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Studies on Tensile Property and Microstructure Behaviour of Boron Carbide and CNT Reinforced Copper based Hybrid Composites

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Abstract: ***The research work focuses on the influence and contribution of multi-walled Carbon-Nano tube (MWCNT) and boron carbide (B4C) to the mechanical properties of copper matrix composites. Different weight fractions of Nano-B4C and MWCNT-reinforced copper composites were prepared using the ultrasonic assisted stir casting methodologies. Various tests such as density, tensile, compression and hardness were conducted as per ASTM standards. The addition of reinforcements showed enhancements in the mechanical properties such as tensile strength, compressive strength and hardness of the composites due to the uniform dispersion of the secondary reinforcement in the copper matrix and the self-lubricating effect of the MWCNTs. The Ultimate tensile strength (UTS) increased from 245.07 MPa to 370.43 MPa, while the yield strength increased from 201.44 MPa to 263.65 MPa, % elongation reduced from 9.2 to 6.8.***

Keywords: Boron Carbide (B4C), Multi-walled Carbon-Nano tube (MWCNT), Tensile and Microstructure

I. INTRODUCTION

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties; when combined it produces a material with characteristics different from the individual. It consists of matrix and reinforcement; matrix is the bulk of material holding the reinforcement together in position. Fibers or particulates embedded in matrix of another material are the best example of modern-day composite materials. The individual component remains separate and distinct within the finished structure in macroscopic level. Composites are preferred more because of Lighter, Stronger, less expensive compared to traditional materials etc. Reinforcement is load bearing material and also provides additional properties like wear resistance, impact strength, corrosion resistance etc. Most commercially produced composite use polymer matrix often called as resin solutions. Most common polymers are polyester, vinyl ester, epoxy, phenolic, poly amide, polypropylene etc.

Composites are usually man-made materials but can also be sometimes natural such as wood. They are mostly formed by the combination of two different materials separated by a distinct interface. The properties of a composite as a whole are enhanced as compared to the properties of its components. The two phases that make up a composite are known as reinforcing phase and matrix phase. The reinforcing phase is embedded in the matrix phase and mainly provides strength to the matrix. The reinforcing phases usually found in composites are particulates, fibers or sheets and the matrix materials can be of the form of polymers, ceramics or metals. Composites are made up of individual materials referred to as constituent materials. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. A variety of moulding methods can be used according to the end-item design requirements. The principal factors impacting the methodology are the natures of the chosen matrix and reinforcement materials. Another important factor is the gross quantity of material to be produced. Large quantities can be used to justify high capital expenditures for rapid and automated manufacturing technology. Composites offer significant weight saving over existing metal hence used for Aircraft bodies. Composite materials for trusses and benches used in satellites for space applications. Since coefficient of linear thermal expansion is low compares to monolithic materials. Unidirectional fiber composites have specific tensile strength about 4 to 6 times greater than that of steel and aluminium.

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Composites are used for abrasive grinding and cutting wheels. Since these are formed from the Alumina, Silicon carbide, cubic boron nitride embedded in glass or ceramic or polymer matrix. Here matrix provides the base and abrasives provide the cutting edge. Unidirectional composites have specific modulus (ratio of stiffness to density) about 3 to 5 times greater than that of steel and aluminium. High corrosion resistances of the composite fibers contribute to reduce life cost. Composite part can eliminate joints/ fasteners thereby providing parts simplification and integrated design. Fiber reinforced composites can be designed with excellent structural damping features. The most important advantage associated with composites is their high strength and stiffness along with low weight. This high strength to weight ratio enables the greater usage of composites in space applications where being light and strong is given prime importance. Also, in composites the fibers present share the load applied and prevents the rapid propagation of cracks as in metals. Another advantage of composites is the flexibility associated with their designing method.

A. Classification of Composites

Composite materials are commonly classified at following two distinct levels:

1) Matrix constituent
2) Reinforcement form

There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic, and polymer) and the second is based on the material structure:

B. Classification of Composites Based on Matrix Material

1) Metal Matrix Composites (MMC): Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.
2) Ceramic Matrix Composites (CMC): Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase).
3) Polymer Matrix Composites (PMC): Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxiy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polysterene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

