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Fabrication and Characterization of Copper Graphite Composite Material

Avinash Sharma [1] ,Rajesh Kr Porwal[2]

1,2 Faculty of Mechanical Engineering, Institute of Technology, Shri Ramswaroop Memorial University, Barabanki, Uttar Pradesh, India

Abstract-This study presents the fabrication and mechanical characterization of a Copper-Graphite (Cu-Gr) metal matrix composite through the powder metallurgy route. The mechanical properties of the composite were investigated for varying percentages of graphite (2%, 05%, 10%) and compression pressures (550MPa, 650MPa), including tensile strength and hardness, as well as the effect of pressure on density and green density. The Cu-Gr composites were prepared under different compaction pressures, and their properties were comprehensively evaluated. The composites underwent sintering at a temperature of 1100°C for 1 hour and 20 minutes. It was observed that an increase in the graphite content resulted in a corresponding increase in both the hardness and tensile strength of the composites. Additionally, the green density, sintered density, and relative density of the Cu-Gr composites were measured for various compaction pressures. As the compaction pressure increased, there was a notable enhancement in the density and relative density of the composites.

Keywords :Copper , Graphite ,Metal Matrix Composite ,Tensile, Hardness, Density

1.0 Introduction

Metal matrix composites (MMCs) have garnered significant attention in recent years due to their unique combination of mechanical properties, making them ideal candidates for various engineering applications. Among the range of MMCs available, copper-based composites have attracted considerable interest due to their exceptional thermal and electrical conductivity, corrosion resistance, and good machinability[1]. This research paper present the fabrication and characterization of a copper graphite composite material, aiming to explore its potential in addressing the limitations of pure copper and enhancing its mechanical properties. Graphite, with its excellent lubricating properties, low density, and high thermal stability, is chosen as the reinforcing material due to its compatibility with copper[2]. The fabrication process involves the careful integration of graphite particles into a copper matrix through various techniques such as powder metallurgy, stir casting, or solid-state sintering. Each method has its advantages and limitations, and the selection of the most appropriate technique is crucial to achieve a homogeneous distribution of the reinforcement particles within the copper matrix. Following the successful fabrication of the copper-graphite composite, an extensive characterization process is undertaken to evaluate its mechanical properties[3-5]. This includes comprehensive mechanical testing, such as tensile, compressive, and flexural tests, to assess the composite's strength, stiffness, and toughness. Furthermore, micro structural analysis techniques like scanning electron microscopy (SEM) and X-ray diffraction (XRD) are employed to examine the distribution of graphite particles within the copper matrix and analyze the formation of any secondary phases. The results obtained from the characterization of the copper-graphite composite material will be compared with those of pure copper[6-9]. This comparative analysis will allow us to determine the extent to which the addition of graphite as reinforcement improves the mechanical properties of the composite. These findings are vital in understanding the potential applications of copper-graphite composites, particularly in industries requiring enhanced strength, wear resistance, and reduced frictional properties[10]. In conclusion, this research paper aims to contribute to the existing knowledge on metal matrix composites by investigating the fabrication and characterization of a copper graphite composite material. By exploring the impact of graphite reinforcement on the mechanical properties of copper, we seek to provide valuable insights into the development of advanced materials for a wide range of industrial applications[11].

2.0 Details of Materials

Copper Copper is extensively utilized in various industrial and functional applications due to its excellent electrical and thermal conductivity. It finds wide usage in thermal and electronic packaging, electrical contacts, and resistance welding electrodes. Coppergraphite powder compacts are particularly valuable for manufacturing electrical contact parts, notably carbon brushes used in automobile kick starters. These carbon brushes often contain a graphite content ranging from 5% to 15%. To optimize electrical conductivity, it is crucial to minimize porosity within the brushes. Additionally, since these brushes rub against rotating metal parts (such as the commutation of a DC generator or motor, or the slip rings of an AC motor or generator), a certain level of wear resistance is necessary[12]. The advantage of using copper-graphite composites lies in the combination of positive characteristics from both elements. Copper provides excellent electrical and thermal conductivity, while graphite contributes to a low thermal expansion coefficient and lubricating properties. Powder metallurgical processes offer several advantages over other techniques, including the ability to obtain uniform brushes and reduce the need for tedious and costly machining processes[13]. Many of the bearing alloys currently in use incorporate a soft phase such as lead to impart the required anti-friction properties. However, due to the harmful effects associated with lead, restrictions have been imposed on its use. Consequently, researchers have sought alternative materials that can offer tribological properties similar to lead. Metal matrix composites (MMCs) containing soft particles have been extensively studied for their tribological properties, demonstrating reduced friction and wear of the counter face[14].

