IRAQI Academic Scientific Journals

Tikrit Journal of Engineering Sciences (2021) 28 (1): 13-20

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

College of Engineering

TJES Tikrit Journal of Engineering Sciences

Farouk M. Mahdi, Omar H. Mahmood. Effect of Adding Nano Ag on Mechanical and Physical Properties of Cu–10% Fe Prepared by Powder Metallurgy Technique. *Tikrit Journal of Engineering Sciences* 2021; 28 (1): 13- 20.

Effect of Adding Nano Ag on Mechanical and Physical Properties of Cu–10% Fe Prepared by Powder Metallurgy Technique

Farouk M. Mahdi *

Omar H. Mahmood

Department of Mechanical Engineering (Production and Metallurgy), College of Engineering, Tikrit University, Tikrit, Iraq

***Keywords*:**

Cu-Fe composite
Electrical conductivity
Bulk density
Compression strength
Wear rate.

ARTICLE INFO

Article history:

Received	15 Oct. 2020
Accepted	01 Mar. 2021
Available online	26 Mar. 2021

ABSTRACT

Copper-matrix composites have received a lot of attention and are used widely in various applications, such as electronics, machinery, automobile, military and aerospace; because of their remarkable electrical conductivity, high thermal conductivity and excellent mechanical properties. Among these are copper-iron composites which found many engineering applications due to the role of Fe in enhancing the mechanical properties of these composites beside its low cost. However, Fe addition reduces electrical and thermal conductivity therefore, binary Cu-Fe composites are not suitable for applications where these properties are the main requirement. Many studies have been done to enhance these properties by the addition of alloying elements. The present work aims to study the effect of adding Nano Ag on mechanical and physical properties of Cu-10 wt% Fe composites prepared by powder metallurgy technique. The results showed the effectiveness of Nano Ag in enhancing both mechanical and physical properties of Cu-10 wt% Fe composite. It is found that bulk density, electrical conductivity, and thermal conductivity have been increased by 1.19%, 46%, and 46% respectively on adding 5% Nano Ag. Hardness and compression strength have been increased by 17.3% and 32.8% respectively by adding 4% Nano Ag, while wear rate was reduced by 13.4% by adding 4% Nano Ag.

DOI: http://dx.doi.org/10.25130/tjes.28.1.02

* Corresponding AuthorE-mail: farouk_1959_1996@tu.edu.iq

تأثيرإضافة الفضة النانوية على الخواص الميكانيكية والفيزيائية لمتراكب نحاس-10%حديد المحضر بتقانة ميتالورجيا المساحيق

فاروق منصور مهدي / قسم الهندسة *الميكانيكية* / كلية الهندسة/ جامعة تكريت/ العراق
وعمر حسن محمود/ قسم الهندسة الميكانيكية/ كلية الهندسة/ جامعة تكريت/ العراق

الخلاصة

نالت المتراكبات ذات الاساس النحاسي اهتماما كبيرا ووجدت استخدامات عديدة مثل التطبيقات الالكترونية والآلات والسيارات والاستخدامات العسكرية والفضائية نظرا لما تتمتع به من توصيلية كهربائية وحرارية عالية وخصائص ميكانيكية ممتازة. يأتي متراكب حديد- نحاس في مقدمة هذه المتراكبات والذي وجد تطبيقات هندسية عديدة نظرا لما يتمتع به عنصر الحديد من رخص الثمن والدور الكبير الذي يلعبه في تحسين الخواص الميكانيكية للمتراكب، إلا أن أثره السلبي في خفض كل من التوصيلية الكهربائية والتوصيلية الحرارية قد قيد كثيرا استخدام متراكبات Cu-Fe في المجالات التي يكون متطلبها الاساس التوصيلية الكهربائية أو التوصيلية الحرارية. وقد أجريت محاولات كثيرة لتحسين هاتين الخاصيتين من خلال إضافة عناصر سبائكية أخرى الى هذه المتراكبات. يهدف البحث الحالي الى دراسة تأثير إضافة الفضة النانوية على الخواص الميكانيكية والفيزيائية لمتراكب Cu-10 wt%Fe والمحضر بطريقة ميتالورجيا المساحيق. أظهرت النتائج حدوث تحسن كبير في الخواص الميكانيكية والفيزيائية بعد إضافة الفضة النانوية. حيث زادت الكثافة بمقدار 1.19% وزادت كل من الموصلية الحرارية والكهربائية بمقدار 46% بإضافة الفضة النانوية بمقدار 5%. في حين زادت الصلادة ومقاومة الانضغاط بمقدار 17.3% و 32.8% على التوالي بعد إضافة الفضة النانوية بنسبة 4% وانخفض معدل البلى بمقدار 13.4% بعد زيادة محتوى الفضة النانوية الى 4%.

الكلمات الدالة: متراكبات نحاس-حديد، التوصيلية الكهربائية، الكثافة الحجمية، مقاومة الانضغاط، معدل البلى

Nomenclatures

A	cross section area of contact (m^2)
BD	Bulk Density (g/cm^3)
d	diameter of the specimen (mm)
F	applied load (N)
h	height of the specimen (mm)
K	thermal conductivity (W/m.k)
N	sliding speed (r.p.m)
PMT	Powder Metallurgy Technique
Q	quantity of exerted heat (W) = 20Watt
r	sliding radius (cm) (from center of disc to center of sample)
s	sliding distance (cm)
t	sliding period (min)
w_1	weight of sample before wear test (g)
w_2	weight of sample after wear test (g)
w_d	dry weight (g)
w_i	suspended weight (g)
w_s	saturated weight (g)
ΔT	temperature difference between the two ends of the specimen (K)
ΔX	distance between the two thermocouples along the sample (m)
ρ_w	density of water (g/cm^3)
σ	compressive strength (MPa)

1. INTRODUCTION

Powder metallurgy technique (PMT) is the main process used to produce composite materials due to its unique characteristics, where PMT produces parts from almost any material, from alloys which cannot be produced by casting or plastic deformation methods. Moreover, PMT reduces material losses, provide segregation free final or near final products with precious control in chemical composition, superior surface finish, and easily automated process [1].

