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FABRICATION AND MECHANICAL CHARACTERIZATION OF COPER-GRAPHITE METAL MATRIX COMPOSITES

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Abstract— **A Copper-graphite metal matrix composition posses the properties of copper likes as excellent thermal electrical conductivity & low strength and graphite likes as solid lubrication, small thermal expansion coefficient. There are some many application likes as bearing material and brushes due to its good thermal & better electrical conductivity, also favorable self-lubricating performances on the bases of strength.**

In copper graphite, low percentage of the graphite is also uses for connectors, plugs & relays, switches, slip-rings & low-voltage dc machine with very high current density.When added a solid lubricant particle into a material, then improve not only anti-friction properties but also improve wear and friction property. In this present investigation, attempts have been made for the fabrication of copper-graphite MMC by conventional & spark plasma sintering technique. Copper-graphite MMC obtained by mixture of 2, 4, 6 &11% volume of graphite powder into copper powder by conventional powder metallurgy route. The metal matrix cold into a closed press & sintering into tubules furnace using vacuum chamber unto 60 minute at 700oC temperature.The MMC are characterised by X-ray diffraction & scanning electron microscopy process. Different mechanical properties likes bulk hardness, density & wear study also conducted.

To study the impression of milling, Cu-2% volume of graphite & also Cu-4% volume of graphite powder mixture are milled for different time period and then it's sintering. Then, its shows increase hardness with milling. The microscopy of Cu-graphite has show the good compatibility & clear interface. So its show that, graphite particle is uniformly (not a randomly) distribution into whole copper matrix.

To study of wear, it's concluded that the wear resistance of metal matrix composite material increased with increased in graphite particle due to its lubricating properties of graphite. It's also show that, wear depth flow decreased with increased in graphite particle. So samples are higher wear resistance. It's also found that compress strength increased with adding of extra graphite up to 6% but compression strength are decreased further addition of graphite due to increased in brittle property in metal matrix composite. Composites are exciting content that are looking for increasing applications in defence, transportation, electricity, electronics, communication, entertainment, sports, aerospace, many other commercial & consumer product.

Index Terms— **Cu-graphite composite, powder metallurgy route, different process of sintering (conventional & spark plasma), scanning electron microscope, X-Ray Diffraction, Milling, wear, compressive strength & hardness.**

I. INTRODUCTION

Recently, new materials have gained significant space in the engineering field. Those materials meet the demand of almost all engineering applications while maintaining tremendous mechanical and physical properties. In the current situation, various scientists and researchers have developed indispensable compatible new engineering materials. Different materials have been linked to each other and provide the desired properties in every part of the world i.e. the development of new materials gives another unique asset and differs from their base materials. Since ancient times, this idea has been effective for humankind. Composite content makes this concept true and contributes to the reinforcement growth properties in the matrix of this material. But, neither matrix nor reinforcement only able to meet the overall material requirement.

Composites are exciting content that are looking for increasing applications in defence, transportation, electricity, electronics, communication, entertainment, sports, aerospace and many other commercial and consumer products. The rapid progress in their characteristics on the last properties of fibre science, matrix materials, processing interface structure, bond and overall quality has occurred in recent years. Composites are hybrids of two or more materials such as reinforced plastic, metal or ceramic. Then the properties of a composite are better than its individual components.

In a typical glass fibre reinforced plastic composite, the fibre is strengthened and hardened by the glass fibre, while the temperature capabilities of the composite are controlled by the plastic matrix. They were also used in car bodies, appliances, boats etc. due to their light weight and ease of production. Complex composite parts are made by injection moulding. Advanced composites are constructed using these polymers with strong fibres such as carbon and Aramid reinforcement.

These composites contain applications in aircraft, automotive industry. The limitations of polymer matrix composites at high temperatures can be recovered using metal matrix composites.

A new generation engineering materials is representing by Metal matrix composites (MMCs). Even though they have been used recently, but due to their useful qualities such as specific strengths, specific rigors, wear resistance, corrosion resistance and elastic modulus etc., they have a great effect. Copper is most commonly used as an industrial and functional area of metal for electrical contact and resistance welding electrodes, thermal and electronic packaging, because it has very good electrical and thermal conductivity. However, when Cu is used as an electrical connection, the mechanical properties lead to the wear of the component. Since graphite has very good electrical conductivity, when it is reinforced in Cu, mechanical properties are greatly improved. Graphite is a solid lubricant that reduces the wearing of Cu-graphite MMC.

