FABRICATION OF COPPER GRAPHITE COMPOSITE MATERIAL & ITS MECHANICAL PROPERTIES

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ABSTRACT

Copper–graphite metal matrix composites possess the properties of copper, i.e. excellent thermal and electrical conductivities, and properties of graphite, i.e. solid lubricating and small thermal expansion coefficient. They are widely used as brushes, and bearing materials because of the above properties. Copper-graphite with low percentages of graphite is also used for slip rings, switches, relays, connectors, plugs and low voltage DC machines with very high current densities. Copper's malleability, machinability and conductivity have made it a longtime favorite metal of manufacturers and engineers.

Keywords: Metal-Matrix Composites; Copper-Graphite Composites; casting; Scanning Electron Microscope; Hardness ,tensile strength

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1- INTRODUCTION

Recently new materials have taken the important position in engineering field. Those materials fulfil the demand of almost all engineering applications maintaining tremendous mechanical and physical properties[45]. In present situation, various scientists and researchers have developed the unavoidable compatible new engineering materials. Various materials have been combined with each other and give intended properties in each and every part of the world i.e. the development of new materials give another unique property and are different from their base materials. From the ancient age, this idea has been effective for mankind. Composite materials make this concept true and reinforcement in a matrix of this material contributes enhancement properties[67]. But, neither matrix nor reinforcement alone but only composite material can be able to fulfil the requirement. Composites are exciting materials which find increasing applications in aerospace, defence, transportation, communication, power, electronics, recreation, sporting, and numerous other commercial and consumer products. Rapid advancement in the science of the fibres, matrix materials, processing interface structure, bonding and their characteristics on the final properties of the composite have taken place in the recent years. Composites are hybrids of two or more materials such as reinforced plastics, metals or ceramics[18]. Then the properties of a composite are superior to those of its individual constituents. In a typical glass fibre reinforced plastic composite, the strength and stiffness are provided by the glass fibres while the temperature capabilities of the composite are governed by plastic matrix. They were also used in car bodies, appliances, boats etc. because of their light weight and ease of production. Complex composite parts are made by injection moulding. Advanced composites are manufactured by using these polymers with reinforcements of stronger fibres such as carbon and Aramid. These composite have applications in aircraft, automotive industry. The limitations of the polymer matrix composites at elevated temperature can be recovered by using metal matrix composites.

1.1 METAL-MATRIX COMPOSITES (MMC)

Advanced composites based on metallic matrices have a somewhat recent history, yet the opportunities look very promising. The first MMCs were developed in the 1970s for highperformance applications using continuous fibers and whiskers for reinforcement [1].

Metal matrix composites (MMCs) combine both metallic properties (ductility and toughness) with ceramic properties (high strength and modulus) possess greater strength in shear and compression and high service temperature capabilities. The extensive use of MMCs in aerospace, automotive industries and in structural applications has increased over past 20 years due to the availability of inexpensive reinforcements and cost effective processing routes which give rise to reproducible properties [2]. The frontier zone between the matrix and reinforcement phase (interface or interphase) is an essential part of MMC. Bonding between the two phases develops from interfacial frictional stress, physical and chemical interaction and thermal stresses due to mismatch in the coefficients of thermal expansion of the matrix and reinforcement. During the design of a MMC the underlying interfacial phenomenon which governs the transmission of thermal, electrical and mechanical properties is of utmost importance [3].

The recent recognition that addition of ceramic reinforcements enables manipulation of physical as well as mechanical properties of MMCs has led to increasingly widespread use of these materials in electronic packaging and thermal-management applications. Recent market forecasts suggest the prospect for accelerating growth of MMC use as the materials are more widely understood and are cheap, suggesting a bright future for this class of materials.

