

Dry Sliding Wear Behaviour of Garnet Particles Reinforced Zinc-Aluminium Alloy Metal Matrix Composites

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The present investigation aims to evaluate the wear behaviour of zinc-aluminium (ZA-27) alloy composites reinforced with garnet particles. The liquid metallurgy technique was used to fabricate the composites. The reinforcement content was varied from 0 % to 20 % by weight in steps of 5 %. A pin-on disc wear testing machine was used to evaluate the wear loss of composites. The results reveal that the wear loss of composites was less than that of the zinc-aluminium alloy, but increased with increase of reinforcement in load and sliding speed. It was found that the wear resistant will increase with increase in garnet content. The observations have been explained using scanning electron microscopy (SEM) analysis of the worn surfaces.

Keywords: metal matrix composites, wear, wear parameters, abrasion, delamination.

1. INTRODUCTION

The increase in demand for lightweight, stiff and strong materials has led to the development of metal matrix composites (MMCs) reinforced with ceramic dispersoids. The MMCs possess excellent mechanical and tribological properties and are considered as potential engineering materials for various tribological applications. Several researchers have worked on sliding wear mechanism of MMCs reinforced with ceramic particulates like SiCp, Al₂O₃ and garnet particles etc, and have observed improvement in wear and abrasion resistance [1–3]. Wear is a common occurrence on most plant and machinery and is often a slow and progressive process, which may be accepted, as normal. However, if the rate of wear on particular machine component is high, so that it requires frequent repair and replacement, then it may constitute a wear problem. Therefore, deciding whether a wear problem exists and requires attention calls for a degree of judgment of the circumstance. Several studies [4, 5] suggest that MMCs under lubricated sliding against a smooth counterface exhibit superior wear resistance over unreinforced alloys. However, under unlubricated conditions, complex and often opposite results have been reported [6]. Zinc-aluminium (ZA) based cast alloys by virtue of their excellent castability, wear resistance and good mechanical properties have found significant industrial usage during the past couple of years. These alloys exhibit good wear resistance under higher loads, poor lubrication conditions and have been used as replacement for bronze and brass in the bearing industry [7, 8]. The attractive properties of the ZA alloy have inspired researchers to reinforce them with ceramic dispersoids in order to obtain much more enhanced

mechanical and tribological properties. The reinforcement of the alloy with particulate graphite [9] and SiCp [10] has shown improvement in the mechanical and wear properties. Considering the encouraging results reported and in view of the facts that wear behavior of a material is a very complicated phenomenon involving various mechanisms and factors, the present study was conducted to evaluate the effect of the garnet particles on wear behaviour of ZA-27 alloy and develop a fundamental understanding of the wear mechanisms and wear induced micro structural changes of a garnet particle reinforced ZA-27 alloy composite during dry sliding against steel counterface.

2. EXPERIMENTAL PROCEDURE

2.1. Preparation of the composites

ZA-27 alloy having the chemical composition as per ASTM B669-82 standard and given in Table 1 was used as the base matrix.

Table 1. Chemical composition of zinc-aluminium alloy

Composition	%
Al	25 – 30
Cu	2.06
Fe	0.065
Mg	0.012
Si	0.02
Zn	Balance

Garnet particles given in Table 2 of size 50 µm – 70 µm were used as reinforcement of refractory index 1.83. The percentage of garnet particles was varied from 0 % – 20 % by weight in steps of 5 %. The liquid metallurgy technique was used to prepare the composite specimens.

