A STUDY ON MECHANICAL, TRIBOLOGICAL & OPTICAL MICROSCOPE BEHAVIOUR OF ALUMINIUM 6061-CARBON FIBER REINFORCED METAL MATRIX COMPOSITE

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ABSTRACT: The Aluminium alloy composite materials have of high strength, high stiffness, more thermal stability, more corrosion and wear resistance, and more fatigue life. Aluminium alloy materials found to be the best alternative with its unique capacity of designing the materials to give required properties. An attempt has been made to fabricate a metal matrix composite through Stir casting technique by taking matrix material as Aluminium Alloy AA6061 and reinforcement as Carbon fiber. The metal matrix composite (MMCs) materials are prepared by using stir casting technique. Development of Al 6061+0% CF, Al 6061+2% CF, Al 6061+4% CF & Al 6061+6% CF a study was carried out to investigate the Mechanical properties, Tribological properties and Microstructure.

KEYWORDS: Metal matrix composites (MMCS), Anova, Mechanical properties, Tribological properties and Microstructure.

1. INTRODUCTION

Aluminum metal matrix composites (AMMC) has gained more attention as engineering materials because of their higher specific strength, stiffness and in addition to their better wear resistance compared to unreinforced aluminium alloys. Preparation of MMCs chiefly dependents upon the type of reinforcement and matrix materials. AMMCs are mainly used in defense, aerospace, sports and in industries because of many desirable properties like higher stiffness, strength, thermal conductivity and combined properties like wear resistance, fracture toughness and corrosion resistance. Carbon fiber have been widely used in recreational equipment, aircraft, and space exploration. Composites are attractive because of much higher strength and stiffness for their weight than metals. Also, they are inherently water and corrosion proof, and they perform well under fatigue, losing little strength in cyclic loading. Composites are materials made up of various elements that rely on the collective integrity of their numerous parallel fibers for their strength. The reason for high modulus of carbon fiber come from the fact that carbon layers are mostly parallel with the fiber axis resulting high modulus (higher strength) parallel to the fiber axis and low modulus (minimum strength) perpendicular to the fiber axis. The greater degrees of the carbon layers alignment to the fiber axis make a fiber stronger. This is a fiber production parameter.

2. LITERATURE SURVEY

Bharath 2014 have fabricated a composite material by Stir Casting in which Aluminium Alloy AA6061 as matrix and Carbon fiber as reinforcement. The amount of Carbon fiber in composite is as 6%, 9% and 12% by weight. The various mechanical and wear test shows that there is increase in the hardness with increasing wt% of alumina, ductility is less, tensile strength is more than Aluminium Alloy.

H.R. Ezatpour 2014 investigated an experiment in which Aluminium Alloy AA6061 taken as matrix phase and Nano Alumina Al2O3 as reinforcement. The mesh sizes are as 50 µm and 40 nm and fabrication is done through Stir Casting and Extrusion process. Result shows that there is fine microstructure with high porosity and the porosity %vol. increased with increasing alumina weight fraction and decrease with extrusion process. Also found that for both as-cast and extruded samples, with increasing amount of Al_2O_3 nanoparticles, yield strength and tensile strength increased but elongation decreased.