Research and development on MMCs have increased considerably in the last 10 years due to their improved modulus, strength, wear resistance, thermal resistance and fatigue resistance and improved consistency in properties and performance in general compared to the unreinforced matrix alloys. The reinforcements are added extrinsically or formed internally by chemical reaction. The properties of MMCs depend on the properties of matrix material, reinforcements, and the matrixreinforcement interface [4].

1.2 COPPER-GRAPHITE COMPOSITE

Copper-Graphite composites are an example of metal matrix composites. Basically they are a dispersion of graphite in pure copper matrix. The composite that we will be studying about has been fabricated by Casting.They exhibit excellent lubricating and anti-seizing properties due to the presence of graphite and good electrical conductivity due to the pure copper. But there is also the problem of poor interfacial bonding between copper and graphite. The properties of the copper-graphite composites are a function of the type and amount of graphite fiber incorporated in the composite[28]Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster and clay. Raw castings often contain irregularities caused by seams and imperfections in the molds,[3] as well as access ports for pouring material into the molds.[4] The process of cutting, grinding, shaving or sanding away these unwanted bits is called "fettling".[5][6] In modern times robotic processes have been developed to perform some of the more repetitive parts of the fettling process, but historically fettlers carried out this arduous work manually, and often in conditions dangerous to their health.

Fettling can add significantly to the cost of the resulting product, and designers of molds seek to minimize it through the shape of the mold, the material being cast, and sometimes by including decorative elements.

Casting process simulation uses numerical methods to calculate cast component quality considering mold filling, solidification and cooling, and provides a quantitative prediction of casting mechanical properties, thermal stresses and distortion. Simulation accurately describes a cast component's quality up-front before production starts. The casting rigging can be designed with respect to the required component properties. This has benefits beyond a reduction in pre-production sampling, as the precise layout of the complete casting system also leads to energy, material, and tooling savings.

The software supports the user in component design, the determination of melting practice and casting methoding through to pattern and mold making, heat treatment, and finishing. This saves costs along the entire casting manufacturing route.

Casting process simulation was initially developed at universities starting from the early '70s, mainly in Europe and in the U.S., and is regarded as the most important innovation in casting technology over the last 50 years. Since the late '80s, commercial programs are available which make it possible for foundries to gain new insight into what is happening inside the mold or die during the casting process.

In metalworking, metal is heated until it becomes liquid and is then poured into a mold. The mold is a hollow cavity that includes the desired shape, but the mold also includes runners and risers that enable the metal to fill the mold. The mold and the metal are then cooled until the metal solidifies. The solidified part (the casting) is then recovered from the mold. Subsequent operations remove excess material caused by the casting process (such as the runners and risers).

2-LITERATURE REVIEW

In order to gain background knowledge on the previous work done in similar fields, various papers and journals were studied. The findings of some of the journals are enumerated below:

K. Rajkumar and S. Aravindan (2009) [2] studied microwave sintering of copper–graphite composites. Coarser microstructure with larger porosity is obtained by this conventional sintering process which decreases the strength, wear resistance as well. In microwave sintering, heat is generated internally within the material and the sample becomes the source of heat. The direct delivery of energy to the material through the molecular interaction, results in volumetric heating. Microwave sintering offers many advantages such as faster heating rate, lower sintering temperature, enhanced densification, smaller average grain size and an apparent reduction in activation energy in sintering. The finer microstructure with relatively smaller and round pores, resulted due to microwave heating, enhances the performance of the composite.

H. Yang et al. (2010) [8] studied the effect of the ratio of graphite/pitch coke on the mechanical and tribological properties of copper–carbon composites. Addition of pitch coke in the matrix can much improve the interfacial bonding strength between carbon particles and phenolic resin (binder). The bending strength and micro-hardness of the copper–carbon composites increased with increase in the content of pitch coke and reached a maximum. The friction coefficient of copper–carbon composites increased significantly with increasing the content of pitch coke. The wear rate of composites initially decreased as the content of pitch coke increased and obtained a minimum and then ascended.

