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Dry Sliding Wear Behaviour of Al-10Si-Tib_2 Particulate Composites

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***Abstract* - The effect of load on the dry sliding wear behaviour of an Al-10si alloy reinforced with TiB_2 particles reported in this paper. The coefficient of friction and wear rate of an Al-10Si alloy and composites were measured using a pin-on-disc apparatus. The wear rate of Al-10Si alloy increased drastically and that of composites decreased with the increase in weight percent of TiB_2 particles. The load bearing capacity of the alloy during wear increases and the same for composites is decreasing with increasing sliding distance. It was observed that increasing in the applied load as well as TiB_2 content there was a decrease in the coefficient of friction for both the alloy and composites. It was also observed that this decrease in coefficient of friction was more for higher 10% TiB_2 content.**

Keywords*: *Al-10Si alloy; TiB_2; Dry sliding wear; Coefficient of friction.

I. INTRODUCTION

Al-Si alloy-based composites are widely used in automotive, aerospace and mineral processing industries because of improved properties such as strength, stiffness, tribological behaviour and a low thermal expansion coefficient. Conventional practice of preparation of Al-Si alloy-based composites involves the addition of ceramic particles to the liquid aluminium could lead to segregation of reinforcement particles and poor adhesion at the interface, unless the matrix and/or particles are suitably modified [1-4]. Recently, in-situ techniques have been developed to fabricate aluminium–based metal matrix composites (MMCs), which can lead to better adhesion at the interface and hence better mechanical properties. In the in situ process, ultrafine ceramic particles are formed by the exothermic reaction between the elements or their compounds with molten aluminium alloy. These in situ routes provide advantages such as uniform distribution of reinforcement, finer reinforcement particle size, clear interface and thermodynamically stable reinforcement. Even though the in situ composites have significant advantages, some synthesis routes may lead to composite with inhomogeneous microstructure with various unstable and/or undesirable phases.

S.Kumar et al.[5] have investigated the Effect of temperature on the wear behaviour of Al-7Si-TiB_2 in-situ composites increasing temperature the wear rate of Al-7Si alloy increased drastically and decreased with the weight percent of TiB_2 particles. B.S.Murty et al. [6] Tensile and Wear behaviour of in-situ Al-7Si-TiB_2 particulate composites. M.Chakraborty et al. [7] a comparative study of mechanical properties and wear behaviour of Al-4Cu-TiB_2 and Al-4Cu-TiC in-situ composites.

A. Mandal et al. [8] Effect of TiB_2 particles on sliding Wear behaviour of Al-4Cu alloy. B.S.Murty et al.[5] Ageing behaviour of A356 alloy reinforced with in-situ formed TiB_2 particles.Scientists have developed various wear theories in which the Physico-Mechanical characteristics of the material and the Physical conditions (e.g. the resistance of the rubbing body and the stress state at the contact area) are taken into consideration.

Most of the work pertaining to wear behaviour of MMCs has been carried out with SiC as the reinforcing medium, particularly in the hypoeutectic Al-Si system [9-11], though a few others have investigated the sliding wear behaviour in eutectic systems [12]. Although some wear studies on Al alloys reinforced with in-situ TiB_2 particles has been carried out [8, 13, 14] very few literatures have focused on the effect of in-situ TiB_2 particles in eutectic Al-Si alloy.

The present report deals with the synthesis of Al-10Si-TiB_2 in situ composites and the influence of TiB_2 reinforcement on wear properties of the Al-10Si alloy.

II. EXPERIMENTAL PROCEDURE

Al-10Si alloy reinforced with TiB_2 composites (2, 4, 6, 8, 10 wt% TiB_2) were fabricated by stir casting, by introducing TiB_2 particles into the molten alloy at 800^0c. Standard wear specimens of 33mm length and 6mm ø were retrieved from the homogenized base alloy and composites castings through wire cut EDM process (figure 3.5). Dry sliding wear tests have been carried out on a pin- on - disc apparatus (Model: Ducom TR- 20 LE) by sliding cylindrical pins against the surface of hardened steel disc (with a hardness value of HRC 62) under ambient condition. The Pin-on-disc wear testing experimental set up was shown in figure 3.6. The disc was ground to a smooth surface finish and renewed for each test.. Prior to testing, the test samples were polished with emery paper and cleaned in acetone, dried and then weighed using an electronic balance (Model: Wensar PGB 200 India) with a resolution of 0.1 mg. The samples were placed on the wear disc and the sliding wear tests were carried out at a load range of 0.5 Kg, 1Kg and 1.5 Kg (4.9N, 9.81N and 14.7 N) with a sliding velocity of 3.35 m/s and sliding distances of 2Km, 4Km and 6 Km. All the specimens followed a single track of 100 mm diameter with a tangential force. Wear loss and frictional traction experienced by the pin during sliding are measured continuously by a PC based data logging system. After running through a fixed sliding distance, wear track disc is cleaned with acetone and dried. After each test, the specimens were removed, cleaned in acetone and weighed with the same electronic balance mentioned above. For each load, the volume loss from the surface of each specimen was determined as a function of sliding distance and applied load. The wear rate (K) was defined as the volume loss (V), divided by the sliding distance (L). Hence, the volumetric wear rate (K) was calculated from the weight loss measurement and expressed in terms of mm^3/Km.