3. METHODOLOGY

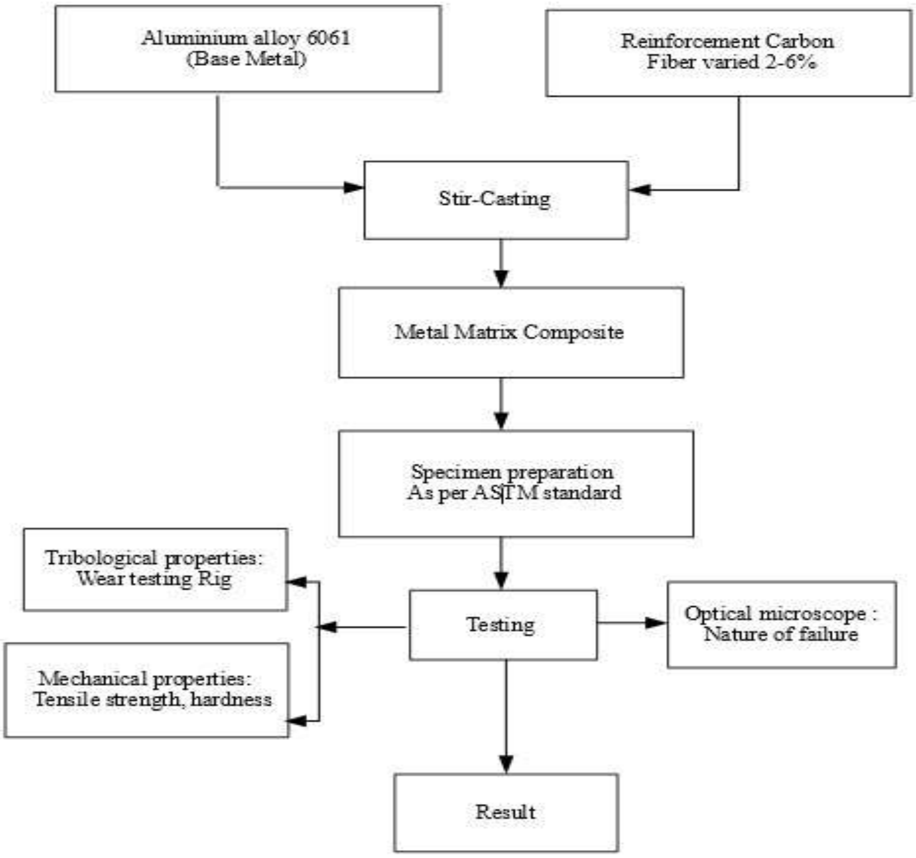


Figure 1: Flowchart of Carbon reinforced Aluminium composite

The aluminium alloy 6061 and carbon fiber is casted using the Stir-casting method to form the Metal Matrix Composite. The specimen is prepared as per the ASTM standard.

The specimen is tested for the properties such as:

1. Mechanical properties:
    a. Tensile strength
2. Tribological Properties:
    a. Wear Rate and
    b. Co-efficient of friction
3. Scanning Electron Microscopy (SEM)
    a. Nature of failure.

3.1 RAW MATERIALS USED FOR SPECIMEN PREPARATION

Aluminium Carbon Fiber

Figure: 2: Raw materials used for specimen preparation

The material selected for the present investigation is based on Al alloy 6061 matrix composite, designated as Aluminium 6061. This matrix alloy has low density 2.6 gm/cm^3 among all Al alloys and provides excellent combination of strength, high corrosion resistance to seawater, high tensile strength, exceptionally tough and good machinability & weld ability. The Carbon fiber particles of 5-8 micrometres microns used to fabricate the composite.

3.2 MANUFACTURING OF METAL MATRIX COMPOSITES

The stir casting process was used for the production of composite billets. Commercial Al6061 alloy was used as the matrix and Carbon fiber particles with an average particle size of 400pm was used as the reinforcement material. The castings were prepared for different weight fractions of Carbon fiber the furnace used for melting the aluminium was electrical resistance furnace of 6 KW. Different components of stir casting process are as shown in the Figure: 3

Figure: 3: Components of stir casting process

For manufacturing the initially 100% of A16061, The crucible in the furnace was cleaned and the weighed Al ingots were inserted in to it. The electrical resistance furnace was switched ON and allowed to reach the melting temperature of Aluminium.