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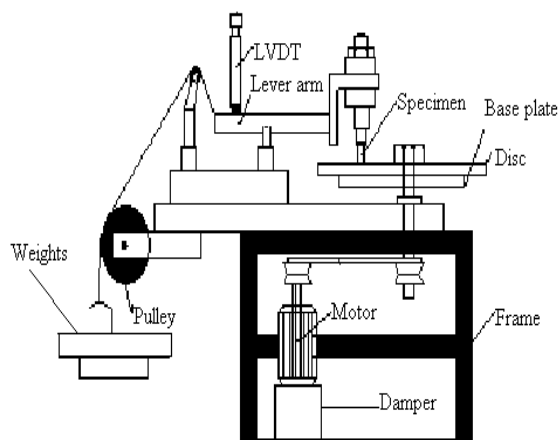
Table 2. Composition of garnet particles

Name	Almandine
Formula	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$
Specific gravity	4.3 kg/m ³
Refractory Index	1.83
Color	Reddish brown

However, Pillai[11], who have worked on aluminium-graphite composites, have reported the use of particles of size varying from 75 μm to 250 μm . According to them, the composites with particle size smaller than 75 μm led to undue segregation during casting, where as particles of larger than 250 μm had no favourable effect on mechanical properties. Singer [12] have worked on aluminium matrix composites using reinforcing particles like SiC and corundum of size ranging from 75 μm to 120 μm . In the present research, preheated garnet particles of size 50 μm to 70 μm were dispersed in molten ZA alloy above its liquidus temperature of 560 °C. The stirring was continued at a speed of 400 rpm for about 5 minutes and then the molten mixture was poured into cast iron permanent mould [13].

2.2. Experimental procedure

The wear specimens were tested under dry (unlubricated) conditions in accordance with ASTM-G99 standards using a pin-on-disc sliding wear testing machine which is similar to the one used by Poonawala [14] shown in Fig. 1.

**Fig. 1.** Pin-on-disc wear testing machine

The apparatus consists of an EN24 steel disc of hardness 57HRC and diameter 250 mm, which is the counterface on which the test specimen slides. The chemical composition of the steel disc in weight % is 0.45 C, 0.35 Si, 0.70 Mn, 1.40 Cr, 0.35 Mo, 1.80 Ni, 0.05 S and 0.05 P. The arrangement were made to hold a specimen and also for application of the load on the specimen. The test sample was clamped in the specimen holder and held against the rotating steel disc. In present investigation, loads of 50 N – 200 N in steps of 50 N and speed varies from 4.31 m/s to 10.08 m/s. the sliding distance used was in the range from 1.19 km to 2.8 km.

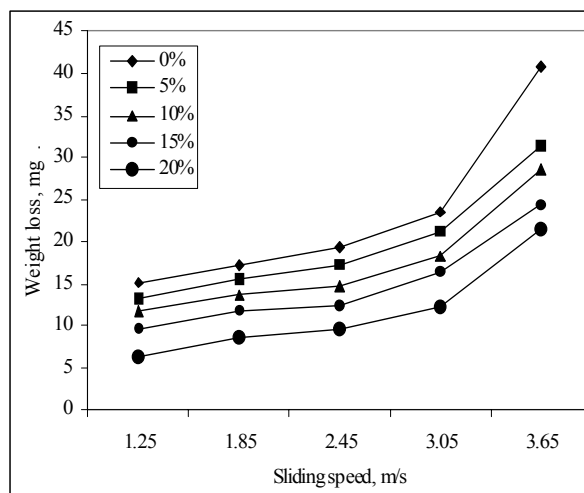
A standard test procedure was employed. The pins of standard material under investigation were 6 mm in diameter and 15 mm in height. A fresh disc was used each

time and before each test, the disc was cleaned with acetone to remove any possible traces of oil, grease and other surface contaminants. The specimen which was cleaned with ethanol was weighed before and after the tests using an electronic balance accurate to 0.0001 g. The dry sliding wear loss was computed using the weight loss of the pin before and after the experiments. The data for the wear tests was taken from the average of three measurements. The surfaces of the worn specimens were cleaned thoroughly to remove the loose wear debris and then observed using a scanning electron microscope. Since the hardness of the counterface (steel disc) was far higher than that of the specimens and its wear volume was very small, the wear properties of the steel disc are not studied in the present paper.

