

Copper–Graphite Based Powder Metallurgy Product and Its Mechanical Properties

Prachi Gupta^{1,*} Er. Shweta Mishra² Dr. Nitesh Dixit³

¹ M.tech Students, Mechanical Engineering, Dr Ram Manohar Lohia Avadh University UP

² Assistant Professor, Mechanical Engineering, Dr Ram Manohar Lohia Avadh University UP

³ Assistant Professor, Mechanical Engineering, Dr Ram Manohar Lohia Avadh University UP

*Corresponding author. Email: pragupt4@gmail.com

ABSTRACT

Powder metallurgy is one of the most efficient and economical manufacturing processes for producing metal matrix composites with improved physical and mechanical properties. In the present research work, copper–graphite composites were fabricated using the powder metallurgy route in order to study the effect of graphite reinforcement on the mechanical properties of copper. Copper powder was selected as the matrix material due to its excellent thermal and electrical conductivity, while graphite powder was used as reinforcement because of its lubricating properties and low coefficient of friction.

Three different compositions were prepared for experimental investigation. The first specimen consisted of pure copper powder, the second specimen contained copper reinforced with 2% graphite powder, and the third specimen contained copper reinforced with 4% graphite powder. The powders were accurately weighed and mixed thoroughly to ensure homogeneous distribution of graphite particles within the copper matrix. The mixed powders were compacted using a hydraulic press under high pressure to obtain green compacts. These compacts were subsequently sintered in a furnace at elevated temperature to achieve proper bonding between the particles.

The fabricated specimens were subjected to hardness testing and compression testing using a Universal Testing Machine (UTM). The hardness values and compressive strength of the specimens were recorded and analyzed. Experimental results revealed that the addition of graphite reduced both hardness and compressive strength due to the soft and lubricating nature of graphite. However, the graphite reinforcement improved the self-lubricating behavior of the composite and enhanced its suitability for applications involving sliding and frictional contact.

The study demonstrates that copper–graphite composites fabricated through powder metallurgy are suitable for applications such as electrical brushes, bearings, bushings, sliding contacts, and current collectors where lubrication and conductivity are essential.

Keywords: Powder metallurgy, copper composite, graphite reinforcement, hardness test, compression test, UTM, sintering.

CHAPTER 1

INTRODUCTION

Powder metallurgy is a modern manufacturing process in which metallic powders are compacted into desired shapes and then heated below their melting point to produce dense and strong components. The process has gained significant industrial importance because it allows the production of complex shapes with

minimum material wastage. Powder metallurgy is widely used in the automotive, aerospace, electrical, and mechanical industries due to its ability to manufacture components with controlled porosity and improved material properties.

Copper is one of the most important engineering materials used in industries because of its high electrical conductivity, thermal conductivity, corrosion resistance, and ductility. Components made of copper

are extensively used in electrical applications, heat exchangers, and conductive elements. However, pure copper possesses low wear resistance and moderate mechanical strength, which limits its use in applications involving friction and sliding motion.

To overcome these limitations, reinforcement materials are added to copper to produce copper matrix composites. Graphite is one of the most suitable reinforcement materials because of its excellent lubricating properties, thermal stability, and low coefficient of friction. The addition of graphite to copper improves the wear resistance and self-lubricating behavior of the composite. Copper-graphite composites are therefore widely used in electrical brushes, sliding bearings, current collectors, and frictional components.

In this study, copper-graphite composites were prepared using powder metallurgy techniques with varying percentages of graphite reinforcement. Three different samples were fabricated: pure copper, copper reinforced with 2% graphite, and copper reinforced with 4% graphite. The prepared specimens were subjected to hardness testing and compression testing to investigate the effect of graphite content on the mechanical properties of the composites.

CHAPTER 2

OBJECTIVES OF THE STUDY

The present experimental investigation was carried out with the aim of studying the influence of graphite reinforcement on the mechanical behavior of copper matrix composites fabricated through powder metallurgy techniques. The major objectives of this research work are listed below:

1. To fabricate copper-graphite composites using powder metallurgy techniques.
2. To prepare three different specimens consisting of pure copper, copper with 2% graphite, and copper with 4% graphite.
3. To study the powder mixing, compaction, and sintering processes involved in powder metallurgy.

