International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-03, Issue-11, Feb 2018

Study of Wear Debris Microstructural Behaviour of Rutile Al Composite at Low Contact Pressure

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Abstract – **Mineral reinforcement is used to enhance the mechanical and wear properties of the metal matrix composite for commercial applications. Addition of hard ceramic rutile particles to the soft matrix not only improve the hardness but also bring changes in the morphology of the composite. Liquid metallurgy method is most appropriate for the particles incorporation which is used for preparing the material. Aluminium alloy is reinforced with rutile coarse particles with the volume fraction of 20% wt. by stir casting. The wear rate studies using pin on disc tribometre showed that the mineral particles effectively improved the tribological behavior of the composite. Study of wear debris with the help of scanning electron microscope (SEM) revealed that microstructural behaviour of debris is beneficial in identifying the adhesive wear phenomenon of rutile reinforced Al alloy at low contact pressure.**

Keywords —Rutile, Aluminium, Wear, Debris.

I. INTRODUCTION

MMCs light weight and low cost materials are extensively used in the aerospace, transportation, construction and leisure industry as they deliver better mechanical and wear behaviour as compared to the metal alloys. The choice of the metal matrix composite needs several considerations, depending upon the application for which composite is to be used. Continuously reinforced matrix composite is used for the effective transfer of load to the reinforcing filament which provides more toughness to the matrix. Discontinuously reinforced composite is preferred when more strength than toughness of the composite is required. The reaction between the matrix and the reinforcement during processing or in service evaluates the performance of a composite. The large difference of coefficient of thermal expansion between the matrix and the reinforcement develops thermal stresses which alters the mechanical behavior of the composite. Even the matrix fatigue behavior on the cyclic response of the composite changes the mechanical properties [1-4]. Special property profile of the composite is achieved by using the particular type of matrix reinforcement and the processing technique which has opened up the unlimited opportunities for the metal matrix to be used on wide variety of engineering applications. In addition to the high strength some time even high electrical and thermal conductivity are the important consideration while making the choice of a matrix. Aluminium and its alloys have enjoyed patronage as matrix materials because of the escalating demand for light weight and high strength components [3]. Low coefficient of thermal expansion, high thermal conductivity, and high wear resistance than the unreinforced alloy makes MMCs attractive for bearings, bushings, cylinder liners, brake rotors etc. Due to light weight composite materials the weight of the next generation aircraft will be 65% less with the use of good proportion of these MMCs. Some commercial application of the composite materials is in the sporting and bicycle industry. The industry requirement is not only to achieve the weight reduction in the automotive components but also has to be cost effective. The particle reinforced MMCs will become a general use engineering material due to the reproducibility of properties in the commercial component and meeting specifications with high yields at the acceptable cost [2].The ceramic particles availability in abundance enhanced their use for preparing composites for structural and thermal management applications .

For structural applications, composites require high modulus and low density reinforcement and for thermal management applications the coefficient of thermal expansion and thermal conductivity are important. Size of the reinforcement determines the processing technique to be used. Since most ceramics are available as particles so it has a wide range of applications. Arora et al. [5] observed refinement in silicon morphology with the addition of rutile particles to aluminium matrix which in turn increases the hardness of the material. Kumar et al. [6] found decrease in wear loss of garnet particles reinforced zinc aluminium alloy metal matrix composites using liquid metallurgy technique. Hashim et al.[7] cocluded from his studies that stir casting method used for the development of composites by the liquid metallurgy route is cost effective for the production of composites at large scale.

 DOI : 10.18231/2454-9150.2018.0031

ISSN : 2454-9150 Vol-03, Issue-11, Feb 2018

Kumar et al. [8] studied the wear behaviour of DPS zircon sand reinforced aluminium alloy composite using pin on disc tribometer which revealed the enhancement in the tribological properties of the prepared material. Sharma et al.[9] investigated the tribological behavior of garnet reinforced LM 13 alloy under dry sliding conditions using pin on disc tribometer. The microstructure obtained reveals nearly uniform distribution of ceramic particles inside the LM13 alloy matrix and particles addition enhanced strength hence wear resistance also.

Present studies are done by taking aluminium alloy as the base and 20% rutile mineral with coarse size particles as reinforcement processed by the liquid metallurgy method as rutile mineral reinforcement is not studied so far .Even addition of this high volume fraction of mineral because of the lack of wettability and to overcome viscosity to achieve the homogeneous distribution of particles involves a tedious task.

II. EXPERIMENTAL SETUP

In this study, piston alloy LM13 was used as matrix material and high-purity rutile mineral as reinforcement. LM13 alloy was obtained in the form of ingots from emmes metal pvt. Ltd., mumbai. Type of reinforcement used for metal matrix composites is governed by production and processing employed where the matrix plays an important role.

