wjert, 2021, Vol. 7, Issue 4, 177-195. *Original Article* ISSN 2454-695X

World Journal of Engineering Research and Technology

WJERT

www.wjert.org SJIF Impact Factor: 5.924

STUDIES ON TRIBOLOGICAL PROPERTIES ON GRAPHENE AND S-GLASS REINFORCED Al-6061 METAL MATRIX COMPOSITES

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Article Received on 24/04/2021 **Article Revised on 14/05/2021** **Article Accepted on 04/06/2021**

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ABSTRACT

This research work investigated the effect of the graphene and S-glass fiber on Tribological properties 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. Nowadays 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 corrosion tests and the wear test carried out with varying load and speed in different combinations. Through the results, it is concluded that wear rate increased with the increase in speed and load for every combination of the composite. However, with Graphene being the main reinforcement with addition of Graphene wear rate has reduced marginally. For corrosion it is concluded that the corrosion resistance of the prepared hybrid composites increases as the compositon of graphene and S-glass fiber increases, and also corrosion resistance increases with increase in time.

KEYWORDS: Al 6061, Graphene, S-Glass fiber, Wear rate, Pin on Disk Apparatus, Corrosion rate, Normality of NaCl Solution.

INTRODUCTION

In this research paper we study the variation of wear rate of different compositions of the hybrid composites, material preparation for the test, test the specimen, results and conclusion. 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.

Wear is the progressive loss of material from the operating surface of a solid occurring as a result of motion between two surfaces. Wear appears as if it occurs due to relative motion between two bodies which are solid. There can be different modes of forms of wear such as abrasion, adhesion (scuffing, wiping, welding, galling and scoring), erosion and fatigue. When two surfaces which appear smooth macroscopically are brought together then contact occurs at isolated asperities on the surfaces. According to the profilometry studies most of the solid surfaces inherently have roughness with varying degrees. It is often found that wear volume or wear rate is inversely proportional to hardness of the materials which are in contact given that hardness is proportional to the yield strength of the same materials.

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 corrosion behaviour.

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),[2] 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. MechmetAcilar, 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.

Methods and Specimen Preparation

Apparatus

Figure 1 shows a typical pin – on – disk wear test system. This consists of a motor drive, revolution counter, specimen holder and a lever–arm device to hold the pin. Rotating speeds of motor drive are typically in the range 0.3 to 3 rad/s (60 to 600 r/min).

Fig. 1: Pin on Disk Apparatus.

Test Specimens

Materials: This test method may be applied to a variety of materials. The only requirement is that specimen's dimensions can be prepared and that they will withstand the stresses imposed during the test without failure or excessive flexure. The materials being tested shall be described by dimensions, surface finish, material type, form, composition, microstructure, processing treatments, and indentation hardness.

Test Specimens: Typical cylindrical or spherical pin specimen diameters range from 2 to 10mm. The typical disk specimen diameters range from 30 to 100mm and have a thickness in the range of 2 to 10mm.

Surface Finish: A ground surface roughness of 0.8µm (32µin.) arithmetic average or less is usually recommended.

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. 2: 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. 3: 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° inclination 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. 4: 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 to get the required castings. The dies are preheated and coated additives to ease the process of removing the casting.

Fig. 5: Pouring of metal.

Fig. 6: Casted Specimen in the die.

Specimen preparation for Wear

The wear test was conducted using a pin-on-disc computerized wear testing machine as shown in figure in accordance with ASTM standards G99-95. The test uses the specimens of diameter of 6mm and length 25mm machined from the cast specimens.

Fig. 7: Wear test specimens.

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

FORMULAE: Wear rate = V/S IN (mm^3/m)

Where, V = Volume of wear m3 = $v_1 - v_2$

$V_1 = \pi r^2 L_1$

$V_2 = \pi r^2 L_2$

r = radius of specimen

L_1 = Initial length of specimen L_2 = final length of specimen Or

S = Sliding distance (m) = π*D*N*T = 2*π*R*N*T

D = Diameter of wear track in meter

R = Radius of wear track in meter

N = Speed of the wheel in rpm

T = Sliding time in minutes

Specimen preparation for Corrosion

The casted specimens are withdrawn from the mold and machined to required dimension according to ASTM for conducting corrosion, and hardness tests and lathe is used for this purpose.

Fig. 8: Corrosion test specimens.

Testing Procedure for Corrosion

The corrosion procedures as per ASTM were carried out with all percentage specimens and the uniform dispersion of reinforcements was studied by optical microscope. The corrodent used was Hydrochloric acid solution. The corrosion tests were conducted using conventional weight loss method similar to ASTM-G67-80 test standards, and the exposure time was varied from 24 to 96 hours, in steps of 24 hours.