C. Classification Of Composite Materials Based On Reinforcing Material Structure

1) Particulate Composites
2) Fibrous Composites
3) Laminate Composites

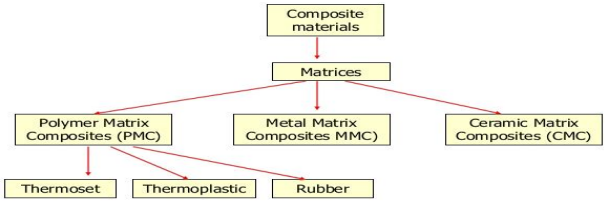

Figure 1.1 Classification based on matrix constituents

In matrix-based structural composites, the matrix serves two paramount purposes viz, binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force. polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. High temperature resins are extensively used in aeronautical applications. Matrix also protects the fibers from environment, chemical corrosion or oxidation

a) Polymer Matrix Composites (PMC): Polymer matrix composites are composed of matrix from thermoset (unsaturated polyester, epoxy) or thermoplastic (polycarbonate, polyvinyl chloride, nylon, polystyrene) polymers and embedded glass, carbon, aramid fibers (dispersed phase). Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the chopped fiber composites form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins.

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b) *Metal Matrix Composites (MMC):* Metal matrix composites are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However, the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high module. Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminum and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to- weight ratios of resulting composites can be higher than most alloys. The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials.

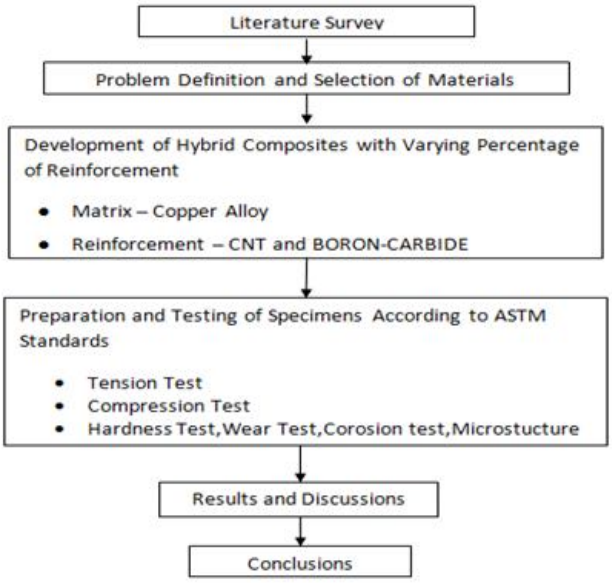
c) *Ceramic Matrix Composites (CMC):* Ceramic matrix composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed or reinforcing phase). Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favor for applications requiring a structural material that doesn't give way at temperatures above1500ºC. Naturally, ceramic matrices are the obvious choice for high temperature applications.

II. METHODOLOGY

The objective of this research work is to introduce Cu/ CNT and B4C particulate metal matrix composites where the CNT and B4C are used as reinforcement material and Copper (Cu) is used as matrix material. The different weight percentage of reinforcement will be added to matrix and liquid casting technique for the preparation of Cu/ CNT and B4C metal matrix composites thus the developed composites will be tested for tensile strength and Microstructural behaviour.

A. Methodology

The methodology followed for the research work.



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III. MATERIALS

The matrix and the reinforcement materials are procured from suppliers and the details are as mentioned in Table 1.1.

Material	Manufacturer/Suppliers	Quantity
Copper	Fenfee Metallurgicals, Uttarahalli, Bangalore	30 kg
CNT	Go Green Products, No. 225 E, 1st floor, Gandhi Road Alwarthirunagar, Chennai.-600087.	500 g
B_4C	Go Green Products No. 225 E, 1st floor, Gandhi Road Alwarthirunagar, Chennai.-600087.	500 g

Table 1.1: Details of Material Procurement

Reinforcement's compositions are selected based on the previous work done by many researchers. In many literatures authors have mentioned the reinforcement percentage should be less than 10% for Copper and 2% for CNT, if it is more than 10% reinforcement will not mix with the casting properly and there is a chance of agglomeration of particles. So, in the present study reinforcement compositions are limited to above mentioned weight percentage.

A. Copper(Cu)

Copper is non-polymorphous metal with face centred cubic lattice zinc addition produces a yellow color, and nickel addition produces a silver colour. Melting temperature is 1083 °C and density is 8900 kg.m-3, which is three times heavier than aluminium. The heat and electric conductivity of copper is lower compared to the silver, but it is 1.5 times larger compared to the aluminium.

Figure1.2: Copper billets cut into small pieces

B. Carbon Nanotubes (CNT)

Carbon nanotubes (CNTs) are procured from Go Green Products, these cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials.