A. METAL MATRIX COMPOSITE (MMC):-

Metal matrix composites are more likely engineering material whose high demand is due to nature and their features on the widely applications in the engineering field. Metal matrix composites (MMCs) combine more metal properties like as flexibility and toughness with ceramic properties like as high power and modulus, posse's better strength in shears & compression and higher power in higher temperature capabilities. Many studies have focused on the dimensional changes between the components of the Unidirectional MMC arising from thermal cycling and chemical and interactive stability. There are two relevant bases of their MMC such Matrix and Reinforcement Phase. Due to the mismatch between coefficients of the thermal expansion of matrix and reinforcement, the relationship between the two phases evolves from interstate frictional stress, physical and chemical contact and thermal stress. The underlying inter-situational phenomenon that controls the transmission of thermal, mechanical & electrical properties during the design of an MMC is of great importance.

MATRIX:-

Metallic matrices are most important components for the formation of metallic matrix composites (MMCs). The selection of matrix material depends primarily on temperature, strength, density and cost requirements for desired applications. Other factors, such as flexibility, electrical conductivity, fatigue resistance and fracture toughness depend on the selected metal. One of the most essential factors is the compatibility of the matrix material with reinforcement. In this case, compatibility means that there will be no undesirable chemical reaction in the interface between matrix and reinforcement. Metal matrix composite can be classified into following ways. One classification is the consideration of type and contribution of the reinforcement in particle, fiber, layer and penetration composite materials. Pure metals are generally not considered as matrix materials for MMCs, because the properties of pure metals are not attractive.

REINFORCEMENTS:-

Reinforcement is either in the form of continuous fibers or in the form of discontinuous reinforcements such as whiskers, particulate, chopped fibred or platelets. Metal-matrix composites can be made by combining discontinuous or continuous or both of these reinforcements. The one of most advantage of the discontinuous reinforced composites leads to continuous ones is that they can be prepared using processing techniques, which are usually used for unchanged matrix materials, making them more cost effective. In some extra, discontinuous reinforced composites have good isotropic properties than continuous reinforced composites, which are due to the low aspect ratio and more random orientation of reinforcement.

Better adhesion properties between matrix & fiber are obtained by essential wetting. Better wetting condition is provided by the strong relationship between fiber atoms. As a result of this interaction, there may be an undesirable effect: (1) the particle in the matrix or dissolution of fiber or (2) the creation of unwanted, uncontrolled and brittle compound. The chemical reaction & interaction between the reinforcement & the matrix component determines the characteristics of the overall component, interface adhesion, and significantly affects mechanical properties. The construction of the interface between the reinforcement and the matrix phase has substantial impact on the characteristics and production of metal composite material. The adhesion of both phases is examined due to interaction between them. In during the production of molten matrix with intrusion, wetting becomes important.


(a)

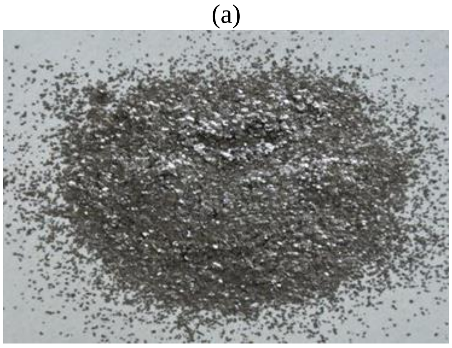
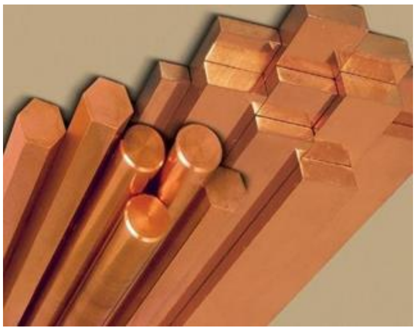

(b)

Fig. 1- Show the image of (a) copper powder & (b) graphite powder.



(a)

(b)

Fig.2-(a) copper rods & (b) copper coil

IMPROVEMENT OF VARIOUS PROPERTIES IN METAL MATRIX COMPOSITE

The tabulated form of various properties and advantages that developed in fabrication of this composite is given below in Table.