4. To conduct hardness testing on the fabricated specimens and determine the hardness values.
5. To perform compression testing using a Universal Testing Machine (UTM).
6. To analyze the effect of graphite percentage on hardness and compressive strength.
7. To compare the mechanical properties of all fabricated samples.
8. To evaluate the suitability of copper-graphite composites for engineering applications.

CHAPTER 3

LITERATURE REVIEW

Copper-graphite metal matrix composites (Cu-Gr MMCs) manufactured through powder metallurgy have attracted significant attention because of their excellent combination of thermal conductivity, electrical conductivity, self-lubrication, and mechanical strength. Copper provides superior electrical and thermal properties, while graphite acts as a solid lubricant and improves wear resistance. These composites are widely used in electrical contacts, bearings, brushes, and automotive components. Several researchers have investigated the influence of graphite content, sintering conditions, and powder metallurgy parameters on the mechanical and tribological behavior of Cu-Gr composites.

Previous studies reported that powder metallurgy is one of the most suitable methods for fabricating Cu-Gr composites because it allows uniform distribution of graphite particles inside the copper matrix. Srivastava and Rajbhar prepared copper-graphite composites with varying graphite percentages using conventional powder metallurgy and studied their compressive strength, hardness, and wear behavior. Their work showed that increasing graphite percentage reduced compressive strength due to the soft and brittle nature of graphite, although wear resistance improved considerably.

Samal et al. investigated the microstructure and mechanical properties of Cu-graphite composites prepared through blending, compaction, and sintering. Their research highlighted that proper mixing and

controlled sintering improved particle bonding and densification, which enhanced hardness and structural stability.

Liu et al. studied spark plasma sintered copper–graphite composites with different graphite concentrations. They observed that graphite particles restricted grain growth during sintering and improved self-lubrication properties. However, higher graphite percentages caused porosity and reduced hardness because graphite is softer than copper. Their work also demonstrated that hardness decreases gradually with increasing graphite content beyond an optimum value.

Khazal et al. fabricated Cu–graphite MMCs using powder metallurgy and reported that the addition of a small amount of graphite initially improved hardness and compressive strength because of better particle reinforcement. However, excessive graphite reduced strength due to weak interfacial bonding and increased porosity. They also concluded that wear resistance improved significantly with increasing graphite percentage because graphite formed a lubricating layer during sliding.

Mahdi et al. examined the influence of graphite content and milling time on hardness, compressive strength, and wear behavior of Cu–Gr composites. Their results showed that increasing milling time improved hardness and compressive strength due to better particle refinement and distribution. Increasing graphite content reduced compressive strength but improved wear resistance and lowered friction coefficient.

Several review studies also emphasized that copper–graphite composites possess a unique balance of conductivity and tribological properties, making them suitable for engineering applications where both strength and lubrication are required. These studies collectively indicate that graphite percentage plays a major role in determining hardness and compressive behavior of the composite.

Table: Previous Research Work on Copper–Graphite Composites

Author/Researcher	Material & Method	Main Parameters Studied	Important Findings
Rahul Srivastava & Sunita Rajbhar	Cu–Graphite MMC Powder Metallurgy	Graphite content by (2–11%), sintering conditions	Increasing graphite reduced compressive strength but improved wear resistance.
Samal et al.	Cu–Graphite Composite by Conventional PM	Blending, compaction, sintering	Uniform graphite distribution improved bonding and mechanical stability.
Liu et al.	Spark Plasma Sintered Cu–Graphite Composite	Graphite wt.% and hardness	Higher graphite content reduced hardness due to graphite softness and porosity.
Khazal et al.	Cu–Graphite MMC using Powder Metallurgy	Wear, hardness, compressive strength	Small graphite addition improved hardness initially, but excessive graphite lowered strength.
Mahdi et al.	Cu–Graphite Composite	Milling time and graphite content	Longer milling improved hardness; graphite

Author/Researcher	Material & Method	Main Parameters Studied	Important Findings
Nayak et al.	Conventional Sintered Cu–Graphite Composite	Density and hardness	reduced friction and wear. Higher density produced better hardness values in Cu–Gr composites.