The cradles containing the measured specimens were kept inside the glass, which contains the corrodant. After the corrosion test the specimen were immersed in acetone solution for 10 minutes and gently cleaned with a soft brush to remove adhered scales. After drying thoroughly the specimen were weighed to determine the percentage weight loss.The values of the corrosion rates for each of the specimens were calculated. The graphs of the varying corrosion rates for the specimens of the different compositions and the same normality were plotted to study the corrosion behavior of the composite with the varying parameters being the composition of the MMC and same normality of the acidic solution in which the specimen of this composition is immersed.

Fig. 9: Specimens during corrosion.

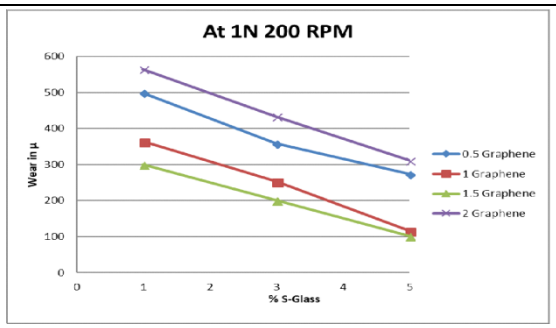
Fig. 10: Corrosion Test Specimens.

RESULTS AND DISCUSSION

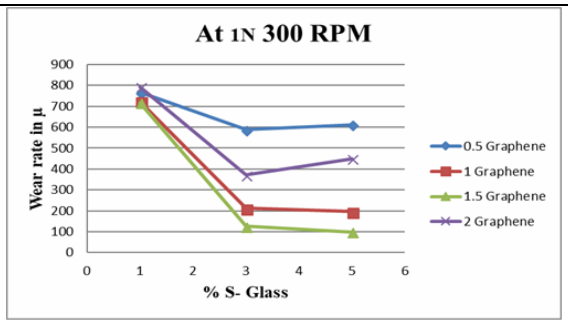
Wear Rate Analysis

Wear rate of the composite under various combinations of loads and speeds are discussed below.

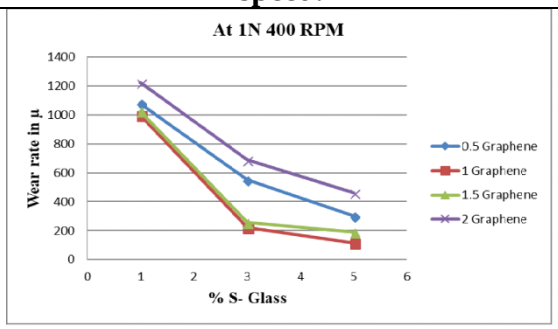
For 1N load



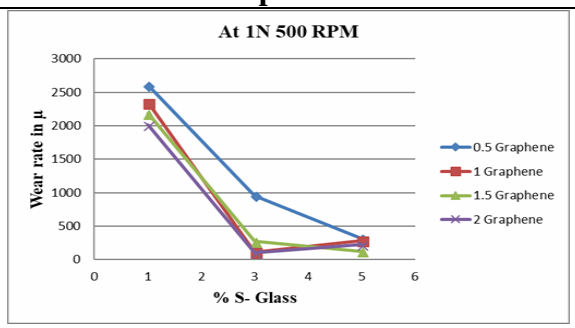
Graph-1: Specimen with 1N load at 200 rpm speed.



Graph-2: Specimen with 1N load at 300 rpm speed.



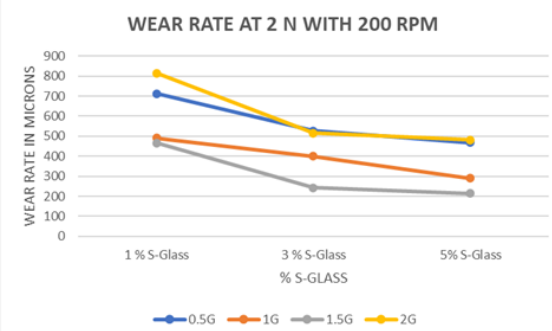
Graph-3: Specimen with 1N load at 400 rpm speed.



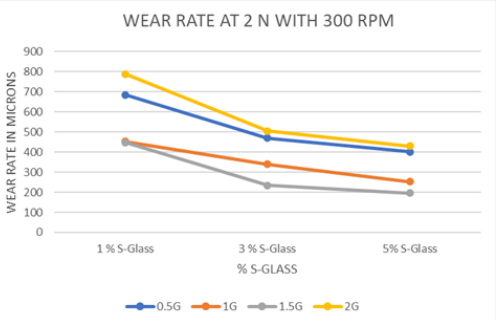
Graph-4: Specimen with 1N load at 500 rpm speed.