Figure 1.3: Carbon Nano Tubes (CNT)

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C. Boron Carbide(B4C)

Boron carbide is an extremely hard and covalent material used in tank or armour, bullet proof vests, engine sabotage powder as well numerous industrial applications. With a Vickers hardness of >30GPA , it is one of the hardest known materials, behind cubic boron nitride and diamond Boron carbide was discovered in 19th century as a by-product of reactions involving metal borides, but its chemical formula was unknown, Approximately B4C. The ability of boron carbide to absorb neutrons without forming long lived radionuclides makes it attractive as an absorbent for neutrons radiations arising in nuclear power plants and from antipersonnel-neutron bombs.

Figure 1.4: Boron carbide

IV. EXPERIMENT

A. Fabrication of Test Specimens.

The microstructure of any material is a complex function of the casting process, subsequent cooling rates. Therefore, composites fabrication is one the most challenging and difficult task. Stir casting technique of liquid metallurgy was used to prepare Copper Alloy Composites.

1) *Copper Based MMC Preparation by Stir Casting:* A stir casting setup as shown in Figure 1.5, Consist of a Coke fired Furnace and a stirrer assembly, which was used to synthesize the composite. Figure1.6 gives the schematic diagram of a typical stir casting setup.

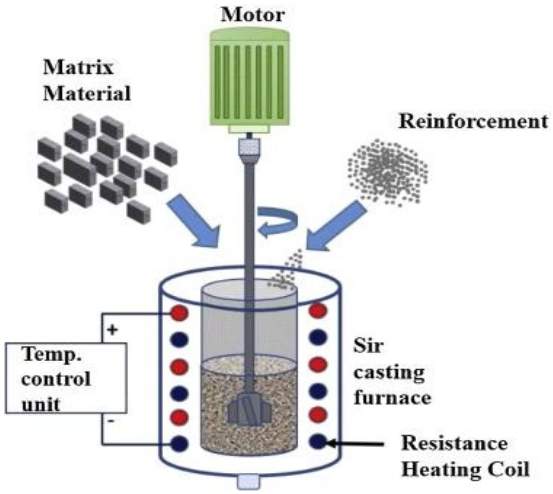

Figure. 1.5 Graphical representation of stir casting setup

2) *Composite Preparation Furnace:* A coal fired 10kg capacity furnace was used for melting the Copper. Figure 4.9 is the picture of the melting furnace used for the present research work. The temperature range of the furnace is more than 20000 C. Figure 4.6 shows the Crucibles for pouring the molten metal and copper Ingots. Preheating of reinforcement Muffle furnace, was used to preheat the particulate to a temperature of 5000C. It was maintained at that temperature till it was introduced into the copper and copper alloy melt. The preheating of reinforcement is necessary in order to reduce the temperature gradient and to improve wetting between the molten metal and the particulate reinforcement.

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3) *Melting of Matrix Alloy:* The melting range of CU alloy is of 1000 – 10830C. A known quantity of Copper ingots were loaded into the Graphite crucible of the furnace for melting. The melt was super-heated to a temperature above 15000C and maintained at that temperature. The molten metal was then degassed using Hexo chloro ethane tablets for about 8 min. Figure 1.6(b) and Figure 1.6(c) gives the photographic image of crucible and Molten Metal respectively.

(a) (b) (c)

Fig 1.6 (a) External View of coal fired Furnace, (b) Crucibles, (c) Molten Metal

4) *Mixing and Stirring:* Alumina coated stainless steel impeller was used to stir the molten metal to create a vortex. The impeller was of centrifugal type with 3 blades welded at 450 inclinations and 1200 apart. The stirrer was rotated at a speed of 300 – 400 rpm and a vortex was created in the melt. The depth of immersion of the impeller was approximately one third of the height of the molten metal. From the bottom of the crucible. The preheated particulates of CNT and BORON CARBIDE were introduced into the vortex at the rate of 100gm/min. Figure 1.7(a) shows the process of adding reinforcing material Chopped CNT and B4C. Stirring was continued until interface interactions between the particles and the matrix promoted wetting. The melt was superheated to temperature of 15000C it was poured into the preheated die.

(a) (b)

Fig 1.7: (a) Reinforcement materials being added to the molten matrix, (b) Pouring Molten Metal into the mould

B. Machining

Figure:1.8 Machining of Casted Product

The casted specimens obtained were machined on a Lathe according to ASTM standards for Wear and Corrosion Tests.
The specimens are fabricated as per ASTM standards, as such the corrosion test specimens fabricated as per ASTM G 31 – 72 with Ø20 mm and length 20 mm, wear test specimens as per ASTM G99 standards with a diameter of 6 mm and a length of 30 mm.