In light of the challenges posed by the low mechanical properties of pure copper, copper-based alloys, and the harmful effects of lead, a suitable alternative material has been developed in the present investigation while certain metals, metal oxides, and non-metallic materials possess desirable characteristics for contact applications, they often exhibit low conductivity. However, combining these materials with copper, which has excellent conductivity, can yield a material with optimized properties. Unfortunately, the metals in question have high melting points and do not readily alloy with copper, making their production through conventional melting techniques impractical. This limitation also applies to combinations of metal oxides and non-metallic materials with copper. Powder metallurgy emerges as the only viable manufacturing procedure at room temperature to produce such combinations, ensuring the development of materials with the desired properties.[15-17]

In general, carbon exists in three main forms: diamond, charcoal, and graphite. Graphite is a crystalline form of carbon, classified as a semimetal and a native element mineral. It is considered the most stable form of carbon under standard conditions and serves as a standard for defining the heat of formation of carbon compounds in thermochemistry. Graphite can be found in different forms, including disseminated flake, crystalline vein (fibrous or columnar), and amorphous structures. Well-crystallized graphite flakes exhibit a black metallic luster, while amorphous graphite appears black and earthy with a microcrystalline compactness. Synthetic graphite is produced from petroleum coke and pitch. Graphite possesses excellent heat and electrical conductivity, as well as a high melting point of 3,500°C[18]. It demonstrates remarkable resistance to acids, is chemically inert, and exhibits high refractoriness. Although graphite can be considered a high-grade coal, superior to anthracite, it is not typically used as fuel due to its difficulty in igniting. Flake graphite concentrates generally command higher prices than microcrystalline (amorphous) graphite, with prices varying based on factors such as carbon content, flake size, distribution, and ash content.

3.0 Preparation of Samples

In the context of sample preparation, an initial step involves filling the powder into a 20mm die to determine the quantity of powder required for each sample, taking into account the desired aspect ratio. The filled powder is then measured using an electronic weighing machine. After defining the powder requirement, then selection of the composition percentages are to be decided[19-20].

Once the powder requirement has been determined, the next step involves deciding the composition percentages. The process for preparing the samples typically follows the following steps:

3.1 Agate Mixing: Agate mixing involves thoroughly blending the required powders in a controlled environment to ensure a uniform distribution of the constituents. Agate mortars and pestles are commonly used for this purpose[21]

3.2 Compaction: After the powders have been mixed, the blended powder mixture is placed into a die or mould. The die is typically designed to achieve the desired shape and dimensions of the sample. The powder mixture is then compacted using a hydraulic or mechanical press to apply pressure. The compaction process helps to consolidate the powder particles and remove any remaining voids or porosity[22]

Figure 1: Experimental set-up for the compaction process

Once the compaction process is complete, the compacted powder is carefully removed from the die. The resulting compacted sample represents the initial shape of the intended final product. Depending on the specific requirements, additional shaping or machining processes may be carried out to refine the sample dimensions or achieve specific features.[23]

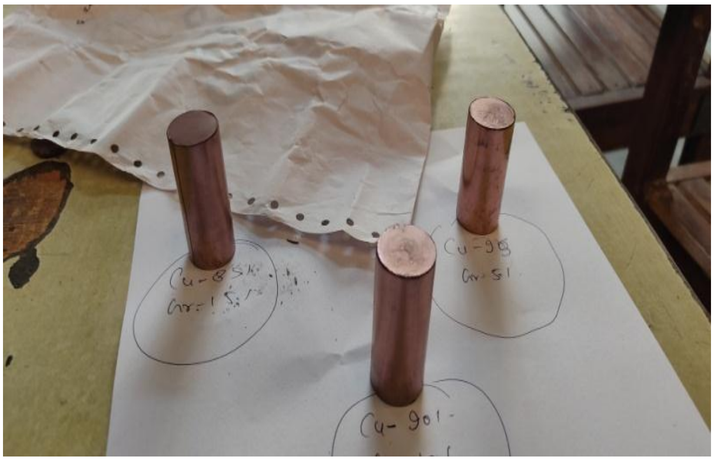

Figure 2: Green compact specimens of Cu-(5, 10, and 15) composites.

