Effect of Heat Treatment on Mechanical and Wear Properties of LM25-Al_2O_3-Graphite Hybrid Composite

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Abstract

Effect of heat treatment on mechanical and dry sliding wear behaviour of LM25 Al alloy reinforced with 9 wt. % Al_2O_3 and 4 wt. % graphite particles were investigated. The specimens were prepared by Stir casting, heat treated at 540°C for three hours, water quenched to room temperature, heated to 180°C in a furnace for four hours and air cooled to room temperature in accordance with T6 heat treatment. Mechanical and wear properties, changes in microstructure due to the heat treatment was studied. Tensile strength, hardness and compressive strength of As-cast Composite after heat treatment increased significantly by 119%, 60% and 32% respectively as compared to those of AC Neat (un-heat treated LM25 alloy). Presence of hard Al_2O_3 and soft Graphite particles in the LM25 matrix alloy significantly control the surface hardness, wear loss and coefficient of friction.

Keyword: *LM25 Al alloy, Al_2O_3, Graphite particles, Stir casting, Mechanical properties, Wear resistance*

1.0 Introduction

Aluminium matrix composites (AMC) are used in automotive, aerospace, microelectronics, marine, recreational and military sectors for a wide range of components and devices [1]. AMC are preferred because of their high specific strength and stiffness, corrosion and oxidation resistance, tribological properties and low coefficient of thermal expansion [2,3]. Mechanical properties of AMC can be increased by reinforcing them with hard ceramic particles such as Al_2O_3 and SiC. These reinforcements tend to decrease the machinability and impact toughness of Al matrix. Its machinability and damping capacity can be increased by reinforcing with soft particles such as graphite which can act as solid lubricant [4]. AMC with two reinforcements such as a hard phase and a soft lubricating phase is explored to overcome the limitations of single reinforcement [5].

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Several authors used stir casting for fabrication of particulate reinforced metal matrix composites with up to 30 wt. % reinforcement to achieve uniform distribution with low porosity [6, 7]. Mechanical properties improved in AMC/SiC and AMC/Al_2O_3, but ductility and fracture toughness decreased [8, 9, 10]. Inconsistent corrosion performance of AMC is reported [11, 12]. Karthikeyan et al [13] reported AMC using Zirconia (3 to 12 wt. %) prepared by using stir casting and reported increase in hardness and ductility. Uniform distribution and interfacial bonding was observed in 12 wt. % Al/Zirconia. Stir casting was used to fabricate AMC with particulate reinforcements namely Silicon Carbide (SiC), Alumina (Al_2O_3) and graphite [14]. Silicon carbide (SiC), alumina (Al_2O_3), boron carbide (B_4C), tungsten carbide (WC), graphite (Gr), carbon nanotubes (CNT) and silica (SiO_2) are some of the synthetic ceramic particulates that have been studied. Silicon carbide and alumina are more widely researched [15].

Dinesh et al [16] fabricated LM25/TiB_2 (10 wt. %) composite using stir casting. Uniform distribution of TiB_2 in the matrix and 10 % increase in hardness of the composite was observed. Kenneth et al [17] investigated mechanical and wear behaviour of stir cast Al-Mg-Si alloy composites using steel, steel-graphite hybrid and SiC particles. Steel particulates increased the hardness of the composites whereas addition of steel-graphite hybrid decreased the wear rates. Abrasive wear was dominant in all the composites.

Radhika et al [18] studied hardness, tensile strength and wear behaviour of LM25/SiC/Al_2O_3. The composites with 30 wt. % reinforcement showed higher tensile strength and hardness than that of LM25 base alloy because of high dislocation density caused by the dispersion of Al_2O_3 and SiC which hinder dislocation motion. Wear rate of the composites decreased with increase in reinforcement. Wear rate increased with the applied load and the same decreased with increase in sliding velocity.

Shanawaz et al [19] fabricated LM25 alloy by stir casting using SiC and activated carbon as reinforcements. Addition of SiC increased the tensile strength and hardness. Wear rate increased with speed at constant load and duration. Zeeshan et al [20] developed LM 25/Boron carbide using stir casting. Homogeneous dispersion at lower content of boron carbide clusters were observed in the composites with 12wt. % reinforcement.

Kumara et al [21] studied wear and frictional properties of LM25/ Alumina/Silicon carbide nano particles hybrid composite using stir-casting. Addition of SiC and Alumina decreased the wear rate at room temperature. Coefficient of friction decreased with load and increased with volume content of reinforcement. Hard ceramic particles resulted in abrasive wear of LM25 composites.

Several researchers studied mechanical and wear properties of LM25 with SiC, zirconia, TiB_2, boron carbide as reinforcements. However, not much work has been done on the synergistic effect of Al_2O_3 and graphite on the mechanical and tribological behaviour of the composites. Hence, this research was aimed at studying the heat treatment effect on structural, mechanical and sliding wear behaviour of LM25-Alumina-Graphite composites.

2.0 Experimental Details

2.1 Material Selection

Fig. 1 shows the SEM micrographs of the initial as-cast LM25 alloy, as-received Al_2O_3 and graphite particles.