Metal matrix composite materials are used in a wide range of engineering applications because they can combine between properties of various engineering materials such as good thermal and electrical conductivity with high fatigue and wear resistance, with the ability to maintain these properties up to 300 ^oC. Metal matrix composites are used in aerospace industry, automobiles, and electrical applications which require high wear resistance [2]. The increasing needfulness for components with almost totally new properties combines between incongruous properties of different materials led for the development of new and unique composites with bimodal micro and Nano-structure [3].

Copper possesses many excellent properties such as high electrical and thermal conductivity, good corrosion resistance, good casting and plastic deformation abilities. However, pure copper cannot be used in many engineering applications because of its low strength which needs to be increased by various methods. Dispersion strengthening by fine particulates is one of the methods that are used to increase the elevated temperature strength of copper besides its enhancing effect on its tribological properties [4]. Therefore, copper matrix composites got a great interest and are developed for many applications like heat exchangers, sensitive electrical circuits, brushes, springs, bearings, and bushing [5-8]. Among copper matrix composites, Cu-Fe composites got the attention of many researchers because of their low cost, compared with other metals beside their good mechanical properties [9-16]. Jerman, G.A. et al [17] have studied and developed the microstructure and properties of Cu-Fe composites which are prepared by powder metallurgy technique. They found that electrical conductivity was enhanced by intermediate heat treatment. Barzegar Visshlaghi M., and Ataei A. [18] studied the Nano Cu-Fe composites prepared by mechanical alloying technique. They found that the

solubility of Fe in Cu can be as high as 20% after 15 hrs of milling. Liu, K.M. et al [19] and Fernee, H. et al [20] studied the effect of a third alloying element on microstructure and physical properties of Cu-Fe composites. They found a respective enhancement in electrical conductivity after the intermediate heat treatment. Mohammad Baghani et al [21] investigate the effect of Nano Al_2O_3 on tribological, and corrosion behavior of Cu-25%Fe composite prepared by mechanical alloying for 60 hrs. They found that corrosion resistance was increased by 75%, wear resistance was increased by 30%. Keming Liu et al [22] studied the effect of Fe content and drawing strain on tensile strength of Cu-Fe composite produced by casting. They found that tensile strength increased with increasing both Fe content and drawing strain.

Adding Ag to Cu-Fe composites was found to refine the microstructure effectively, increase the strength, and enhance the electrical conductivity. Hong, S.I. et al [23] studied the effect of Ag, Co, and Cr as a third alloying element on the properties of Cu-Fe composites. Their results reveal that Ag addition provides good enhancement in both mechanical and electrical properties. Song, S.Hong et al [24] have studied the effect of thermo-mechanical treatment on strength and conductivity of Cu-Fe-Ag micro-composites. The optimum strength/conductivity was obtained at cold drawing strain ($\eta=(\ln A_o/A)$) = 6.3 with three intermediate heat treatments, where A_o and A are the original and the final cross-sectional area respectively. Gao, H. et al [25] have studied the effect of Ag on thermal properties of in-situ Cu-Fe composites after thermo-mechanical treatments. Ag was found to increase both strength and thermal conductivity. Li et al [26] studied the effect of Ag on cast and drawn Cu-Fe composites. Ag was found to reduce the solubility of Fe in Cu-Fe castings, and increase strength and conductivity of the drawn Cu-Fe composites.

The results of previous studies reveal the effective effects of micro-Ag on the properties of Cu-Fe composites. The present work aims to study the effect of Nano Ag on the properties of Cu-10 wt%Fe composites prepared by powder metallurgy technique.

2. EXPERIMENTAL PART

2-1 Used Materials

Cu-10wt%Fe composites with up to 5wt% Nano Ag were prepared from Cu powder with 99.969% purity and 50 µm mean particle size, Fe powder with 99.9% purity and 10 µm mean particle size, and Ag powder with 99.9% purity and 50 nm mean particle size. Electric balance of 0.00001g accuracy was used to weight the metal powders.

2-2 Composite Preparation

The powders were mixed with a ball milling machine at 330 rpm using 8 mm diameter chromium steel balls with 1:1 balls to powder ratio for 30 min. Figure (1) represents a schematic diagram of the ball milling machine [27].

