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Mechanical Behavior of Aluminum Metal Matrix Composite Reinforcement with Graphene Nano Fillers

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Abstract:- Graphene is an extraordinary material being the lightest and strongest material, it has an incredible mechanical property. It being allotrope of carbon, also has exclusive optical and thermal properties, which make it evident filler for producing multipurpose composites significantly metal matrix composites. Aluminium contributing to highly used metal due its cost effectiveness, corrosion resistance and light weightiness in numerous industries. Aiming to synthesize aluminium metal matrix reinforced with graphene nano filler and to investigate its mechanical behavior by using stir casting method. By varying the weight percentages of graphene nano particulates are used to fabricate metal matrix composite by using 6061 Aluminium grade. The developed nano composite is further verified by metallurgical microscopic images to discuss the distribution of reinforcement in the metal matrix base. The strength of the developed composite is determined by tensile test, hardness of the material by Brinell's hardness test and toughness by impact test. The interference of two material causing various properties to change in the material and helps in choosing the best combination for our required material for the product.

***Keywords*:-** *Aluminium, Graphene, Composite.*

I. INTRODUCTION

On the bases of different field in the industries in engineering have a high utility of aluminium due to its cost effectiveness, abundance, and the light weight property. By various techniques and different composition of aluminium, material properties can be changed as per our requirements. As we know graphene is one of the most distinctive materials with extraordinary electrical, mechanical, thermal properties among the carbonaceous material. Through this research we attempt to combine both remarkable material aluminium and graphene as one by aluminium being the matrix material and graphene nano filler acting as a reinforcement of the composite. By different testing method we try to validate the composite material properties with different ratios of matrix and reinforcement and optimize the most efficient out of all the compositions. Through this the obtained results can be considered as a choice of material selection for various applications of aerospace, automobile, marine and many more growing industries.

➢ *The Research Process*

The research process gives a better understanding of the problem and its outline is effective in carrying out all stages inherent in the process. The skills required to write a report, proposal or to put together a presentation involves in identifying, detecting, assessing and the info essential to support research questioning, developing and expressing our ideas.

➢ *Graphene*

Graphene is the thinnest, strongest and most conductive material known to man today. Even though 3 million sheets of graphene were stacked on top of one another it would be just 1mm thick. A single layer of graphene is 1 carbon atom thick having a honey comb lattice. Each side of the carbon hexagon has a length of 0.142 nanometers. Carbon has a 2- dimensional lattice with sp2 hybridization in every graphene layer or graphite an allotrope of carbon. Flakes of graphite are actually made of many layers' graphene stacked on top of each other, with a weak bond holding them together.

• *Carbon*

Carbon is highly versatile and an incredible element, it is also known as life element. It is the sixth-most abundant element in the universe and seventeen most abundant element by mass in the earth crust. It exists in free state (element) and combined state(compound). Carbon naturally occurs as carbon-12 isotope which is 99 percentage of carbon in the universe. Carbon being a pattern maker by bonding in diverse ways, results in various amorphous and crystalline allotropes. Among the hardest and softest materials known, both Diamonds and Graphite belong to the carbon respectively. Furthermore, millions of compounds are formed, both organic and inorganic. 18.5% of the human body is made from carbon, by mass it is the second most abundant element in the human body after oxygen.

- *Frist Studies Of Graphene*

The electronic structure of graphite was the first step to understanding graphene by physicist R. Philip in 1947. The designation graphene was a result of combination of word graphite and suffix-ene (referring to aromatic hydrocarbons), in 1986 by chemists Ralph Setton, Eberhard Stumpp, Hanns-Peter Boehm. Isolation of a single-layer graphene was exfoliated using an extremely simple method by physicist of University of Manchester Konstantin Novoselov and Andre Geim in the year of 2004. The top layers from the graphite sample were remove by adhesive tape and then the layers were applied to substrate material. Graphene which has remained on the substrate was in the form of single layer graphene, where this method was known as "scotch tape method". The achievement of not only isolating the graphene in the form of flakes but also studying their physical properties, particularly electron mobility in graphene is very high, it led to the possibility of using graphene in electronics.

Table 1 Properties of Defect Free Graphene

Property	Value
Tensile Strength	130 GPa
Youngs modulus	1 TPa
Density	2267 kg/m^3
Thermal conductivity	3000-5000 kW/mK (parallel) 6W/mK (perpendicular)
Optical absorption coefficient	2.3%

Different exceptional properties caused research to expand in different subfields and due to simple method of preparation triggered multiple number of companies and research labs to develop commercial graphene and led to stampede in research and development and a patent land rush with 31,000 patents and hundreds of thousands of scientific papers. There are well as over 100 graphene producers worldwide and is a growing market. The estimation of graphene market value in 2020 was over €100 million and by 2025 it is expected to be €150-550 million. Furthermore, University of Manchester was established as the National Graphene Institute.

- *Applications of Graphene*

New era of industrial revolution could be created by combining all astonishing properties of graphene. Graphene is a ground breaking material which is said to be the future of technology, vast number of applications in products, process and industries for which graphene could disrupt the existing by creating a significant impact in all stems of technologies or materials, opening up new markets. Graphene in various fields, here are few Biomedical, Composites and coatings, Energy, Membranes, Sensor, Sports, Electronics and these are just only the start.

➢ *Composites and Coatings*

In addition to the impressive intrinsic mechanical properties of graphene, its low mas and low loading requirements (with relatively little material we can get a big change) make graphene stand out as a reinforcing agent in composites.