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1) Composition of Specimens Prepared

Table 1.2. Composition of developed Copper metal matrix composite.

Specification	CNT%	B4C%	COPPER %
C	0	0	100
C1	0.5	1	98.5
C2	0.5	3	96.5
C3	0.5	5	94.5
C4	1.0	1	98.0
C5	1.0	3	96.0
C6	1.0	5	94.0
C7	1.5	1	97.5
C8	1.5	3	95.5
C9	1.5	5	93.5

C. Testing

1) Density: Density of the composites plays an important role in drawing inferences for variation in other essential Characteristics for the materials synthesized. Density of the as cast base metal, as well as stir cast composites are determined using Archimedes principle. The Archimedes principles involve a rationale procedure of weighing the specimen in air and weighing the same specimen in distilled water of known density.

2) Tension Test

Figure 1.9 Tensile Test Specimens before test

A specimen with specified shape and size is gradually subjected to increasing uni-axial load (force) until failure occurs, simultaneous observations are made on the elongation of the specimen, and this is the typical procedure for tensile testing. The operation is accomplished by gripping opposite ends of the work piece and pulling it, which results in elongation of test specimen in a direction parallel to the applied load. The ultimate tensile strength tests were done in accordance with ASTM E8-82 standards. The tensile specimens of diameter 12.5mm and gauge length 50mm were machined from the cast specimens with the gauge length of the specimen's parallel to the longitudinal axis of the casting. Yield strength of the specimens was evaluated in terms of MPa. The test was carried out at room temperature using Universal Testing Machine shown in Figure 4.18. The tensile specimens prepared in accordance with ASTM E8-82 were subjected to homogenous and uniaxial tensile stresses in the Universal Testing Machine. The ultimate tensile strength of the hybrid composites specimens and of the base alloy were plotted against the CNT content and B4C.

Figure 1.10. Universal Testing Machine

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Fig. 1.11 Tensile Specimens after Test

V. RESULTS

The composites fabricated are evaluated for characteristics like Density, Tensile strength, Yield strength, Compression strength, Hardness, and Microstructure for different weight percentages of CNT and boron carbide in copper alloy. The present work attempts to understand the influence of reinforcements on the matrix alloy.

Figures and tables show the effect of CNT and B4Creinforcements on the various mechanical properties of all alloy composites. Viz. Density, Tensile strength, Yield strength, Compression strength, Hardness, Wear, Corrosion and microstructure respectively.

A. Density

The actual density of the composite specimen is determined by Archimedes principle by making use of a beaker filled with 100 ml of distilled water. The weight of the empty beaker as well as the filled beaker is noted, further the weight of the specimen in air as well as the weight of the specimen in distilled water is determined.

The table 5.1 gives an overview of the density and porosity of the various specimens considered for experimentations.

Specimen	Theoretical Density (g/cm^3)	Measured Density (g/cm^3)	Relative Density	Porosity
C	8.92	8.8897	0.9697	0.3396
C1	8.509	8.4676	0.9585	0.4865
C2	8.121	8.054	0.933	0.825
C3	8.587	8.5394	0.9524	0.5543
C4	7.952	7.8656	0.9136	1.0865
C5	8.153	8.0932	0.9401	0.7334
C6	7.791	7.7011	0.9101	1.1538

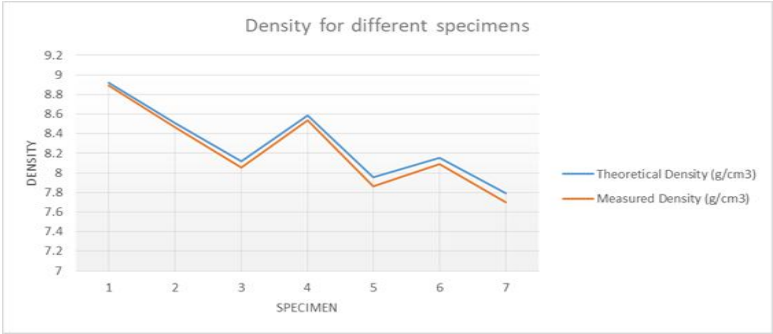

Figure 1.17 Density for different specimens

The density of the composite decreases with the increase in the weight percentage of reinforcements, this is majorly attributed to the fact that the addition of CNT and B4C having densities of 1.6 and 2.52 diminishes the density of the composite. Further the porosity measured as percentage difference in the theoretical and actual density values increases with the increase in the weight percentage of reinforcements. This is majorly attributed to the fact that the voids are formed in composite due to entrapment of gases while melting the base metal and reinforcing the composite with CNT and B4C.

