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Samah El-khatib
Future University in Egypt (FUE), samah.elmetwally@fue.edu.eg

A. H. Elsayed

A. Y. Shash

A. El-Habak

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Effect of Dispersions of Al_2O_3 on the Physical and Mechanical Properties of Pure Copper and Copper-Nickel Alloy

S.El-Khatib [a,*], ***A.H.Elsayed*** [b], ***A.Y. Shash*** [c], ***A. El-Habak*** [d]

[a] *Mechanical Engineering Dept. Future University in Egypt. Cairo, Egypt*

[b] *Powder Technology Lab., Central Metallurgical Research and Development Institute, Cairo, Egypt*

[c] *Mechanical Design and Production Engineering Dept. Cairo University. Cairo, Egypt*

[d] *Housing and Building National Research center (HBRC). Cairo, Egypt*

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ABSTRACT

This paper illustrates the mechanical and physical properties of pure Copper (Cu) and Copper-Nickel (Cu-Ni) (50-50 wt. %) alloy mixed with Aluminium Oxide (Al2O3) (1- 4 wt. %) as micro-particle reinforcement materials, which prepared by powder metallurgy technique. Pure Cu/ Al2O3 and Cu-Ni alloy/ Al2O3 composites emerge as promising candidates for a lot of industrial engineering applications which are superior in withstanding high temperatures and high loading stress like heat exchangers, seam welding wheels, spot welding electrodes, and in defense, and space as rocket nozzles. The attained composite alloy specimens' characteristics were estimated such as microstructure, relative density, electrical and thermal conductivity, hardness, and compression yield stress properties to adjust the suitable optimum percentage of reinforcing material. The micron-sized Al2O3 was added to determine the enhancement of the mechanical and physical properties of the pure Cu and Cu-Ni alloy composites. The electrical and thermal Conductivity for pure Cu and Cu-Ni alloy matrix composites has a definite percentage improvement compared to the other composites specimens' composites. The hardness and compression yield stress of pure Copper and for Cu-Ni alloy composites have enhancement values and for Cu-Ni base composites, hardness and compression yield stress have improved with the most positive enhancement values of up to (~ 27-55 %) and (~153-278 %) of the matrix, respectively.

Nomenclature

W_a Mass of the sample in air
W_w Mass of the sample in water
$\rho_{act.}$ Actual density
ρ_{th} Theoretical density
V_M Volume fraction of the matrix
V_R Volume fraction of the reinforcement
ρ_M Density of the matrix
ρ_R Density of the reinforcement

* *Corresponding author.* Tel.: +0-100-982-8777.
E-mail address: *Samah.elmetwally@fue.edu.eg*

σ Electrical Conductivity (S/m).
L Distance between the ohmmeter terminals
A Area of the surface that the ohmmeter is measuring current across
R Electrical resistance of the specimen
K Thermal Conductivity W/(m·K)
L Lorenz number (2.45 x10-8 WΩk^{-2})
T Room temperature (K)
PM Powder metallurgy
SEM Scanning Electron Microscopy

1. Introduction

Mechanical alloying is a manufacturing process that concludes several hardening mechanisms instantaneously, which defines mechanical milling when applied to pure materials. It is reported before that the Copper-Nickel (Cu-Ni) alloys have a good combination of physical and mechanical properties (BNF Metals Technology Center and (Navy), 1982). They can resist high loading stress, as well as high temperatures. Also, they have corrosion resistance with the required properties such as electrical and thermal Conductivities together which make Copper-Nickel alloys standout options in a lot of industrial sectors (Printing, 1992)(Hummel, 2004)(M. Ashbyet et al., 2010). For Copper-based alloys, the most important alloying elements used are Si, Sn, Al, Zn, and Ni. Except for Ni, These elements have limited solubility in the solid form (8, 9, 19, and 37%, at maximum), respectively (S.El-Khatib et al., 2018)(C. Brooks, 1984). Nickel has a positive effect on the mechanical and physical properties of Cu-Ni alloys in terms of liquidus and solidus temperatures and corrosion resistance. It has been stated in several types of research that the matrix can be enhanced by emerging it with different types of reinforcement with various mass fractions. Moreover, Aluminium Oxide Al2O3 is ideal reinforcement for developed composite materials for several engineering applications.

Al2O3 is a chemical compound of aluminum and oxygen. Al2O3 is an electrical insulator but with high thermal Conductivity (30 W/m.K), wear-resistant, and high stiffness, hardness, and strength. it is desirable for use as an abrasive and as a component in cutting tools ('"Alumina (Aluminium Oxide) – The Different Types of Commercially Available Grades"', 2007). Dispersion strengthened Copper- Aluminium oxide (Cu/ Al2O3) composite materials are widely used as materials for products, which need high mechanical and physical properties, for instance, contact supports, electrode materials for lead wires, and relay blades for spot welding. To achieve the main requirements for dispersion-strengthened structure materials they should have homogenous distribution with a small size of oxide particles. The effect of Al2O3 particles on supporting the matrix is vital since it provides the deformation and recrystallization of the Copper-based alloy (Viseslava Rajkovic *et al*, 2008).