Mineral particles reinforcement not only improve the mechanical properties of a matrix by dispersion strengthening but also block the movement of dislocations and also impart isotropic properties [8]. Rutile particles of coarse size (106–125 µm) with 20 wt.% were used to study microstructural behaviour of wear debris of composite at low contact pressure.

Liquid state casting of the metal matrix composite is preferred over the solid state processing like Diffusion Bonding and Vapor Deposition because of its low cost and ability to produce large complex shape. The mixing of particles into the metallic melts depends upon the wettability between the particles and the melt. Stir casting involves the mixing of the preheated ceramic particles to the molten metal using a mechanical stirrer is suitable for composite with maximum 30% of reinforcement. The particle distribution in the molten matrix depends upon the geometry, position of impeller, speed and characteristics of the added particles [7].

Dry sliding wear tests of the composites were done by using pin-on-disc method. Effect of applied load was observed by with load of 9.8 N. Wear rate was determined by measuring specimen height change using a linear variable displacement transducer (LVDT) were tested at a constant speed of 1.6 m/s against EN 32 steel disk having hardness 65 HRC To study the wear behavior, wear rate was calculated by using the formula, [W (mm3/m) = height change (mm) × pin area (mm2)/sliding distance (m)]. Study of wear debris was done the help of SEM (JOEL, JSM-6510LV) to identify the underlying wear phenomenon of composite at low contact pressure

III. RESULTS AND DISCUSSION

The wear process is defined as the progressive loss of material from the operating surface of a body occurring as a result of relative motion at that surface [10]. The interaction at the discrete points of asperities of the sliding surfaces in contact causes friction and wear due to the binding through the adhesion at the points of actual contact. Any relative motion leads to the variation in strain in the perpendicular to the surfaces thus leads to the deformation of the asperities under the application of the load. Tribological behaviour of the samples of LM13 Al alloy reinforced with rutile mineral 20wt.% with coarse sized particles (106-125µm)has been studied under different loading conditions varying from 9.8N to 49.0N is shown in Fig.1. Wear rate analysis indicates that the wear rate of the composite $^{20}C_{coarse}$ increases with increasing the applied load but improvement in wear resistance caused by the ceramic rutile particles.

For all the composites the wear rate is mild at low loads (9.8N). Formation of oxide layer which acts as a lubricant prevents the direct contact between the sliding surfaces which further decreases the wear loss [11]. On increasing the load from 9.8N to 49N, the frictional heat accelerates the plastic deformation which changes the wear mode from mild to severe. Under the effect of low contact pressure (9.8N), the composites exhibited improved wear resistance as compared to the base alloy.

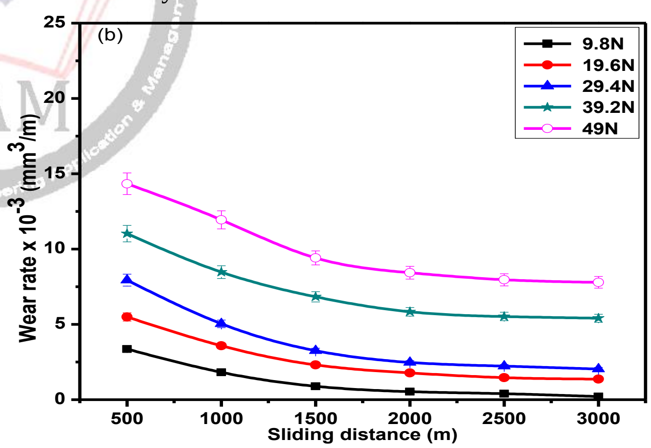

Figure 1: Wear rate of composites against sliding distance at different loads for composite $^{20}C_{coarse}$.

Arora et. al clearly demonstrated in earlier studies that higher the volume fraction of rutile reinforcement, higher is the wear resistance of composite material. It is observed that 20wt.% rutile reinforced composite, because of high hardness, suffers minimum loss of material[12].The wear loss in the composite with 20wt.% rutile particle has also reduced significantly as compared to the unreinforced base alloy.