As seen in above graphs (1-4) the wear rate decreases as the percentage of Graphene and S – Glass increases from 1%, 3%, and 5% in 1.5% Graphene, S – Glass reinforced Al 6061 based hybrid MMC, at 1N load and different speeds, and at track diameter of 100mm in pin on disc experiment, this is because of increase in the amount of reinforcements in MMC.

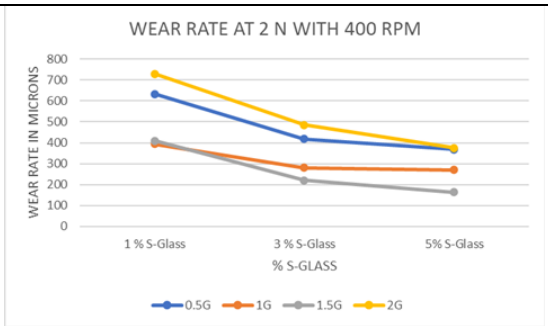
For 2N load



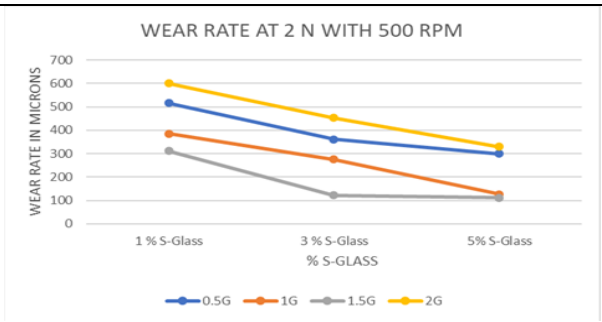
Graph-1: Specimen with 2N load at 200 rpm speed.



Graph-2: Specimen with 2N load at 300 rpm speed.



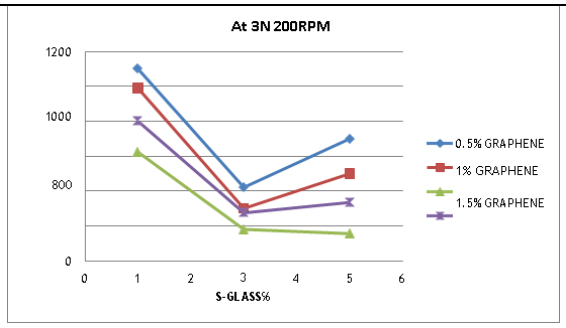
Graph-3: Specimen with 2N load at 400 rpm speed.



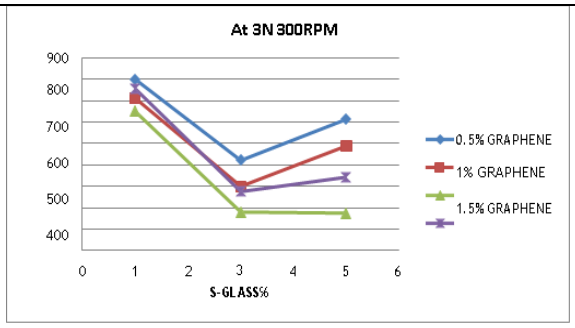
Graph-4: Specimen with 2N load at 500 rpm speed.

As seen in above graphs (4-8) the wear rate decreases as the percentage of Graphene and S – Glass increases from 1%, 3%, and 5% in 1.5% Graphene, S – Glass reinforced Al 6061 based hybrid MMC, at 2N load and different speeds, and at track diameter of 100mm in pin on disc experiment, this is because of increase in the amount of reinforcements in MMC.

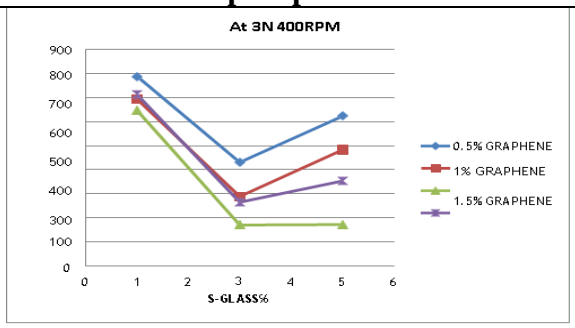
For 3N load



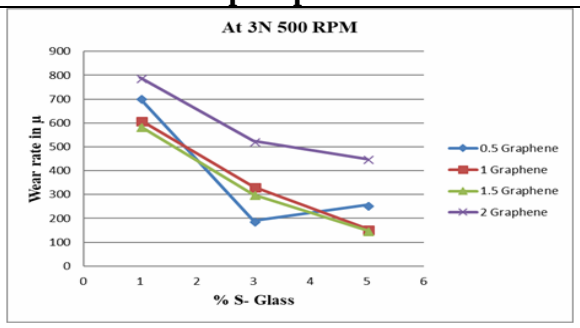
Graph- 9: Specimen with 3N load at 200 rpm speed.