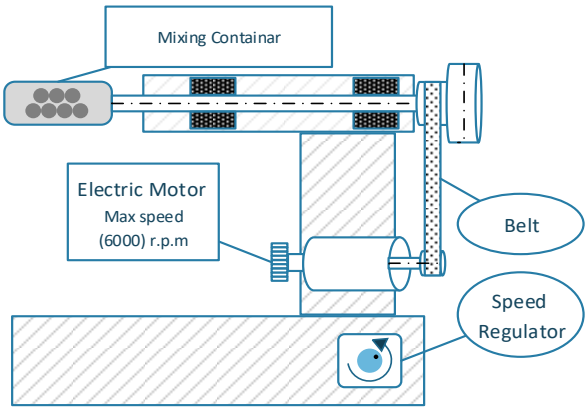


Fig.1. The ball milling machine [27]

The mixed powders were compacted by uniaxial cold compaction, using HOYOTOM universal testing machine at 700MPa for 3min to obtain cylindrical specimens with 10mm diameter and 6mm height. The green specimens were sintered at 1000 °C for 1hr into Muffle Furnace. To protect the samples from oxidation, they were placed inside a ceramic container and surrounded by multilayers of graphite powder and gray cast iron chips with a fireclay seal as shown in Figure (2). This configuration was found to provide excellent protection against atmospheric oxygen [28, 29].

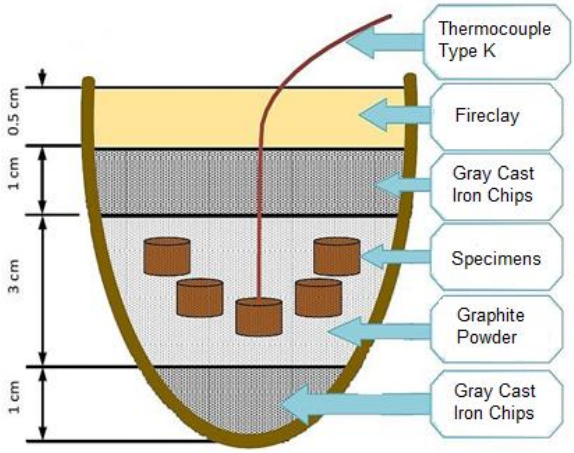


Fig.2. Sintering container [28]

2-3 Physical Tests

2-3-1 Microscopic Tests

The polished surface was examined with a binocular optical microscope attached with digital camera. The examined surface was ground with emery paper and polished according to the ASTM-C373-88 standard.

2-3-2 Bulk Density

Bulk density was determined according to the ASTM C373-88 standard with the following steps:

1- The samples were dried into an electric furnace at 150 °C for 1 hr to obtain the dry weight (w_d).
2- The suspended weight (w_i) was determined while the sample being sunk and suspended in distilled water.
3- The saturated weight (w_s) was found by the immersion of each sample into boiling distilled water for 5 hrs followed by 24 hrs immersion at room temperature into distilled water.

4- The bulk density (B.D.) was calculated from the formula [30]:

$$B.D. = \frac{w_d}{w_s - w_i} * \rho_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2-3-3 Electrical and Thermal Conductivity

P.A.Hilton Ltd;England Heat Conduction Unit was used to determine the thermal conductivity, while the electrical conductivity was calculated from the formula [27]:

$$-K = \frac{Q}{A * \frac{\Delta T}{\Delta X}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2-4 Mechanical Tests

2-4-1 Hardness Test

Vickers micro-hardness was determined using the France MEKTON THV-501E tester by applying 500g load for 5s. The average of five readings was taken as the hardness of the examined surface.

2-4-2 Compression Test

The radial compression test was done on the Chinese HOYOTOM universal testing machine as shown in Figure (3).

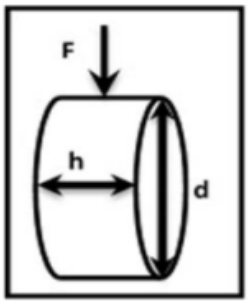


Fig.3. Radial Compression test

The compression strength was calculated from the following equation [28]:

$$\sigma = \frac{2F}{\pi dh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

2-4-3 Wear Test

Wear tests were carried out using the Indian Wear and Friction Monitor ED-201 under dry sliding condition, 470 rpm, 10 N normal load, 3cm sliding radius, and 30min testing period. The wear rate was calculated according to the following formula [29]:

$$Wear\ rate = \frac{\Delta w}{s}\left(\frac{g}{cm}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where:

$\Delta w = w_1 - w_2$

$S = 2\pi\ r\ t\ N$

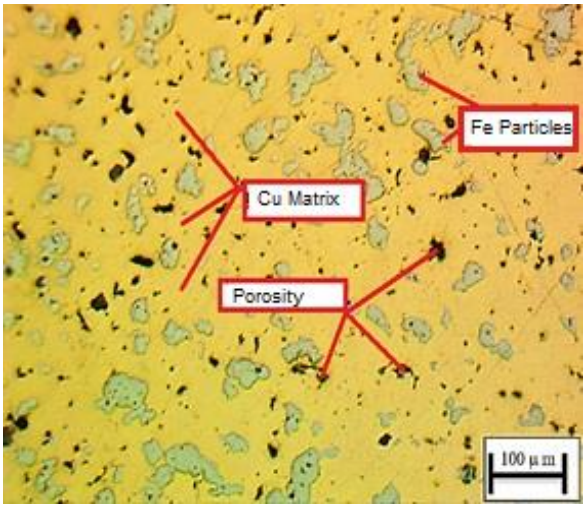
2-5 X-Ray Diffraction

XRD examinations were done by Shimadzu XRD-6000 instrument in order to examine the composite phases. The XRD charts were analyzed by Match! 3 software.