The dispersion of micro-sized Aluminium Oxide (Al2O3) particles that are employed as strengthening with pure Copper (Cu) powder and Copper-Nickel (Cu-Ni) mechanically alloyed matrix, was the main subject of some last studies (S. El-Khatib *et al.*, 2017)(Bakshi SR et al., 2008)(Suvarna Raju and Kumar, 2014). Previously, some researchers were concerned with improving the mechanical properties (hardness, compression …etc.) (S.El-Khatib *et al.* 2018)(ɰurišinová *et al.*, 2015), thermal and electrical Conductivities of Cu-Ni composites (Moustafa, *et al*., 2002)(Hashemi *et al.*, 2014) using powder metallurgy technique(Bataineh *et al.*, 2021). Moreover, some studies concentrated on powder metallurgy technique for processing (Al2O3) ceramic powder (Rojas *et al.*, 2016) as Aluminium oxide - Al2O3- is one of the most commonly used materials in ceramics material with high-performance technical grade ceramic and with an excellent mixture of properties that is readily obtainable (Sadoun *et al.*, 2020). Where, micro-sized Al2O3 particles have a great effect on the microstructure, and mechanical and physical Conductivity of the Copper-based composites (Rajkovic *et al.*, 2012)(Rajkovic *et al*., 2010)(Depczyski and Miek, 2018) and on the Copper-Nickel mechanical alloying (Bhaskararao and Janardhana, 2020).

(S. Moustafa *et al*., 2002), established the densification and compression properties of Cu–20% coated Al_2O_3, and Cu–20% Al_2O_3 composites. The Cu-composites were made by mixing uncoated powders and sintered at a constant temperature of 900 ºC. The Cu matrix Ni coated reinforced composites showed higher relative density and lower porosity content than the uncoated composites, due to the good bonding between the reinforcements and the Cu-matrix. Compression strengths of coated reinforcement powders-containing composites are higher than those of uncoated ones.

On the other hand, (Rojas *et al.*, 2016), demonstrated the consolidated 50% Cu-50% Ni and 60% Cu-40% Ni alloys obtained by powder metallurgy illustrated better behavior in terms of corrosion resistance concerning Copper and Nickel specimens. The process requirements of sintering temperature and compaction pressure values utilized were 300ºC and 900 MPa with 5 hours of milling.

Moreover, (Rajkovic *et al.*, 2012), investigated the effect of the instantaneous presence of micro-sized Al2O3 particles on the properties and microstructure of the Copper matrix. The used mixture of inert gas-atomized pre-alloyed Copper powder with (0.6 wt. % Al2O3) powder as micro-sized particles and (1 wt. % Al) as the starting materials. Strengthening was performed on the Copper matrix by treating the powders in the air for up to 20 hours in the planetary ball mill. The highest values of micro-hardness were obtained from 10 h-milled powder and it was 3 times higher than the micro-hardness of compact processed from non-milled pre-alloyed powder. Moreover, at the maximum micro-hardness, the grain size reaches the smallest value as a result of the matches' effect of micro-sized Al2O3 and nano-sized particles which results due to recrystallization during prolonged milling and the Electrical Conductivity of compacts after 15 hours of milling will be increased.

This study presents the powder metallurgy method where the microparticles Al2O3 grain size as reinforcement materials for pure Copper powder matrix and with Copper-Nickel mechanical alloying matrix of the sintered composites at several percentages (1-4 wt. % Al2O3) to optimize the best composites physical and mechanical properties. Moreover, the pure Copper specimen, Copper-Nickel alloy specimen, and the obtained composites specimens were investigated with different physical and mechanical tests as well as microstructural (optical and Scanning Electron Microscopy (SEM)), relative density, electrical and thermal conductivity, hardness, and compression yield strength.

2. EXPERIMENTAL SETUP

2.1. Materials and methodology

In this research, the composite samples which were prepared by powder metallurgy technique consisted of pure Copper and Copper-Nickel alloy strengthened by Al_2O_3 ceramic powders reinforcement. Al_2O_3 (60 microns particle size) was used with percentages from (1-4 wt. %). The Copper-Nickel alloy with equal percentage wt. % was prepared using mechanical alloying of (1 micron) grain size for Nickel and (2-3 microns) grain size for pure Copper powder mixed using high energy milling in a SPEX 800 rpm mixer/mill with a ball-to-powder ratio of 10:1. The milling time was set at 20 hours to have a homogeneous mixing between Nickel and Copper powders to procedure the matrix of the composite.

2.2. Specimens preparation

2.3. It has been provided in many previous reports that mixing Cu and Ni powders with ceramic powders, is an obstacle as they are easily separated from each other. So, this paper seeks to provide an effective way to form a mixture using chemical dispersant as (0.5 wt. %) paraffin wax as a lubricant and (20 wt. %) cyclohexane-C6H12 to form a suitable environment for mixing during compaction to decrease friction. The mixing process was performed for one hour by a SPEX mixer/mill stainless steel container at 800 pm. After mixing, the mixture was dried in a 100 oC oven for one hour where it allows to melt the wax and to form Al2O3 well mixture with pure Cu or mix with Cu-Ni powder. Then, the composite mixture was compressed in a (DIN W302) rectangular Cr-Mo alloy steel die. The die cavity had a rectangular (6x8 mm2) cross-section area of 15 mm in height. The hydraulic uni-axial press machine used compaction pressure at 600 MPa to make the required compacted specimens. The sintering process was performed for 2 hours in a 1050°C vacuum furnace. The adjusted heating rate was at (4°C / min) till (250°C) and to complete the de-binding stage, the temperature was preserved constantly for 30 min. Then, the heating rate was increased to (6°C/ min) till the maximum at (1050 oC sintering temperature). Then the specimens were cooled in the furnace. Figure 1 illustrates the details of the whole powder metallurgy process.

