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Experimental Studies on Wear Resistance & Mechanical Properties of Aluminium Hybrid Composites (LM25/Al_2O_3/Graphite)

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Abstract: This paper involves the fabrication of hybrid Aluminium matrix composite samples of different compositions using Stir casting technique and testing the prepared hybrid composite test specimens for analysing their wear and mechanical properties. LM25 Al alloy was used as matrix material reinforced with constant 9 wt.% of Al_2O_3 with particle size of 6-23 μm and different wt. percentages of Graphite (particle size of 24-94 μm) as 3%, 4% and 5% to prepare hybrid composite samples of three different compositions. Mechanical properties, for examples, tensile strength, hardness, compression strength and impact strength were analysed for both base LM25 Al. alloy and composite samples. Wear loss and coefficient of friction of composite samples also were studied using Pin-on-disc apparatus. Microstructure images of the hybrid composite samples were examined to study dispersion of dual reinforcement particles in the matrix material, porosity and shrinkage cavities developed during the casting of the composite samples using Optical Microscope. Results revealed that Tensile strength, Hardness and Wear properties of the hybrid composite sample, having 9 wt.% of Al_2O_3 and 4 wt.% of Graphite particles, were found to be superior to those of re-cast LM25 Al. alloy. This study is mainly focussed on achieving the improved wear resistance and mechanical properties of the hybrid aluminium matrix composite materials for meeting the desired properties of the products by exploring newer compositions of the dual particles reinforced hybrid composites.

Keywords: LM25 Al Alloy, Al_2O_3, Graphite Particles, Aluminium Hybrid Composites, Mechanical Properties, Wear Resistance, Stir Casting Process

1. Introduction

Metal Matrix Composite (MMC) is composed of a metal matrix and one or more reinforcement materials. It provides improved properties over those of the individual constituent acting alone. MMCs offer improved properties over those of conventional materials. Mechanical Properties, for example, mechanical strength, wear resistance, damping and machinability etc. can be appreciably enhanced.

In recent years, in particular, particulate reinforced Aluminium Metal Matrix Composites are preferred over conventional materials by several high tech- manufacturing industries such as aerospace, defence, automotive, defence, aerospace, sports and recreation owing to their outstanding combination of properties, for example, high strength to weight ratio, good thermal properties, good corrosion resistance, cast-ability etc. These are economically available and it is cheaper in fabricating them.

The major problem with the particulate type of Al-MMCs is its difficulty in machining due to the abrasive nature of the ceramic particles. The reinforced particles are hard and very stiff, which also cause high tool wear rate. Particulate-reinforced Al-MMCs have become more attractive to researchers because of the problem of anisotropy and high cost of fibre reinforcement [1, 2]. It is also fact that the properties of the Al-Metal Matrix Composites are mainly affected by shape, size, orientation, distribution and volume or weight fraction of the reinforcements.

Extensive researches have been undertaken on Al-MMCs with a single reinforcement. Sometimes the use of Al.-matrix with single reinforcement may not meet today's requirements of high product quality and better surface finish due to negative effects of single reinforcement. In order to compensate the negative effects of single reinforcement on the characteristics of MMC, the idea of use of different types of reinforcements more than one is being discovered in Al matrix. Reinforcements like SiC, Al_2O_3, TiO_2, TiB_2 etc., will increase tensile strength, hardness and abrasive wear resistance of Al matrix. But these have negative effects on machinability, thermal properties and impact strength of Al matrix. Hence soft reinforcement like graphite, which is a solid lubricant, can be reinforced with Al matrix to improve machinability, wear resistance, damping capacity. Al-MMCs involving more than one reinforcement is denoted as hybrid Al-MMCs., which are considered as improved substitutes for composites with single reinforcement [3-5]. Researches have been carried out continuously to explore newer compositions to achieve desired properties of dual particles reinforced hybrid composites [6, 7].

From the literature survey, it is understood that there is much scope for the application of Al-MMCs in most of the high tech-industries. But there is some major difficulty in the production of these hybrid composites. The main process for producing hybrid Al-MMCs on a large scale is either solid metallurgy technique or liquid metallurgy technique. Among all the available processing routes the liquid metallurgy technique is considered as most economical to produce MMCs. There are four types of liquid metallurgy technique such as pressure infiltration, stir casting, spray deposition and in situ processing. Out of these types stir casting process is simple, most economical and suitable for large scale production. Though there are some problems in stir casting process such as: poor wettability and improper distribution of the reinforcement materials etc., stir casting is a promising route to produce Al-MMCs [8-10].

2. Literature Review

Ted Guo et al. [11] reported that addition of graphite (Gr) particulates improves machinability and reduces wear of Al–Gr composites when compared to Al alloy. It was also reported that high amount of Gr. may increase wear owing to decrease in fracture toughness. Yilmaz et al. [12] prepared hybrid composites with Al. as matrix material, a constant 10 wt.% of Al_2O_3 and varying wt. % of Gr (1, 2, 3, 4 and 5 wt. %) as reinforcement materials. They reported that the surface texture parameters decrease as Gr. content increases in the matrix. Moreover, the hardness also started to decrease when the graphite content in the matrix increased more than 1wt.%. Miyajima et al. [13] concluded that particulate reinforcements are most useful in improving the wear resistance of Al-MMCs. The microstructure parameters such as the type, size, distribution of the reinforcement and the manufacturing technique of the composite primarily affect the degree of enhancement of wear resistance.

Kok [14] prepared 2024 Al-alloy composites reinforced with Al_2O_3 particle using stir casting process with the application of pressure. He reported that the coarser particles led to more uniform dispersion, whereas the finer particles caused agglomeration and segregation of particles. Decreasing size and increasing weight percentage of particles increased the porosity of the composites, the tensile strength and hardness but decreased the elongation of MMCs. Dunia Abdul Saheb [15] developed aluminium based MMCs with silicon carbide particulate and Gr as reinforcements. He conducted experiments with varying wt.% of SiC (5, 10, 15, 20, 25, and 30) and varying wt.% of Gr (2, 4, 6, 8 and 10), while all other parameters were constant. He reported that increase in wt.% of ceramic materials increased hardness. The maximum hardness was found at 25 wt.% of SiC and 4 wt.% of Gr.

