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Wear Behavior of LM6 – Borosilicate Glass Reinforced Metal Matrix Composite

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***Abstract*: The work focuses on the fabrication of aluminium based metal matrix composite and then studying its mechanical properties such as tensile strength, compressive strength hardness and wear behavior of produced test specimen. Wide application of the metal matrix composite is mainly depends on the cost of production. In the present study a modest attempt has been made to develop aluminium based MMC reinforced with borosilicate glass, which is usually a waste material from chemical laboratories. The matrix material selected for the production of MMC is aluminium - 12% silicon eutectic alloys which is also known as LM 6. For the homogenous distribution of reinforcement particles stir casting method is selected and the test specimens are prepared as per the ASTM standards.**

Experiments are conducted by varying the % addition of borosilicate glass from 2.5 to 10 %. The result shows that the tensile and compressive strength of the composites increases as the increase in the % addition of borosilicate glass and reaches maximum at 7.5% addition of reinforcement. The addition of borosilicate glass improves the wear behavior of the matrix material which is the main drawback of LM6.

***Keywords*: Aluminium Metal Matrix Composites, LM6, Borosilicate glass, Stir Casting, Wear behavior**

1. Introduction

Aluminium MMCs are preferred to other conventional materials in the fields of automotive, aerospace and marine applications owing to their improved properties like high strength to weight ratio, good wear resistance etc. Aluminum alloys are broadly used as a main matrix element in Composite materials. The broad use of aluminum alloys is dictated by a very desirable combination of properties, combined with the ease with which they may be produced in a great variety of forms and shapes [1]. Matrix is a relatively 'soft' phase with specific physical and mechanical properties, whose sole purpose is to bind the reinforcements together by virtue of its cohesive and adhesive characteristics, to transfer load to and between reinforcements. The reinforcement phase (or phases) have been usually stronger and stiffer than the matrix and mainly carries the applied load to the composite [5]. Discontinuously reinforced aluminium matrix composites are fast emerging as engineering materials and competing with common metals and alloys. They are gaining significant acceptance because of higher specific strength, specific modulus and good wear resistance as compared to ordinary unreinforced alloys [2].

2. Materials and method

Aluminium metal was first produced around 170 years ago. Now a day, structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. Aluminium is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. The versatility of aluminium makes it the most widely used metal after steel. However, the poor high-temperature performance and wear resistance is the main weaknesses of aluminium alloys. To overcome these problems, aluminium alloys reinforced by ceramic particles, known as metal matrix composites (MMCs).

A. LM 6

LM6 alloys are aluminium-12% silicon eutectic alloy which is normally used to produce marine 'on deck' castings, pump parts, water-cooled manifolds and jackets, motor-car and road transport fittings, etc. The main chemical composition of LM6 aluminum alloy is shown in table 1. LM6 alloy has the lowest melting point which can be seen from the Al–Si phase diagram. The main composition of LM6 is about 85.95% of aluminium, 11% to 13% of silicon. One of the main drawbacks of this material is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites.

Table 1
Chemical composition of LM6

Material	**Percentage**
Copper	0.1 max.
Magnesium	0.10 max.
Silicon	10.0-13.0
Iron	0.6 max
Manganese	0.5 max
Nickel	0.1 max.
Zinc	0.1 max.
Lead	0.1 max.
Aluminum	Remainder
Titanium	0.2 max

B. Reinforcement

SiC, TiC, Al2O3 etc. are themost common reinforcements using for the production of aluminium metal matrix composites.

These are costlier and have a higher density, which will increase the total weight of the components. The key factor determining wider application of MMC in various fields is the cost and the two factors that determines the cost are the type of reinforcement using and the technique which is being used to produce the MMC. It is found that the use of unwanted or useless solid materials generated from residential, industrial and commercial activities can significantly reduce the cost of metal matrix composite. Borosilicate glass is a type of glass with silica and boron trioxide as the main glass-forming constituents. The chemical composition of borosilicate glass is shown in Table 2.

