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Evaluation of mechanical properties of CNT and Eglass fiber reinforced aluminium metal matrix composites

Manjunatha[*1], Dr. H N Vidyasagar[2], Dr. H K Shivanand[2], Murali R[3], Prashanth[4]

PG Scholar, Mechanical Engineering, UVCE, Bengaluru, India[1,3,4]

Professor, Mechanical Engineering, UVCE, Bengaluru, India[2]

Abstract: In contrast with most metallic materials, copper alloy has many remarkable properties, such as its excellent electrical and thermal conductivities, good strength, and formability, having outstanding resistance to corrosion and fatigue, and others. Due to their excellent properties, copper alloy is widely used in electrical, automotive, architecture, petrochemicals, transportation, and marine industry.

The Main objective of this work is to develop Carbon Nano tubes and E-Glass Fibre reinforced Aluminium Al-7075 Hybrid Metal Matrix Composite (AHMMC) and to evaluate the mechanical properties of these hybrid composites developed. The different types of Hybrid Composites are fabricated with varying composition of Carbon Nano Tubes and E Glass Fibre and the specimens are prepared as per ASTM Standards and experiments are conducted for characterization of mechanical properties like Tension, Compression, and Hardness.

Keywords: Metal Matrix Composites, Mechanical Properties, Tension, Compression, and Hardness.

I. INTRODUCTION

The possibility of taking advantage of particular properties of the constituent materials to meet specific demands is the most important motivation for the development of composites. A composite is a material made with several different constituents intimately bonded. When it comes to composites, the terms matrix and reinforcement are often used. The matrix is a percolating “soft” phase (with in general excellent ductility, formability and thermal conductivity) in which are embedded the “hard” reinforcements (high stiffness and low thermal expansion). The reinforcements can be continuous or discontinuous, orientated or disorientated. The composites are classified by:

- Their matrix (polymer, ceramic, metal).
- Their reinforcement, which includes the chemical nature (oxides, carbides, nitrides), shape (continuous fibres, short fibres, whiskers, particulates) and orientation.
- Their processing routes.

Aluminium is the most popular matrix for the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Aluminium matrix composites (AMCs) have been widely studied since the 1920s and are now used in sporting goods, electronic packaging, amours and automotive industries. They offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix. Like all composites, Aluminium-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong, though brittle.

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

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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 moduli.
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.
MMCs are made by dispersing a reinforcing material into a metal matrix. As the name implies, for Metal-Matrix Composites (MMCs), the matrix is a ductile metal. These materials may be utilized at higher service temperatures than their base metal counterparts; furthermore, the reinforcement may improve specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability.
Some of the advantages of these materials over the polymer matrix composites include:

- Higher operating temperatures
- No flammability
- Do not absorb moisture
- Have better electrical and thermal conductivity
- Are resistant to radiation damage
- Greater resistance to degradation by organic fluids

Low cost, therefore, their (MMC) use is somewhat restricted. In polymeric composites, matrix materials play important but secondary role of holding the fibers in place and providing proper load dispersion in the fibers, while material strength and stiffness are controlled by the reinforcements. By contrast, mechanical properties of metal matrix composites are controlled by the matrix to a considerably larger extent, though fibers still provide the main contribution to strength and stiffness of the material. The super alloys, as well as alloys of aluminum, magnesium, titanium, and copper, are employed as matrix materials. The reinforcement may be in the form of particulates, both continuous and discontinuous fibers, and whiskers; concentrations normally range between 10 and 60 vol. %.
Continuous fiber materials include carbon, silicon carbide, boron, alumina, and the refractory metals. On the other hand, discontinuous reinforcements consist primarily of silicon carbide whiskers, chopped fibers of alumina and carbon, and particulates of silicon carbide and alumina. In a sense, the cermets fall within this MMC scheme. In the automotive industry, MMCs have been used commercially in fiber reinforced pistons and particle-strengthened brake disks.
Aerospace structural applications include advanced aluminum alloy metal matrix composites. Boron fibers are used as the reinforcement for the Space Shuttle Orbiter, and continuous graphite fibers for the Hubble Telescope. Reinforcements for metal matrix composites have a manifold demand profile, which is determined by production and processing and by the matrix system of the composite material. The following demands are generally applicable

- Low density
- Mechanical compatibility (a thermal expansion coefficient which is low but adapted to the matrix)
- Chemical compatibility
- Thermal stability
- High Young’s modulus
- High compression and tensile strength
- Good process ability
- Economic efficiency

Which components are finally used, depends on the selected matrix and on the demand profile of the intended application.

