International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

# Studying the Mechanical Properties of Cu- 20Fe- Gr Composites for Chain Brake Bits Applications Manufactured by Powder Technology

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***Abstract***— *Cu-Fe is an important alloy that has a superior mechanical property suitable for many engineering applications. In this study Cu-20 % Fe alloy is reinforced with 2,4 and 6 % graphite for manufacturing of a new material suitable for chain brake bits application. Cu-20Fe is prepared by mechanical alloying. Graphite powder is chemically coated with 5% nano Ag by electroless chemical deposition, then 10wt.% nano copper layer to improve it's wettability with both Cu and Fe. 2,4 and 6 % Gr are mixed with Cu-20 %Fe alloy by 6 :1 ball to powder ratio & 300 rpm for 6 hrs milling time. All mixed composite powders were compacted under 700 Mpa by a uniaxial press, then sintered in a vacuum furnace at 950°C for 90 min. Density, XRD and microstructure for all sintered samples are examined. The hardness and wear resistance also estimated. The results indicated that 2% Gr sample has the highest density value and as the graphite percent increase the density decrease. XRD revealed only the main peaks of Cu, Fe and Gr and no any foreign phases were recorded 2% Gr sample has the most homogenous microstructure with no porosity. Hardness and wear also indicated that 2% Gr sample has the highest hardness value and low wear rate.*

***Keywords***— *Copper composites - Microstructure- Hardness- Wear rate- Lubricant materials.*

## I. INTRODUCTION

Composite material is a new material that can collect the properties of two or three constituents. It is consisting of two phases the matrix and the reinforcing agent. They are mostly insoluble in each other, but have a good adhesion. must exist at their interface (s). (1,2). Copper metal has high electrical & thermal conductivities with good strength, but it suffers from low wear resistance & a high coefficient of thermal expansion (CTE). When copper reinforced with a hard ceramic material the CTE & wear rate are decreased. Graphite is a ceramic material has a lamellar structure which helps in decreasing the friction coefficient & wear rate. As it has a lubricant nature with low cost, It is considered one of the most important lubricant materials that used for improving the wear resistance and friction coefficient also it decreases the CTE & density, consequently reduces the weight (3,4,5). Copper-graphite is widely used as brushes, electrical contacts and sliding bearing materials (6,7) due to the excellent thermal and electrical conductivities, and the favorable self-lubricating performance. Mostafa et al. (8) studied the Cu–graphite composites manufactured by P/M route. Comparison Cu-coated graphite composite with Cu-mixed with uncoated graphite. The results indicated that all mechanical properties of the Cu coated composites are higher than that of the uncoated ones. Kovacik et al. (9) prepared the copper/graphite composite by the Hot Isostatic Press (HIP) technique in the range of 0–50 vol.% graphite content. The coefficient of friction of Cu–graphite decreases with increasing graphite percentage. Samal et al. (3) prepared Cu- Graphite composites by both milling technique and spark plasma sintering (SPS). The results showed that the spark plasma sintering and milling at 20hr improves the densification, hardness and transverse rupture strength (TRS). Yang et al. (10) studied the effect of Cr addition on the wetting behavior of Cu/graphite composite prepared by P/M route. The results showed that wettability improved with increasing Cr content in Cu/graphite. Rajkumar and Aravindan (11) studied the effects of graphite particle size, spatial distribution, normal load and sliding speed on the friction and wear performance of microwave sintered copper-based composites. The results showed that copper/nano-graphite composite exhibited high physical and mechanical properties compared with the copper–graphite composites. Jun Tu el al (12) studied the effect of sliding wear behavior of Zn-coated graphite/Cu matrix for the self-lubricating applications. The results showed that the electroplating Zn on graphite played an important role in improving the wear resistance. Omayma et.al (13) studied the effect of graphene nano sheets on the mechanical properties of Cu- WC/Cu-TiC-Co nano composite, in which the results indicated that both hardness, and tribological properties were improved by graphene additions.