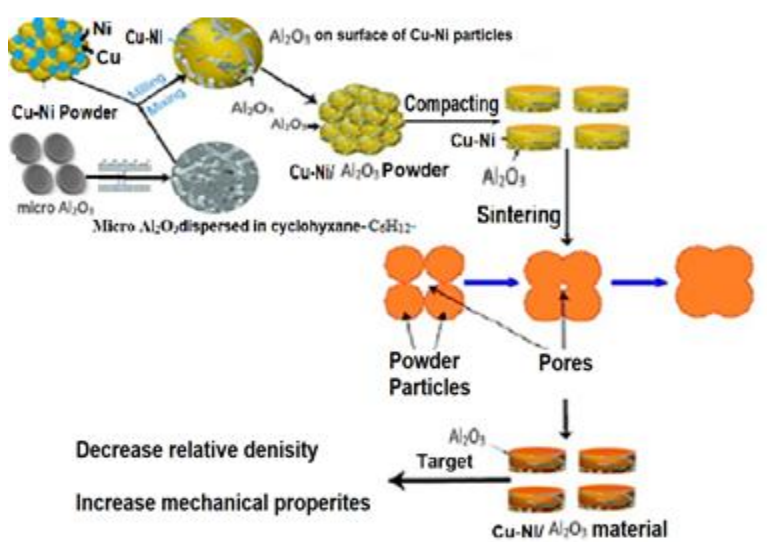

Fig. 1- Powder metallurgy process Cu- Ni alloy/ Al_2O_3

2.4. Basic testes carried out for sintered Specimen

The sintered samples were investigated under various types of tests. For microstructure examination, the specimens were prepared using standard grinding with 120, 220,400, 600, 800, 1000, 1200, 2000, and 3000 grit SiC papers, and then they were polished with 6-micron diamond paste. An optical microscope (type Axioplan) was used to demonstrate microstructure features using a digital camera type Canon PC1049 fitted with ZEISS lenses. The microstructure of the polished samples was inspected by field emission scanning electron microscope (FESEM; QUANTAFEG250, Holland. Also, the actual density of the sintered composites was calculated using the Archimedes rule, using water as a floating liquid. The sintered specimens were weighed in air and in distilled water and their actual densities ($\rho_{act.}$) were determined according to the following equation:-

$$\rho_{act.} = {W_a}/{(W_a - W_w)} \quad (1)$$

The theoretical density (ρ_{th}) for the investigated composite was determined according to the following equation:-

$$\rho_{th.} = (V_M \times \rho_M) + (V_R \times \rho_R) \quad (2)$$

The degree of porosity of the sintered compacts was determined according to the following equation:-

$$\text{Porosity }\% = 1 - \frac{\rho_{act.}}{\rho_{th.}} = {(\rho_{th.} - \rho_{act.})}/{\rho_{th.}} \quad (3)$$

The electrical conductivity was measured using a four-terminal ohmmeter for high accuracy. One pair of terminals measures current, while the other pair measures voltage. This permits the ohmmeter to ignore the resistance of the second pair of terminals. Then, the resistance of the specimen was recorded using the ohmmeter.

$$\sigma = {L}/{AR} \quad (4)$$

By using Wiedemann-Franz law, the thermal Conductivity was estimated from the electrical Conductivity.

$$K = LT\sigma \quad (5)$$

For all specimens, Vickers hardness was measured at a load of 10 Kgf and the time to make an indentation was 10 seconds. The reported Vickers hardness values of the specimens represent the average of 5 readings of each sample. The compression yield strength test of the investigated samples was performed using a micro-computer-controlled [HT-9501uniaxial universal testing machine]. The rectangular samples 8x8 mm^2 cross-section and a height of 15mm were used for compression tests. In this study, the test was conducted at room temperature and the applied cross-head speed of the universal test machine used was 2 mm/min.

3. Results and discussion

3.1. Composites Characterization

3.1.1. Optical microstructure

This section illustrates the optical microstructure of all sintered specimens, it is an important tool to assess the structure and configuration, distribution of reinforcement, and presence of voids greatly the physical and mechanical properties of the produced composites (M. Ashby, *et al.*, 2010). Shown in Figures 2-6 shows a uniform homogeneous distribution of reinforcement in the matrix (Ming *et al.*, 2016).

Figure 2 illustrates the un-etched microstructure of the sintered pure Copper and Copper-Nickel alloy (50-50 wt. %) samples. It is noted that the matrix alloy is almost free from holes and voids due to an excellent homogenous distribution of both Copper and Nickel. Also, the Nickel grain size is smaller than the Copper grain size which permits them to occupy the Copper particle spaces. The black dots represent the voids while there is no sign of incomplete powder particle bonding.

