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Evaluation of Mechanical Properties on Boron Carbide and CNT Reinforced Copper based Composites

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Abstract **The study 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, 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.**

Keywords — Boron Carbide(B4C), Multi-walled Carbon-Nano tube (MWCNT), Compression and Hardness.

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.

Reinforcement may be fibers, flakes, particulates or whiskers etc. while fibers are classified as natural fibers and man-made fibers.

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.

Normally in the composite material have a hard phase in the soft ductile matrix where the hard phase act as a reinforcing agent increase the strength and modulus, and soft phase act as matrix material.

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

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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.

Engineered composite materials must be formed to shape. The matrix material can be introduced to the reinforcement before or after the reinforcement material is placed into the mould cavity or onto the mould surface. The matrix material experiences a melding event, after which the part shape is essentially set. Depending upon the nature of the matrix material, this melding event can occur in various ways such as chemical polymerization or solidification from the melted state.

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.

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.

It is because they can be moulded to form various shapes be it easy or complex. Composites with proper composition and manufacturing can withstand corrosive and high temperature environments. With all these advantages it is obvious to think why the composites have not replaced the metals. One major drawback linked with the composites is its high cost which is often due to the use of expensive raw materials and not due to the manufacturing processes.

Classification of Composites

Composite materials are commonly classified at following two distinct levels:

- **Matrix constituent**
- **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:

Classification of composites based on matrix material

- **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.

- **Ceramic Matrix Composites (CMC):** Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase).
- **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).

Classification of composite materials based on reinforcing material structure.

- **Particulate Composites**

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles. Composites with random orientation of particles. Composites with preferred orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

Fibrous Composites

Short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter).

- Composites with random orientation of fibers.
- Composites with preferred orientation of fibers.

Long-fiber reinforced composites. Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.

- Unidirectional orientation of fibers.
- Bidirectional orientation of fibers (woven).

- **Laminate Composites**

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite.

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Classification based on matrix constituents

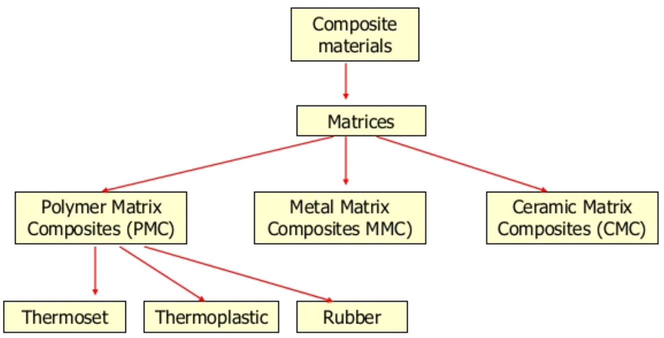

Figure1.1 Classification based on matrix constituents

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

- **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.

Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds. Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the morphology to a considerable extent, prompting the reinforcement to empower nucleation.

- **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. 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, Aluminium 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.

- **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.

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II. OBJECTIVE AND 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 compression strength and Hardness.

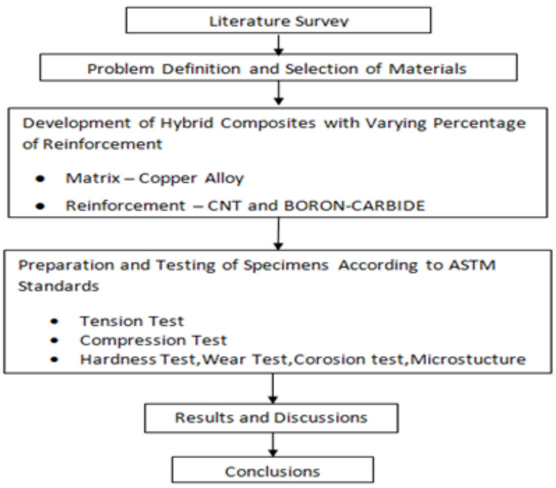
2.1 OBJECTIVES

The objective of the present research work is development and characterization of the Copper based CNT and B4C reinforced metal matrix composites.

- Development of Copper based CNT and B4C reinforced hybrid metal matrix composite by stir casting method.
- Fabrication of different hybrid composites castings, by adding varying percentage of CNT and B4C to the molten metal.
- Preparation of specimens for testing according to ASTM standard.
- Experimental investigation of various Mechanical properties like Compression and Hardness on developed composites.

2.2 METHODOLOGY

The methodology followed for the research work.



3. 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.

- **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

- **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)

- **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

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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

III. EXPERIMENT

3.1 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.

- **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.

