Evaluation On Mechanical Properties Of Graphene And S-glass Reinforced Al-6061 Metal Matrix Composites

1Verma. R, 2Dr. H k shivanand, 3Dr. Tukaram Jadhav, 4Dr. Ranjith V, 5Puneeth P
1Research Scholar, 2Professor, 3Guest Faculty, 4Assistant Professor, 5PG Scholar
1UVCE, 2UVCE, 3UVCE, 4Dr. AIT, 5UVCE

Abstract* - This research work investigated the influence of the graphene and S-glass fiber on the hardness of the Al6061 / S-Glass & Graphene particulate MMCs. Metal Matrix Composites (MMC's) consist of either pure metal or an alloy as the matrix material, while the reinforcement generally a ceramic material. Aluminium composites are considered as one of the advanced engineering materials which have attracted more and more benefits. Now a day these materials are widely used in space shuttle, commercial airlines, electronic substrates, bicycles, automobiles, etc., Among the MMC's Aluminium composites are predominant in use due to their low weight and high strength. The key features of MMC's are specific strength and stiffness, excellent wear resistance, high electrical and thermal conductivity. Hence, it is proposed to form a new class of composite. The Al 6061(Aluminium alloy 6061) reinforced with graphene and S-glass fiber to form MMCs were investigated. The stir casting technique of liquid metallurgy was used for the fabrication of the composite material. The composite was produced for different percentages of graphene and S-Glass fiber (varying Graphene with constant S-Glass fiber and varying S-Glass fiber with constant Graphene percentage). The specimens were prepared as per ASTM standard size by turning and facing operations to conduct tensile, compression and hardness and they were tested using Universal Testing Machine and Brinell hardness testing machine. The effect of Graphene and S-glass particles on the strength in Al-6061 alloys has been studied.

***keywords* - Al 6061, Graphene, S-Glass fiber, Tensile Test, Compression test and Hardness**

I. INTRODUCTION

In this research paper we study evaluation of Tensile and Compressive strength and the variation of hardness of different compositions of the hybrid composites, material preparation for the test, test the specimen, results and conclusion. A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as ceramic or organic compound. 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. They offer a large variety of mechanical properties depending on the chemical composition of the Al – matrix. They are usually reinforced by Al2O3, SiC, C but SiO2, B, BN, B4C, AlN may also be considered.

In the 1980s, transportation industries began to develop discontinuously reinforced AMCs. They are very attractive for their isotropic mechanical properties and their low costs. MMCs are nearly always more expensive than the more conventional materials they are replacing. As a result, they are found where improved properties and performance can justify the added cost. Today these applications are found most often in aircraft components, space systems and high – end or "boutique" sports equipment. The scope of applications will certainly increase as manufacturing costs are reduced.

The main objective of this project is to develop Al (6061)/ S-Glass & Graphene particulate MMCs where the S-glass & Graphene are used as reinforcement material &Al (6061) is used as matrix material. The different weight % of reinforcement will be added to matrix and liquid casting technique for the preparation of Al (6061)/ S-Glass & Graphene MMCs thus the developed composites will be tested for hardness.

A. K. Dhingra (1986), had derived that the composite structures have shown universally a savings of at least 20% over metal counterparts and a lower operational and maintenance cost. R.L. Trumper (1987), stated that the researchers all over the world are focusing mainly on Aluminium because of its unique combination of good corrosion resistance, low density and excellent mechanical properties. The unique thermal properties of Aluminium composites such as metallic conductivity with coefficient of expansion that can be tailored down to zero, add to their prospects in aerospace and avionics. Mechmet Acilar, FerhatGul (2004), have shown in their work that the choice of Silicon Carbide as the reinforcement in Aluminium composite is primarily meant to use the composite in missile guidance system replacing certain beryllium components because structural performance is better without special handling in fabrication demanded by latter's toxicity. A.Alahelisten (1996) , J.Q.Jiang (1996), P.N.Bindhumadhan (2001), stated that though their low density (35% lower than that of Al) makes them competitive in terms of strength/density values. Magnesium alloys do not compare favorably with Aluminium alloys in terms of absolute strength. The reason for Aluminium being a success over magnesium is said to be mainly due to the design flexibility, good wettability and strong bonding at the interface.

In this present investigation, the effect of S-Glass & Graphene particle with Aluminium & its percentage will be studied. Thus this will aid in reaching an optimum weight of percentage reinforcement the specific objective & scope of the present investigation.

The organization of this document is as follows. In Section 2 (Methods and Specimen Preparation), gives detailed information of preparation of MMCs of different composition. In Section 3 (Result and Discussion), represents the evaluation of tensile strength and compression strength and the variation of hardness due to the variation in the composition of the composites and also includes the SEM images of the tested specimens. The Section 4(Conclusion) compiles the conclusions drawn from experiment followed by references.