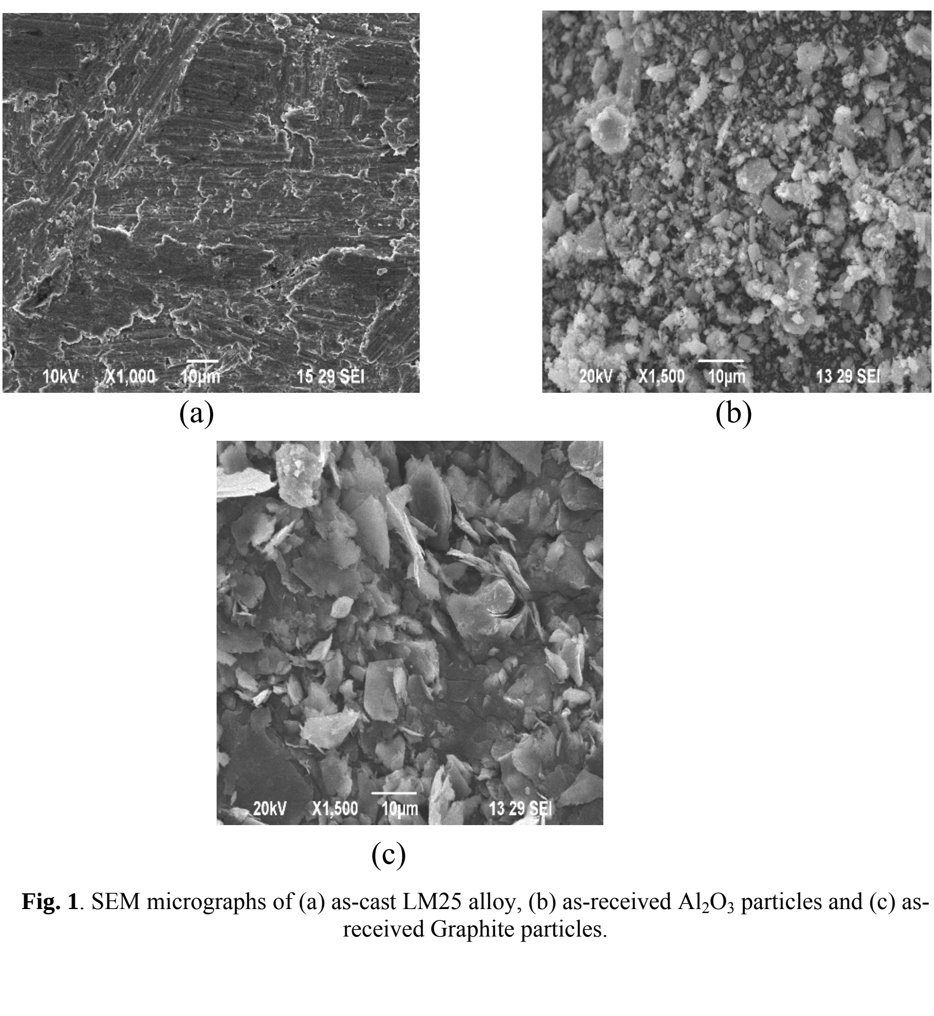


Fig. 1. SEM micrographs of (a) as-cast LM25 alloy, (b) as-received Al_2O_3 particles and (c) as-received Graphite particles.

(a) LM25 consists of primary alpha-Al dendrites (Coarse Al matrix) surrounded by needle shaped Si particles along their boundaries, (b) Al_2O_3 particles with rough surface morphology, (c) Graphite particles - polygonal with lamellar structure

2.1.1 LM25 Al alloy

LM25 Al alloy (BS1490), procured from Laxmi Metal Exchange, Coimbatore, was selected as a matrix alloy. The properties of LM25 alloy can be improved by addition of suitable ceramic particles and heat treatment. Chemical composition of LM25 Al. alloy is shown in Table 1.

Table 1. Chemical composition (by weight%) of LM25 Al. alloy

Cu	**Mg**	**Si**	**Fe**	**Mn**	**Ni**	**Zn**	**Pb**	**Sn**	**Ti**	**Al**
0.2 max	0.2-0.6	6.5-7.5	0.5 max	0.3 max	0.1 max	0.1 max	0.1 max	0.05 max	0.2 max	REM

2.1.2 Alumina (Al_2O_3)

Alumina with particle size in the range of 6-23 μm was selected as hard reinforcement since it has good wettability with base aluminium matrix and also it has high strength, high hardness, excellent size and shape, better corrosion resistance, wear resistance and heat resistance, Alumina is readily available, more stable, inert and cheaper compared with silicon carbide. Al-Al_2O_3 composites are used in cylinder block liners, vehicle drive shafts, automotive pistons and bicycle frames [1,14,21]. Physical properties of Alumina (Al_2O_3) are listed in Table 2.

Table 2. Physical properties of Al_2O_3

Density	3.75-3.98 g/cm^2
Melting point	2030 $^\circ$C-2040 $^\circ$C
Mechanical Strength	150-600 MPa
Thermal conductivity	20 to 30 W/mK
Compression Strength	2000-4000 MPa
Molar mass	101.96 gm/mol
Hardness	1300-2000 HV1.0/1600 HV50/18 –23 GPa
Young Modulus	330 – 380 Gpa
CTE	5.4-8.4 10^{-6}/K

2.1.3 Graphite

Graphite particles of 24-94 µm was selected as soft reinforcement to improve wear resistance, damping capacity and machinability of the matrix alloy. It serves as a solid lubricant and also prevents seizure in the Al alloy matrix. [19]. Physical properties of Graphite are shown in Table 3.

Table 3. Physical Properties of Graphite (Gr.)

Density	1.3-2.26 g/cm^3
Elastic Modulus	8-15 GPa
Thermal conductivity	25-470 W/mK
Melting Temperature	3350 °C- 36000C
Hardness	5 BHN/40HV/1.7 Mohs scale
Ultimate Tensile Strength	14 MPa
Compressive Strength	20-200 MPa
CTE	1.2-8.2 10-6/K

2.2 Fabrication of Test Specimens

2.2.1 Preparation of matrix alloy and reinforcements for casting

Alumina and graphite particles were sieved to fine grain size in the range of 6-23 µm and 24-94 µm respectively. Two pieces, one weighing 500 gm. and the other weighing 435 gm. were cut from LM25 alloy ingot. The details of weight fractions of the matrix alloy and the selected reinforcements and respective measured weights are shown in Table 4.

Table 4. Composition of Sample Weight of LM25 alloy, Al_2O_3 and Graphite

Sample No.	**Material**	**LM25 Al. alloy (gm)**	**Micro Alumina (Al2O3) (gm)**	**Micro Graphite (Gr) (gm)**	**Total Weight (gm)**
1	LM25 Al. alloy	500	-	-	500
2	87 wt.% LM25 9 wt.% Alumina 4 wt.% Graphite	435	45	20	500

2.2.2 Fabrication of hybrid composite sample

Hybrid composite of LM25 9 wt.% Al_2O_3 4 wt.% Gr was fabricated by stir casting process as shown in Fig.2. Before casting 45 gm of Al_2O_3 particles (6-23 μm) and 20 gm of graphite (24-94 μm) were preheated in the range of 300-350 °C for about 20 min. to remove moisture, gases and other organic contaminants from the surface of the particulates. 435 gm. of LM25 Al. alloy was melted at a temperature of 750 °C, in a graphite crucible using induction electric resistance furnace. When the alloy was in fully molten condition, 0.3% of Hexachloroethane (C_2Cl_6), degassing tablet, was added to the molten metal for removing the unwanted gases entrapped in the melt. The molten metal was then cooled to 600 °C to turn into semi-solid state.

