CHARACTERIZATION AND COMPARATIVE STUDY OF ALUMINIUM HYBRID METAL MATRIX COMPOSITES REINFORCED WITH Al2O3/Gr & SiC/Gr

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Abstract:

An attempt has been made to fabricate and compare the properties of aluminium hybrid metal matrix composites in this current work. Two specimens were fabricated by adding 10% (wt) of each Al2O3 and SiC along with 1% (wt) Graphite to AA6351. The stir casting route with bottom pouring technique has been employed to fabricate the two specimens. Morphology of the cast composites reinforced with Al2O3/Gr and SiC/Gr were studied in detail by optical microscopy to analyze particle distribution in the aluminium metal phase. The hardness test is carried out to find out the hardness of the cast composites and parent metal using Vickers micro hardness testing machine. Mechanical testing is carried out on the tensile samples prepared from the two cast composite specimens and parent metal specimen. Wear test is carried out to study the wear resistance behaviour of cast composites and parent metal specimen. The hardness, tensile strength and wear rate of the two HMMCs are compared with the parent metal specimen and the better HMMC is determined based on the comparison of test results.

Keywords: Hybrid Metal matrix composite, Wear, Optical Microscopy, Stir casting, Aluminium Oxide, Silicon carbide, Graphite.

1. Introduction

Composites are extensively used in aerospace, defense and it in automotive industries because of its exclusive properties like high hardness, high strength-to-weight ratio, high strength-to-cost ratio, high specific strength and high wear resistance etc. Efforts had been taken to pioneer hard ceramic particulates like SiC, Al2O3 and B4C into aluminum metal matrix. Literature survey shows that among the reinforcements SiC is chemically compatible with aluminum metal matrix and forms an adequate bond with the metal matrix without forming inter-metallic phase and has other benefits such as good thermal conductivity, required workability at low cost. In the earlier days, main focus was offered for the improvement of metal matrix composite with SiC in various weight percentages and importance was given to study its mechanical, tribological, and machinability properties etc. Presently due to the need of engineering materials with elevated strength, improved wear resistance and superior temperature performance, various reinforcements compatible with aluminum metal matrix are under research. Al2O3 is one of the widely used second reinforcement. But it has its own demerits like poor wetting behavior with aluminum and more weight percentage leads to increase in porosity.

2. Literature Review

Rama rao et al. [1] examined the properties of aluminium alloy-boron carbide composites which were fabricated by liquid metallurgy techniques with different particulate weight fraction (2.5, 5 and 7.5%). X-ray diffraction studies on boron carbide were used for phase identification, microstructure analysis was done with SEM and composites were characterized by hardness and compression tests. The results shows that with increase in the amount of the boron carbide, the density of the composites decreased where as the hardness is increased. The ultimate compressive strength of the composites was found to increase with increase in the weight percentage of the boron carbide in the composites. Balasivanandha prabu et al. [2] investigated dependence of microstructure and mechanical properties of composites on stirring speed and stirring time. The high silicon content aluminium alloy-silicon carbide MMC material, with 10% SiC by using a variance stirring speeds and stirring times. The microstructure examination on the produced composite was done by optical microscope and scanning electron microscope. The results proved that stirring speed and stirring time had influenced the microstructure and the hardness of composite to a significant level.

Karunamoorthy et al. [3] developed a 2D microstructure-based FEA models to study the mechanical behavior of MMC. The model has taken into account the randomness and clustering effects. From the developed model, particle clustering effects on stress-strain response and the failure behavior were studied. The optimization of properties was carried out from analysis of microstructure of MMC since the properties depend on particles arrangement in microstructure. In order to model the microstructure for finite element analysis (FEA), the micro-structure images were converted into vector form from the raster than its conversion push to IGES step and mesh in FEA model in ANSYS 7. The failure such as particle interface de-cohesion and fracture are predicted for particle clustered and non-clustered micro structures. The failure mechanisms and effects of particles arrangement were also analyzed. Radhika et al. [4] investigated the tribological behaviour of aluminium alloy reinforced with alumina and graphite fabricated by stir casting process. The wear and frictional properties of the hybrid metal matrix composites was studied by performing dry sliding wear test using a pin-on-disk wear test. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. L27 orthogonal array was selected for analysis of the data. Investigation was carried out to find the influence of sliding speed, applied load, sliding distance, on wear rate as well as the coefficient of friction. The results show that sliding distance has the highest influence followed by load and sliding speed. Finally confirmation test were carried out to verify the experimental results and scanning electrons microscopic studies were done on the wear surfaces. The incorporation of graphite as primary reinforcement increases the wear resistance of composites by forming a protective layer between pin counter face and the inclusion of alumina as a secondary reinforcement also has a significant effect on the wear behavior. The regression equation generated for the model was used to predict the wear rate and coefficient of friction of HMMC for intermediate conditions with reasonable accuracy.

