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DRY SLIDING WEAR BEHAVIOUR OF STIR CAST LM 25/ZrO_2 METAL MATRIX COMPOSITES

Summary

In the present study, an investigation into wear properties has been carried out to identify the influence of ZrO_2 as the reinforcement material on the LM25 MMC composite. Aluminum LM25 is selected as the base material, and it is reinforced with varying proportions of 0, 3, 6, 9, 12 and 15% of zirconia (ZrO_2) manufactured by stir casting. Six tensile test and wear test samples were prepared according to the ASTM B-557-M-94 and ASTM G99 standards. Then, the prepared samples were subjected to the wear test using a pin-on-disc wear tester by varying the parameters such as loads of 10 N, 20 N and 30 N and sliding distances of 1,000 m, 1,200 m and 1,400 m for various percentages of ZrO_2 reinforcement composites, and corresponding wear losses were measured. The wear test results reveal that an increase in the percentage of ZrO_2 decreases the wear loss. It is also found that an increase in load and sliding distances increases the wear loss and hence the low wear loss is obtained for the sample which contains 15% of ZrO_2 and is subjected to a wear test load of 10 N at a 1000 m sliding distances. Finally, the wear test samples are subjected to the surface roughness test. The surface roughness test reveals that an increase in the percentage of ZrO_2 enhances smoothness and decreases surface roughness.

Key words: *metal matrix composites, aluminium LM25 alloy, zirconia (ZrO_2), sliding wear test*

1. Introduction

Metal Matrix Composites (MMCs) have emerged as an important class of materials used in structural, wear, thermal, transportation and electrical applications because they offer a high strength-to-weight ratio, high stiffness and good wear resistance [1]. The aluminum based metal matrix composites are excellent novel materials for applications in aerospace, automotive and transportation industries [2]. The fabrication methods of the aluminum based composites can be categorized into three processes: solid-state methods, semisolid state methods and liquid state methods [3]. Stir casting is a liquid state method for composite fabrication, in which a dispersed phase is mixed with a molten matrix metal by mechanical stirring [3]. The aluminum LM25 alloy exhibits low density and high thermal conductivity. However, its wear resistance is low [4-5]. In order to avoid this drawback, this LM25 alloy was reinforced with ZrO_2 to form LM25- ZrO_2 composites. This composite is used for marine casting, the manufacture of motorcars, engine parts, switch boxes, hydraulic systems (piston, cylinder) and in food-processing industries. Ceramic materials, such as SiC, TiC, TiB_2, ZrB_2, AIN, Si_3N_4, Al_2O_3 and SiO_2 are generally used to reinforce aluminum alloys[6]. Among all the reinforcements used in aluminum based composites ZrO_2 particulates alone have shown potential superiority in improving mechanical properties and microstructure. Further, ZrO_2 particulates provides noticeable weight saving.