The friction force (F) was continuously monitored during the wear test for determining the coefficient of friction (μ). The friction force was measured for each pass and then averaged over the total number of passes for each wear *test.* The average value of coefficient of friction (μ**)** of composite was calculated from the following expression.

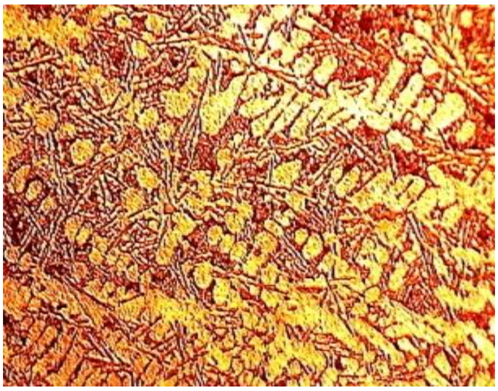
$$\mu = F_f / F_n$$

Where: F_f is the average friction force and F_n is applied load.

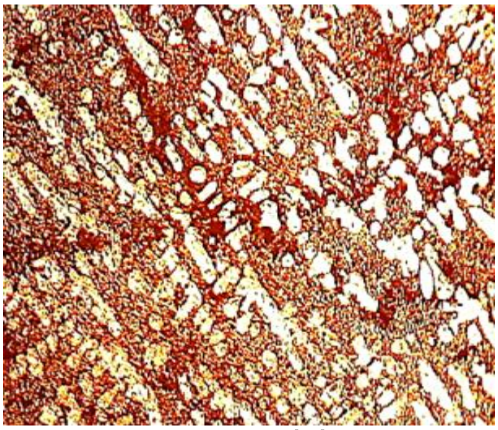
III. RESULTS AND DISCUSSION.

A. Micro structural characterization

The microstructures were taken in the etched condition at 200 X magnifications. The Etched matrix shows dendritic pattern of Al-Si eutectic particles in alpha aluminium phase solid solution. The needle shaped particles are Al-Si. The Al-Si is acicular shaped and sharp angled. The rapid solidification in the chill cast could have resulted in dendritic formation. The primary alpha phase also shows the presence of formation of primary silicon due to higher silicon content. Fig-1. Shows the optical microstructures of the Al-10Si alloy. This alloy is a hypoeutectic alloy and consisting of soft aluminium solid solution matrix (α) and hard TiB_2 phase. Hence the microstructure is composed of white (α) primary grains and a dark eutectic (α + Al-10Si). Figures 2–10 shows the optical microstructures of Al-10Si alloy – 2, 4, 6, 8 and 10 (by wt.)TiB_2 composites respectively. These figures revealed That Presence of TiB_2 particles in Al-10Si matrix and further confirm that there was a uniform distribution of TiB_2 particles in the base matrix of Al-10Si alloy. It was also observed that there was an increase in TiB_2 content for 2%, 4%, 6%, 8% and 10% TiB_2 composites compare to 2% TiB_2 composite. 200X in etched condition showed good distribution commensurate with the percentage addition of the TiB_2. 200X in etched condition showed good distribution commensurate with the percentage addition of the TiB_2.

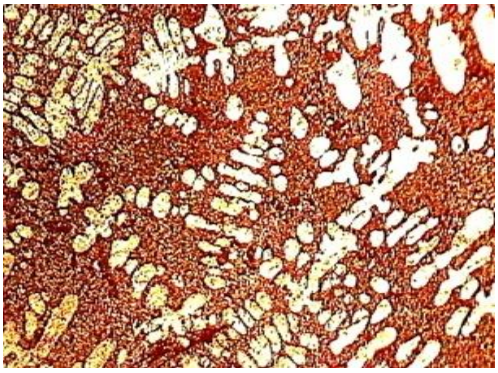


200X as etched
Fig.1 Al -Si alloy

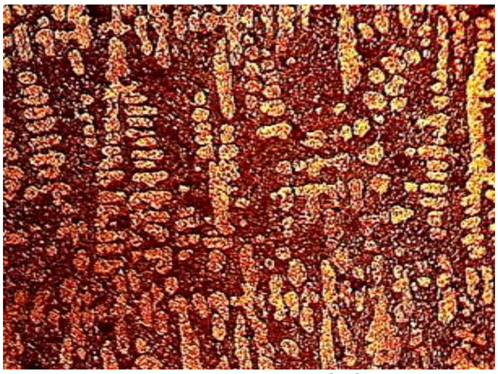


200X as etched
Fig.2 Al –Si – 2%TiB_2.