Ramesh et al. [5] studied the friction and wear behavior of Al6061 matrix composite reinforced with nickel coated silicon nitride particles fabricated by liquid metallurgy. Microstructure and tribological properties of both matrix alloy and developed composites have been evaluated. Wear tests and dry sliding friction were carried out using pin on disk type wear testing machine over a load range of 20-100N and sliding velocities is 0.31-1.57m/s. Results exposed that, nickel coated silicon nitride particle are homogeneously distributed throughout the matrix alloy. Al6061-Ni-p-Si3N4 composite exhibited lower wear rate and coefficient of friction compared to matrix alloy. The coefficient of friction decreased with increased in load up to 80N. Beyond this, with further increase in load, coefficient of friction increases slightly. However, with increase in sliding velocity coefficient of friction of both matrix alloy and developed composite increases continuously. Wear rates of both matrix alloy and developed composites increased with increase in both load and sliding velocity. Mahendra boopathi et al. [6] studied the mechanical properties of aluminium 2024 in the presence of fly ash, silicon carbide and its combinations. Stir casting method was used for the fabrication of aluminium MMC. Structural characterization was carried out on MMC by X-ray diffraction studies and optical microscopy was used for the micro structural studies. The mechanical behavior of MMC like density, elongation, hardness, yield strength and tensile test were established by performing carefully designed laboratory experiments that duplicate as nearly as possible the service conditions. In the presence of silicon carbide and fly ash [SiC (5%) + fly ash (10%) and fly ash (10%) + SiC (10%)] with aluminium, it was fairly observed that the density of the composites was decreased and the hardness was increased. Correspondingly, the increase in tensile strength was also observed but elongation of the hybrid metal matrix composites in comparison with unreinforced aluminium was decreased. The aluminium-SiC-fly ash hybrid metal matrix composites significantly differed in all of the properties measured. Aluminium in the presence of SiC (10%)-fly ash (10%) was the hardest instead of aluminium-SiC and Aluminium-fly ash composites.

Bienias et al. [7] studied the microstructure characteristics and corrosion behavior of aluminium matrix Ak12 composites containing of fly ash particles, obtained by gravity and squeeze casting techniques. In this work, pitting corrosion behavior and corrosion kinetics are presented and discussed. It was found that one in the comparison with squeeze casting, gravity casting technology is advantageous for obtaining higher structural homogeneity with minimum possible porosity levels, good interfacial bonding and quite a uniform distribution of reinforcement, second one the fly ash particles lead to an enhanced pitting corrosion of the Ak12/9% flyash (75-100 µm fraction) composite in comparison with unreinforced matrix (Ak12 alloy), and third one the presence of nobler second phase of fly ash particles, cast defects like pores, and higher silicon content formed as a result of reaction between aluminium and silica in Ak12 alloy and aluminium fly ash composite determine the pitting corrosion behavior and the properties of oxide film forming on the corroding surface. Dora Siva Prasad et al. [8] investigated the mechanical properties of hybrid metal matrix composites with up to 8% rice husk ash and SiC particles which could be easily fabricated using double stir casting process. The uniform distribution of rice husk ash and SiC was observed in the matrix. The porosity and hardness increases with the increase in percentage of the reinforcement whereas the density of hybrid composites decreases. The yield strength and ultimate tensile strength increase with the increase in RHA and SiC content. It was found that in comparison to that of base aluminium alloy, the precipitation kinetic was accelerated by adding the reinforcement.

