Effect of garnet and carbon on dry sliding wear behavior of chill cast aluminum hybrid composites

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***Abstract*—The aim of this investigation was to develop and characterize aluminum alloy LM13 reinforced with garnet and carbon for hybrid composites by chill casting technique. Conventional stir casting technique was used to fabricate the composites. Various chill materials like Copper, Steel, Iron and Silicon carbide was used to improve the directional solidification. The garnet being added ranges from 3 to 12 wt-percent in steps of 3wt-percent and constant 3wt-percent of carbon. The experiment evaluates the microstructure and wear properties of the metal matrix composites by dry sliding wear test using a pin-on-disc wear tester by varying the applied load from 10-50N. The result reveals that, the reinforcement particles are randomly and fine dispersed in matrix alloy as seen in microstructure. SEM was used for examine worn surfaces. The addition of garnet and carbon reinforcement decreases the wear rate of hybrid composites. Further, directional chilling improves the wear resistance of the composites.**

***Index Terms*—Chill cast, garnet, hybrid, sliding wear, stir casting.**

I. INTRODUCTION

The desire to increase the longevity of systems led to the recognition and development of hybrid metal matrix composite materials (HMMCs). High performance materials are of great interest for modern material applications due to the possibility to develop innovative materials with specific properties. Composites are very attractive materials, since their mechanical properties are superior to those of the individual components [1]. Hybrid metal matrix composites has been developed to overcome specific inherent deficiencies and to get more suitable qualities from the conventional monolithic and metal matrix composites (MMCs). Major deficiencies of common MMCs of low wear resistance are overcome in such HMMCs [2, 3]. Aluminum based metal matrix composites (AMCs) are of lightweight high performance material systems [4]. Among the several types of aluminum alloys being used, LM13 series are extensively used in automobile applications because of their superior corrosion resistance, excellent thermal conductivity and formability characteristics [5]. Hard reinforcing material ceramic particles like SiC, Al_2O_3 and B_4C etc. are to be reinforced with Aluminum matrix composites posses a unique combination of high specific strength, high elastic modulus, good wear resistance and good thermal stability than the corresponding non-reinforced matrix alloy system [6,7,8].

Soundness of the composite developed is highly dependent on the chilling rate as well as the dispersoid content. An increase in the rate of chilling and increase in the dispersoid content of the material both result in an increase in the UTS (ultimate tensile strength) of the material [9]. The casting of extrusion billets and rolling ingots of aluminum alloys has principally been carried out by the direct-chill (DC) casting process. The temperature gradient developed during solidification and VHC (volumetric heat capacity) of the chill used are the important parameters controlling the soundness of the composite. Maximum interface temperature attained by the chill decreases with the increase in their VHC (volumetric heat capacity) and the total heat absorbed by the chill increases with increase in VHC. Thermal properties of the end chills are used to determine the magnitude of the temperature gradients developed along the length of the casting solidifying under the influence of chills [10, 11].

Devaraju aruri [12] investigated effect of SiC and Al_2O_3 tribological properties of AA6061 composites fabricated by stir cast processing. It was observed that high wear resistance exhibited due to presence of SiC and Gr acted as load bearing elements and solid lubricant respectively. Ajit kumar S [13] studied the effects of different ceramics size and volume fraction on wear behavior of aluminum matrix composites. A number of composites were manufactured by reinforcing SiC, B_4C and Al_2O_3. The composite having 30% volume fraction of 20 µm SiC gives the best wear performance. Effect of reinforcement on wear behavior of aluminum hybrid composites was investigated by N Radhika [14] revealed that the aluminum alloy reinforced with 9 wt-% alumina and 3 wt-% graphite has highest wear resistance compared to unreinforced alloy. The experimental results revealed that the addition of reinforcement improves the wear rates. The composite developed is shown to provide significant weight savings and improved mechanical properties. Joel Hemanth [10] investigated the effect of reinforcement and chilling on strength, hardness and wear behavior of aluminum based metal matrix hybrid cast composites reinforced with kaolinite (Al_2SiO_5) and carbon (C) particulates. It is discovered that chilled HMMCs with Al_2SiO_5-9%/C-3% dispersoid content proved to be the best in enhancing the mechanical and wear properties. Although there are several studies reported in the literatures on wear behavior of aluminum metal matrix composites, no published work has been seen on the effect of garnet and carbon reinforcement on dry sliding wear of LM13 series HMMCs. Hence, the present research work has been undertaken, with an objective to explore the use of garnet with carbon as reinforcing materials in aluminum matrix LM13 alloy.