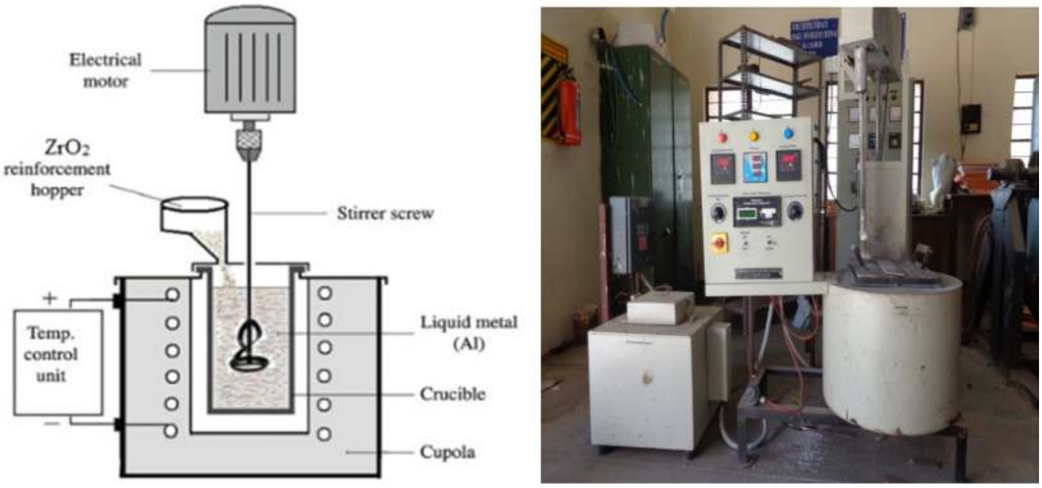
The ZrO_2 reinforcement is very attractive as it exhibits a density of 8.18 gm/cm^3, the melting point of 1860˚C, UTS-425 MPa, VHN-150, and Young's modulus of 98 GPa. It was also found that ZrO_2 shows superior strength and higher hardness and fracture toughness with a slight reduction in ductility [8]. Wear resistance is the most important property of a material, when it is a candidate for engineering applications. Hence, this property of various aluminum alloys has been widely investigated by researchers [3]. The studies on LM25/ZrO_2 reinforced composites are not found in any of the previous investigations. It was also found that only a few papers studied the sliding wear behaviour of composites with the ZrO_2 reinforcement material in situ [7-8]. Wear properties of composites mainly depend on the grain size [6]. Various studies carried out on Al_2O_3, SiC, TiO_2, TiB_2, ZrO_2, Si_3N_4 in various contact situations showed mild wear [5, 9-10]. It has also been found that the wear test carried out on Al-SiC MMCs used for commercial break pads confirmed that the break loss increases with the increasing sliding velocity [11]. It has also been found that the transfer layer of MMCs acted as a protective cover, and it helped to reduce both wear rate and friction coefficient. So, this experimental method was chosen for the present study.

The literature review showed, that MMCs play a vital role in replacing metals, due to their advanced mechanical and metallurgical properties. A lot of researchers have concentrated on developing new composites such as Al 6061, LM25 reinforced with various elements such as TiB_2, SiC, TiC, ZrB_2, AIN, Si_3N_4, Al_2O_3 and their wear properties were analyzed in earlier studies [3-5]. No papers have been found to analyze the effect of ZrO_2 on the LM25 base material while subjected to wear. The papers mainly concentrated on developing a new composite material by taking LM25 as the base material and varying the percentage of ZrO_2 to identify the influence of ZrO_2 on the wear behaviour.

2. Materials and Methods

2.1 Materials

The aluminium LM25 alloy was taken as the base material and the ZrO_2 powder (particle size 1-10μm) was chosen as the reinforcement material. The corresponding chemical compositions are given in Table 1 and 2. In this study, six cast samples were prepared by keeping LM25 as the base material and varying the weight percentage of ZrO_2 as follows: 0%, 3%, 6%, 9%, 12% and 15%. Casting was carried out by using a stir casting process as shown in Fig. 1 (a-b). Initially, the aluminum LM25 alloy was melted in a pot by heating in a blower furnace at 850˚c for 15 min. The ZrO_2 powder was preheated at 575˚C in a separate muffle furnace. The furnace temperature was raised above the liquid temperature of LM25 to about 850˚C to melt LM25 completely and then LM25 was added to the preheated ZrO_2 powder slowly. Stirring was carried out with the help of a drilling machine for about 15 minutes, and the stirring rate maintained the speed of about 950 rpm. This mixture was then poured into the mould cavity, and was cooled at the room temperature. This procedure was repeated in the preparation of six specimens with different proportion of ZrO_2 as shown in Fig.1(a-b).



(a) Schematic view of stir casting setup (b) Photographic view of stir casting setup

Fig. 1 (a-b) Casting of MMC by using stir casting method.

Table 1 Chemical composition of aluminum LM25 alloy (weight percentage)

Cu	**Mg**	**Si**	**Fe**	**Mn**	**Ni**	**Zn**	**Pb**	**Sn**	**Ti**	**Al**
0.1%	0.20-0.60%	6.5 – 7.5%	0.5%	0.3%	0.1%	0.1%	0.1%	0.05%	0.2%	Bal

Table 2 Chemical composition of ZrO_2 (weight percentage)