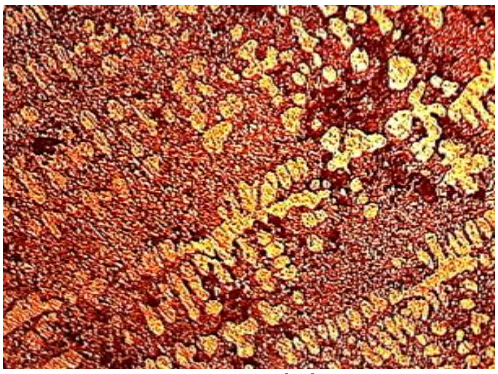
200X as etched
Fig.3 Al – Si – 4% TiB_2.



200X as etched
Fig.4 Al – Si– 6% TiB_2.



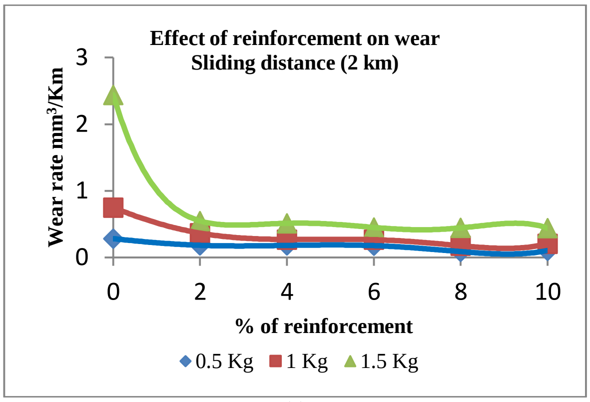
200X as etched
Fig.5 Al – Si – 8% TiB_2.



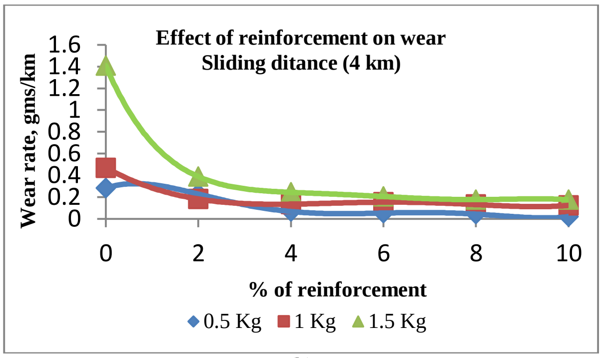
200X As etched
Fig.6 Al – Si– 10% TiB_2.

B. Effect of Reinforcement on Wear

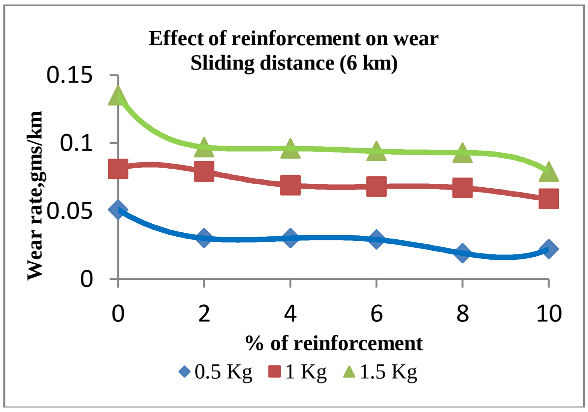
Figs.7(a)-(d) shows the wear rates as a function of percentage of reinforcement for 0.5 kg, 1.0 kg and 1.5 kg (4.9, 9.8, 14.7 N) applied loads. It can be seen that the wear rate of the alloy decreases with the increase in sliding distance from 2 km, 4km and 6km. A slight increase in the wear rate was observed for all applied loads, while composites shows lower wear rates at the low loads (0.5 kg and 1.0 kg) due to the presence of hard TiB_2 particles in the alloy matrix Presence of reinforcement strengthens the matrix, resulting in increased wear resistance. At the higher loads and longer sliding distances the wear rate of the alloy found to be increasing more than that of the composite. All the composites exhibit better wear resistance compared to the alloy. The wear resistance of the TiB_2composites has increased with increase in reinforcement content. Al-10Si Alloy exhibits higher wear, and its composite with 10% TiB_2 reinforcement showed lower wear. B.S.Murty.et al through their investigations on Al-7Si alloy, have suggested that the grain refinement and/or modification improves wear resistance and the load bearing capacity during dry sliding of cast Al-7Si alloy [15]. Similarly, addition of TiB_2 particles resulted in a combined effect of grain refinement, modification and dispersion strengthening leading to an improvement in wear resistance of Al-7Si alloy. The normalized wear rate decreases as the applied load increases for any given amount of TiB_2 particles. This may be attributed to the work hardening of the matrix and possible refinement of TiB_2 particles during wear at high loads. Other investigators also reported the same trend of wear behaviour.