II. Experimental Details

Materials

Aluminum alloy, LM13, was selected as a matrix material because of its excellent casting properties with reasonable strength. Its chemical composition is presented in Table 1. The garnet particles with size of 25 µm and carbon with average size of 45 µm were used as the reinforcement materials for fabrication of composites. Garnets are naturally occurring substances and are highly cost effective. It is basically a silicate, abundantly available and having hardness of 6.5-7.5 mho. It is chemically inert at high temperature. Constant 3wt% carbon improves the self-lubricating behavior of chill cast composites. Chill materials of various materials are used to control the rate of solidification to promote directional solidification. The thermo-physical properties of metallic and non-metallic chill materials are listed in Table 2.

Stir casting procedure

The composites were fabricated by stir casting method to ensure uniform distribution of the reinforcements. Stir casting is one of the low cost process out of available manufacturing techniques for AMCs, with advantage of low cost; it also offers a wide range of material and processing conditions and can manufacture composites with up to 30% volume fraction of reinforcement with better bonding of metal matrix with reinforcement particles because of stirring action [15].

Commercially available Aluminum alloy LM13 material is used and melted in a resistance furnace at around 750^{0}C; Garnet and carbon particulates were preheated to 700^{0}C. A stir casting process is used to fabricate hybrid composites reinforced with various weight fractions of garnet and carbon particulates. Fig.1 shows a sectional view of the stir casting arrangement. Combination of dispersoid varies from 3 to 12 wt.% in steps of 3wt.% of garnet and 3wt.% Carbon particulates. The size of garnet and carbon particulates dispersed is between 30 and 80 µm. Meanwhile, the molten HMMCs was well agitated by means of a mechanical mixing which was carried out for about 15 min at an average mixing speed of 760 rpm. The melt was next poured into a sand mold with a chill attached to it at one end. Different molds are prepared with different chill materials like copper, steel, iron and silicon carbide.

Specimen preparation

The same type of mold was used to sand-cast a specimen in which case no chill was used. The chills were of 150 mm long, 35 mm high and 25 mm thick in dimension. The moulds produced plate-shaped ingots of dimensions 150*x*120*x*25mm. Fig. 2 shows the arrangement of mold used for casting specimens. Specimens for all the tests were selected only at the chill end of the casting and all the specimens were heat-treated by aging before testing. Properties such as hardness, tensile strength of the developed hybrid composites were tested as per ASTM standards. The HMMC specimens were prepared according to ASTM standards (16,17). The specimens were taken from chill end by using cast aluminum alloy, LM13, as matrix and garnet and carbon particles as reinforcing materials (Fig. 3).

Wear test

Dry sliding wear tests were performed in accordance with the ASTM G99-05 standards for pin-on-disc equipment (Fig. 4). Wear disc of hardened steel material was used in pin-on-disc. Prior to testing, the pins and disc surface were cleaned with acetone. All of the tests were performed on hybrid composite pins of various compositions with applied load ranges from of 10 to 50 N. A varying sliding distance of 1200 and 1600 m was employed, with sliding speeds of 1 m/s and 2 m/s. After each test, the specimen and counter face disc were cleaned with organic solvents to remove traces. The pin was weighed before and after testing to an accuracy of 0.1 mg to determine the amount of wear loss. The coefficient of friction was determined from the applied normal load and the obtained tangential load from the strain gauges. Each test was repeated three times, and the average results were taken.