SiO_2	TiO_2	Fe_2O_3	Y_2O_3	Zr
0.25%	0.16%	0.07%	3 to 5%	bal

2.2 SEM-EDS analysis with element distribution

Energy dispersive spectrometry (EDS) analysis had been applied to all prepared samples of various percentages of ZrO_2 before they were subjected to the wear test. The present section, helps to find out information about the type of the element present in all cast samples. Fig. 2 (b), (d), (f) and (h) shows the EDS of aluminium LM25 with its elements. And Fig. 2 (a), (c), (e) and (g) presents the topographical image produced by a scanning electron microscope (SEM). From the graph obtained from the EDS test the results are used to confirm the chemical composition of the LM 25/ZrO_2 composites, such as aluminium, zirconium, iron, copper, magnesium, zinc, silicon and all other elements present in the prepared composites as shown in Fig. 2 (b), (d) (f) and (h). The shrinkage and porosity were not identified in the micrograph. This is evidence of good quality casting. An increase in the percentage of ZrO_2, resulted in the oxide formation at the pin surface, and the developed oxides act as a wear protective layer for various loads. This is clearly seen in Fig. 2 (d), (f) and (h). Finally, the EDS analysis confirmed the presence of aluminium and ZrO_2 particles, as shown in Fig 2 (b), (d), (f) and (h).