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B. Tensile Test Results

The ultimate tensile strength of the hybrid composites specimens and of the base alloy show a remarkable increase in ultimate tensile strength with the incorporation of reinforcements in the matrix phase. It follows from the graph that the specimens show an increase in UTS as the content of CNT in the composite is increased in as cast conditions.

The factors that influence in the UTS are complex and interrelated. Several variables, such as distribution of the particles/ fiber in the matrix, the mechanical properties of the matrix and reinforcing particles/ fiber and the bonding between the matrix and reinforcement, are reported to influence the strength of discontinuously reinforcing composites strongly. Also, various strengthening mechanisms have been proposed to explain the improvement in strength in the case of discontinuously reinforced MMCs. It can be observed in the result how the UTS varied from C1 specimen to C6. Same trend is observed in the some of the literatures [27, 28-30]. The ultimate tensile strength varied from 245.07 MPa for unreinforced copper (C Specimen) to 370.43 for reinforced composite (C6 Specimen) thereby justifying the use of reinforcements in the matrix phase. Further the increase in tensile strength of the composites is attributed to the strong interfacial bonding between the reinforcement and matrix phase. Further the yield strength increases with the incorporation of reinforcements from 201.44 MPa to 263.65 MPa, while the percentage elongation reduces from 9.2 to 7.2, this is majorly due to the addition of boron carbide that will enhance the tensile strength and reduce the free deformation of the specimens thereby reducing its elongation.

Table – 5.2 Ultimate Tensile Strength

Specimen Designation	Wt. % of CU	Wt.% of CNT	Wt. % of B4C	Max. load (N)	Max. Displacement (mm)	UTS (N/mm^2)
C	100	0	0	1000	250	245.07
C1	98.5	0.5	1	1000	250	256.72
C2	96.5	0.5	3	1000	250	268.15
C3	98	1.0	1	1000	250	298.55
C4	96	1.0	3	1000	250	333.52
C5	97.5	1.5	1	1000	250	351.68
C6	95.5	1.5	3	1000	250	370.43

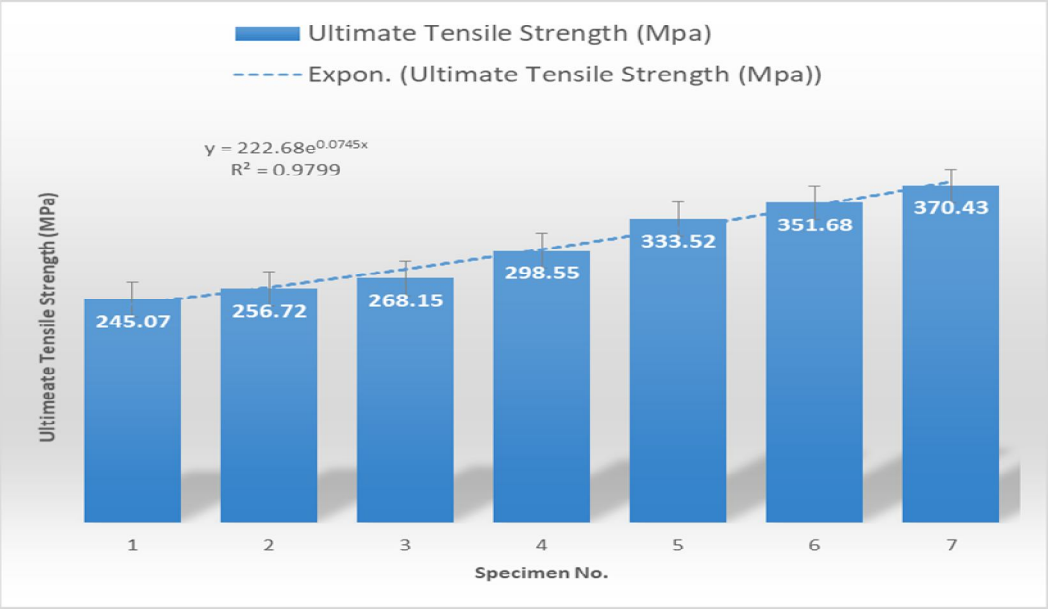

Figure 1.18 Ultimate Tensile Strength for different specimens

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Table – 5.3 Yield Strength for different specimens