Radhika et al. [16] fabricated Al-Si10Mg alloy reinforced with varying wt.% of alumina and with constant 3 wt.% of graphite using stir casting method to study mechanical properties and wear behaviour. It was reported that addition of alumina and graphite improved hardness and tensile strength of hybrid MMCs. The wear rate and coefficient of friction for base alloy and hybrid composites decreased with increase in sliding speed and increased with increase in applied load. They concluded that the wear rate and coefficient of friction reduced with increase in wt.% of reinforcement. Suresh et al. [17] studied wear resistance and microstructure of Al6061-MMCs. Composites containing different wt. % 2, 4, 6, and 8 of Al_2O_3 and keeping 2 wt.% of Gr constant were fabricated using stir casting method. They concluded that the specific wear rate and frictional coefficient decreased linearly with increase in wt.% of Al_2O_3. The best result of wear resistance was obtained at 8 wt.% of Al_2O_3. Sharanabasappa et al. [18] studied the tensile strength and hardness of LM25 composites reinforced with fly Ash and Al_2O_3. It was reported that hardness and tensile strength increased with increasing wt.% of Al_2O_3, but impact strength and ductility decreased.

Baradeswaran et al. [19] studied the effect of graphite on the wear behaviour of Al7075/Al_2O_3/Gr hybrid composite casted through stir casting. He concluded that the hybrid composites containing graphite developed higher wear-resistance. Criston et al. [20] observed the compression behaviour of Al alloy hybrid composites (Al6061/Al_2O_3/Gr) with constant wt. % of Gr and varying wt. % of Al_2O_3. From this study, it was reported that when reinforcement materials with different wt.% were added to base Al. matrix. They observed that the type of dispersion and wt.% of ceramic material in the composites caused the changes in compression strength. When Al_2O_3 particles were distributed uniformly in the composite, compression strength increased, which was found to be less than that of the base Al. alloy. Decrease in compression strength was due to the presence of Gr in composite as in the case of 9% Al_2O_3 reinforced composite.

Kumari Archana et al. [21] fabricated three different composite samples of different compositions. Al. 6061 was used as matrix metal and Gr. was used as reinforcement with varying wt. percentages. They reported that hardness and tensile strength of the composites increased on increasing the graphite reinforcement up to 4 wt.% of Gr. but both hardness and tensile strength showed a decreasing trend on further increase beyond 4 wt.% of Gr. Hashim et al. [22] focussed on possibility of four technical problems in stir casting such as problem of achieving a uniform distribution of the reinforcement material, problem of achieving wettability between the matrix material and the reinforcements, problem of avoiding porosity in the cast metal matrix composites; and problem of preventing chemical reactions between the reinforcement material and the matrix alloy, which affect mechanical properties. They also stressed for the need in controlling some significant process parameters such as stirring speed, holding temperature, size of the impeller and the position of the impeller in the molten metal during casting of MMCs. Rajesh kumar et al. [23] synthesized a hybrid aluminium composite using stir casting process. Al6061 alloy was used as matrix material and Silicon carbide, Alumina and Gr. as reinforcements. During the preparation of composites the process parameters such as stirring speed, blade angle and number of blades were varied using design of experiments. It was reported that the reinforcement should be added at the semisolid stage to increase the wettability of the reinforcement with matrix. For homogeneous mixture, the blade angle should be 45 or 60 and the number blades in the stirrer should be 4. The mould should be preheated to 500°C to reduce the porosity of the composite.

From the context of current research in the field of processing MMCs and exploring newer compositions of the composites, first, it is well understood that one of the major technical challenges when processing MMCs is to achieve a homogeneous distribution of reinforcements in the matrix, which has a direct effect on the properties and the quality of the composite. Secondly, it is learnt that limited literatures are available on studies of mechanical properties and wear resistance of hybrid LM25 Al. alloy/Al_2O_3/Gr. composites, Henceforth, the current research study was submitted with an objective to evaluate the application of reinforcement materials such as Aluminium oxide (Al_2O_3) of constant 9 wt.% along with Graphite (Gr.) of varying wt. percentages as 3, 4 and 5 in LM25 Al alloy through Stir casting process and also through analysis of wear resistance and mechanical properties.

3. Materials

3.1. LM25

Matrix material used for the preparation of hybrid AMCs was LM25 Al alloy since its mechanical properties can be enhanced through its combination with suitable reinforcements and also through its heat treatment. This alloy conforms to BS1490. It was procured from Laxmi Metal Exchange, Coimbatore. The 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

LM25 Al alloy is generally used for achieving high strength casting alloy. [15]. It is preferred because of its attractive properties such as excellent cast-ability, soundness, good weldability, good corrosion resistance, very light weight, better thermal and electrical properties, formability as well as better machinability. But this alloy is not suitable for high wear resistance application due to its poor wear resistance [24]. This alloy is mostly used in the food, chemical, marine, electrical, and many other industries. Moreover, it is used in automobile industry for manufacturing cylinder blocks and heads, wheels etc. as well as for making castings of aircraft frame and missile structure components [25, 26].

3.2. Alumina (Al_2O_3)

Among the hard-ceramic reinforcement materials, Silicon Carbide (SiC) is most commonly used in MMCs. The second most reinforcement material is Alumina (Al_2O_3). But in Silicon Carbide (SiC), the carbon will cause interface reactions in Aluminium matrix, depending upon the melting temperature and mixing time [5, 17, 27].

In this study Alumina with particle sizes 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, better corrosion and wear resistance and excellent size and shape capability etc. Compared with Silicon Carbide, Alumina is more stable, inert and cheaper. It is readily available [28, 29]. Its physical properties are listed in Table 2.

Table 2. *Physical properties of Alumina (Al_2O_3).*

Density	**3.95 g/cm³**
Melting point	2040 degree C
Mechanical Strength	300-630 MPa
Thermal conductivity	20 to 30 W/mK
Compression Strength	2000-4000 MPa
Molar mass	101.96 gm/mol

3.3. Graphite

Graphite with particle size in the range of 24-94 μm was selected as reinforcement to improve wear resistance, damping capacity and machinability of the base alloy. Its presence in the Al. alloy matrix prevents seizure [27].

