# WEAR STUDY OF HYBRID MMCS BASED COPPER BY POWDER METALLURGY ROUTE

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## SUMMARY:-

In our experimental study, 99% copper with 1% graphite metal matrix composite reinforced with 1, 2, 3, 4 and 5% volume fraction of alumina particulates were prepared by means of powder metallurgy method. Microstructure, hardness, compressive strength and wear resistance of the hybrid composites were evaluated and discussed.

The 900°C sintering temperature and 90 minutes holding time are stated experimentally for matrix composites (99% Cu and 1% Gr). The influences of alumina volume fractions on compressive strength and microhardness have the same tendency. The obtained relationship between compressive strength and hardness was linear. The improvements of higher compressive strength, hardness with high wear resistance are obtained at 4% volume fraction of alumina, while the reverse indications of previous results were obtained when the fraction of alumina content increased to 5%.

## 1. INTRUDUCTION:-

Copper-graphite composites offer a unique balance of physical and mechanical properties, including high friction and wear resistance in addition to high electrical conductivity [1 and 2]. As a result, several graphite fiber and graphite-particulate copper reinforced composites are commercially used as tribological materials in sliding contacts, industrial bearings and electric motor and generator brushes [3, 4, and 5].

There are two major problems hindering further development and application of advanced copper/graphite composites, liquid copper cannot wet graphite, so conventional liquid infiltration processes cannot be used. Secondly, the low affinity between copper and graphite results in weak interfaces, with deleterious effects upon mechanical, thermal and electric properties that limit performance and service life [2]. However, powder metallurgy routes have been traditionally employed to consolidate the composites in available pressure impregnation technologies with increased cost [1].

Powder metallurgy processing involving high-energy milling followed by consolidation operations thus appears to be a suitable route to process these composites with improved mechanical properties. However, mechanical alloying of copper/graphite composites presents specific challenges: continued milling of graphite induces amorphization [6]. To overcome those issues a strategy was developed were copper, graphite and alumina powders are simultaneously milled using alumina as milling media.  Alumina particles are a popular choice of reinforcement for copper matrix, owing to its high melting point, high hardness, thermal stability and chemical inertness [7 and 8].

(Esezobor and Oladoye, 2011), studied hybrid particulate Cu-Sic- Graphite composite have improved wear resistance with increasing volume of graphite so, enhancing its use in tribological applications [9].

(Dash K. et al. 2011), discussed the effects of different sintering atmosphere on hardness and density and microstructure evolution of copper-alumina MMCs. Three fractions (5, 10 and 15%) of ~ 5.7 µm alumina particles are using to reinforce the copper matrix. Conventional sintering route in argon, nitrogen and hydrogen atmospheres are using to produce Cu-$Al_2O_3$ micro composites. The microstructure of composites sintered in hydrogen atmosphere reveals better matrix-reinforcement bonding. The formation of $Cu_2O$ during sintering in nitrogen and argon atmosphere reduced the extent of bonding of copper with alumina. The densification processes more efficient in the case of hydrogen than in argon or nitrogen atmosphere. Maximum Vickers hardness of (60, 75 and 80) is obtained when the Cu-15% $Al_2O_3$ is conventionally sintered in $N_2$, Ar and $H_2$ atmosphere respectively [10].

(Dewidar M. et al., 2010), revealed the higher the sintering temperature, the higher mechanical properties and the wear resistance. Copper-graphite MMC's was fabricated by powder metallurgy where, copper reinforced with 2.5, 5, 7.5 and 10 wt. % of graphite particles. Three-compaction pressure (150, 250 and 350) MPa and sintering temperature (900, 950 and 1000) °C were applied. The results show that wear resistance and mechanical properties are improved when the addition of graphite content up to 5 wt. % and reduced after this fraction. Then hybrid composites are obtained by adding Zinc or Lead with (0.5, 1 and

1.5) wt. % to composites (copper 2.5 or 5 wt. % graphite composites). They found increasing in the wear resistance, compressive strength, true strain and surface hardness for hybrid composites [11].

## 2. EXPERMINTAL METHODS:-

### 2.1 Properties of Matrix and Reinforcement Materials:-

In this investigation, extra pure copper powder Art.2715 manufactured by E. Merck-Dramstadt – pure graphite powder manufactured by Laboratory chemical-India composite matrix materials are used in constant volume fraction 99% for copper and 1% for graphite. Pure alumina powder used as a reinforcement material with different volume fractions 1, 2, 3, 4, and 5% respectively. Main physical properties of the selective powders, which inspected at Iraqi Geological survey company and materials research center at ministry of science and technology, are listed in Table (1).

**Table (1) Physical Properties of Material Used.**

| Materials | Average Grain size (μm) | Density ($g/cm^3$) | Purity (%) |
|---|---|---|---|
| Copper | ≤ 36 | 8.6895 | 99.925 |
| Graphite | ≤ 11 | 2.2332 | 99.99 |
| Alumina | ≤ 1.5 | 3.01 | 99.00 |

Tool steel is used as a selective material to manufacture the compacting die that is used to produce the wear and compression specimens for all mixed investigated in this research work.

The composite matrix and hybrid composite for all mixes are blended using pestle and mortar for 15 minutes to ensure uniform distribution of matrix and reinforcement materials. 1-2% of n-butanol is used as binder materials to obtained specimens can be handled with uniform final shape. The green powder metallurgy specimens for composite matrix and hybrid composites are obtained by cold compaction for blended particulate materials. The applied compacting pressure is 20 $ton/in^2$ through 80-tones German hydraulic press (KNUTH). Figure (1) illustrates the used press and green specimens.

### 2.2 Selecting the Sintering Process Parameters:-

The ultimate objectives for sintering studies is to be able to predict densification with mechanical behavior results under different thermal histories (sintering temperature and holding time) for a given processing method. Sintering process done in Material laboratory at Technical Engineering College – Baghdad by electrical furnace in presence of an inert atmosphere (99.99% pure argon gas). The compressive strength and Vickers hardness of 1% $Al_2O_3$ hybrid composite are at four sintering temperature-holding times to state the best environmental of sintering as shown in Table (2). 900°C and 90 min. is the best sintering temperature and holding time that will be used in this investigation, which gives higher hardness and acceptable compressive strength.