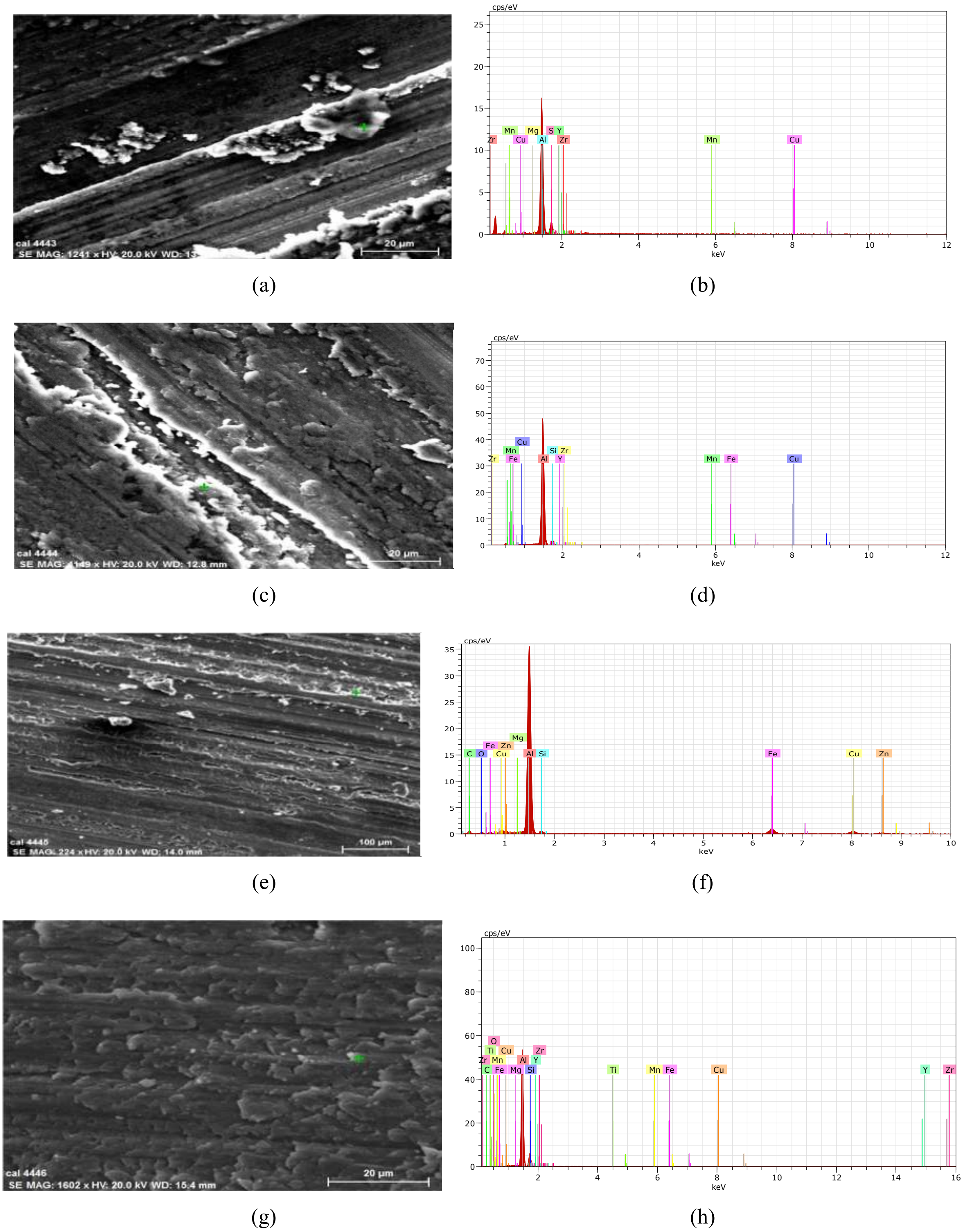


Fig. 2 SEM images and EDS patterns of various composites (a) SEM image of LM25 (b) EDS pattern of LM25 (c) SEM image of LM25-3% ZrO_2 composites (d) EDS pattern of LM25-3% ZrO_2 composites (e) SEM image of LM25-6% ZrO_2 composites (f) EDS pattern of LM25-6% ZrO_2 composites (g) SEM image of LM25-9% ZrO_2 composites (h) EDS pattern of LM25-9% ZrO_2 composites

2.3 Sliding wear test

The wear test was conducted by using a computerized wear test pin-on-disc machine (DUCOM, TR-20LE-PHM-400) as per ASTM G99 standard [12]. The EN31 steel was used as the counter disc material. Before testing, acetone was applied to clean the surface of the pin and the disc. The initial roughness of all cast samples was tested, the data of which is given in Table 4. Then, all six samples were subjected to the wear test for a load range of 10 N, 20 N and 30 N at a constant speed of 200 rpm, sliding velocity of 2.5 m/s and continuous sliding distance of 1000 m, 1200 m and 1400 m, respectively. While testing, the circular disc was rotated, and the pin specimen was kept stationary and perpendicular to the disc. Initially, the samples were weighed by using a simple pan electronics weighing machine with the precision of 0. 0001 g. The contour face disc was cleaned with an organic solvent to remove the traces obtained during each test. Similarly, the pin was also weighed before and after the testing to identify the amount of wear loss in each test. The obtained weight loss resulted from each test was converted into the wear loss based on the corresponding density of prepared composites by using equation (2). First, the densities of all cast samples are calculated by using equation (1).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \tag{1}$$

$$\text{Wear loss} = \frac{\text{Before weight} - \text{After weight}}{\text{Sliding distance } (2\pi rnt) \times \text{Density} g/cm^3} \quad 2)$$

(r-disc radius, n-sliding velocity, t-time)

The coefficient of friction is obtained from the experiments using a data acquisition system for the steady-state period of the last considered 100s. From the calculated wear volume, the specific wear rate and the coefficient of friction (COF) were calculated by using the following equation from literature [12].

$$\text{Coefficient of Friction} = \frac{\text{Frictional Force}}{\text{Normal Load}} \tag{3}$$