The physical properties of Graphite are shown in Table 3.

Table 3. *Physical Properties of Graphite.*

Density	**2.266 g/cm^3**
Modulus of Elasticity	8-15 GPa
Thermal conductivity	25-470 W/mK
Melting point	4300 K
Crystal structure	Hexagonal

4. Methodology

Stir casting process is simple, most economical and suitable for large scale production of Aluminium matrix composites. Its main parts are melting furnace, stirrer assembly, controller and pre-heating furnace as shown in Figure 1.

Figure 1. *Stir casting setup.*

Graphite crucible was placed inside the furnace. At a time 440 gm. of LM25 Al. alloy was placed in the graphite crucible. The furnace was heated to a temperature of 750°C, When the alloy was in fully molten condition 0.3% of Hexachloroethane (C2Cl6) was added to the molten metal for reducing blow holes in the castings. Simultaneously weighted quantities of alumina powder (9%) and graphite particles (3%) measured as 45gm. and 15gm. respectively were preheated in a separate furnace to a temperature 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.

Figure 2. *Casted samples of composites.*

The molten metal was then cooled to 600°C to turn in to semi-solid state. At this state first stirring at 300 rpm was started. During stirring the preheated reinforcements were added manually to the semi-solid slurry. Soon after the mixing of reinforcements 0.5% of Magnesium particles wrapped in aluminium foil were added to improve wettability. The stirring was continued for approx. 5 min at the same speed to achieve proper mixing of the reinforcements in the melt. After the completion of the first stirring the slurry was again re-heated to a temperature of 750°C to turn into fully molten condition. In this fully molten condition re-stirring using automatic stirrer was executed for approx. 5 minutes at the same speed to ensure more uniform distribution. The molten metal was then poured in to a cavity of preheated mould. The pouring temperature was maintained in the range of 700-750°C and then allowed to cool in the atmospheric temperature [15, 22, 28, 30].

The process used is similar for casting other two composites with same wt.% of alumina (9%) and different weight percentages of Graphite (4% and 5%) and for casting one un-reinforced LM25 alloy sample for the purpose of comparison. The casted samples are shown in Figure 2.

Test Specimens for Microstructure Examination, analysis of Mechanical properties and Wear resistances were prepared from the casted samples, one sample of base Al. alloy and other three samples with different wt. percentages of reinforcements in accordance with ASTM Standards and their dimensions are shown in Table 4.

Table 4. *ASTM/IS codes for microstructure, mechanical, wear tests.*

Test No	ASTM/IS Code	Mechanical/Wear/Microstructure Tests	Dimensions (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 G 99-04	Sliding Wear rate	10 X 10 X 30
6	ASTM E3-11	Microstructure	10 X 10 X 10

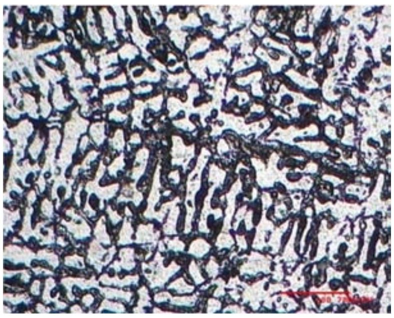
5. Results and Discussions

5.1. Microstructure

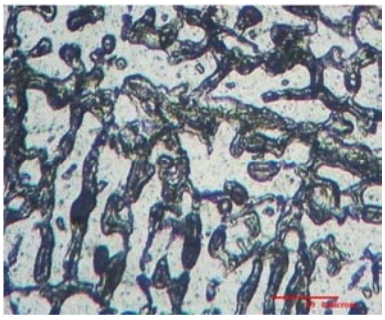
The samples of Microstructure test specimens were prepared as per ASTM as shown in Table 4. The samples, as shown in Figure 3, were examined using Metallurgical Microscope (METASCOPE T 2003 U).

Figure 3. *Samples of Microstructure test specimens.*

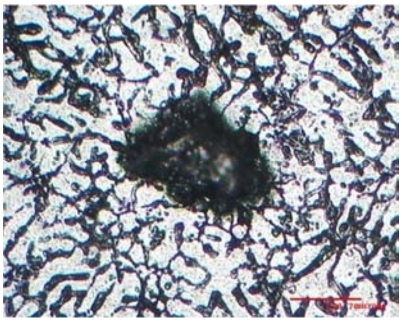
From Figure 4 (a) and (b) Aluminium - Silicon eutectic structure was observed in the matrix of aluminium solid solution. The uniform distribution of reinforcements in the matrix material was clearly noticed. From Figure 4 (c) Porosities & Shrinkage cavities were observed with maximum Ø 0.27mm. The images are as shown below.



(a) Magnification 100X.



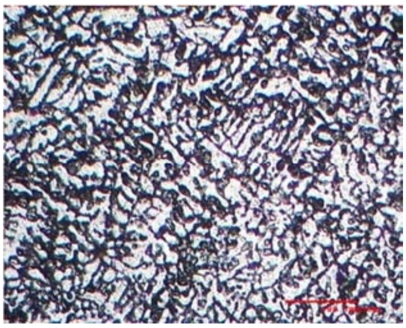
(b) Magnification 200X.



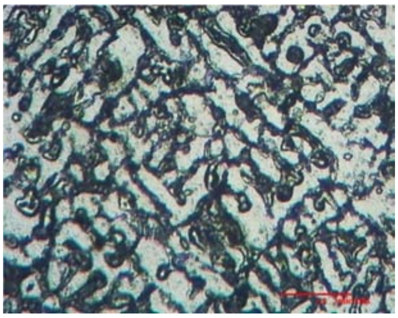
(c) Magnification 100X (Porosity).