3.3 Sintering: Sintering is a crucial step in the sample preparation process. The compacted samples are subjected to high temperatures under controlled atmosphere conditions. During sintering, the samples are heated to a point where the powder particles bond together, resulting in a denser and more cohesive structure. The temperature and duration of the sintering process are carefully controlled to achieve the desired properties and final density of the samples.[23-26]

Figure 3:Experimental set-up for the sintering process

4.0 Mechanical Testing and Results:

4.1 Hardness Test

The presented data illustrates the impact of varying pressure levels on the hardness (measured in BrinellHardness Number, BHN) of composite materials composed of different ratios of copper and graphite. The experiments were conducted at a constant temperature of 1100 degrees Celsius for a duration of 1 hour and 20 minutes. Under a pressure of 550 MPa, it is evident that increasing the graphite content from 2% to 10% in the copper matrix results in a remarkable increase in hardness, with values progressing from 38 BHN to 68 BHN. Similarly, at a higher pressure of 650 MPa, the hardness of the materials experiences a substantial rise as the graphite proportion is augmented. For instance, the hardness elevates from 42 BHN to 75 BHN when the copper-to-graphite ratio shifts from 98:2 to 90:10. This data emphasizes the significant influence of pressure and graphite composition on the hardness of copper-graphite composites at the specified temperature and duration.

Table 1: Hardness Test Results for sample prepared under 550MPa

Pressure :550MPa			
Composition	Temperature	Time	Hardness(BHN)
Copper 98 % graphite 2%	1100 C	1hr20min.	38
Copper 95 % graphite 5%	1100 C	1hr20min.	42
Copper 90 % graphite 10%	1100 C	1hr20min.	68

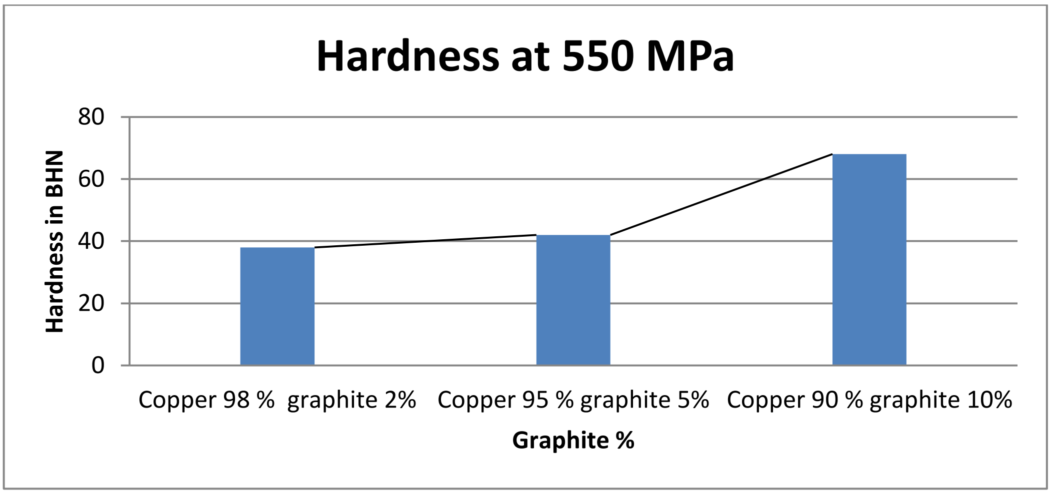

Figure 4: Hardness Vs Graphite percentage

Table 2: Hardness Test Results for sample prepared under 650MPa

Pressure :650MPa			
Composition	Temperature	Time	Hardness(BHN)
Copper 98 % graphite 2%	1100 C	1hr20min.	42
Copper 95 % graphite 5%	1100 C	1hr20min.	52
Copper 90 % graphite 10%	1100 C	1hr20min.	75