**Table (2) Mechanical Properties of 1% $Al_2O_3$ Hybrid Composite at Variable Sintering Temperature and Holding Time.**

| Sintering Temperature and Holding Time | Compressive Strength (MPa) | Vickers Hardness (Hv) |
|---|---|---|
| 900°C – 60 min. | 169.50 | 77.25 |
| **900°C – 90 min.** | **254.21** | **69.70** |
| 950°C – 60 min. | 252.45 | 52.20 |
| 950°C – 90 min. | 264.12 | 46.25 |

## 2.3 Mechanical and Wear Tests:-

The standard compression specimens were carried out according to ASTM E9 have dimension of (20mm × Ø10mm) with 2:1 height to width ratio as shown in Figure (1). The compression test was occurred in a UTM (300KN capacity). A speed rate of 0.1mm/min, was maintained through the experiment. The specimens were reduced to the 50% of the initial height.

The microhardness was measured in Material laboratory at university of technology by digital Micro Hardness Tester, (LARYEE) model HVS-1000. The tests are according to ASTM E 384. All specimens are grinding with emery papers have grades (400, 800, 1000, 1200, 1500, 2000 and 2500) µm and then polished by 0.35µm alumina. The indenting load was $0.5Kg_f$ for 15 second dwell time and recorded the readings at four positions for each sample. The average of four position hardness readings per three-hardness specimen for each mixes used in this research work.

Wear test samples manufactured under ASTM G99-04 have dimension (Ø10×20mm) and tested by pin on disc wear test machine that shown in Figure (2). The test is carried out at room temperature, constant rotating speed (150 rpm), constant time for each reading (15 minutes) and various applied normal loads 2.5, 5, 7.5, 10 and 12.5N. Average wear loose was measured from five readings for each applied load.