Figure 4. *Optical Micrographs of Specimen-1(Base LM25 Alloy).*

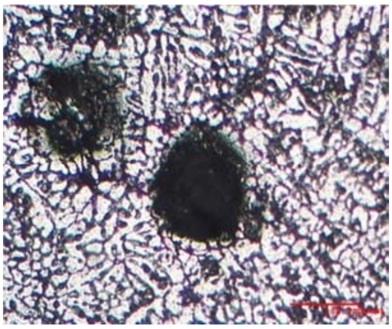
From Figure 5 (a) & (b) Aluminium - Silicon eutectic structure was observed in the matrix of aluminium solid solution. The uniform distribution of reinforcements in the matrix material was clearly noticed. From Figure 5 (c) Porosities were observed with maximum Ø 0.42mm. The images are as shown below.



(a) Magnification 100X.



(b) Magnification 200X.

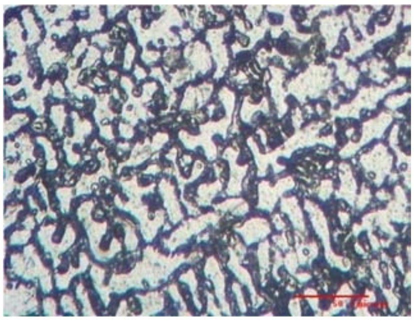


(c) Magnification 100X (Porosity).

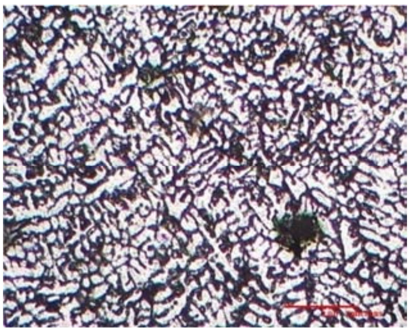
Figure 5. *Optical Micrographs of Specimen- 2(LM25 Alloy/9 % of Al_2O_3/3 % of Gr.).*

From Figure 6 (a) & (b) Aluminium - Silicon eutectic structure was observed in the matrix of aluminium solid solution. The more uniform distribution of reinforcement in the matrix material was clearly noticed. From Figure 6 (c) Porosities were observed with maximum Ø 0.06mm. Most uniform distribution and least sized porosities were observed when compared with all three samples 1, 2 & 4. The images are as shown below.

(a) Magnification 100X.



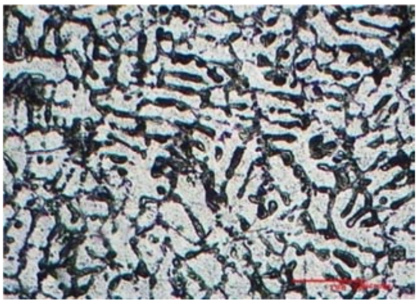
(b) Magnification 200X.



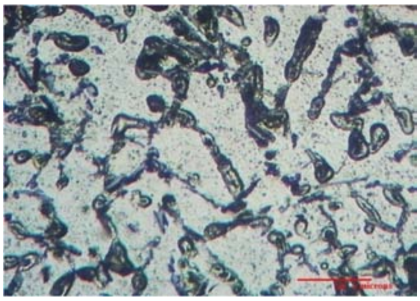
(c) Magnification 100X (Porosity).

***Figure 6**. Optical Micrographs of Secimen-3 (LM25/9 wt.% of Al_2O_3/4 wt.% of Gr.).*

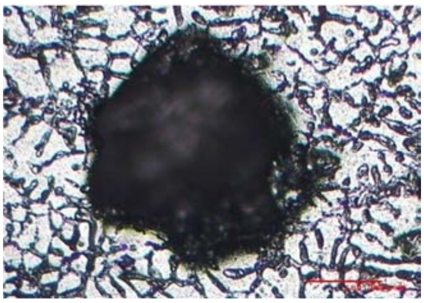
From Figure 7 (a) & (b) Aluminium - Silicon eutectic structure was observed in the matrix of aluminium solid solution. The uniform distribution of reinforcement in the matrix material was clearly noticed. From Figure 7 (c) Porosities & Shrinkage cavities were observed with maximum Ø 0.88 mm. Larger sized porosities were observed when compared with samples 1, 2 & 3. The images are as shown below.



(a) Magnification 100X.



(b) Magnification 200X.



(c) Magnification 100X (Porosity).

***Figure 7.** Optical Micrographs of Specimen-4 (LM25 Alloy/9 wt.% Al_2O_3/5 wt.% Gr.).*

5.2. Tensile Strength Test

The samples of Tensile strength test specimens were prepared as per ASTM E8 as shown in Table 4. The samples, as shown in Figure 8, were tested using Computerized Universal Testing Machine (Model-TFUC-1000). The results of the tests are tabulated in Table 5 and variation of UTS with wt.% of reinforcements is shown in Figure 9.

***Figure 8.** Samples of Tensile strength test specimens after the tests.*

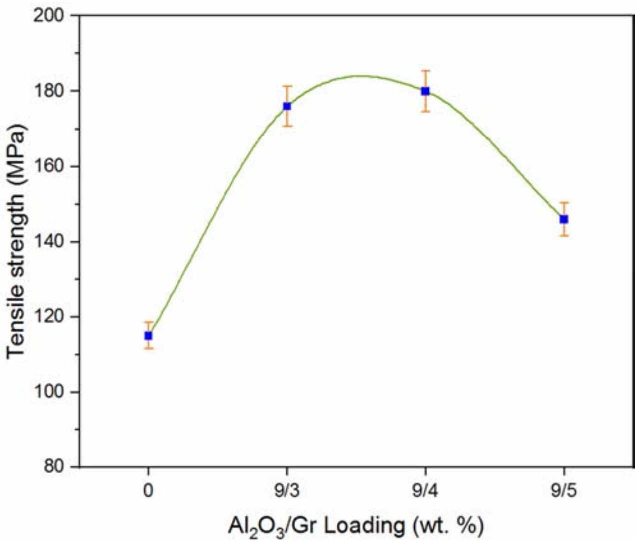


Figure 9. *Variation of Ultimate Tensile Strength with Al_2O_3/Gr loading.*

Table 5. *Tabulated Tensile Strength Testing Results.*

Specimen No./Properties	1	2	3	4
Initial Gauge Length (mm)	24	24	24	24
Ultimate Tensile Strength (N/mm^2)	115	176	180	146
Yield strength (N/mm^2)	106	158	149	57
Elongation % (on 24 mm GL)	2.8	3.8	4.6	2.7