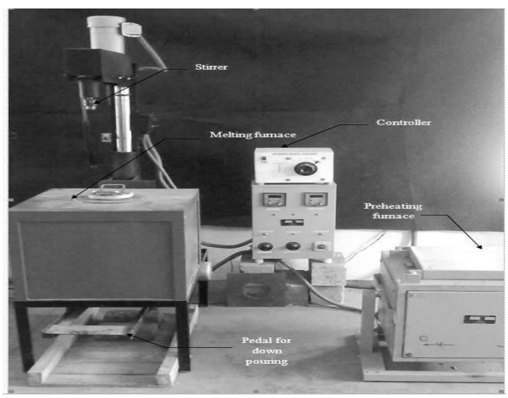


Fig. 2. Stir casting setup **Fig. 3.** Casted samples of composites

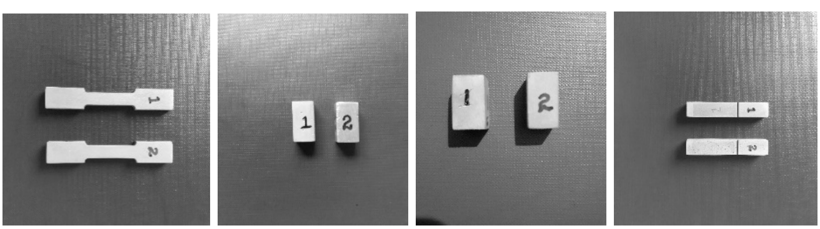
Stirring was started at 300 rpm and at the same time the preheated reinforcements were added manually to the semi solid alloy. 0.5% of Mg particles wrapped in aluminium foil were added to the melt to improve wettability. Stirring was continued for 5 min at the same speed to achieve proper mixing of the reinforcements in the melt. After completion of the first stirring the semi-solid mixture was again reheated to a temperature of 750 °C to turn into fully molten condition. Second stirring was started using automatic stirrer for 5 min at the same speed to ensure more uniform distribution. The molten metal was then poured into a cavity of preheated metal mould at 700-750 °C and then allowed to cool in atmospheric air. [20-23]. Similar process was used for casting LM25 alloy sample for the purpose of comparison. The casted samples are shown in Fig. 3.

2.2.3 Machining of Test-specimens

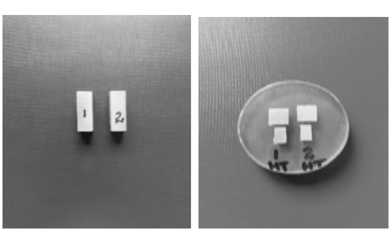
Test-specimens for tensile, hardness, compressive, impact, wear and microstructure tests were machined (Figure 4) according to ASTM standards (Table 5)

Table 5. ASTM/IS codes for microstructure, mechanical and wear tests

Test No	ASTM/IS Code	Mechanical /Wear/ Microstructure Tests	Dimension (mm)
1	ASTM E8	Tensile Strength	12 X 06 X 100
2	IS 1501 (P-1) 13	Hardness	10 X 10 X 25.4
3	ASTM E9	Compressive Strength	10 X 10 X 25
4	IS 1598-1977	Impact Strength	10 X 10 X 75
5	ASTM G99-04 A	Sliding Wear rate	10 X 10 X 30
6	ASTM E3-11	Microstructure	10 X 10 X 10



(a) (b) (c) (d)



(e) (f)

Fig. 4. Test-specimens for (a) Tensile Strength, (b) Hardness, (c) Compressive Strength, (d) Impact Strength, (e) Sliding Wear rate and (f) Microstructure

2.2.4 T6- Heat Treatment

The machined specimens were T6-heat treated (solution heat treated at 540° C in Heat treatment furnace as shown in Fig.5 and Table 6), for a holding time of 3 hours and then rapidly immersed in water at room temperature. The cooled specimens were then artificially aged at 180° C for 4 hours followed by cooling in air under normal room temperature.

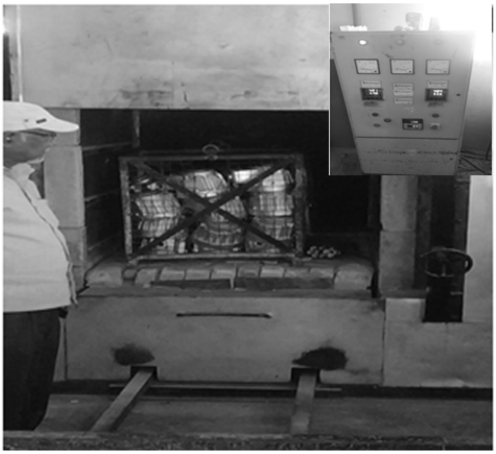


Fig. 5. Electric furnace

Table 6. Specification of Electric Furnace

Make	H.H. Engineers, Bangalore
Maximum Temperature	1200°C
Heating rate	+ or - 5°C for 2 min.
Dimensions of heating Chamber(mm)	1000 x 1000 x 12000

3.0 Mechanical and Wear Testing

Microstructure, hardness, tensile strength, compressive strength, wear rate and impact strength tests were performed on all the specimens before and after heat treatment.

3.1 Microstructure Analysis

The samples, as shown in Fig.4f, were examined, using metallurgical microscope (METASCOPE T 2003 U) for microstructure analysis.

3.2 Tensile Test

Tensile Strength Tests were performed on specimens as shown in Fig.4a, with the help of Computerized Universal Testing Machine (Model-TFUC-1000).

3.3 Hardness Test

Microhardness tests were conducted on the specimens as shown in Fig.4b, with the help of Vickers Hardness tester (Model-NEXUS EW 4304). In this experiment a constant direct load of 1kgf was applied on the specimens for a dwell time of 10 seconds. Three hardness values were measured at different locations on each specimen. The average of these three values was then computed for each specimen.

3.4 Compression Test

Compression tests were conducted on the specimens as shown in Fig.4c using Computerized UTM (Model-TFUC-1000).

3.5 Impact Test

Izod impact tests were conducted on the specimens as shown in Fig.4d with the help of Impact testing machine.

3.6 Wear Test

Wear tests were performed on the specimens as shown in Fig.4e in dry sliding condition with the help of Pin-on-disc wear testing machine (Magnum Engineers, Bangalore) at room temperature according to the ASTM G99-04A. The mass was measured using an electronic digital balance with an accuracy of 0.0001 g and noted. Each specimen was mounted in the wear test machine (Fig.6). A hardened steel disk was in contact with the specimen surface with a load of 50 N, a constant sliding velocity of 3 m/s and distance of 3250 m.