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The analysis of the wear debris and worm surfaces allows identifying the dominating wear mechanism. The lumpy particles wear debris is symptomatic of adhesive wear and it produces chip-like particles. The wide and deep grooves on the worn surfaces are the clear indication of the adhesive wear .Wear mechanism is strongly governed by the nature of the contact surfaces e.g. the surface texture, strength of bonds at the points of real contact, elastic or plastic deformation of the bonds, nature of the surface films present between two sliding surfaces. Adhesive wear is dominant phenomenon responsible for the loss of material on the basis of the interactions between the sliding surfaces and transfer of material during relative motion by a process of solid phase welding at low load. During sliding, the localized bonding between the contacting particles surface are removed either by the roughening of the asperities accompanied by the rapid wear loss. During sliding, shearing stress dominates and damages the softer material which gets attached to the harder one .The superior wear resistance of $ZrSiO_4$ reinforced aluminium matrix composite at applied load was attributed to high frictional heating thus the localized adhesion and softening of the surface with counter surface [13]. Our results are consistent with Mazahery et al. that alloy reinforced with minerals acquire more hardness and display better adhesive wear resistance.

The SEM micrographs of wear tracks and wear debris of composite-^{20}**C**$_{coarse}$ in Fig 2 shows that uneven tracks shallow tracks in the parallel to the sliding direction. The deformed asperities of the specimen material adhered on the sides which can be seen in the form of ridges in Fig.2a.

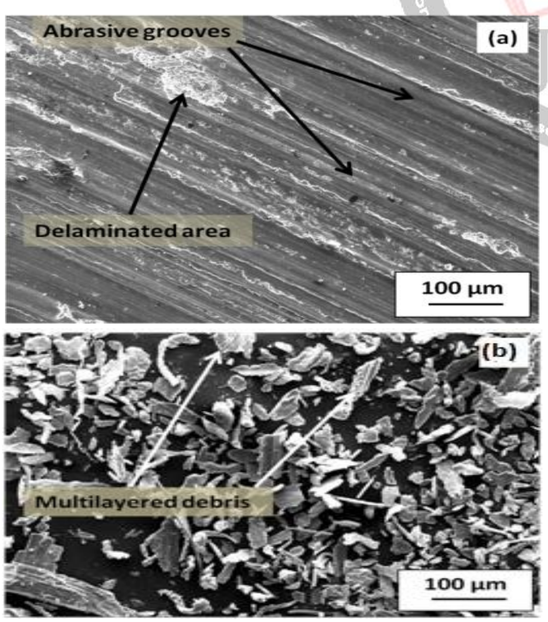

Figure 2: SEM micrographs of composite-^{20}C$_{coarse}$: wear tracks (a) 9.8N, (b) 9.8N wear debris

The removal of the upper layer has exposed the bonded particle which can be seen as big black spot on the track. Small black spots are the voids created due to the plastic flow of the material around the particles. The mild wear is also confirmed by the small flake type debris generated by micro-cutting (Fig.2b.) Some debris are having small plate like structure which is indicative of material removal by continuous sliding. The smaller debris is agglomerated due to welding by repetitive forces.

Thread type morphology of debris is due to the result of pulling off the plastically deformed matrix under loading conditions. Molten debris observed in SEM micrographs are due to generation of frictional heat between the specimen and counter surface at higher loads causing melting of trapped debris

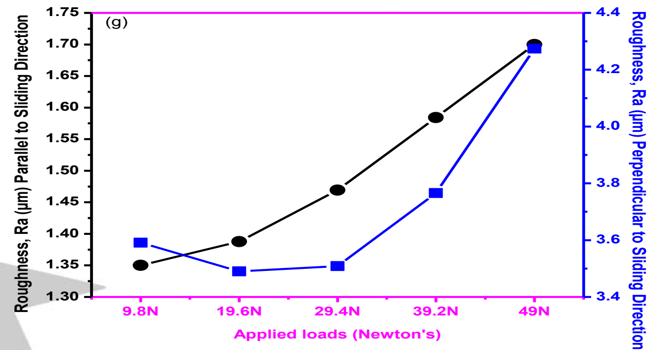

Figure 3: Roughness of wear tracks at different loads.

Fig 3 shows that the roughness decreases with increased load from 9.8N to 19.6N because at this condition asperities are plastically deformed which decreases the surface roughness. With the increase in load from 19.6N to 49N, the roughness increases in both, perpendicular and parallel to sliding direction due to the formation of cavity area, damage area and delamination area on the wear track of the composite-^{20}**C**$_{coarse.}$

IV. Conclusion

Adhesive wear is caused by the interaction at the discrete points of asperities of the sliding surfaces at the points of actual contact. In the initial stages of run, the wear loss is inclusively determined by the rubbing of the sharp edged asperities during the sliding of the prepared specimen under the dry sliding conditions. The grinding and the subsequent continuous motion of the sample on the disc in round track produces numerous marks which can be seen as the wear tracks.The roughness of the wear track determines the wear loss and its magnitudes in two perpendicular directions give the estimation of the wear resistance. Study of morphology of debris reveals that deformation of the soft aluminium matrix during wear and the subsequent hard rutile particles movement leads to the removal of material from the traced tracks.

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