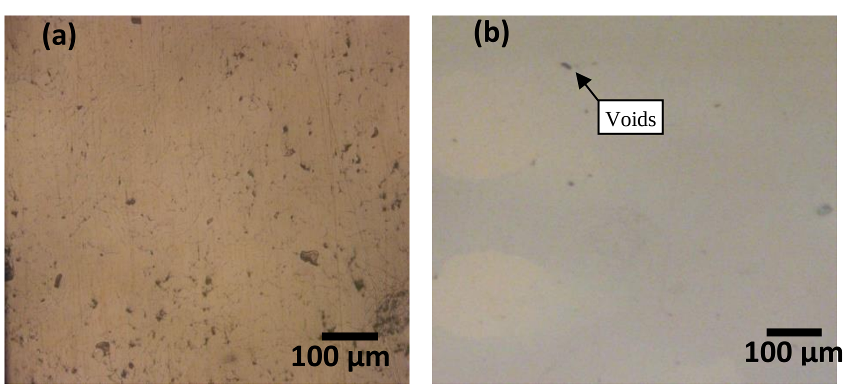

Fig. 2 - Optical micrograph of sintered pure Copper and Cu-Ni (50-50 Wt. %) sintered in vacuum furnace at 1050 ºc.

s.amics material Figure 3 illustrates the microstructure of sintered Copper with 1 % wt. Al2O3 and 4% wt. Al2O3. It shows that micron-sized Al2O3 particles have a great effect on the optical microstructure of Copper composite sintered samples (Cu/ Al2O3), where it appears with uniform homogenous distribution in the Copper matrix. Before the mixing process, the Al2O3 particle size was bigger than that of Copper. However, it can be inferred from the figure that during the mixing process, the Al2O3 particles have become finer with sufficient distribution. It might also be worth mentioning that grain growth has already occurred in the composite sintered samples in both images in Fig. 2 (a) and (b) in a non-homogeneous manner which is a characteristic of vacuum sintered Cu matrix composites.

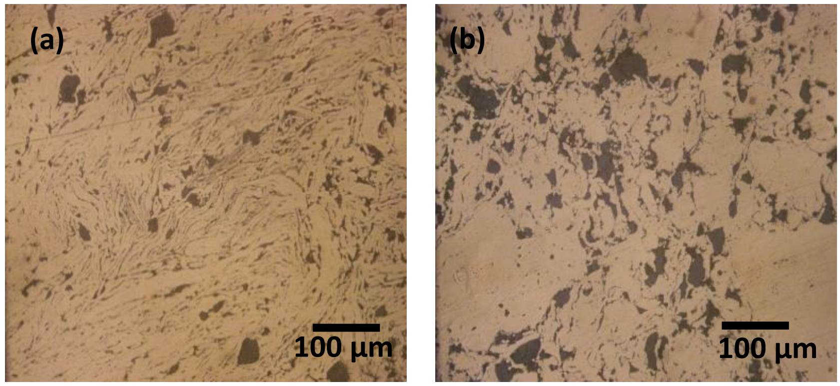

Fig. 3 - Optical micrographs of sintered (a) pure Copper /1 wt. % Al_2O_3; (b) pure Copper /4 wt. % Al_2O_3.

Figure 4 shows the microstructure of sintering Copper-Nickel with 1 wt. % Al_2O_3 and 4 wt. % Al_2O_3 composites. It is shown that micron-sized Al_2O_3 particles have a great effect on the optical microstructure of Copper-Nickel alloy composite (Cu-Ni/ Al_2O_3), where the specimens have a uniform homogenous distribution with Al_2O_3 reinforcement. Before the mixing process, the Al_2O_3 particle size was bigger than that of Copper. However, it can be concluded from the figure that during the mixing process, the Al_2O_3 particles have become finer with sufficient distribution. It is also clear that the Al_2O_3 agglomeration and voids increase with increasing the Al_2O_3 mass fraction. It might also be worth mentioning that grain growth has already occurred in the composite sintered samples in both images in Fig. 3 (a) and (b) in a non-homogeneous manner which is a characteristic of vacuum sintered Cu matrix composites.

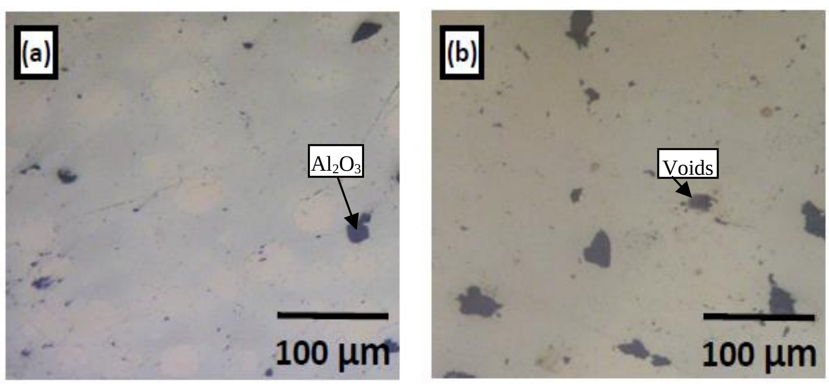

Fig. 4 - Optical micrographs of sintered (a) Cu-Ni /1 wt. % Al_2O_3; (b) Cu-Ni /4 wt. % Al_2O_3.

3.1.2. SEM microstructure

Figure 5 illustrates the SEM micrographs of Cu/1 wt. % Al_2O_3 and Cu/4 wt. % Al_2O_3 micro-composites. The Al_2O_3 reinforcement particles show a good homogenous distribution in the Copper matrix at low concentrations. There are several Al_2O_3 agglomerations and a small number of pores on the Cu/4 wt. % Al_2O_3 micro-composites because Al_2O_3 has a high volume fraction of (4 wt. %). The Cu/ Al_2O_3 interaction has also aided in the formation of a new phase, that is, Cu AlO_2 which has been identified in the gray areas by SEM-EDS of Cu/4 wt. % Al_2O_3 sample.