II. Methods and Specimen Preparation

CASTING

- **Fabrication of Test Specimens**
  Stir casting technique of liquid metallurgy is used to prepare Al 6061 Hybrid composites. It consists of resistance Muffle-furnace and a stirrer assembly was used to synthesize the composite.

- **Preheating of reinforcement**
  Muffle furnace was used to preheat the particulate to a temperature of 700° C. It was maintained at the temperature till it was introduced in to the Al 6061 alloy melt.

Fig. 1 Furnace Setup

- **Melting of matrix alloy**
  The melting range of Al 6061 alloy is of 700-800°C. A known quantity of Al 6061 ingot wear pickled in 10% NaOH solution at room temperature for 10 min. The smut formed was removed by immersing the ingots for 1 min mixture of one-part nitric acid and one-part water followed washing in methanol. The cleaned ingot after drying in air were loaded into the graphite crucible of the furnace for melting. The melt was super-heated to a temperature of 800°C and maintained at that temperature. The molten metal was then degassed using Hexa-Chloro ethane tablets for about 8 min.

Fig. 2 Melting Ingots

- **Mixing and stirring**
  Alumina coated stainless steel impeller was used to stir the molten metal to create a vertex. The impeller was of centrifugal type with three blades welded at 45° inclinations and 120° apart. The stirrer was rotated at a speed 300-400 rpm and a vertex was created in the melt. The depth of immersion of impeller was approximately one third of the height of the molten metal from the bottom of the crucible. The pre-heated particulates of Graphene and short S-Glass fiber were introduced into the vertex at the rate of 120 gm/min. Stirring was continued until interface interactions between the particles and the matrix promoted wetting. The melt was degassed using Hexo chloro ethane tablets and after reheating to superheated temperature (800°C) it was poured into the preheated die.

Fig. 3 Mechanical Stirrer in Action

- **Pouring of molten metal into dies**
  Then after few minutes of stirring, the liquid metals with reinforcements are poured into the dies. The dies were being preheated and coated additives to ease the process of removing the casting.

Fig. 4 Pouring of Molten metal into die

Fig. 5 Casted specimen in the die

The percentage of reinforcements used in different specimens is as shown in table 1

Table 1: Percentage of Reinforcements

Specifications	% Graphene	% S-Glass Fiber	% of Al-6061
A0.5G1S	0.5	1	98.5
A0.5G3S	0.5	3	96.5
A0.5G5S	0.5	5	94.5
A1G1S	1	1	98
A1G3S	1	3	96
A1G5S	1	5	94
A1.5G1S	1.5	1	97.5
A1.5G3S	1.5	3	95.5
A1.5G5S	1.5	5	93.5
A2G1S	2	1	97
A2G3S	2	3	95
A2G5S	2	5	93

EXPERIMENTATION

TENSILE TEST:

Tensile test is destructive test which is conducted for obtaining the strength of a material. It is a simplest and most widely used mechanical test. The specimen is uniaxially loaded in tension when it experiences opposing forces acting on both the faces. The specimen is stretched by an increasing load and resulting stress-strain graph produced. Such a graph indicates the behavior of material under tensile load. It provides information of materials like elongation, tensile strength, Yield strength and ultimate strength and that will permit design engineers to predict how material will behave in their intended applications.

Fig: 6 Universal Testing Machine

Fig 7: Specimen before and After test

COMPRESSION TEST:

A compression test is destructive test in which a material experiences opposing forces that push inward upon the specimen from opposite sides or is otherwise compressed, "squashed", crushed, or flattened. The test sample is generally placed in between two plates that distribute the applied load across the entire surface area of two opposite faces of the test sample and then the plates are pushed together by a universal test machine causing the sample to flatten. A compressed sample is usually shortened in the direction of the applied forces and expands in the direction perpendicular to the force. A compression test is essentially the opposite of the more common tension test.

Fig 8: Specimen before Compression test and After test

HARDNESS TEST

The specimen is placed on the top of the table and raised it with the elevating screw, till the test sample just touched the ball. Load is applied on the specimen for a certain period, during which indenter presses onto the specimen. The steel ball during this period moved to the position of the sample and made indentation.

The diameter of the indentation made in the specimen is recorded by the use of the micrometer microscope. The diameter of indentations is taken and the BHN is calculated. Figure 7 shows the Hardness specimen after the test and Table 2 represents the test results.