- *Lightweight composites for body structures*
- *Lubricants with enhanced anti-wear properties*
- *Nanolaminates as ultra-high permeation barrier films*
- *Corrosion protection*
- *Transparent, flexible and conducive thin films*
- *High performance sheets for EMI shielding*
- *Reduces the effects of lightning strikes and increases fuel efficiency in aircraft*
- *De-icing*

➢ *Aluminium*

Aluminium is a silvery white metallic which is the most abundant metal in the earth crust which belongs to the 13th group the boron family of the main periodic table. The moon surface also features large amount of Aluminium. It was once called king of metals and was discovered in 1825 in Denmark. Aluminium being a light weighted metal is used majorly in aerospace industry. Boeing -747 contains 66,000kg of Aluminium. Pure aluminium does not have high strength so, highly alloys of aluminium is used in various industries. Aluminium reflects 98% of infra-red rays. Aluminium is one third times lighter than steel and copper. It is the 3rd most common element in the earth crust which can be easily recycled.

Table 2 Aluminium Properties

Aluminium Elemental Properties	
Atomic number	13
Atomic weight	26.9815384
Melting Point	660
Boiling Point	2,467
Specific Gravity	2.70 (at 20
Valence	3
Electronic Configuration	$1s^2 2s^2 2p^6 3s^2 3p^1$

- *Aluminium 6061*

Due to vast number of applications in various industries, each industry has different properties requirements. Since all the properties required are not available in a single material, formation of alloys and composites took place. Wrought alloys are alloys with low percentage of alloying elements (around less than 4 %) and they are workable material. Whereas cast alloys have higher percentages up to 22 % and they are usually brittle. Aluminium 6061 is an alloy where aluminium is the base metal and 6xxx aluminium, which entails those alloys which use silicon and magnesium as the primary alloying elements. Second digit designates the degree of impurity control for Al base and "0" specifies that the bulk of alloy is commercial aluminium. Designators for individual alloys is simply specifying the last two digits. Aluminium 6061 has increased strength, toughness, conductivity and furthermore is heat treatable, easily formed and good at resisting corrosion.

Table 3 Physical and Electrical Properties of Aluminium 6061

Physical and Electrical Property	
Property	**Value**
Density	2.70 g/cm^3
Electrical resistivity	3.66 x 10$^{-6}\Omega$

Table 4 General Characteristics of Aluminium 6061

General Characteristics	
Characteristics	**Appraisal**
Strength	Medium to High
Corrosion Resistance	Good
Weldability & Breakability	Good
Workability	Good
Machinability	Good

Table 5 Thermal Properties of Aluminium 6061

Thermal Properties	
Property	**Value**
Coefficient of Thermal expansion (20-100°C)	23.6μm/m-°C
Thermal Conductivity	180 W/m-K
Specific Heat Capacity	0.896 J//g-°C
Melting Point	582 - 651.17°C

Table 6 Mechanical Properties of Aluminium 6061

Aluminium 6061 Mechanical Properties	
Property	**Metric**
Ultimate Tensile Strength	124MPa
Tensile Yield Strength	55.2MPa
Shear Strength	82.7MPa
Fatigue Strength	62.1MPa
Modulus of Elasticity	68.9 Gpa
Shear Modulus	26.0 Gpa
Machinability	30%
Hardness, Brinell	30

- *6061 Aluminium Applications*

Aluminium 6061 grade material is one of the most frequently and commonly used among the versatile world of Aluminium alloys. It is highly familiar for its strength workability, ease of joining, resistance corrosion, stress and cracking, and this means it is a grade which features good formability. This alloy particularly tends useful in the world of architecture, structures and automotive industries. Few major applications of grade6061 aluminium include:

- ✓ *Aircraft structures and body*
- ✓ *Welded Assemblies*
- ✓ *Truck and Automobile parts and frames*
- ✓ *Marine frames*
- ✓ *Chemical equipment*
- ✓ *Electronics parts*
- ✓ *Heat sinks and exchangers*
- ✓ *Scuba diving high pressure tanks*
- ✓ *Packing for food and beverages*

➢ *Composite*

Simply to put, Combination of different components is a composite. The combination of two or more natural or artificial elements with non-identical physical or chemical properties, that make the material well-built as a team than as individual players. The components combine and contribute their most useful traits to enhance the final product outcome, without losing their individual identities by not merging together completely. Just like the saying hitting two birds with one stone, through composites we attain different features in a single material. Which make reason for use of composites over traditional material. Matrix and reinforcement material are the different phases in composite. When reinforcement or the filler is added to the matrix, the matrix acts as the binder. Reinforcements are primarily classified into four types. They are

- *Short fibers or Flakes or whiskers*
- *Continuous fibers*
- *Plates or sheet*
- *Particles*

- *Classification of Matrix*

Composite matrix is primarily and majorly classified into three types. They are:

- ✓ *Polymer Matrix Composite (PMCs)*
- ✓ *Metal Matrix Composite (MMCs)*
- ✓ *Ceramic Matrix Composite (CMCs)*

- *Metal Matrix Composite (MMC)*

The composite consisting of at least two components and one being metal and other being any other material such as ceramics and organic compounds. In a hybrid composite at least three types of material are present.

- *Apllications of Metal Matric Composites*

Composites provide many useful benefits such as corrosion resistance, light weight, strength, lower material costs, improved productivity, design flexibility, and durability. So, composites have applications in numerous fields. Few of them are

- ✓ *Aerospace, Marine*
- ✓ *Architecture and Robotics*
- ✓ *Automotive and transportation*
- ✓ *Corrosive environments*
- ✓ *Energy, sports and recreation*

II. LITERATURE SURVEY

A. Review of Literature

➢ *Survey on "Effect of Graphene nanoparticles on microstructural and mechanical properties of aluminium based nanocomposites fabricated by stir casting."*

Composite materials have a widespread application in different areas of manufacturing sectors for metals and new class of engineering materials is the current demand for aircraft and automobile companies, which is a highly developing field. By using the stir casting method, an aluminium-based nano metal matrix composite reinforced with graphene nanoparticles has been developed. By using weight percentage (0.4%, 0.8% and 1.2% by weight) of graphene nanoparticles are used to fabricate metal matrix composites (MMCs) and the metal being used is aluminium 1100(AA1100).