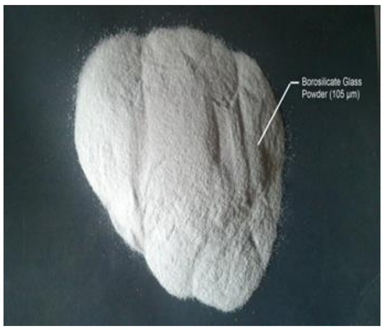

Fig. 1. Borosilicate glass

Table 2
Chemical composition of borosilicate glass

Material	Percentage
SiO_2	80.6
B_2O_3	13.0
Na_2O	4.0
Al_2O_3	2.3

C. *Stir Casting Process (Vortex Method)*

The vortex method is one of the bester known approaches used to create and maintain better distribution of the reinforcement material in the matrix alloy [2]. It comes under the classification of liquid-phase processes which involves the incorporation of dispersed phase (Borosilicate glass) into a molten matrix metal (LM6), in this method, after the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The stirring is continued for a few minutes before the slurry has been casted. There are different designs of mechanical stirrers. Wettabilty is a most significant problem when producing cast metal matrix composites. Wettability can be defined as the ability of a liquid to spread on a solid surface. The particle –matrix interface have an important effect on the mechanical properties of the composites, as a good bonding promotes load transfer to the higher strength ceramic particles. On the other hands, extensive inter facial reactions may deteriorate the mechanical properties of the composites. The magnesium played an important role during the synthesis of aluminum alloy matrix composites with dispersoids. Magnesium addition to aluminium reduces its casting fluidity at the same time as it reduces the surface tension of the aluminium sharply. Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix [3].

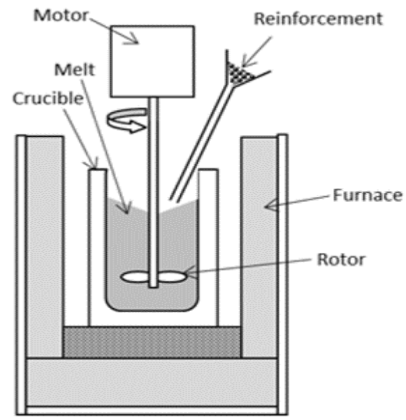

Fig. 2. Stir casting process

Preparation of reinforcement material (borosilicate glass) is carried out by crushing it with the help of a ball mill. The borosilicate glasses are collected from a recycling plant which is then properly cleaned and dried. The crushed glass particles are then seived to the size of 105µm. 1Kg of commercially available LM 6 and desired amount of Glass particles were taken in the preparation of each sample. The Glass particles ware preheated to 400˚C for 30 min before adding to the aluminium melt in order to remove any moisture present in it. The LM 6 alloy is then melted by using a resistance furnace. The melt temperature was raised up to 850˚C and a small amount of magnesium was added to the molten metal to increase the wettability of the aluminium melt. The melt was stirred with the help of a stainless steel stirrer. The stirring was maintained between 5 min at an impeller speed 300 rpm.

D. *Wear test*

The removal of material from one or both of two solid surfaces in solid state contact is known as wear. Dry sliding Wear test was carried out by using Pin on Disc Wear Testing Machine. The pin was held against the counter face of a rotating disc through a dead weight loading system. The wear test for all specimens was conducted under the normal loads of 5 Kg, 10Kg, 15 Kg and a sliding velocity 1.5 m/s. Initially, the pin surface was made flat such that it will support the load over its entire cross-section. Run-in-wear was performed in the next stage, which avoids initial turbulent period associated with friction and wear curves. The final stage is the actual testing called steady state wear. Before the start of each experiment, precautionary steps were taken to make sure that the load was applied in the normal direction. Schematic diagram of the pin-on-disk apparatus is shown in Fig. 3.