Fig. 9 Specimens after testing

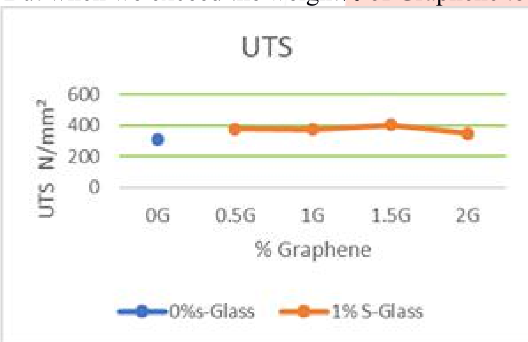
III. RESULTS AND DISCUSSION

TENSILE TEST RESULTS

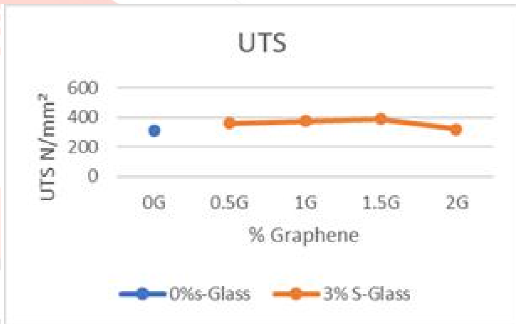
Table 2 Tensile test results of hybrid composite with varying percentage of reinforcements

Designation	Maximum Load in N	Maximum displacement in mm	Ultimate Tensile Strength (UTS) N/mm²
A0.5G1S	1000	250	380.26
A0.5G3S	1000	250	360.23
A0.5G5S	1000	250	372.44
A1G1S	1000	250	373.78
A1G3S	1000	250	375.22
A1G5S	1000	250	375.48
A1.5G1S	1000	250	405.22
A1.5G3S	1000	250	390.65
A1.5G5S	1000	250	395.26
A2G1S	1000	250	350.12
A2G3S	1000	250	320.55
A2G5S	1000	250	300.45
100Al	1000	250	310

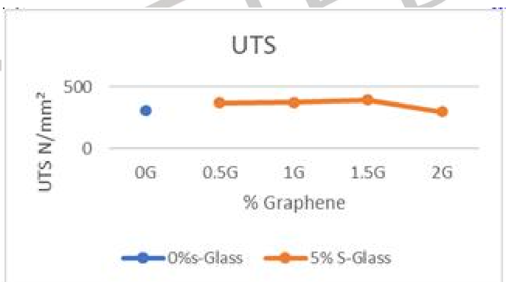
Table 2 shows the tensile test results. From the test it is inference that the improvement in ultimate tensile strength in base matrix with 0.5% to 1.5% Graphene, is due to the fact that Graphene is the strongest material, it is the only form of carbon in which every atom is available for chemical reaction for two sides. And the S-Glass fibre which also has high strength and stiffness by adding the weight percentage 1, 3 and 5. This on reinforcement forms a stronger composite. From the graph, tensile strength of composites containing wt% of Graphene and S-glass particulates is higher when compared to as base Al 6061. It is clear from the Graphene and S-glass is that the tensile strength increases with the increase in the percentage of Graphene particulates. But when we exceed the weight% of Graphene to 2% the strength of the material gets decreased.



a.



b



c

Fig 10: (a,b,c).UTS of composite with constant % of S-Glass and Varying % of Graphene.

Figure 10 (a,b.c) shows tensile strength of Al6061/G/S-Glass composite with constant percentage of S-Glass fiber and Varying percentage of graphene. It is observed that tensile strength decreases above 1.5% weight of graphene with constant (1%,3%,5%) weight percentage of S-Glass fiber. The composite with 1.5% Graphene and 1% S-Glass fiber showed the maximum ultimate tensile strength.

Tensile test reveals that increasing of graphene wt. % increasing tensile strength till 1.5% Graphene, but above that tensile strength decreases due to agglomeration. The results of tensile test on the samples revealed that addition of 1.5 wt. % graphene and 1% S-glass lead to increase the tensile strength by 30.716 %. The maximum tensile strength obtained for the pure Aluminium 6061 specimens was 310 MPa. The maximum tensile stress obtained for the sample with the composition Aluminium 6061 reinforced with 1.5 wt. % graphene and 1% S-Glass fiber in was observed to be 405.22 MPa which shows significant growth in the tensile strength upon comparing to the last specimen which is pure aluminium 6061. The minimum tensile strength for the specimen which contains 2 wt. % of graphene and 5 wt.% of S-glass as reinforcement in Aluminium

6061 is 300.45 MPa. The previous work on Aluminium 6061 and 0.5 wt.% of graphene showed the ultimate tensile strength of 227 MPa[122].Then in this work considering the tensile strength of Aluminium 6061 reinforced with 0.5 wt.% of Graphene and 1 wt.% of S-Glass fiber found to be 380.26 MPa which revealed that addition of S-glass Fiber enhances the strength property by 67.51%