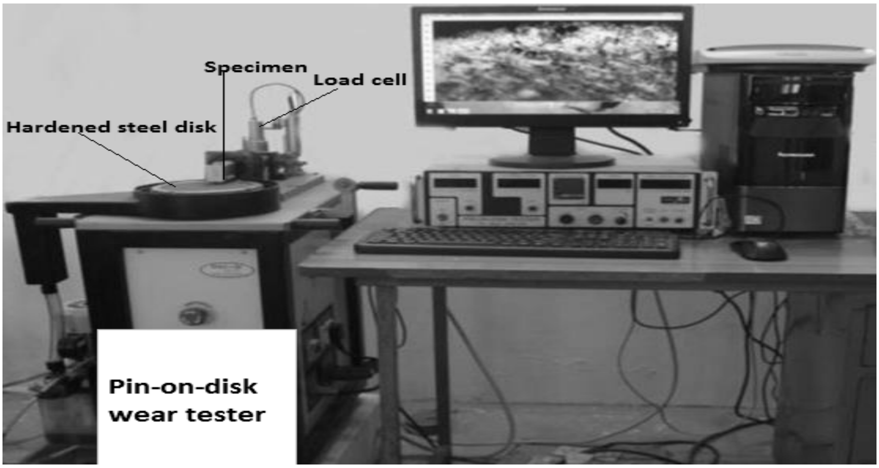


Fig. 6. Pin-on-disk wear tester

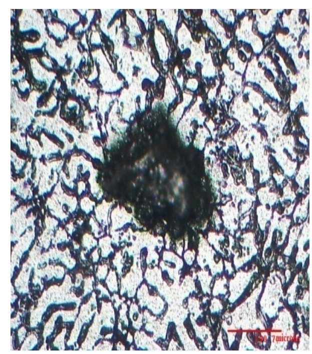
4.0 Results and Discussion

Mechanical properties such as tensile strength, hardness, compressive strength, impact strength and wear characteristics were determined on test specimens before and after heat treatment. The effects of addition of reinforcements and influence of heat treatment on these properties were studied

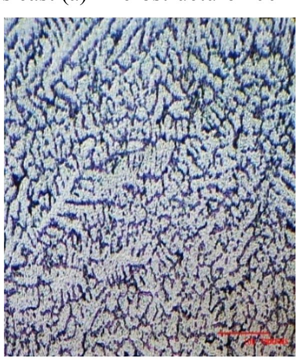
4.1 Microstructural Analysis

Fig.7a and Fig.8a. shows the microstructure of non-heat-treated cast Al–Si-.28Mg (LM25) alloy dendrites of α-Al and needle shaped eutectic silicon in the inter-dendritic regions and around the dendrites of α-Al in the matrix of aluminium solid solution. Fairly uniform distribution was noticed. From Fig.7b porosities and shrinkage cavities were observed with maximum diameter of 0.27mm. From Fig.7c and Fig.8b the microstructure of the heat-treated cast Al–Si-.28Mg (LM25) alloy revealed the network of fine dendrites of α-Al and fine precipitates of spheroidized eutectic silicon in the inter-dendritic regions and around the dendrites of α-Al in the matrix of aluminium solid solution caused by solution treatment and artificial aging. Fig.7d porosities and shrinkage cavities were observed with maximum diameter of 0.19 mm.

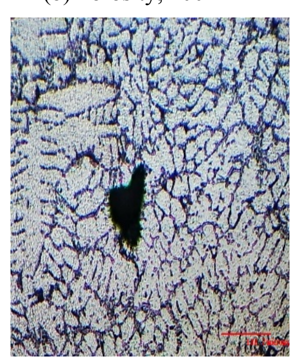
As cast (a) Microstructure 100X



(b) Porosity, 100X

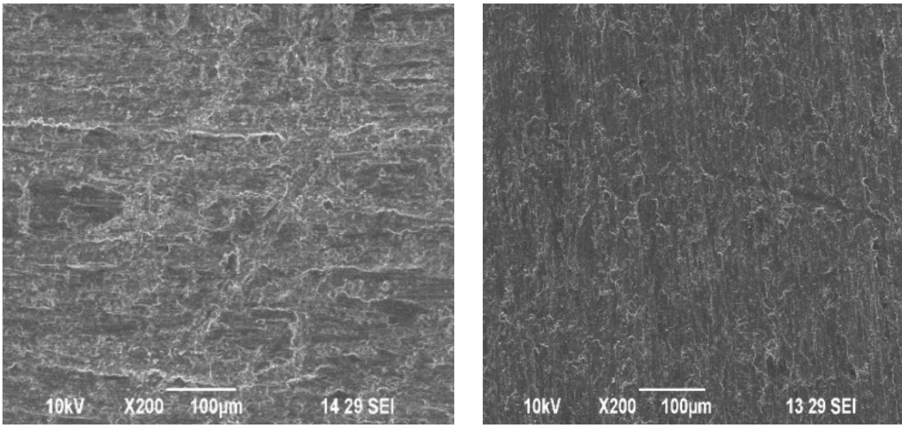


Heat Treated (c) Microstructure 100X



(d) Porosity, 100X

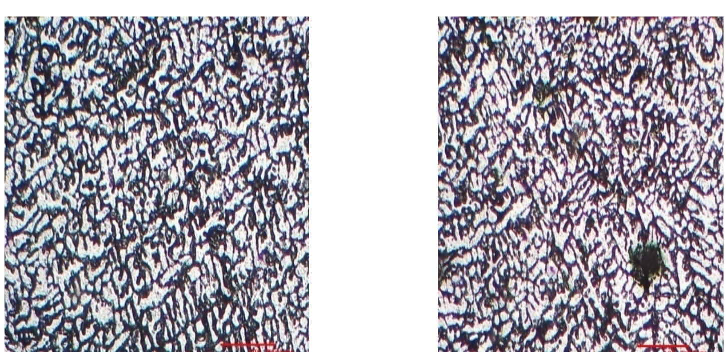
Fig. 7. Optical Micrographs of As- cast and Heat treated LM25 alloy



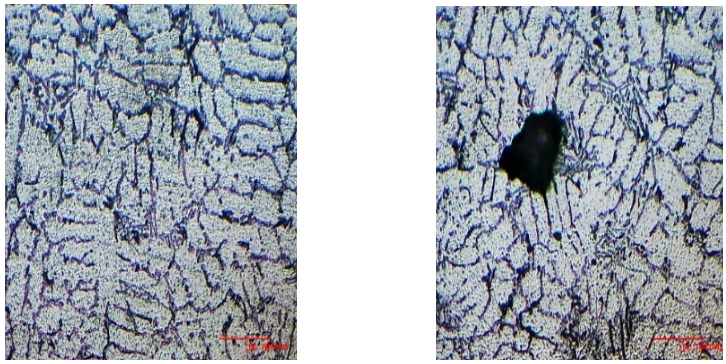
(a) As-cast (b) Heat-treated

Fig. 8. SEM of As-cast and Heat treated LM25 Alloy

Fig. 9a and Fig.10a shows the microstructure of non-heat treated cast composite depicted fine dendrites of α-Al, needle shaped eutectic silicon and the reinforcements in the inter-dendritic regions and around the dendrites of α-Al in the matrix of aluminium solid solution. Fairly uniform distribution of reinforcements was observed. From Fig.9b porosities and shrinkage cavities were observed with maximum diameter of 0.06 mm. Fig.9c and Fig. 10b presents the microstructure of the heat-treated cast composite revealed the network of coarser dendrites of α-Al and reinforcements with fine precipitates of spherodized eutectic silicon particles in the inter-dendritic regions and around the dendrites of α-Al in the matrix of aluminium solid solution. Most uniform distribution of reinforcements and spherodized eutectic silicon particles in the heat-treated composite material was clearly observed. Porosities and shrinkage cavities were observed with maximum diameter of 0.10 mm (Fig. 9d)