4. TESTING AND RESULTS

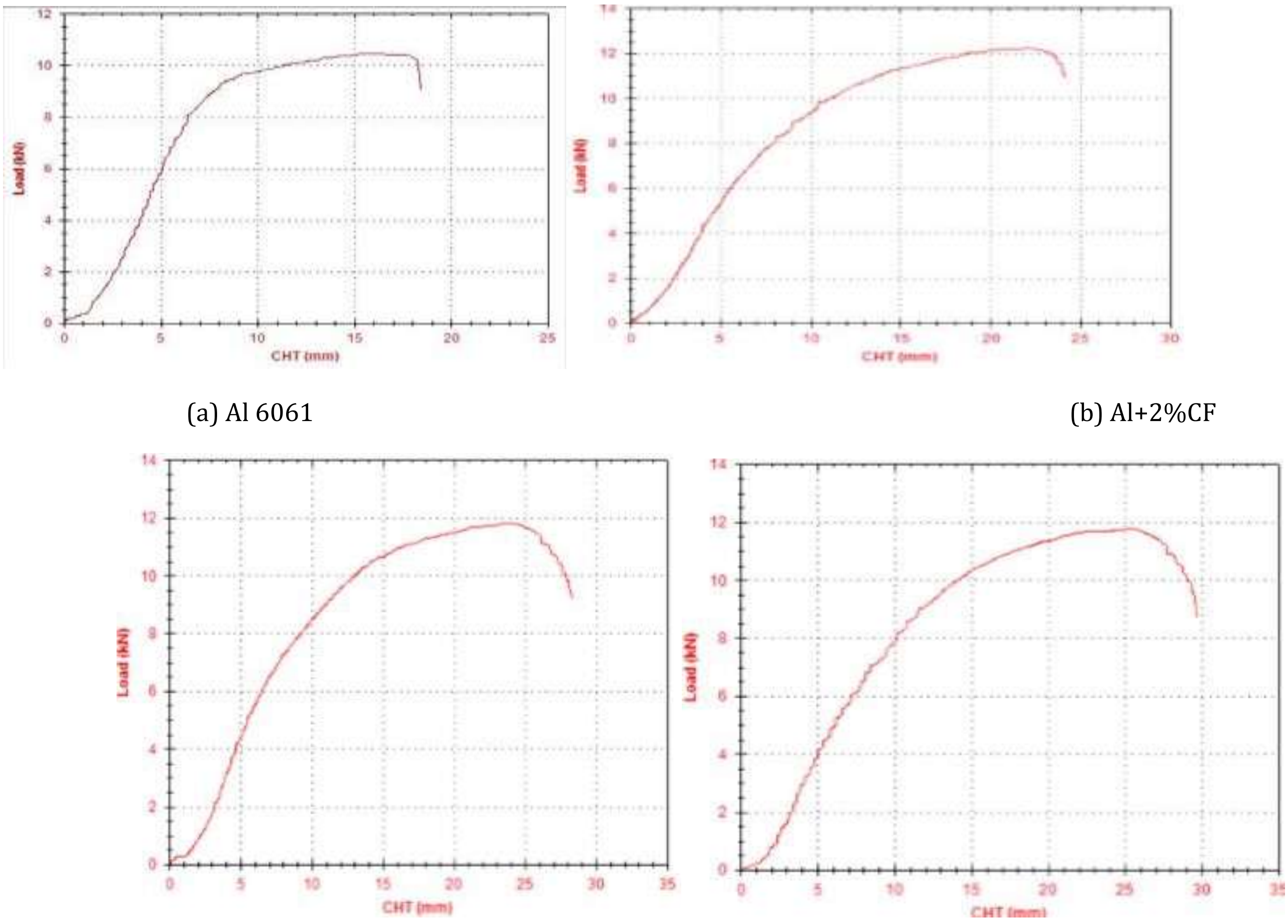
4.1 TENSILE TEST

The Tensile strength is determined by using Universal Testing Machine (UTM) as well as Electronic Tensometer. The specimen has the dimensions as per ASTM E8-16a.

Table 1: Mechanical properties for different weight % of Carbon fiber

Parameters	**Al 6061**	**Al+2%CF**	**Al+4%CF**	**Al+6%CF**
Tensile Strength N/mm^2	104.9	116.58	118.60	119.60
Yield Stress N/mm^2	90.7	103.28	103.43	103.63
Load at Yield KN	9.03	10.28	10.3	10.32
% of Elongation	19.1	16.84	13.84	10.24

Different mechanical properties related to the strength are tabulated in the weight fractions of Al6061, Al+2%CF, Al+4%CF and Al+6%CF identified that with increase in fraction tensile, yield strength increases.



(a) Al 6061 (b) Al+2%CF

(c) Al+4%CF (d) Al+6%CF

Figure 4: Load vs Elongation curve for different weight fractions

From the curve, maximum load was approximately 10.45KN. After the peak load a little elongation (necking) took place and the stress decreased until the specimen fracture for 0% of carbon fiber.

For 2% carbon fiber maximum load was 11.60KN. After the peak load a little elongation (necking) took place and the stress decreased until the specimen fracture for 2% of carbon fiber.

For 4% carbon fiber maximum load was 11.81KN. After the peak load some elongation (necking) took place and the stress decreased until the specimen fracture for 4% of carbon fiber.

For 6% carbon fiber maximum load was 11.91KN. After the peak load some elongation (necking) took place and the stress decreased until the specimen fracture for 6% of carbon fiber.