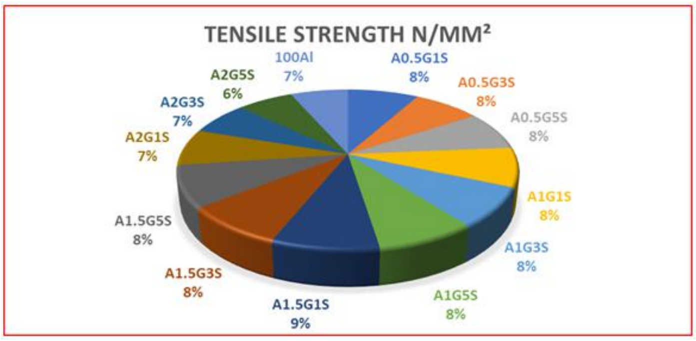


Fig: 11. Total Percentage contribution of UTS in Each Specimen

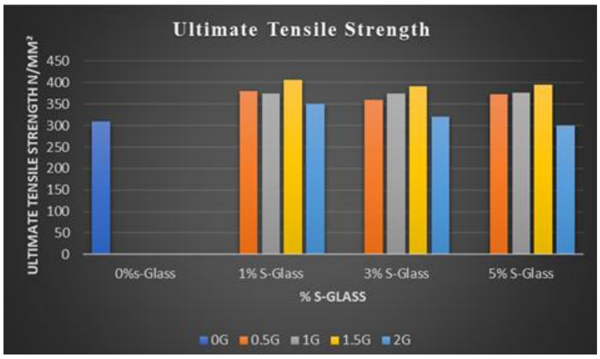


Fig: 12 Comparative Bar chart of Ultimate Tensile Strength

Figure 12 shows Comparative UTS graph of Al6061/G/S-Glass Composite. The increase in strength can be attributed to the addition of S-Glass along with Graphene as a reinforcement which impart strength to the matrix alloy(Al6061) there by enhanced resistance to tensile stresses. There is a reduction in the inter-special distance between particulates, which cause an increase in the dislocation pile-up as the particulate content increased. 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 higher percentage of reinforcement, the increase in the strength may be due to better bonding of Graphene particles up to 1.5%.

The improvement in tensile strength is the effect of strengthening mechanism contribution: Dispersion strengthening, load transfer effect, Hall-Petch strengthening, Orowan strengthening and thermal mismatch strengthening .but in this work, the enhancement in the mechanical properties can mostly be credited to coupled impacts of increment in grain boundary region because of grain refinement, the mismatch in coefficient of thermal expansion (CTE) and in elastic modulus (EM) between the reinforcements(S-Glass and Graphene) and the metal matrix(Al 6061 is accommodated during material cooling and straining by the formation of geometrically necessary dislocations. transfer of tensile load to the uniform dispersion of S-glass and Graphene.

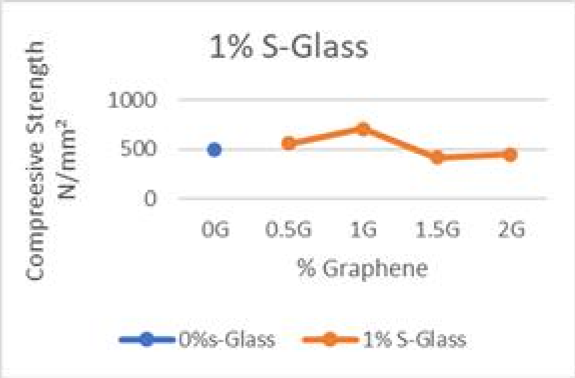
However, increasing the measure of Graphene above 1.5wt% was found to break down the elasticity of the composite to an estimation of 300.45 MPa for 2 wt% Graphene and 5%S-Glass fortified composite. The lower estimation of tensile strength for the 2 wt% fortified composite might be credited to troubles of hydrogen capture during the support expansion. Including of Graphene over the ideal worth will cause the composite to turn out to be progressively fragile. This might be the aftereffect of incredible agglomeration of nanoparticles and further extent of micro porosity present in the nanocomposite with higher Graphene content.

COMPRESSIVE TEST RESULTS

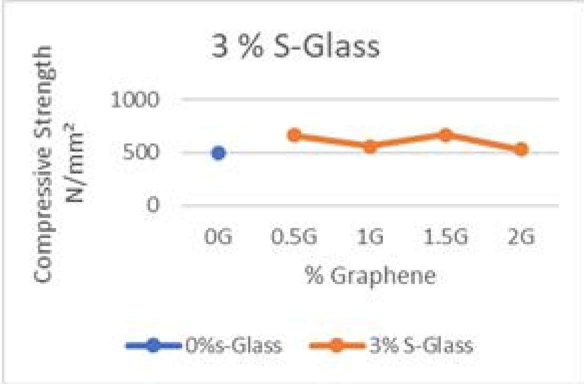
Table 3 Compressive test results of hybrid composite with varying percentage of reinforcements