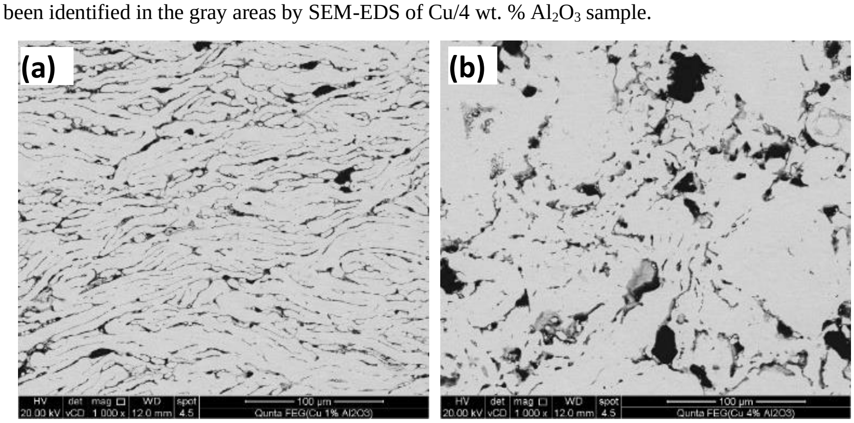

Fig. 5 - SEM images of sintered micro-composites (a) pure Copper /1 wt. % Al_2O_3; (b) pure Copper /4 wt. % Al_2O_3.

Figure 6 demonstrates the SEM micrographs of Cu-Ni/1 wt. % Al_2O_3 and Cu-Ni/4 wt. % Al_2O_3 micro-composites, respectively. It can be observed that the micro size Al_2O_3 particles reinforced sintered sample has a great effect on SEM structure of Copper-Nickel alloy composite (Cu-Ni/ Al_2O_3), where the specimens have good homogenous dispersion of Al_2O_3 reinforcement. It is noted that the Al_2O_3 agglomeration increases with increasing the Al_2O_3 mass fraction. Also, the specimens have fewer voids and their size is very small concerning Al_2O_3 agglomeration.

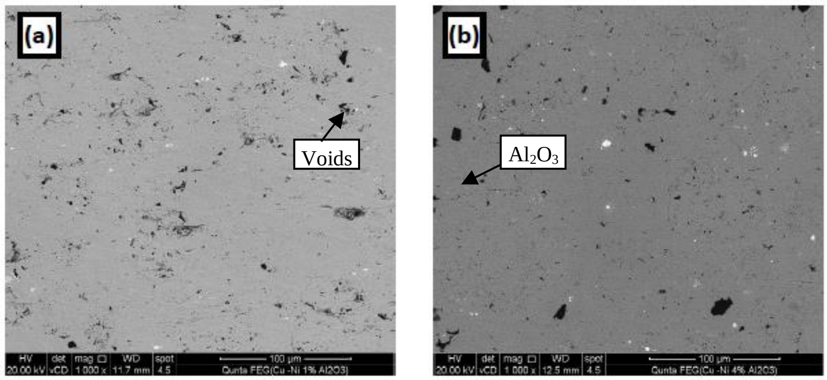

Fig. 6 - SEM images of sintered micro-composites (a) Cu-Ni /1 wt. % Al_2O_3; (b) Cu-Ni /4 wt. % Al_2O_3.

3.2. Physical and mechanical properties

This section illustrates and discusses the physical and mechanical properties of the sintered composites such as hardness, compression yield stress, thermal and electrical Conductivity, and the relative density for Copper and Copper-Nickel composites specimens measured value as shown in Table 1 and Table 2.

Table 1 - Physical and Mechanical properties Cu and Cu /Al_2O_3 measured value

Alloy	Relative Density	Electrical Conductivity (S/m) 10^6	thermal Conductivity (W/m K)	Vickers hardness (kgf/mm^2)	Compression Yield stress (MPa)
Pure Cu	0.86	46.2521	305.5947735	28.2639	121.34
Cu +1% Al_2O_3	0.85	38.97	257.48	24.499	132.41
Cu +2% Al_2O_3	0.81	41.40	273.55	32.967	147.49
Cu +3% Al_2O_3	0.78	37.79	249.70	34.547	215.84
Cu +4% Al_2O_3	0.772	33.64	222.24	35	243.31

Table 2 - Physical and Mechanical properties Cu-Ni and Cu-Ni /Al_2O_3 measured value

Alloy	Relative Density	Electrical Conductivity (S/m) 10^6	thermal Conductivity (W/m K)	Vickers hardness (kgf/mm^2)	Compression Yield stress (MPa)
Cu-Ni	0.764	2.00162	14.36862011	34.326	139.588
Cu-Ni +1% Al_2O_3	0.780	1.46973	10.55049183	43.8911	152.9376
Cu-Ni +2% Al_2O_3	0.767	1.66208	11.93121935	47.0201	220.7506
Cu-Ni +3% Al_2O_3	0.766	1.55158	11.13803507	49.188	250.756
Cu-Ni +4% Al_2O_3	0.752	1.27573	9.157853266	53.272	278.1438

3.2.1. Relative densities

The relative density of a composite, made by powder metallurgy, is the most essential parameter which greatly affects its mechanical and physical properties. Figure 7 shows the relative densities of pure Copper, Copper-Nickel alloy, Copper composites, and Copper-Nickel alloy with various types of reinforcements. Generally, the composite specimens have shown less relative density than that of pure Cu. It can be noted that the relative density decreases with increasing the reinforcement mass fraction for Al_2O_3. Decreasing the density of the Cu composite, while was not intended in this study, still makes no negative effects on other properties providing a better solution for weight reduction for the composite. Moreover, the relative density of Copper-Nickel alloy with Al_2O_3 specimen was slightly decreased with increasing the Al_2O_3 mass fraction. It is common that with increasing reinforcement mass fraction, the porosity will be increased, while Cu-Ni/ Al_2O_3 composite has the least relative density due to the miss-match of Al_2O_3 with Cu-Ni alloy.