4.2 WEAR TEST

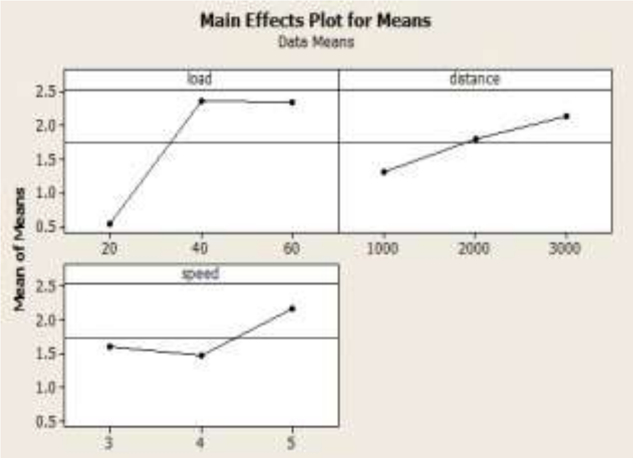
Table 1 (a): Result of dry sliding wear tests as per Orthogonal Array L_9 (3^4) For Al6061

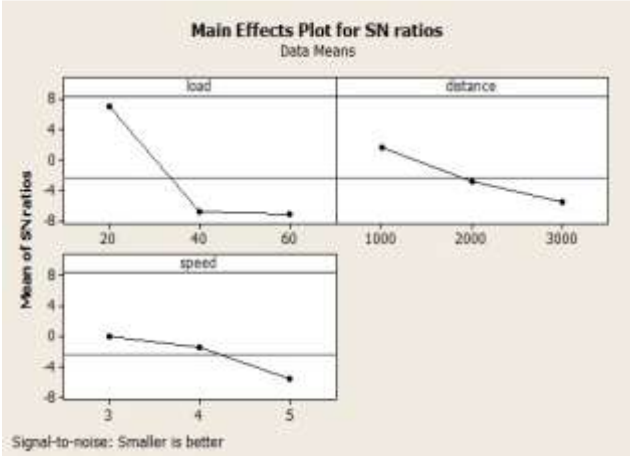
Sl. No	**Speed (m/sec)**	**Load in N**	**Sliding Distance (m)**	**Wear loss in mg**
1	3	20	1000	0.2
2	4	20	2000	0.5
3	5	20	3000	0.9
4	4	40	1000	1.2
5	5	40	2000	3.1
6	3	40	3000	2.8
7	5	60	1000	2.5
8	3	60	2000	1.8
9	4	60	3000	2.7

Table 1(b): Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Of Contribution
load	2	391.140	391.140	195.570	51.16	0.019	74.38
distance	2	75.893	75.893	37.947	9.93	0.092	14.43
speed	2	51.120	51.120	25.560	6.69	0.130	9.72
Error	2	7.646	7.646	3.823			1.45
Total	8	525.799					100

DOF: degrees of freedom; Seq SS: sequential sum of squares; Adj SS: adjusted sum of squares; Adj MS: adjusted mean of square.





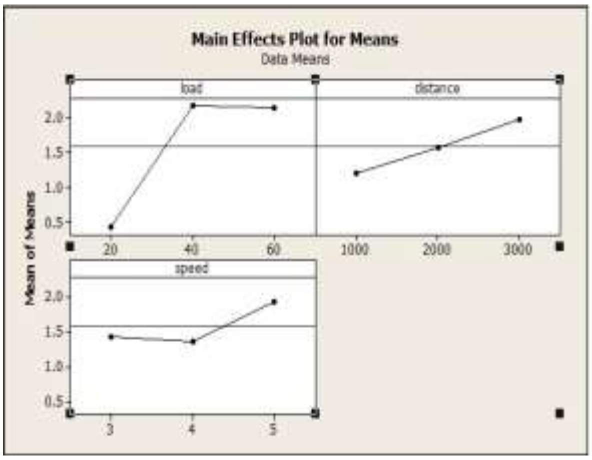
(a) Main effects plot for Means (b) Main effects plot for SN ratios

Table 2 (a): Result of dry sliding wear tests as per Orthogonal Array $L_9\,(3^4)$ for Al+2%CF