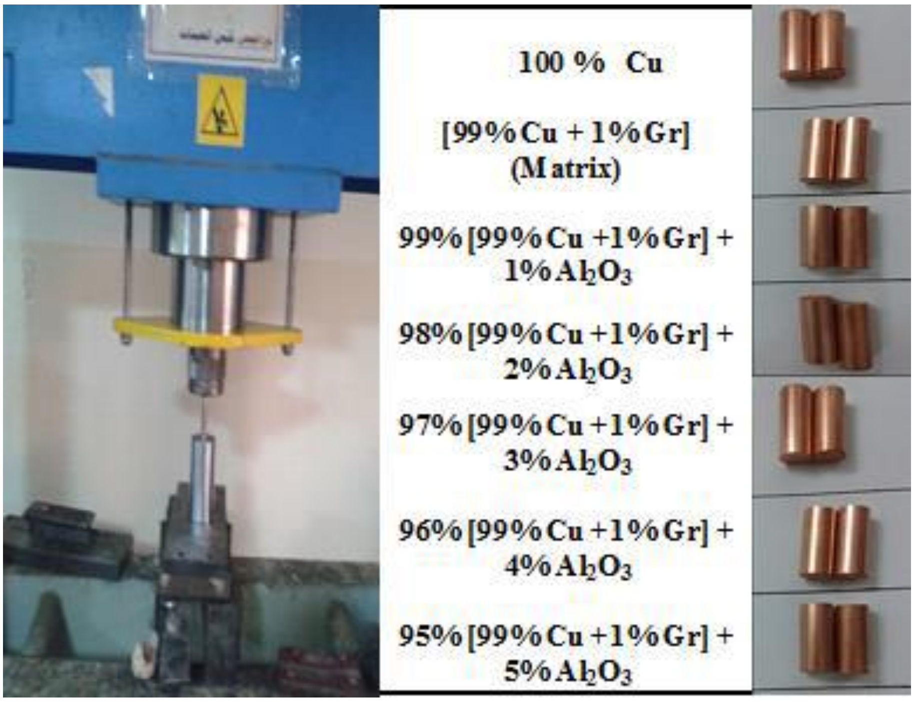



**Figure (1) Shows the Compaction and Green Samples.**

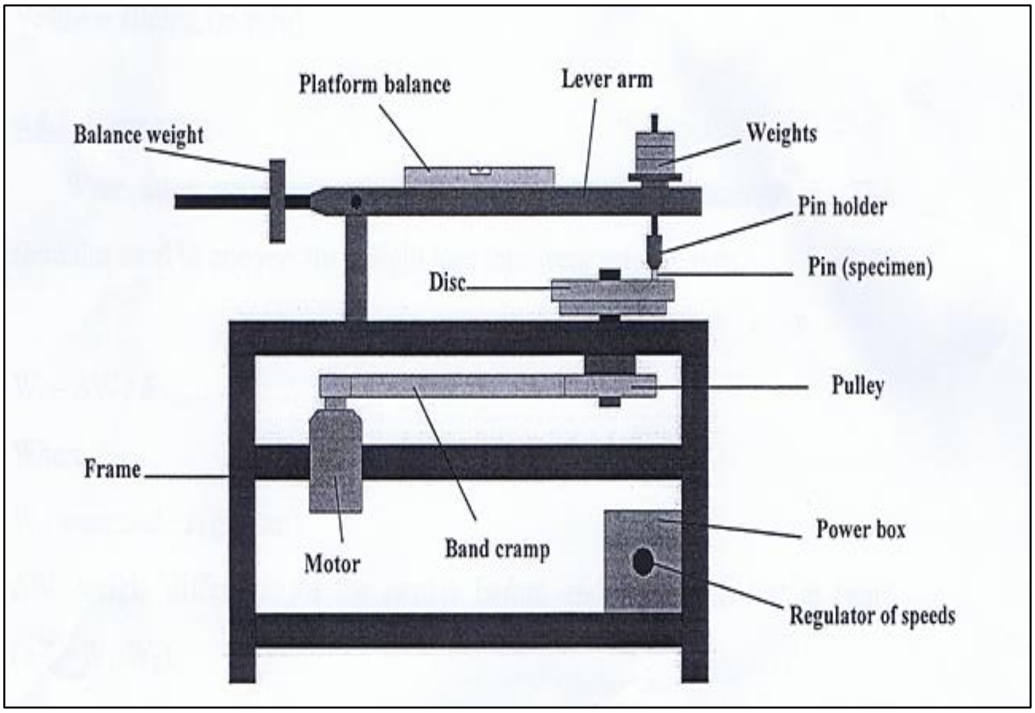



**Figure (2) Schematic of Pin on Disc Wear Test Machine.**

## 3. RESULTS AND DISCUSSION:-

### 3.1 Compression Strength Test:-

The addition of 1% volume of graphite to copper matrix improved compressive strength as listed in table (3) and as shown in Figure (3) because of the better dispersion of graphite particles in matrix formed pinning in the composite preventing grain growth and increase strength. Copper hybrid composites [Cu-Gr -$Al_2O_3$] show improvement in compressive strength when compared with copper-graphite composite as shown in Figure (4), and as listed in table (3). Therefore, the addition of alumina made better enhance of compressive strength because the hard particles of alumina dispersed in grain boundaries and restrict the dislocations motion and deformation when compared with the graphite. It is found from the figure and table (3) that maximum compressive strength at 4 % of alumina more than pure copper and copper-graphite composite. The addition of alumina more than 4% produced decreases in compressive strength because of increasing in brittle nature and agglomeration of alumina-reduced bond between particles act as impurities.

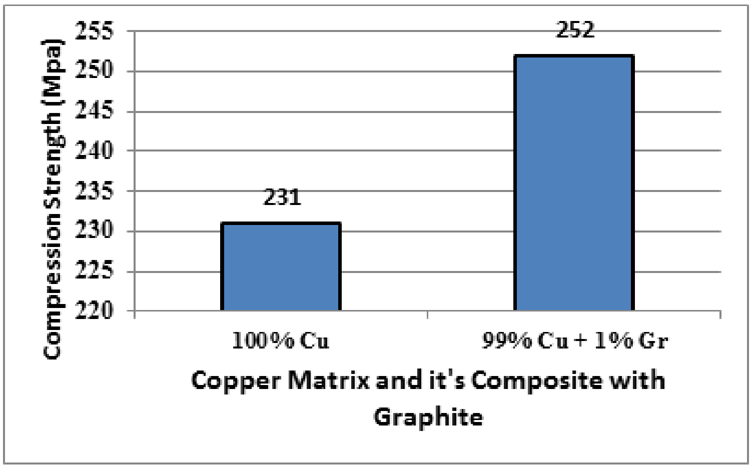



**Figure (3) Compressive Strength of Copper and Copper-Graphite Composites.**

**Table (3) Compression strength Improvements by adding graphite and alumina to copper matrix and to 99% copper-1% graphite composite.**

| Matrix , Composite and Hybrid Composites | *Improvement (%)* | |
|---|---|---|
| | With respect to Cu – Matrix | With respect to 99%Cu–1%Gr |
| 100% Cu | - | - |
| 99% Cu + 1% Gr | 9.4% | - |
| 99%(99%Cu + 1%Gr) + 1% $Al_2O_3$ | 10.8% | 1.3% |
| 98%(99%Cu + 1%Gr) + 2% $Al_2O_3$ | 14.6% | 4.7% |
| 97%(99%Cu + 1%Gr) + 3% $Al_2O_3$ | 21.2% | 10.8% |
| 96%(99%Cu + 1%Gr) + 4% $Al_2O_3$ | 23.7% | 13.0% |
| 95%(99%Cu + 1%Gr) + 5% $Al_2O_3$ | 15.6% | 5.6% |

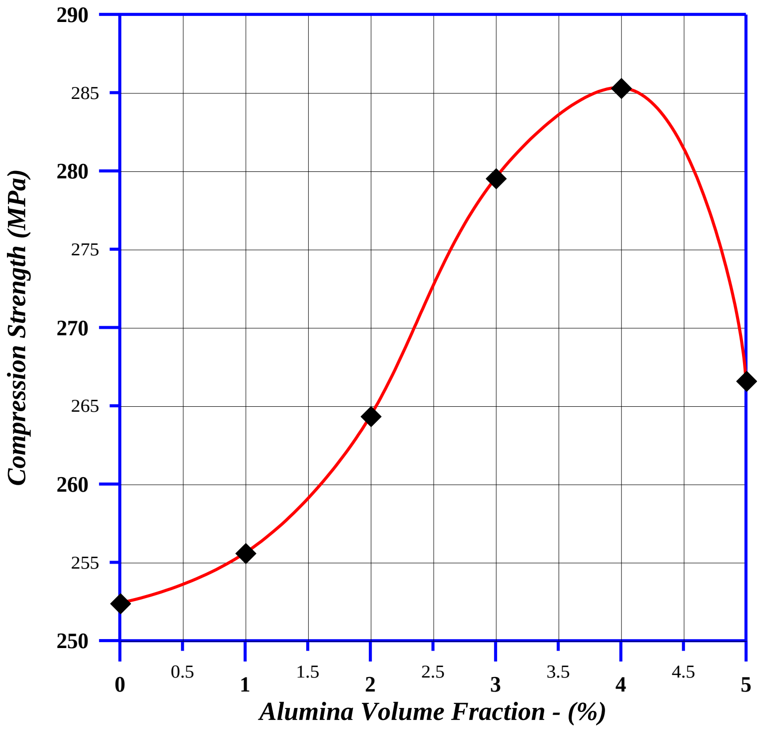



**Figure (4) Effect of $Al_2O_3$ Content on Compressive Strength of Hybrid Composite [Cu-Gr-$Al_2O_3$].**

### 3.2 <u>Micro Hardness Test:-</u>

Copper hybrid composites [Cu-Gr-$Al_2O_3$] show improvement in hardness when compared with Cu matrix and Cu-Gr composite matrix as shown in Figure (5) and as listed in table (4). The adding 1% of Gr to Cu-matrix improved increasing in hardness due to the better dispersion of graphite particles in copper matrix that act as obstacle prevent grain growth leads to increasing hardness. The hybrid composites have higher hardness due to the addition of alumina ($Al_2O_3$) made more improvement in the hardness as shown in Figure (6) and as listed in table (4). The reason of increasing in hardness due to the hard nature of $Al_2O_3$ particles, which reduce plastic deformation, acts as pinning for grain growth and motion of dislocations. The maximum hardness obtained at 4% of $Al_2O_3$ that is more than Cu matrix and Cu-Gr composite matrix.