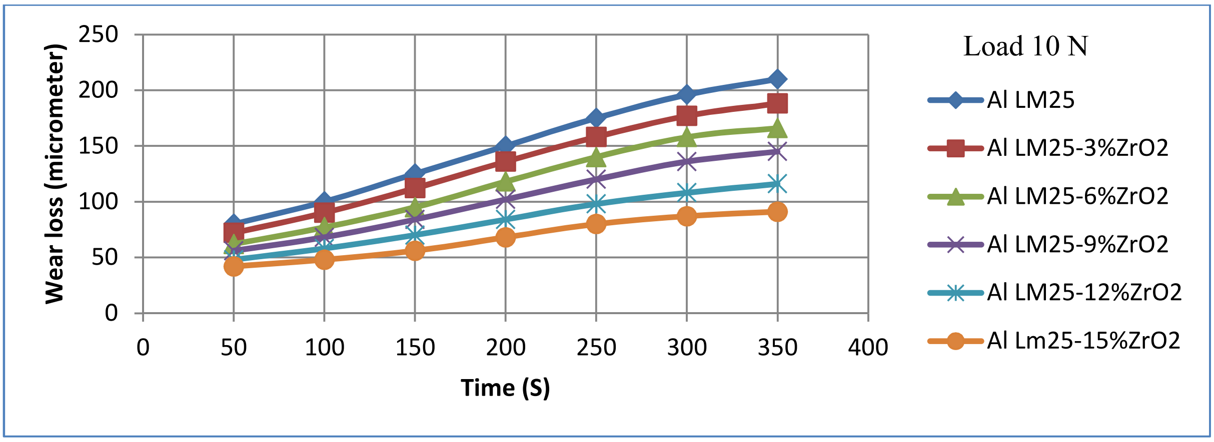
2.4 Surface Roughness Test

A cylindrical rod of 8 mm in radius and 4 mm in length was prepared for the wear test. Then, the wear tested samples were subjected to the surface roughness test by using a Mitutoyo, SJ210 tester. The reason for using the surface roughness test is to find the influence of ZrO_2 on the surface roughness performance of the component. Irregular surface may form nucleation sites for cracks or corrosion. It is also noted that rough surfaces usually wear more quickly and have a higher coefficient of friction than smooth surfaces. On the other hand, roughness may promote adhesion [1].

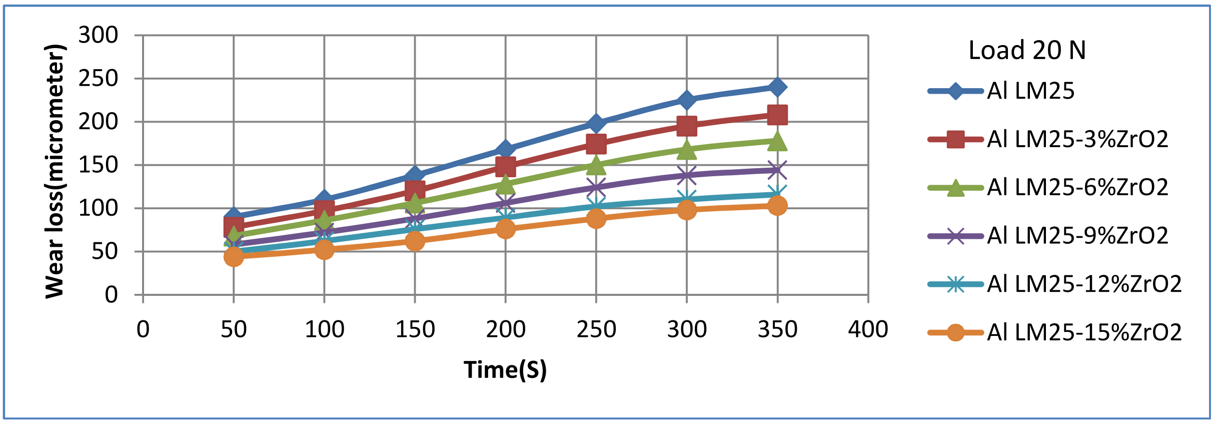
3. Results and discussion

3.1 Effect of wear on various composites

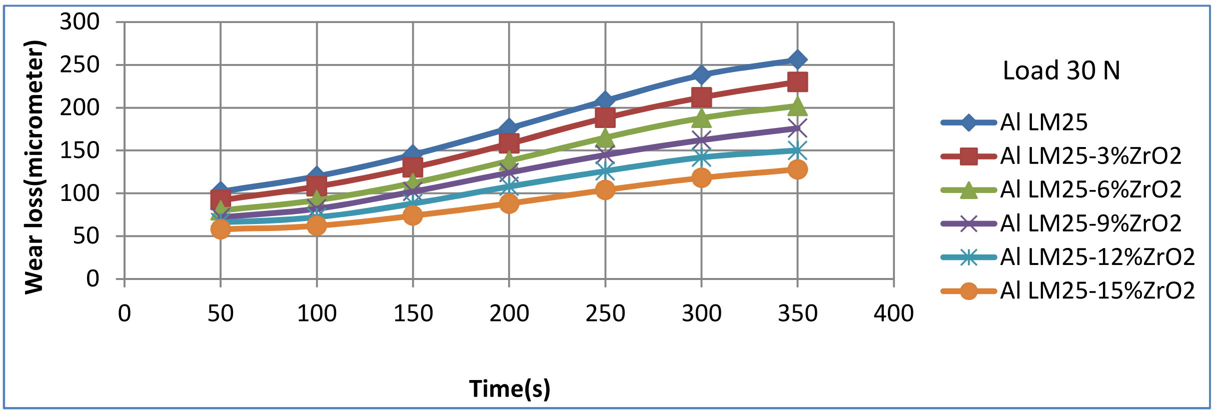
The wear results were observed for various loads of 10, 20 and 30 N for six cast samples of LM25 with 0, 3, 6, 9, 12 and 15 % of ZrO_2 reinforced composites as given in Fig. 3 (a-c). For obtaining each point in the curve five tests were performed and an average of all the five values is applied to obtain the points in the curve. The wear loss of pure LM25 is compared with various percentages of ZrO_2 reinforced composites for all the above three load levels. From Fig. 3 (a), 3 (b) and 3 (c), it is clear that lower wear was obtained in the composites which were reinforced with a higher weight percentage of ZrO_2, and this holds true for all the three load levels. Hence, it is clearly observed that the percentage of an increase in ZrO_2 reduces the wear loss. Similarly, while comparing Fig. 3 (a) with 3(b) and 3 (c), it is found that when the load increases, the wear loss also increases in all six samples. It is also noted that the wear loss decreases gradually with an increase in the percentage of the ZrO_2 reinforcement, when compared to pure LM25. In the wear samples, an increase in ZrO_2 decreases the wear in a non-linear manner [13-14].