Graph-10: Specimen with 3N load at 300 rpm speed.



Graph-11: Specimen with 3N load at 400 rpm speed.



Graph-12: Specimen with 3N load at 500 rpm speed.

As seen in above graphs (9-12) the wear rate decreases as the percentage of Graphene and S – Glass increases from 1%, 3%, and 5% in 1.5% Graphene, S – Glass reinforced Al 6061 based hybrid MMC, at 3N load and different speeds, and at track diameter of 100mm in pin on disc experiment, this is because of increase in the amount of reinforcements in MMC.

Wear rate increased with the increase in speed and load for every combination of the composite. However with Graphene being the main reinforcement with addition of Graphene wear rate has reduced marginally. Addition of S – glass also to some extent decreased the wear rate but Graphene plays a major role in reducing the wear rate, Graphene is been semi-metal material. Above the critical load, transition to severe wear occurs in unreinforced matrix alloy. But the reinforced MMCs have superior wear resistance. With increase in Graphene wear rate has decreased and is clear from the results that as the percentage of S – Glass increases in the composite the wear rate decreases, which is a good sign for production of low cost material.

1. CORROSION RATE ANALYSIS

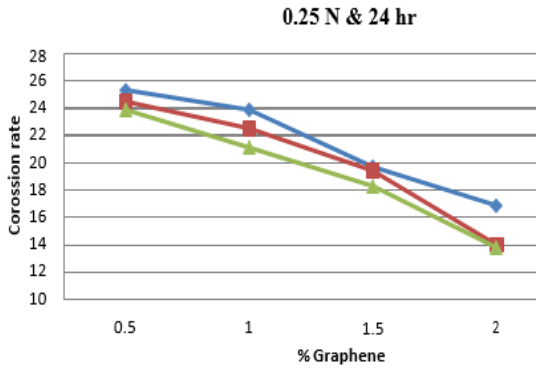
The effect of percentage of reinforcements, aging, corrosion duration and normality of corrosion media (0.25N, 0.5N, 0.75N, 1N) on corrosion rate (mpy) Graphene and S-Glass in Al 6061 alloy are noted and are as shown in table (2-5) and graphs below. The present work attempts to understand the influence of corrosion on Graphene and S-glass reinforced Al 6061 metal-matrix composites.

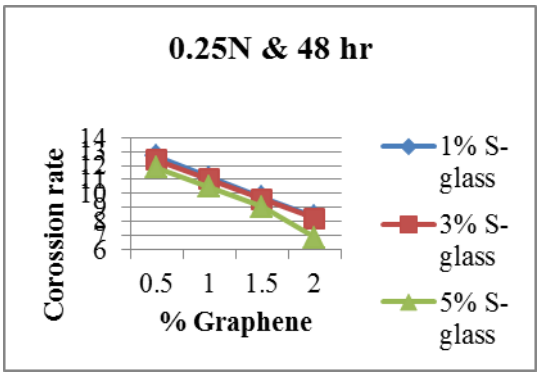
For Normality 0.25

Table 2: Corrosion rate for 0.25N.

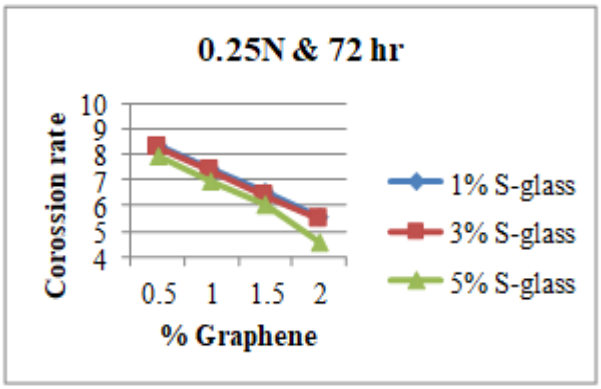
Specifications	Time in hrs.			
	24	48	72	96
Al-6061	25.34	12.67	8.34	6.25
0.5+1	25.3	12.6	8.34	6.25
0.5+3	24.5	12.4	8.26	5.91
0.5+5	23.9	11.8	7.89	5.91
1+1	22.53	11.15	7.42	5.56
1+3	22.24	11.01	7.33	5.5
1+5	21.12	10.45	6.96	5.2
1.5+1	19.71	9.75	6.5	4.87
1.5+3	19.43	9.62	6.4	4.8
1.5+5	18.3	9.06	6.03	4.38
2+1	16.89	8.36	5.57	4.17
2+3	14	8.22	5.47	3.48
2+5	13.8	6.83	4.55	3.41