Table 1 Chemical composition of matrix material (Al-alloy LM 13)

Elements	Zn	Mg	Si	Fe	Mn	Cu	Al
% by wt	0.5	1.4	11.8	1.0	0.5	1.2	Balance

Table 2 Thermo-physical properties of chills used in the test

Type of chill	Density (g/cc)	Specific heat (J/kg/K)	Thermal conductivity (W/mk)	VHC for 25mm chill (J/k)
Copper	8.96	0.448	1.022	597.0
Steel	7.85	0.421	0.109	491.5
Cast iron	7.61	0.401	0.160	453.9
Silicon carbide	2.36	1.095	0.039	384.3

III. Results and Discussion

The microstructure of cast composite (Fig. 5) reveals the formation of –aluminum dendritic network structure which is formed due to super-cooling of casting during solidification, with less impurities present. The microstructural examination revealed good distribution of garnet particles throughout the matrix. The microstructure of the chilled Al/garnet/carbon composites containing 9wt-% garnet cast using copper chill of thickness 25 mm is shown in Figs. 5(a and b).

Effect of load

Variation of wear loss of hybrid composite with respect to load is shown Fig 6. It is observed that the wear resistance of the Al LM13/garnet/carbon hybrid composite increases with the addition of garnet. From graph (Fig 6)), it was observed that both wear loss increases for all applied loads. From 10 N to 20 N, marginal increase of wear rate was observed, whereas drastic increase from 20 N to 30 N. This trend can be attributed to the plastic deformation of the material. At low loads (10 N and 20 N), temperature rise over the sliding surface had less effect on the plastic deformation. Increased load (30 N) on the specimen leads to increase in temperature over the sliding surface even at low sliding velocities. Due to this high temperature, plastic deformation of the surface occurred leading to the adhesion of pin surface onto the disc. This adhesion results in more material removal, thereby drastically increasing the wear rate.