The melted metal is stirred continuously and the dispersed phase is mixed with the molten matrix using a mechanical stirrer, this is a liquid state method for the fabrication of composite material and this method is known as Stir casting. AA1100 is one of the pure commercial wrought alloys containing 99% aluminium. AA1100 and is It in the making of lighter crafts and engine components. the aluminium material is heated in an electric resistance furnace at a temperature of 800°C to 950°C (above the melting temperature of AA1100 alloy). Adding wetting agents before reinforcement to the melt does not reduce the wettability of the unreinforced alloy as if not added oxidation and the reinforcement particles remain unmixed. the reinforcement was preheated simultaneously in a different furnace at a certain temperature of 350°C for about 10–15min to remove moisture, impurities. The vortex and the stirrer are kept at a constant speed of 400 rpm to mix the reinforcement into the molten, after the metal is completely melted. After completion of stirring process, the molten is let into the dye and left cool naturally and solidify.

The developed composites were further validated by tensile test, Rockwell hardness test, impact test (toughness), density calculation and optical microstructures. Graphene nano particles were observed from the imaging, that they were distributed throughout the matrix phase. By comparing the increasing percentages of reinforcement, it was found that the yield strength and ultimate strength have also shown an increasing trend. It is also observed from the graph that the elongation at peak goes decreases with an increasing percentage of graphene nanoparticles.

- *Survey on “Strengthening effect induced by interfacial reaction in graphene nano- platelets reinforced aluminium matrix composites.”*

Graphene nanoplatelets reinforced aluminium matrix composites with the different volume fractions of reinforcement (0.3, 0.6, 0.9 and 1.2 vol %) have been successfully fabricated by spark plasma sintering. The interfacial Al_4C_3 phases take on nano-rod or granulate with a mean diameter of ~30 nm has been indicated by microscopy observation. The interfacial bonding state between Graphene nanoplatelets and Al matrix changes from mechanical bonding to strong chemical bonding and nano-sized Al_4C_3 phases are uniformly distributed and intimately contacted with graphene nanoplatelets, because Al_4C_3 phases are tightly locked into matrix forming an anchor effect. The grain refinement strengthening, Orowan strengthening, dislocation strengthening by CTE mismatch and load transfer was investigated and has shown strengthening effect induced by interfacial reaction composite. Load transfer in graphene nanoplatelets-Al composites has been significantly affected by interfacial nano-sized Al_4C_3 phases. During tension and the anchor effect of Al_4C_3 phase, load transfer has been calculated from the experimental value and it was one- to twofold higher than its theoretical maximum.

- *Survey on “Fabrication and heat treatment of graphene nanoplatelets reinforced aluminium nanocomposites.”*

Synthesis of graphene nano particulate reinforced in aluminium matrix was successfully done through noncontact ultrasonic vibrations assisted by stir casting process. the mechanical and physical properties that have established in the addition of graphene nanoplatelets in aluminium matrix have improved. Such as the microstructure, tensile strength, hardness and tribological characteristics have been experimentally investigated by fabricating the composites. Base matrix resulted in grain refinement due to the incorporation of graphene, caused ultimate tensile strength to increase by 33% and micro hardness by 27% .0. The influence of T6 heat treatment caused further enhancement in properties 37% and 34% in ultimate tensile strength and microhardness of fabricated composites as compared to samples attributed to age hardening. Decrease of about 24% in coefficient of friction of graphene aluminium composites as compared to base matrix was caused due to the addition of self-lubricating graphene in aluminium matrix resulted in improved wear behavior of prepared composites.

III. FABRICATION PROCESS

The key ingredients for manufacturing are materials, which are the driving force behind the technological revolutions. Casting process manufactures objects with high compressive strength. Creates any complex and complicated structure economically and easily. Isotropic structures are formed with accuracy and wide varying range of properties. Significantly, it is the low-priced and object size is not limited among all the manufacturing process.

- *Material Composition*

Graphene nano particulates of 90 nano microns reinforced into aluminium metal matrix of Al6061 grade. The cast having dimensions 200x200x25mm, a pure aluminium block has the weight of 2,700grams (2.7kg).

Table 7 Composite Composition

Sample no	GNP%	Aluminium(gr)	GNP (gr)
1	0.2	2,694.6	5.4
2	0.4	2,689.2	10.8
3	0.6	2,683.8	16.2
4	0.8	2,678.4	21.6
5	1.0	2673	27
6	1.2	2,667.6	32.4

Fig 1 Graphene powder and Casting Block of Dimensions 200x200x25mm

➢ *Stir Casting*

For uniform distribution of reinforcement, stir casting method highly recommended due to its simplicity, flexibility, low manufacturing cost and also its availability for mass production. We used a modern stir casting method rather than choosing conventional type, as it results in higher quality product with fine mixing of reinforcement and formation of less voids in the grain structure. Stirring occurs in a medium frequency induction furnace. The furnace contains a non-conductive crucible made out of graphite which can melt nearly 15Kgs of metal.