Specimen Designation	Wt.% of CU	Wt.% of CNT	Wt.% of B4C	Max. load (N)	Max. Displacement (mm)	Yield Strength (N/mm^2)
C	100	0	0	1000	250	201.44
C1	98.5	0.5	1	1000	250	216.51
C2	96.5	0.5	3	1000	250	227.25
C3	98	1.0	1	1000	250	236.72
C4	96	1.0	3	1000	250	248.97
C5	97.5	1.5	1	1000	250	255.54
C6	95.5	1.5	3	1000	250	263.65

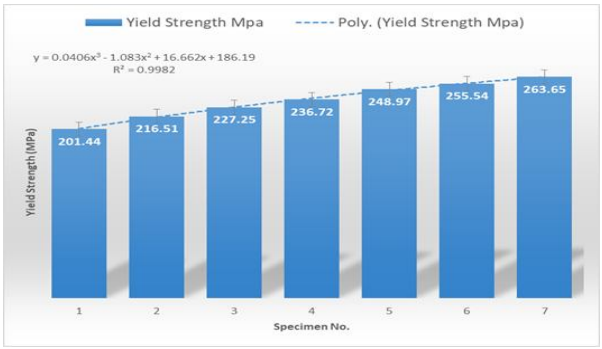

Figure 1.19 Yield Strength for different specimens

Table – 5.4 % Elongation for different specimens

Specimen Designation	Wt.% of CU	Wt.% of CNT	Wt.% of B4C	Max. load (N)	Max. Displacement (mm)	% Elongation
C	100	0	0	1000	250	9.2
C1	98.5	0.5	1	1000	250	8.9
C2	96.5	0.5	3	1000	250	8.5
C3	98	1.0	1	1000	250	8.3
C4	96	1.0	3	1000	250	7.6
C5	97.5	1.5	1	1000	250	7.2
C6	95.5	1.5	3	1000	250	6.8

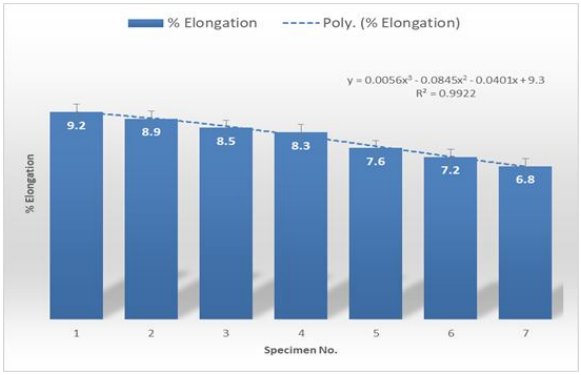

Figure 1.20 Elongation for different specimens

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C. Micro structural Analysis

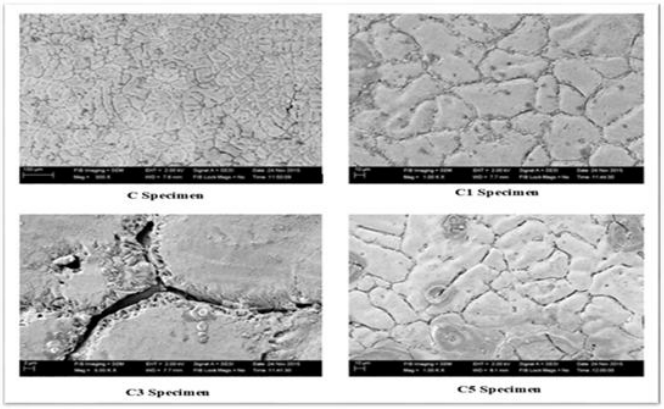

Figure: 1.24. SEM images of different Specimens

The microstructure from fig 1.24 clearly reveals that the addition of boron carbide and CNT has been uniformly distributed in the copper matrix phase attributed to the stir casting of the matrix phase reinforced with the B4C and CNT, further the dendritic structure of the B4C alongside CNT in the grain periphery has led to better properties of the composites fabricated en-route stir casting.