Wang et al (14) investigated copper–graphite composites by studying the effect of milling on the mechanical and tribological properties. The results showed that bending strength and friction coefficient decreases with increasing ball-milling expanded graphite content.

Yang et al. (15) observed that bending strength and micro hardness increases, whereas wear rate decreases with increasing the pitch coke content in copper–carbon composite. Omayma et.al (16) studied the effect of GrNSs on the mechanical properties of Cu- Zn alloy prepared by powders metallurgy in the presence of process controlling agent, which reveals the enhancement of the mechanical characters by Gr additions.



Omayma A. Elkady, Ayman Elsayed, Shaimaa A. Elkassem, Mai Essam, Ahmed Osama, Hossam, M Yehia, and Hadir M. Zidan, "Studying the Mechanical Properties of Cu- 20Fe- Gr Composites for Chain Brake Bits Applications Manufactured by Powder Technology," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 6, Issue 3, pp. 182-187, 2023.

From all the above survey one can notice that addition of graphite to copper has a good and positive effect on the mechanical & tribological properties of Cu composites, but the strength of the final product needs some improvement to make it suitable for more mechanical applications. So, in this work iron particles are added to the copper matrix by 20 weight ratios to give a strength to the matrix.

## II. EXPERIMENTAL WORK

Copper powder with <=67 µm average particle size and 99.95% purity were used as a matrix.

20 % iron powder with purity of 99.95%, & 5-10nm particle size was added to the copper matrix by mechanical milling for ten hours. Then pure graphite (Gr.) with 325 mesh & 99.8% purity was added to the Cu- 20-Fe by 2,4 & 6 wt.% as a reinforcement material using ball milling machine in which 10 :1 ball to powder ratio with 350 rpm for 24 hr milling time to obtain a more homogeneous structure. Graphite powder (Buffalo product), is supplied by United Group Company for Chemicals Trade and Medicals, Cairo, Egypt.

Graphite is a ceramic material has a lubricant nature, so it can be used as a reinforcement material to a metal matrix in the manufacturing of a composite material suitable as an engineering part used in a machine exposed to a high wear to decrease the friction coefficient and wear rate. But unfortunately, it has a non- wettability with most metals, consequently it's addition to coper – iron alloy a large gap is formed at the interface between them due to the high surface energy which causes the formation of an internal pores that have a negative effect on the mechanical properties of the final product. So, the challenge here is how to improves the wettability between copper & graphite to obtain a good compacted and sintered composites with good densification & superior mechanical properties. coating of graphite powder with a nano layer of 10% wt Cu by electroless chemical deposition technique to make a capsulation of the graphite powder by a nano metallic copper layer that decreases the surface energy between graphite & both copper and iron. For Cu deposition, $CuSO_4 . 5H_2O$ is reduced by formaldehyde after adjusting the pH of the medium at 11-13 by sodium hydroxide at room temperature as shown in Table (1).

TABLE (1). Chemical composition of electroless nano-Cu deposition bath

| Chemical composition | Concentration g/l |
|---|---|
| $CuSO_4.5H_2O$ | 35 |
| NaOH | 50 |
| Potassium sodium tartrate | 120 |
| PH | ~11- 13 |
| HCHO | ~200 ml |

The graphite powder coated with a nano copper layer was mechanically mixed with copper -20 % iron in an argon atmosphere to protect it from any oxidation in the planetary ball mill and10:1 ball to powder ratio. The composite powders were consolidated by a uniaxial cold press under pressure of 700 MPa. The samples were compacted in a cylindrical die with 10 mm diameter, then sintered in a vacuum furnace at 950˚C for 90 min by the sintering cycle shown in Figure (1).