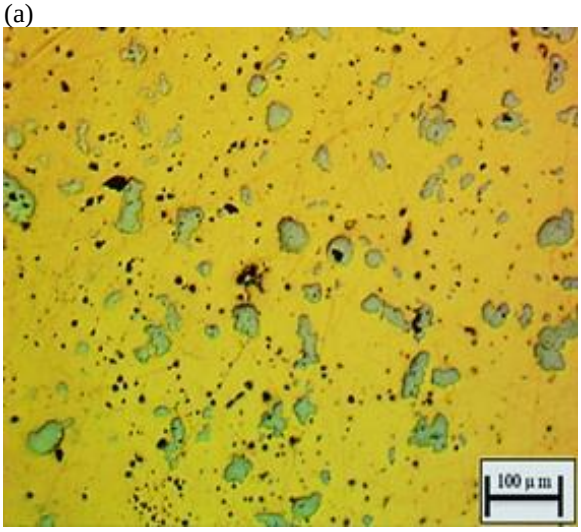
3. RESULTS and DISCUSSION

3.1. Microscopic Tests

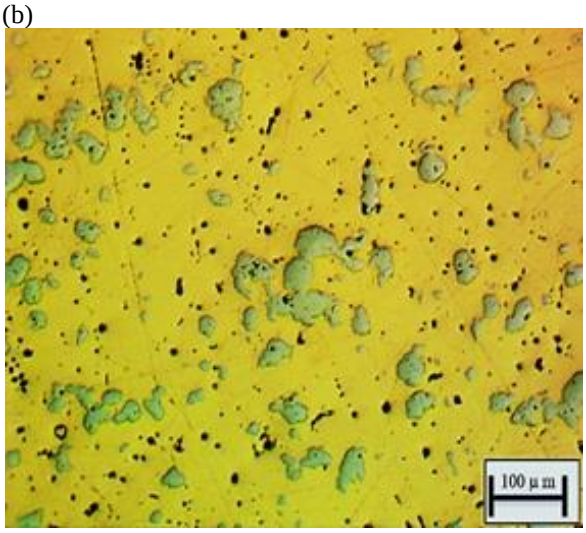
Figure (4) shows the results of the polished surface examination of Cu-10%Fe- Nano Ag composites. This figure reveals the uniform distribution of Fe particles in the Cu matrix, no signs for particle agglomeration with the presence of a uniformly distributed micro porosity.



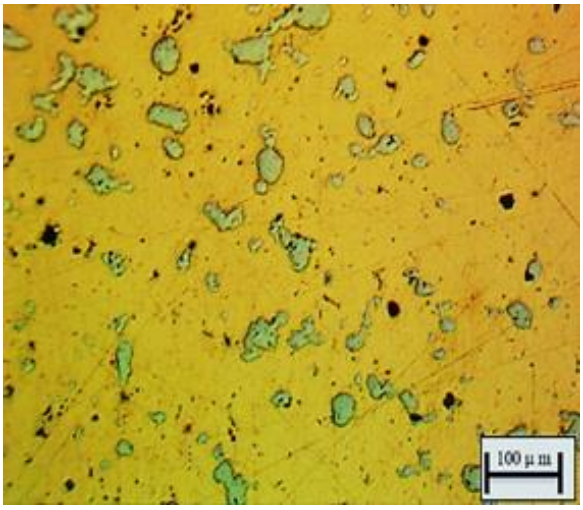
(a)



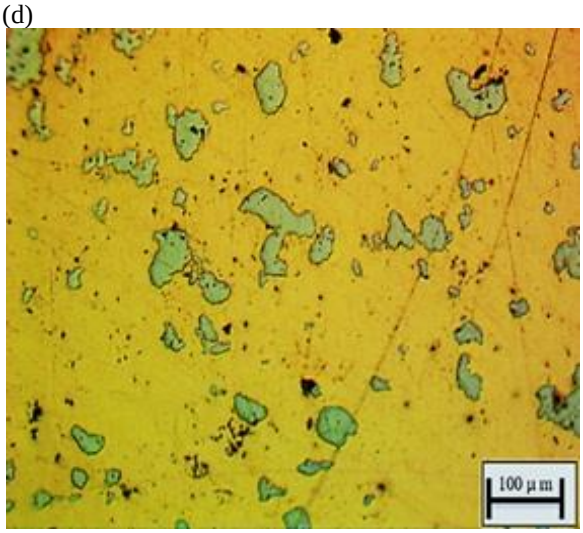
(b)



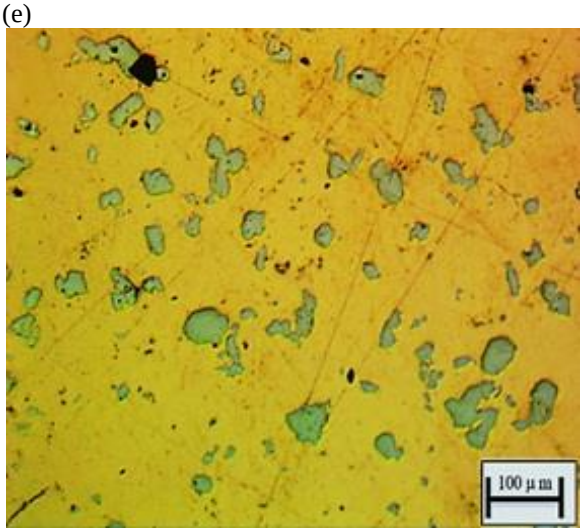
(c)



(d)



(e)



(f)

Fig.4. Microstructure of Cu-10%Fe-nano Ag. a- 0%Ag, b- 1% Ag, c- 2%Ag, d- 3%Ag, e- 4%Ag, and f- 5%Ag

3.2. Bulk Density

Figure (5) represents the relationship between bulk density and Nano Ag-content in Cu-10%Fe composite. The bulk density as shown in this figure increases continuously with increasing Ag content. This increase in bulk density is attributed to the higher density of Ag compared with both Cu and Fe besides its action as filler material due to its Nano-scale size, a situation which increases the composite density by closing or reducing the micro porosity.