By observing Figure 9 and the tensile test report details as given in Table 5 (above) it was noticed the UTS and percentage elongation both improved linearly as wt.% of Gr. increased up to 4%, keeping 9wt.% of Al_2O_3 as constant. It was due to proper distribution of Al_2O_3/Gr. Particles in the matrix material, least porosity and better wettability. It was also observed that addition of Gr. particles beyond 4 wt.% decreased the tensile strength. This may be due to more content of Graphite particles, the presence of porosity and reduction of wettability. Porosity affects adversely ductility also [31]. In this study the Sample-3 (LM25/9 % Al_2O_3/4 %Gr. composite) has maximum tensile strength and %Elongation when compared with other three samples such as Sample-1(base LM25 alloy), Sample-2(LM25/9% Al_2O_3/3%Gr) and Sample-4(LM25/9% Al_2O_3/5%Gr).

5.3. Hardness Test

The samples of Hardness test specimens were prepared in accordance with IS 1501 (P-1) 13 as shown in Table 4. The samples, as shown in Figure 10, were tested using Vickers Hardness tester (Model-NEXUS EW 4304). In this experiment a direct load of 1Kgf was applied constantly on all the specimens for a dwell time of 10 seconds and at least three hardness values were measured at different locations on each specimen, the average of these three values was then obtained for each sample. The results of the tests are tabulated in Table 6 and variation of Hardness value with wt.% of reinforcements is shown in Figure 11.

Figure 10. *Samples of Hardness test specimens.*

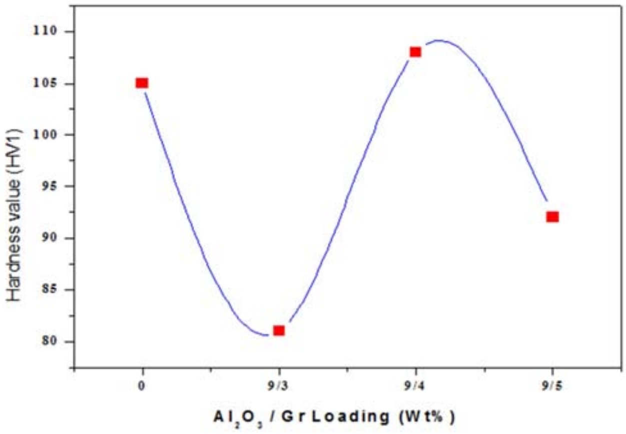


Figure 11. *Variation of Hardness with Al_2O_3/Gr loading.*

Table 6. *Tabulated Hardness values of the prepared composite specimens.*

Specimen No.	Vickers Hardness (HV1)
1	105 (Avg. of 109, 101, 105)
2	81 (Avg. of 83, 81, 80)
3	108 (Avg. of 100, 110, 115)
4	92 (Avg. of 93, 93, 91)

From the above Figure 11 and Table 6, it was noticed that the hardness of composite specimen-2 displayed lower hardness compared with the base matrix material. This may be due to poor distribution of reinforcements combined with more porosity. In case of composite specimen-3, hardness was observed to be more than that of the base LM25 alloy and found to be maximum i.e. 108 HV1 compared with all the test specimens. This may be due to presence of least pores and shrinkage cavities and better distribution of reinforcements in the matrix material. Furthermore, decrease in hardness for composite specimen- 4 was observed when compared with composite specimen-3. This may be due to the presence of more porosities and shrinkage cavities. It was also noticed that when wt. percentage of Gr. increased beyond 4 wt.%, there was a sudden decrease in hardness value. This may be due to the cluster formation [34]. Therefore, the combination of hybrid composite as 9wt.%

Al_2O_3 and 4wt.% Graphite reinforced with LM25 alloy (Sample-3) was observed to be the best to have maximum hardness.

5.4. Compression Test

The samples of Compression test specimens were prepared as per ASTM E9 as shown in Table 4. The samples, as shown in Figure 12, were tested using Computerized U. T. M. (Model-TFUC-1000). The results of the tests are tabulated in Table 7 and variation of Compression strength with wt.% of reinforcements is shown in Figure 13.

Figure 12. *Samples of Compression test specimens.*

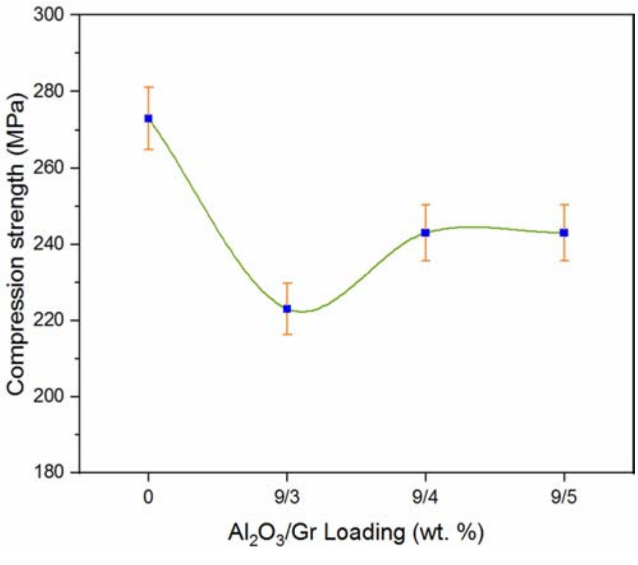


Figure 13. *Variation of Compressive Strength with Al_2O_3/Gr loading.*

Table 7. *Tabulated Compressive Strength values of the prepared composite specimens.*

Specimen No.	Compressive Strength at 10% Strain, MPa
1	273
2	223
3	243
4	237

From the above Figure 13 and Table 7, it was noticed that there was decrease in compressive strength in the Specimen-2 when 9%Al_2O_3 and 3%Graphite were added to the base LM25 Al. alloy and this compressive value was observed to be lower than that of the base LM25 Al. alloy. From Figure 5 (c) of optical micrograph of sample-2, uniform distribution of reinforcements in the matrix material was clearly noticed, but there was presence of more porosity, which may be the cause for decrease in compressive strength.