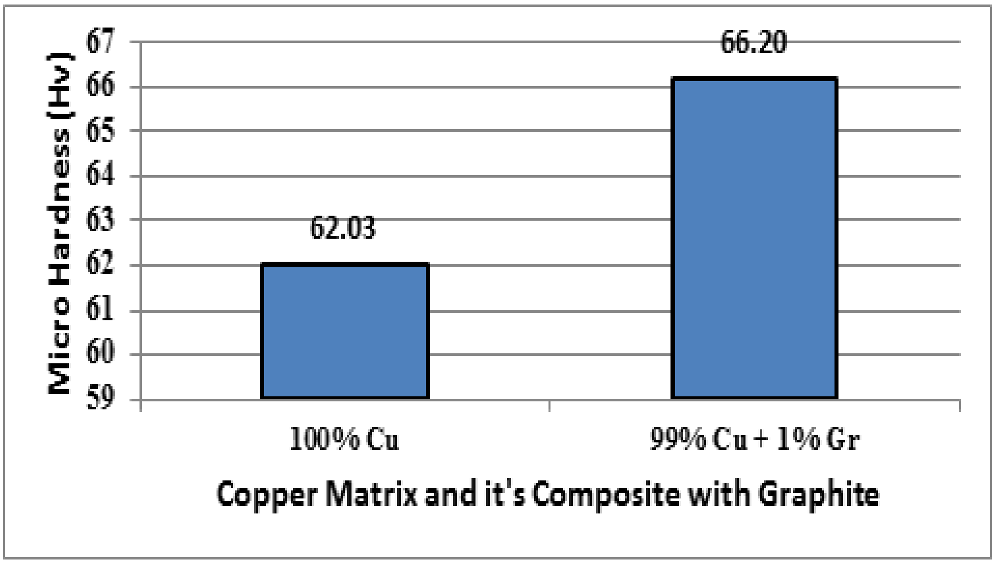



**Figure (5) Micro Hardness Strength of Copper and Copper-Graphite Composites.**

**Table (4) Micro Hardness Improvements by adding graphite and alumina to copper matrix and to 99% copper-1% graphite composite.**

| Matrix , Composite and Hybrid Composites | *Improvement (%)* | |
|---|---|---|
| | With respect to Cu – Matrix | With respect to 99%Cu–1%Gr |
| 100% Cu | - | - |
| 99% Cu + 1% Gr | 6.7% | - |
| 99%(99%Cu + 1%Gr) + 1% $Al_2O_3$ | 12.4% | 5.3% |
| 98%(99%Cu + 1%Gr) + 2% $Al_2O_3$ | 19.2% | 11.7% |
| 97%(99%Cu + 1%Gr) + 3% $Al_2O_3$ | 30.7% | 22.5% |
| 96%(99%Cu + 1%Gr) + 4% $Al_2O_3$ | 35.7% | 27.2% |
| 95%(99%Cu + 1%Gr) + 5% $Al_2O_3$ | 16.6% | 9.3% |

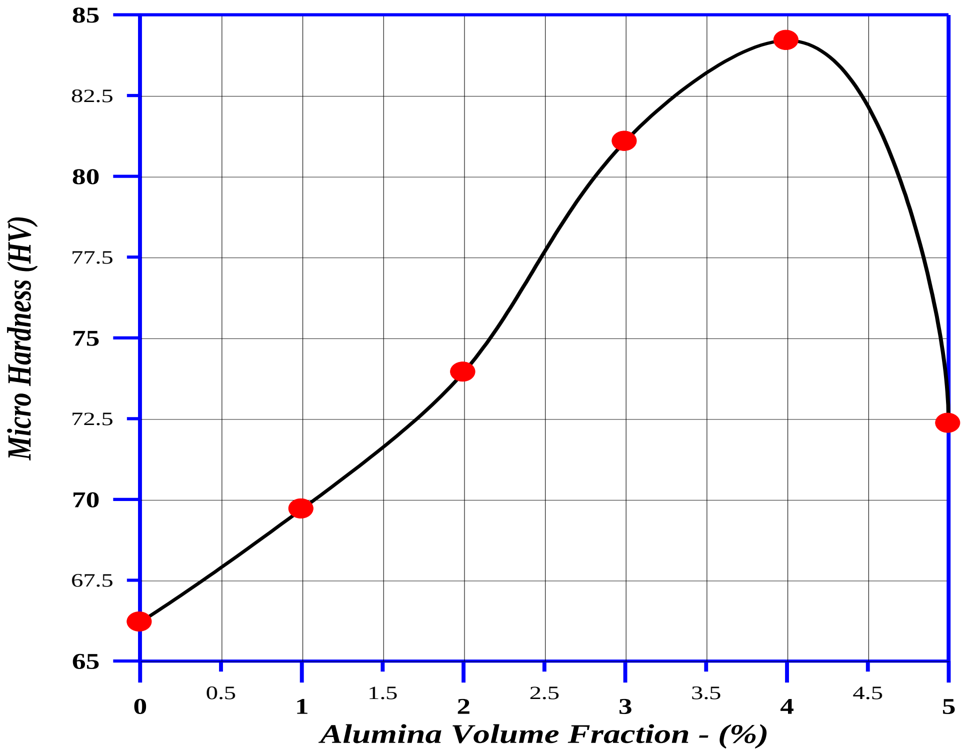



**Figure (6) Effect of $Al_2O_3$ Content on Micro Hardness of Hybrid Composite [Cu-Gr-$Al_2O_3$].**

The behaviors of mechanical properties (compressive strength and micro-hardness) have the same tendency with the variation of $Al_2O_3$ volume fraction in hybrid composites (Cu-Gr-$Al_2O_3$) as shown in Figure (7). In addition, there is a linear relationship between compressive strength vs. micro-hardness for hybrid composites (Cu-Gr-$Al_2O_3$) and their matrix composite (Cu-Gr) as shown in Figure (8) and Equation (1). As previously expressed, the addition of graphite and alumina make better improvements in hardness and compressive strength.

$$\sigma_C = 125.131 + 1.89787 H_V \qquad \dots\dots\dots Eq. (1)$$

Where;
**$\sigma_C$ :** Compressive Strength (MPa).
**$H_V$ :** Micro-Hardness (HV).