Table 1: There are several properties and advantages of the metal matrix composite:

Properties	Better fatigue resistance.
	Good strength-to-density ratios.
	Minimum coefficients of thermal expansion.
	Better elevated temperature properties 1. Higher strength 2. Lower creep rate
	Good stiffness-to-density ratios.
	It provides good wear resistance.
Advantages	Better temperature capability.
	It not moisture absorption.
	Negligible out gassing.
	Better Fire resistance.
	Higher electrical and thermal conductivities
	Good radiation resistance
	Higher transverse stiffness and strength
	Fabric ability of matrix & particulate- reinforced MMCs due to conventional Metal working equipment.

Fig.3- copper-graphite composite rod

Table- 2. Properties of copper are given below in

Melting point	1357k, 1084^{o}C & 1984F
Density	8.95g/cm^3
Thermal conductivity	401W/(m.k)
Shear modulus	48GPa
Vickers hardness	343-369MPa

Table 3:- various strengthening mechanisms of MMC

Strengthening mechanism	Properties
Grain boundary strengthening	There are two important method by which grain boundary that perform as a difficultly to dislocation motion are a) two different grain orientations, b) Discontinuity of slip planes from first grain to other gain. Small grain materials are stronger & harder because more amount of grain boundaries.
Solid solution strengthening	In this method, dislocation of solute atoms motion gives more impact on the frictional resistance &strengthening effect increased by the increasing in solute atoms.
Strain hardening	The material becomes harder & stronger due to plastic deformation. Increased dislocation density due to deformation & cold working.
Precipitation or Age hardening	The fine particles of the new phase precipitate in metal matrix which hardens material by generating difficulty in dislocation motion.

METAL MATRIX COMPOSIT BY POWDER METALLURGY

Powder metallurgy (PM) is a procedure for forming metal parts by heating compacted metal powders too immediately below their melting points. In other words, it is the process of shaping a metal that produces near-pure parts from powder metal.

Powder metallurgy is the procedure of blending sharp/fine powder materials, they are pressed into a definite shape or form (compacting), and then to heat the compressed material in a controlled atmosphere, the material (sintering) is brought to the bond.

There are mainly four basic steps of powder metallurgy:

1. Powder manufacture
2. Powder blending
3. Compacting
4. Sintering

Compacting is usually done at room temperature, and high-temperature processing of the sintering is usually conducted under atmospheric pressure. Alternative secondary processing is often to achieve special qualities or increased precision. The high-precision forming capability of PM generates components with near-net shape, intricate features and good dimensional precision pieces.

FABRICATION OF COPPER-GRAPHITE MMC BY ROUTE OF POWDER METALLURGY

Cu-graphite composites are an example of metal matrix composites. Generally they are the spread of graphite in pure copper matrix. The overall composite we are studying has been produced by the Powder Metallurgical Way. Due to the presence of pure copper, good electrical conduct and due to presence of graphite, they exhibit good lubricant and anti-sealing properties. But there is the problem of bad interfacial bonding between cu-graphite. The properties of cu-graphite composites are special type and quantity of graphite fibers involved in the overall and the orientation of that fiber. We normally, prefer to use less percentage of graphite material in Copper matrix. In fact, the amount should be such as-

- Is the conductivity of pure copper is not very interrupted.
- Effective lubrication properties of graphite are obtained in the final fusion because most of their usage comes in sliding contact (electricity).
- Cu-graphite composites also have high resistance to thermal shock.
- It change the all properties of pure metal in process of composition

II. LITERATURE REVIEW:

There are so many researchers have fabricated Cu-graphite MMC by path of powder metallurgy. A brief of the literatures available is presented here.