3. Experimental Procedure

Aluminium oxide particles and graphite particles of average size of 10 microns were selected as reinforcement for the first specimen. Silicon carbide particles and graphite particles of average size of 10 microns were selected as reinforcement for the second specimen. The metal matrix phase is AA 6351. In the HMMC Al2O3/Gr, the wt % of reinforcement of Al2O3 is 10% and Graphite is 1%. In the HMMC SiC/Gr, the wt % of reinforcement of SiC is 10% and Graphite is 1%. Al2O3 & Gr particles were preheated at 500°C for 2 hours to improve the wetability by removing the absorbed hydroxide and other gases. The furnace temperature was raised to 750°C to melt the matrix completely. At this stage the preheated Al2O3 & Gr particles were added and mixed. Two grams of magnesium is added in order to increase the wetability. A little amount of Hexa chloro ethane is added to remove dissolved gases. Mechanical stirring was carried out for 15 min at 500 rpm average stirring speed. The molten metal is poured into the mould by vacuum casting. Similarly, the second specimen reinforced with SiC/Gr is fabricated. The dimensions of the specimens were 300 mm in length and 50 mm in diameter. Morphology of different specimens was studied by optical microscopy. The hardness testing was carried out using Wilson Wolpert-Germany make Micro Vickers hardness testing machine with 0.5 kgf load for 10 seconds. Ten readings were taken with standard distance of 0.5 mm from every indentation to achieve reliability in results. Diamond indenter is used. Four samples were made from each specimen to have high reliability in results. The tensile test was carried out using tensile testing equipment with digital encoder, Auto instruments-Kholapur make. The specimens were made as per ASTM standards. A wire EDM machine was used to cut the specimens as per standards. The set up used to carry out wear test experiment was a pin-on-disc wear testing machine. Standard steel disc having surface roughness of less than one micron is used as disc. The pins are made up of HMMC of 32 mm length and 10 mm diameter. Wear tests were conducted with a load of 10N respectively. The distance travelled by mild steel pin on the specimen prepared is 1000 m. The temperature range is from 32°C with a frequency of 10Hz. After conducting all experiments the results and its values were tabulated. A comparative study was carried out between Al2O3/Gr and SiC/Gr hybrid metal matrix composite.

4. Results And Discussion 4.1 Microstructure Analysis

4.1.1 Metal matrix Composite AA6351 with Aluminium Oxide 10% + 1% Graphite a. Micro Examination in Polished condition:

AA 6351 is Aluminium alloy with silicon and magnesium as alloying elements. The stir cast metal matrix composite would show the composite particles in metal matrix which is in polished condition. The metal matrix would reflect the light and the composite particles which are compounds are opaque and will not reflect the light. Hence the distribution of the composite in metal matrix is resolved as dark particles and light metal matrix. Fig. 1(a) and

(b) show even distribution of the composite particles in metal matrix. The Al_2O_3 are relatively bigger in size and the graphite being fine in size occupied the grain boundaries sites.

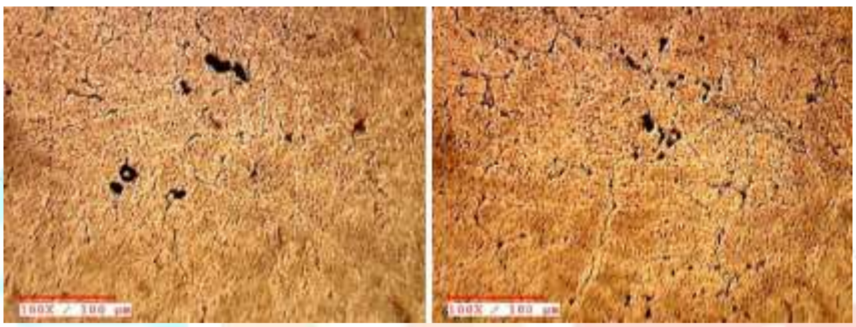

Fig. 1 (a) and (b)

b. Micro Examination in Etched condition:

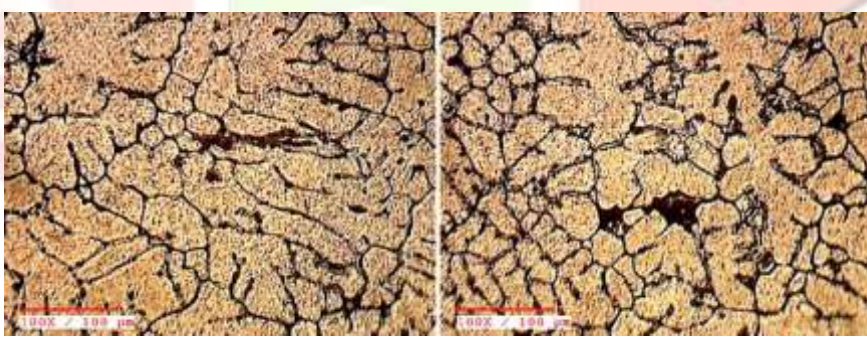

Fig. 2 (a) and (b)

Fig. 2(a) and (b) shows both Al_2O_3 and graphite distributed uniformly in the matrix. The graphite particles being fine in size occupied the grain boundaries sites.