Table 8 Manufacturing Conditions

Manufacturing conditions	
Frequency of furnace	600 hertz (rps)
Power of furnace	125 kilowatts
Crucible material	Graphite
Melting temperature	700°C
Pouring temperature	710°C
Mixing time	7-10 min
Stirring	1500rpm
Preheat of reinforcement	300-350°C
Casting die material	Cast Iron

Induced current is produced from the varying magnetic field which is called eddy current, eventually leading to joule heating. The unique electromagnetic waves known as radio frequency energy is responsible for induction heating caused by passing eddy currents. The action of medium frequency-based furnace results in homogenous melt with effectively controllable frequency and cleaner melt without any by products. Melt of the composite is poured in to a preheated die cast made out of cast iron. The die is preheated for the removal of moisture, impurities and to not cause rapid cooling of the melt.

Fig 2 Medium Frequency Induction Stir Casting Furnace

➢ *Specimen and Specimen Sizing*

Table 9 Specimen Sizing

Specimen	Dimensions (mm)
Impact test	10x10x55
Impact specimen notch depth	2 (notch angle 45°)
Hardness test	25x25x25
Tensile test	150x20x12.6
Original gauge length	50

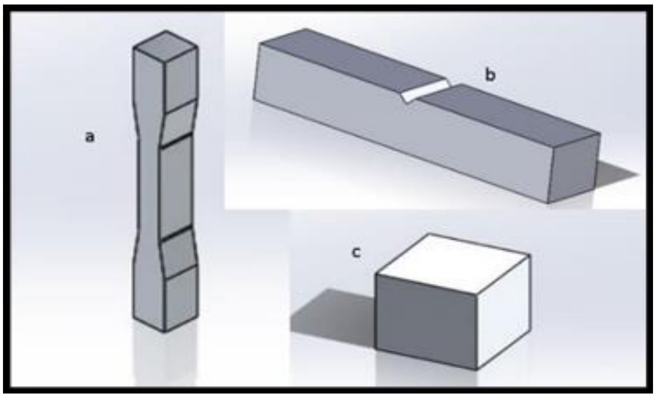

Fig 3 (a) Tensile Test, (b) Impact Test, (c) Hardness Test Specimen

➢ *Machining*

We have selected CNC (Computer numerical control) machine due to its increased efficiency speed production and also ensures accuracy and consistent product quality. By removal of material using rotary cutters by advancing the workpiece, this type of machining is milling. Each casted block of composite is machined with CNC Milling machine. We obtain three specimens in every individual block, all together eight-teen specimens.

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Fig 4 CNC Milling

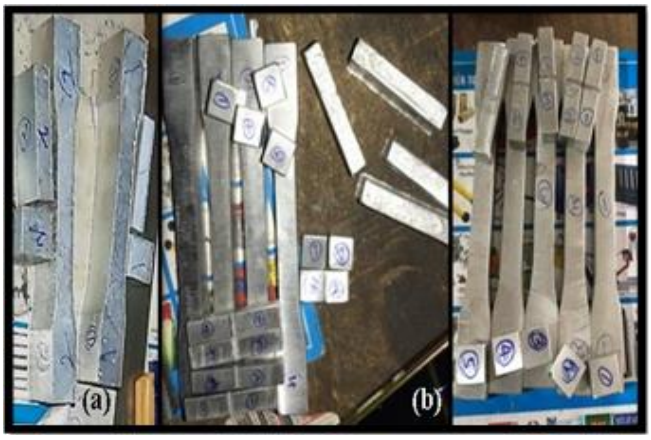

Fig 5 (a) Machined specimens (b) Surface finished specimens

IV. TESTING

➢ *Tensile Test*

Tensile properties frequently are included in material specifications to ensure quality and they are often measured during development of new materials and processes, so that different materials and processes can be compared. Tensile tests are used in selecting materials for engineering applications, their results come in handy during selection process. The material is tested on the basis of ASTM B557 - 15 Test Methods for Tension Testing Wrought and Cast Aluminium- and Magnesium-Alloy Products.

Fig 6 Universal Testing Machine

Fig 7 Specimen tested by UTM

➢ *Impact Test*

Studying the toughness of material relies on the factor of the materials ability to absorb energy during plastic deformation. Toughness is measured by testing the material with impact testing machine. More brittle the material, less is the materials toughness and that means the material results to endure only small amounts of plastic deformation. Often the impact energy of a material is decreased, at lower temperatures as impact value of material can also change with temperature. The test procedure was on the basis of IS 1757(Part-1) 2014 and the type of impact was Charpy – V grooved at room temperature.

Fig 8 Charpy Impact Testing Equipment

Fig 9 Specimens Tested for Impact

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➢ *Hardness Test*

The hardness test is, by far, the most valuable and most widely used mechanical test for investigating the properties of metals and other materials. Resistance to permanent indentation of a material usually is considered hardness. The primary purpose of the hardness test is to determine the suitability of a material for the application that has been taken into consideration, or the particular treatment to which the material has been subjected. The simplicity with which this mechanical test can be made has made it the most common method of inspection for metals and alloys. The test is conducted on Rockwell cum Brinell Hardness machine, with an indenter of 5mm and with a load of 250 Kgf. According to the test procedure of IS 1500-2015.