J.F. Silvain et al. (1993) [9] studied the elastic moduli, thermal expansion and microstructure of copper-matrix composite reinforced by continuous graphite fibers. Coppermatrix composites reinforced by continuous graphite fibers (Cg) were processed by hotpressing layers of metallic pre-pregs, each fiber within the yarns having previously been coated with copper by electroplating. Composites processed according to this procedure were evaluated by tensile testing and by determination of thermal expansion coefficients and chemical and structural characterizations of the graphite/copper interface. An electroplate coating followed by diffusion bonding was found to be a successful and original way to produce fully dense Cg/Cu laminated composites.
Chromium can be added to improve the chemical bonding.
Wenlin Maa and Jinjun Lu (2010) [10] studied the effect of surface texture on transfer layer formation and tribological behavior of copper–graphite composite. Metal matrix composites (MMC) containing graphite particulates usually have reduced friction under dry sliding, which is closely dependent on the formation of continuous transfer layer on the sliding surface of counterpart. Friction and wear tests were conducted under low and high load conditions and various sliding distances to evaluate the validity of the textures and their effect on the formation of the transfer layer of Cu/Gr composite.

Haijun Zhao et al. (2006) [11] investigated the wear and corrosion behavior of Cu–graphite composites prepared by electroforming. Cu–graphite composites were prepared by electroforming technique in an acidic sulfate bath with graphite particles in suspension. The interfacial bonding between metal matrix and particles is much strengthened and porosity is eliminated in the composites in case of electroforming. Corrosion takes place at grain boundaries rather than the interface between graphite particles and Copper matrix. Wear resistance is improved after the incorporation of graphite particles into copper matrix.

Simon Dorfman & David Fuksb (1996) [12] studied the stability of copper segregations on Copper/Carbon Metal-matrix Composite interfaces under alloying. Stability of interfaces in MMCs is linked to the conditions of the formation of segregations of the metal alloy at the metal/fiber interface. It is shown that alloying of the matrix, substituting copper in the interstitial metalmetalloid solid solution, changes the value of the mixing energy and influences the volume fraction of twodimensional segregations of copper. We expect that the wettability of carbon fibers by the pure copper matrix may be improved by the addition of small amounts of zirconium or iron to the matrix.

Dash, K., Ray, B.C. and Chaira, D. (2011) [13] synthesized copper–alumina metal matrix composite by conventional and spark plasma sintering and then performed characterization. The composites fabricated by SPS route do not show any peak of cuprous oxide as sintering was carried out in vacuum atmosphere. Presence of cuprous oxides was observed in the Cu/Al2O3 interface in the EDS of the sample fabricated by conventional sintering in hydrogen, nitrogen and argon atmosphere. The density of composites sintered by spark plasma sintering technique is quite high as compared to the other techniques. The average micro hardness value for 5% alumina reinforced Cu–Al2O3 composite is 67.8 HV for conventionally sintered samples, whereas in the present study, nano-composites fabricated by SPS method produce an average of 124.5 HV for the same composition.

S.F. Moustafa et al. (2002) [14, 15] studied the friction and wear of copper– graphite composites made with Cucoated and uncoated graphite powders. They have shown that composites made by Cu-coated and uncoated graphite have lower wear rates and friction coefficients than those made from pure copper which can be attributed to the fact that the smeared graphite layer present at the sliding surface of the wear sample acts as a solid lubricant.

Jaroslav Kovacik et al. (2007) [16] investigated the effect of composition on the friction coefficient of copper–graphite composites in the range of 0–50 vol. % of graphite at constant load to determine critical graphite content above which the coefficient of friction of composite remains almost composition independent and constant. They investigated that up to critical concentration threshold of graphite the decrease of the coefficient of friction is governed by the synergic effect of graphite phase sliding properties and its spatial distribution within composite microstructure. Better homogeneity of graphite phase spatial distribution leads to lower coefficient of friction of composite. Then the coefficient of friction of composites becomes independent on the composition and corresponds probably to the dynamic coefficient of friction of used graphite material whereas the wear rate decreases.