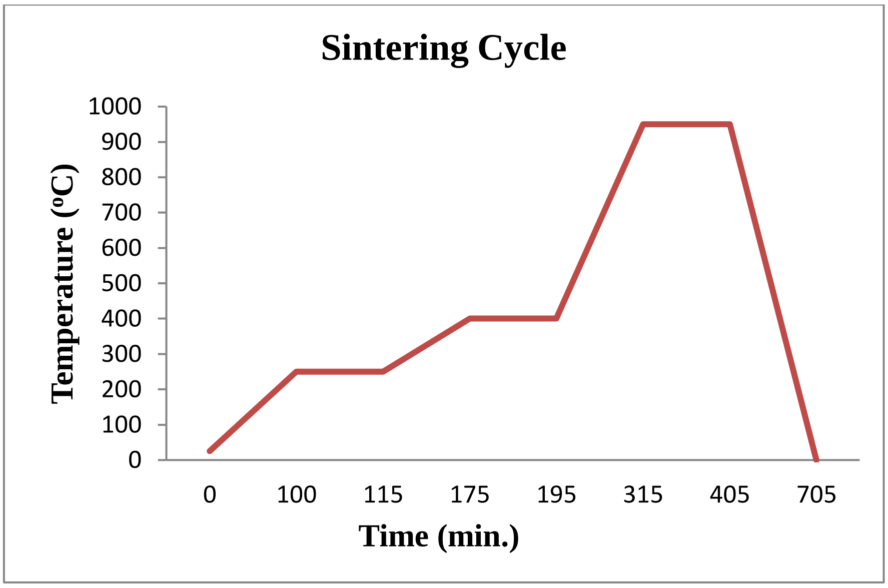


Fig. (1): Heating cycle for the sintering process

The sintered samples were ground successively with 800, 1000, 1200 and 2000 grit SiC papers. Then, polished with 0.3 micrometer alumina paste, the polishing technique used a machine model "Buhlertm".

X-ray diffraction (XRD) investigation using X-ray diffraction instrument, Brukur advanced X-ray diffractometer model D8 Kristalloflex (Ni-filtered Cu Kα radiation) was used to estimate phase structure & phase composition of the sintered samples. The morphology was investigated by a field emission scanning electron microscope (FE-SEM) equipped with an EDS unit. The bulk density of the sintered specimens were determined according to Archimedes immersion technique, in which the sintered specimens were weighed in air and in distilled water, then the density (D; g/cm$^3$) was calculated according to Eq.(1) :

$$\text{Density (D)} = \frac{\text{Wa}}{\text{Wa} - \text{Ww}} \quad \text{Eq. 1}$$

Where $W_a$ and $W_w$ are the masses of the sample in air and water respectively.

The hardness for polished samples was estimated by applying 4.9 N load and load time 10 sec. The wear test was carried out on Cu/graphite composites using a pin-on-ring technique according to ASTM (G77-98). The steel ring of counter face diameter of 73mm, surface roughness of 60 µm was used. For each specimen, the sliding distance was maintained constant at room temperature without lubrication. The test subjects were rectangular samples with dimensions of 8*8*12 mm. The specimens were ground using abrasive papers up to grades 1200, 2000, and 4000, respectively, before being loaded against the ring at standard loads of 5 and 10 N. All wear tests were carried out over a sliding distance of specimens were cleaned with acetone before testing. Each specimen was weighed before and after the test.

Wear rate was calculated by the following Eq. (2):

$$w = \frac{V}{l} \quad (2)$$

Where w is the wear rate, v is the worn volume of the specimen.

Coefficient of friction (COF) was estimated, in which it displayed by sliding of the specimen against the stainless-steel surface by measuring the friction force and applied normal force.

## III. Results & Discussions

The morphology of copper, iron and graphite powders are shown in Figure (1- a,b &c) respectively. It shows the fine structure of the powders. The microstructure of the sintered composite materials which are Cu- Fe- Gr are presented in Fig (2). A scanning electron microscope (SEM) was used to study the particle size and shape of the as-received powders copper, iron, and graphite, respectively, as shown in Figure 1. It is noted that copper has spherical particles with 3-25µm, iron has a fine cubic particle with 10µm particle size, and the graphite in the form of flake particle shape 20µm, respectively. The powder's purity is 99.99%. Fig. 1 SEM (BSE) Micrograph of (a) Copper powder, (c) Iron powder, and (b) Graphite powder The morphology of Cu and graphite powders was studied by FE-SEM and the micrographs are shown in Fig. The shape of copper particles is fine spherical with particle size ~50µm. Graphite powders has fine flake particles with 20µm.