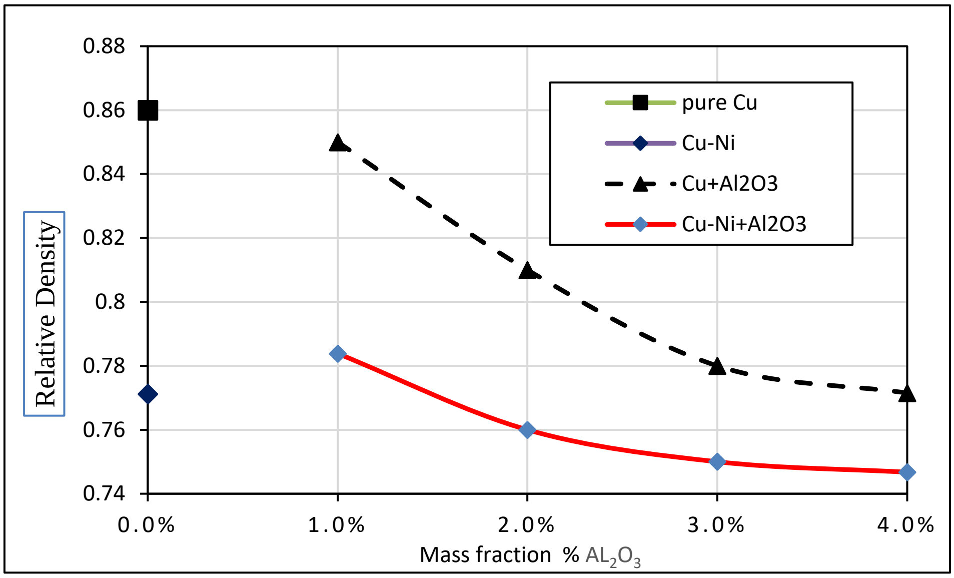

Fig. 7 - Relative Density versus mass fraction of pure Copper, Cu/ Al_2O_3, Cu-Ni/ Al_2O_3 and Cu-Ni sintered samples.

3.2.2. Electrical Conductivity

Figure 8 illustrates the electrical Conductivity for different types of specimens. It can be noted that pure Copper has the best electrical conductivity compared to other specimens. Also, the electric Conductivity of sintered pure Copper is slightly lower than the casting pure Copper (60*10^6 s/m) because of the voids. Moreover, the (Cu/ Al2O3) composites curve at the region with 2% Al2O3 has more electrical Conductivity concerning other composites specimens but this advantage is limited at a certain range of mass fraction percentage according to the powder metallurgy technique (Shehata *et al.*, 2011).

While the electrical Conductivity uses Copper-Nickel (50%-50%) alloy as the main matrix for different types of specimens which has a very low electrical Conductivity. It can be noted that Copper-Nickel alloy with 2% Al2O3 has the best electrical conductivity compared to other composites specimens due to the presence of Al2O3. Moreover, the (Cu-Ni/ Al2O3) has the lowest electrical Conductivity compared to other specimens attaining a drop of 37% due to the Al2O3 particle's size as a ceramic material with poor Conductivity properties.

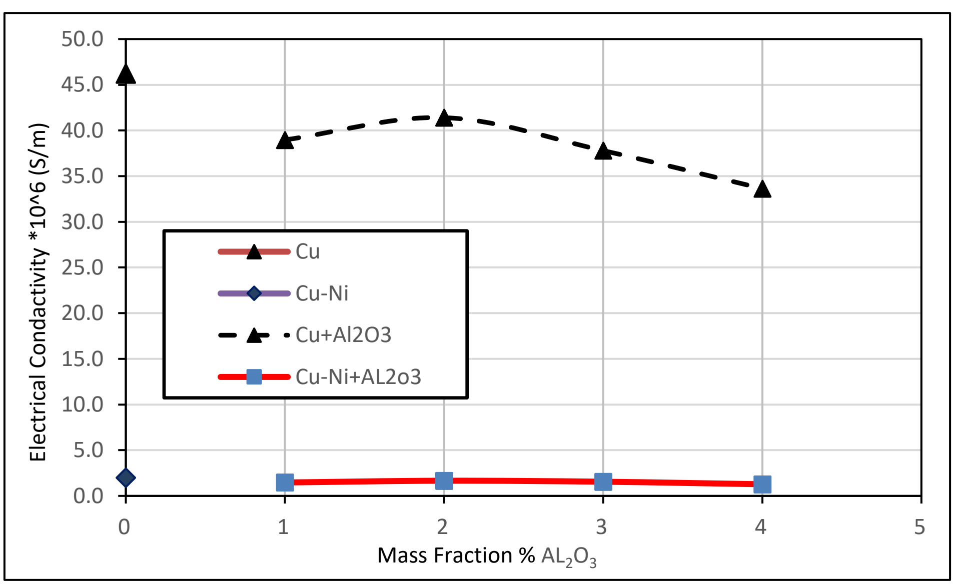

Fig. 8 - Electrical Conductivity versus mass fraction of pure Copper, Cu/ Al_2O_3, Cu-Ni/ Al_2O_3 and Cu-Ni sintered powder.