1) *Wear Calculation*

1. Area

Cross sectional Area = length × breadth × height

2. Volume loss
Volume loss = Cross sectional Area x Height loss

3. Wear rate
Wear rate = Volume loss / Sliding distance

4. Wear resistance
Wear resistance = 1/ Wear rate

5. Specific wear rate
Specific wear rate = Wear rate/load

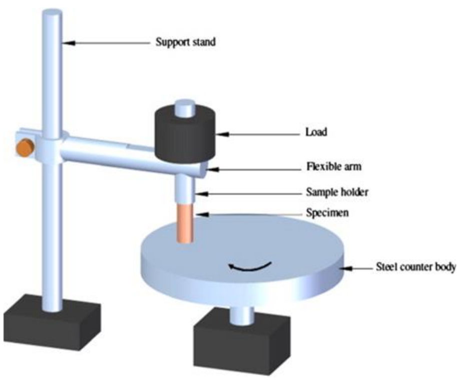

Fig. 3. Schematic views of the pin-on-disk apparatus

3. Experimental procedure

The specimens for different tests are prepared as per ASTM standards for material testing. The tensile test specimens are prepared as per the standard ASTM B557 to conduct the test at room temperature. The specimens for compression test are prepared according to ASTM standard E9–89a. The hardness test is conducted on the Rockwell hardness testing machine. The specimen for the test is prepared (dia 20mm and length 20 mm) from the cast samples and the surface were ground using a grinding machine. The indenter has 1.588 mm diameter and a force of 100Kgf was applied on the surface for 30 Sec.

Fig. 4. Test specimen for tensile, hardness and compressive test

The samples for the wear test were prepared as per the dimensions of 10 × 10 × 40 mm. The test is going to conduct on pure LM6 and AMMC with 7.5 % addition of borosilicate glass. The wear test is conducted at 3 different forces (5kg, 10kg, 15kg) and at three different sliding distances (500 m, 1000m and 1500m). The sliding velocity is kept at constant at each test (1.5 m/s). The test setup is shown in the figure5. The alloy and composite samples are cleaned thoroughly with acetone and each samples are then weighed using a digital balance. Then the sample is mounted on the pin holder of the pin on disk apparatus. After each test the specimen is again weighed to determine the loss of material during the test.

Fig. 5. Pin on disc apparatus

Polishing is the one of the main criteria that gives a definite property to the microstructure obtained. For that the rough grinding of the specimens were done by using the belt polisher. Then the samples were ground on different emery papers (SiC) starting with 120, 240, 320, 400, 600 grit sizes. After that polishing of the specimens was done by using Cloth polishing machine and diamond paste (3 and 0.5µm). The images were taken in both secondary electron (SE) and back scattered electron (BSE) mode according to requirement. The EDX (energy dispersive X-ray) analysis of respective samples are also conducted during the analysis. The test setup and specimens are shown in the Fig. 6.

Fig. 6. Scanning electron microscope

4. Results and discussions

A. Effect of % addition of borosilicate glass on mechanical properties

The addition of borosilicate glass into the LM 6 matrix improves the mechanical properties, but also reduces the overall density of the composite. This will improve the strength to weight ratio of the component, which is essential for the development of various products in the fields of automobile, aerospace, etc. From the Table 3 it is evident that the tensile as well as compressive strength of the component increases as the increase in the percentage and reaches the maximum value at 7.5% addition of borosilicate glass. After this limit the tensile and compressive strength tends to reduce due to clustering of reinforcement particles. The hardness test has conducted on each specimen using ASTM standard E23. These experimental values show that the hardness of the samples tends to increase as the % addition of reinforcement increases.