- Simon Dorfman and David Fuxb (1996)(14) studied the stability of copper separation at the Cu- carbon metal-matrix composite interface under alloy. The stability of the interface in MMCs is related to the conditions of isolation of metal alloy in metal -fiber interfaces.
- S.F. Mustafa et al. (2002)(15) studied friction and wear of Cu-graphite composites produce by Cu-coated and non-coated -graphite powder. They have shown that composites produce by Cu-coated and uncoated graphite have minimum wear rates and friction coefficients compared to pure copper fabric, which can be attributed to the fact that the slip of wear samples on the surface serves as a graphite layer, solid lubricant.
- Hajun Zhao et al. (2006)(16) examined the corrosion and wear behavior of Cu- graphite composites prepared by electroforming. Copper-graphite composites were prepared by electroforming technology in the acidic-sulphate bath with graphite particles in suspension.
- Jaroslav Kovacik et al. (2007)(5) check the impact of composite on the friction coefficient of Cu-graphite composites in the range of 1-40 percentage of volume of Graphite on constant load To Determine Critical graphite material on which the coefficient of friction of the composite of the whole is almost free and stable.
- S. Arvindan & k. rajkumar (2009)(9) study about the microwave sintering of Cu- graphite composites. Coarser microstructure with large porous is achieved by this traditional sintering process which reduces power, as well as resistance. In microwave sintering, heat is produced internally within the material and the sample becomes a source of heat. Direct distribution of energy to the material through molecular contact results in volumetric heating.
- H. Yang et al. (2010)(20) studied the effect of graphite / pitch coke on mechanical properties of copper-carbon composites. The combination of pitch coke in the matrix can improve the strength of the correlation between carbon particles and phenolic resin.
- Dash. K., Ray. B.C. And Chara. D. (2011)(8) converged the copper-alumina metal matrix into conventional and spark plasma sintering and then described the symptom. The composite cups produced by the SPS route do not show any peak of oxide because the vacuum was sintered in the atmosphere.

III. SAMPLE PREPARATION

Samples of copper-graphite MMC is made by path of conventional powder metallurgy such as blending, compaction & finally sintering, etc. Formation of composite was made by two sintering method (spark plasma & conventional sintering) to study the various mechanical & characteristic properties of the composite. In this process, we take pure copper powder & graphite powder mixture of 100 gram mixed with the volume fraction of graphite such as 2%, 4%, 6% & 11% respectively. Then they are blending together properly used by mortar & pestle for 50-60 minute. To easily that the check perfect distribution of graphite particle in over all copper matrix. The samples are cold compacted by applying load of 600MPa for 60 minute in a diameter of 30 mm.

CONVENTIONAL SINTERING

To ensure uniform distribution of the graphite in copper, the blade and mortar were blended. The precision of the initial material Cu and graphite powder was 99% and 100% pure. Copper powder was mixed with graphite to get ready the mixed powder mixture of 2, 4, 6 and 11 volumes % Of Graphite The mixed powder mixture was then cooled by the uni- axial press and then was used to sintering in the tubular furnace using noble gas (neon gas). Here various sintering parameters like as sintering time, compaction pressure and sintering temperature, etc.

Table 5: various sintering parameter for conventional sintering,

Sintering Temperature	800, 750 & 700^{0}C
Compaction pressure	650, 700 & 800MPa
Holding time	1.2h, 1h & 0.8h
Atmosphere	helium
Heating rate	5 C/minute
Relaxation time in compaction	2minutes

IV. TO STUDY OF THE MECHANICAL PROPERTIES:-

A. MEASUREMENT OF HARDNESS:-

Hardness (Vickers hardness) values of all specimens are calculated by micro hardness tester LM248AT under 3N load and 0.1hour residence time. At least 3 measurements were taken for equivalent samples for each sample.