Figure (3) shows the X-ray diffraction pattern of the prepared series of nano Cu-2- Fe- 2,4, & 6 wt,% graphite composite. From the Figure, it can be observed that peaks corresponding to Cu & iron are recorded, and some peaks belongs to iron carbide ($Fe_2C$) which is formed during the sintering process. No any oxide phases are observed due to the controlled sintering atmosphere.

Figure (4) shows the microstructure of the sintered samples, as it is an important parameter in which many mechanical properties can be interpreted based on it. From the SEM pictures, it can be noticed that there are three areas, the first is the white gray which represents the copper matrix, the gray phase represents the iron metal and the black spots corresponding to the graphite. All samples show a good diffusion of the iron in the copper matrix and good-distribution of graphite in the Cu phase. By increasing graphite content at the expense of nano-Cu particles, these quantities inhibit the grain growth of Cu particles and the excessive amounts will be agglomerated in the form of pockets, including pores. The good dispersion & homogeneous distribution of Both Gr & Fe is attributed to the coting process of Gr with the nano copper layer & the suitable sintering parameters. Also, the relative density of these composites is mainly depending upon the sinterability level of nano copper particle and the ability to remove the pores between them.

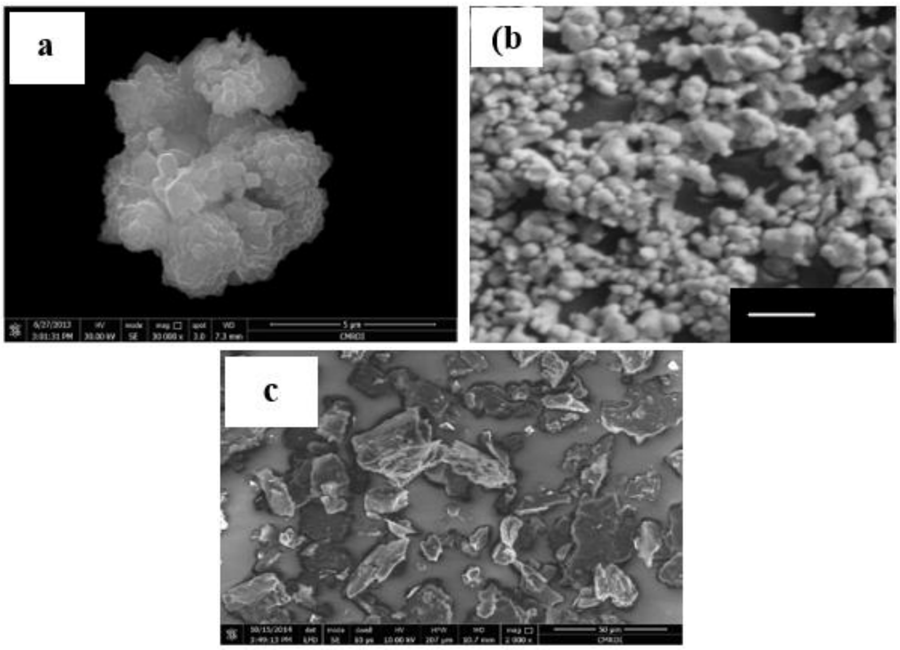