3.2.3. Estimated thermal Conductivity

Figure 9 represents the estimated thermal Conductivity for all specimens. As it follows the electrical Conductivity, it is obvious that pure Copper has the best thermal Conductivity compared to others specimens. Also, the thermal conductivity of sintered pure Copper is slightly lower than the casting pure Copper (401 W/(m·K)) because of the voids (Silvain *et al.*, 2020)(Butler *et al.*, 2021). Moreover, the thermal conductivity of the investigated composites using Copper-Nickel (50%-50%) alloy matrix as the main matrix is estimated based on the empirical equation. Cu-Ni has a very low thermal Conductivity. As it follows the electrical Al2O3 composites have the lowest thermal Conductivity compared with pure Copper specimens. This could be related to the high insulating properties of Al2O3 ceramic powder. The high thermal Conductivity of pure Copper of 305.6 W/ (m.K) is severely reduced by Nickel addition (50% Ni) to attain 14 W/ (m.K).

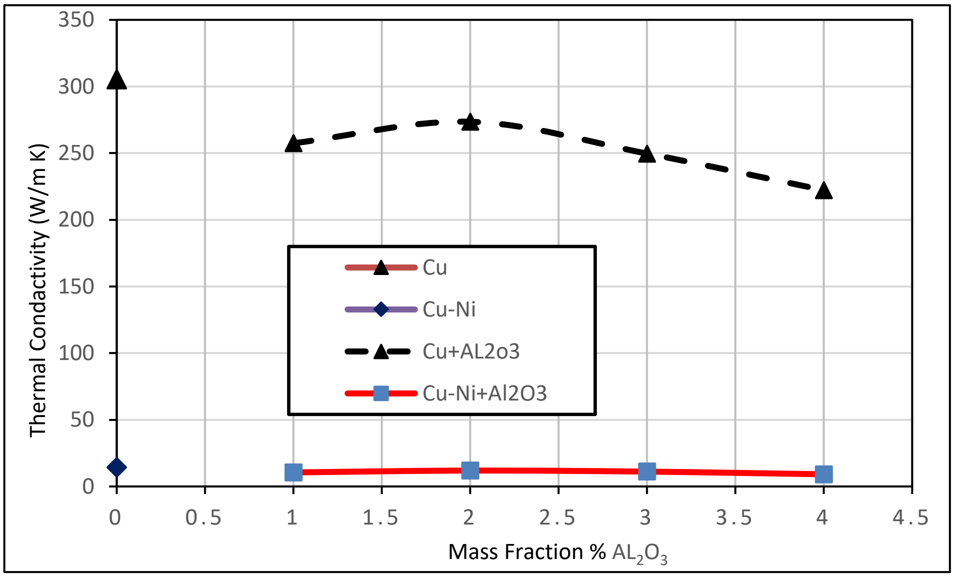

Fig. 9 - Estimated thermal Conductivity of pure Copper, Cu/ Al_2O_3, Cu-Ni/ Al_2O_3 and Cu-Ni sintered composites.

3.2.4. Hardness test

The Vickers Microhardness test was carried out to investigate the apparent hardness of the specimens of Cu/ Al2O3 and Cu-Ni / Al2O3 micro-composite at 10 KgF for 10 sec. Figure 10 demonstrates the Vickers hardness of different types of investigated composites averaged from 5 readings per sample. In the case of the Cu matrix with Al2O3, It can be obvious that the hardness values of the Cu matrix with Al2O3 addition have increased to 3% Al2O3. After that, it has the same enhancement with an increase in the Al2O3 concentration due to the Miss-match of particle size of Al2O3 and Cu particle powders which leads to increasing the pores with higher Al2O3 percentage because the particle size of Al2O3 is greater than the Cu particle size.

Moreover, It can be noticed that the hardness of Cu-Ni / Al2O3 increased with increasing the ceramics reinforcement mass fraction and has a high value compared to the Cu-Ni matrix showing a net progressive increase in macro-hardness of (~ 27-55%) concerning the matrix (Hashemi, *et al.*, 2014).