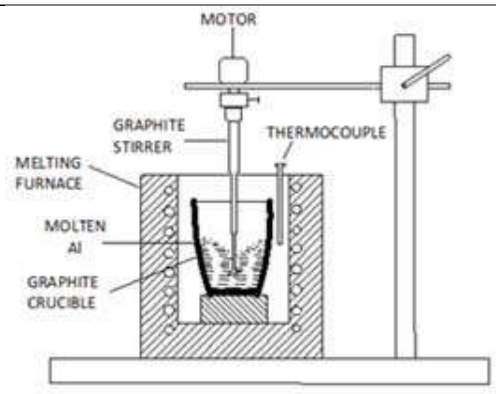

Figure 1 Stir casting setup

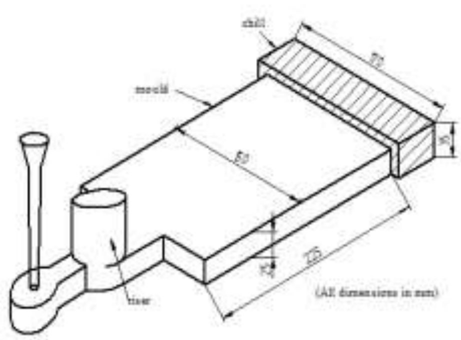

Figure 2 Sand mold

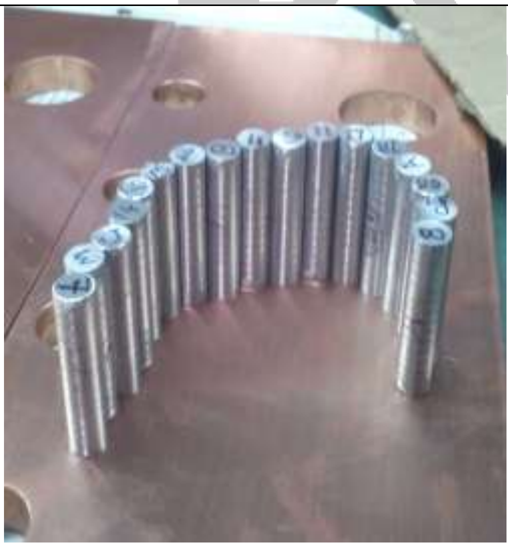

Figure 3 Specimen

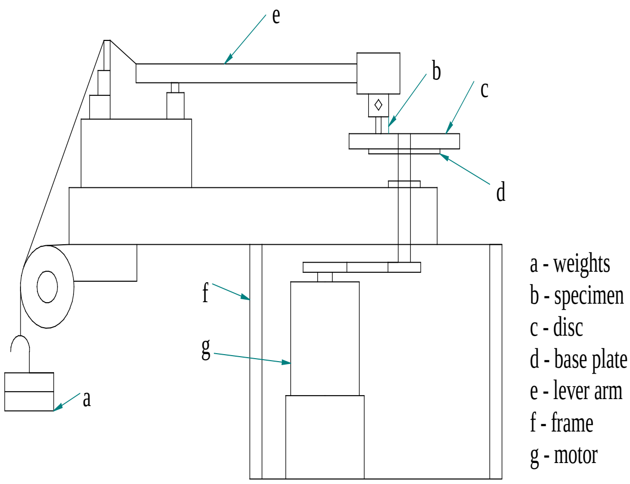

Figure 4 Pin-on-disc equipment

Effect of reinforcements

It was higher than that of base alloy characterized to the hard nature of garnet particles. The garnet hard ceramic particles act as the obstacles to the movement of dislocation. The garnet particles in the matrix alloy provide protection to the softer matrix. Thus, limiting the deformation and also resists the penetration and cutting of slides on the surface of the composites. This result is a good agreement with the result of S. Basavarajappa[18].

Use of carbon reinforcement in aluminum matrix composites has been reported to be beneficial in reducing wear due to its solid lubricant property, which prevents metal to metal contact of the sliding surfaces, but it results in reduction of mechanical strength. The wear has been significantly influenced by the formation of a thin lubricating film of carbon particulates and removal of worn material was noticed consequent to the failure of this film [19].

Effect of distance

As distance increases, both wear rate and coefficient of friction were observed to be decreasing. This decreasing trend interprets the inverse relation as indicated in the graph (Fig 4(a) & 5(a)). Wear rate decreased to a large extent from 1000 m to 1500 m when compared with the wear rate between 1500 m to 2000 m. This behavior can be supported by the presence of hard reinforcements that act as sharp asperities on the surface of the composite specimen. Initially at low distance, reinforcement particles which protrude out of the composite surface decrease the contact area between the specimen and the disc, which in turn increases the wear rate and friction. As the distance increases, these asperities get compacted between the sliding surfaces and becomes blunt, thereby considerably increasing the contact area between the two sliding surfaces [18]. This could be the reason for improvised wear behavior under high distance.

Effect of cooling rate/ chilling

The cooling rate is related to the heat extraction from the sample during solidification [3]. At low cooling rate, the rate of heat extraction from the sample is slow, and the slope of the cooling curve is small. But at high cooling rate condition, the rate of heat extraction is fast, and the slope of the cooling curve is steep. When the melt of the AlHMMCs solidifies under chilling conditions, the temperature of the chill and the hot melt come in contact and hence, the melt experiences severe super-cooling. Many publications and detailed researchers studied for several decades the effect of solidification on aluminum alloys. It was found that parameters like secondary dendrite arm spacing, grain size and porosity increase as the solidification rate decreases. The microstructure of the material is refined when solidification proceeds at a faster rate. The critical nucleus size of the solidified melt is reduced and a greater number of nuclei are generated, causing a finer microstructure. Additionally, because of the rapid cooling of the melt and stirring the dispersoid results in a more uniform distribution of garnet particles in the matrix and lead to improved soundness of the chill cast composite [20].

Wear mechanism

The SEM micrographs of the worn surface of 3wt-% composite specimen's slide at load of 50 N are shown in Fig. 8. The worn surface of the Al LM13 matrix composite (Fig. 8a and b) clearly exhibits the presence of deep permanent grooves, micro cutting, grain pullouts and fracture of the oxide debris, which may have caused the increase of wear loss. This morphology shows that the matrix has undergone significant severe plastic deformation. However, the worn surfaces of the other composites exhibit finer grooves and slight plastic deformation at the edges of the grooves. As the garnet weight fraction increases the surface morphologies also have been changed. The surfaces also appear to be smooth because of the graphite reinforcement content.