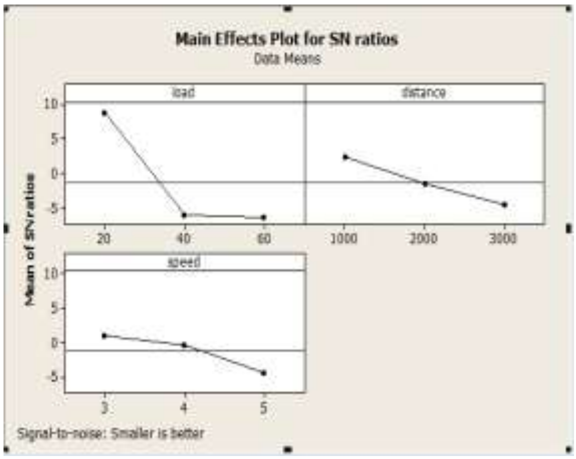
Sl. No	Speed (m/sec)	Load in N	Sliding Distance(m)	Wear loss in mg
1	3	20	1000	0.18
2	4	20	2000	0.40
3	5	20	3000	0.70
4	4	40	1000	1.10
5	5	40	2000	2.80
6	3	40	3000	2.60
7	5	60	1000	2.30
8	3	60	2000	1.50
9	4	60	3000	2.60

Table 2 (b): Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Of Contribution
load	2	440.505	440.505	220.253	57.87	0.017	78.09
distance	2	69.211	69.211	34.605	9.09	0.099	12.26
speed	2	46.754	46.754	23.377	6.14	0.140	8.28
Error	2	7.613	7.613	3.806			1.34
Total	8	564.082					100



(a) Main effects plot for Means



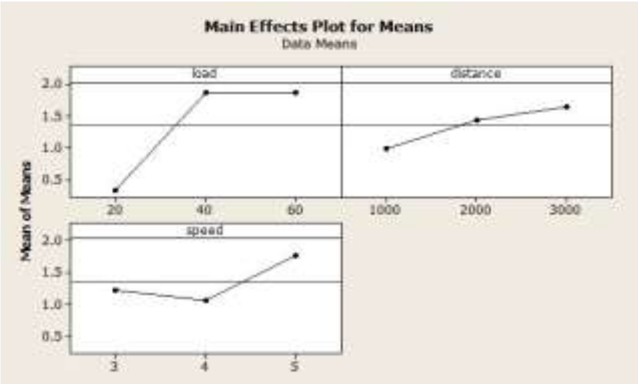
(b) Main effects plot for SN ratios

Table 3 (a): Result of dry sliding wear tests as per Orthogonal Array $L_9\,(3^4)$ for Al+4%CF

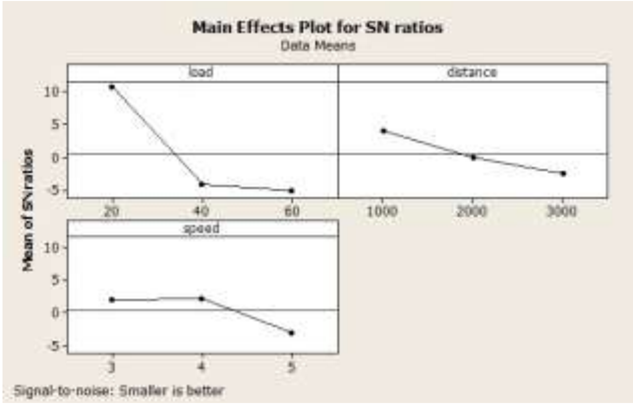
Sl. No	**Speed (m/sec)**	**Load in N**	**Sliding Distance (m)**	**Wear loss in mg**
1	3	20	1000	0.17
2	4	20	2000	0.30
3	5	20	3000	0.50
4	4	40	1000	0.70
5	5	40	2000	2.70
6	3	40	3000	2.20
7	5	60	1000	2.10
8	3	60	2000	1.30
9	4	60	3000	2.20

Table 3 (b): Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Of Contribution
load	2	468.736	468.736	234.368	28.29	0.034	77.43
distance	2	66.360	66.360	33.180	4.01	0.200	10.96
speed	2	53.673	53.673	26.837	3.24	0.236	8.86
Error	2	16.569	16.569	8.284			2.74
Total	8	605.339					100



(a) Main effects plot for Means



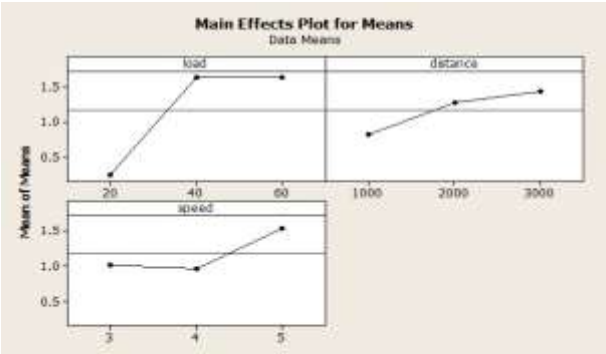
(b) Main effects plot for SN ratios

Table 4(a): Result of dry sliding wear tests as per Orthogonal Array $L_9 (3^4)$ for Al+6%CF