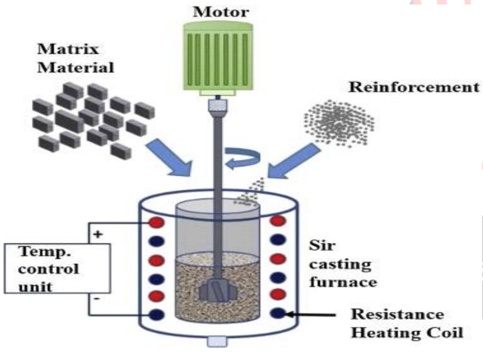

Figure. 1.5 Graphical representation of stir casting setup

- **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.

- **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

- **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

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3.2 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.

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

3.3 TESTING

1. Compression Test

Specimens were machined in according with ASTM E9 standards, diameter=20mm and length=20mm and test were conducted using a computerized UTM. Compressive strength of the specimen was evaluated in terms of MPa. Three specimens for each composites composition were tested and average results are noted down.

Figure. 1.9 Compression Specimens before Test

Figure 1.10 Compression Specimens after Test

2. Hardness Test

Figure 1.11 Brinell hardness testing machine.

Hardness, which is the resistance of the specimens to deformation, is a measure of their resistance to plastic or permanent deformation. The static indentation test was the test used in the present study to examine the hardness of the specimens in which a ball indenter was forced into the specimens being tested. The relationship of the total test force to the area or depth of indentation provides the measure of hardness. The hardness tests were conducted in accordance with the ASTM E10 standards. The hardness test indenter of diameter 5mm was used and load of 250 kg was applied over the specimens of diameter 20mm for a period of 30 seconds. Three readings were taken for each specimen at different locations in order to circumvent the possible effects of particle segregation. Hardness is described as a measure of material resistance to surface indentation and may be thought of as a function of the stress. The hardness is a surface property measured by resistance to abrasion or wear, cutting, machining and crusting. Thus hardness is surface property measured by resistance to indentation or penetration by some hard body.

Figure 1.12 Hardness test specimens before test

Figure 1.13 Hardness test specimens before test

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IV. RESULTS

1. Compressive Test Results

The table shows the effect of CNT and B4Con compressive strength of copper hybrid composites. It can be seen that the compressive strength of the hybrid composites increases monotonically as the reinforcement contents are increased. The increase in compressive strength is mainly due to the decrease in the inter-particle spacing between the particles. Since B4C are much harder than copper alloys. The presence of CNT and B4C resist deforming stresses, thus enhance the compressive strength of the composite material. The figure 5.6 shows the load displacement curves for compressive loading of various combinations of CNT and B4C.The effect of addition of reinforcements on UCS of the composites is presented in graphs.

It is observed that the UCS of the composites monotonically increases as the particulate content is increased up to 1.5 Wt. % of CNT and it decreases beyond 1.5 Wt.%. The increase in strength can also be attributed to the addition of B4C which impart strength to the matrix alloy there by enhancing resistance to compression. There is a reduction in the inter-special distance between particulates, which cause an increase in the dislocation pile-up as the particulate content increases [44]. This leads to restriction to plastic flow due to the random distribution of the particulate in the matrix, thereby providing enhanced strength to composites. At lower percentage of reinforcement, the decrease in the strength may be due to poor bonding of CNT particles. Further, the compressive strength increases from 1279.43 MPa to 1548.33 with the addition of Boron carbide and CNT reinforcements thereby validating the addition of reinforcements, also the % reduction diminishes with the addition of reinforcements, i.e., from 6.52 to 3.73, this is majorly due to the addition of Boron carbide along with the CNT that will enhance its ability to withstand the compression and give better strength capabilities, thereby reducing % compression in the specimens.

Table – 4.1 Compressive Strength for different specimens

Specimen Designation	wt% of CU	wt% of CNT	wt% of B4C	Peak Load (KN)	Compressive Strength (N/mm^2)
C	100	0	0	600	1279.43
C1	98.5	0.5	1	600	1332.28
C2	96.5	0.5	3	600	1359.43
C3	98	1.0	1	600	1385.54
C4	96	1.0	3	600	1446.12
C5	97.5	1.5	1	600	1511.7
C6	95.5	1.5	3	600	1548.33