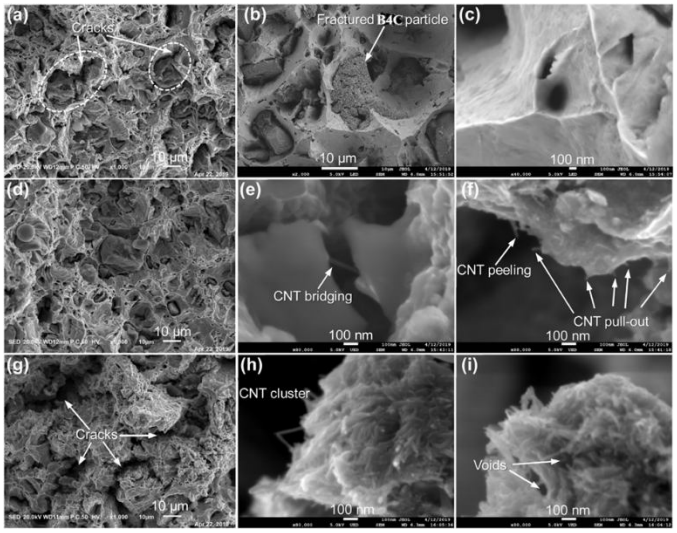

Figure: 1.25. SEM Images of fracture surface

Fig. 1.25shows the typical fracture surface morphologies of the (CNT-B4C)/Cu composites prepared with different mixing ratios after room temperature tensile testing. As shown in Fig. 1.25a, the fracture surface of (0CNT-1B4C)/Cu composite exhibited well-dispersed B4Cmicroparticles together with cracks around the particles (indicated by the dotted oval). Apparently, some B4Cmicroparticles were cracked under the tensile stress (Fig. b).

These micrographs implied that the failure of the composite was initiated by B4Cparticle frac-turing, causing crack initiation with subsequent propagation through the Cu matrix. During tensile loading, local stress initially concentrated on the interfacial bond and transferred to the brittle B4Cparticles. As the load increased, local stress built up near micro-cracks inside B4Cparticles, resulting in crack initiation and propagation in the matrix.

These results explained why the B4Cparticles reduced the ductility of the composite. While for the (1CNT-3B4C)/Cu composite in Fig. 1.25d, it was difficult to observe the cracks and fractured B4Cparti-cles.

The morphologies of CNTs on the fracture surface are shown in Fig. 5e and f. The CNTs behaved as a bridge to connect the broken Cu matrix and prohibited crack growth (Fig. 1.25e), which explains why plasticity improved with the(1CNT-3B4C)/Cu composite. Additionally, CNT peeling and pull-out were observed on the fracture surface (Fig. 1.25f). This suggested the effective load transfer strengthening of CNTs in the composite is due to the enhanced interfacial bonding between CNTs and Cu matrix (Fig. 1.25a).

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As stress was applied to CNTs, fracturing occurred from the outermost layer to the inner layer when the applied load transferred from the matrix to the CNTs walls, leading to CNTs peeling and the consequent effective load transfer.

Furthermore, this effect greatly reduced the load-bearing of B4C micro particles and inhibited particle fracturing and Cu matrix crack growth. As the mixing ratio was increased to 3:1, obvious cracks could be observed at the fracture surface of the composites (Fig. 1.25g).

From high-magnification images (Fig. 1.25h and i), CNTs aggregated into the cluster and bulk, causing no direct contact with the Cu matrix. This confirmed that many voids and defects were formed inside CNTs clusters (Fig. 1.25i), which were the crack sources that damage the strength and plasticity during tensile testing.

VI. CONCLUSIONS

The present research work on preparation of Carbon Nano Tube and Boron carbide reinforced Copper metal matrix composite by stir casting and evaluation of mechanical and micro structural characteristics has led to following conclusions.

A. Copper/ Carbon Nano Tube / Boron carbide composites have been successfully developed and fabricated using stir casting technique.

B. The microstructures of produced composites were executed using Scanning Electron Microscopy (SEM) which revealed uniform distribution of reinforced particles with good bonding between reinforcement and matrix.

C. The density of the composite materials decreases with the increase in reinforcement particles, however the porosity tends to increase with the increase in Wt.% of reinforcement particles attributed majorly due to the entrapment of gases while reinforcing the composites. i.e., the density decreased from 8.8897 g/cm3 to 7.7011 g/cm3; porosity increased from 0.3396 to 1.1538.