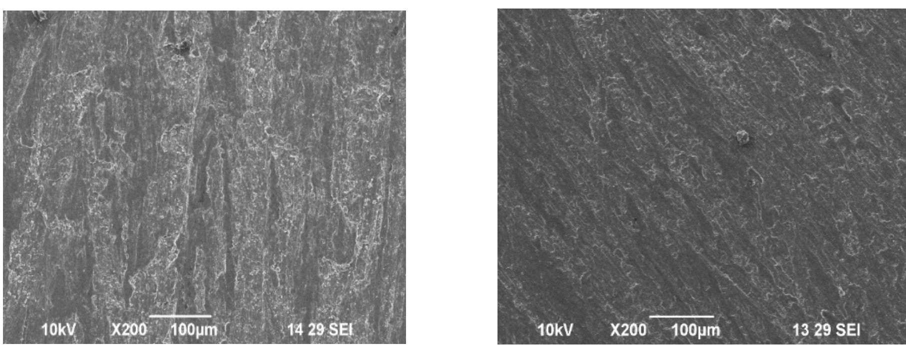


(a) NHT (100X) (b) NHT (Porosity, 100X)



(c) HT (100X) (d) HT (Porosity, 100X)

Fig. 9. Optical Micrographs of As-cast and Heat treated LM25 Alloy composite



(a) As-cast Composite (b) Heat treated Composite

Fig.10. SEM of As-cast and Heat treated LM25 Alloy composite

4.2 Tensile Strength

The results of the tensile tests are shown in Fig.11 and Fig.12

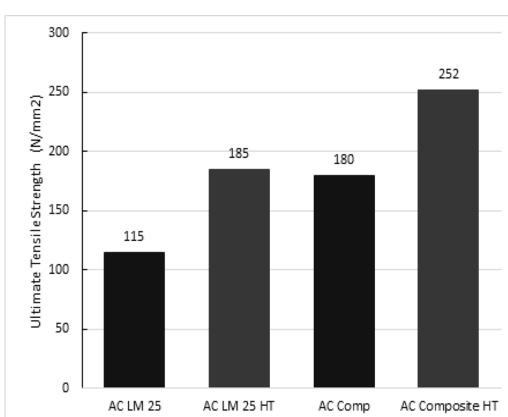


Fig.11. Tensile strength of as-cast and heat treated LM25 and its composites

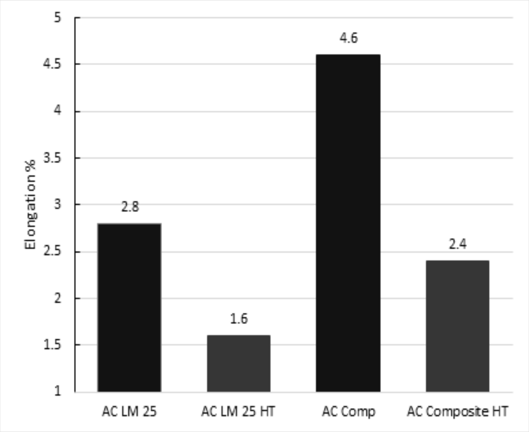


Fig. 12. Percentage elongation of as-cast and heat treated LM25 and its composites

Tensile strength of the as cast LM25 alloy increased significantly by 56% due to the addition of 9 wt.% of Al_2O_3 and 4 wt.% of Graphite and further increased by 40% after heat treatment of the composite. The results revealed that there was an improvement in Tensile strength by 119% and decrease in elongation% by 1.4% compared to As Cast LM25 alloy.

This increase in UTS is due to uniform distribution of reinforcements and spheroidized silicon precipitates and their strong bonding with matrix alloy. The strength also increased due to the large stress developed during solidification and due to mismatch of thermal expansion between the metallic matrix and the reinforcement, which is a major mechanism for increasing the dislocation density of the matrix. Under normal cooling condition, Si particles occur as coarse acicular needles acting as crack originators and decrease the tensile properties. During heat treatment, silicon particles are broken down and gradually become spheroidized, resulting in higher tensile properties of heat-treated specimens in comparison with As cast specimen. Harder and stronger interfacial bonding strength of Al-Si eutectic phase are responsible for improved tensile properties. Thermal mismatch between the reinforcements and the matrix was also one of the reasons for increase in tensile strength [24].

Elongation% of the As cast LM25 increased significantly due to the addition of reinforcements but dropped marginally after heat treatment of the composite. It is observed that micro-shrinkage/porosity is relatively common in all specimens casted by stir casting method. However, elongation % of AC Composite increased significantly from that of AC Neat due to decrease in porosity and shrinkage size as shown in Figs.7b and Fig.8b. The elongation% of AC Composite HT decreased significantly from that of AC Comp due to increase in porosity & shrinkage size as shown in Fig.7d and Fig.8d [5].

4.3 Hardness

Hardness results of the tests are shown in Fig.13.

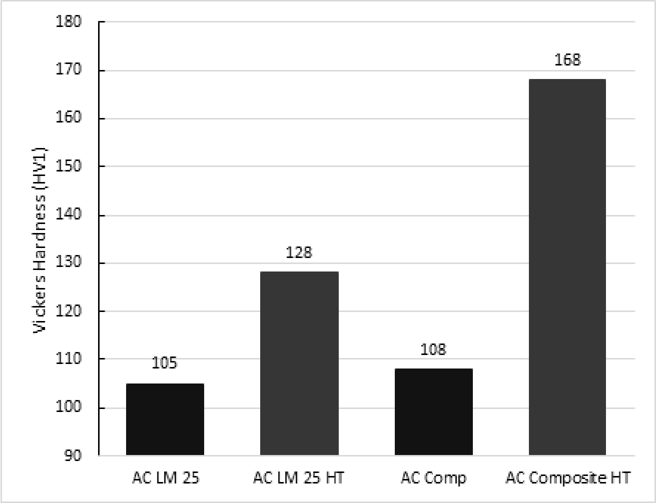


Fig. 13: Hardness of as-cast and heat treated LM25 and its composites

Hardness of the As cast LM25 alloy increased marginally due to the addition of 9 wt.% of Al_2O_3 and 4 wt.% of Graphite and finally increased significantly by 60% after heat treatment of the composite. T6 treatment was a dominant factor on hardness improvement in comparison with hardness increasing due to the addition of dual reinforcements. In addition, T6 treatment can contribute to the strong bonding between reinforcements and matrix alloy and also it can change eutectic silicon morphology from needle shaped eutectic silicon to spherodized silicon precipitates. In Al–Si–Mg ternary alloys, the presence of Mg and Si together can promote to the formation of Mg_2Si precipitates causing the hardening. These precipitated constituents account for increase in hardness. This may be due to the enhanced resistance against plastic deformation as Al_2O_3/Gr dual particles serve as barriers to the movement of dislocation [5].