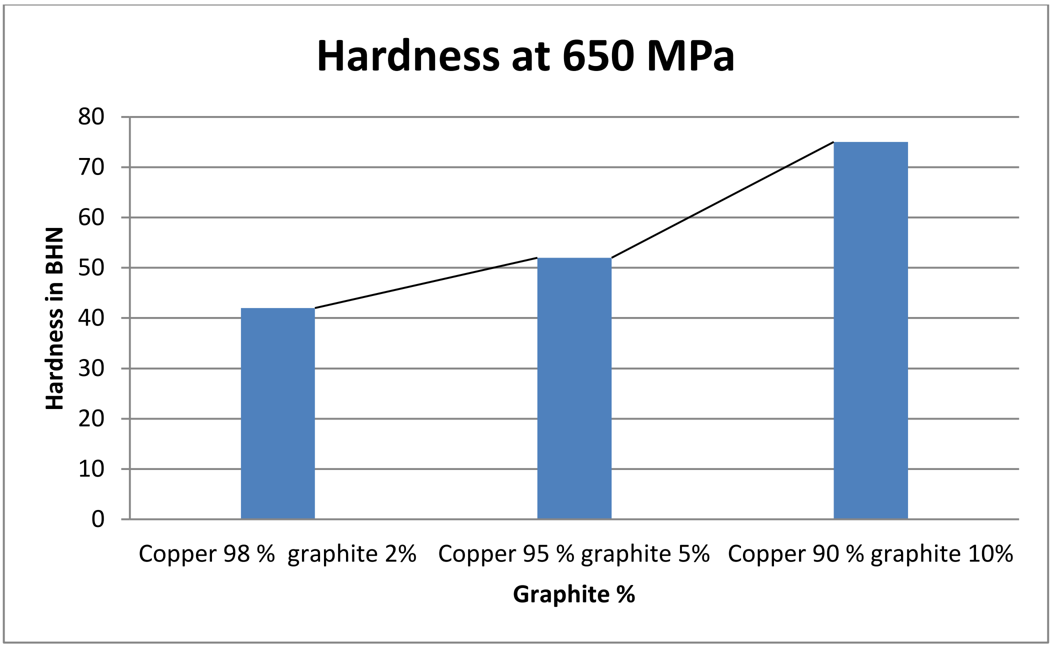

Figure 5: Hardness Vs Graphite percentage

4.1.1 Results

Figure 4 and Figure 5 depicts the relationship between the hardness and the percentage of graphite in a copper matrix. As the graphite percentage increases in copper, the hardness of the composite material also increases, indicating an enhancement in material strength. For instance, when the composite consists of 2% graphite and 98% copper, the hardness value is 38 BHN for sample prepared at 550Mpa at pressure 650 under same composition value of hardness observed 42 BHN .With 5% graphite and 95% copper, the hardness value rises to 45 BHN. Furthermore, at 10% graphite and 90% copper, the hardness value reaches 75 BHN. Notably, the hardness increment between 2% and 5% graphite is only 5 BHN. However, when the graphite percentage reaches 10%, the hardness escalates significantly to 75 BHN.

4.2 Tensile Testing:

The tensile test results of the fabricated composite are presented in tables given below. The data provides clear evidence that the tensile strength of the composite increases with an increase in graphite content in copper. Table 3 and Table 4 shows variation of tensile strength values of the composite under different pressure.

Table 3:Tensile Strength Test Results at 550 MPa

Pressure :550MPa			
Composition	Temperature	Time	Tensile Strength(Mpa)
Copper 98 % graphite 2%	1100 C	1hr20min.	142.22
Copper 95 % graphite 5%	1100 C	1hr20min.	162.10
Copper 90 % graphite 10%	1100 C	1hr20min.	179.23

