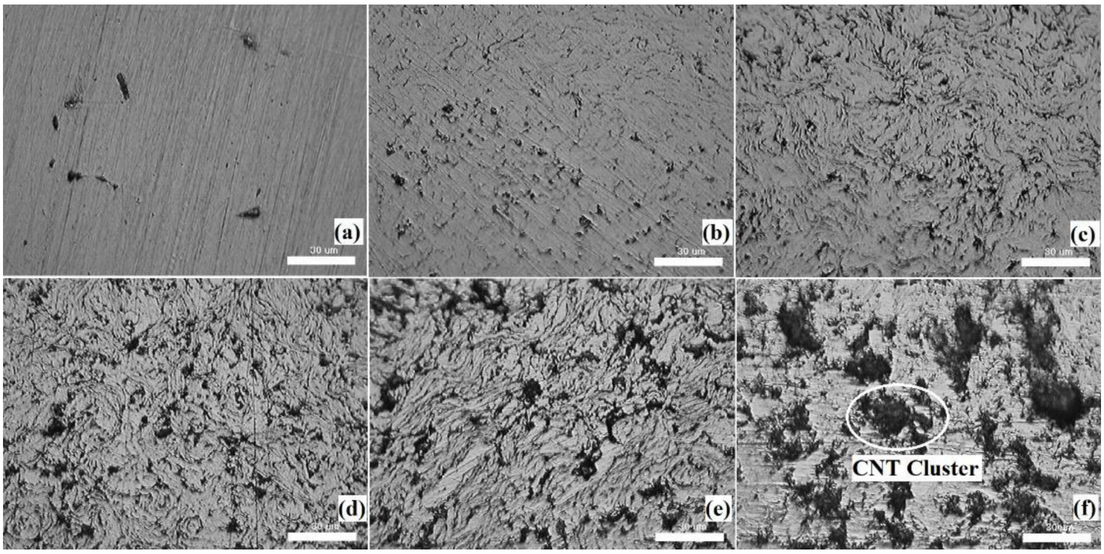

Fig. 1. Optical microscope images of composites that different amounts of CNT added: (a) pure Cu, (b) pure Cu + 0.5% CNT, (c) pure Cu + 1% CNT, (d) pure Cu + 1.5% CNT, (e) pure Cu + 2% CNT, (f) pure Cu + 2.5% CNT.

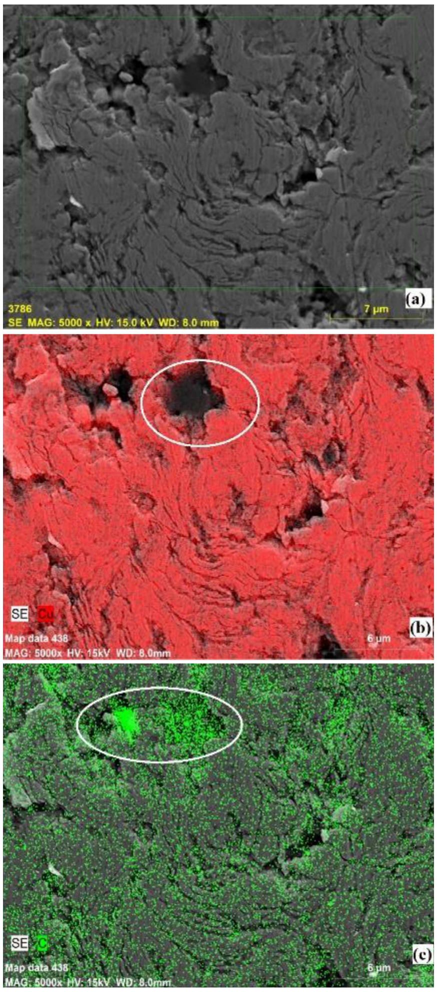

Fig. 2. EDS (mapping) results of Cu–CNT composite with 2% CNT added: (a) SEM image, (b) Cu EDS mapping image, (c) C EDS mapping image.

microscope, given in Fig. 1a, and the EDS (mapping), given in Fig. 2, are examined, it is obvious that as the amount of added carbon nanotubes increases, the distribution in the structure is not homogeneous and agglomerated. Previous studies emphasized that there is agglomeration due to size difference between reinforcement element and matrix in nanocomposites and the difficulties of homogeneous distribution of carbon nanotubes [9, 10]. Changes of the hardness of the composites produced by adding different amounts of CNT are given in Fig. 3.

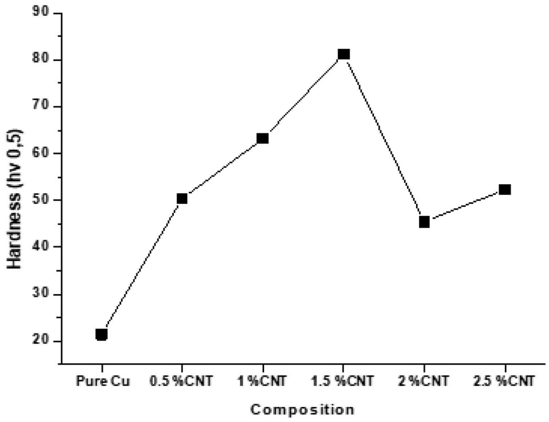

Fig. 3. Changes of the hardness of the Cu-based composites added different amounts of CNT.