C G Kang et al. [17] in their paper have described the one-dimensional heat-transfer analysis during centrifugal casting of aluminum alloy and copper base metal matrix composites containing Al2O3, SiCp, and graphite particles. The model of the particle segregation has been calculated by varying the volume fraction during centrifugal casting, and a finite difference technique has been adopted. The results indicated the thickness of the region in which dispersed particles are segregated due to the centrifugal force is strongly influenced by the speed of rotation of the mold, the solidification time, and the density difference between the base alloy and the reinforcement. This study also indicated the presence of particles increases the solidification time of the casting.

J. Zhang et al. [18] have investigated the effect of Silicon Carbide and Graphite particulates on the resultant damping behavior of 6061 A1 metal matrix composites to develop a high damping material. The microstructural analysis has been performed using scanning electron microscopy, optical microscopy and image analysis. It was shown that the damping capacity of Al 6061 could be significantly improved by the addition of either Silicon Carbide or graphite particulates through spray deposition processing.

M. L. Ted Guo et al. [19] in their research paper have studied the tribological behavior of selflubricated Aluminium/Silicon Carbide/Graphite hybrid composites with various amount of graphite addition synthesized by the semi-solid powder densification (SSPD) method. It has been found that the seizure phenomenon which occurred with a monolithic aluminium alloy did not occur with the hybrid composites. The amount of graphite released on the wear surface increased as the graphite content increased, which reduced the friction coefficient. Graphite released from the composites bonded onto the wear surfaces of the counter faces.

R.F. Cooper et al. [20] in their study have presented Silicon Carbide continuous fibre-reinforced glass and glass-ceramic matrix composites showing high strength and fracture toughness using thin-foil transmission electron microscopy and scanning transmission electron microscopy (AEM). The exceptional mechanical behaviour of these materials is directly correlated with the formation of a cryptocrystalline carbon (graphite) reaction-layer interface between the fibers and the matrix. AEM results are used to comment upon a possible mechanism for the hightemperature embrittlement behavior noted for these materials when they undergo rupture in an aerobic environment.

L.C. Davis et al. [21] in their research thesis have explained the thermal conductivity of metal matrix composites, which are potential electronic packaging materials, has been calculated using effective medium theory and finite element techniques. It has been found that Silicon Carbide particles in Al must have radii in excess of 10 μm to obtain the full benefit of the ceramic phase on the thermal conductivity. Comparison of the effective medium theory results to finite element calculations for axisymmetric unit cell models in three dimensions and to simulation results on disordered arrays of particles in two dimensions confirms the validity of the theory.

SCem Okumus, Sredar Aslan et al. [22] in their paper have studied on Thermal Expansion and Thermal Conductivity behaviours of Al/Si/SiC hybrid composites. It clearly highlights that Aluminium-Silicon based hybrid composites reinforced with silicon carbide and graphite particles has been prepared by liquid phase particle mixing and squeeze casting. The thermal expansion and thermal conductivity behaviours of hybrid composites with various graphite contents (5.0; 7.5; 10 wt.%) and different silicon carbide particle sizes (45 μm and 53 μm) has been investigated. Results indicated that increasing the graphite content improved the dimensional stability, and there was no obvious variation between the thermal expansion behaviour of the 45 μm and the 53 μm silicon carbide reinforced composites.

Na Chen, Zhang et al. [23] have reviewed on metal matrix composites with high thermal conductivity for thermal management applications, it emphasizes that the latest advances in manufacturing process, thermal properties and brazing technology of SiC/metal, carbon/metal and diamond/metal composites has been presented. Key factors controlling the thermo-physical properties were discussed in detail. The problems involved in the fabrication and the brazing of these composites were elucidated and the main focus was put on the discussion of the methods to overcome these difficulties. This review shows that the combination of pressure-less infiltration and powder injection molding offers the benefits to produce near-net shape composites.

