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Effect of Mineral Garnet Reinforced on the Tribological Properties of Composite at High Temperature

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ABSTRACT

Aluminum alloys are widely used as engineering materials because of their high strength. Natural mineral garnet reinforced aluminum composite was developed using conventional stir casting technology. As Garnet refracting particles offer high mechanical strength and thermal stability so these are the potential reinforcement materials for the composite to be used for high temperature applications. The wear tests under the dry sliding were performed using pin on steel disc equipment at high load of 5 kg by varying the ambient temperature from 50˚C to 300˚C . Wear mode changes in the composites is observed beyond 200˚C for higher loads due to delamination of oxide layer, which occurs by nucleation of crack in particle matrix interface and its consequent growth. The increase in amount of garnet particulate prevents the loss of material of the composite. The morphological studies of wear track and debris provide clues about the wear mechanism. It is observed that delamination is the primarily cause of the wear loss because of the dominance of the plastic deformation at high temperature.

Keywords:SEM, Reinforced, Wear, MMC, Temperature.

I. INTRODUCTION

The aluminum alloys and its composite are the preferred materials by the designers, manufacturers and industrial users due to their better-performance and various innovative fabrication processes [1-3]. Aluminum and its alloy has low weight, good electrical and thermal conductivity, corrosion resistance, ease of use and therefore it can be recycled. Because of these properties, it has multiple industrial applicationse.g.in aerospace, automotive industry marine transport, rail transport applications building, packaging, mechanical industry and engineering. With the advent of growing industrial technology, the development of the smart materials is in demand [4]. These new advanced materials also constitute a particulate reinforced aluminum alloys which has the advantage to be used for high temperature applications.Various processing methods can be adopted for the fabrication of metal matrix composite. Stir cast technique is used for developing composite which not only ensures the homogeneous distribution of the particulates but also provides better adhesion at the interface. The strong bond between the reinforcement and the matrix make the composite capable of its usage for the wear resistant applications.

The large amount of wear of the composites under the high applied load causes the abrupt rise in temperature at the surfaces in contact [5]. Delamination wear mechanism prevails at high temperature due to adiabatic conditions which accelerates adhesive wear between the sliding surfaces. The incompatibility between the oxide layer and the underlying plastically deformed surface at high temperature is the important factor for the subsurface deformation [6]. This leads to rise in surface temperature causing adhesion wear which is the onset of the severe wear. In the last decade, numerous studies have been reported with the particulate reinforcement in aluminum alloy but the wear mechanism studies using garnet material as reinforcement need to be explored for high temperature applications.

Studies on the tribological behaviour and mechanical properties of AMCs containing different types and percentage of reinforcements such as Al_2O_3, SiC, TiO_2, $ZrSiO_4$,and fly ash of different particle sizes can be found in literature [3-7]. However, the wear performance studies of the particle reinforced composites are still limited [1, 5-8]. Moreover, study of tribological behaviour of different mineral particles size reinforced composites with reference to delamination wear mechanism needs some attention. The interfacial layer's elements composition is the deciding factor which determines the type of wear mechanism .The entire tribological behaviour of AMCs with the change in parameters eg. temperature, load, sliding speed confirms the operative mechanism, which can be correlated from the wear micrographs.

II. METHODS AND MATERIAL

Aluminum alloy (LM13) ingot with 11.6% of silicon composition is reinforced with natural mineral garnet particles.The composite was developed using stir casting route by adding different amount of garnet particulates of 5, 10 and 15wt.%. The composite's preparation experimental detail is described in our earlier work [4]. Al alloy was melted in a graphite crucible fitted with an electrically controlled furnace. Molten melt is stirred at a speed 630 rpm with a graphite impeller.The formed vortex was charged with fine sized garnet particle (50-75µm) and coarse sized (106-125µm).The homogeneous distribution of the garent particles was ensured by stirring the melt at high temperature of 830ºC and the melt was allowed to solidify in metal mould at room temperature.

A. MATERIALS CHARACTERIZATION

Wear tests of the reinforced composites under non-lubricating conditions were done under the different temperatures between 50-300 ºC.These wear tests were done using a wear and friction monitor (TR-20, Ducom, Bangalore) and at a relative humidity between 35-50% .The cylindrical shaped specimen of dimensions (30 x 9 mm) were tested after sliding against the hardened steel disc EN32 having hardness 65 HRC. The adherent greasy material of the specimen was removed by ultrasonicating in acetone before testing. The specimen was made to rotate with velocity of 1.6 m s^{-1}on the steel disc covering distance 3000 meters under high temperature and loads. Scanning Electron Microscope (JEOL, JSM-6510LV, Japan) was used for the microstructural analysis at various magnifications.