3 (a)



3 (b)



3 (c)

Fig. 3 (a-c) Wear loss of various composites under different load (a) 10 N, (b) 20 N and (c) 30 N

3.2 Effect of weight loss on load

The effects of weight loss when the load is varied for 250 sec are shown in a graph (Fig. 4). it is obvious from the graph, that the wear loss increases with an increase in load from 10 to 20, and 30 N, respectively. Similarly, while comparing the weight loss from 10 to 30 N, the percentage of weight loss for 30 N is higher. When comparing pure LM25 with the 15% ZrO_2 reinforcement, a significant difference in the wear loss is observed. In the same way, while comparing the percentage of the weight loss in LM25 and various percentages of the ZrO_2 reinforcement it is observed that the weight loss decreases with an increase in the percentage of the ZrO_2 reinforcement [12].

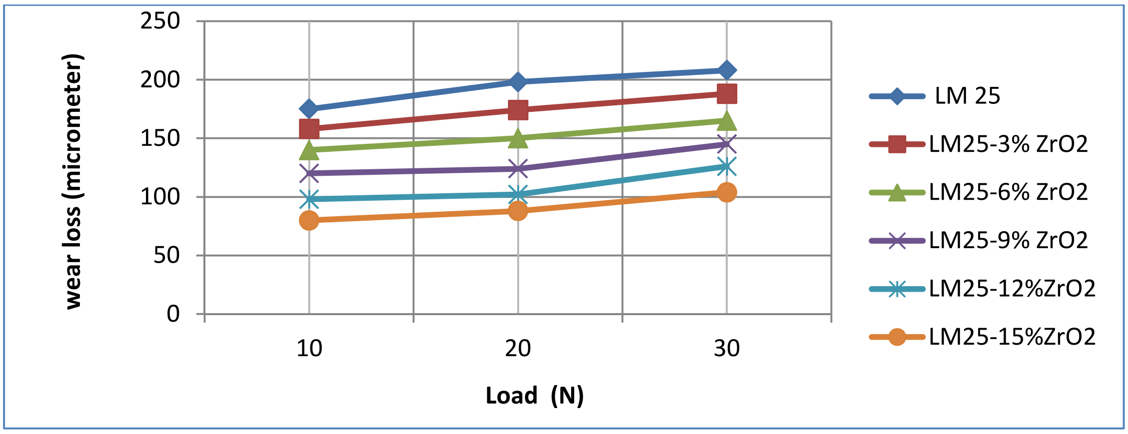


Fig. 4 Wear Loss for Various Composite Materials

A graph was plotted between the various weight percentages of ZrO_2 in LM25/ZrO_2 composites versus the calculated coefficient of friction for the load ranges of 10, 20 and 30 N at a constant speeds of 200 rpm with a sliding velocity 2.5 m/s, and a sliding distance of 1400 m, as shown in Fig. 5. So, Fig. 5 shows, that the coefficient of friction is high at the beginning and decreases gradually due to the reinforcement of aluminium alloy with ZrO_2. Similarly, it is also observed that, when the load increases from 10 to 30 N, the coefficient of friction also increases. While comparing the coefficient of friction of pure LM25 with various levels of ZrO_2 reinforcement, it is observed that the coefficient of friction decreases with an increase in the percentage of the ZrO_2 reinforcement. Because the increase in the percentage of ZrO_2 leads to the lowering of the coefficient of friction in the composites, it reduces the pin-to-disc contact. This effect is due to the good bonding and the nature of the reinforcement of ZrO_2. These results are well in agreement with earlier studies [1, 6 & 12].