In Specimen-3 the compressive strength increased, whose value was more than Specimen-2, but less than the base LM25 Al. alloy. This may be due to more uniform distribution of the reinforcements in the matrix material and presence of least porosities. From the Figure 6 of micrograph it revealed that there could be proper mixing of reinforcements with the composition as 9%Al_2O_3 and 4%Graphite in the matrix material.

In Specimen-4, the compressive strength decreased. This revealed that further addition of Graphite particles beyond 4 wt.% caused improper mixing of reinforcements. Figure 7 (c), large sized porosities were observed. The reduction in compression strength may be due to poor wettability between the reinforcements and the matrix material. It was concluded that if graphite and alumina were mixed properly with base material, the compression strength would increase as seen in the case of 9% Al_2O_3 and 4% Gr. reinforced composite [20].

5.5. Toughness (Impact) Test

The samples of Izod impact test specimens were prepared as per IS 1598-1977 as shown in Table 4. The samples, as shown in Figure 14., were tested using Impact testing machine. The results of the tests are tabulated in Table 8 and variation of Impact strength with wt.% of reinforcements is shown in Figure 15.

Figure 14. *Samples of Impact test specimens.*

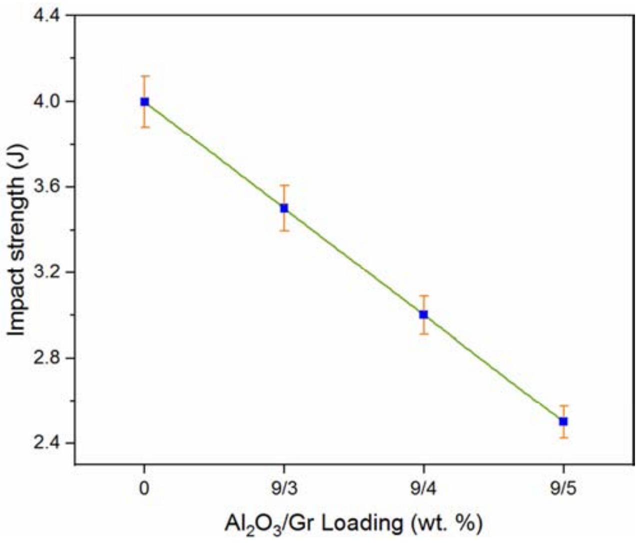


Figure 15. *Variation of Impact Strength with Al_2O_3/Gr loading.*

Table 8. *Tabulated Impact Strength values.*

Specimen No.	Impact Strength (J)
1	4
2	3.5
3	3
4	2.5

From the above Figure 15 and Table 8, it was noticed that the impact strength decreased linearly as wt. % of Graphite increased. The results revealed that the impact strength of the composite decreased as wt.% of reinforcements increased.

5.6. Wear Test

The samples of Wear test specimens were prepared as per ASTM G 99-04 as shown in Table 4. The samples, as shown in Figure 16, were tested in dry sliding condition using Pin-on-disc Wear test apparatus under the application of 3 m/s as sliding velocity, 50 N as normal load, 3250m as sliding distance. The results of the tests are tabulated in Table 9. The variation of Wear loss with wt.% of reinforcements is shown in Figure 17 and that of Coefficient of Friction with wt.% of reinforcements is shown in Figure 18.

Figure 16. *Samples of Wear test specimens.*

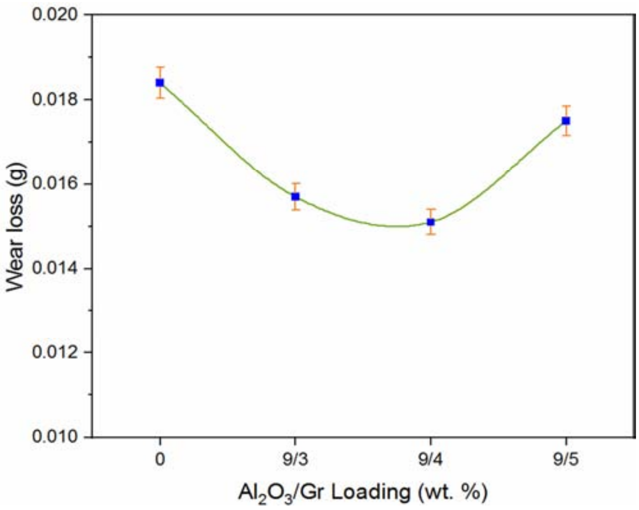


Figure 17. *Variation of wear loss with Al_2O_3/Gr loading.*

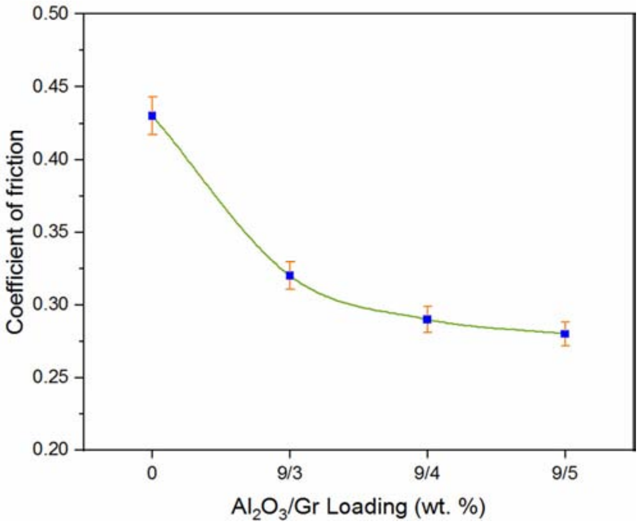


Figure 18. *Variation of Coefficient of Friction with Al_2O_3/Gr loading.*

Table 9. *Tabulated Wear loss and Coefficient of friction values.*

Specimen No.	Load, L (N)	Sliding Velocity, S (m/s)	Sliding distance, D (m)	Wear loss (gm)	Coefficient of Friction (COF)
1	50	3	3250	0.0184	0.43
2	50	3	3250	0.0157	0.32
3	50	3	3250	0.0142	0.29
4	50	3	3250	0.0175	0.28

From the above Figures 17 & 18 and Table 9, it was observed that wear loss and coefficient of friction (COF) both decreased with the addition of Al_2O_3 and Graphite particles to LM25 Al alloy. At the same time wear loss started increasing when the wt. % of Graphite increased beyond 4 wt.% whereas the COF decreased linearly with the increase of wt.% of Graphite.