4.1.2 Metal matrix Composite AA6351 with Silicon Carbide 10% + 1% Graphite

a. Micro Examination in Polished condition:

In Fig. 3 (a) and (b), the SiC particles at all the fields show the cluster of particles in primary aluminium matrix. The particles of silicon carbide are present as lumps and not effectively distributed. However the graphite particles are evenly distributed in the matrix.

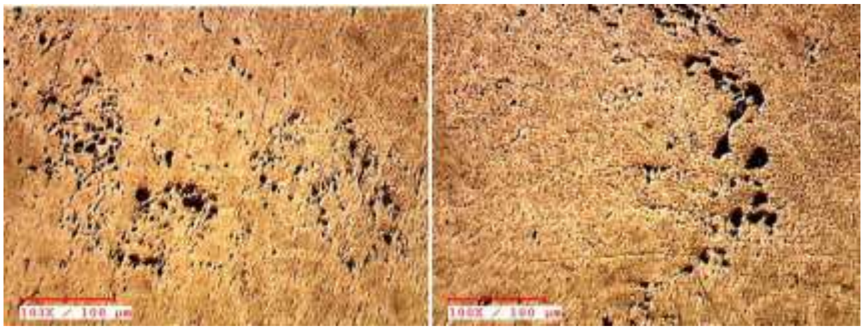

Fig. 3 (a) and (b)

b. Micro Examination in Etched condition:

Fig. 4 (a) and (b) shows the distribution of the composite particles of silicon carbide and graphite particles in grains of primary aluminium matrix. The graphite particles occupied the grain boundary voids and the silicon carbide being bigger in size is present inside the grains. The distribution is present as lumps and agglomerated in the matrix.

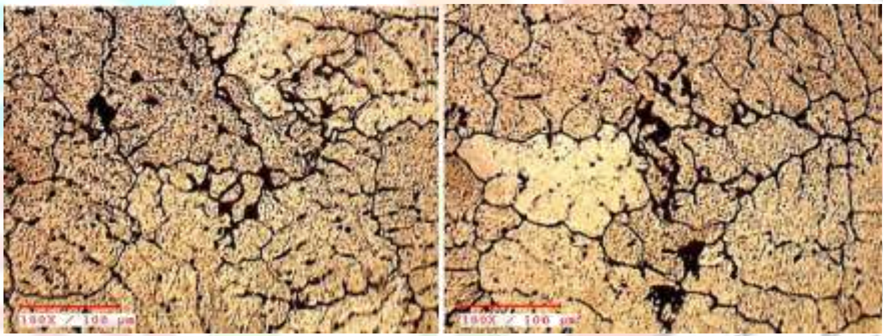

Fig. 4 (a) and (b)

4.2 Hardness test of AA 6351 reinforced with Al_2O_3/Gr and SiC/Gr

The average values are plotted in graph HV versus nature of reinforcements Al2O3/Gr and SiC/Gr respectively. Table 1 gives the micro hardness values of two specimens. Fig. 5 shows that the micro hardness value of Al2O3/Gr is higher than SiC/Gr composite specimen. High Hardness of the Al/SiC HMMC may be due to physical properties of Al2O3/Gr particles. The replacement of SiC/Gr with Al2O3/Gr or the effect of Al2O3/Gr exhibits 38.6% increase in micro hardness value of the composite.