D. The Ultimate tensile strength (UTS) increased from 245.07 MPa to 370.43 MPa, while the yield strength increased from 201.44 MPa to 263.65 MPa, % elongation reduced from 9.2 to 6.8, The increase in UTS is attributed to the presence of hard B4C reinforcement particles which imparts strength to the matrix alloy, thereby providing enhanced tensile strength. There is substantial increase in tensile strength of C6 composites when compared with ‘C’ Specimen. Ductility of the composites were low probably because of high porosity content, early void formation at low strains during tensile elongation and heterogeneous particle distribution. The percentage elongation of the MMC’s decreased with increase in B4C and CNT content, which confirmed that B4C addition increased brittleness. The reduction in ductility can be attributed to the presence of a hard ceramic phase that is prone to localized crack initiation and increased embrittlement effect due to local stress concentration sites at the reinforcement matrix interface.

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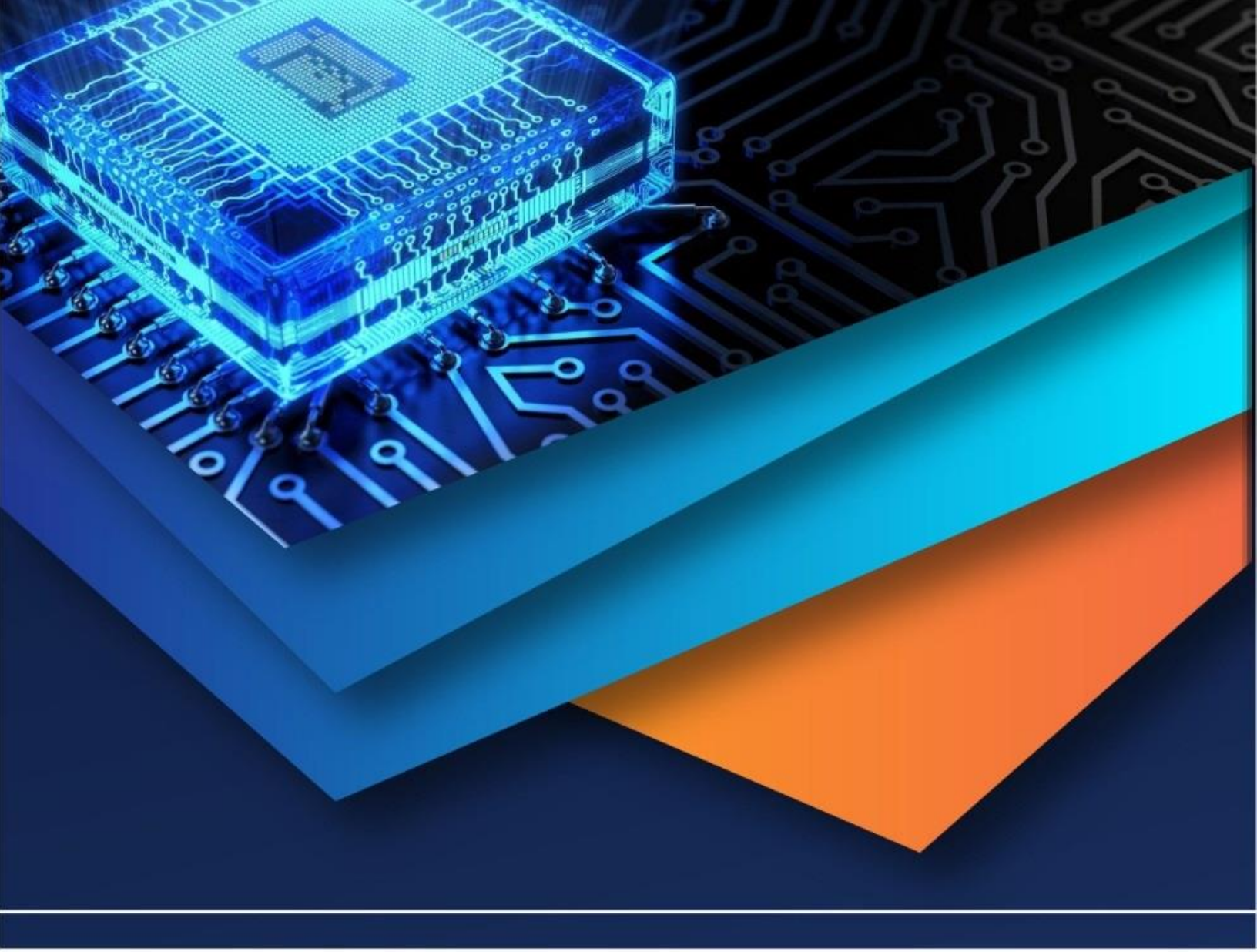

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