B. STUDY OF WEAR:-

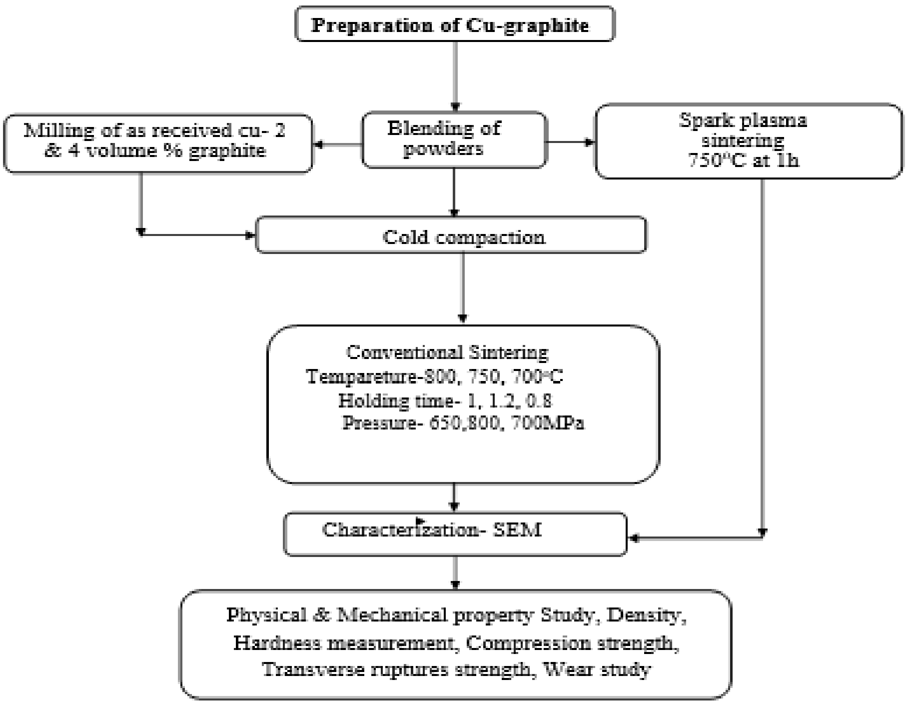
Ball-on-plate type-ware testing instrument (model: DUCOM TR-208-M1) used to harder steel ball indenters to study the behaviour of the overall sample wear. The sliding wear of the specimens was assessed. For a period of 15 minutes, 2 mm diameter ball, 20 rpm with 25N applied load of rotational motion was used but testing. There is an idea about the wearing mechanism under wear samples SEM was observed.

C. MEASREMENT OF TRANSVERSE STRENGTH:-

According to ASTM B 312, transversal strength of samples was obtained by making standard transverse breakage strength test block at 700oC sintering for 1 hour, the TRS test was done on Instron-1195. Seeing the fracture surface on the SEM was a failed analysis of composites.

D. STUDY OF COMPRESION TEST:-

Compression test samples were prepared by cold compaction at 7000C for 1 hour maintaining sintering. Compression testing was done at SATEC, 600KN INSTRON. Maximum compressed power, maximum % elongation and yield power also measured.



E. MECHANICAL PROPERTIES:-

1) HARDNESS MEASUREMENT:-

a) EFFECT OF TIME:-

In given fig. 11 & shows the hardness graphs of copper-graphite MMC sintering at 7500C for 0.8h, 1h and 1.2h. It can also observe the maximum hardness value at 1h of sintering. So, the result of 0.8h for sintering timing is under sintering & also the result of 1.2h for sintering timing is over sintering. So maximum density obtained by also for 1h sintering of samples.

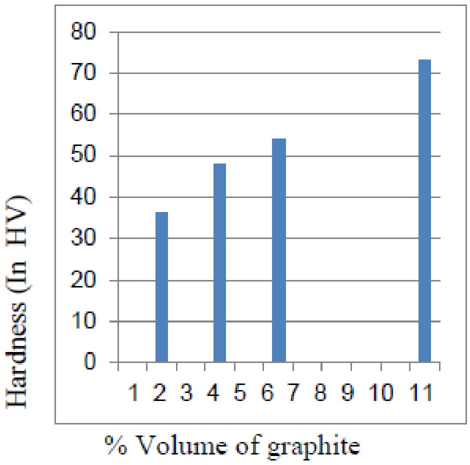


Fig.11(a)

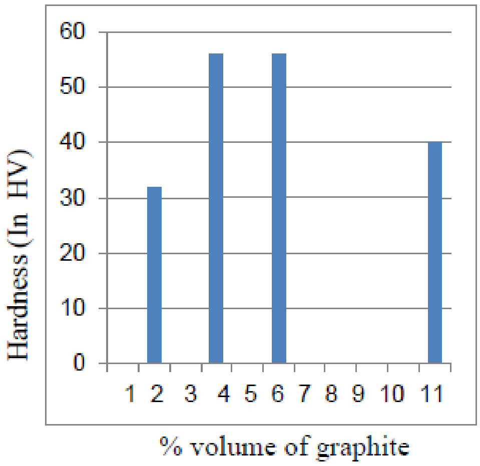


fig.11(b)