Table 1. Micro hardness values of two specimens

Sl. No	Type of reinforcements	Micro Hardness Value (HV)
1	AA6351(Parent Metal)	35
2	AA6351/Al_2O_3/Gr	61
3	AA/SiC/Gr	44

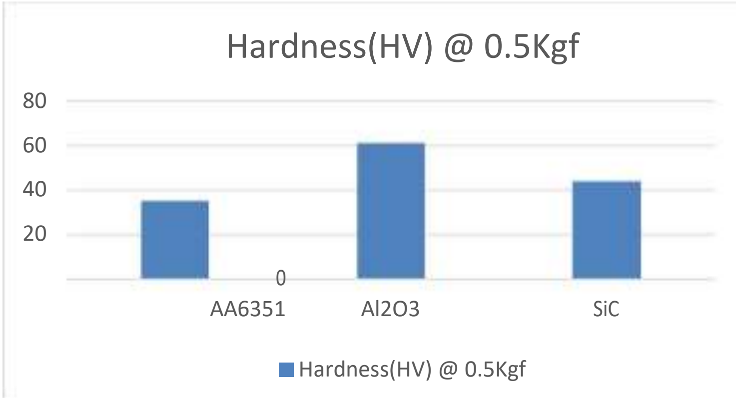

Fig. 5 Comparative hardness chart

4.3 Tensile test of AA 6351 reinforced with Al_2O_3/Gr and SiC/Gr

Tensile tests were carried out for Al2O3/Gr and SiC/Gr composite specimens and the average values were tabulated in Table 2. The development in tensile property of the composites can be imputed to the contact between particles and dislocations; reinforcement particles operate as barriers to the movement of dislocations under the load, enhances higher tensile strength of composites. The tensile value of Al2O3/Gr composite which is 137 MPa reveals that there is increase in strength of composite than base alloy. This is due to the Al2O3/Gr particles which evenly distributed in the matrix and the interfacial bonding between particle and the matrix phase. The second specimen of SiC/Gr composite exhibits lower strength than Al2O3/Gr composite. The replacement of SiC/Gr with Al2O3/Gr or the effect of Al2O3/Gr exhibits 14% increase in tensile strength of the composite. This comparative study concludes Al2O3/Gr composites have higher tensile strength than SiC/Gr. Fig.6 shows the comparison of tensile strength of Al2O3/Gr with SiC/Gr composite which clearly depicts the 14.1% increase in tensile strength of Al2O3/Gr composite.

Table 2. Tensile test values of two specimens

Sl. No	Type of reinforcements	Tensile strength (MPa)
1	AA6351(Parent Metal)	104
2	AA6351/Al_2O_3/Gr	137
3	AA6351/SiC/Gr	120

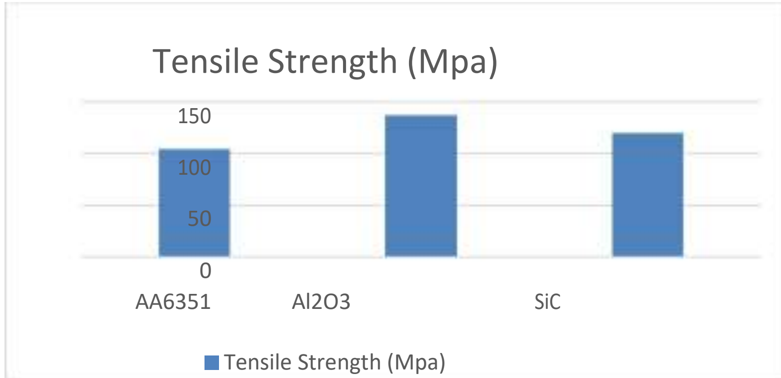

Fig. 6. Comparative tensile strength chart

4.4 Wear test analysis of Al2O3/Gr and SiC/Gr composite under a load of 10N

Wear test was carried out separately in order to evaluate the wear resistance of the composites and results are shown in Fig 7 & Fig 8. The graphs are plotted using experiment results. Also the specimens were weighed before and after the experiment and wear mass loss was tabulated. Test was carried out for 1000m travelling distance with a load of 10N and the wear value of Al2O3/Gr and SiC/Gr was 750 ìm and 1120 ìm respectively as shown in Fig.7 and Fig. 8. This show wear resistance property increases by 49.3% when SiC/Gr is replaced by Al2O3/Gr. Table 3 depicts the wear mass loss percentage of the Al2O3/Gr composite is 0.282% and the wear mass loss of the SiC/Gr composite is 0.389%. This is due to the hardness, high stiffness and thermodynamic stability of Al2O3/Gr particles and replacement of SiC/Gr with Al2O3/Gr composite can greatly improve wear resistance of composite. Fig. 9 shows the wear mass loss of HMMC pins which were used to conduct wear test against standard steel disc. As the wear mass loss percentage of Al2O3/Gr pins for 10N load wear test, is lesser than the SiC/Gr, we can confirm the high wear resistance property of Al2O3/Gr composite than SiC/Gr composite.