The results revealed that the wear loss reduced with increase in graphite content and it was found to be minimum at 4 wt.% of graphite, which exhibits the superior wear properties than those of cast base LM25 Al. alloy and other composites [32]. More-over the incorporation of Al_2O_3 reinforcement to Aluminium matrix increases the wear resistance of the composites. The addition graphite reinforcement in LM25 Al/Al_2O_3/Gr. composite as hybrid reinforcement further increases the wear resistance of the composite [33].

6. Conclusion

In the present work LM25 Al/Al_2O_3/Gr. hybrid composites were effectively casted by stir casting process. The effects of Alumina (Al_2O_3) and Graphite (Gr.) on wear resistance and mechanical properties of the composites studied and reported.

From this work the conclusions made are as follows: -

1. From tensile it was noticed that tensile strength showed increasing trend up to 4 wt.% of Gr. addition and on further addition of Graphite beyond 4 wt.%, the tensile strength showed decreasing trend. It was found to be more than the that of the base LM25 Al alloy and maximum in case of LM25/9 wt.%Al_2O_3/4 wt.% Gr hybrid composite.
2. Hardness test revealed that hardness of the composite (LM25/9 wt.%Al_2O_3/4 wt.% Gr) was highest among other composite samples and more than the base LM25 Al alloy.
3. The optical micrographs of sample 3 (4 wt.% of Gr.) composite showed proper distribution of Al_2O_3 and Gr. particles in base LM25 Al alloy with least sized porosity when compared with the sample 2 (3 wt. % of Gr.) and sample 4 (5 wt. % of Gr.) Hence, the mechanical properties and wear resistance of LM25/9wt.%Al_2O_3/4wt.% Gr. hybrid composite were improved over those of other composite samples and the base LM25 Al alloy.
4. Compression test revealed that addition of Al_2O_3 and Graphite particles resulted in decreasing compressive strength of the base LM25 Al alloy. It concluded that the compressive strength of the composite (LM25/9 wt.%Al_2O_3/4 wt.% Gr) was highest among other composite samples but lower than that of the base LM25 Al alloy.
5. Impact test results confirmed that increase in wt.% of Graphite reduced impact strength linearly.
6. Wear test revealed that wear loss of sample 3 (4 wt.% of Gr.) was observed to be lower than base matrix alloy, sample 2 (3 wt % of Gr.) and sample-4 (5 wt. % of Gr.) under the same load, same sliding velocity and same sliding distance. Under the same operating parameters Frictional coefficient of sample-3 was o observed to be lower than base matrix alloy, sample-2 and nearly equal to that of sample-4. This showed that increase in Graphite content could effectively reduce the friction coefficient of LM25 Al/Al_2O_3/Gr. linearly whereas as the Graphite content increased, the wear loss firstly decreased up to 4 wt.% of Graphite addition and then increased beyond 4 wt.% of Graphite.
7. The Sample-3 (4 wt.% of Gr) exhibited better results than those of the base LM25 Al alloy and all other two metal matrix composites thus produced and tested.
8. The Comparison of Properties between un-reinforced LM25Al. alloy & Hybrid (LM25/9% Al_2O_3/4%Graphite) composite is shown in Table 10.

Table 10. *Comparison of Properties between un-reinforced LM25Al. alloy & Hybrid (LM25/9% Al_2O_3/4%Graphite) composite.*

Mechanical properties	**Sample-1 (LM25 Al Alloy)**	**Sample-3(LM25 Al. Alloy with 9 wt.% of Al_2O_3/4 wt.% Gr)**
Hardness (Hv)	105	108
Tensile Strength (MPa)	115	180
Compressive Strength (MPa)	273	243
Impact Strength (J)	4	3
Wear (Weight) loss (g)	0.0184	0.0142

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References

[1] Ahmad, K. R., Shamsul, J. B., Hussain, L. B. and Ahmad, Z. A. (2003), The Effect of Reinforcement Particle Size on the Microstructure and Hardness of Al/(Al_2O_3) composite Via P/M Route, Conference Paper.

[2] Khandey, U. and Ghosh S. (2015), Optimization of turning process parameters for Al/SiC-MMC using Response Surface Methodology, ISME Journal of Manufacturing Sciences, Vol. 06, No. 2, pp. 08-18.

[3] Xavior M. A. and Kumar, J. P. A. (2016), Machinability of Hybrid Metal Matrix Composite A Review, 13th Global Congress on Manufacturing and Management (GCMM).

[4] Revanasidappa, M. D., Venkatesh, K. C., Naveen, C. R. (2016), Mechanical and Wear Behaviour of Al6061-SiC-Gr Hybrid Composites., National Conference on Advances in Mechanical Engineering Science (NCAMES), ISSN: 2231-5381, Page 376.

[5] Mahalingegowda, H. B. and Mahesh, B. S. (2014), Mechanical and Wear Behaviour of Al60601-Al_2O_3 composites and AL6061-Al_2O_3-Gr Hybrid Composites, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 6.

[6] Pitchayyapillai, G., Seenikannan, P., Raja, K. and Chandrasekaran, K. (2016), Al6061 Hybrid Metal Matrix Composite Reinforced with Alumina and Molybdenum Disulphide, Advances in Materials Science and Engineering, Article ID 6127624, 9 pages.

[7] Venkateswarlu, M. (2018), Synthesis and Mechanical Characterization of duel particle reinforced hybrid composites, International Journal of Applied Engineering Research, ISSN 0973-4562, Volume 13, Number 2.