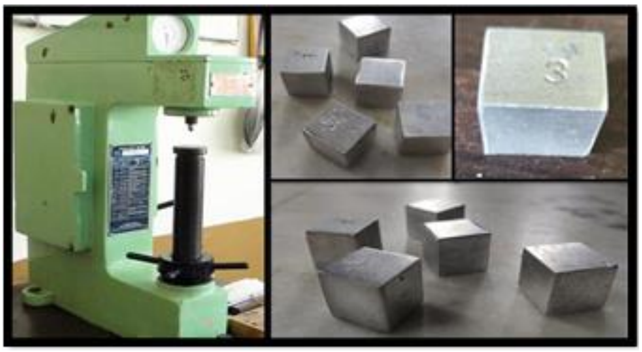

Fig 10 Brinell's Hardness equipment and its Work Pieces

➢ *Microscopy Grain Structure Test*

The mechanical and technological properties of materials is directly linked to the grain size and orientation. Graphene nano particulates distribution also causes a primary factor for different measure of properties. The fine distribution of graphene causes progressively high strength than the non-uniform distribution of particulates. The specimens have been tested as per the ASTM E112 standards. The area analyzed is 0.5791mm2, with magnification of 100X and by adding the Keller reagent as the etchant**.**

V. RESULTS AND OBSERVATIONS

➢ *Utm Results*

The load versus elongation graphs is developed according to the ASTM B577 standards for the tensile test. All the six specimens having varying graphene percentage reinforced into aluminium metal matrix. The specimen is flat having dimension 150x20x12.6mm and with a gauge length of 50mm. The ultimate load, ultimate tensile strength, elongation, yield load and yield stress are evaluated.

Table 10 Tensile Test Results of Al6061-GNP composite

GNP %	**0**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**
Ultimate tensile strength Mpa	124	135.86	143.87	141.5	152.60	149.76	149.95
Elongation %	-	5.940	7.00	8.88	13.56	14.94	14.28
Ultimate load kN	25	34.78	36.20	35.90	38.70	37.74	37.8
Yield load kN	-	25.98	26.2	25.98	29.54	26.54	28.98
Yield stress N/mm2	-	101.48	104.13	102.44	116.48	105.32	114.8
Final gauge length mm	-	52.97	53.3	54.44	56.78	57.47	57.14

The test is conducted at room temperature, it is revealed from the curves that the increasing percentage of graphene nana flakes, increased the yield strength and ultimate tensile strength. The maximum yield strength and ultimate tensile strength obtained are 116.48Mpa and 152.6Mpa at 0.8 % GNP respectively. As compared to raw material the tensile strength increased by 28Mpa, it credits the fact that there is strong physical bonding between the both materials causing the increase in tensile properties. It is observed that the elongation has a slight increase till 1.0% of GNP and then a decrease in the curve, this is due to increase in reinforcement percentage the brittleness increases in the composite. High interfacial strength has caused the transfer of load from aluminium to high strength graphene. The slight decrease in ultimate tensile strength at high weight fraction of reinforcement is due to non-uniform distribution of filler and base matrix. Agglomeration (clustering) of nano particulates in the tensile specimen leads to early failure of composite as compared to other mixture of composites.

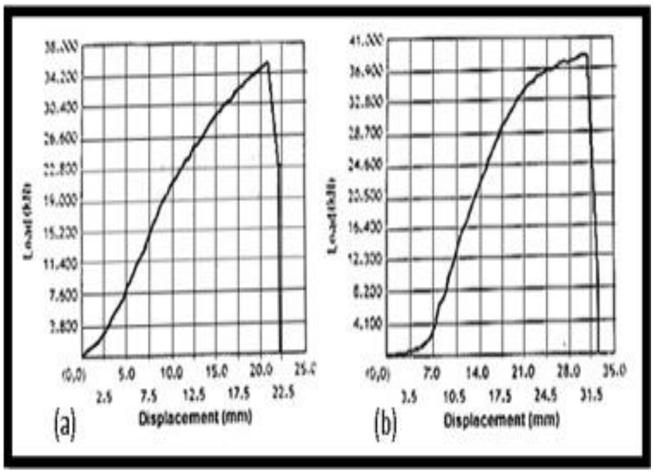

Fig 11 Load Versus Elongation Curve of (a) 0.2% (b) 0.4% GNP

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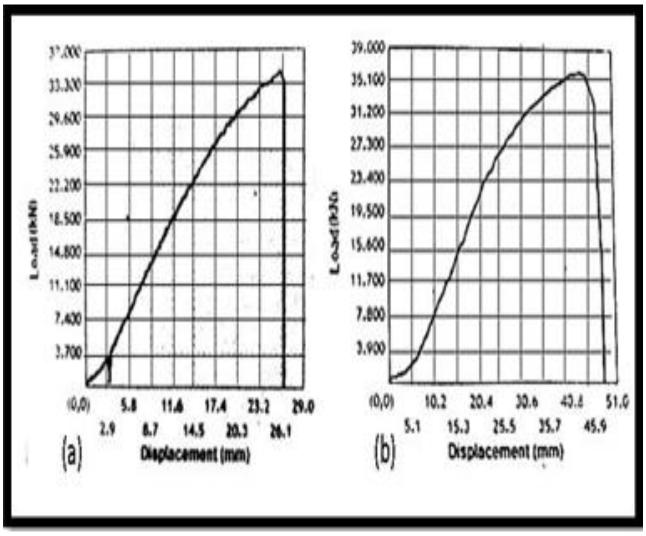