Fig. (2): Microstructure of the as – revised Cu -Fe/ graphite sintered samples

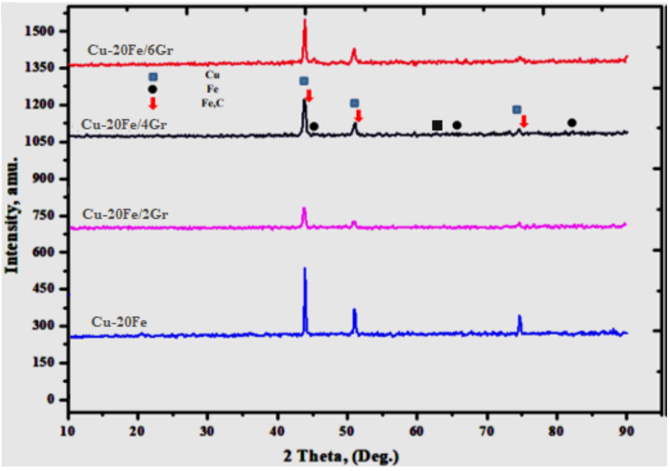

Fig. (3): XRD pattern of Cu/Fe/ graphite sintered samples

The SEM images indicate a uniform distribution of ultrafine graphite particles in composites containing up to 2.5%graphite.

Since the graphite particles are in microscale level and have large surface areas, the further increase of graphite particles content agglomerates to form either lumps or secondary particles to minimize the total surface or interfacial energy of the system. The agglomeration of these particles is caused by the attractive van der Waals force and/or the driving force between the particles ( 17).

The density of sintered samples was measured using Archimedes principal using water as a floating liquid. The results presented in Fig. (5) indicated that the density was decreased gradually by increasing the graphite ratio This may be due to the lower density value of Gr which is about 2.2 g/cc compared with that of copper which is 8.6 g/cc. In which addition of a reinforcement material with low density to a heavier one decreases the overall density of the final produced composite material (18). The microstructure refers to the good densification & sent ability of the samples with no recorded pores which was confirmed with the following hardness results.

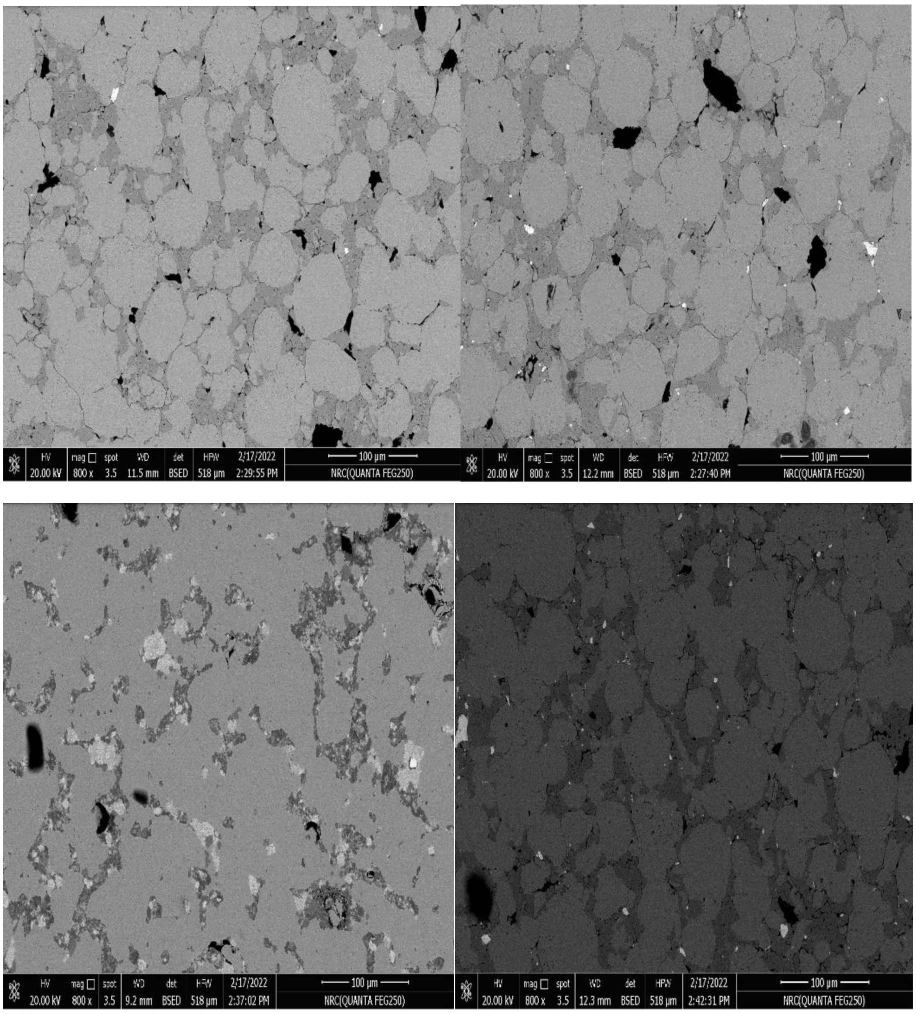
Fig. (4): SEM (BSE) Micrograph of (a) Copper 20 % Iron (b) Copper 20Iron- 2Gr- (c) Copper -20 Iron- 4Gr (d) Copper 20 Iron- 6 Gr composites