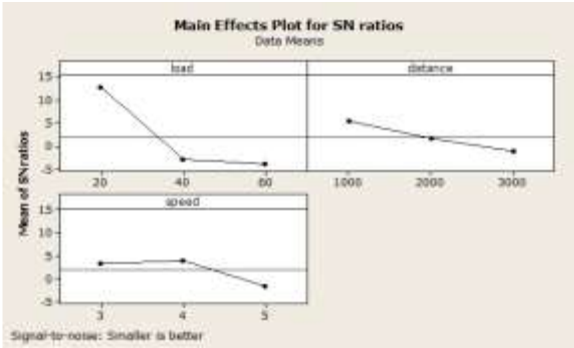
Sl. No	Speed (m/sec)	Load in N	Sliding Distance (m)	Wear loss in mg
1	3	20	1000	0.15
2	4	20	2000	0.20
3	5	20	3000	0.40
4	4	40	1000	0.60
5	5	40	2000	2.50
6	3	40	3000	1.80
7	5	60	1000	1.70
8	3	60	2000	1.10
9	4	60	3000	2.10

Table 4(b): Analysis of Variance for SNRA1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Of Contribution
load	2	528.17	528.17	264.09	32.07	0.030	79.15
distance	2	66.28	66.28	33.14	4.02	0.199	9.93
speed	2	56.29	56.29	28.14	3.42	0.226	8.43
Error	2	16.47	16.47	8.24			2.48
Total	8	667.22					100



(a) Main effects plot for Means

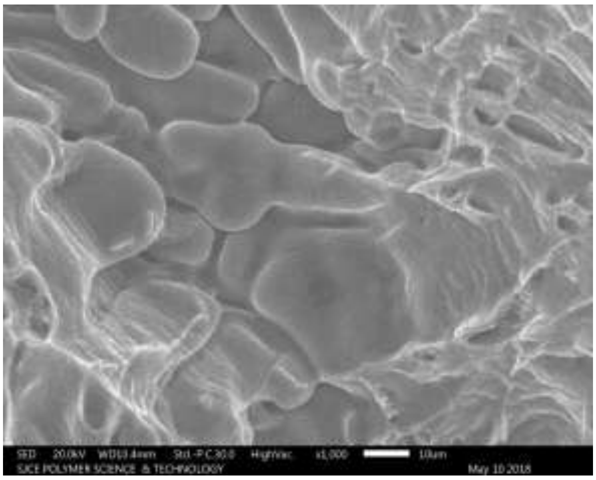


(b) Main effects plot for SN ratios

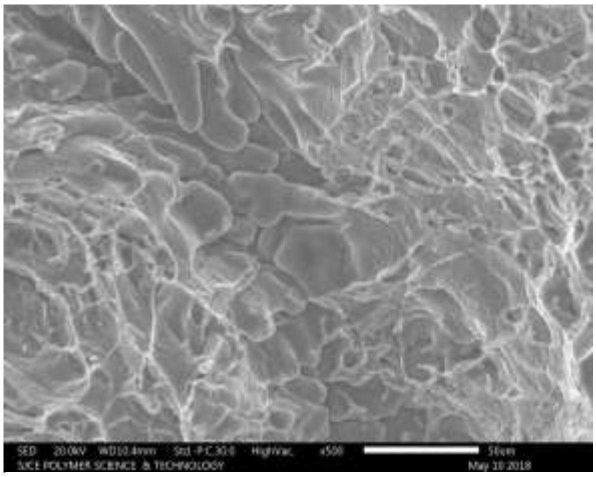
Dry sliding wear test was conducted on the prepared samples for the different combinations of wear parameters like loads, sliding speed and sliding distance using Taguchi and ANOVA techniques. The following conclusions can be drawn from this work. The composites, both sample - II and sample - III prepared by reinforcing Al6061+2% CF , Al6061+4% CF and Al6061+6% CF has shown good resistance to wear rate compared to the unreinforced alloy. A good approximation was achieved between the experimental and the predicted value and thus Taguchi and ANOVA techniques were effectively utilized to identify the optimal level of the wear parameters. Among the four wear parameters, the sliding distance was the most significant parameter influencing the wear rate followed by applied load, sliding speed and percentage of reinforcement material respectively. The wear rate increases with increase in the applied load for both the AL6061 alloy and the prepared composites decreases with increase in the sliding speed.