S.F. Moustafa et al.[24] suggested that the Cu matrix Ni coated reinforced composites have higher relative density and lower porosity content than the uncoated composites, due to the good adhesion between the reinforcements and the Cu-matrix. Yield and compression strengths of coated reinforcement powders containing composites are superior to those of uncoated ones .

D. H. He et al.[25] explains that the layer transfer function of CGCMs (Carbon Composite Materials) can reduce wear and provide protection to contact wires and are self-lubricating materials which also exhibit a special electrical conduction mechanism .

S.F. Moustafa et al.[26] pointed that both Cu-coated and uncoated graphite composites exhibit the same wear mechanisms, namely, oxidation induced delamination, high strained delamination, and sub-surface delamination .

V.V. Rao et al.[27] showed that thermal contact conductance increases, as a function of contact pressure and it is a weak function of mean interface temperature in case of Al2O3/Al–AIN MMC .

X.C. Ma et al.[28] proposed that the wear loss increased with increasing normal stress and electrical current. Adhesive wear, abrasive wear and electrical erosion wear are the dominant wear mechanisms during the electrical sliding wear processes .
K. H. W. Seah et al.[29] reported that the increase in compressive strength is due to graphite particle acting as barriers to the dislocations in the microstructure and with increasing the graphite content within the ZA-27 matrix results in significant increases in the ductility, UTS, compressive
strength and Young’s modulus, but a decrease in the hardness .

S.F. Moustafa et al.[30] gives the idea about the densification of compacts fabricated from coated powders is much faster with 2.5 times than those made from uncoated powders. The Cu matrix Ni-coated reinforced composites have higher relative density and lower porosity content than the uncoated composites, due to the good adhesion between the reinforcements and the Cumatrix. Yield and breaking compression strengths of coated reinforcement powders containing composites are superior to those of uncoated ones .

C.S. Ramesh et al.[31] suggested that micro hardness and tensile strength of hybrid composites are higher as compared to the matrix copper. Increased content of hard reinforcement in the hybrid composites leads to enhancement in micro hardness and strength of the hybrid composites, however, ductility decreases .

K. Rajkumar et al.[32] noticed that copper–graphite composites were effectively sintered using microwave hybrid heating without any crack. The finer microstructure with relatively smaller and round pores, resulted due to microwave heating, enhances the performance of the composite .

C.S. Ramesh et al.[33] reported that the Ni-P coated Si3N4 particles reinforced Al6061 composites exhibited lower coefficient of friction and better wear resistance when compared with unreinforced alloy at all the loads and sliding velocities studied. Formation of the oxide at the interface plays a significant role in reducing both coefficient friction and wear rate .

K. Rajkumar et al.[33] gives that hardness of hybrid composites is higher than the unreinforced copper. Increased content of harder reinforcement (TiC) in the hybrid composites leads to enhancement in hardness. Hardness of hybrid composites is decreasing with the increase in

graphite content. Wear rate and coefficient of friction of hybrid composites and unreinforced copper increases with increase in normal load and Wear rates and coefficient of friction of hybrid composites are lower than those
of unreinforced copper. Wear rate of hybrid composites is reduced with increasing % TiC and % graphite, due to the cooperative effect offered by both the reinforcements. Coefficient of friction of hybrid composites is decreased with increase in % graphite reinforcement .

S.K. Ghosh et al.[34] suggested that the specific wear rate increases with the decrease of reinforcement size for a certain volume percentage of SiCp .