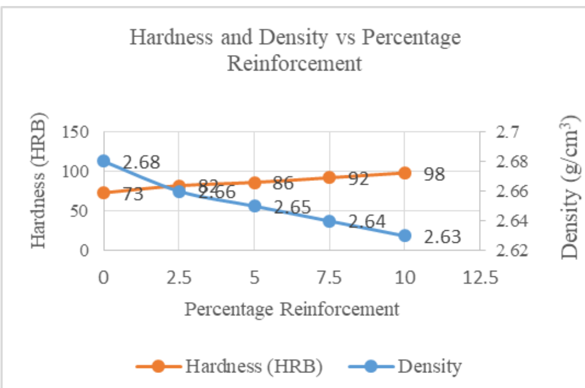

Fig. 7. Hardness and Density vs. Percentage Reinforcement

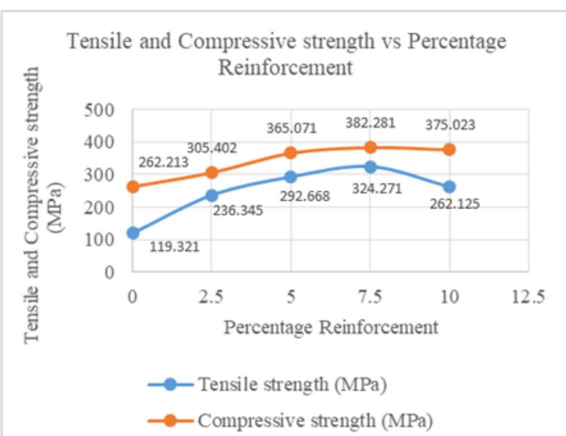

Fig. 8. Tensile and Compressive strength vs. Percentage Reinforcement

B. Wear test

During the wear test of Glass reinforced MMC, a high pitch sound can be audible from the contact region, most likely because of the hard glass particles becoming exposed to the surface and being in direct contact with the steel disk.

Since the best properties of the MMC are attained at 7.5% of borosilicate glass reinforcement, wear test is mainly focused on this particular specimen. Table 5 shows the comparison between the wear behavior of the pure LM 6 alloy and 7.5% glass reinforced AMMC. The test was conducted for loads ranging from 5 kg, 10 kg, and 15kg. The sliding velocity is maintained at 1.5 m /s and sliding distance is 500m.

It is observed the wear volume and wear rate both have increased as the normal load increases. It is due to the fact that glass is a harder material and it imparts the hardness property to the composite. Fig. 9, 10, 11, 12, shows the variation of Volume loss, wear rate, specific wear and wear resistance with respect to normal loads.

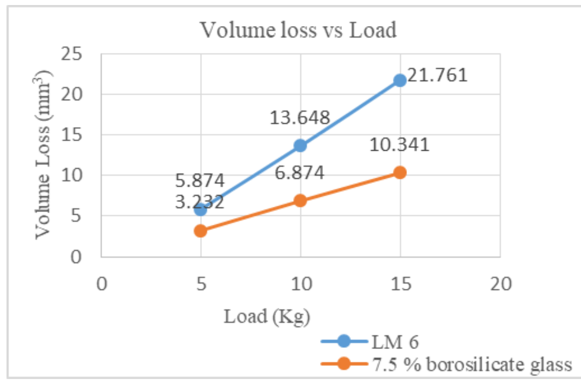

Fig. 9. Volume loss vs. Load

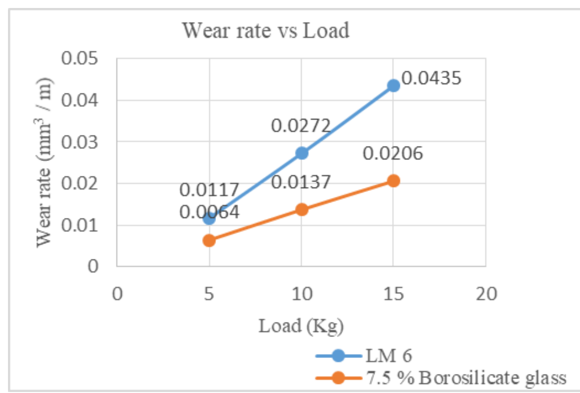

Fig. 10. Wear rate vs. Load

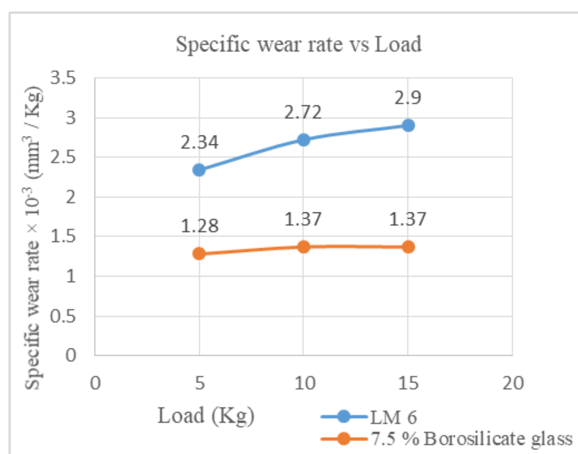

Fig. 11. Specific wear rate vs. Load

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Table 3
Properties vs. Percentage of Reinforcement