3. RESULTS AND DISCUSSIONS

3.1. Effect of sliding speed and applied load on the weight loss

The incorporation of garnet particles to zinc-aluminium alloy improves the sliding wear resistance in comparison with the unreinforced alloy. The effects of both applied load and speed were investigated as a function of percentage of garnet in zinc-aluminium alloy. Figure 2 represents the weight loss of the composites as well as the base alloy specimens as a function of sliding speed at different percentage of reinforcement from 0 % to 20 % by weight in steps of 5. The effect of applied load on weight loss at different percentages of reinforcement is presented in Fig. 3 which indicates that the weight loss of the matrix alloy as well as the composite specimen increases with increase in applied load as percentage of reinforcement increases from 0 % to 20 % by weight.

**Fig. 2.** Effect of sliding speed on weight loss of zinc-aluminium alloy composites

It is clearly observed from Fig. 3 that there exists a transition load at which there is a sudden increase in the weight loss of both unreinforced and as well as reinforced materials.

When load applied is low, the wear loss is quite small, which increases with increase in applied load. It can be considered that it is quite natural for the weight loss to increase with load. The load further attains a transition

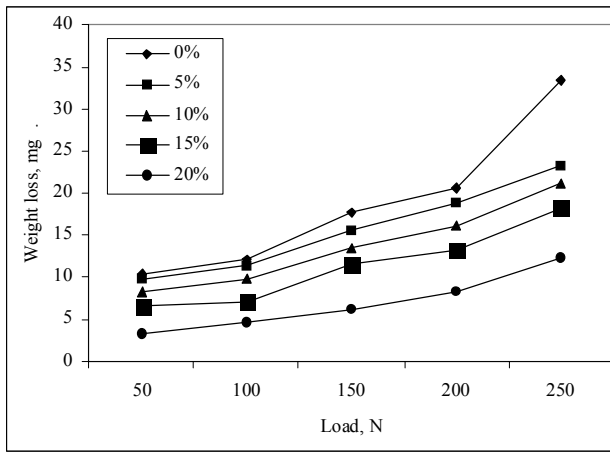


Fig. 3. Effect of applied load on weight loss of zinc- aluminium alloy composites

value, at which wear mechanism change from mild to severe wear. However, the transition loads for the composites were much higher than that observed for the unreinforced alloy, and also the transition load increased with increase in garnet content. The experimental data suggest that there is a certain applied load i.e. a transition phenomena at which there is a sudden increase in the wear rate of both reinforced as well as unreinforced materials. However, the transition loads for the composites were very much higher than that observed for the unreinforced alloy, and also the transition load increases with the increase in garnet particle content. Sarkar and Clarke [15] who have worked on aluminium-silicon alloys have reported transition wear rate with load. The unreinforced material shows a transition at 200 N but no transition in composites. It has been reported that ceramic reinforcement delays transition from mild to severe wear by increasing either the load [16] or speed [17] at which transition occur. This observation indicates that the addition of garnet reinforcement delays the transition from mild to severe wear.

3.2. Effect of garnet particle reinforcement

The weight loss of both unreinforced alloy as well as the composites specimen increases with the increase in the sliding speed. It is observed that the composite specimen exhibited significantly lower weight loss than the base alloy. The weight loss of each composite specimen reduces with the increase in garnet content at a constant sliding speed of 2.45 m/s and at different loads of 25 N, 30 N, 35 N, 40 N and 45 N as shown in Fig. 4. The experimental data suggest that there is a certain applied load i.e. a transition phenomena at which there is a sudden decrease in the weight loss of both reinforced as well as unreinforced materials. However, the transition loads for the composites were very much higher than that observed for the unreinforced alloy, and also the transition load increases with the increase in garnet particle content. However, the beneficial effect of the reinforcement on the wear resistance of the composites is observed to be the best at low loads, which reduces with increase in load applied. This observation is on par with one observed by Jacobson [18], who worked on silicon carbide reinforced aluminium alloy composites have reported that the beneficial effect of