A. Fathy et al.[35] observed that the increasing strain rate from 10-4 s-1 to 102 s-1 increased compressive strengths of all tested nanocomposites. The wear rates of the composites increased with increasing applied loads or sliding speed.
The wear rate of the monolithic copper is more than that of the nanocomposites
.
A. Yeoh et al.[36] gives that the expansion of the cylindrical specimens is observed in both the longitudinal and lateral dimensions with the greatest expansions measured for those composites in the 50 vol. % copper-50 vol. % graphite ranges. Spheroidization is due to result of non-wetting between copper and graphite. The maximum expansion is observed at Cu-50 vol. % and such a composite presents the highest number of interfaces between the constituents .

3-SAMPLE PREPARATION

There are make 3 sample of cooper graphite composite material make through by casting process.so there are mixing powder of cooper & graphite .each sample has weight of 200 gm .material melt in furness at temperatures of 1190 c to 1350c .after melting material , graphite crucible is removed to die for take shape. Sample is square in shape has dimension length 15 cm width 4mm and depth 3mm.

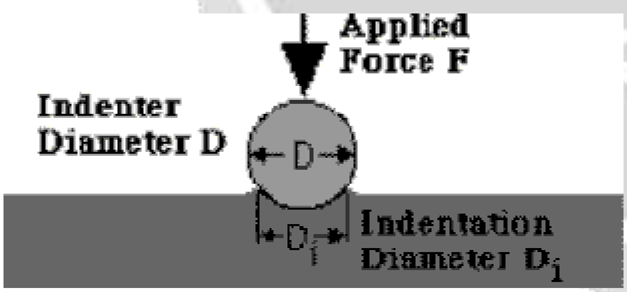
composition	temperature	time
Copper 98 %-graphite 2%	**1190c**	**58 min**
Copper 95 %-graphite 5%	**1250c**	**1hr10min.**
Copper 90 %-graphite 10%	**1350c**	**1hr45min.**

FIGURE 1- SAMPLE OF CU- GR COMPOSITE MATERIAL

4-Testing result

4.1-Brinell hardness

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope.



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

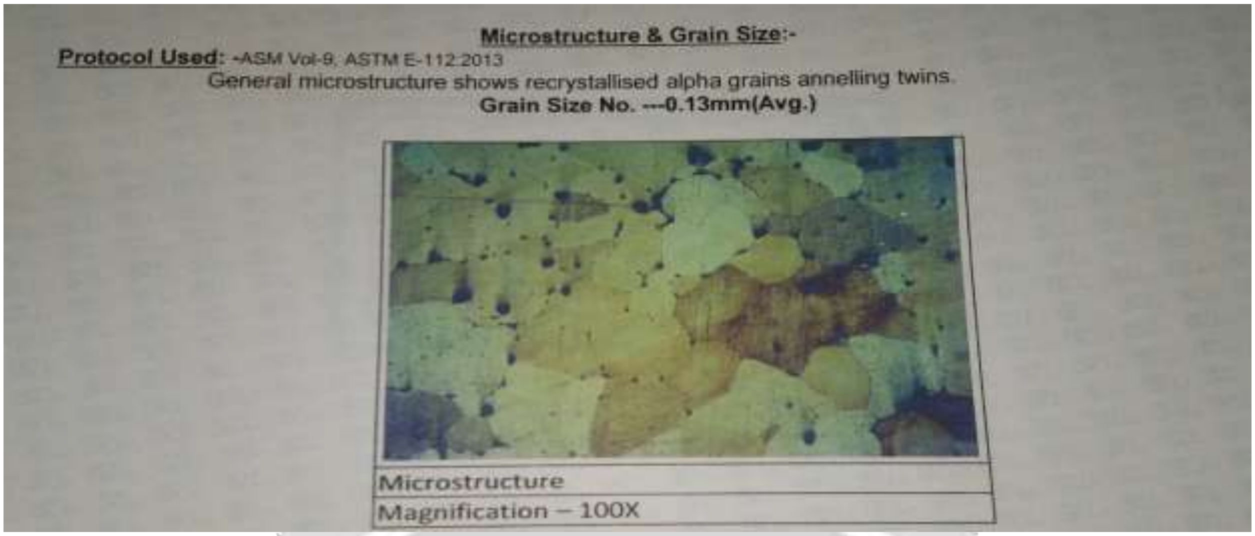
The diameter of the impression is the average of two readings at right angles and the use of a