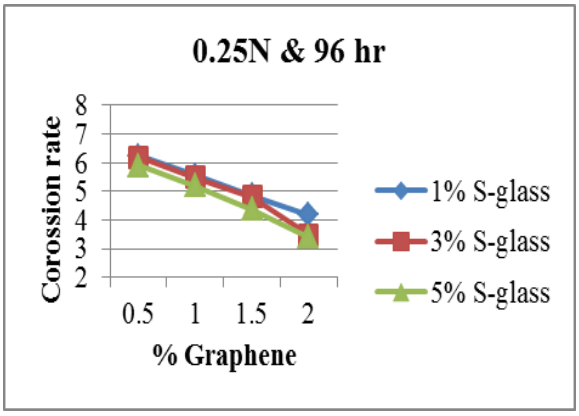
The effect of graphene and S-glass fiber on corrosion rate for 0.25N at 24 and 48hrs are plotted below





Graph 1: Effect of Graphene and S-glass fiber for 24hr. Graph 2: Effect of Graphene and S-glass fiber for 48hrs.





Graph 3: Effect of Graphene and S-glass fiber for 72hrs. Graph 4: Effect of Graphene and S-glass fiber for 96hr.

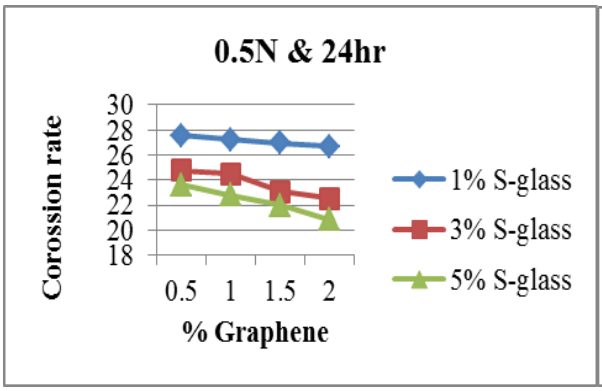
Graphs 1-4 shows the variation of corrosion rate with the normality of the corrosion medium. It is observed that, the corrosion rate is decreases as the percentage of Graphene and S-glass fiber increases. In above graph at 0.25 normality of NaCl solution the specimen is immersed in a beaker at period of 24hr, 48hr 72hr and 96hr respectively.

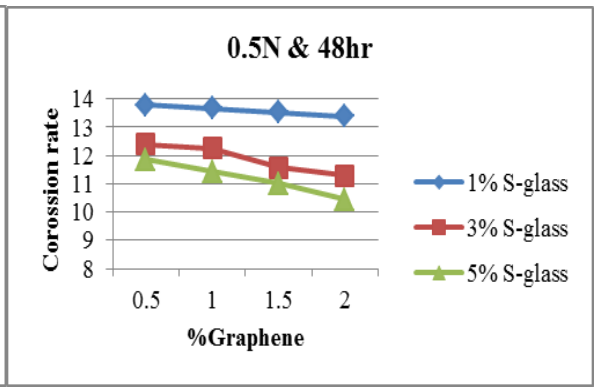
Table 3: Corrosion rate for 0.5N.

Specifications	Time in hrs.			
	24	48	72	96
Al-6061	27.5	13.8	9.19	6.89
0.5+1	27.54	13.8	9.19	6.89
0.5+3	24.7	12.4	8.26	6.19
0.5+5	23.6	11.8	7.89	5.91
1+1	27.26	13.66	9.1	6.82
1+3	24.48	12.26	8.17	6.12
1+5	22.81	11.43	7.61	5.7
1.5+1	26.98	13.52	9	6.75
1.5+3	23.09	11.57	7.7	5.77

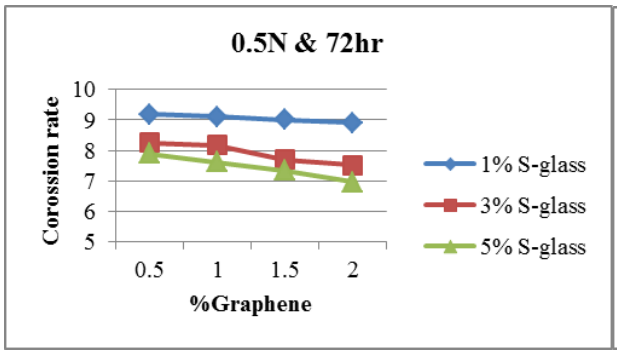
1.5+5	21.97	11.01	7.33	5.5
2+1	26.7	13.38	8.9	6.68
2+3	22.53	11.29	7.52	5.63
2+5	20.8	10.4	6.96	5.22