Designation	Peak Load KN	Compressive Strength N/mm²
A0.5G1S	600	556.45
A0.5G3S	600	660.96
A0.5G5S	600	496.88
A1G1S	600	709.9
A1G3S	600	560.52
A1G5S	600	526.23
A1.5G1S	600	419.88
A1.5G3S	600	665.91
A1.5G5S	600	547.79
A2G1S	600	447.23
A2G3S	600	524.45
A2G5S	600	383.82
100Al	600	495.4

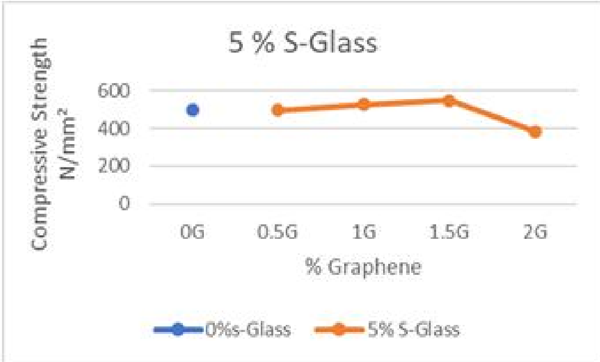
Table 3 shows the compression test result. It can be seen from the graph is that as the graphene and S-Glass to Aluminium 6061 content increases, the compressive strength of the hybrid composite material increases by significant amount. In fact, as the graphene content is increased from weight% 0.5 to 1.5% the compressive strength increases due to the graphene particles acting as barriers to dislocations in the microstructure. And the compressive strength improved with increase in proportion of composites till 5% of S- Glass and 1.5%of Graphene.



a



b



C

Figure: 13(a,b,c).Compressive of composite with constant % of S-Glass and Varying % of Graphene.

Figure 13(a, b.c) shows compressive strength of Al6061/G/S-Glass composite with constant percentage of S-Glass fiber and Varying percentage of graphene. It is observed that compressive strength decreases above 1.5% weight of graphene with constant (1%,3%,5%) weight percentage of S-Glass fiber. The composite with 1% Graphene and 1% S-Glass fiber showed the maximum compressive strength.

Compression test reveals that increasing of graphene wt. % increasing tensile strength till 1.5% Graphene, but above that tensile strength decreases due to agglomeration. The results of compression test on the samples revealed that addition of 1.5 wt. % graphene and 1% S-glass lead to increase the tensile strength by 43.29 %. The maximum compressive strength obtained for the pure Aluminium 6061 specimens was 495.4 MPa. The maximum compressive stress obtained for the sample with the composition Aluminium 6061 reinforced with 1wt. % graphene and 1% S-Glass fiber in was observed to be 709.9 MPa which shows significant growth in the compressive strength upon comparing to the last specimen which is pure Aluminium 6061. The minimum compressive strength for the specimen which contains 2 wt. % of graphene and 5 wt.% of S-glass as reinforcement in Aluminium 6061 is 383.82 MPa

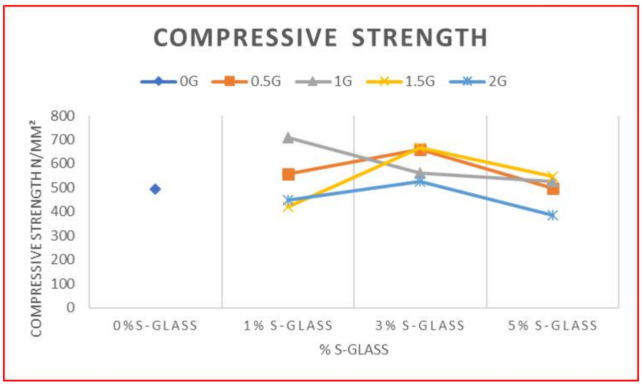


Figure:14 Line chart of Compressive Strength

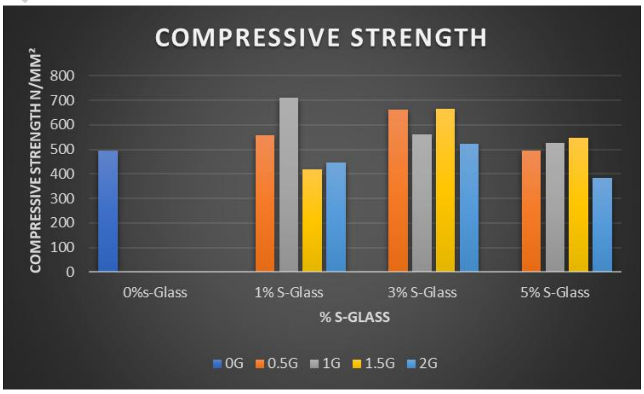


Figure:15 Bar chart of Compressive Strength

From figure it is clear that incorporation of 1 % S-Glass fiber in 0.5 % Graphene Al 6061 hybrid composite has 18.78 % percentage in compressive strength whereas in 1 % Graphene Al 6061 has 27.56%. It is seen that the compressive strength of the composites is higher than that of their base matrix and also it can be observed that the increase in the Graphene contributes in increasing the compressive strength of the composite. But this increase in strength is observed only up to the 1wt% of Graphene and further increment has resulted in reduced strengths. Also from the figure it can be observed that the compressive strength decreases with increase in S-Glass fiber. This decrease in strength is due to the long aspect ratio of the fibres which makes it seem so; i.e., because a typical S-Glass fibre is long and narrow, which buckles easily under compressive loading.