Brinell hardness number table can simplify the determination of the Brinell hardness. A well structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

composition	**Brinell hardness**
Copper 98%-graphite 2%	**40 bhn**
Copper 95%-graphite 5%	**45 bhn**
Copper 90%-graphite 10%	**75 bhn**

4.2-Microstructure

Microstructure is the small scale structure of a material, defined as the structure of a prepared surface of material as revealed by a microscope above 25× magnification.[1] The microstructure of a material (such as metals, polymers, ceramics or composites) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior or wear resistance. These properties in turn govern the application of these materials in industrial practice. Microstructure at scales smaller than can be viewed with optical microscopes is often called nanostructure, while the structure in which individual atoms are arranged is known as crystal structure. The nanostructure of biological specimens is referred to as ultrastructure. A microstructure’s influence on the mechanical and physical properties of a material is primarily governed by the different defects present or absent of the structure. These defects can take many forms but the primary ones are the pores. Even if those pores play a very important role in the definition of the characteristics of a material, so does its composition.



Microstructure & Grain Size:-

Protocol Used: -ASM Vol-9, ASTM E-112:2013

General microstructure shows recrystallised alpha grains annelling twins.

Grain Size No. ---0.13mm(Avg.)

Microstructure

Magnification – 100X

Figure-2- Copper 90%-graphite 10% composite microstructure

Microstructure & Grain Size:-

Protocol Used: -ASM Vol-9, ASTM E-112:2013

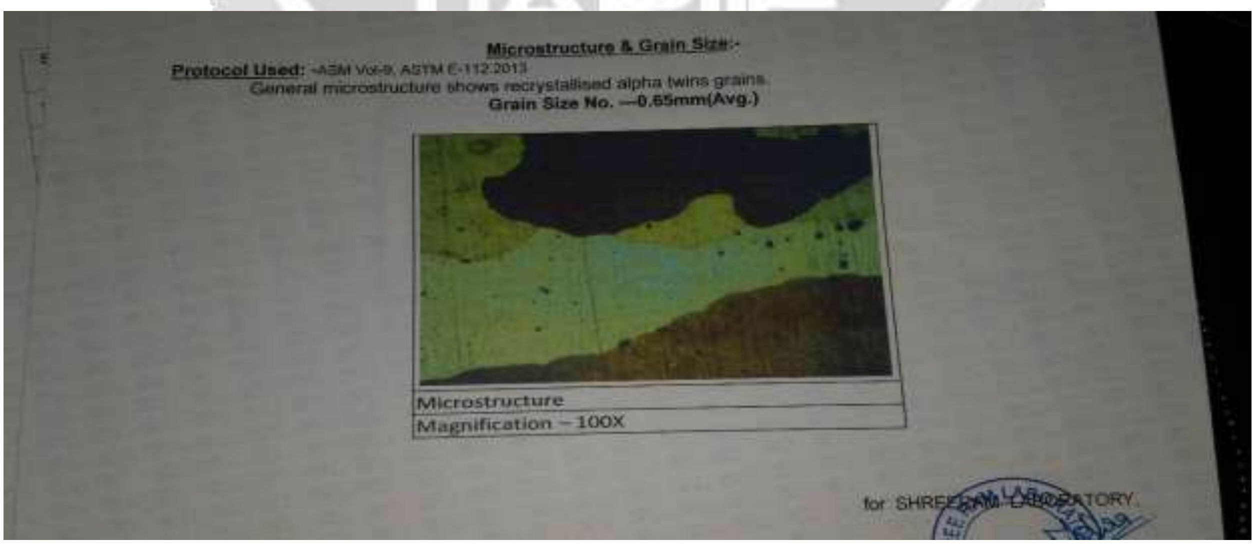
General microstructure shows recrystallised alpha twins grains.