When the variations in hardness given in Fig. 3 are examined, the lowest hardness value is measured in pure Cu (21.4 HV). As the amount of CNT increases, the hardness value increases. The hardness value reaches the highest value when 1.5% CNT is added to the composite (81.3 HV), and the hardness decreases at 2% and 2.5% CNT's reinforced composites. As can be understood from the microstructure images given in Figs. 2

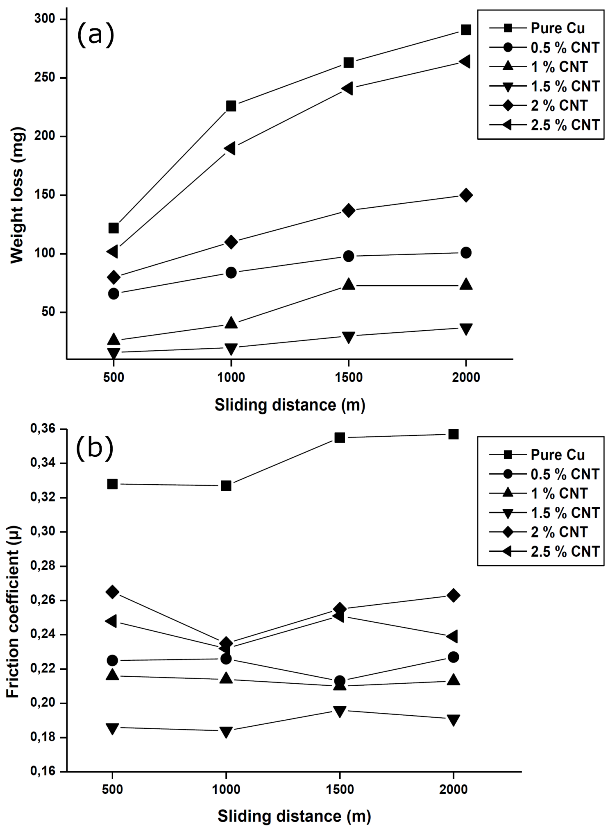

Fig. 4. Weight loss (a) and friction coefficients (b) of composites produced by different amounts of CNT addition.

and 3, the hardness decreases by agglomeration. Previous studies emphasized that agglomeration that occurs in the composites produced with addition of CNTs reduces the mechanical properties [1–4]. Results of wear tests, the weight loss, and friction coefficient of the composites produced by different amounts of CNT addition are given in Fig. 4.

When the weight loss and friction coefficients after wear tests of Cu–CNT composites are examined, it can be seen that weight loss decrease as the amount of carbon nanotubes added up to 1.5% increase and the highest weight loss is obtained from pure Cu which has no CNT. However, weight loss and friction coefficient of composites added with 2% and 2.5% CNT are increased. The obtained weight loss and friction coefficients correspond to the hardness results given in Fig. 4a and b. This reduction in the weight loss and friction coefficient is due to the breakdown of the large agglomerating parts in the structure as the amount of CNT increases. This can be seen from the microstructure images presented in Figs. 1 and 2.

4. Conclusion

In this study the effect of carbon nanotube content on the wear behaviours of Cu–CNT composites produced by powder metallurgy method was investigated. The results obtained from this study are given below.

As the amount of CNT in Cu–CNT composites increases, the CNT's accumulate in certain regions and the agglomeration increases. In the hardness and wear tests, the highest hardness and the lowest weight loss are obtained with 1.5% CNT reinforced composites, while friction coefficients support these results.

Acknowledgments

The authors are pleased to acknowledge the financial support for this study from Karabuk University Scientific Research Projects Department (KBÜ-BAP-15/2-YL-035)

References

[1] F. Akhtara, S.J. Askaria, K.A. Shaha, X. Du, S. Guo, *Mater. Charact.* **60**, 327 (2009).

[2] J.P. Tu, W. Rong, S.Y. Guo, Y.Z. Yang, *Wear* **255**, 832 (2003).

[3] H. Xing, X. Cao, W. Hu, L. Zhao, J. Zhang, *Mater. Lett.* **59**, 1563 (2005).

[4] S.F. Moustafa, Z. Abdel-Hamid, A.M. Abd-Elhay, *Mater. Lett.* **53**, 244 (2002).

[5] E.T. Thostenson, Z. Ren, T.W. Chou, *Compos. Sci. Technol.* **61**, 1899 (2001).

[6] S.C. Tjong, *Mater. Sci. Eng. R* **74**, 281 (2013).

[7] C.F. Deng, D.Z. Wang, X.X. Zhang, A.B. Li, *Mater. Sci. Eng. A* **444**, 138 (2007).

[8] S. Bal, S.S. Samal, *Bull. Mater. Sci.* **30**, 379 (2007).

[9] N. Al-Aqelli, K. Abdullahi, C. Suryanarayana, T. Laoui, S. Nouarı, *Mater. Manufact. Process.* **28**, 984 (2013).

[10] M. Yildirim, D. Özyürek, M. Gürü, *Fullerenes Nanotubes Carbon Nanostruct.* **24**, 467 (2016).

[11] H.J. Choi, J.H. Shin, B.H. Min, D.H. Bae, *Composites A* **41**, 327 (2010).

[12] J.M. Torralba, C.E.D. Costa, F. Velasco, *Mater. Process. Technol.* **133**, 203 (2003).