5. Microstructure Test:

The samples that were chosen for SEM analysis and their respective failure loads are displayed below figure. During the process of separating these samples to expose the interlaminar fracture surface. The only samples chosen which displayed the end effect, were significantly more difficult to separate than the other samples.



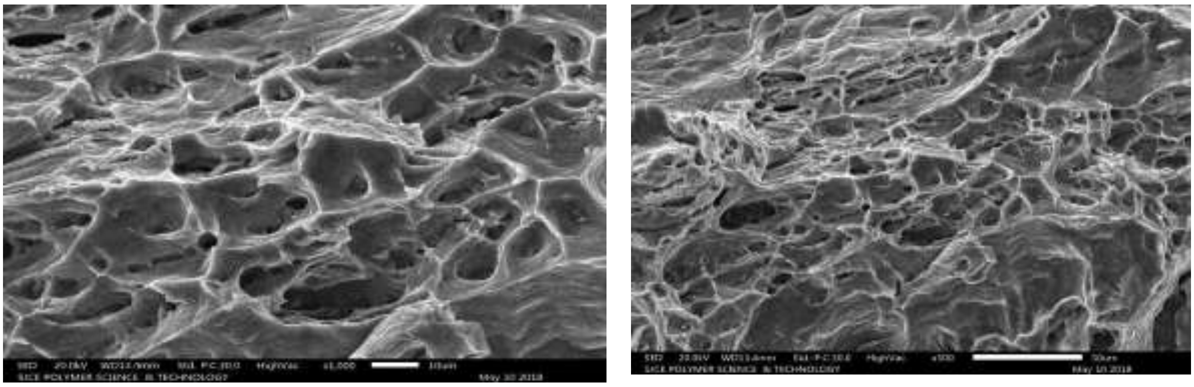
(a)



(b)

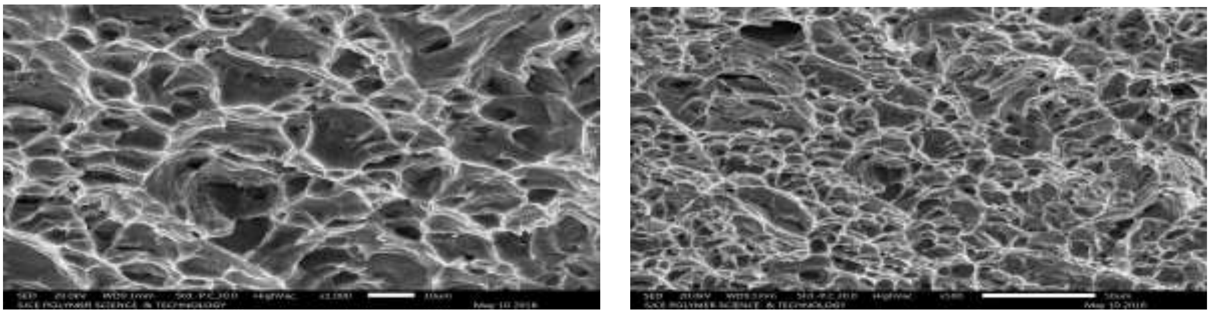
Figure 5.1: SEM image of pure Al 6061

Fig.4.8 (a) shows the SEM image of Al 6061 particles. Fig. 1(b) shows the microstructure of cast Al6061, and the microstructure contains solid solution of inter-dendritic network of aluminium. The low density of aluminium melt resulting in non-uniform distribution. The microstructures of all composites contain solid solution of aluminium and inter-dendritic network of aluminium silicon eutectic.