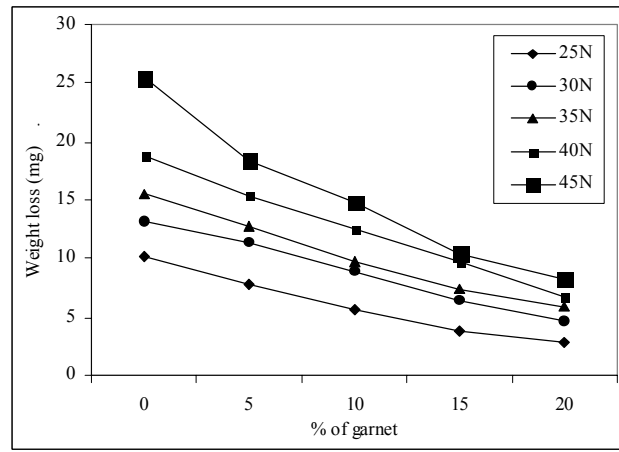


Fig. 4. Effect of garnet particle on weight loss of zinc-aluminium alloy and its composites at constant speed of 2.45 m/s

particle reinforcement was gradually reduced with increasing load. The effect of each reinforcement particle is able to carry a larger portion of load it is exposed, from an individual abrasive particle. Consequently, the effect of the reinforcement on the composite wear resistance is better for low loads.

3.3. Coefficient of friction

All the tests were conducted at atmospheric conditions. Figure 5 shows the variation of friction coefficient (μ) with sliding distance for both matrix alloy and composites at applied loads of 10 N, 20 N, 30 N, 40 N and 50 N with sliding speed of 2.45 m/s. The amplitude of the friction fluctuations was seen at all the stages. Due to sliding surface irregularities, the speed and applied load causes a typical stick-slip oscillation as observed in the frictional profiles. In all these cases the average coefficient of friction of the composite decreases with increasing reinforcement content.

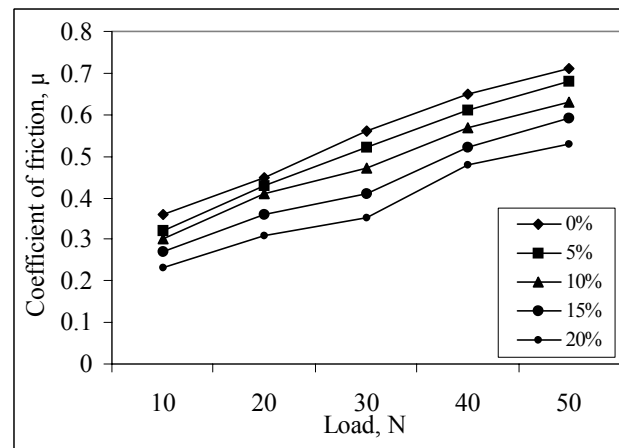


Fig. 5. Effect of coefficient of friction with load on zinc-aluminium alloy composites

It was observed that the coefficient of friction of matrix alloy and garnet reinforced composite material increases with increasing the load. It is observed from Fig. 5 that the stick-slip type frictional behaviour of both unreinforced alloy and reinforced metal matrix composites decreases and is a function of sliding distance. The sliding

surface is covered with alumina layer. This layer formed is very brittle and acts as an insulator [19].

3.4. Examination of the worn surfaces

For ease and convenience, the micrographs of only 5 % garnet composites at all the loads tested at 2.45 m/s have been presented. It can be seen from the micrographs that a lot of parallel, continuous and deep ploughing grooves exist on the wear surface of the composite and there is an abrasion phenomenon observed at low loads [20]. The worn surfaces in some places reveal patches from where the material was removed from the surface of the material during the course of wear as shown in Fig. 6. The parallel grooves suggest abrasive wear as characterized by the penetration of the hard garnet particle into a softer surface, which is an important contributor to the wear behavior of zinc-aluminium alloy-garnet particle composites. It is possible that the scored grooves might have been formed due to the action of the wear-hardened deposits on the disc track. But at high load of 50 N the locally damaged and even fractured spots are observed in Fig. 7. Similar observations were found when the garnet percentage is 10 %, 15 % and 20 %.