Fig 12 Load versus Elongation Curve of (a) 0.6% (b) 0.8% GNP

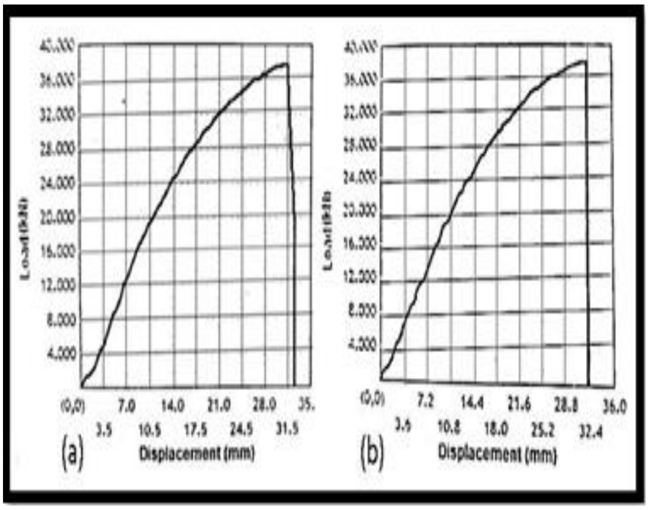

Fig 13 Load Versus Elongation Curve of (a) 1.0% (b) 1.2% GNP

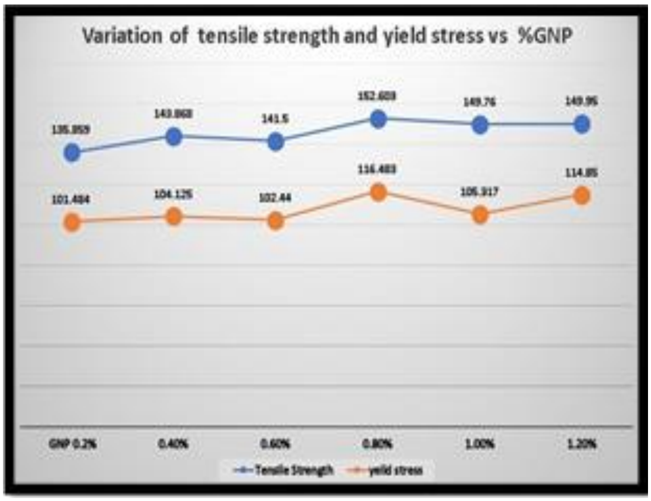

Fig 14 Variation of tensile strength and yield stress versus % GNP

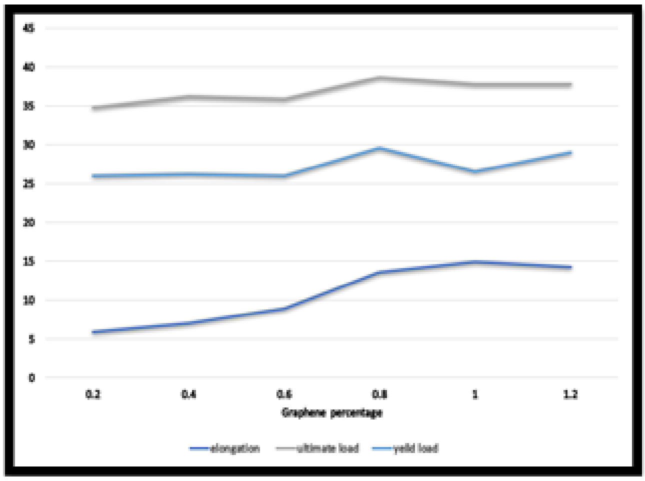

Fig 15 Elongation, Ultimate load and yield load versus GNP%

➢ *Charpy Impact Test Results*

As per IS 1757 (part-1): 2014 the impact test is done by using Charpy-V Impact Test equipment having 2mm deep notch with a notch angle of 45° and with dimension of 10x10x55mm, at room temperature. The impact energy has increased with the increase addition of graphene nano particulates in the matrix material but there is a slight drop at 0.8% of GNP. The impact energy results in the toughness of the material which is linked with both strength and ductility as single measurable property. Impact test represents the change in crushing speed as a specimen that absorbs the impact energy and the material reproduces the behavior of a structure in an actual crash. We can observe from the tensile test that at 0.8% GNP the material has high yield strength and ultimate tensile strength, the fact that the composites impact energy will be seen to decrease if the yield strength is increased. The maximum impact energy seen is at reinforcementmixedwith1.0%.

Table 11 Impact test results of Al6061-GNP composite

GNP%	0.2	0.4	0.6	0.8	1.0	1.2
Impact strength J	6.0	10.0	10.0	8.0	16.0	12.0

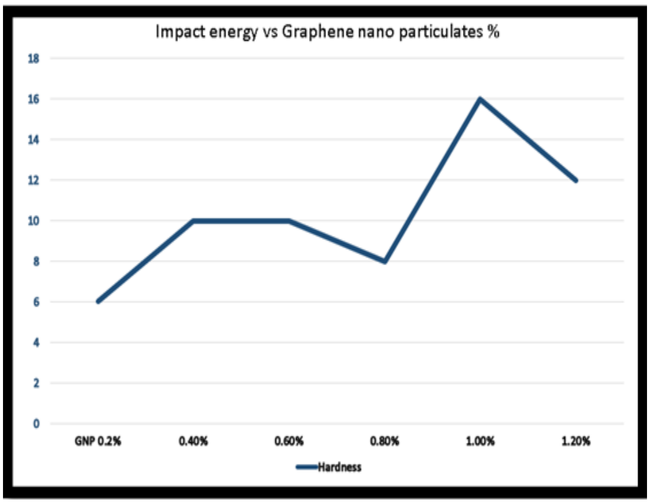

Fig 16 Impact Energy versus GNP%

➢ *Brinell's Hardness Test Results*

At room temperature, the specimens are tested and the obtained results are plotted in graphical form. The Brinell's test is done with an indenter of 5mm with an applied load of 250 Kgf according to the IS 1500 standards. Each specimen is tested in three different locations of the specimen with the indenter. The Brinell's hardness number (BHN) after addition of reinforcement to Aluminium significantly increased. The minimum hardness value of 30 BHN was noted for the unreinforced AL6061 alloy. The hardness value highly increased after the addition of the reinforcement. The maximum hardness was 68 BHN at 1.2% of reinforcement addition and after the addition of particulates the hardness increased gradually from 0.2 to 1.2 % of GNP. To add it up, the increase in the weight percentage of graphene nano particulates can be contribute to the GNP providing high restraining force for deformation during indentation, owing to aberrant structural properties. It can also be observed that at 0.8% of GNP we can see the optimistic result of low brittleness.