S. No.	Composition	Density (g/ cm^3)	Tensile strength (MPa)	Compressive strength (MPa)	Hardness (HRB)
1	LM 6 + 0.0% Borosilicate Glass	2.68	119.321	262.213	73
2	LM 6 + 2.5% Borosilicate Glass	2.66	236.345	305.402	82
3	LM 6 + 5.0% Borosilicate Glass	2.65	292.668	365.071	86
4	LM 6 + 7.5% Borosilicate Glass	2.64	324.271	382.281	92
5	LM 6 + 10.0% Borosilicate Glass	2.63	262.125	375.023	98

Table 4
Wear behavior of LM 6compared to7.5% glass reinforced AMMC

Material	Load (Kg)	Initial weight (g)	Final Weight (g)	Weight loss (g)	Volume Loss (mm^3)	Wear rate (mm^3 / m)	Specific wear rate × 10^{-3} (mm^3 / Kg)	Wear resistance (m/mm^3)
LM6	5	10.720	10.704	0.0157	5.874	0.0117	2.34	85.470
	10	10.720	10.683	0.0365	13.648	0.0272	2.72	36.764
	15	10.720	10.661	0.0583	21.761	0.0435	2.90	22.988
LM6 + 7.5% Borosilicate Glass	5	10.560	10.551	0.0085	3.232	0.0064	1.28	156.25
	10	10.560	10.541	0.0181	6.874	0.0137	1.37	72.99
	15	10.560	10.532	0.0273	10.341	0.0206	1.37	48.54

Table 5
Wear behavior of the AMMC

Sliding Distance (m)	Load (Kg)	Initial weight (g)	Final Weight (g)	Weight loss (g)	Volume Loss (mm^3)	Wear rate (mm^3 / m)	Specific wear rate × 10^{-3} (mm^3 / Kg)	Wear resistance (m/mm^3)
500	5	10.560	10.551	0.0085	3.232	0.0064	1.28	156.25
	10	10.560	10.541	0.0181	6.874	0.0137	1.37	72.99
	15	10.560	10.532	0.0273	10.341	0.0206	1.37	48.54
1000	5	10.560	10.542	0.0179	6.801	0.0068	1.36	147.05
	10	10.560	10.523	0.0369	14.003	0.0140	1.40	71.42
	15	10.560	10.503	0.0567	21.502	0.0215	1.43	46.51
1500	5	10.560	10.531	0.0285	10.803	0.0072	1.44	138.88
	10	10.560	10.502	0.0574	21.750	0.0145	1.45	68.96
	15	10.560	10.473	0.0867	32.850	0.0219	1.46	45.66