HARDNESS TEST

Hardness are found for the developed composites of different weight % of Graphene, S-Glass Fiber and Al-6061. The present work attempts to understand the influence of reinforcements on hardness of the Al alloy-based Hybrid composites

Table 4: Hardness Test Results

Designation	Indentation Diameter(mm)	BHN
A0.5G1S	1.1	40.26
A0.5G3S	1.2	42.55
A0.5G5S	1.2	43.22
A1G1S	1.3	41.30
A1G3S	1.1	45.23
A1G5S	1.3	41.30
A1.5G1S	1.25	45.61
A1.5G3S	1.3	46.22
A1.5G5S	1.3	49.22
A2G1S	1.35	44.22
A2G3S	1.1	47.05
A2G5S	1.3	48.30
100Al	1.4	35

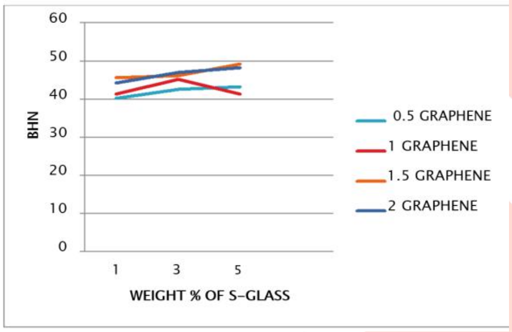


Fig. 16 The effect of Graphene and S-glass fiber on the Brinell Hardness of the composite

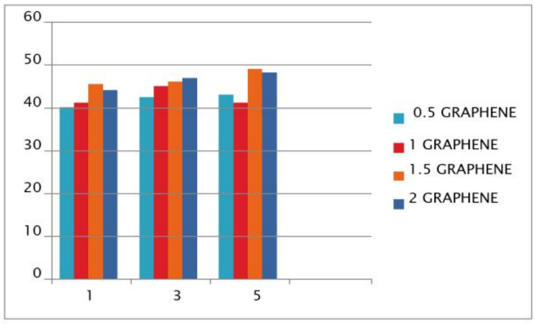


Fig. 17 Bar representation of the Hardness Test Result

From above figure, it is observed that hardness increases with increase in Graphene wt.% at constant S-Glass Fiber reinforcement in Al6061 matrix. By considering the effect of S-glass as reinforcement. We can conclude that hardness value shows the trend of hike as wt.% of S-Glass from 1 to 5. Only Composite specimen with 5% S-glass in 0.5G/Al 6061 shows the hardness value of 43.22 BHN, sudden fall due to the agglomeration of reinforcement. A1.5G5S Composite showed the hardness value of 49.22 BHN that is 40.62 % is more than hardness value of the pure Al 6061(35BHN).

The Brinell's hardness test shows the relation between weight percentage of materials particulates and hardness of fabricated composites. It is observed from the figure that the hardness increases with increasing weight percentage of glass fibre 1% to 3% of fibre and Graphene up to, 1.5 weight percentage of graphene, and then decreases with increasing 2 weight percentage of graphene. It may be due to the fact that S-glass is the strongest and harder than the base matrix, they act as barriers to dislocations. Graphene is the strongest material it is the only form of carbon in which every atom is available for chemical reaction for two side

Above results show that by using 1.5 wt.% of graphene increasing (1,3 &5) wt.% of S-Glass fiber as reinforcement in Aluminium 6061 increases the hardness. It is also observed that when Aluminium 6061 is reinforced with % of graphene, the hardness value increases and further by increasing the composition of graphene in the samples the value of hardness decreases. Then it shows the value of hardness depends upon the reinforcement and also on their weight percentages as it can be seen that the hardness of the samples increased as compared to parent aluminium.

SCANNING ELECTRON MICROSCOPE STUDIES

The cleaned, dried and etched specimens are prepared and subsequently mounted on specially designed Aluminium suturing (holder). The specimens thus mounted were viewed under JeolJSM6510 LV scanning electron microscope at an accelerating voltage of 20KV below figures (18-25) shows the SEM micrograph of the different combinations of the hybrid MMC at different magnifications.