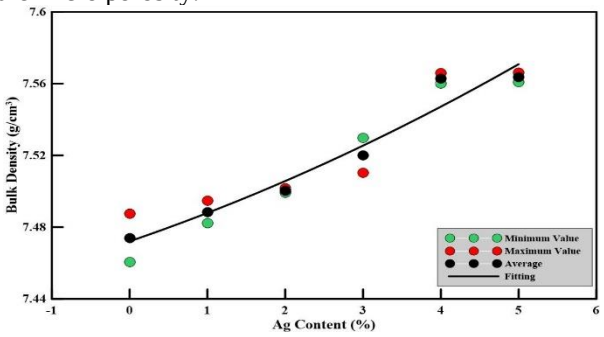


Fig.5. Bulk density and Nano Ag content in Cu-10%Fe composite.

3.3. Thermal and Electrical Conductivity

Figures (6) and (7) show the effect of Nano Ag-content on electrical and thermal conductivity of Cu-10%Fe composite respectively. Considerable increase in both conductivities was found on increasing Nano Ag content. Thermal and electrical conductivity were increased from 196.35 W/m.K to 286.48 W/m.K and from 29.398 (μΩ.m)-1 to 42.95 (μΩ.m)-1 on increasing Ag content from 0 to 5% respectively. The main drawback of binary Cu-Fe composites is their low electrical and thermal conductivity due to add Fe. According to the results of the present study, this drawback can be overcome by adding Nano Ag particles. This increase in conductivity is attributed to the high thermal and electrical conductivity of Ag ((448.37 W/m.K) and (62.64 (μΩ.m)-1)) besides its effect as filler material which increases the actual cross section of the material by decreasing its porosity and its role in enhancing both densification and consolidation of the sintered composite. Similar results were found by [31] with add micro Ag to Cu-13% graphite composite where thermal and electrical conductivity were increased from 228.63 W/m.K to 264.81 W/m.K and from 32.14 (μΩ.m)-1 to 36.08 (μΩ.m)-1 on increasing the micro Ag-content from 0 to 5% respectively. The results of the present study reveal the considerable effect of adding Nano Ag compared with micro Ag in increasing thermal and electrical conductivity.

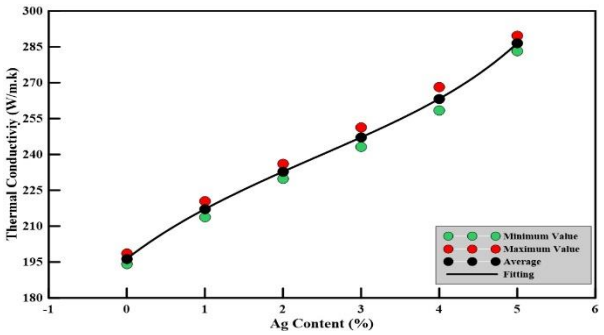


Fig.6. Effect of Nano Ag content on thermal conductivity of Cu-10%Fe composite

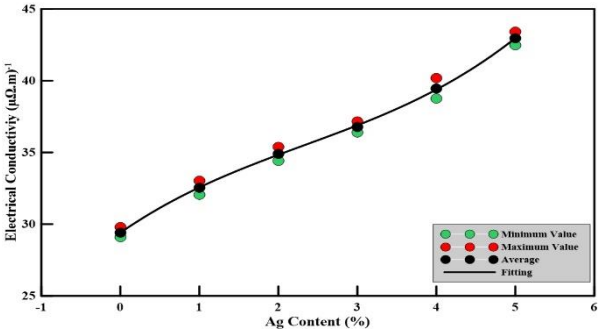


Fig.7. Effect of Nano Ag content on electrical conductivity of Cu-10%Fe composite

3.4. Hardness, Wear Rate and Compression Strength

Figures (8), (9) and (10) show the effect of Nano Ag-content on hardness; wear rate and compression strength of Cu-10%Fe composite respectively. The composite hardness, as shown in Figure (8), is increased from 77.41 to 90.81 kg/mm^2 on increasing Ag-content from 0 to 4% respectively. Further increase in Ag content to 5% reduces the hardness to 88.49 kg/mm^2. The considerable increase in hardness is due to the effect of Nano Ag in increasing the density of the composite and reducing its porosity by the action of Nano Ag as filling material besides its effect in enhancing the consolidation action and the formation of intermetallic phases as is found by the XRD examination. Adding of micro Ag to the Cu-graphite composite which, is used in similar applications as of Cu-Fe composite, is found to reduce the hardness from 51.4 kg/mm2 to 47.21 kg/mm^2 on increasing the micro Ag-content from 0 to 4% respectively [32]. This comparison reveals the higher initial hardness of Cu-Fe composite compared with Cu-graphite composite and the considerable effect of Nano Ag in increasing the hardness of Cu-Fe composite.