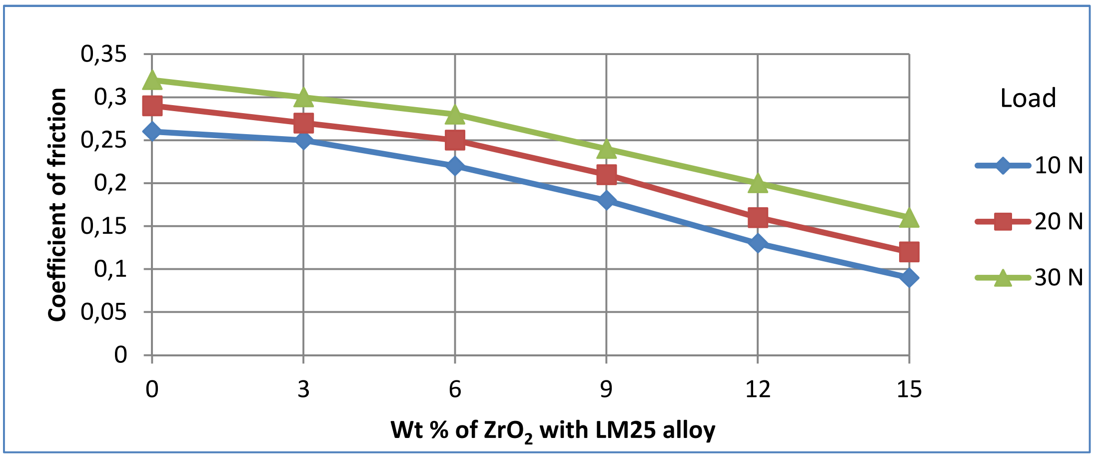


Fig. 5 Co-efficient of friction of Al LM 25–Weight % of ZrO_2

A graph was plotted between the various weight percentages of ZrO_2 in LM25/ZrO_2 composites versus wear loss for the sliding distance of 1000, 1200 and 1400 m as shown in Fig. 6. It is observed that, the wear loss in samples of different compositions increases with an increase in the sliding distance. An increase in the percentage of ZrO_2 will decrease the wear loss at all sliding distances.