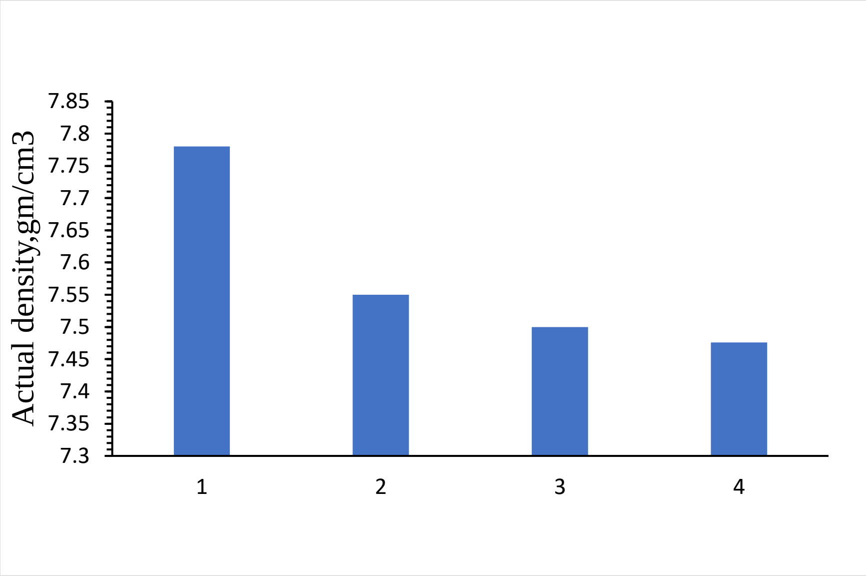


Fig. (5): Density values the sintered samples

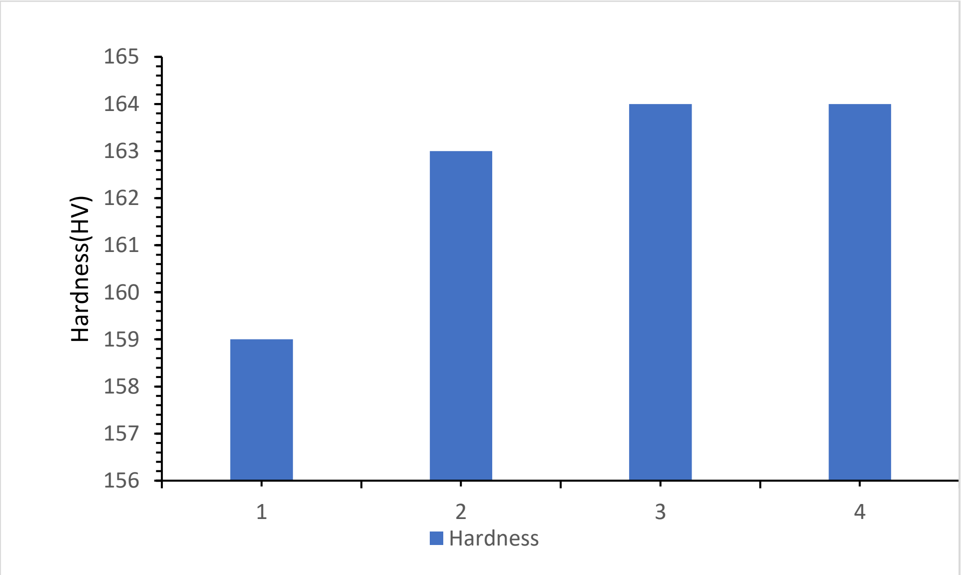


Fig. (6): Hardness values of original & all the prepared samples

Effect of graphite content on the Vickers hardness values is presented in Fig. (6). The hardness decreases by increasing graphite percentage due to the incorporation of softer nature graphite powders in the Cu matrix. This concept matches with the obtained results at all sintering temperatures. Figure (6) shows the effect of iron & different graphite ratios on the hardness of Cu- 20 Fe/graphite samples. It was increased gradually by increasing the graphite percentage. This is may be attributed to many factors which are the good sintering parameters, better microstructure due to the good homogenous distribution of both Fe & Gr in the copper matrix owing to the improving the wettability between Cu coated graphite particle with the copper matrix & finally the uniform small pores, with good densification. Reinforcing copper with graphite has also a good advantage of preventing the grain growth as it acts as internal barriers hampers the neck growth. These results are in good agreement with the densification and microstructure of the specimens. The high bonding and adhesions between matrix and reinforcement is also responsible for the improvement of the hardness. Also, the iron carbide phase formed during the sintering process, which helps in preventing the hardness load from the penetration, so the hardness decreases.

From Table, the results indicated that for the three manufactured copper composites which are Cu- 20 % Fe- 2 ,4, or 6 % Gr, the wear rate is decreased gradually by increasing the Gr ratio and sample contains 6 % Gr has the lowest wear rate. This is may be attributed to the high graphite percentage that acts as a lubricant material helps n sliding of the wear pin on the sample surface, consequently the wear rate decreased. Also, graphite has a low density so it floats on the sample surface causing the formation of a tribo layer that increases the wear resistance (19).