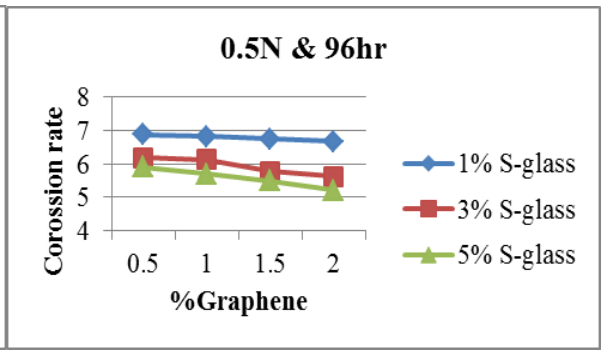
The effect of graphene and S-glass fiber on corrosion rate for 0.5N at 24, 48, 72, 96hrs are plotted below.





Graph 5: Effect of Graphene and S-glass fiber for 24 hrs. Graph 6: Effect of Graphene and S-glass fiber for 48 hrs.





Graph 7: Effect of Graphene and S-glass fiber for 72hrs. Graph 8: Effect of Graphene and S-glass fiber for 96hrs.

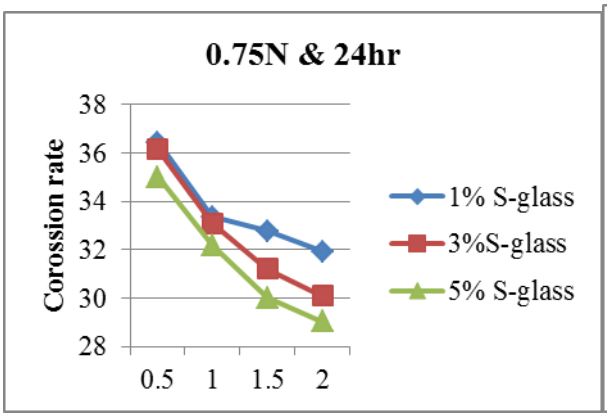
Graphs 7-8 shows the variation of corrosion rate with the normality of the corrosion medium. It is observed that, the corrosion rate is decreases as the percentage of Graphene and S-glass fiber increases. In above graph at 0.5 normality of NaCl solution the specimen is immersed in a beaker at period of 24hr, 48hr 72hr and 96hr respectively.

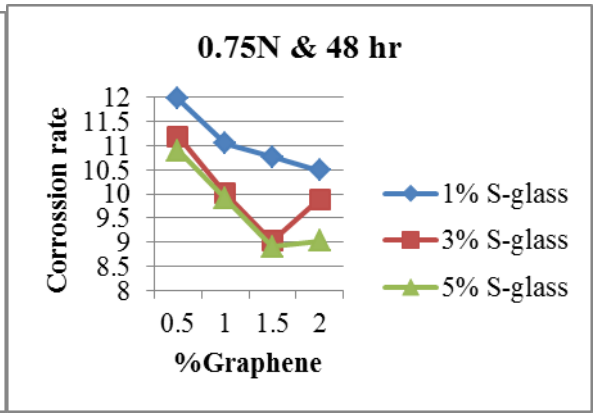
For Normality 0.75

Table 4: Corrosion rate for 0.75N.

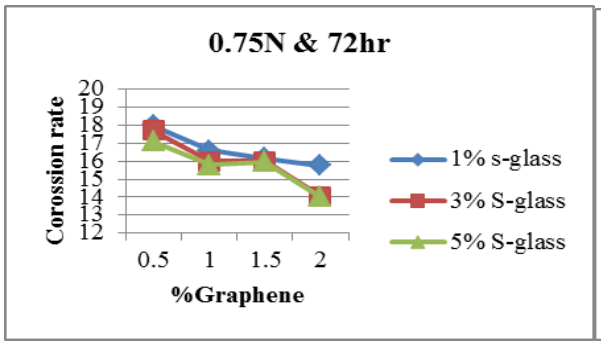
Specifications	Time in hrs.			
	24	48	72	96
Al-6061	36.4	17.9	11.9	8.98
0.5+1	36.44	17.98	11.98	8.98
0.5+3	36.1	17.7	11.2	8
0.5+5	35	17.1	10.9	8
1+1	33.36	16.59	11.05	8.28
1+3	33.1	16.01	10.01	8
1+5	32.2	15.8	9.9	7.89
1.5+1	32.77	16.17	10.7	8.076
1.5+3	31.2	16.01	9.02	7.82
1.5+5	30.02	15.98	8.9	7.21
2+1	31.92	15.75	10.49	7.86
2+3	30.1	1405	9.89	7.08
2+5	29	14	9.02	6.89