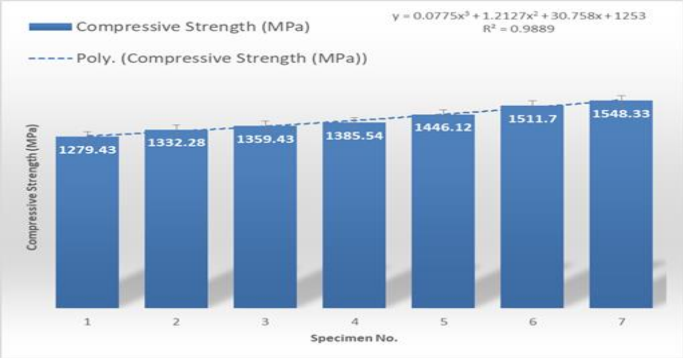

Figure 1.14 Compressive strength for different specimens

Table: 4.2 % Reduction for different specimens

Specimen Designation	wt% of CU	wt% of CNT	wt% of B4C	Peak Load (KN)	% Reduction
C	**100**	**0**	**0**	**600**	**6.52**
C1	**98.5**	**0.5**	**1**	**600**	**5.58**
C2	**96.5**	**0.5**	**3**	**600**	**5.13**
C3	**98**	**1.0**	**1**	**600**	**4.88**
C4	**96**	**1.0**	**3**	**600**	**4.27**
C5	**97.5**	**1.5**	**1**	**600**	**3.94**
C6	**95.5**	**1.5**	**3**	**600**	**3.73**

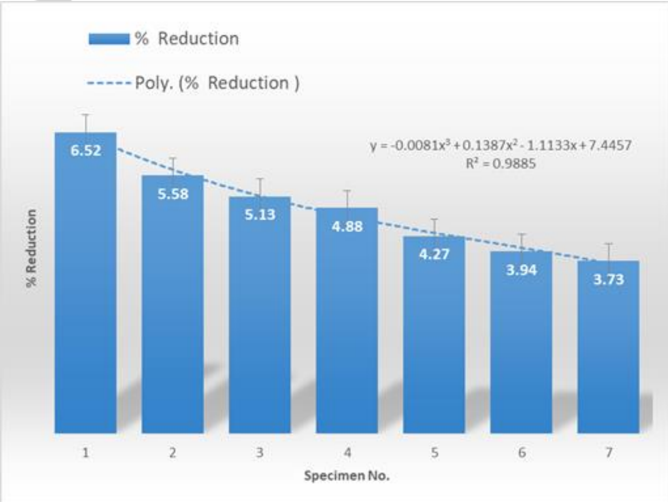

Figure 1.15 % Reduction for different specimens

2. Hardness Test Results

Hardness, which is the resistance of the specimens to deformation, is a measure of their resistance to plastic or permanent deformation. The static indentation test was the test used in the present study to examine the hardness of the specimens in which a ball indenter was forced into the specimens being tested. The hardness is a surface property measured by resistance to abrasion or wear, cutting, machining and crusting. Thus hardness is surface property measured by resistance to indentation or penetration by some hard body.

The test results are tabulated for the as cast conditions. The graph shows the effect of addition of reinforcement on

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the hardness of the composites. It is evident that as the percentage of reinforcement is varied by weight, the hardness of the composites increases. It is also observed that the hybrid composite shown good hardness property. Various other researches also reported that addition of CNT in metal alloys could lead to improved strength and hardness.

Table: 4.2 Hardness test Results

Specimen Designation	wt% of CU	wt% of CNT	wt% of B4C	BHN
C	100	0	0	75.24
C1	98.5	0.5	1	76.34
C2	96.5	0.5	3	76.72
C3	98	1.0	1	78.16
C4	96	1.0	3	83.08
C5	97.5	1.5	1	85
C6	95.5	1.5	3	86.15

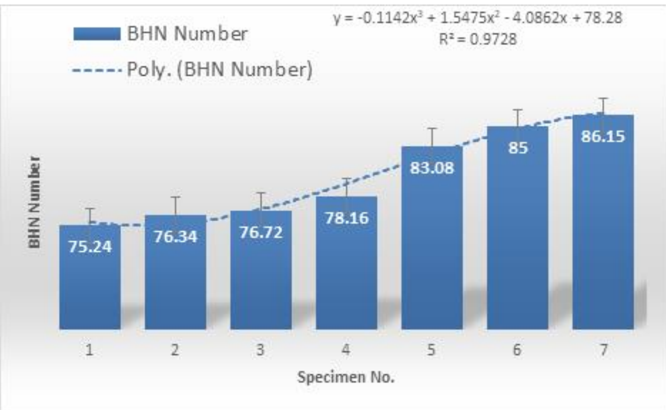

Figure: 1.16 BHN for different specimens.

V. 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 characteristics has led to following conclusions.

- Copper/ Carbon Nano Tube / Boron carbide composites have been successfully developed and fabricated using stir casting technique.
- The compressive strength increased from 1279.43 MPa to 1548.33 MPa, while % reduction dropped down from 6.52 to 3.73, this is majorly due to the bonding of reinforcements with the matrix phase that will ultimately enhance its ability to resist compression.
- The hardness increased from 75.24 to 86.15, the increase in hardness is probably attributed to the fact that the hard Boron carbide reinforcements act as barriers to the movement of the dislocations within the matrix. An improvement in hardness is observed for C6 composites when compared with C Specimen

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