Table 12 Hardness test results of Al6061-GNP composite

GNP%	0.2	0.4	0.6	0.8	1.0	1.2
Hardness	60.83	61.6	62.0	62.0	62.2	68.13

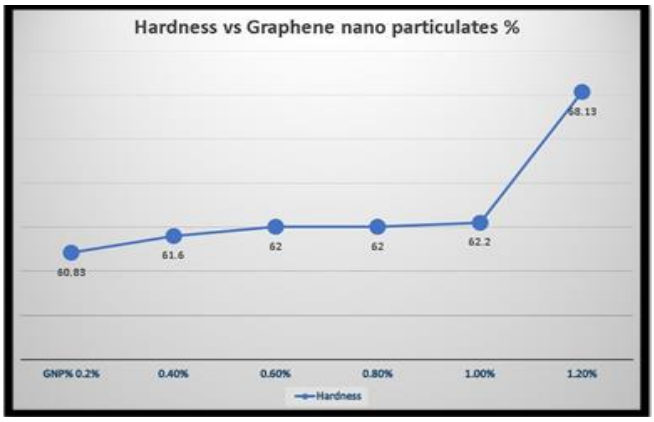

Fig 17 Hardness versus GNP%

➢ *Microscopy Test Results*

The microstructure of grain shows the clusters and agglomeration formed in the grain and it has particle diameter of 10 µm (micro-microns). The mixing of the reinforcement in the base matrix leads to various morphology transition and the columnar microstructure proceeds toward equiaxed micro structure with increasing percentages of graphene. But homogenous mixing is reported mostly in 0.2, 0.6 and 0.8 weight% graphene nano particulates fraction. However, agglomeration of graphene at some locations as reported for composites with 0.4, 1.0 and 1.2 weight percentage of GNPs. High quantity of GNPs offers difficulties in settling down during casting and leads to un even distribution matrix.

Table 13 Microstructure test results of Al6061-GNP composite

GNP%	0.2	0.4	0.6	0.8	1.0	1.2
ASTM grain size	8	8.5	8.5	8.5	8	
Intercepts	465	551	510	540	436	515
Mean Int. length (µm)	18.899	15.948	17.230	16.273	20.154	17.063

Fig 17 shows each at which the crack or the deformation growth takes place through the matrix when graphene flakes are thick or clustered. The homogenous distribution increases with Few-layered graphene (FLG) and size, the mechanical properties are highly benefited.

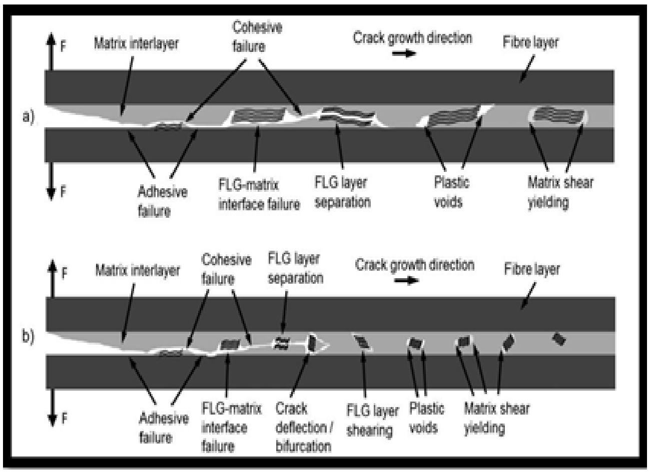

Fig 18 Showing delamination crack growth due to different thickness of with (a) comparable large lateral dimensions (b)small lateraldimensions.