Aluminum Matrix Composites (AMC)
Magnesium Matrix Composite
Copper Matrix Composite
Titanium Matrix Composite

Aluminium as such is a light weight material and available at low costs, but employing plain aluminium into automotive could be a disadvantage because of weak bonding of the matrix which is intolerant towards mechanical stresses. Henceforth, it becomes necessary to introduce other materials into the aluminium matrix to make it a better option for various applications.
Current work has utilized this lacuna to bring out a more feasible Aluminium composite which is reinforced with other economically available materials like CNT, E Glass to produce good quality stress resistant composite material.

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A lot of research has been done on aluminum alloy 1XXX to aluminum 6XXX based composites but research on aluminum alloy 7XXX based composites is very rare, also the properties of these composites are still not clear. Against this background, the present research work has been undertaken, with an objective to study the effect of different composition of reinforcement as E-Glass and CNT on the Al 7075 based metal matrix composites.

II. MATERIALS AND METHOD

A. Material used

- **Graphene**

Graphene is a crystalline allotrope of carbon with 2-dimensional properties. Its carbon atoms are densely packed in a regular atomic-scale chicken wire (hexagonal) pattern. Each atom has four bonds, one σ bond with each of its three neighbours and one π- bond that is oriented out of plane. The atoms are about 1.42 Å apart. Graphene's hexagonal lattice can be regarded as two interleaving triangular lattices. This perspective was successfully used to calculate the band structure for a single graphite layer using a tight-binding approximation.

- **Kenaf fiber**

The kenaf fiber derived from the outer fibrous bark is also known as bast fibre. Kenaf bast fiber has superior flexural strength combined with its excellent tensile strength that makes it the material of choice for a wide range of extruded, moulded and non- woven products. Kenaf fiber could be utilized as reinforcement material for polymeric composites as an alternative to glass fiber.

- **Banana fiber**

Banana fiber a ligno-cellulosic fiber obtained from the pseudo-stem of banana plant (Musa sepientum) is a bast fiber with relatively good mechanical properties are shown in the table 4.4. In the recent past, banana fiber as shown in fig had a very limited application and was primarily used for making items like ropes, mats, and some other composite materials.

- **Glass fiber**

Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiber glass. Glass fibers shown in fig are generally produced using melt spinning techniques. These involve melting the glass composition into a platinum crown which has small holes for the molten glass to flow.

- **Epoxy resin**

The epoxide group can be referred to as a glycidyl group. The resins are adaptable in nature, especially in erosion to opposition, high quality to weight proportion, adhesion properties and dimensional dependability. They are the polymers that are normally made up by methods for gathering epichlorhydrin with bisphenol A. The resins are shaped at temperatures in the locale of 50-100ºC because of the way that the consistency is high, so that because of this, they disintegrate in a inert solvent dissolvable to limit the thickness with the goal that cover at encompassing temperature is conceivable.

Fig 1: a) Graphene powder, b) Kenaf fabric mat, c) Banana fabric mat, d) Glass fabric mat, e) Epoxy resin.

B. Fabrication Technique

Hand lay-up technique is basically an open moulding that is suited for fabricating from small to large varitey of composites. Through it is lesser in terms of production volume per mould, it is possible to make up the composites in large quantites using multiple stamps. The hand lay technique is the most basic type of fabrication which ia sample in the process, offers varying ranges of sizes and also provides tooling at low price, however skilled operators are needed to obtain the consistency in quality and good production rates. The changes in design can be made at the spot with a minimum share for the equipment.

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Fig 2: Hand lay-up technique process

A. Materials

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 E-Glass 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 wt. %.

Table 1: Details of Materials Procured

Material	**Manufacturer/Suppliers**	**Quantity**
Al 7075 alloy	FENFE METALLURGICALS located at Uttarahalli, Bangalore	50 kg
E-Glass fiber	Suntech fiber india pvt. Ltd, Vasanth nagar, bangalore.	2 kg
CNT	United nanotech innovations pvt. Ltd. Hosakote, bangalore	600 g

B. Fabrication method

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 Al 7075 and Al 7075 Hybrid composites.