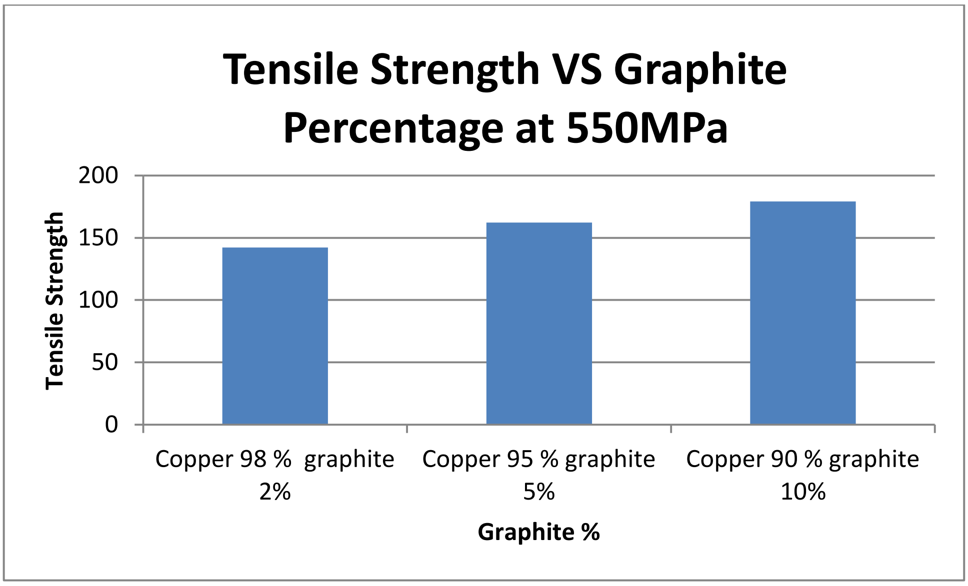

Figure 6: Tensile Strength Vs Graphite percentage for 550MPa

Table 4:Tensile Strength Test Results at 650 MPa

Pressure :650MPa			
Composition	Temperature	Time	Tensile Strength(Mpa)
Copper 98 % graphite 2%	1100 C	1hr20min.	152.23
Copper 95 % graphite 5%	1100 C	1hr20min.	172.55

Copper 90 % graphite 10%	1100 C	1hr20min.	190.11

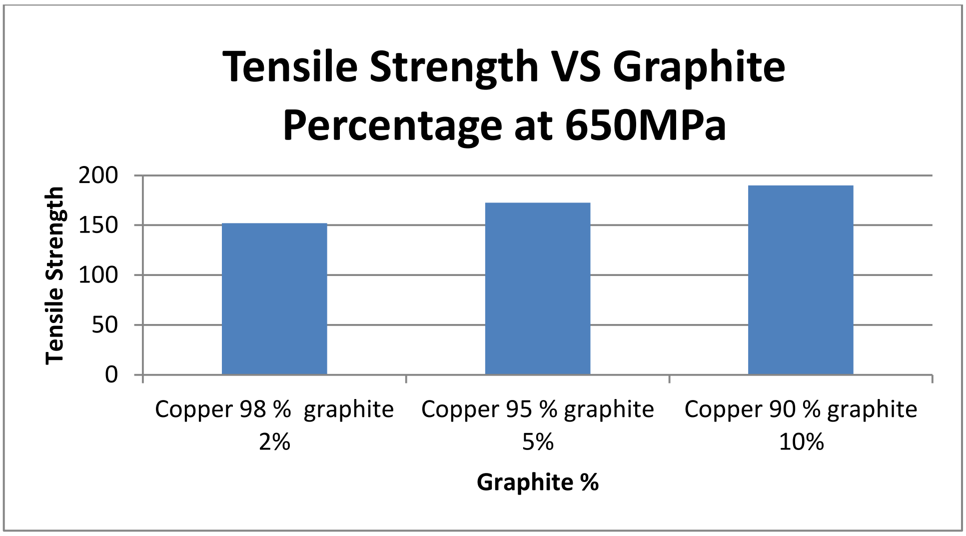

Figure 7: Tensile Strength Vs Graphite percentage for 650 MPa

4.2.1 Results

The provided data presents a comprehensive analysis of the effect of pressure variations on the tensile strength of composite materials comprised of copper and graphite at distinct composition ratios. The experiments were conducted under a constant temperature of 1100 degrees Celsius for a duration of 1 hour and 20 minutes. When subjected to a pressure of 550 MPa, it is evident that the tensile strength of the composite materials exhibits a consistent increase with higher graphite content. For instance, at a composition of 98% copper and 2% graphite, the tensile strength is measured at 142.22 MPa, which increases to 162.10 MPa and 179.23 MPa for compositions of 95% copper - 5% graphite and 90% copper - 10% graphite, respectively. Furthermore, under a higher pressure of 650 MPa, the trend continues, showcasing the reinforcing impact of graphite on tensile strength. At the 98:2 copper-graphite composition, the tensile strength rises to 152.23 MPa, while the composition of 95% copper - 5% graphite demonstrates a tensile strength of 172.55 MPa. Notably, the highest tensile strength among the tested compositions is achieved with the 90% copper - 10% graphite composition, yielding a value of 190.11 MPa. This data underscores the substantial influence of pressure and graphite composition on the tensile strength of copper-graphite composite materials at the specified temperature and duration, providing valuable insights for material engineering and design applications.