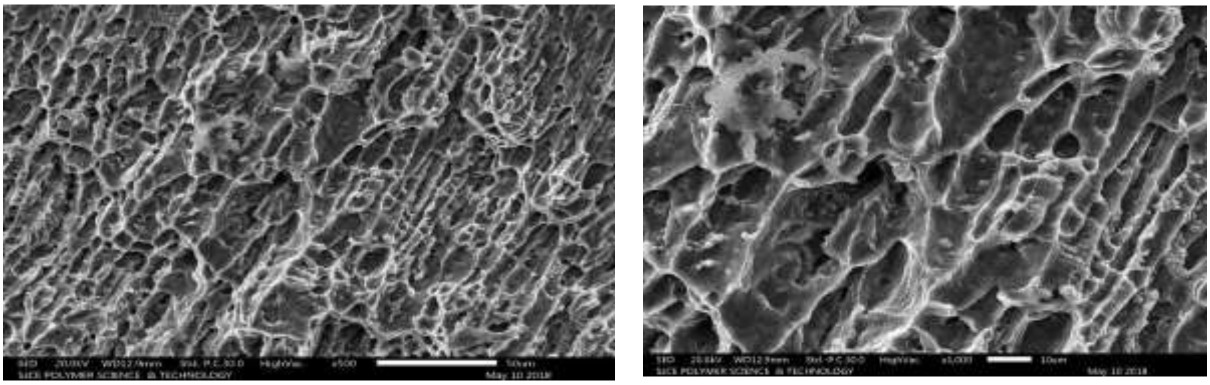
(a) (b)

Fig. 5.2: SEM image of Al 6061+2% CF



(a) (b)

Fig. 5.3: SEM image of Al 6061+4% CF



(a) (b)

Fig. 5.4: SEM image of Al 6061+6% CF

Figure 5.1, 5.2, 5.3 and 5.4 shows the elemental maps of Al 6061+2% CF, Al 6061+2% CF, Al 6061+2% CF particles. From the elemental maps of the composite it is evident that the main elements present in the composite are Al (largest amount) and Carbon fiber. Which are constituents of base metal Al6061 are also present in small amount of carbon fiber.

The micrographs are composed of dendritic structure. From the above figures 4.9, 5.0 and 5.1 it is clearly seen that with the increase in percentage of Carbon fiber particles the grain size also increases. The reinforced Al 6061+2% CF, Al 6061+2% CF, Al 6061+2% CF particulates induce modification in the dendritic structure and the grain refinement. During the solidification process the Carbon fiber particles provide resistance to the growth of a Al. Carbon fiber particles act as nucleation centres on which the aluminium grains solidify. The SEM micrographs of the fabricated composites for varying composition of Carbon fiber particles Uniform distribution of particles throughout the matrix can be noticed from the micrographs, which plays a major role in the betterment of Mechanical properties. Distribution of reinforced particulates is influenced by process of solidification. The presence of clear interface between two constituent phases can be clearly seen. This plays a major role in improvising the Mechanical and Tribological properties of the developed composites. With the increase in Carbon fiber particles the nucleation sites also get increased and this also offers more resistance to the growth of the grains leading to grain structure modification.

6. CONCLUSION

In the present investigation, carbon fiber reinforced aluminium 6061 composites are fabricated and their mechanical properties are evaluated. Based on the experimental investigation and analysis, the following conclusions are drawn,

The tensile strength, are observed for 4 different specimen. The tensile strength increases as the Al 6061 for 2% carbon fiber maximum load was 11.60KN. After the peak load a little elongation (necking) took place and the stress decreased until the specimen fracture for 2% of carbon fiber.

Al 6061+4%CF for 4% carbon fiber maximum load was 11.81KN. After the peak load some elongation (necking) took place and the stress decreased until the specimen fracture for 4% of carbon fiber.

Al 6061+6%CF for 6% carbon fiber maximum load was 11.91KN. After the peak load some elongation (necking) took place and the stress decreased until the specimen fracture for 6% of carbon fiber.

Dry sliding wear test was conducted on the prepared samples for the different combinations of wear parameters like loads, sliding speed and sliding distance using Taguchi and ANOVA techniques. The following conclusions can be drawn from this work. The three composites sample-2, sample-3 and sample- 4 prepared by reinforcing Al6061+2% CF, Al6061+4% CF and Al6061+6% CF has shown good resistance to wear rate compared to the unreinforced alloy.

The SEM micrographs of the fabricated composites for varying composition of Carbon fiber particles Uniform distribution of particles throughout the matrix can be noticed from the micrographs. This plays a major role in improvising the Mechanical and Tribological properties of the developed composites. With the increase in Carbon fiber particles the nucleation sites also get increased and this also offers more resistance to the growth of the grains leading to grain structure modification.

7. REFERENCES

[1] H.R. Ezatpour 2014 investigated an experiment in which Aluminium Alloy AA6061 taken as matrix phase and Nano Alumina Al2O3 as reinforcement.

[2] ‘Raw materials used for specimen preparation’ process in carbon fiber labtech.com