Al based MMC preparation by Stir Casting

A schematic of stir casting setup is as shown in figure, It consists of a coke fired furnace and a stirrer assembly, which was used to synthesize the composite.

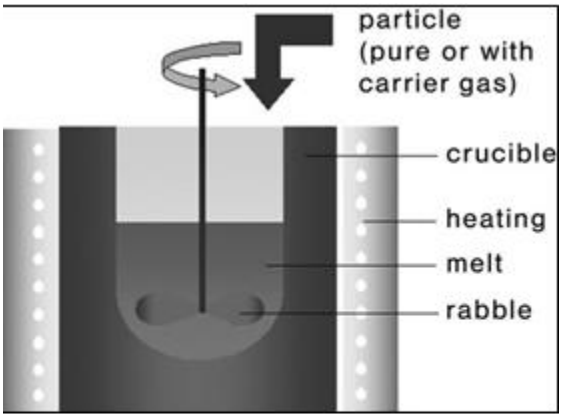

Fig 3: Graphical representation of stir casting

Table 2: Composition of Cast Hybrid Metal Matrix Composite

Composite Designation	**E-Glass %**	**CNT %**	**% Al 7075**
C1	0	0	100
C2	1	0.5	98.5
C3	1	1.0	98
C4	1	1.5	97.5
C5	1	2.0	97
C6	5	0.5	94.5
C7	5	1.0	94
C8	5	1.5	93.5
C9	5	2.0	93

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III. EXPERIMENTATION

- **Tensile 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 10mm and gauge length 60 mm 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.

Fig 4: Universal Testing Machine

Fig. 5: Tensile Specimens before Test

Fig. 6: Tensile Specimens after Test.

- **Compression Test**

Specimens were machined in according with ASTM [E9] standards, diameter of 20mm and length of 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.

Fig. 7: Compression Specimens before Test

Fig. 8: Compression Specimens after Test

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- **Hardness Test**

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 20 mm 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.

Fig. 9: Hardness Test Specimen before Testing

Fig. 10: Hardness Test Specimen after Testing

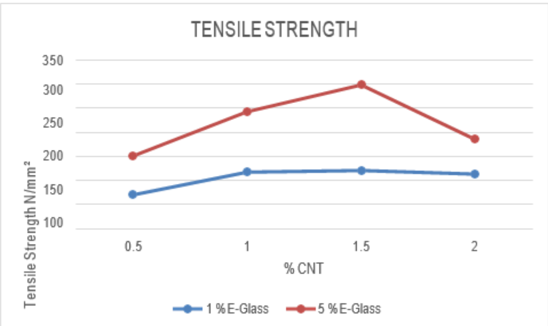
IV. RESULTS

- **Tensile Test Results**

To explore the properties of developed metal matrix (Al 7075) composite with varying weight percentages of CNT and E-Glass under tensile load, are tested and obtained values is given in the below table and Graphs are plotted.

Table 3 Tensile Strength of Al 7075.

Specimen Designation	wt% of Al 7075	wt% of E-Glass	wt% of CNT	Max. load (N)	Max. Displacement (mm)	Tensile Strength (N/mm^2)
C1	100	0	0	2667.4	2.368	51.1
C2	98.5	1	0.5	1951.5	1.358	70.393
C3	98	1	1.0	3285.2	4.345	117.7
C4	97.5	1	1.5	3363.7	5.134	121
C5	97	1	2.0	3138.1	4.676	113.57
C6	94.5	5	0.5	1412.2	0.789	80.52
C7	94	5	1.0	1265.1	0.9	125.2
C8	93.5	5	1.5	4883.7	3.666	177.357
C9	93	5	2.0	1990.7	2.096	71.568



Graph 1: Tensile Strength of AHMMC

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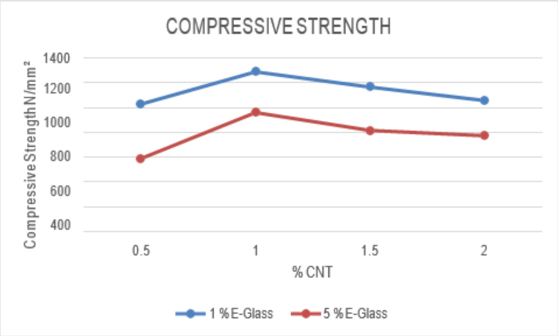
- **Compression Test Results**

To explore the properties of developed metal matrix (Al 7075) composite with varying weight percentages of CNT and E-Glass under compressive load, are tested and obtained values is given in the below table and Graphs are plotted.