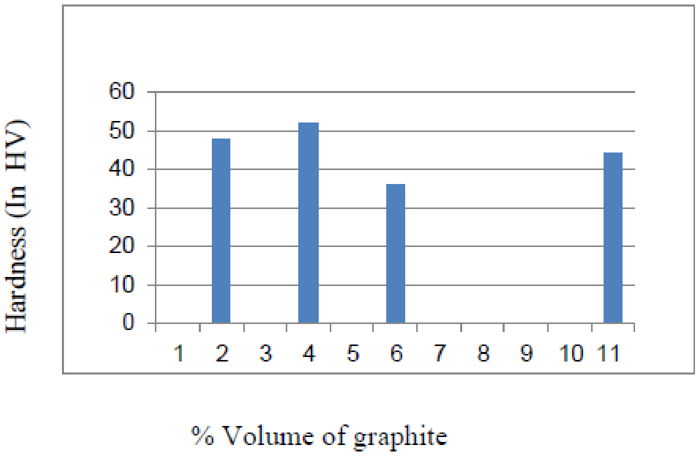
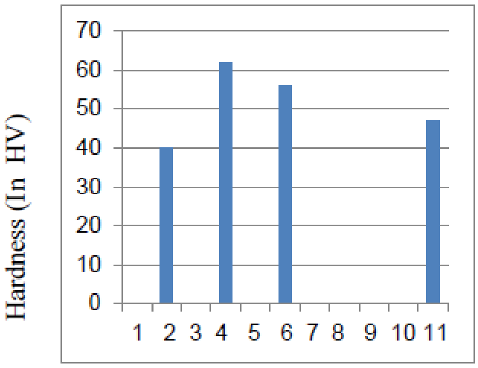


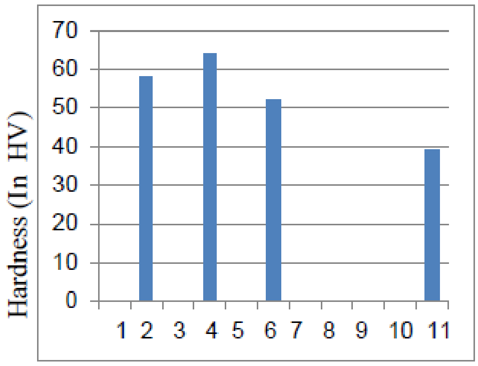
Fig11.(c)

b) EFECT OF PRESSURE:-

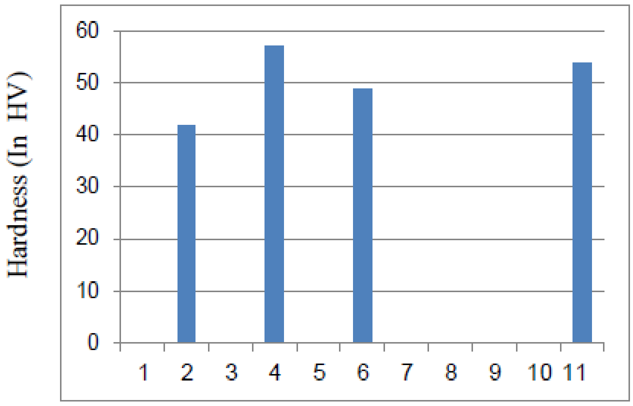
In fig. 12 shows the effect of compression pressure on the hardness of the produced composite. From the graph, it is understand that the maximum hardness is achieved under the compression pressure of 700MPa, which corresponds to the density value. So that's the optimum pressure. However, if the pressure grows or falls, then it is observed that the hardness decreases, indicating that the response to the reduced treatment of MMCS is cold on 600 and 700 MPA. Hardness values are also consistent with the density values on these two compression pressures.



% Volume of graphite
Fig.12 (a)



% volume of graphite
fig.12 (b)



% volume of graphite
Fig.12(c)

c) EFFECT OF TEMPURETURE:-

Variation in hardness with graphite reinforcement at various temperatures is shown in fig. 13. The general stiffness tendency is that due to the soft nature of the graphite this graph decreases with increase in percentage. However, there are few hardness data that are uneven and scattered. The maximum Vickers hardness value is obtained for approximately 70 at Cu-2% volume of Graphite reinforces traditional sintering composites However, due to heat and pressure during sintering, applications get high hardness value of about 100 for Spark Plasma Sintering Composites. Another reason for maximum hardness is sharp grain size in case of SPS. Strengthening the dispersion and refining grain size is the main strengthening mechanism that is responsible for increasing the hardness of Copper-graphite composites.

d) EFFECT OF MILLING:-

Fig.14. shows the effect of the milling on Copper-graphite composite. It is clear that hardness of the composite increase with increase the milling timing. After the milling process done, as results of composite such as fine & tightly bound, increase particle to particle closeness with increase in sharpness & fineness due to milled particle surface area increased. When we improve the bonding between Cu-graphite then increased the hardness value.