Particle size	10-25µm
Purity	99.9%

4.2 Graphite Powder

Graphite powder was used as the reinforcement material. Graphite is soft in nature and acts as a solid lubricant. It improves the tribological properties of the composite and reduces friction during operation.



Figure 2. Graphite Powder 8g and 16 gm

Properties of Graphite

Property	Value
Density	2.2 g/cm ³
Color	Black
Nature	Soft
Lubrication	Excellent
Thermal Stability	High
Electrical Conductivity	Good
Particle size	15µ

CHAPTER 4

MATERIALS USED

4.1 Copper Powder

Copper powder was used as the base matrix material in the present investigation. Copper possesses excellent electrical and thermal conductivity and provides good ductility and corrosion resistance. Fine copper powder with high purity was selected to ensure proper bonding during sintering.



Figure 1. Copper Powder 400g

Properties of Copper

Property	Value
Density	8.96 g/cm ³
Melting Point	1085°C
Color	Reddish Brown
Thermal Conductivity	High
Electrical Conductivity	Excellent
Ductility	Good

CHAPTER 5

EXPERIMENTAL METHODOLOGY

5.1 Powder Composition

Three different compositions were prepared during the experimental work. The first specimen consisted entirely of copper powder and served as the reference sample. The second specimen contained 98% copper

and 2% graphite, while the third specimen contained 96% copper and 4% graphite.



Figure 3. Powder composition with 2% and 4% Graphite

Sample	Copper (%)	Graphite (%)
Sample A	100	0
Sample B	98	2
Sample C	96	4

5.2 Powder Mixing

The powder mixing process was carried out to obtain a homogeneous distribution of copper and graphite particles before compaction. Pure copper powder was used as the base material, while graphite powder was added in varying proportions of 2% and 4% by weight to prepare the composite samples. To improve the binding characteristics and enhance the green strength of the compacted specimens, **Polyethylene Glycol (PEG)** (approx 0.5% of the total weight of the specimen) was used as a binder agent during mixing.

Initially, the required quantities of copper and graphite powders were weighed accurately using a digital weighing balance. A small amount of PEG was then added to the powder mixture to act as a temporary binder and improve particle adhesion during compaction. The powders were thoroughly blended using mechanical/manual mixing for a specific duration to ensure uniform distribution of graphite and PEG throughout the copper matrix.

The addition of PEG helped in reducing powder segregation, improving flowability, and increasing the bonding between particles during the compaction stage. After achieving a uniform mixture, the blended powders were dried if necessary and subsequently used for die compaction to prepare the test specimens.



Figure 4. Graphite Powder mixed with Copper powder and PEG

5.3 Compaction Process

After mixing, the powder blend was transferred into a hardened steel die cavity. A hydraulic press was used to apply high compaction pressure to the powder mixture. During compaction, powder particles rearranged and bonded mechanically to form a green compact.



Figure 5. Compaction process under 15 ton hand press

Compaction Parameters

Parameter	Value
Compaction Pressure	732 MPa
Holding Time	1 minute
Die Material	Hardened Steel

The compacted specimens were carefully removed from the die to avoid damage.



Figure 6. Die made up of forged steel

5.4 Sintering Process

The green compacts were sintered in a muffle furnace at a temperature of 850°C for one hour. Sintering improves bonding between powder particles and increases the strength and density of the specimen.



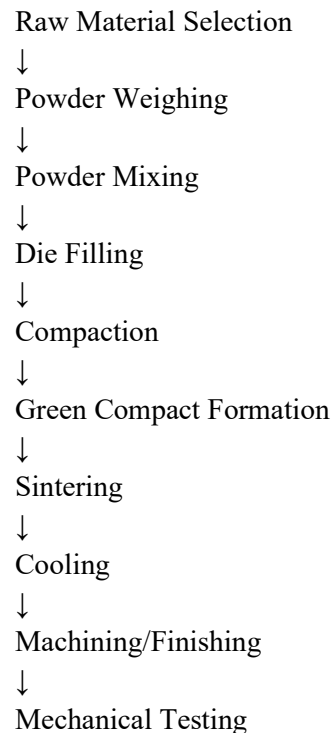
Figure 7. Sintering of specimen in electric furnace muffle type

Sintering Parameters

Parameter	Value
Sintering Temperature	850°C
Sintering Time	1 hour
Cooling Method	Furnace Cooling

After sintering, the specimens were allowed to cool gradually inside the furnace to prevent thermal cracking.