Pure Al-6061

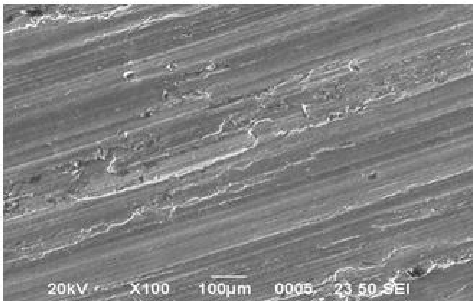


Fig 18 Al6061 seen under SEM at 100X

0.5%Graphene +1%S-Glass 98.5% Al6061 MMC

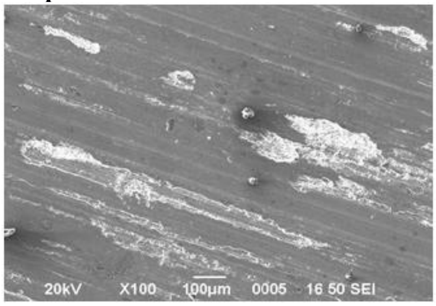


Fig 19- 0.5%Graphene +1%S-Glass+98.5% Al6061 MMC seen under SEM at 1000X

1%Graphene+1%S-Glass+98%Al6061 MMC

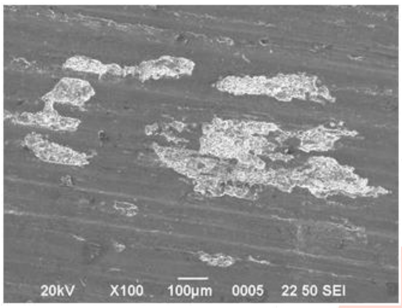


Fig 20 1%Graphene +1%S-Glass+98% Al6061 MMC seen under SEM at 100X

1%Graphene +3%S-Glass +96% Al6061 MMC

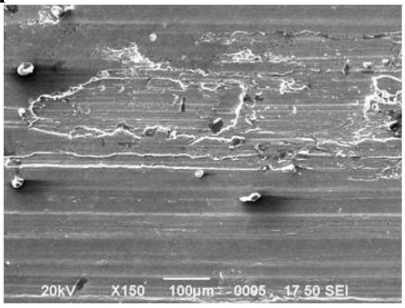


Fig 21 1%Graphene+3%S-Glass+96% Al6061 MMC seen under SEM at 150X

1.5%Graphene+1% S-Glass +97.5% Al6061 MMC

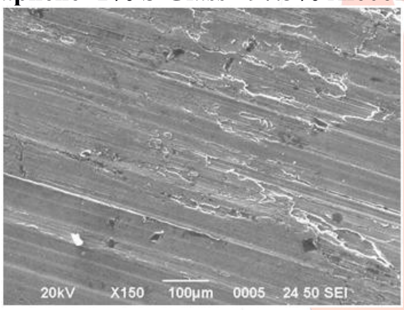


Fig 22 1.5%Graphene +1%S-Glass +97.5% Al6061 MMC seen under SEM at 150X

1.5%Graphene+5%S-Glass+93.5% Al6061 MMC

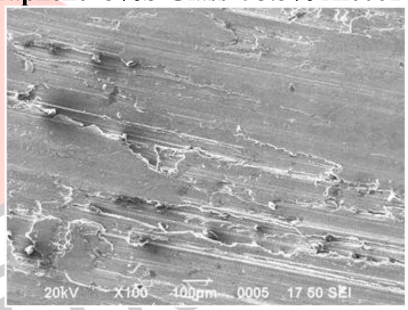


Fig 23 1.5%Graphene+5%S-Glass+93.5% Al6061 MMC seen under SEM at 100X

2%Graphene+1%S-Glass+97% Al6061 MMC

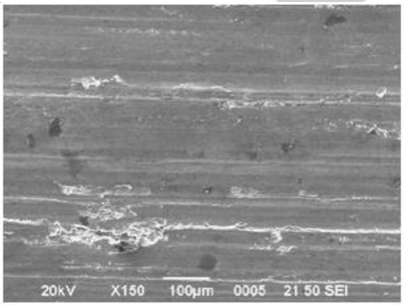


Fig 24 2%Graphene+1%S-Glass+97% Al6061 MMC seen under SEM at 150X

2%Graphene +5%S-Glass +93% Al6061 MMC

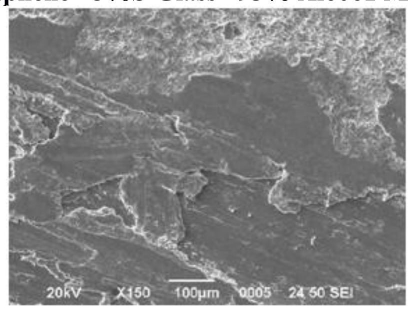


Fig 25 2%Graphene+5%S-Glass+93% Al6061 MMC seen under SEM at 150X

SEM microstructure of Aluminums S-glass & Graphene composites containing in different compositions are shown in figures. The photographs show that the graphene and S-glass are uniformly dispersed in the aluminum matrix. Graphene particles were also clearly visible dendrite microstructure observed in the sample containing 0.5 wt % Graphene sintered at 650°C indicates to the formation of composites phase due to reaction between Aluminum and Graphene particles. The microstructure of the composites materials was determined by scanning electron microscope, the micrograph reveled a relative uniform distribution of reinforced particles and good interfacial integrity between matrixes.