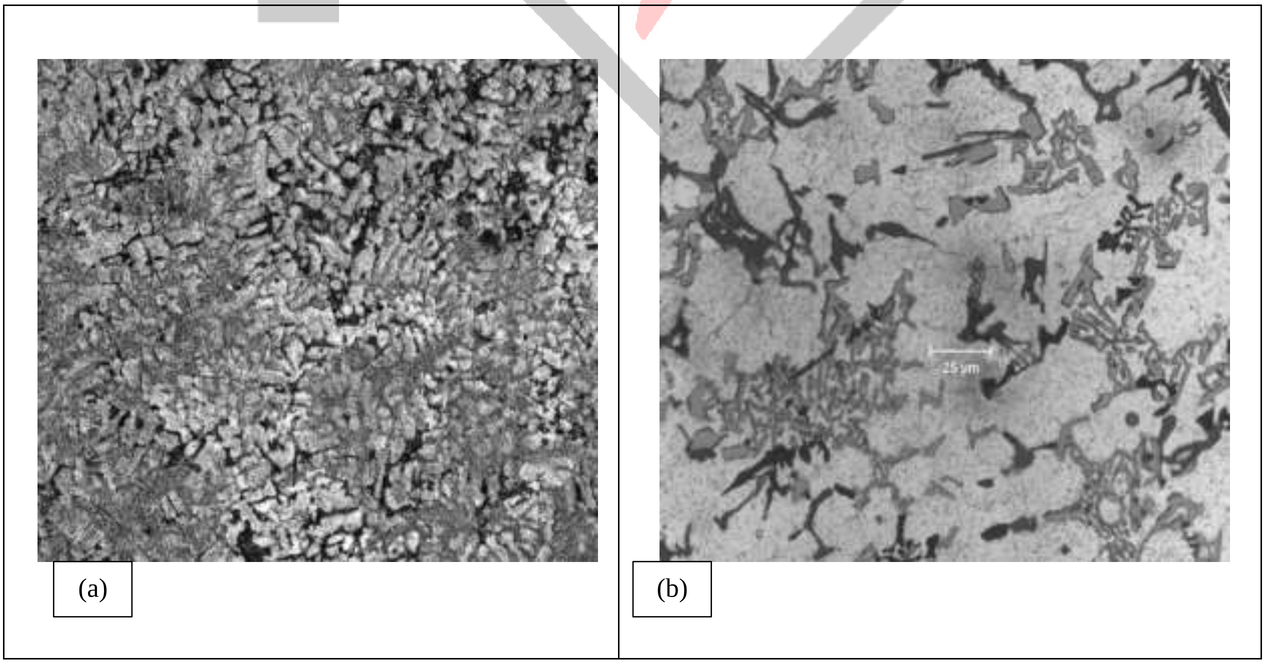

Figure 5 Microstructure of chill cast composite (a) 100X (b) 500X

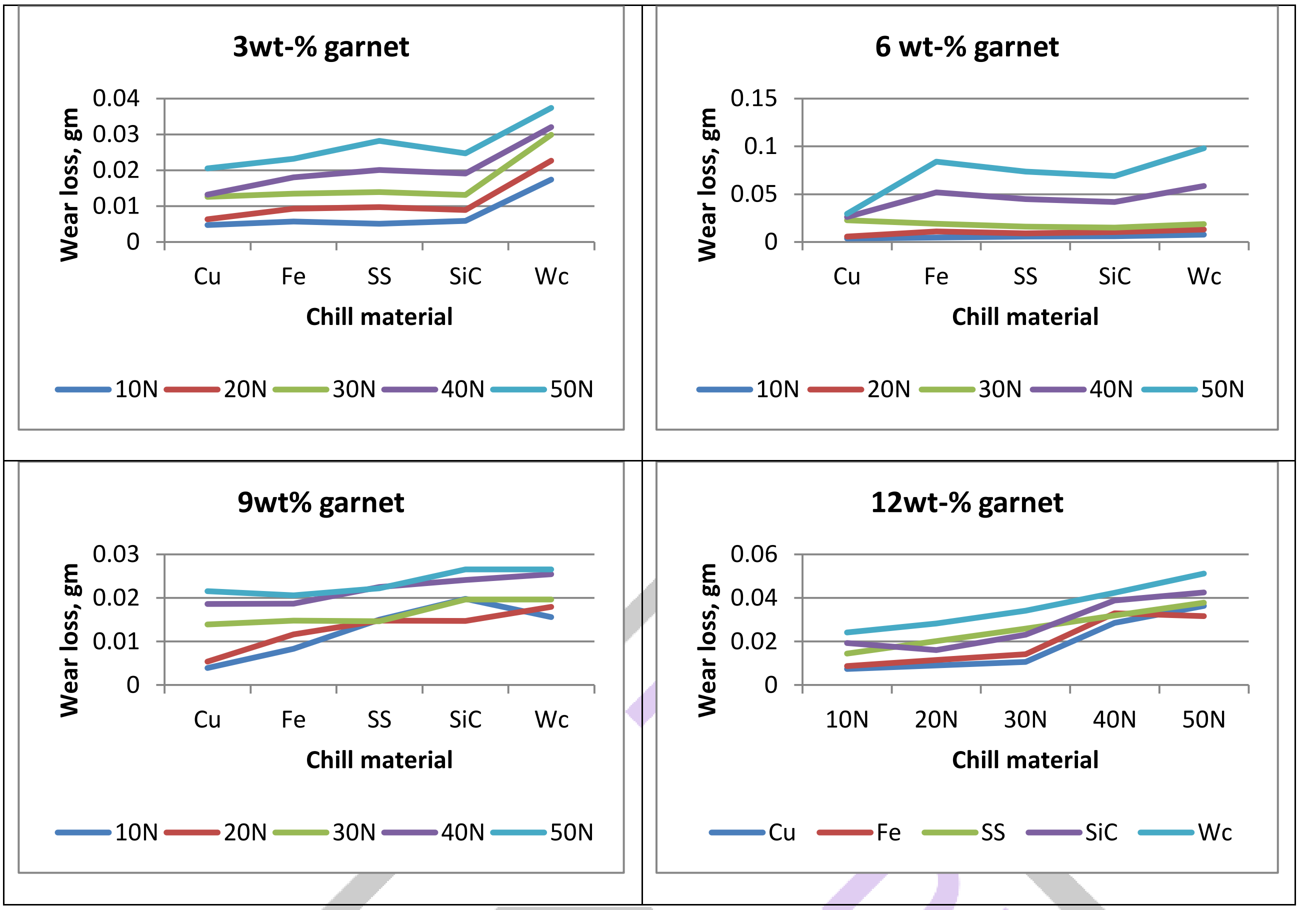