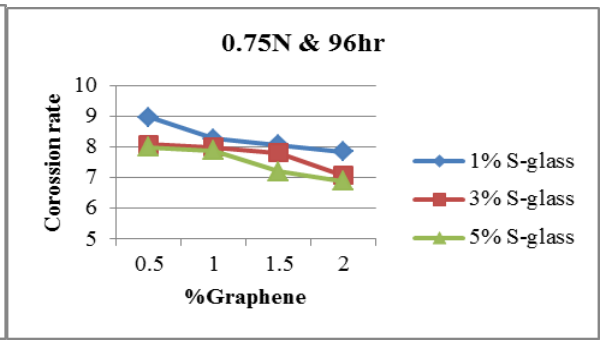
The effect of graphene and S-glass fiber on corrosion rate for 0.75N at 24, 48, 72 and 96hrs are plotted below.





Graph 9: Effect of Graphene and S-glass fiber for 24 hrs. Graph 10: Effect of Graphene and S-glass fiber for 48 hrs.





Graph 11: Effect of Graphene and S-glass fiber for 72h. Graph 12: Effect of Graphene and S-glass fiber for 96hrs.

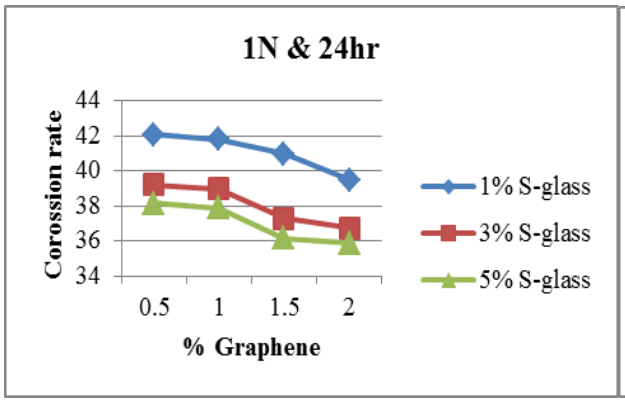
Graphs 10-12 shows the variation of corrosion rate with the normality of the corrosion medium. It is observed that, the corrosion rate is decreases as the percentage of Graphene and S-glass fiber increases. In above graph at 0.75 normality of NaCl solution the specimen is immersed in a beaker at period of 24hr, 48hr 72hr and 96hr respectively.

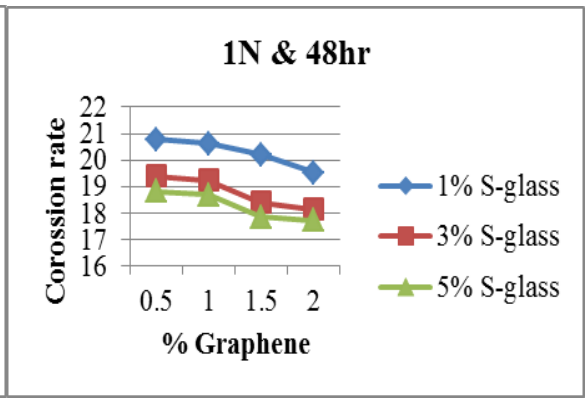
For Normality 1:

Table 5: Corrosion rate for 1N.

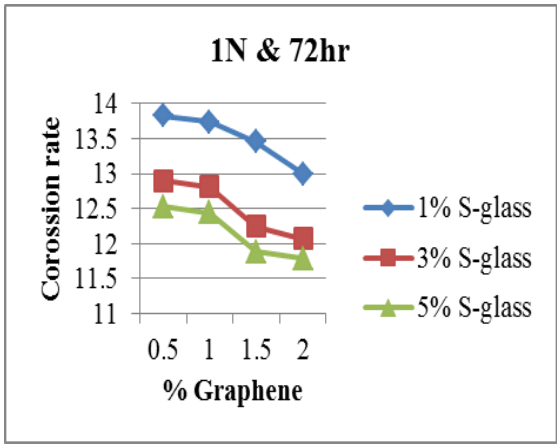
Specifications	Time in hrs.			
	24	48	72	96
Al-6061	42	20.7	13.8	10.3
0.5+1	42.09	20.77	13.83	10.37
0.5+3	39.2	19.3	12.9	9.67
0.5+5	38.1	18.8	12.5	9.39
1+1	41.81	20.63	13.74	10.3
1+3	38.99	19.24	12.81	9.6
1+5	37.86	18.68	12.44	9.32
1.5+1	40.96	20.21	13.46	10.09
1.5+3	97.29	18.4	12.25	9.19
1.5+5	36.16	17.84	11.88	8.91
2+1	39.5	1.51	13	9.74
2+3	36.73	18.12	12.07	9.05
2+5	35.8	17.7	11.7	8.8