This increase in hardness on increasing Nano Ag content was reflected directly on wear rate and compression strength of Cu-Fe composite as shown in Figures (8) and (9) respectively, where wear rate was reduced from 6.998*10^{-8} g/cm to 6.057*10^{-8} g/cm and the compression strength was increased from 34.78 MPa to 46.2 MPa on increasing Ag content from 0 to 4% respectively. This inverse relation between wear rate and hardness of copper matrix composite was found previously by [33]. Further increase in Ag to 5% increased wear rate to 6.151*10^{-8} g/cm and reduced the compression strength to 43.5 MPa.

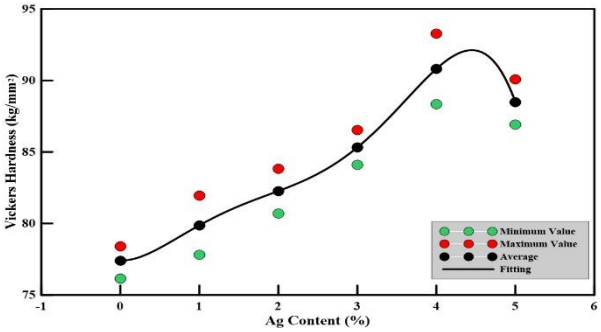


Fig.8. Relationship between hardness and Nano Ag content of Cu-10%Fe composite

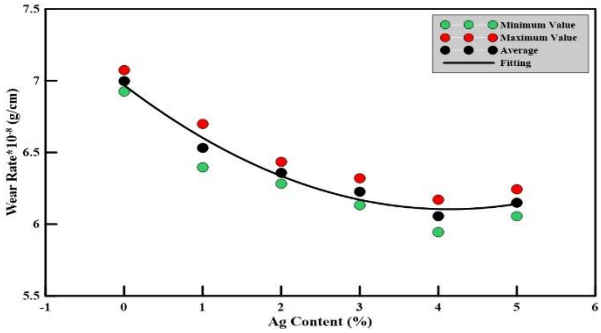


Fig.9. Relationship between wear rate and Nano Ag content of Cu-10%Fe composite

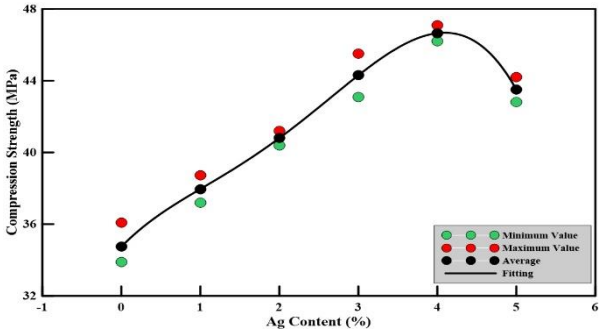
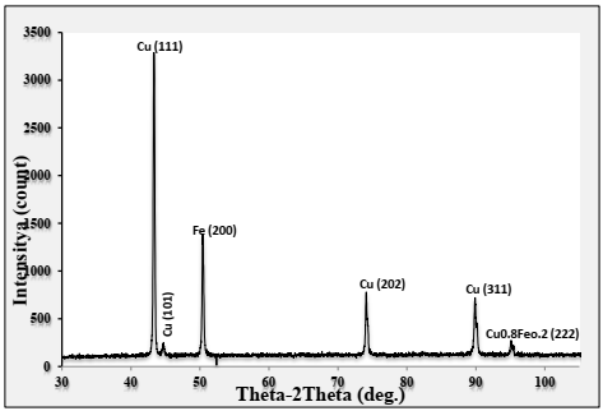


Fig.10. Relationship between compression strength and Nano Ag content of Cu-10%Fe composite

3.5. X-Ray Diffraction

Figure (11) represents the XRD results of Cu-10%Fe composite with different Nano Ag-contents. This figure reveals the presence of pure Cu and Fe with the formation of Cu0.8Fe0.2 and Ag0.04Cu3.96 intermetallic phases which indicates the achievement of good consolidation during sintering and elucidates the enhancement in the mechanical and the metallurgical properties of the composite. Some Ag_6O_2 was appeared on increasing Ag content to 4%.



(a)