IV. CONCLUSION

The developed composite has improved properties compared to the basic alloy. The inclusions of the Graphene and S-glass fibers have extended their good properties to the alloy which acts as the matrix alloy.

- The effect of Graphene and S-glass particles on the strength in Al-6061 alloys varies with the applied load. From the experiments conducted to study the effect on adding various volumes of S-Glass and Graphene with Al-6061 for the Tensile, Compression & Hardness properties. The following conclusion can be drawn. Composite material of Al- 6061 reinforced with S– Glass fibre and Graphene was successfully casted.
- The strength increased with the increase in adding various amount of S-Glass and Graphene thus the S-Glass fibre composite material has a higher tensile strength and modulus of elasticity is also high. Particulate composite was successfully synthesized by the stir casting method. The tensile strength of the composite increased with increase in wt% of glass particulates up to 1.5%.
- Compression of S-Glass fibre, graphene reinforced with aluminum metal matrix composites has been successfully completed by adopting stir casting technique by keeping volume fraction of 0.5%,1%,1.5%,2% loading of graphene by weight of the matrix considered. Compression testing was done for all the prepared samples using digital UTM. For the applied load corresponding strain and displacement was recorded and different plots for different samples have been documented. It is concluded that sample filled with 0.5% to 1.5% of graphene shows excellent resistance to compressive loading proves the saturation of graphene particles dispersed uniformly and maintain better bonding characteristics with aluminum matrix which enhance very good malleable properties for this particular proportion of metal matrix composites.
- For the hardness Al 6061 hybrid composite material containing S-Glass & Graphene particulates were fabricated successfully by varying wt% of Graphene from 0.5 to 2% using stir casting method. Keeping S-Glass 5% as constant, by increasing the Graphene particulates, we can conclude that Hardness of the prepared hybrid composites is higher than the base AL 6061 alloy. Addition of 5wt% S-Glass increases hardness considerably. Whereas the addition of Graphene 2wt% particulates decreases the hardness but is higher than the Al6061 alloy.
- SEM micrographs show the formation of a dense phase microstructure along with some minute amount of channel pores. Graphene particles were also clearly visible. Thus, with increase in the concentration of graphene the load bearing capacity of the samples increased as maximum load was beard by the samples containing graphene

REFERENCES

[1] A. K. Dhingra, "metal replacement by composite", JOM 1986, Vol 38 (03), p. 17.
[2] R.L. Trumper Met. Mater, Vol. 3, 1987, p. 662.
[3] Mechmet Acilar, Ferhat Gul "Effect of applied load, sliding distance and oxidation on the dry sliding wear behaviour of Al-10 Si/Cp composites produced by vacuum infilatration techniques. Journal of Materials & Design Vol.25, (2004) pp 209-217 & Liu Yao-hui, Du Jun et.al. "High temperature friction and Wear behaviour of Al2O3 and /or Carbon short fiber reinforced Al-1 Si alloy composites" Wear 56, 004, pp 75-285.
[4] A.Alahelisten, F.Bergman, M.Olsson, S.Hogmark, "on the wear of Aluminium and magnesium metal matrix composites", Wear Vol.165, 1993, pp 1-226.
[5] J.Q.Jiang, R.S.Tan, A.B.Ma, "Dry sliding wear behaviour of Al2O3-Al composite produced by centrifugal force infiltration", Material Science and Technology, Vol. 1, 1996, pp 483-488.
[6] P.N.Bindhumadhan, H.K.Wah, O.Prabhakar, "Dual particle size (DPS) composites: effect on wear and mechanical properties of particulate matrix composites" Wear, Vol. 48, 2001, pp 112-120. `
[7] S. Tjong, S.Q. Wu, and H. Liao: "Wear behavior of an Al–12% Si alloy reinforced with a low volume fraction of Si particles." Journal of composite science and technology, Vol–57, Issue–12, Dec 1997, pp 1551-1558.
[8] S. Tjong, H.Z.Wang and S.Q.Wu "Wear Behavior of Aluminium based Metal Matrix Composites Reinforced with a Perform of Aluminium silicate Fiber" Metallurgical and Materials Transactions A, Vol 27A, (1996) 2385-2389.
[9] M.Singh, D.P.Mondal et.al. "Development of light weight Aluminium alloy hard particle composite using natural minerals for wear resistance application. National conventions on emerging materials on wear applications. Paper no TS- 4/5, 2003, Bhopal.
[10] Ferdinand A.A. & Gregoire R.R., Fr1, 157, 477 May 29, 1958, Chem. Abstr. 1960, 54, 194