FLOW CHART OF POWDER METALLURGY PROCESS



CHAPTER 6

TESTING PROCEDURES

6.1 Hardness Test

The hardness test was performed using a Brinell Hardness Testing Machine. Hardness testing is used to determine the resistance of a material against indentation or localized plastic deformation.

During the test, the surface of each specimen was cleaned properly before testing. A hardened steel ball indenter was pressed against the specimen surface under a specified load for a fixed duration of time. The diameter of the indentation produced on the specimen surface was measured, and the hardness number was calculated.

The hardness test provides important information regarding the wear resistance and surface strength of the material.

6.2 Compression Test using UTM

Compression testing was carried out using a Universal Testing Machine (UTM). Compression testing helps in determining the ability of a material to withstand compressive loads without failure.

The dimensions of each specimen were measured before testing. The specimen was placed carefully between the compression plates of the UTM. Load was applied gradually until deformation occurred. The maximum load sustained by the specimen was recorded, and compressive strength was calculated.

Compression testing is particularly important for powder metallurgy products because these materials are commonly used in applications where compressive loads are dominant.

CHAPTER 7

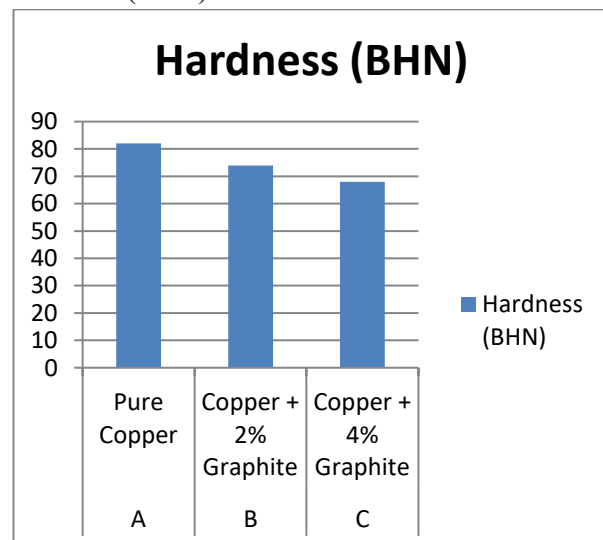
OBSERVATIONS AND READINGS

7.1 Hardness Test Readings

Sample Composition	Hardness (BHN)
A Pure Copper	82
B Copper + 2% Graphite	74
C Copper + 4% Graphite	68

Hardness Comparison Chart

Hardness (BHN)

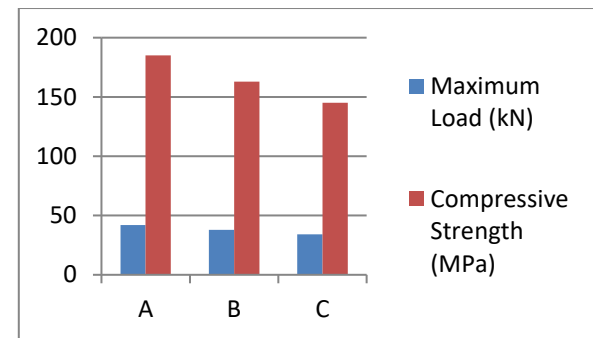


7.2 Compression Test Readings

Sample	Maximum Load (kN)	Load Compressive Strength (MPa)
A	42	185
B	37	163
C	33	145

Compression Strength Comparison Chart

Compressive Strength (MPa)



CHAPTER 8

RESULTS AND DISCUSSION

The experimental investigation showed a clear variation in the mechanical properties of copper with increasing graphite content. The hardness test results indicated that pure copper exhibited the highest hardness value of 82 BHN. When 2% graphite was added, the hardness reduced to 74 BHN, while the specimen containing 4% graphite showed the lowest hardness value of 68 BHN.