Also, Table shows that the coefficient of friction of samples decreases to 4 wt.% Gr sample, then increased for 6wt.% Gr sample. This is due to the lubricant nature of graphite with good distribution in the copper matrix due to the good milling parameters. But for sample contains 6wy.% Gr some agglomerations of Gr takes place which leads to the non-homogeneous distribution of Gr, causing scratching of the sample by the wear pin machine in the areas contains lower Gr.

| Samples | Wear Rate | | Friction Coefficient |
|---|---|---|---|
| | 5N | 10N | |
| (Cu-20 Fe-2 Gr) | 0.011 | 0.019 | 0.18 |
| (Cu-20 Fe-4 Gr) | 0.009 | 0.015 | 0.16 |
| (Cu-20 Fe-6 Gr) | 0.003 | 0.005 | 0.19 |

## IV. Conclusions

The results obtained from this study revealed that:

1. Powder metallurgy is a good technique for fabrication of Cu/ Fe- graphite composites.
2. The mechanical mixing milling technique is an suitable method in producing graphite reinforced copper – Fe composite.
3. The highest relative density, hardness and compression strength for Cu/Fe - graphite composites were obtained by compaction at 700 MPa and 1000 °C sintering temperature for 1 hr.
4. SEM was used for microstructure investigation which indicated the good homogeneity of both Fe & Gr in the copper matrix due to the coating process.
5. The hardness values is increased gradually by increasing graphite content.
6. Addition of graphite reduces the wear rate & COF of the prepared Cu- Fe- Gr composites.

## Acknowledgement

The authors wish to thank the Science, Technology & Innovation Funding Authority (STDF) - The Egyptian Ministry of Higher Education and Scientific Research in Egypt for cooperation, funding and good support of the project which this paper is part from it.

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