4.4 Compressive Strength

Compressive strength results of the tests are shown in Fig.14.

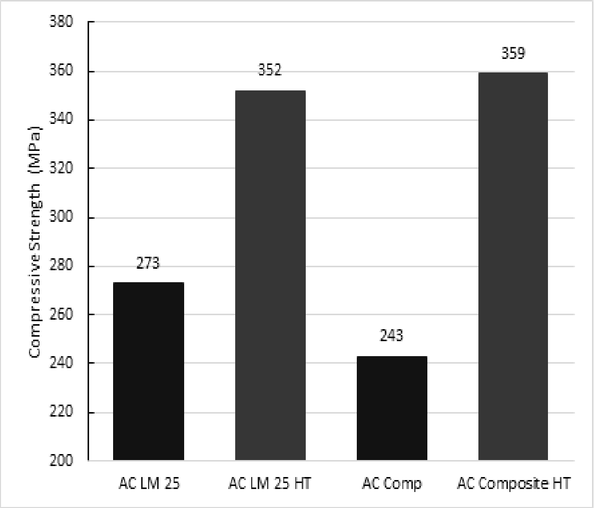


Fig. 14. Compression strength of as-cast and heat treated LM25 and its composites

Compressive strength of As cast LM25 alloy dropped marginally due to the addition of 9 wt.% of Al_2O_3 and 4 wt.% of Graphite but increased significantly by 48% after heat treatment of the composite. The results revealed that there was an improvement in Compressive strength by 32% over that of As Cast LM25 alloy. Decrease in compression strength of AC composite may be due to the presence of graphite particles in the composite, which were not dispersed equally in the matrix alloy due to variation of density of graphite with that of the matrix alloy. [25]

The results showed that T6 heat treated composites showed better compressive strength, which may be due to the change of morphology from needle shaped eutectic silicon particles to spheroidized silicon precipitates after heat-treatment and uniform distribution of reinforcements and silicon particles.

4.5 Impact Strength

Impact Strength of AC Neat (as cast LM25 alloy) decreased significantly by 25% due to the addition of 9 wt.% of Al_2O_3 and 4 wt.% of Graphite but increased marginally after heat treatment of the composite. Impact strength results of the tests are shown in Fig.15.

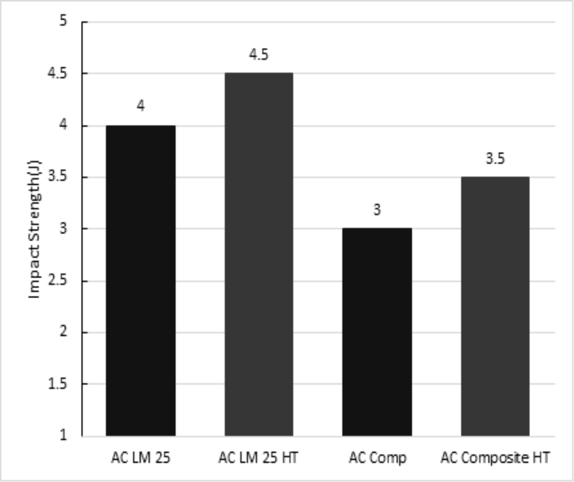


Fig. 15. Impact strength of as-cast and heat treated LM25 and its composites

Higher Impact strength in AC Neat exhibits ductile nature which undergoes plastic deformation at room temperature. Decrease in impact strength of AC composite may be due to the presence of reinforced particles which exhibit brittle nature and act as stress concentration areas. The heterogeneous dispersion of reinforced particles in the matrix results in the formation of clusters which also decreases the matrix-reinforcement bonding and reduces the impact strength of the composite. From the literature survey it is evident that when tensile strength increases the impact strength will reduce due to the presence of brittle and cavity area in the fractured surface. [24]

It was also observed that the impact strength of heat-treated AC Composite increased marginally. This marginal increase after ageing at 180°C for 4 h followed by air cooling may be due to the coarsening and increase in size and shape of the silicon particles and spacing between intermetallic particles that were formed, hence aiding the dislocation movement [26].

4.6 Wear Analysis

Wear rate of the specimen was computed after measuring the mass loss of the specimens due to the wear test and subtracting it from the original mass of the specimens as shown in eq (1) and (2)

Net mass loss = mass before wear test- mass after wear test ……….. (1)

Wear rate = Net mass loss/time ……………………………………. (2)

Wear rate of LM25 and LM25/Al_2O_3-Gr hybrid composite specimens showed a clear variation in the wear resistance, which is related to the compositions of the LM25 alloy and the combined Al_2O_3-Gr microparticles. Heat treatment improved the wear resistance of the LM25 alloy by 17.4% from that of the As-cast LM25 alloy (Fig. 16). This improvement was due to the grain refinement caused by the T6 heat treatment. For the hybrid composite specimens with combined Al_2O_3-Gr microparticles with and without heat treatment, significant improvements of 39% and 23%, respectively, were achieved. However, As-cast LM25 alloy showed minimum wear resistance compared to other specimens, which can be related to voids and large grains that softened the LM25 matrix surface. It can be concluded that wear resistance was affected by the heat treatment and also by inclusion of combined Al_2O_3-Gr microparticles.

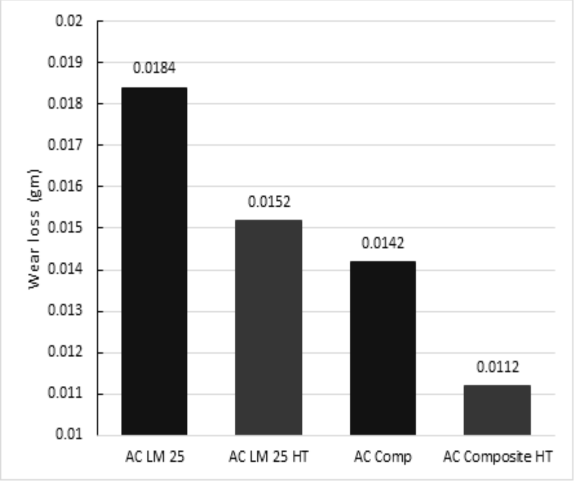


Fig.16. Effect of heat treatment and reinforcement particles on the wear loss

Table 6. Wear rate and coefficient of friction of LM25 alloy and LM25/ Al_2O_3/Gr hybrid composite specimens