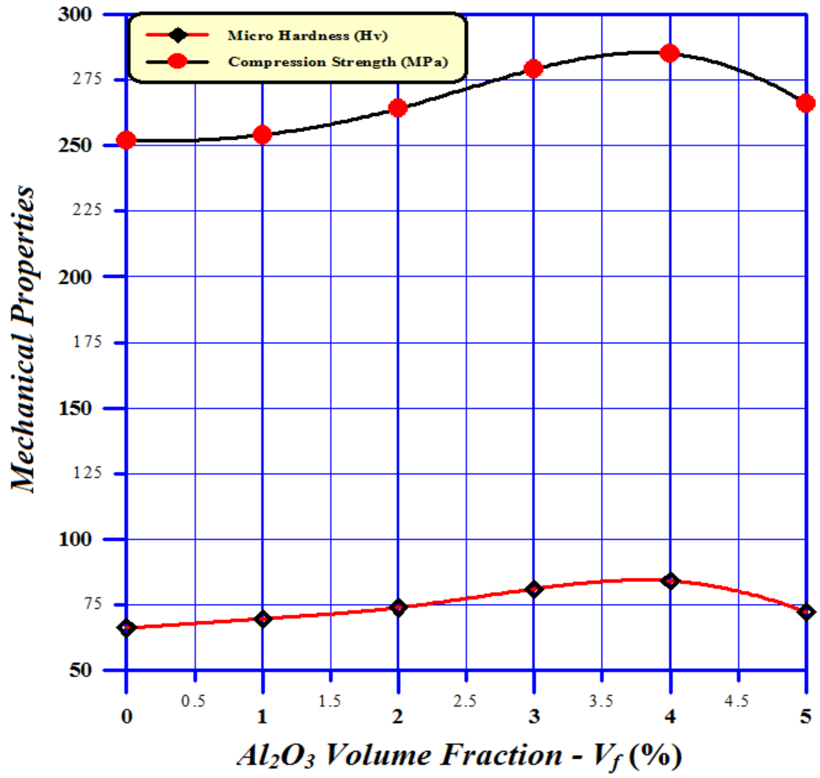



**Figure (7) Effect of $Al_2O_3$ Content on Mechanical Properties of Hybrid Composite [Cu-Gr-$Al_2O_3$].**

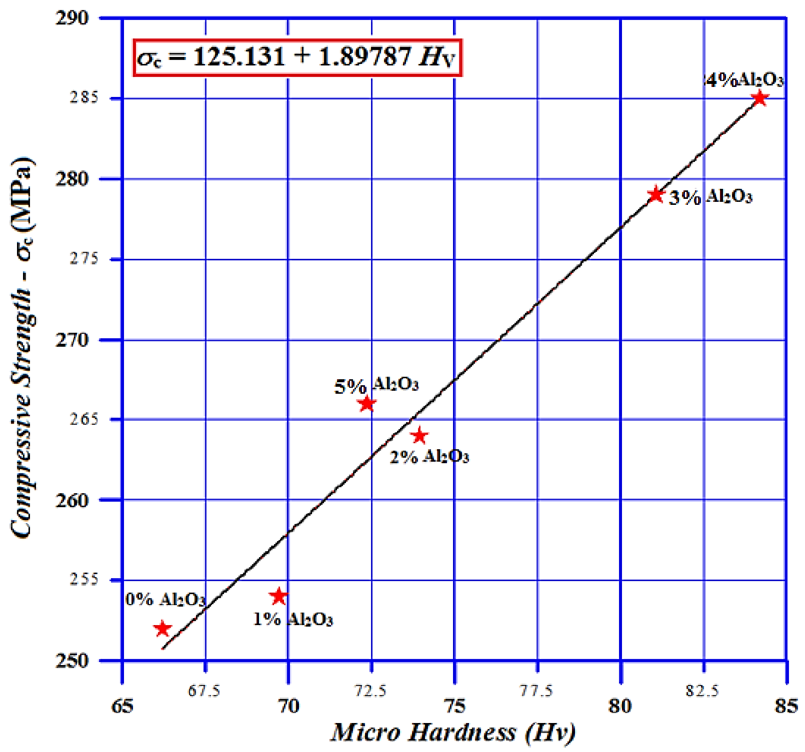



**Figure (8) The Relation Between Compressive Strength and Hardness.**

## 3.3 Wear Tests:-

The bar chart shown in Figure (9) represents the wear loose (wear resistance) results at variable applied loads (2.5, 5, 7.5, 10, and 12.5N) for Cu matrix, Cu-Gr Composite and Cu-Gr-$Al_2O_3$ hybrid MMC's. The wear loses increases with increase in the applied load that means decreases in the wear resistance. There is proportionality between the wear loose rate and the addition of graphite and alumina to the copper and copper-graphite matrix composites as shown in Figure (10) similar to the tendency of variation of compressive strength and micro-hardness vs. the alumina contents. The hybrid composites have better wear resistance compared with Cu and Cu-Gr matrix and matrix composite respectively as listed in table (5). The wear resistance is proportional to with alumina contents till 4% and after this percentage (5%) proportional inversely as indicated in compressive strength and micro-hardness.

Compared with  show decrease in wear rate lower than copper alone as the list of average improvements of the average wear rate that listed in table (5).  The contacts between metal and metal are transferred to contact between graphite film and metal or graphite film which, lead to lower friction due to the adding graphite that adhere to the wear surface forming smeared graphite layer (solid self –lubricant film) at the sliding surface of the specimen. Therefore, the wear of copper-graphite composite improved in comparison with pure copper.

Copper hybrid composite show better hardness than copper-graphite composite and pure copper because the addition of hard particles of Alumina mixed with soft copper reduced grain growth and constrain plastic deformation  enhance hardness and reduce the wear rate due to large reduction of  weight  loss  result in  contact between samples and disk in comparison with composite and pure copper. The lower value of wear rate obtained at 4% volume of Alumina less than pure copper and copper-graphite composite see that in Figures (11). Because in hybrid composites two reinforcement effect introduced the first is the effect of graphite as lubricant reduced friction and hard particle alumina which increased hardness and reduced weight loss of copper.