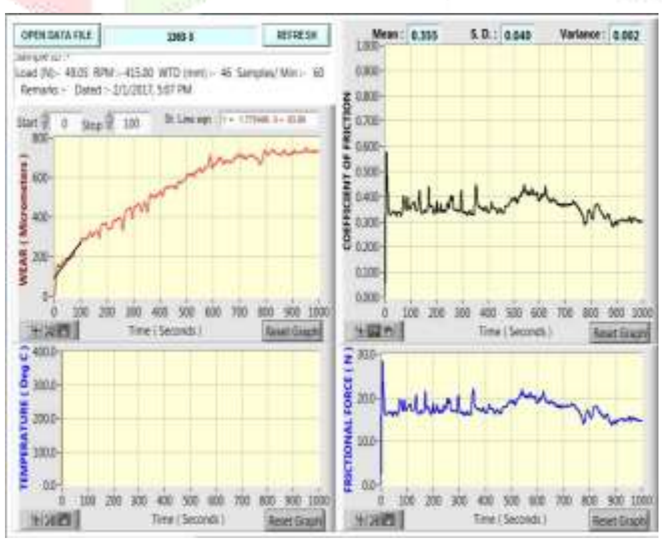

Fig.7. Wear rate under 50N load for AA6351/Al_2O_3/Gr specimen

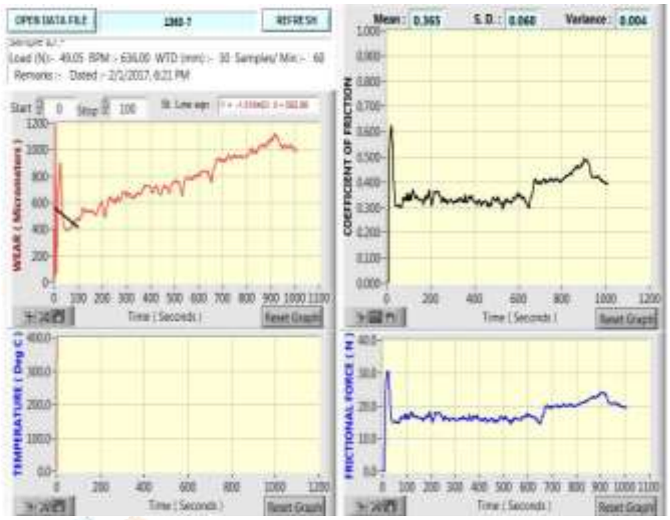

Fig.8. Wear rate under 50N load for AA6351/SiC/Gr specimen

Table. 3 Comparison of Weight loss% of Pins of Three Specimens

S.No.	Weight Loss of Pin	Before	After	Wear Loss	Loss In Percentage
1	AA6351 (Parent Metal)	3.758	3.737	0.021	55.8%
2	AA6351/Al_2O_3/Gr	4.241	4.229	0.012	28.2%
3	AA6351/SiC/Gr	4.382	4.365	0.017	38.9%

Fig. 9 Comparative wear mass loss chart for 10N load

5. Conclusion

1. The Al_2O_3/Gr and SiC/Gr metal matrix composites were successfully fabricated using stir casting route.
2. Micro Structural analysis shows the presence of Al_2O_3/Gr and SiC/Gr and its uniform distribution in the metal matrix.
3. It has been concluded from hardness test that hardness value of Al_2O_3/Gr is higher than SiC/Gr composites. The replacement of SiC/Gr with Al_2O_3/Gr or the effect of Al_2O_3/Gr exhibits 38.6% increase in Micro hardness value of the composite.
4. This comparative study concludes Al_2O_3/Gr composites have higher tensile strength than SiC/Gr. The replacement of SiC/Gr with v or the effect of Al_2O_3/Gr exhibits 14.1 % increase in tensile strength of the composite.
5. It has been proved from wear analysis that Al_2O_3/Gr particles increase the wear resistance behavior of aluminum metal matrix. It is concluded that wear resistance property increases by 49.3% when SiC/Gr replaced by Al_2O_3/Gr.

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