III. RESULTS AND DISCUSSIONS

The wear behavior of the materials is goverened by the ambient temperature and load. The wear behavior of the developed garnet particle reinforced alminium composite was observed by performing wear tests at different temperature range from 50-300˚C . The study was carried out from 1kg to 5kg at room temperature but more emphasis was given to the studies at high 5kg loads at 50˚C temperature keeping in view of the transition temperature which changes the wear mode from mild to severe.

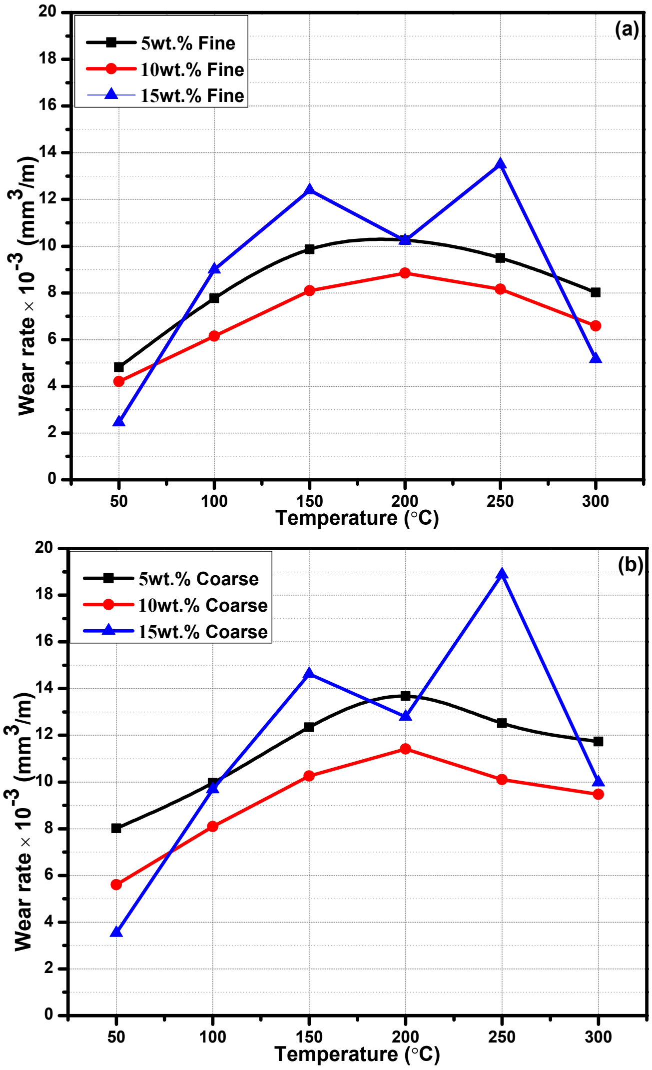

Figure 1: Wear rate against the temperature for LM13/garnet composite reinforced with (a) fine size (20-32 µm), and (b) coarse size (106-125 µm) particles with different amount at 5kg loads.

So dependency of wear rate with temperature is presented in the above studies. The wear rate of the all the prepared composites reinforced with different sized garnet particles with changing the temperature from 50-300˚C at high load (5kg)are presented in Fig. 1 and 2. It indicates continuous rise in wear with an increase in temperature up to 150˚C. Which is observed for all the compositions inspite of the percentage content of reinforcement.The improvement in wear rate is evaulated with the increase in volume fraction of garnet particles which is the also proven fact[9].Another important parameter which is hampering the wear performance of the composite is the large size of the additive garnet particulates which can be easily concluded by comparing the wear of the prepared material at a particular temperature in Fig1(a and b).

In Figure 1(a and b) depicts the fall in wear rate with the enhancement of temperature up to 200˚C which is detected as the critical temperature,due to the increased thermal oriented activity of the metal oxide layer formation whch provides a glazed interface between two sliding surfaces as confirmed by Wilson and Alpas [10]. This smooth layer acts as a interface between the two metal surfaces and its presence lowers the friction (around 200˚C). Hence reduces the wear rate of the composite material.The change in type of wear mild-to-severe at 200˚C for all the composite materials can not be ruled out which is accompanied by the gross extrusion of material and extensive plastic deformation which is one of the characteristics of the severe wear. The temperature range of $0.4T_m$-$0.5T_m$ two surfaces of contact are under strong adhesion as soft metal material sticks tothe sliding surfaces [11].At this critical temperature, deformation process is main cause of the removal of material [12]. So the reduction in significant decrease in wear of the garnet aluminium composite at such high temperature can not be achieved without the formation of the oxide film.