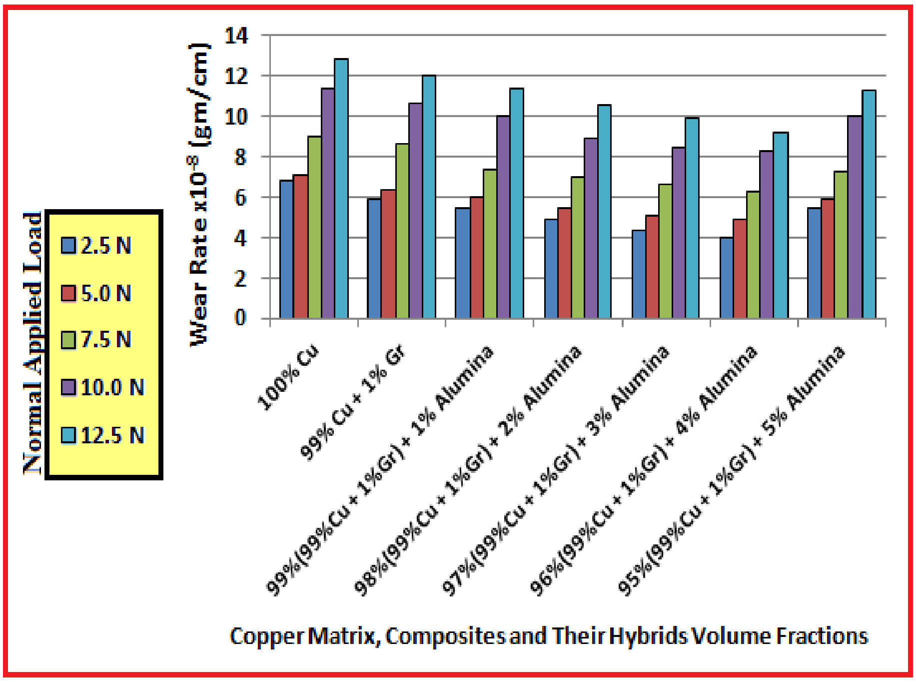



**Figure (9) Average Wear Loose Rate Results for Cu-Matrix, Cu-Gr Composite and Cu-Gr-$Al_2O_3$ Hybrid Composites at Variable Applied Loads.**

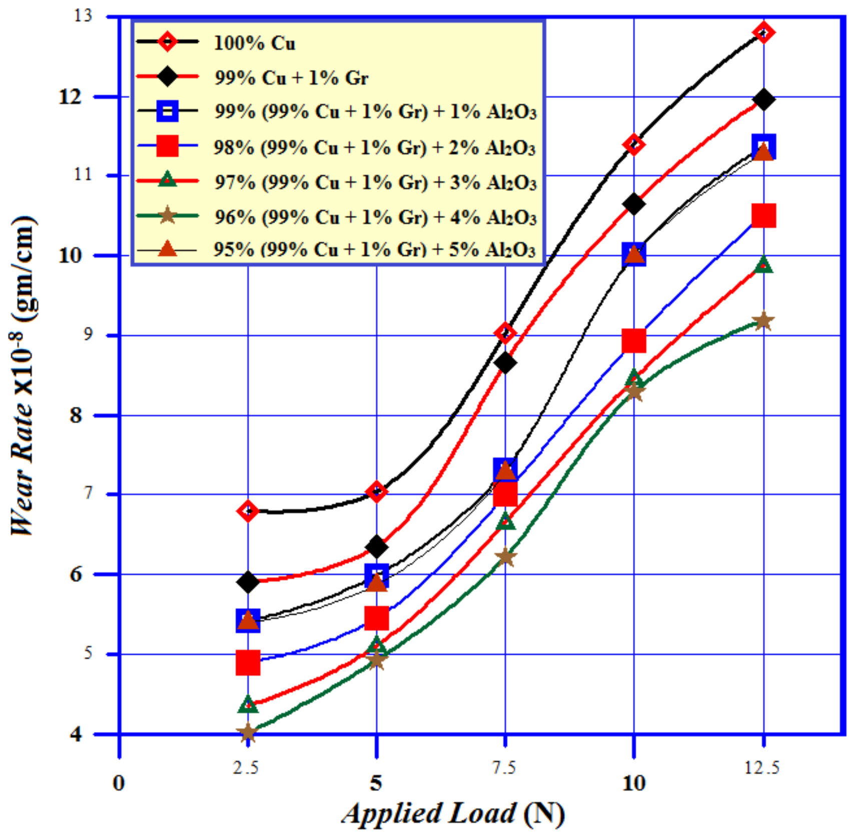


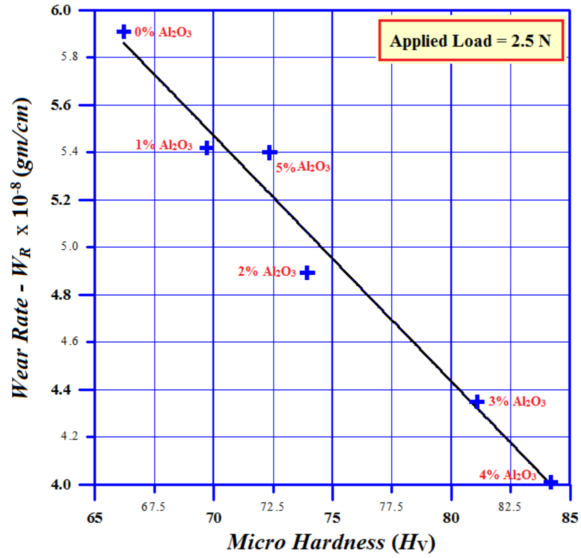

**Figure (10) Wear Tests for Copper Matrix, Composite and Hybrid.**

**Table (5) Average wear loose improvements by adding graphite and alumina to copper matrix and to 99% copper-1% graphite composite.**