4.3 Green and Sintered Density

To investigate the impact of compaction pressure on the initial density of the material, it is necessary to establish a relationship between density and pressure across the entire range of compaction pressures. The initial density, also known as green density, can be determined by comparing the weight to the volume of the copper (Cu) material at corresponding compaction pressures, as described in equation 1. This compaction process occurs within a die and punch assembly, featuring a 20 mm diameter with appropriate tolerances. Density can be computed by measuring the height of the metal plug. As pressure increases, the punch moves linearly within a confined die space, resembling the forward motion of a piston in a piston-cylinder system. The punch's displacement is recorded from the machine's data output at the corresponding load. Given that the die's cross-sectional area is constant and the punch's displacement is known, the volume of the metal powder can be calculated for a given pressure using equation 2. As the metal powder's weight remains relatively constant throughout the compaction process, the green density of the compacted material can be readily calculated using equation 1 for the corresponding pressure.

Green Density (ρg) = Powder Weight (m) / Volume (V) (1)

Volume (V) = $\pi r^2 h$ (2)

Where:

ρg → Green Density

m → Weight of Powder

h → Height of Powder

r → Radius of the Die

V → Volume

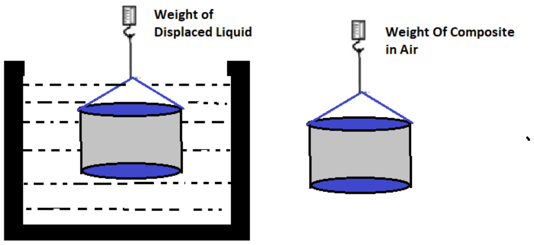

Figure 8 density test

4.3.1. Green and Sintered Density

Figure 9 in the text illustrates the relationship between green density and compaction pressure. As compaction pressure increases, green density also increases. The graph demonstrates that at low compaction pressures below 250 MPa, the green density is quite low. However, it rises as the load is increased, reaching its peak value at 750 MPa.

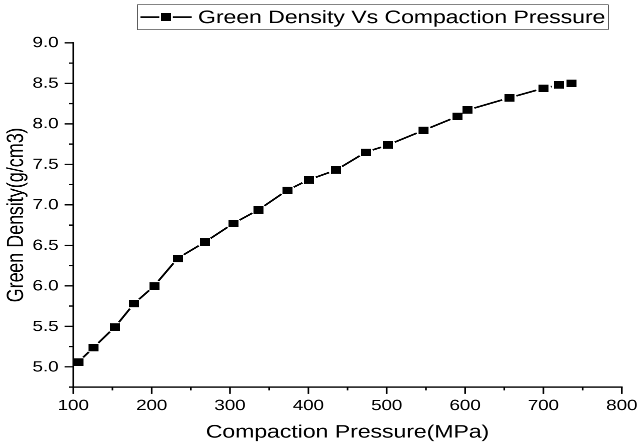

Figure 9: Shows the effect compaction pressures on the Green density of Copper

The sintered density of the specimen is determined using the Archimedes principle. Figure 9 and Figure 10 illustrates the variations in green and sintered density of copper (Cu) under different compaction pressures: 400, 500, 600, 700, and 750 MPa. As the compaction pressure increases, the loose powder particles begin to consolidate. At compaction pressures below 150 MPa, the Cu powder exhibits a low green density of 5.49

g/cm³. This low density is a result of inadequate contact between particles, leading to inefficient packing of the Cu powder. Figure 9 illustrates a rise in green density to 8.02 g/cm³ at a compaction pressure of 600 MPa. This increase can be attributed to significant plastic deformation of Cu particles, which enhances particle-to-particle contact and strengthens the packing within the green compact. The figure shows sintered density of 8.34 g/cm³ at 600 MPa, indicative of a favourable densification parameter. Initially, the green compact is characterized by weak mechanical bonds, resulting in limited particle-to-particle contact and the presence of pores and voids.