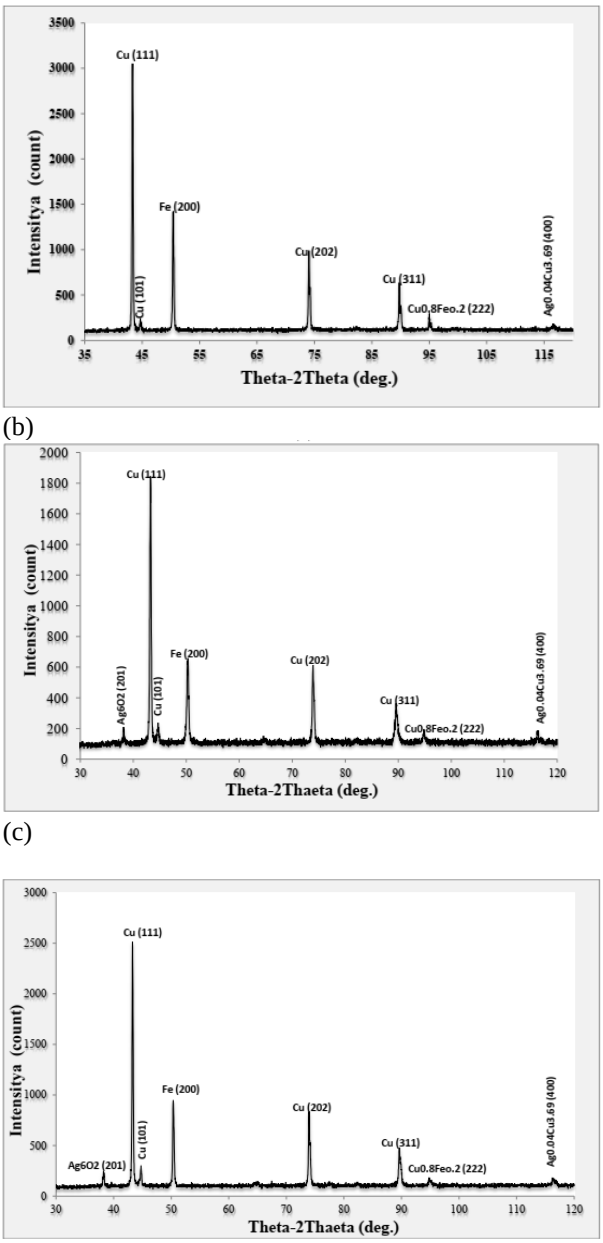


Fig.11. XRD for Cu-10%Fe composite with different Nano Ag content. (a) 0%Ag, (b) 1%Ag, (c) 4%Ag, and (d) 5%Ag

4. *CONCLUSIONS*

1- Adding Nano Ag has an effective role in enhancing both densification and consolidation of Cu-Fe composite.
2- Considerable increase in electrical and thermal conductivity was achieved by adding Nano Ag to Cu-Fe composite.
3- Remarkable increase in hardness, compression strength, and wear resistance was found on adding Nano Cu-Fe composite.
4- Adding Nano Ag to Cu-Fe composite increases the composite density and reduces its porosity.

REFERENCES

[1] G. S. Upadhyaya "Powder Metallurgy Technology" Published by Cambridge International Science Publishing, Cambridge CB1 6AZ, England, 2002.

[2] François Cardarelli "Materials Handbook" A Concise Desktop Reference, second Edition, Springer, 2008.

[3] Andra Mihaela Predescu, Ruxandra Vidu, Petrică Vizureanu, Andrei Predescu, Ecaterina Matei, and Cristian Predescu, "Properties of Cu-xFe_3O_4 Nanocomposites for Electrical Application", Materials, 2020, 13, 3086; doi:10.3390/ma13143086

[4] S. N. Alam and H. Singh, "Development of copper-based metal matrix composites: An analysis by SEM, EDS and XRD," Microscopy and Analysis,2014, vol. 28, pp. S8-S13.

[5] L. Deng, K. Han, B. Wang, X. Yang, and Q. Liu, "Thermal stability of Cu–Nb microcomposite wires," Acta Materialia, 2015, vol. 101, pp. 181-188.

[6] X. Zuo, K. Han, C. Zhao, R. Niu, and E. Wang, "Microstructure and properties of nanostructured Cu28wt% Ag microcomposite deformed after solidifying under a high magnetic field," Materials Science and Engineering: *A*, 2014, vol. 619, pp. 319-32.

[7] N. Stepanov, A. Kuznetsov, G. Salishchev, N. Khlebova, and V. Pantsyrny, "Evolution of microstructure and mechanical properties in Cu–14% Fe alloy during severe cold rolling," Materials Science and Engineering: *A*, 2013, vol. 564, pp. 264-272.

[8] J. Song, H. Kim, C. Lee, and S. Hong, "Deformation processing and mechanical properties of Cu–Cr–X (X= Ag or Co) microcomposites," Journal of materials processing technology, 2002, vol. 130, pp. 272-277.

[9] V.A. Beloshenko, V. Yu. Dmitrenko, and V. V. Chishko, "Modifying the Structure and Properties of Cu–Fe Composites by the Methods of Pressure Formation", THE PHYSICS OF METALS AND METALLOGRAPHY, 2015, vol. 116 No. 5.

[10] De Ping Lu, Wei Guo, Jiang Jiang, Lei Lu, Jin Zou, Qing Feng Fu, and Ke Ming Liu, "Effect of Carbon on the Microstructure of a Cu-Fe Alloy", Solid State Phenomena, 2018, vol. 279, pp 49-54, doi:10.4028/ www.scientific.net/SSP.279.49

[11] Hua Bai and Dong Xu, "Improved flexural strength of diamond/Cu–Fe composites with Cu–B–B4C coating", Surface Engineering, ISSN: 0267-0844 (Print) 1743-2944 (Online), Nov 2019, 29, pp 1-9.

[12] Xiaohui Zhang, Yi Zhang, Baohong Tian, Kexing Song, Ping Liu, Yanlin Jia, Xiaohong Chen, Junchao An, Zhuan Zhao, Yong Liu, Alex A. Volinsky, Xu Li, and Ting Yin, "Review of nano-phase effects in high strength and conductivity copper alloys ", DE GRUYTER, Nanotechnol Rev 2019; 8, pp 383–395

[13] J Kora´b , S Krcho, P Sˇtefa´nik, and J Kova´cˇik, "Electrical and thermal conductivities of the Cu–CF composite", Journal of Composite Materials, 2019, 0(0), pp 1–8; DOI: 10.1177/ 0021998319872261

[14] Yeon Beom Jeong, Hee Ra Jo, Hae Jin Park, Hidemi Kato, and Ki Buem Kim, "Mechanical properties and microstructural change in (Cu-Fe) immiscible metal matrix composite: Effect of Mg on secondary phase separation", Journal of Materials Research and Technology, 2020, 9, 6, pp 15989-15995.