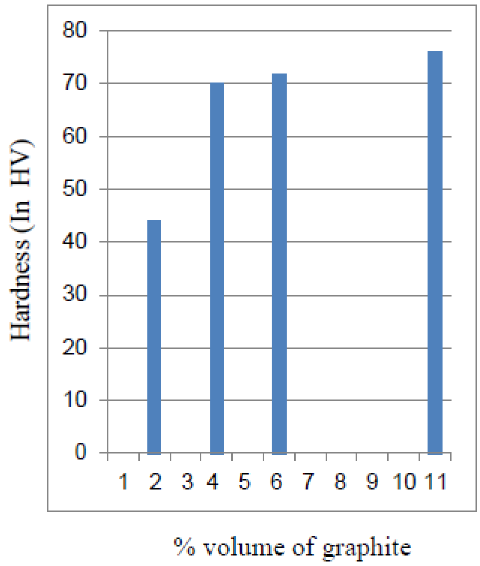


Fig14.(a)

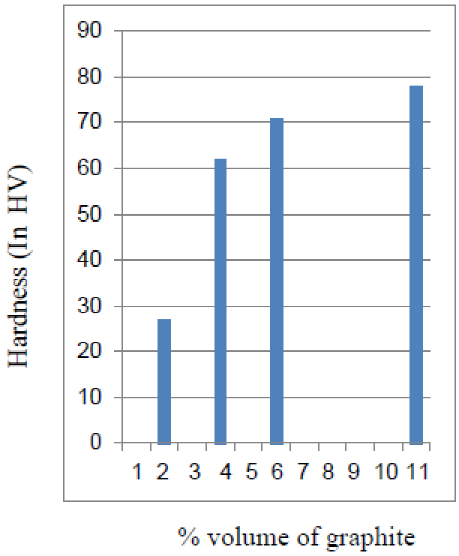


fig.14(b)

The above fig. 14 shows the variation of hardness such as (a) copper-2% volume of graphite & (b) copper-4% volume of graphite composite through milling.

F. STUDY OF TRANSVERSE RUPTURE STRENGTH:-

The modulus of rupture strength represents the maximum stress experienced within the material at its moment of failure. It's also known as bend strength of material.

The bend strength graph of copper-graphite metal matrix composite with volume of graphite are 2%, 4%, 6% & 11% respectively manufacture by conventional sintering for 1hour shows by graphical representation. In graph it is clear that the maximum bending strength & minimum elastic modulus in copper with 4%voume of graphite in the composite. When volume of graphite percentage is decrease then increase the maximum elastic modulus of the material are achieved. Brittleness of the material increased due the increased the graphite percentages.

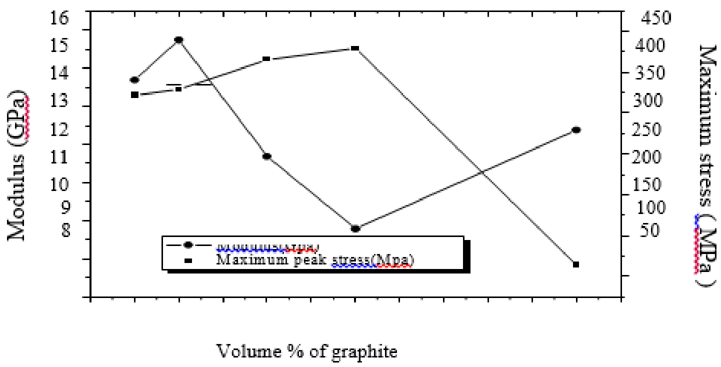


Fig.15

In fig. 15 plots the elastic modulus & flexural strength of copper-graphite MMC.