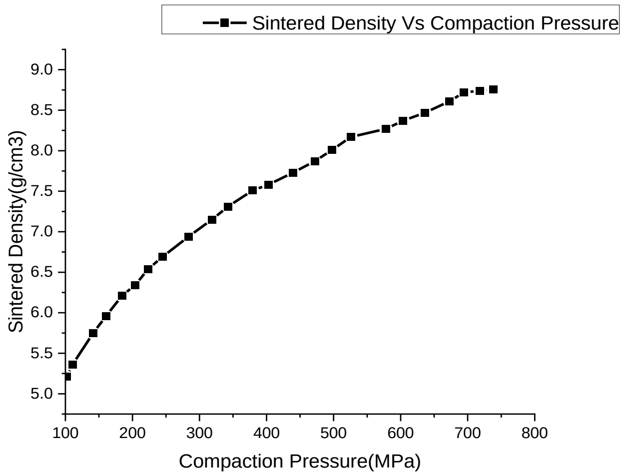

Figure10: Shows the effect compaction pressures on the Sintered density of Copper

However, through sintering at elevated temperatures, these weak mechanical bonds can transform into robust metallic bonds, thereby increasing the sintered density of the Cu material.

Beyond the compaction pressure of 550 MPa, copper particles undergo significant plastic deformation, which contributes to an increase in both green and sintered density. The escalation in compaction pressure induces work hardening, resulting in an expanded contact area between particles. This phenomenon enhances the densification process, thereby positively affecting the green and sintered density of the copper material .

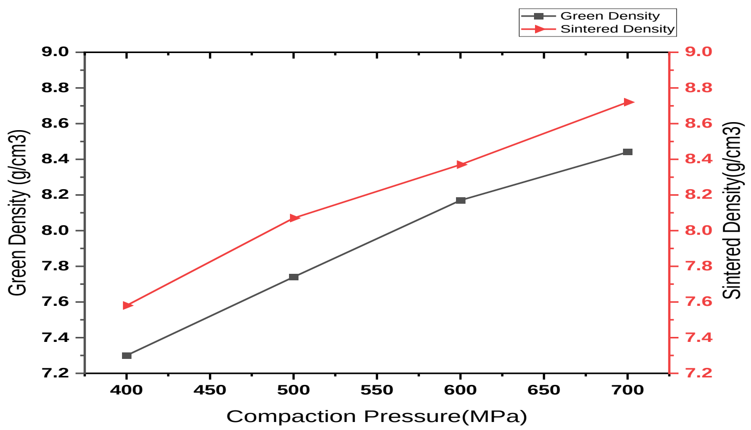

Figure 11: Comparison of Green and Sintered Density

Figure 11 validates that as the compaction pressure rises, both the green and sintered densities follow suit. Additionally, it suggests that the sintered density surpasses the corresponding green density, indicating a more substantial densification in the sintered state.

Table5 : Impact of compaction pressure on copper's densification response

S.No	Compaction Pressure (MPa)	Green density g/cm^3	Sintered density(g/cm^3)	Relative density (%)
1	400	7.31	7.58	80.59
2	500	7.69	8.08	90.17
3	600	8.02	8.34	93.08
4	700	8.24	8.62	96.20
5	750	8.79	8.82	98.48

Table 5 presents the values of green density, sintered density, and densification parameter for various compaction pressures. The findings demonstrate that the highest sintered density value (8.82 g/cm^3) is attained at 750 MPa. Nevertheless, it is evident that the sintered density reaches saturation beyond 690 MPa, signifying the point of maximum plastic deformation for copper particles. Further elevating the compaction pressure triggers excessive work hardening, which distorts particle shapes and subsequently diminishes the mechanical properties of the copper material.

5.0 Conclusions: This paper presents the fabrication of a Cu-Gr metal matrix composite through the casting route and investigates its mechanical properties, including tensile strength and hardness. The findings indicate that both tensile strength and hardness increase with an increase in the weight percentage of graphite. By employing the casting process, we successfully fabricated the Cu-Gr composite and analyzed its mechanical properties. It was observed that as the weight percentage of graphite increased, the tensile strength of the composite also increased. Similarly, the hardness of the composite showed an increasing trend with the increase in the weight percentage of graphite. These results highlight the potential of incorporating graphite into the copper matrix to enhance the tensile strength and hardness of the composite material. The findings from this study contribute to the understanding of the relationship between graphite content and the mechanical properties of Cu-Gr composites, providing valuable insights for future research and potential applications in various industries.

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