[15] Keming Liu, Xiaochun Sheng, Qingpeng Li, Mengcheng Zhang, Ningle Han, Guangyu He, Jin Zou, Wei Chen, and Andrej Atrens, "Microstructure and Strengthening Model of Cu–Fe In-Situ Composites", Materials, 2020, 13, 3464; doi:10.3390/ma13163464

[16] V. V. Sanina, M. R. Filonova,, V. I. Yukhvidb, Yu. A. Anikinb, and D. M. Ikornikov, "Production of the 70% Cu–30% Fe Alloy by SHS Metallurgy and Electrometallurgy: Comparative Analysis of Microstructures", RUSSIAN JOURNAL OF NON-FERROUS METALS; 2020, vol. 61 No. 1, pp 119-125; DOI: 10.3103/ S1067821220010137

[17] Jerman, G. A., I. E. Anderson, and J. D. Verhoeven. "Strength and electrical conductivity of deformation-processed Cu-15 vol pct Fe alloys produced by powder metallurgy techniques. " Metallurgical Transactions *A*; 1993, 24, 1, pp 35-42.

[18] M. Barzegar Vishlaghi and A. Ataei, "Characterization of the metastable Cu-Fe nanoparticles prepared by the mechanical alloying route," Journal of Ultrafine Grained and Nanostructured Materials, 2014, vol. 47, pp. 57-61.

[19] Liu, K. M., Lu, D. P., Zhou, H. T., Atrens, A., Zou, J., Yang, Y. L., & Zeng, S. M.. "Effect of Ag micro-alloying on the microstructure and properties of Cu–14Fe in situ composite". Materials Science and Engineering*: A*, 2010, *527*(18-19), pp 4953-4958.

[20] Fernee, H., J. Nairn, and A. Atrens. "Precipitation hardening of Cu-Fe-Cr alloys part I Mechanical and electrical properties." Journal of materials science; 2001, 36,11, pp 2711-2719.

[21] Mohammad Baghani, Mahmood Aliofkhazraei, Amir Seyfoori and Mehdi Askari "Mechanical alloying of CuFe-alumina nanocomposite: study of microstructure, corrosion, and wear properties" Sci Eng Compos Mater, 2018, 25, 6, pp 1085–1094.

[22] Keming Liu, Xiaochun Sheng, Qingpeng Li, Mengcheng Zhang,1 Ningle Han,1 Guangyu He,1 Jin Zou, Wei Chen, and Andrej Atrens "Microstructure and Strengthening Model of Cu–Fe In-Situ Composites" Materials (Basel). Aug 2020, 13, 16; doi:10.3390/ ma13163464

[23] Hong, S. I., Song, J. S., & Kim, H. S. "Thermo-mechanical processing and properties of Cu–9Fe–1.2Co microcomposite wires". Scripta materialia, 2001, 45, 11, pp 1295-1300.

[24] J. Song, S. Hong, and Y. Park, "Deformation processing and strength/conductivity properties of Cu–Fe–Ag microcomposites," Journal of alloys and compounds; 2005, vol. 388, pp. 69-74.

[25] Gao, H., Wang, J., Shu, D., & Sun, B. "Microstructure and properties of Cu–11Fe–6Ag in situ composite after thermo-mechanical treatments". Journal of alloys and compounds, 2007, *438*,1-2, pp 268-273.

[26] Li, Y., Yi, D., & Zhang, J. "Comparative study of the influence of Ag on the microstructure and mechanical properties of Cu-10Fe in situ composites". Journal of Alloys and Compounds, 2015, *647*, pp 413-418.

[27] Farouk M.Mahdi, Raed N.Razooqi, Saif S. Irhayyim "Effect of Graphite Contentand Milling Time on Physical Properties of Copper - Graphite Composites Prepared by Powder Metallurgy Route" Australian Journal of Basic and Applied Sciences, 2013, vol. 7, PP. 245-255.

[28] Farouk M. Mahdi Raed N. Razooqi Saif S. Irhayyim, The Influence of the Graphite Content and Milling Time on the Hardness, Compressive Strength and Wear Volume of Copper -Graphite Composites Prepared Via Powder Metallurgy, Tikrit Journal of Engineering Sciences, 2017, vol 24, No 3, pp. 38 – 44.

[29] Farouk M. Mahdi1 , Jawadat A. Eaqoob , Fouad R. Muhialdeen, "Mechanical and Physical Properties of Hybrid Cu-Graphite Composites Prepared via Powder Metallurgy Technique", Tikrit Journal of Engineering Sciences, 2017, vol 24, No 1, pp. 11-24.

[30] Hashim Shukur, "Effect of Pressing Pressure on properties of Copper-10% Graphite Composites Prepared by Powder Metallurgy Technique", Tikrit Journal of Engineering Sciences, 2017, vol 24, No 2, pp. 28 – 34.

[31] R. Rao and S. Das, "Effect of matrix alloy and influence of SiC particle on the sliding wear characteristics of aluminium alloy composites," Materials & Design, 2010, vol. 31, pp. 1200-1207.

[32] Abass Abdulkareem Hassian " Studying the Effect of Particle Size Distribution and Particle Shape on the Properties of Cu-Graphite Composites Prepared by Powder Metallurgy" M.Sc. Thesis, Mechanical Engineering Department, University of Tikrit, 2014

[33] S. Moustafa, S. El-Badry, A. Sanad, and B. Kieback, "Friction and wear of copper–graphite composites made with Cu-coated and uncoated graphite powders," Wear, 2002, vol. 253, pp. 699-710.