Rajaram et al. [13] have described the improved in wear rate due to the decrease the metal to metal actual contact area but further heating will increase the wear due to the reduced strength of the asperities. Due to continuous sliding, these asperities under the action of stresses like normal and shear and the removal of thin oxide film will lead to exposure of new areas, thereby increasing the wear rate. The transition temperature at which there is sudden change in wear is observed at this critical temperature (250˚C). Wear rate for all the composites, decreases sharply with increasing the temperature near 300˚C at high load. The transfer of steel inclusion from the steel disc surfaces to the specimen surface at this temperature is also helping to increase in superficial observed wear resistance of the composites owing to the large plastic deformation. Thesoftening of the surrounding matrix alloy deactivate the strain transfer to the interfaces and the crushing and grinding action of the surfaces sharp edges lead to negative wear rate of both composites. However, it is generally observed that composites reinforced with large sized particle shows lower wear resistance than the fine particles reinforced composite as in Fig 1 (a-b).

A. Topographical Analysis of the Wear Pin-headand Debris of Specimen

Topographical analysis of the specimen surface after wear test predicts the wear mechanism involved at different testing conditions.

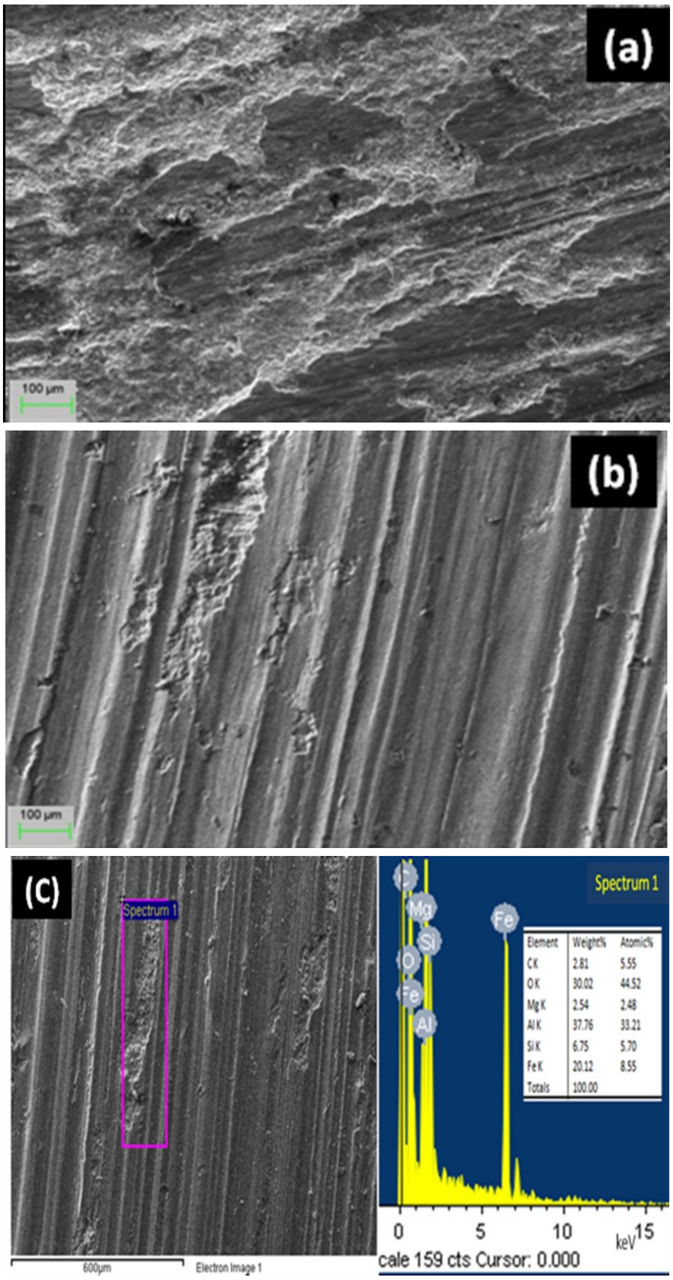

Figure 2: SEM micrographs of 5wt.% coarse size garnet composite: Wear pinhead at different temperatures (a) 100 ºC, (b) 200 ºC and (c) EDS spectrum of track with 49N load at 200 ºC.

Topographical analysis of the composite worn surface is discussed with lower content of 5wt.% garnet reinforced. Figure 2 (a-b) shows the wear surface of LM13/5wt.% garnet composite tested at 100˚C and 200˚C respectively, in which the continuous wear grooves and ridges formation along with damaged regions are visible. The delamination of surface material and debris generation arises from the cracking of surface materials are the main features which support the delamination mechanism. Figure 2a shows the wear surface of the LM13/5wt. % garnet composite at high (5kg) load and tested at 100˚C temperature. The width and depth of the grooves depends upon the temperature at which wear studies have been done. But the decreased wear surface roughness also confirms the transition temperature 200˚C which is the critical temperature of the composite. Fractured garnet particles were also observed in grooves as high load accelerates the grinding and crushing in Fig. 2b.