[8] Manna, A., Bains, H. S. and Mahapatra, P. B. (2011), Experimental study on fabrication of Al–Al_2O_3/Grp.metal matrix composites, Journal of Composite Materials.

[9] Suresh, S. M., Mishra, D., Srinivasan, A., Arunachalam, R. M. and Sasikumar**,** R. (2011), Production and Characterization of Micro and Nano Al_2O_3 parrticle-reinforced LM25 Aluminium Alloy Composites, ARPN Journal of Engineering and Applied Sciences, Vol. 6, No. 6.

[10] Sajjadi, S. A., Ezatpour, H. R., Beygi, H. (2011), Microstructure and mechanical properties of Al–Al_2O_3 micro and nano composites fabricated by stir casting, Materials Science and Engineering A 528, 8765-8771.

[11] Ted Guo, M. L. and Tsao, C. Y. A. (2000), Tribological behaviour of self-lubricating aluminium/SiC/graphite hybrid composites synthesized by the semi-solid powder densification method, Compos. Sci. Technol. 60, 65–74.

[12] Yılmaz, O. and Buytoz, S. (2001), Abrasive wear of Al_2O_3-reinforced aluminium-based MMCs, Compos. Sci. Technol. 61, 2381–2392.

[13] Miyajima, T. and Iwai, Y. (2003), Effects of reinforcements on sliding wear behaviour of aluminium matrix composites, *Wear*, Vol. 255 Nos 1-6, pp. 606-16.

[14] Kok, M. (2005), Production and mechanical properties of Al_2O_3 particle-reinforced 2024 Aluminium alloy composites, Journal of Materials Processing Technology 161, 381–387.

[15] Saheb, D. A. (2011), Aluminium Silcon Carbide and Aluminium Graphite Particulate Composites, ARPN Journal of Engineering and Applied Sciences Vol. 6, No. 10.

[16] Radhika, N., Subramanian, R., Venkatprasat, S. and Anandavel, B. (2012), Dry Sliding Wear Behaviour of Aluminum/Alumina/Graphite Hybrid Metal Matrix Composites, Emerald Group Publishing Limited, Vol. 64, 359-366.

[17] Suresh, R. and Kumar, M. P. (2013), Investigation of Tribological Behaviour and its relationship with Processing and Microstructures of Al 6061 Metal Matrix Composites, International Journal of Research in Engineering & Technology (IJRET*)* Vol. 1, Issue 2, 91-104.

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

[19] Baradeswaran, A. and Perumal, A. E. (2014), Study on mechanical and wear properties of Al7075/Al_2O_3/graphite hybrid composites, Journal of Composites, 56, 464–471.

[20] Veigas, C. V., Nishan, N. S., Prakash A. S., Joshuva, N. (2016), Compression Behaviour of Al6061/Al_2O_3/Graphite Hybrid Composite, Material National Conference on Advances in Mechanical Engineering Science (NCAMES).

[21] Archana, K. (2018), Analysis of Graphite reinforced Aluminium-6061 Metal Matrix Composite using Stir Casting Method, International Journal of Applied Engineering Research, Vol. 13, Number 6, pp. 189-193.

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

[23] Bhandare, R. G. and Sonawane, P. M. (2014), Preparation of Aluminium Matrix Composite by using Stir Casting Method and its Characterization, International Journal of Current Engineering and Technology ISSN 2277 – 4106, Special Issue-3, (April 2014).

[24] Deepakaravind, V., Gurubaran, B. K., Selvam, B., Kumar, T. S. (2015), Investigation of Mechanical properties on Nano Alumina and Nano Silicon Carbide in reinforced hybrid LM25 Composite, Inter National Conference on EETA, Journal of Chemical and Pharmaceutical Sciences.

[25] Badiger, A., Krishan V. S. A., Sumandas, D., Vinayaka, H. L. (2016), Wear and Mechanical Properties Assessment of Al-Si/Al_2O_3 Nano Composites Processed by Stir Casting, *International Journal of Research and Innovation in Applied Science (IJRIAS)*|Vol. I, Issue IX.

[26] Arunagiria, K. S. and Radhika, N. (2016), Studies on Adhesive Wear Characteristics of Heat Treated Aluminium LM25/AlB2 Composites, Tribology in Industry, Vol. 38, No. 3, 277-285.

[27] Rohatgi, P. K., Dan, T. K., Arya, S. C. S. V. P., Das, S., Gupta, A. K., Prasad, B. K., Jha, A. K. (1990), Process for the manufacture of aluminum-graphite composite for automobile and engineering applications, United States Patent (19).

[28] Ekambaram, S. (2015), Synthesis and Characterization of Aluminium Alloy AA6061-Alumina Metal Matrix Composite, International Journal of Current Engineering and Technology, 2347 – 5161, Vol. 5, No. 5.

[29] Sameer, M. D. and Birru, A. K. (2016), 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*,* Volume 7, Issue 6, 37 ISSN 2229-5518.

[30] Bihari, B. and Singh, A. K. (2017), An Overview on Different Processing Parameters in Particulate Reinforced Metal Matrix Composite Fabricated by Stir Casting Process, Int. Journal of Engineering Research and Application, ISSN: 2248-9622, Vol. 7, Issue 1, (Part -3), pp. 42-48.

[31] Borina, D. and Odenbach, S. (2013), Viscosity of liquid metal suspensions -experimental approaches and open issues, The European Physical Journal Special Topics.

[32] Sharma, P., Paliwaa, K., Garg, R. K., Sharma, S., Khanduja, D. (2017), A study on wear behaviour of Al/6101/graphite composites, Journal of Asian Ceramic Societies 5, 42–48.

[33] Aatthisugan, Razal Rose, A., Iruthayaraj, R., Palani, S., Shanmugan, S. (2017), Wear and Mechanical properties of Aluminium hybrid composite (Al2024/Al_2O_3/Graphite) fabricated by powder metallurgy, International Journal of Pure and Applied Mathematics*,* Volume 116, No. 23, 231-236.