G. STUDY OF COMPRESSIVE STRENGTH:-

Fig. 16 shows the compressive strength of the composite material. It is clear that the maximum compressive strength is observed in Cu-2% % Cu-4% of volume of graphite composite material. If the graphite percentages in the composite are increase then immediate decreased of compressive strength due to increase the brittleness nature of material. It also observes that the definite amount of strain, compressive strengths of Cu-graphite matrix higher than the pure copper metal.

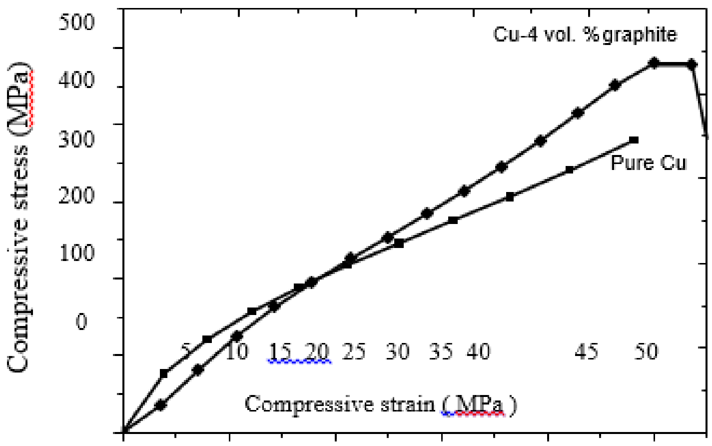


Fig.16

Fig. 16 represents the compressive stress & compressive strain of composite material of copper-4 % volume of graphite.

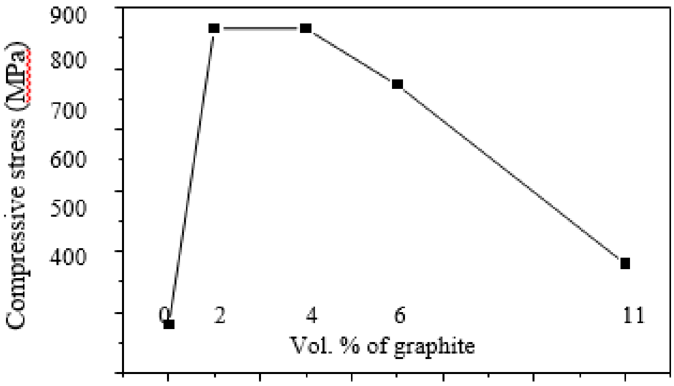


Fig.17

Fig. 17 represents the graphs between compressive stresses of copper- vol. % graphite.

V. CONCLUSIONS

There are so many conclusion can be obtained by the present investigation-

1. The Cu-graphite MMC was successfully made by both SPS as well as conventional sintering.
2. SEM analysis provides the better bonding between graphite reinforcement & copper matrix.
3. In conventional sintering process the copper & graphite particle with some copper oxide are observed in XRD but in the SPS no oxide takes place due to vacuum atmosphere.
4. The maximum sintering time, pressure & temperature are 1hour, 750MPa & 700oC in conventional sintering.
5. A very fine & homogenously distribution of graphite into whole matrix due to milling method.
6. When volume of graphite percentage is decrease then increase the maximum elastic modulus of the material are achieved.
7. The graphite (after the 4 %) percentages in the composite are increase then immediate decreased of compressive strength due to increase the brittleness nature of material.
8. Cu-4% volume of graphite by spark plasma sintering is optimum wear resistance.
9. Increased the wear resistance was seen by maximum percentage volume of graphite by SPS samples.
10. SPS gives is better & advanced technology as compared o the conventional sintering.

VI. SCOPE FOR FUTURE PROJECT WORK:-

1. Improvement of interfacial bonding of Cu-graphite by pitch coke is added.
2. It helps the study of coefficient of friction & effect of load.
3. It helps to understanding the wear rate, wear volume & wear mechanisms.

4. It also measures the electrical conductivity of copper-graphite MMC.
5. Copper-graphite MMC can also be made by microwave sintering.
6. It help to understanding of better mixing method are used during the composition
7. It helps to improve the overall performance of composite material.
8. It helps to better understanding for the effect of temperature on the composite.
9. It helps to achieve the better composite material & material made of copper-graphite.

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