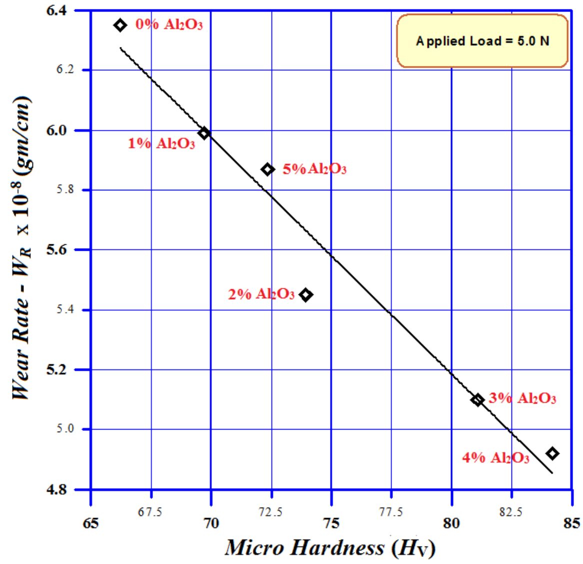
| Matrix , Composite and Hybrid Composites | *Improvements* | |
|---|---|---|
| | With respect to Cu – Matrix | With respect to 99%Cu–1%Gr |
| 100% Cu | - | - |
| 99% Cu + 1% Gr | 8.0% | - |
| 99%(99%Cu + 1%Gr) + 1% $Al_2O_3$ | 15.5% | 8.1% |
| 98%(99%Cu + 1%Gr) + 2% $Al_2O_3$ | 22.5% | 15.7% |
| 97%(99%Cu + 1%Gr) + 3% $Al_2O_3$ | 27.7% | 21.5% |
| 96%(99%Cu + 1%Gr) + 4% $Al_2O_3$ | 31.6% | 25.6% |
| 95%(99%Cu + 1%Gr) + 5% $Al_2O_3$ | 16.2% | 8.8% |

The increased of hardness proportion inversely with wear rate because the hard material loss low weight during wear test. Both reinforcement graphite and alumina restrict grain growth and hard particle of alumina reduced plastic deformation and decreased weight loss of copper matrix during abrasive as seen in Figures (11) for the entire applied loads.

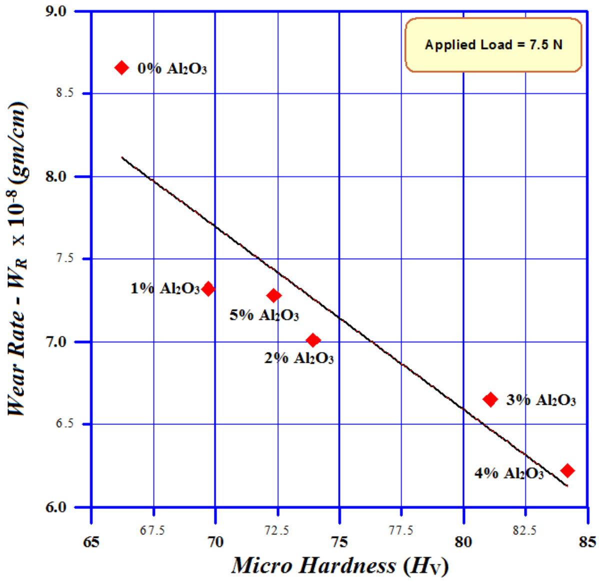
The average wear rates loose is proportional inversely with compressive strength as indicated in compressive strength effects. Because the addition of graphite to copper matrix led to form pinning prevent grain growth and the addition of hard alumina reduced plastic deformation which make the matrix so hard and hard material loss low weight during wear test for all applied loads as shown in Figures (12).