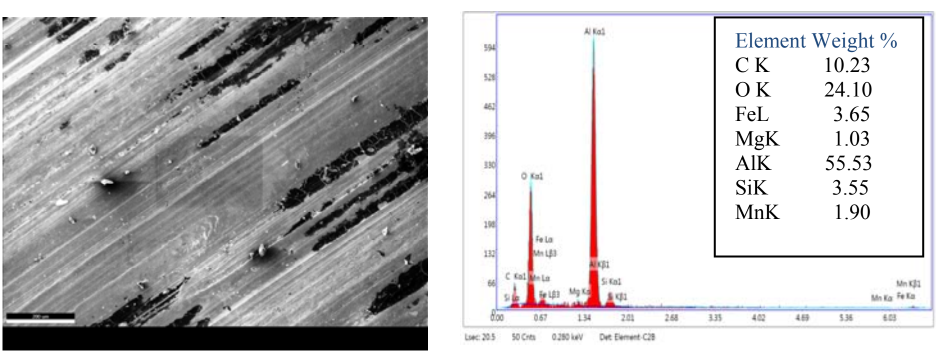
Speci-men No.	Load, L (N)	Sliding Velocity, S (m/s)	Sliding distance, D(m)	Heat Treatment Condition	Wear loss (gm)	Coefficient of Friction (COF
1	50	3	3250	As-cast LM25 alloy	0.0184	0.43
				Hear treated LM25 alloy	0.0152	0.33
2	50	3	3250	As-cast LM25 / 9% Al_2O_3 / 4% Gr. Hybrid composite	0.0142	0.29
				Heat Treated LM25/9% Al_2O_3 /4% Gr. Hybrid composite	0.0112	0.28

Coefficient of friction (CoF) of LM25 and LM25/Al_2O_3-Gr hybrid composites with and without heat treatment are shown in Table 9. From the table, it is observed that the compositions of LM25 alloy and combined Al_2O_3-Gr micron-sized reinforcements significantly contributed to the CoF. The CoF decreased for As-cast and heat-treated hybrid composites, when compared to LM25 alloy due to the oxidation of aluminum alloy, which forms an oxide layer, during wear process, preventing sliding, thereby decreasing the wear rate and CoF.

Incorporation of Al_2O_3 reinforcement to Aluminium matrix increases the wear resistance of the composite. Addition of graphite particles to LM25 alloy further increases the wear resistance of the composite [10] . This improvement in wear results can be attributed to the enhancement of alloy hardness due to the reinforcements of Al_2O_3 and Graphite particles, precipitation, hardening and spheroidization of silicon particles as a result of heat treatment [5].

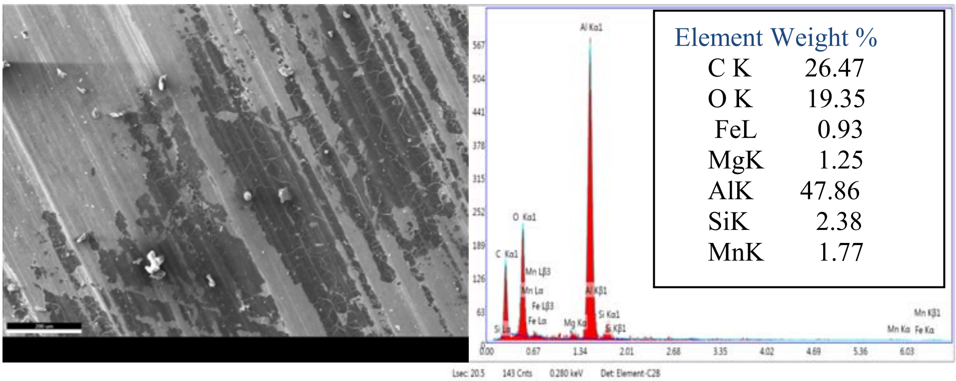
4.7 Morphological Analysis of Worn Surfaces

LM25 alloy and heat treated LM25 hybrid composite were tested at fixed applied normal load, sliding velocity and sliding distance to understand the effects of combined micro-sized reinforcements (Al_2O_3 and Graphite particles) on dry sliding wear behaviour. Fig.17a and 17b show the worn surfaces of heat treated LM25 alloy and heat treated LM25 hybrid composite at an applied load of 50N, sliding velocity of 3 m/s and a sliding distance of 3250 m.



(a) (b)

Fig. 17 Heat treated LM25 alloy worn surface under an applied load of 50N (a) SEM (b)EDS



(a) (b)

Fig. 18. Heat treated LM25/Al_2O_3/Gr. Composite worn surface under an applied load of 50N

(a) SEM (b) EDS

During wear studies, the entire wear surface of each specimen was in constant contact with the counter surface made of hardened steel disk. SEM micrograph (Fig.17a) shows delamination due to sliding of metal at 50N load on the LM25 alloy worn surface. Heat treated LM25 alloy showed higher wear and exhibited a rough surface as compared to the worn surface of the hybrid composite (Fig.19a). SEM micrograph of the heat treated LM25 alloy (Fig.17a) showed extensive removal of material from the surface, the network of micro-cracks and deeper furrows in the sliding direction on the worn surface depicts gradual and considerable wear loss in these regions due to lower hardness (Fig. 13) of the heat treated LM25 alloy.

Fig.19a shows SEM micrograph of the worn surface of heat treated LM25/ Al_2O_3-Gr hybrid composite. As the matrix alloy was reinforced with combined Al_2O_3-Gr reinforcements and heat treated, the depth and number of grooves on the surface of the specimen decreased, thus reducing the wear rate as shown in Fig.17. The change in wear mechanism from severe to mild wear can be ascribed to the presence of hard and soft reinforcements in the LM25 alloy. Amount of material removed as debris was less in hybrid composite and a relatively smooth worn surface was observed leading to least damage on the worn surface (Fig.19a). Smooth surface and tiny grooves in the sliding direction (indicated by arrow) on the worn surface depicts lower wear loss in the hybrid composite. The graphite particles in the hybrid composite specimen act as a self-lubricant and form a protective outer layer (white region in the SEM image) against the frictional force which reduced both the wear rate and coefficient of friction. In the present work, it was observed that an improvement in hardness was due to incorporation of combined reinforcements of Al_2O_3 and graphite, resulting in increased wear resistance and reduced the friction coefficient.

5.0 Conclusion

LM25 alloy and its hybrid composite reinforced with 9 wt.% of Al_2O_3 and 4 wt.% of Graphite particles were successfully fabricated by Stir casting method. A uniform distribution of Al_2O_3 and Graphite particles in As-cast composite was revealed through optical microstructure and SEM images. Tensile strength, hardness and compressive strength of As-cast Composite after heat treatment increased significantly by 119%, 60% and 32% respectively as compared to those of AC Neat (un-heat treated LM25 alloy). Elongation % of Heat treated Composite decreased by 14% as compared to that of As-cast LM25 alloy. T6 treatment significantly improved hardness of the specimens when compared to hardness due to the addition of dual reinforcements. Addition of dual reinforcements improved the tensile strength of the specimen. T6 treatment was only factor on compressive strength and impact strength improvements whereas there was a drop in compressive strength and impact strength due to the addition of dual reinforcements. After the addition of reinforcements Impact strength of the As-cast Composite reduced by 25% from that of As-cast LM25. But after heat treatment Impact strength of the composite increased marginally. Wear rate and Coefficient of Friction of As-cast LM25 alloy reduced by the addition of reinforcements as well as due to T6 heat treatment. Consequently, wear resistance of the heat treated composite increased in comparison with that of As-cast LM25 alloy. The presence of hard Al_2O_3 and soft Graphite particles in the LM25 matrix alloy significantly control the surface hardness, wear loss and coefficient of friction.