The reduction in hardness occurred because graphite is inherently soft in nature and acts as a lubricating phase inside the copper matrix. The graphite particles reduce the resistance of the material against indentation and therefore decrease hardness.

Similarly, the compression test results demonstrated that the compressive strength decreased with increasing graphite content. Pure copper showed the highest compressive strength of 185 MPa. The specimen reinforced with 2% graphite exhibited a compressive strength of 163 MPa, while the specimen containing 4% graphite showed a compressive strength of 145 MPa.

The decrease in compressive strength may be attributed to the reduction in metallic bonding between copper particles and the increase in porosity caused by graphite addition. Since graphite is softer and less dense than copper, the overall load-bearing capability of the composite decreases.

Although graphite reduced hardness and compressive strength, it improved lubrication characteristics and reduced friction. Therefore, copper-graphite composites are highly suitable for tribological applications where self-lubrication is required.

CHAPTER 9

MICROSTRUCTURAL ANALYSIS (THEORETICAL)

The microstructure of pure copper specimens generally shows closely packed copper particles with minimum porosity after sintering. In copper-graphite composites, graphite particles are distributed throughout the copper matrix. The distribution of graphite becomes more visible as graphite content increases.

The specimen containing 2% graphite exhibited relatively uniform graphite distribution with moderate porosity. In the specimen containing 4% graphite, higher graphite concentration and increased porosity were expected. Increased porosity reduces inter-particle bonding and consequently decreases mechanical strength.

A uniform microstructure is essential for achieving good mechanical properties in powder metallurgy composites.

CHAPTER 10

APPLICATIONS OF COPPER–GRAPHITE COMPOSITES

Copper-graphite composites have wide industrial applications due to their excellent combination of electrical conductivity, thermal conductivity, and self-lubricating behavior. These composites are commonly used in electrical brushes for motors and generators

because graphite reduces friction and wear during sliding contact.

They are also used in bearings and bushings where lubrication is required without the use of external lubricants. In addition, copper-graphite materials are used in current collectors, sliding electrical contacts, friction plates, and railway pantograph strips.

Because of their improved wear resistance and conductivity, copper-graphite composites are highly useful in electrical and tribological engineering applications.

CHAPTER 11

ADVANTAGES OF POWDER METALLURGY

Powder metallurgy offers several advantages over conventional manufacturing processes. The process minimizes material wastage because components are manufactured near net shape. Complex shapes can be produced with high dimensional accuracy and minimal machining operations.

Powder metallurgy also allows the fabrication of composite materials such as copper-graphite composites with controlled composition and porosity. The process is economical for mass production and provides good surface finish and repeatability.

Furthermore, powder metallurgy enables the production of materials that are difficult to manufacture through casting or machining processes.

CHAPTER 12

CONCLUSION

Copper-graphite composites were successfully fabricated using powder metallurgy techniques. Three different specimens were prepared consisting of pure copper, copper reinforced with 2% graphite, and copper reinforced with 4% graphite.

Hardness testing and compression testing were performed to evaluate the mechanical properties of the fabricated specimens. Experimental results indicated

that both hardness and compressive strength decreased with increasing graphite percentage. Pure copper showed the highest hardness and compressive strength among all specimens.

The addition of graphite improved the self-lubricating characteristics of the composite and made the material more suitable for frictional and sliding applications. The study confirmed that powder metallurgy is an effective method for producing copper-graphite composites with controlled composition and properties.

The fabricated composites can be effectively used in bearings, electrical brushes, sliding contacts, and tribological components where lubrication and conductivity are important requirements.

FUTURE SCOPE

Future investigations can be carried out to further improve and analyze the properties of copper-graphite composites. Wear testing can be performed to evaluate frictional behavior under sliding conditions. Electrical conductivity testing and thermal conductivity measurements can also be conducted.

Microstructural characterization using Scanning Electron Microscopy (SEM) and X-Ray Diffraction

(XRD) can provide detailed information about particle bonding and phase distribution. Density and porosity measurements may also be included for a more detailed understanding of powder metallurgy products.

Future research may additionally focus on the addition of other reinforcement materials such as silicon carbide, alumina, or tungsten carbide to improve the mechanical properties of copper composites.

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