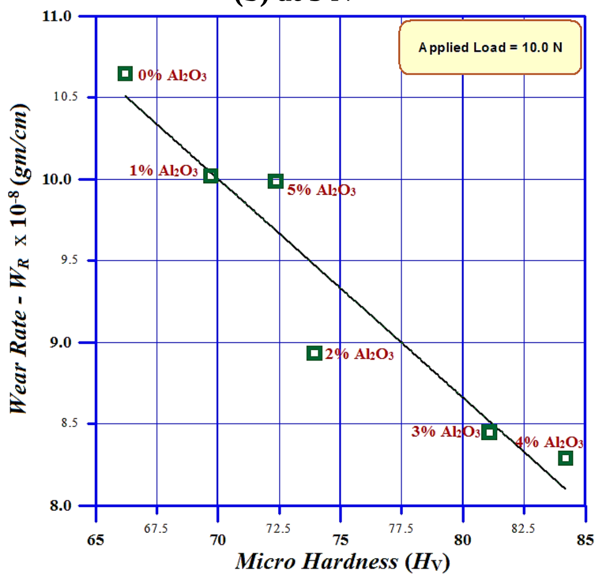

(a) at 2.5 N



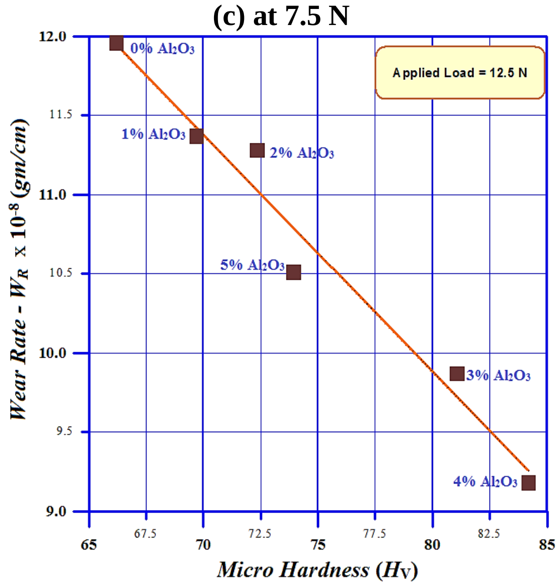

(b) at 5 N




(c) at 7.5 N

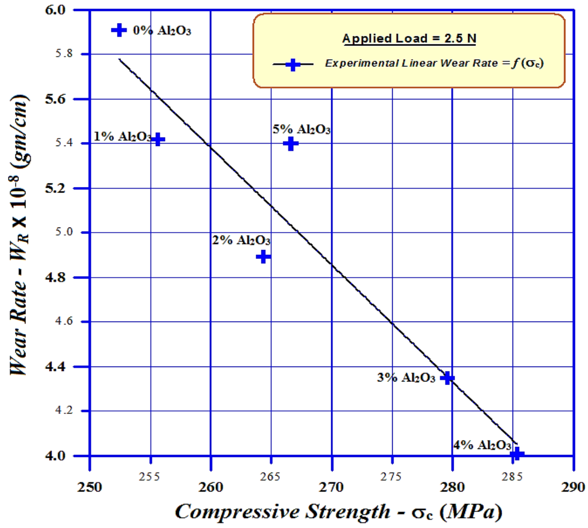



(d) at 10 N

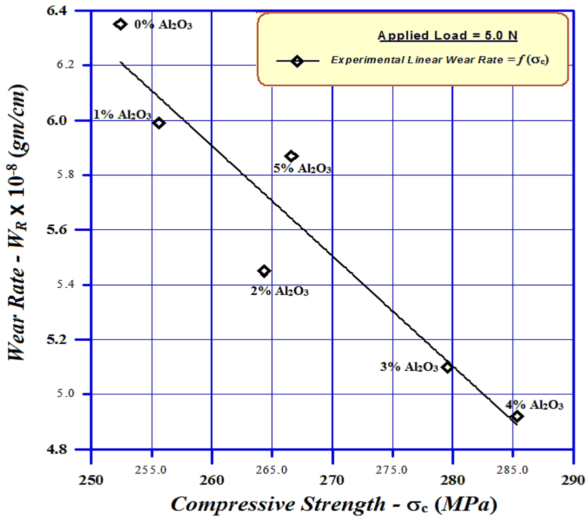



(e) at 12.5 N

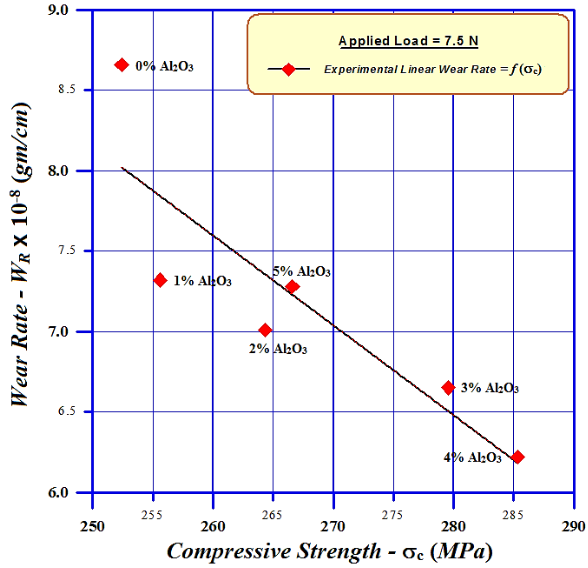
**Figure (11) The Relationship of Average Wear Loose Rates vs. Micro-Hardness at Variable Applied Loads for Cu-Gr Composite and Cu-Gr-$Al_2O_3$ Hybrid Composites**



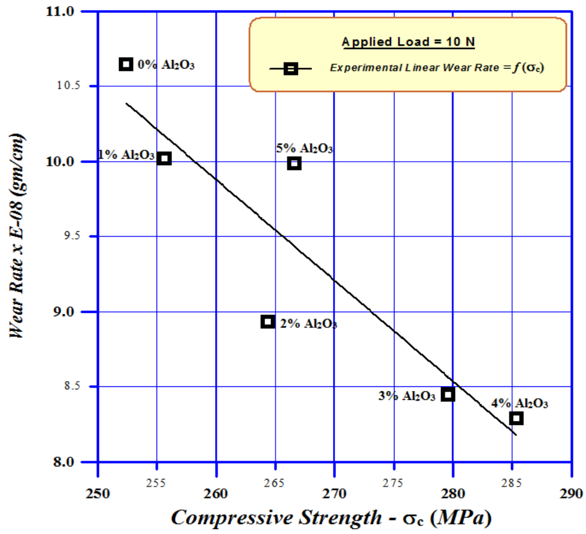

(a) at 2.5 N



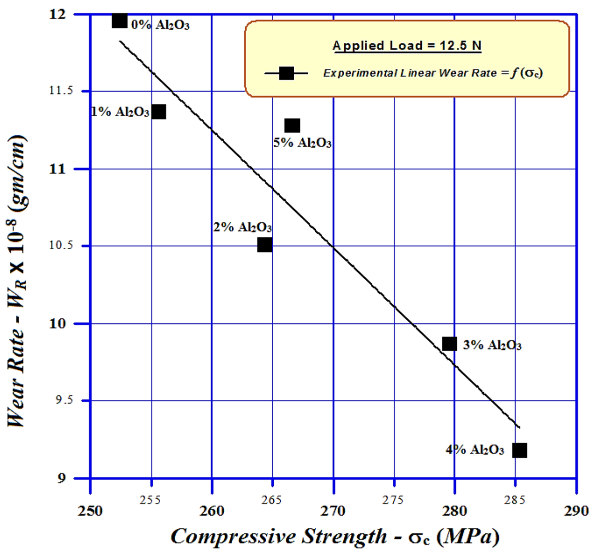

(b) at 5 N




(c) at 7.5 N




(d) at 10 N




(e) at 12.5 N

**Figure (12) The Relationship of Average Wear Loose Rates vs. Compressive Strength at Variable Applied Loads for Cu-Gr Composite and Cu-Gr-$Al_2O_3$ Hybrid Composites.**

## 4. CONCLUTION:-

1- The best sintering temperature and holding time 900° C & 90 minutes, which provide better compressive strength with acceptable hardness.

2- The mechanical property of hybrid composite [Cu-Gr-$Al_2O_3$] higher than Copper-graphite composite.

3- Compressive strength and micro-hardness of hybrid composite increase with addition of alumina up to 4% volume fraction, and reduced when the alumina content increased to 5%.

4- The average wear rates decrease with addition of graphite and alumina up to 4% volume fraction, and decreased when the alumina content increased to 5%.

5- The effect of alumina volume fraction has the same tendency on mechanical properties and wears loose rates.

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