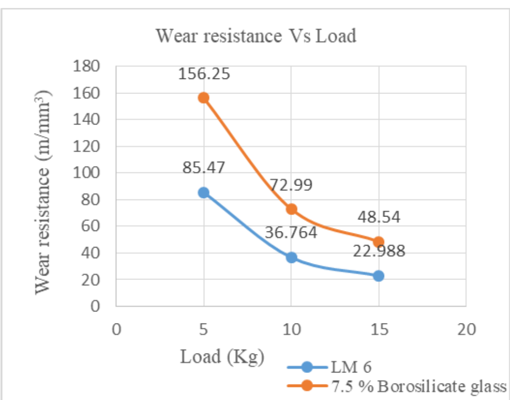

Fig. 12. Wear resistance vs. Load

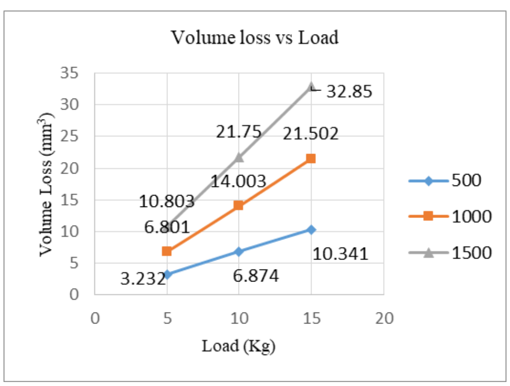

Fig. 13. Volume loss vs. Load

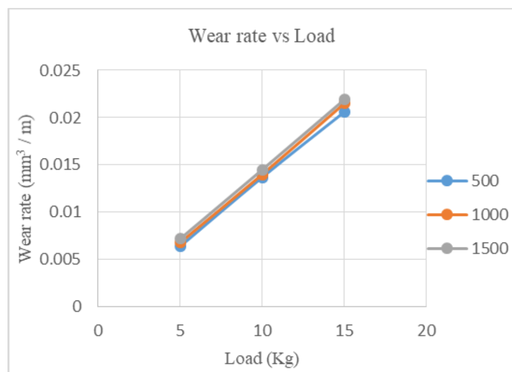

Fig. 14. Wear rate vs. Load

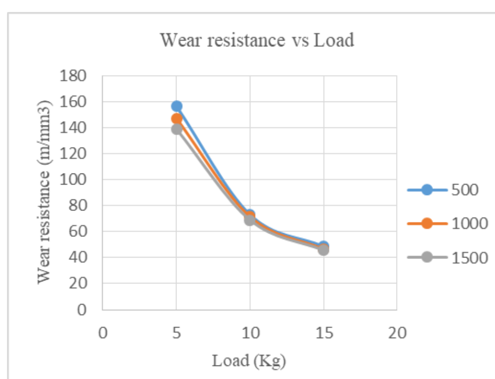

Fig. 15. Wear resistance vs. Load

The wear behavior of 7.5% glass reinforced AMMC was found by varying the load and sliding distance. The sliding velocity is maintained at 1.5 m /s for all sliding distances. The wear rate at various conditions are shown in the table 5. From the table it is observed that the wear resistance decreases with the increase in sliding distances and load.

The Fig. 13, 14, 15, 16, shows the variation of Volume loss, wear rate, specific wear and wear resistance with respect to normal loads and sliding distance.

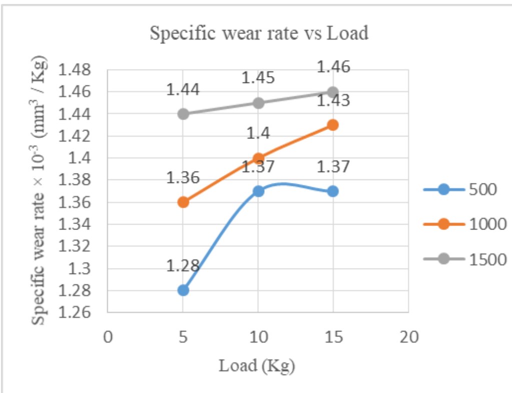

Fig. 16. Specific wear rate vs. Load

C. Microstructure Analysis

From the SEM with EDX result, it can be seen that the formation of oxide layer also formed in the glass particulates also which will confirm that the glass particulates are properly mixed with the matrix and the corrosion resistance of the MMC increased.

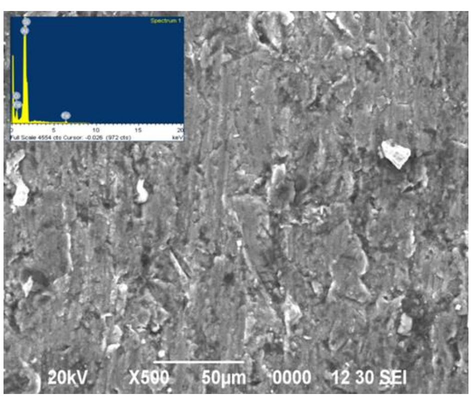

Fig. 17. Optical micrographs of LM 6 with 7.5% Borosilicate Glass

5. Conclusion

The metal matrix composite is successfully manufactured by stir casting method. The addition of the borosilicate glass satisfied to produce a low cost metal matrix composite with good mechanical properties. Based on the test results and interpretation following conclusions were reached

- Increasing the amount of borosilicate glass reinforcement will increase the hardness of the metal matrix composite.
- The tensile and compressive strength of the composite has been increased by adding the reinforcement material up to 7.5%, then decreases due to the clustering of the glass particulates.
- The wear resistance of the MMC has been improved compared with pure LM 6.
- The wear rate of the composite increases as the load and sliding distance increases.
- SEM image of the MMC shows the uniform distribution of glass particles in the LM 6 matrix.

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