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References

1. Puneet Bansal, Lokesh Upadhyay, Effect of Turning Parameters on Tool Wear, Surface Roughness and Metal Removal Rate of Alumina Reinforced Aluminum Composite, *Procedia Technology*, 23, 304-310, 2016.
2. Anil Kumar T, Ganjanam Anne, N D Prasana and M K Muralidhara, Effect of Electromagnetic induction and heat treatment on mechanical and wear properties of LM25 alloy, *Procedia Materials Science* 5, 550 – 557, 2014.
3. Tiwery H, Hoziefa W, Adel B El-Shabasy and El-Mahallawi I, The Effect of Heat treatment on microstructure and mechanical properties of A356/ZrO2 nano reinforced composites, *Proceedings of International Conference on Applied Mechanics and Mechanical Engineering*, 2018.
4. Revanasidappa M D, Venkatesh K C, Naveen C R, Mechanical and Wear Behaviour of Al6061-SiC-Gr Hybrid Composites., *National Conference on Advances in Mechanical Engineering Science (NCAMES-2016)*, ISSN: 2231-5381, 376-379, 2016.
5. Pio L Y, Effect of T6 Heat Treatment on the Mechanical Properties of Gravity Die Cast A356 Aluminium Alloy, *Journal of Applied Sciences,* 11(11), 2048-2052, 2011.
6. Saravanakumara A, Sasikumar P and Sivasankaran S, Synthesis and mechanical behavior of AA 6063-x wt. % Al_2O_3-1% Gr hybrid composites, *Procedia Engineering,* 97, 951-960, 2014.
7. Bhandare R G, Parshuram M. Sonawane, Preparation of Aluminium Matrix Composite by Using Stir Casting Method, *International Journal of Engineering and Advanced Technology* ISSN: 2249 – 8958, 3 (2), 2013.
8. Kok M, Production and mechanical properties of Al_2O_3 particle-reinforced 2024 Aluminium alloy composites, *Journal of Materials Processing Technology,*161, 381–387, 2005.
9. Baradeswaran A, Elaya Perumal A, Study on mechanical and wear properties of Al7075/Al_2O_3/graphite hybrid composites, *Journal of Composites,* 56 , 464–471, 2014.

10. Aatthisugan, Razal Rose, A., Iruthayaraj, R., Palani, S., Shanmugan, S.,Wear and Mechanical properties of Aluminium hybrid composite (Al2024/Al_2O_3/Graphite) fabricated by powder metallurgy, *International Journal of Pure and Applied Mathematics*, 116, (23), 231-236, 2017.

11.]Mallikarjuna G B and Basavaraj E, Studies on Mechanical Properties of Al LM13-Al_2O_3 Composites, *Journal of Engineering Research and Application*, ISSN:2248-9622, 32-35, 2018.

12. Sameer M D and Birru A K, Experimental Investigations on Mech. behaviour of Al_2O_3 and Graphite reinforced Aluminium Hybrid Metal Composites by Stir Casting Process *International Journal of Scientific & Engineering Research*, 7(6), ISSN 2229-5518, 2016.

13. Sharanabasappa Patil R, and B.S. Motgi, A Study on Mechanical Properties of Fly Ash and Alumina Reinforced Aluminium Alloy (LM25) Composite, *Journal of Mech. and Civil Engineering,* 7, 41-46, 2013.

14. Dinesh J, Mohammad Ashraf G and Radhika N, Fabrication and Characterization of Al LM25/TiB_2 insitu composites, *Journal of Engineering and Applied Sciences,*11(9), 2016

15. Kenneth Kanayo Alaneme , Adetomilola Victoria Fajemisin , Nthabiseng Beauty Maledi, Development of aluminium-based composites reinforced with steel and graphite particles: structural, mechanical and wear characterization, *Journal of Material Research and Technology* 8(1), 670–682, 2019.

16. Radhika N, Balaji T V, Palaniappan S, Studies on Mechanical Properties and Tribological behaviour of LM25/SiC/Al_2O_3 composites, *Journal of Engineering Science and Technology,* 10 (2), 134 – 144, 2015.

17. Shanawaz Patil, Robinson P, Madhu B P, Manjunath G, Kalyana Kumar M, Investigation of Mechanical Properties and Wear Behavior of LM25 Aluminum Alloy Reinforced with Silicon Carbide and Activated Carbon, *International Journal of Research and Scientific Innovation*, 5(1),70-77, 2018. ISSN 2321–2705

18. Zeeshan Ahmad and Sabah Khan, Mechanical characterization of LM25 alloy matrix composite reinforced with boron carbide, *Journal of Composite Materials*, 55(22), 1-8, 2021

19. Kumara Gurubaran B, Gopal P, Deepakaravind V, Senthilkumar T, Experimental analysis of the wear behaviour of reinforced hybrid LM25 metal matrix nano composite, *Journal of Optoelectronics and Advanced Materials,*17, (11-12), 1794-1798, 2015.

20. Hashim, J. A., Looney, L. and Hashmi, M. S. J., Metal matrix composites: production by the stir casting method, *Journal of Materials Processing Technology*, 92-93,1999.

21. Bihari, B. and Singh, A. K., An Overview on Different Processing Parameters in Particulate Reinforced Metal Matrix Composite Fabricated by Stir Casting Process, Int. *Journal of Engineering Research and Application*, 7(1), 42-48, 2017.

22. Manikandan R and Arjunan T V, Mechanical and tribological behaviours of aluminium hybrid composites reinforced by CDA-B4C, *Mater. Res. Express,* 7, 016584, 2020.

23. Criston Vinuth Veigas, Nishan N S, Sathya Prakash A, Nithin Joshuva, Compression Behaviour of Al6061/Al_2O_3/Graphite Hybrid Composite Material, *National Conference on Advances in Mechanical Engineering Science*, 2016.

24. Ebenezer Donkoh, A Thesis on Study of the effects of ageing temperature and ageing time on the microstructure and some mechanical properties of sand cast Al-Si-Cu and Al-Si-Mg alloys, Kwame Nkrumah University of Science and Technology, Kumasi, 2016.