Grain Size No. ---0.20mm(Avg.)

Microstructure

Magnification – 100X

Figure-3- Copper 98%-graphite 2% composite microstructure



Microstructure & Grain Size:-

Protocol Used: -ASM Vol-9, ASTM E-112:2013

General microstructure shows recrystallised alpha twins grains.

Grain Size No. ---0.65mm(Avg.)

Microstructure

Magnification – 100X

for SHREE[illegible]ATORY

Figure-4- Copper 95%-graphite 5% composite microstructure

4.3- Universal tensile testing

A universal testing machine (UTM), also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials.

The strength of material is the prime factor that explains the quality of the material. The strength refers to the ability of material to resist loads without failure because of excessive stress or deformation. The strength of the materials can be determined easily with Tensile Test.

Tensile test is a measurement of the ability of material that reacts to forces that are applied in the form of tension on different materials such as plastic, textile, rubber, etc. to know the maximum stress that the material can withstand. The tensile force tends to pull the material apart from both the ends and determine the strength of the material that to what extent the material stretches before breaking. All samples should be made to the sizes specified in the standard and be free from observable surface flaws, including molding flash, shorts, or surface scratches.

coposition	**Tensile strength (mpa)**
Copper 98%-graphite 2%	**159.11 mpa**
Copper 95%-graphite 5%	**171.11 mpa**
Copper 90%-graphite 10%	**183.04 mpa**

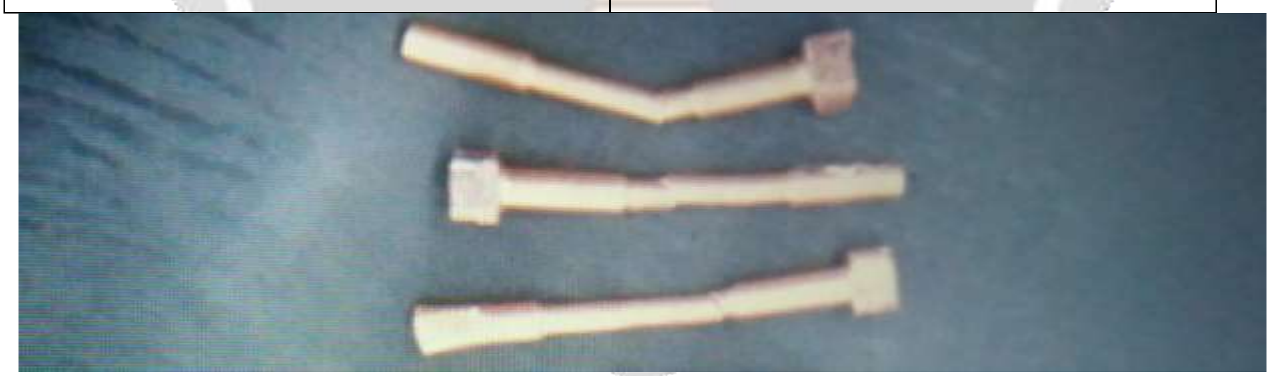


Figure 5- after tensile test breaking piece of cu-gr

5-Conclusion

In this paper, we generate Cu-Gr metal matrix composite by casting route and analyse the fabrication of Cu-graphite MMC by casting Process and different mechanical properties like tensile and hardness, microstructure are also analysed. And we examined that tensile strenght increases as wt% of graphite increases and hardness increase as wt% of graphite increases. Microstructure study shows the existence of both copper and graphite (carbon) phases along some copper oxide in samples. The casting samples were devoid of any oxide inclusions because of the vacuum conditions. Microstructure study suggests proper bonding between matrix and reinforcement along their interface Density study shows an increasing trend with increase in content of graphite.

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