Table 4: Compressive Strength of Al7075 Hybrid Metal Matrix Composite.

Specimen Designation	Wt.% of Al 7075	Wt.% of E-Glass	Wt.% of CNT	Peak Load (KN)	Compressive Strength (N/mm^2)
C1	100	0	0	96.9	554.24
C2	98.5	1	0.5	181.02	1028.47
C3	98	1	1.0	227.16	1288.9
C4	97.5	1	1.5	197.44	1166.37
C5	97	1	2.0	186.72	1058.03
C6	94.5	5	0.5	105.78	588.79
C7	94	5	1.0	169.2	960.03
C8	93.5	5	1.5	143.7	815.35
C9	93	5	2.0	136.56	772.77



Graph 2: Compressive strength of Al 7075 Hybrid Metal Matrix Composite.

- **Hardness Test Results**

To explore the hardness property of developed metal matrix (Al 7075) composite with varying weight percentages of CNT and E-Glass under load, are tested and obtained values is given in the below table and Graphs are plotted.

Table 5: Hardness of Al7075 Hybrid Metal Matrix Composite

Specimen Designation	Avg. Dia. of indentation (mm)	Brinell Hardness Number			Avg. BHN
		Trial 1	Trial 2	Trial 3	
C1	2.4	58	50.1	47.6	51.9
C2	1.98	75.2	78.3	80.2	77.9
C3	1.94	79.2	83.5	81.2	81.3
C4	2.1	65	71	70.4	68.8
C5	2.38	56.5	54	47.9	52.8
C6	1.94	79.5	82.3	82.1	81.3
C7	1.85	88.2	92.1	88.8	89.7
C8	2	75.3	80.1	73.5	76.3
C9	2.06	68.7	77.2	69.2	71.7

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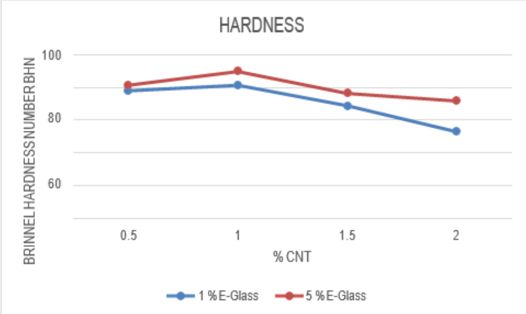

Graph 3: Hardness of Al 7075 reinforced with E-Glass and CNT

V. CONCLUSION

In this present research work we take part the exploration of a new Hybrid composite material and finally fabricated an Al 7075 reinforced with E-Glass and CNT hybrid metal matrix composite. Newly developed metal underwent through different test to determine its properties. After brainstorming, we arrived into the following conclusions.

- It is observed that with varying Percentage of CNT, Tensile Strength increases from 70.393 N/mm2 to 113.57 N/mm2 for 1% E-Glass and for 5% E-Glass the tensile Strength increases from 80.52 N/mm2 to 71.568N/mm2
- The increase of tensile strength is due to the increased area of bonding at the interfacial region of the matrix and the reinforcement. The maximum tensile strength of 177.357 MPa is obtained for C8 hybrid composites
- For 1% E-glass it is observed that with varying Percentage of CNT compression strength increases from 1028.47 N/mm2 to 1058.03 N/mm2 and for 5% E-glass the compression strength increases from 588.79 N/mm2 to 772.77N/mm2.
- The increase of compression strength is due to the increased area of bonding at the interfacial region of the matrix and the reinforcement.
- The maximum compression strength of 1288.9 MPa is obtained for C3 hybrid composites. The percentage increase found to be 132.55%.
- It is obvious that hardness increases with increase in weight percentage of E-Glass even though it decreases with increase in weight percentage of CNT.
- The maximum hardness of 89.7 BHN is obtained for C7 hybrid composites. The percentage increase found to be 72.83%.
- The hardness increases with the addition of CNT up to 1 wt. % and further hardness decreases with increase in weight % of CNT. This is due to higher hardness of dispersoids particles and further increase in this dispersoids particles (CNT) may result in decrease in bonding strength of matrix with reinforcement...

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