These trapped particles in wear tracks delays the delamination of matrixby forming thin oxide layer which hinders the removal of material. With the increase inthe temperature from 100˚C to 200˚C, composite also shows abrupt rise in delaminated area as can be seen in Electron Dispersive Spectroscopy which also verify the presence of oxide layers.

Figure 3 (a-b) represent the wear debris collected at 5kg load of LM13/5wt.% garnet composite at 200˚C and 300˚C respectively. Figure 3(a) shows the larger size debris with conical and edges debris with fractured particles because of the delamination of the material. The crack initiation at high stress and joining of voids results in generation of large size debris which is further responsible for higher wear rate.

The cold welded asperities to the composite surface may be removed during the ploughing thus resulting in corrugated type debris which authenticates the higher wear rate [13].Thin wear sheet type flakes elongation in the direction of sliding are produced with the wear arising from the cracks formation and its travelling to the nearest neighbours leading to the material removal in the form of layers. Figure 2(b). The smaller fractured size of the larger size debris can be explained due to the high applied loads during the wear tests. White sparkling phase in debris shown in Fig 3(b) further confirms the presence of oxidation at high temperature.

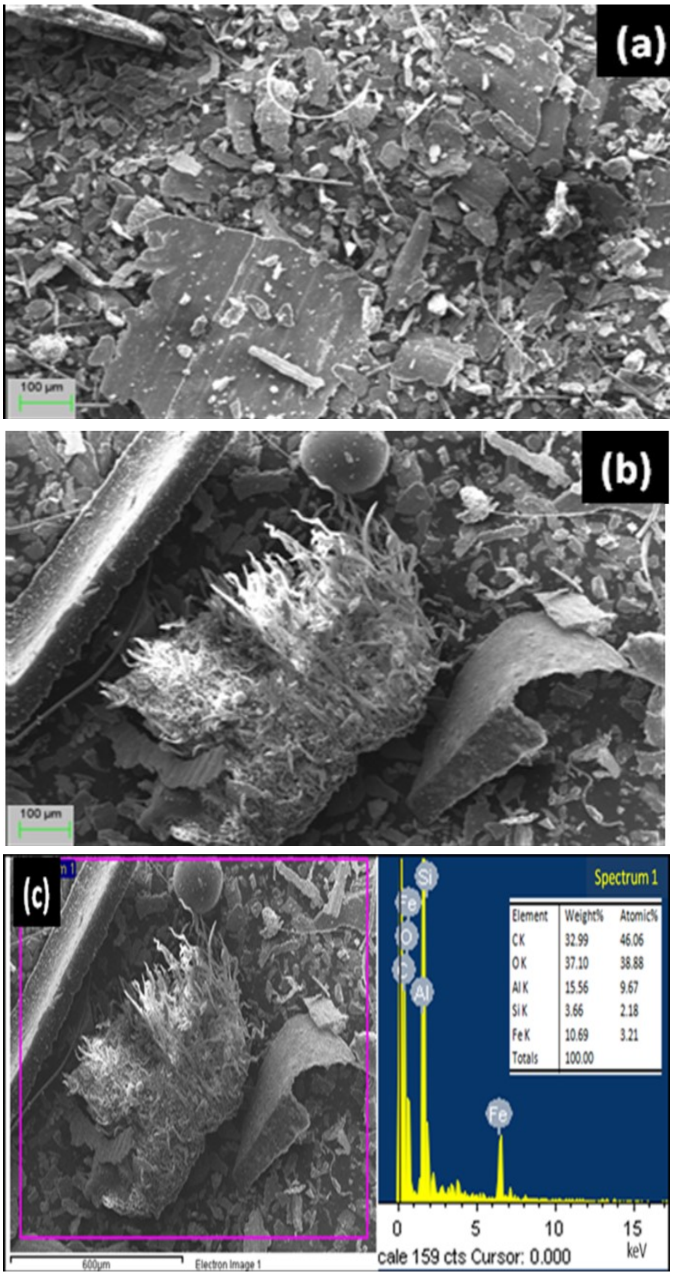

Figure 3: SEM images of wear debris of LM13/ 5wt.% garnet composite with coarse size particles at 5kg load with variation of temperature (a) 200˚C and (b) 300˚C.

IV.CONCLUSIONS

1. The decrease in garnet reinforcement size provides better wear performance to the composite at higher loads and elevated temperatures.
2. Oxide-layer formation is the evidence which support minimum wear rate at 200˚C for composites studies at higher loads.
3. At critical temperature,nucleation of crack in particle matrix interface followed by its growth governs the delamination wear mechanism.
4. The plastic deformation of composites at the elevated temperature was found to be the main cause of huge removal of material and causes delamination.

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