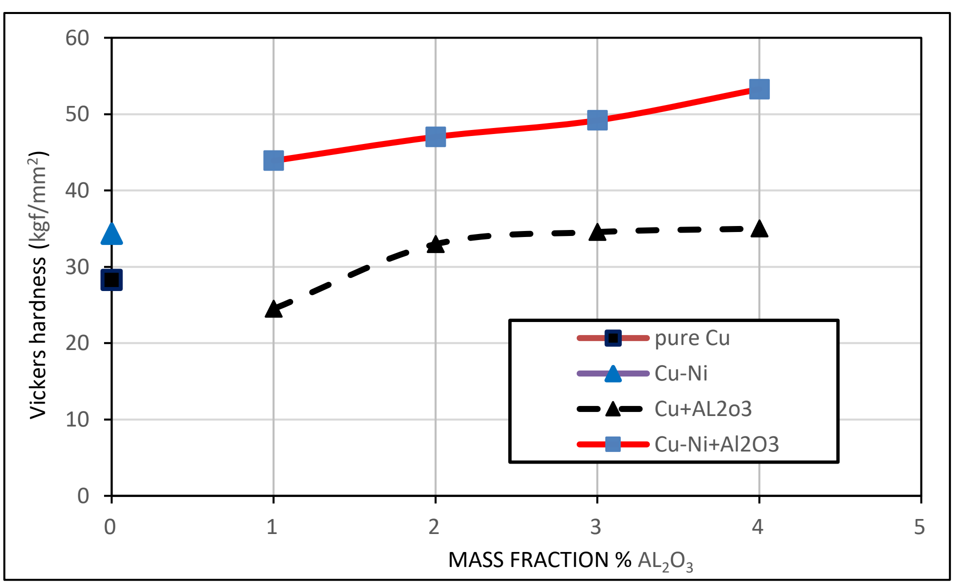

Fig. 10 - Hardness versus mass fraction of pure Copper, Cu/ Al_2O_3, Cu-Ni/ Al_2O_3 and Cu-Ni sintered powder.

3.2.5. Compression stress test

Figure 11 shows the compression yield strength results of Cu/ Al_2O_3, pure Copper, Cu-Ni/ Al_2O_3 and Cu-Ni sintered powder. It can be noted that pure Copper has low compression strength compared to most Cu/ Al_2O_3 specimens. In the case of the Cu/ Al_2O_3, the compression stress has increased gradually with increasing the Al_2O_3 mass fraction and has a higher compression strength compared to most Cu/ Al_2O_3 specimens. This shows that alumina can be easily integrated into the Copper matrix as was also previously shown in the microstructure. On the other hand, it can be noted that In the case of the Cu-

Ni/ Al_2O_3, the compression strength increased with increasing the Al_2O_3 mass fraction because of Al_2O_3 ceramics material properties (Zygmuntowicz *et al.*, 2019)(Zhang and Jiang, 2018). Whereas Cu-Ni/ Al_2O_3 showed a net increase of (~153-278 MPa).

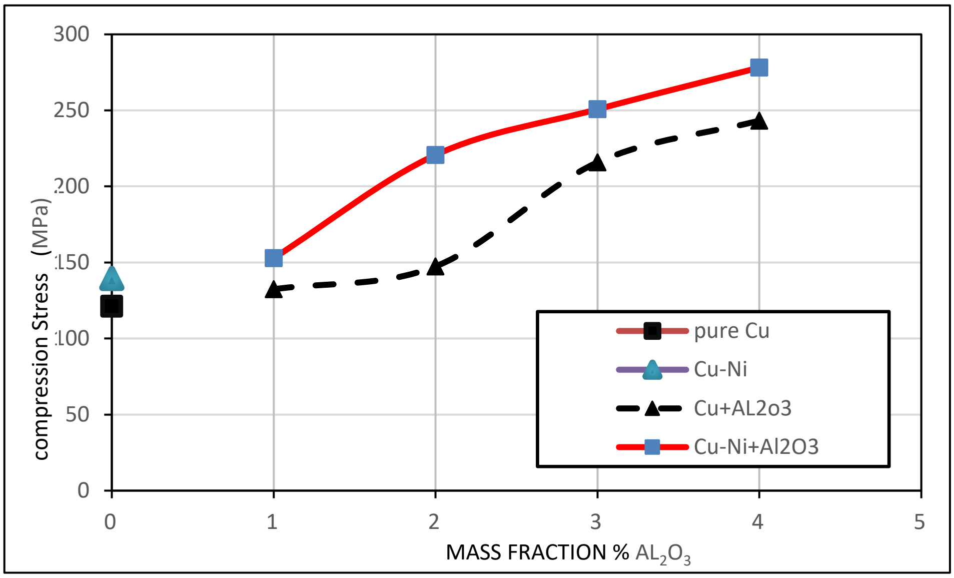

Fig. 11 - Compression yield stress versus mass fraction of pure Copper, Cu/ Al_2O_3, Cu-Ni/ Al_2O_3 and Cu-Ni sintered powder.

4. CONCLUSIONS

This paper sought to study the Al2O3 that was used as reinforcements to the pure Copper matrix composites and Copper-Nickel mechanical alloy matrix composites, which were successfully developed through powder metallurgy. Sintering temperature at a vacuum furnace was used to produce good sintered products at 1050oC temperature with a 2 hours sintering time and the characterizing of their microstructure, and physical and mechanical properties were achieved. The results have shown that the proposed manufacturing method was proven adequate to produce near Copper and Cu-Ni composites at full density, and the powder particle diffusion bonding can be realized in the optical microscope and SEM observations of the composites. Practical experiments have established that the measured Copper matrix and Copper-Nickel mechanical alloy matrix composite results of the electrical and thermal Conductivities have shown a good enhancement at a certain percentage (2% Al2O3) compared to the other composites specimens' composites and less than pure Copper and Cu-Ni alloy values. Where electrical and estimated Thermal Conductivity of the Copper matrix was 23 times that of Cu-Ni alloy with the addition of Al2O3 reinforcement particles.

In addition, the mechanical properties showed an improvement with microparticles size Al_2O_3 reinforcement compared to pure Copper and Cu-Ni alloy concerning the matrix, and the relative density was measured for the Copper-based and the Copper-Nickel alloy matrix composites were below that of pure Copper and Copper-Nickel matrix. Moreover, there was a great improvement in hardness and compression yield stresses values in Copper-Nickel based composites with a net progressive increase in micro-hardness (~ 27-55) and (~153-278 MPa), respectively.

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