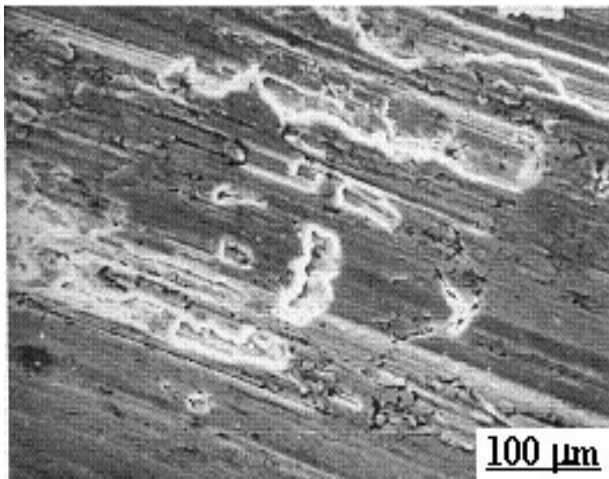


Fig. 6. Micrograph of worn surface of zinc-aluminium alloy composite at 2.45 m/s sliding speed and 30 N load (with 5 % garnet)

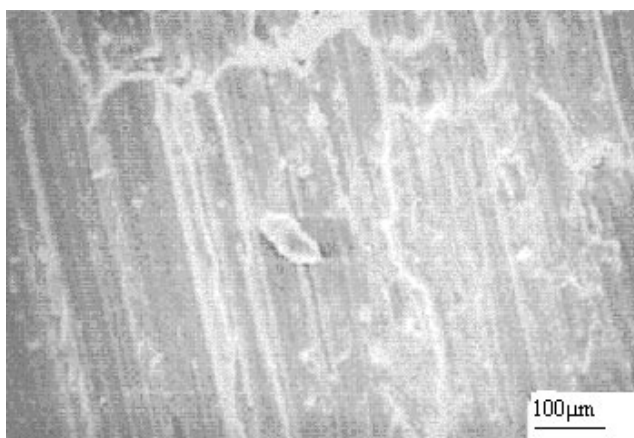


Fig. 7. Micrograph of worn surface of zinc-aluminium alloy composite at 2.45 m/s sliding speed and 50 N load (with 5 % garnet)

Under high loads, the protective layer of the reinforcing particles can no longer remain stable under the ploughing action, and the wear strips formed are more distinct. Material removal during the process is in the form of small pieces resulting in the formation of flake type debris. The shear strain induced in the process is transmitted to the matrix alloy and the wear mechanism proceeds by subsurface crack propagation causing the elimination of wear. The surface material is removed and cracks get nearer to the surface and shear strain is increased, thus causing the removal of the surface layers by delamination [21, 22]. These observations suggest that the main wear mechanism at high loads is delamination wear causing excessive fracture of the reinforcement and the matrix, resulting in the wear resistance of the composite.

4. CONCLUSIONS

Particulate reinforced ZA-27 alloy-garnet MMCs were fabricated by the "Liquid Metallurgy Technique". The mechanical and wear properties of cast ZA-27 alloy-garnet particulate composites are significantly changed by varying the amount of garnet therein. The final conclusions obtained were as follows:

1. Garnet particulate obtained from naturally available rock represent an attractive dispersoids to provide low cost MMCs.
2. The garnet particle reinforced exhibited reduced dry sliding wear loss than the unreinforced alloy. The wear loss decreased with increasing in garnet content.
3. The dry sliding wear loss of composites as well as the matrix alloy increased with the increase in speed of the disc and load applied.
4. The friction coefficient of zinc-aluminium alloy metal matrix composite decreases with increase in percentage of reinforcement from 0 % to 20 % by weight.

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