Figure 6 Variation of wear loss of hybrid composite with respect to load

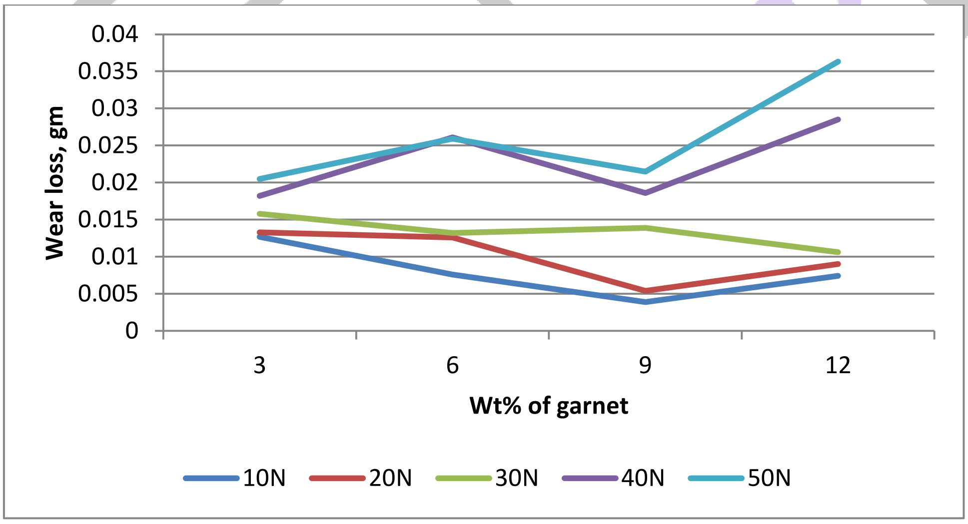

Figure 7 Variation of wear loss of hybrid composite with weight percentage of garnet