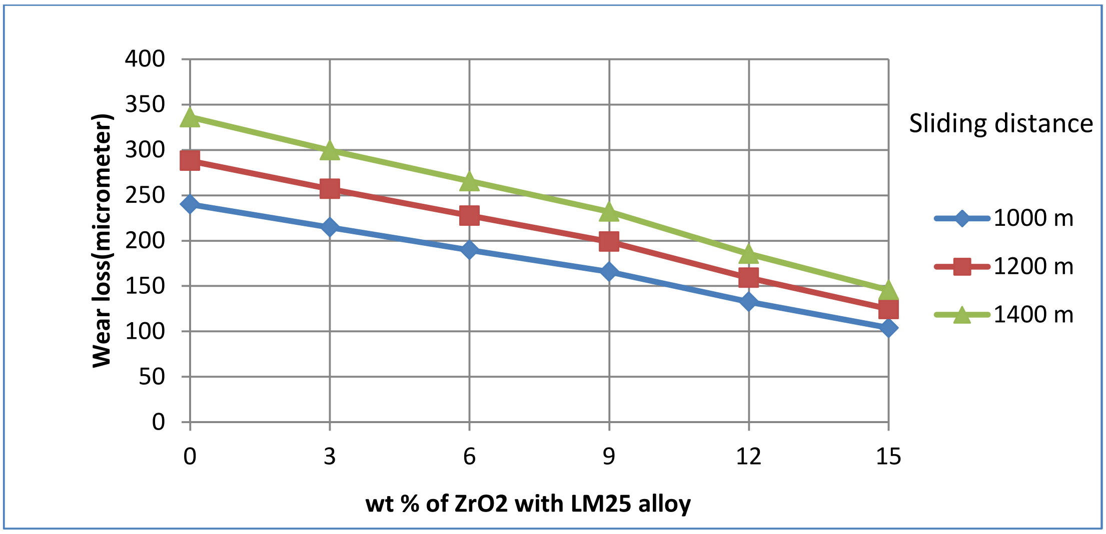


Fig. 6 Wear loss of LM25 - wt % ZrO_2 for various sliding distances

3.3 Surface roughness of pin

The measured worn surface roughness of various composites for the 30 N load is given in Table 3. From the Table 3, it is obvious that the surface roughness value is higher for the pure LM25 alloy, and the roughness value decreases with an increase in the percentage of the ZrO_2 reinforcement material. A graph was plotted between the various weight percentages of ZrO_2 in LM25/ ZrO_2 composites versus surface roughness as shown in Fig. 7. It is obvious that the curve varies linearly up to 6% ZrO_2. Then, the curve decreases slowly with a further increase in the percentage of ZrO_2.

Table 3 Worn surface roughness of various composites (30 N load).

% of composition	Initial surface roughness (Ra) (before being subjected to load)	Surface roughness (Ra) (after being subjected to load)
Al LM25	3.623	4.031
Al LM25-3% ZrO_2	1.923	2.877
Al LM25-6% ZrO_2	1.023	1.954
Al LM25-9% ZrO_2	0.998	1.654
Al LM25-12% ZrO_2	0.888	1.504
Al LM25-15% ZrO_2	0.800	1.367

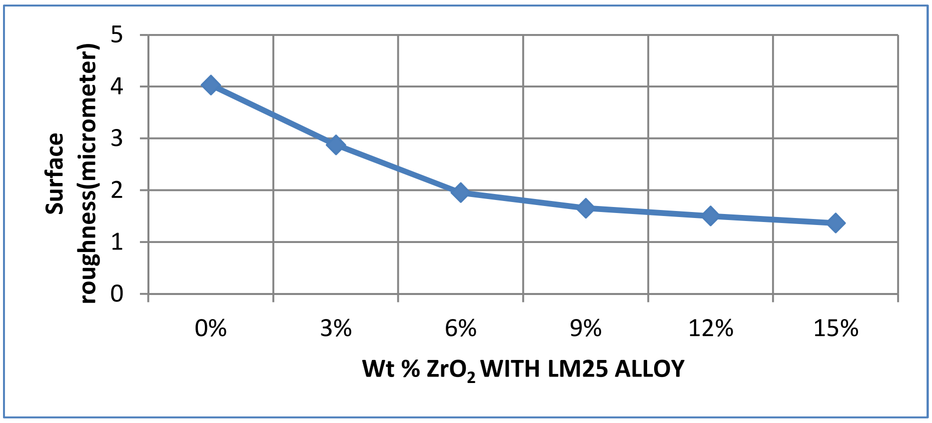


Fig. 7 Worn surface roughness for various composites

4. Conclusions

Wear characteristics of the stir cast LM25/ZrO_2 metal matrix composites were investigated experimentally. From the experimental results, the following conclusions are made:

1. EDS studies were carried out to confirm the presence of aluminium, zirconium, iron, copper, magnesium, zinc, silicon, etc in the developed LM25/ ZrO_2 metal matrix composites. The oxide formation, which acts as a protective layer for the surface at various loads, is also identified based on the EDS results.
2. The percentage of the oxide formation increases with an increase in the percentage of the ZrO_2 reinforcement, which causes a decrease in wear rate. The same result was confirmed in the wear test results.
3. The wear test results showed that the wear loss decreases with an increase in the percentage of ZrO_2.
4. The wear loss increases with an increase in load from 10 to 30 N for all samples.
5. The coefficient of friction of the LM25/ZrO_2 metal matrix composites decreases with an increase in ZrO_2, hence the maximum coefficient of friction is obtained under the 30 N load when compared to the load of 10 and 20 N.
6. The wear test results show that, when the load and the sliding distance increase, wear loss will also increase. Therefore, the maximum wear loss is obtained for the 30 N load and the 1400 m sliding distance, which was also confirmed by the wear test results.
7. The surface roughness value decreases with an increase in the percentage of the ZrO_2 reinforcement.

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