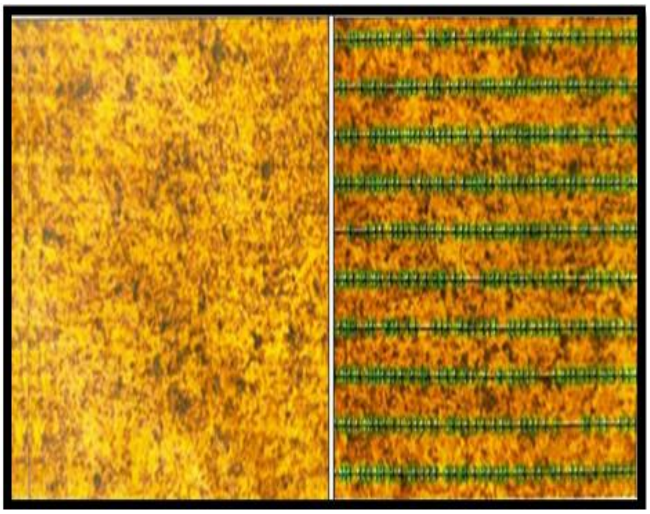

Fig 19 Metallurgical Microscopy (10µm) of Aluminium 6061- 0.2%GNP

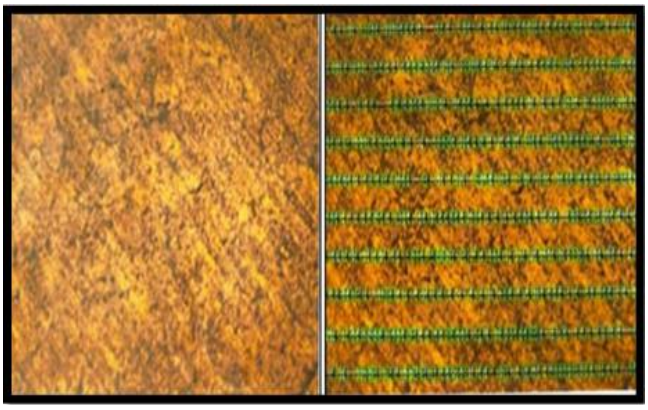

Fig 20 Metallurgical Microscopy (10µm) of Aluminium 6061- 0.4%GNP

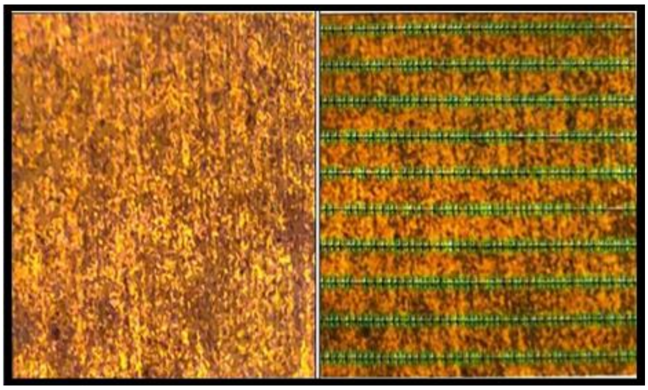

Fig 21 Metallurgical Microscopy (10µm) of Aluminium 6061- 0.6%GNP

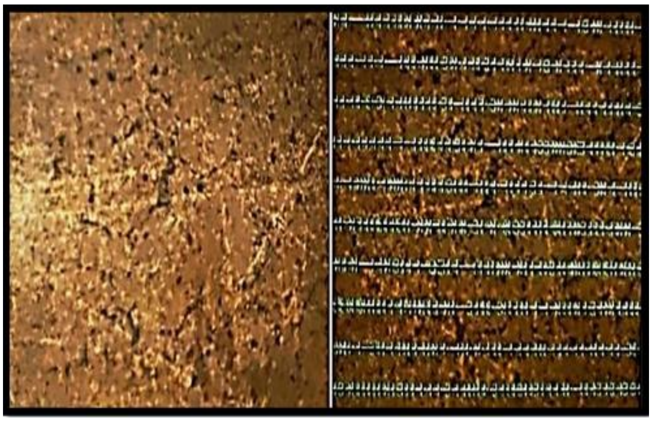

Fig 22 Metallurgical Microscopy (10µm) of Aluminium 6061- 0.8%GNP

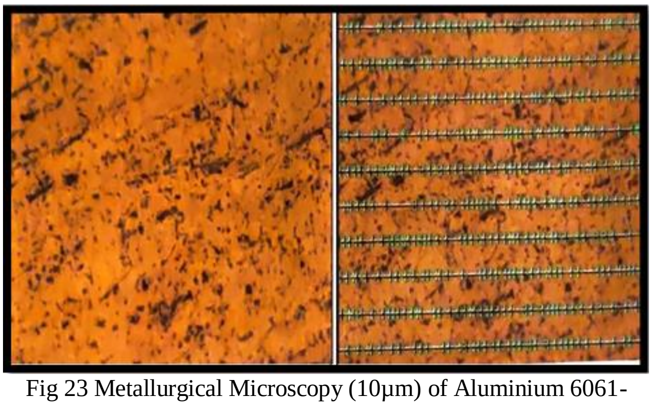

Fig 23 Metallurgical Microscopy (10µm) of Aluminium 6061- 1.0%GNP

Fig 24 Metallurgical Microscopy (10µm) of Aluminium 6061- 1.2%GNP

VI. CONCLUSIONS

The investigation and development of Aluminium metal matrix composite reinforced with varying weight percentages of graphene nano particulates is done successfully. The develop samples are Al6061 with 0.2%, 0.4%, 0.6%, 0.8%, 1.0% and 1.2% GNPs were validated by metallurgical microscopy images to discuss the distribution of the reinforcement throughout the matrix material. The mechanical properties such as tensile strength, hardness and toughness was obtained.

Graphene nano particulates distribution throughout the metal matrix phase has been observed. The grain size, boundaries, size are seen and measured. Additionally, observed the effect of clustering of GNPs and also seen agglomeration of GNPs in the specimens produces from the imaging, they can be comparatively low and can be avoidable.

The yield strength and ultimate tensile strength values show an increasing trend when compared to the increasing percentage of graphene nano particulates percentage. The maximum yield strength and tensile strength reported are 116.48Mpa and 152.6Mpa, respectively, for 0.8 % GNP-Al6061 metal matrix. As compared to the raw aluminium 6061 the strength has significantly increased. It is observed that due to the increase of reinforcement the materials brittleness also increases graphene reinforced composite. The maximum value of Brinell's hardness number is 10 seen in the material at 1.0% of GNPs.

To the whole, the aluminium – graphene reinforced composite when compared the pure aluminium grade its mechanical properties have enhanced. While the material itself is showing a good behavior at mixing the graphene nano fillers 0.8 % where the tensile strength is high, the brittleness is low that is ductility is good and has good impact strength, owing to the observation of further improvement in strengthening the material around that region of mixing of reinforcement percentage of graphene nano fillers.

FUTURE SCOPE OF WORK AND RECOMMENDATIONS

- The research can be further carried out on the different type of heat treatment process to increase the mechanical characteristics of the aluminium reinforced with graphene nano fillers.
- The manufacturing method can be changed for more homogenous distribution of reinforcement which can be further analysed
- The effect of Grain size, grain orientation and the reinforcement size and orientation can be further studied.
- Further understanding the effect of thermal and electrical properties under different manufacturing methods.
- Comparing different qualities of composites prepared by various manufacturing procedure ranging from economical to expensive ones.

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