IV. Conclusions

In this investigation, Al/Garnet/C hybrid composites were successfully fabricated using the stir casting route. The composites with 9 wt % Garnet exhibited both excellent wear resistance and friction coefficients. The addition of solid lubricant particles as the second reinforcement in the aluminum matrix effectively improves friction and wear properties.

The most significant variables affecting the sliding wear of the composites (in terms of their individual percentage contributions) were the sliding distance (58.21 %), sliding speed (16.23%), applied load (13.88 %), and carbon content in the composite within the selected range of investigations.

SEM studies of the worn surfaces and wear debris revealed that the wear mechanism involved with the Al–12% Garnet composites was oxidative wear with severe plastic deformation. The wear mechanism with the Al–9% Garnet hybrid composites was oxidative wear with delamination wear. With the Al/9% Garnet /3% C hybrid composites, delamination wear was the prominent wear mechanism. A uniform graphite film on top of the worn surface helped to decrease both the wear loss and friction coefficient. Therefore, severe wear was avoided with the Al/9% Garnet/3% C composites.

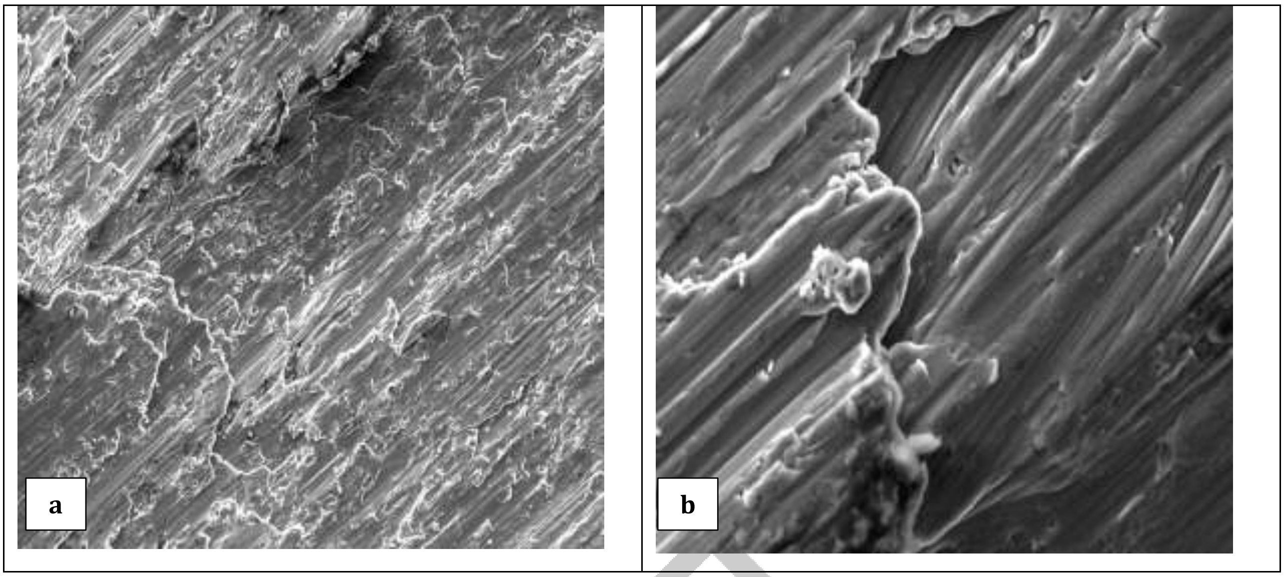

Figure 8 SEM micrographs of the worn surface

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