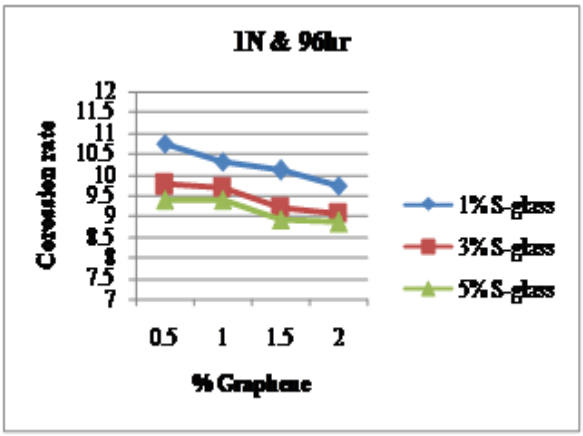
The effect of graphene and S-glass fiber on corrosion rate for 0.5N at 24, 48, 72 and 96hrs are plotted below.





Graph 13: Effect of Graphene and S-glass fiber for 24 hrs Graph. 14: Effect of Graphene and S-glass fiber for 48 hrs.





Graph 15: Effect of Graphene and S-glass fiber for 72hrs Graph 16: Effect of Graphene and S-glass fiber for 96hrs.

Graphs 15-16 shows the variation of corrosion rate with the normality of the corrosion medium. It is observed that, the corrosion rate is decreases as the percentage of Graphene and S-glass fiber increases. In above graph at 0.1 normality of NaCl solution the specimen is immersed in a beaker at period of 24hr, 48hr 72hr and 96hr respectively.

CONCLUSION

The effect of Graphene and S-glass particles on the sliding wear resistance in Al-6061 alloys varies with the applied load and speed. From the experiments conducted to study the effect on adding various volume fraction of S-Glass and Graphene with Al-6061 for the wear properties. The following conclusion can be drawn.

Wear Rate

- Composite material of Al-6061 reinforced with S– Glass fibre and Graphene was successfully casted.
- Wear rate increased with the increase in speed and load for every combination of the composite. However with Graphene being the main reinforcement with addition of Graphene wear rate has reduced marginally. Addition of S – glass also to some extent decreased the wear rate but Graphene plays a major role in reducing the wear rate, Graphene is been semi-metal Material.
- Above the critical load, transition to severe wear occurs in unreinforced matrix alloy. But the reinforced MMCs have superior wear resistance.

- With increase in Graphene wear rate has decreased and is clear from the results that as the percentage of S – Glass increases in the composite the wear rate decreases, which is a good sign for production of low cost material.
- The best wear resistant combination is at 5% of S– Glass and 1% &1.5%of Graphene as consideration.
- In material Metal-metal and metal-particle wear resistance increased with increasing distance from the centre of the specimen. Worn surface examination of the material revealed formation of iron rich transfer layer during metal-metal wear test. Abrasive wear progressed by grooving action of the abrasion grains. Abrasion resistance of the composite was decreased with the size of particle. Composites exhibited abrupt increase in abrasion rate for higher speeds and loads.

Corrosion Rate

- At room temperature, the Graphene and S-glass reinforced Al-6061 composites exhibited better corrosion resistance than the pure Al matrix in NaCl aqueous solution.
- Increasing the composition of the Graphene and S-glass particulates increased the corrosion resistance of the Graphene and S-glass Reinforced Al-6061 composites.
- The corrosion resistance increases with increase in duration of time. The improvement in corrosion resistance is due to this factor is attributed to a protective layer formed on the surface of the material which gradually builds up and reaches a steady state with time.
- The Corrosion resistance was also found to improve with increase in S-glass concentration, probably since they act as physical barriers to the corrosion process, as well as the aluminium intermetallic compounds at the matrix, restricting pit formation and propagation there in.
- The composite specimens showed better corrosion /pitting resistance than the unre-enforced matrix alloy, also it is seen that corrosion rate increase with increase in normality of the solution.
- The S-glass content in Al alloys plays a significant role in the corrosion resistance of the material. Increase in the percentage of addition will be advantageous to reduce the density and increase in the strength of the alloy, and thus the corrosion resistance is there-by significantly reduced.
- The corrosion resistance of the composites was higher than that of the corresponding matrix alloy, which may be due to dislocation density and porosity of MMC's.

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