(a)



(b)



(c)

Fig.7. (a) Variation of wear rate as a function of reinforcement at 2 km sliding distance; (b) Variation of wear rate as a function of reinforcement at 4 km sliding distance ; (c) Variation of wear rate as a function of reinforcement at 6 km sliding distance.

C. Friction Characteristics

The variation of coefficient of friction (μ) with sliding distances (2 km, 4 km and 6 km) for the alloy and composites at different loads (0.5Kg, 1Kg, 1.5kg) are shown in Fig.8, Fig.9 and Fig.10. It can be noted that with the addition of TiB_2 particles to the Al-10Si, the friction coefficient decreases irrespective of applied load. For both Al-10Si alloy and TiB_2 composites coefficient of friction found to be decreasing with increasing applied load. Also, coefficient of friction of the composites is less than that of the Al-10Si and decreases as the amount of TiB_2 particles increases. This demonstrates that the friction property of Al-10Si is changed by incorporating of TiB_2 particles and this could be due to the characteristics of composites such as clear interface, improved dispersion and smaller particle sizes. Thakur and Dhindaw [16] demonstrated that good Dispersion and better interface of the particle in matrix leads to a lower value of coefficient of friction. It has also been proved that the coefficient of friction is reduced by TiB_2 more effectively than SiC [14]. Recently, Min et al. [17] compared the coefficient of friction of Al/TiB2 composites with Al/SiC composites and found that it is 0.70 for Al/SiC and 0.16-0.17 for A/TiB_2. The lower μ values in the present composites in comparisons to the base alloy could be attributed to uniformly distribute fine TiB_2 particles. S. Kumar et al. [5] has also observed the same trend of decreasing the coefficient friction. The base alloy shows more fluctuation in the μ values, and these fluctuations are reduced with the addition of TiB_2 particles.

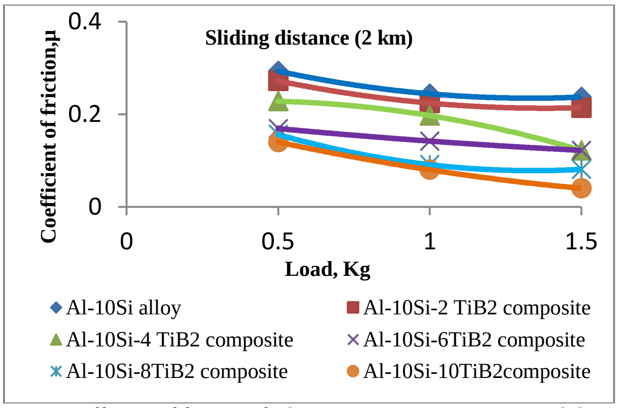


Fig.8 Coefficient of friction of Al-10Si-TiB_2 composites over a sliding distance of, 2 km.

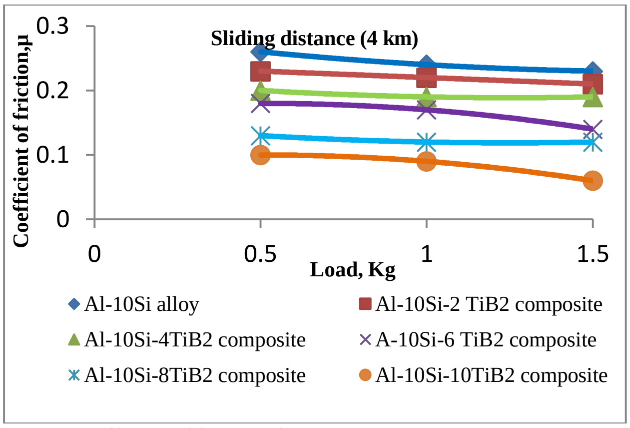


Fig.9 Coefficient of friction of Al-10Si-TiB_2 composites over a sliding distance of, 4 km.

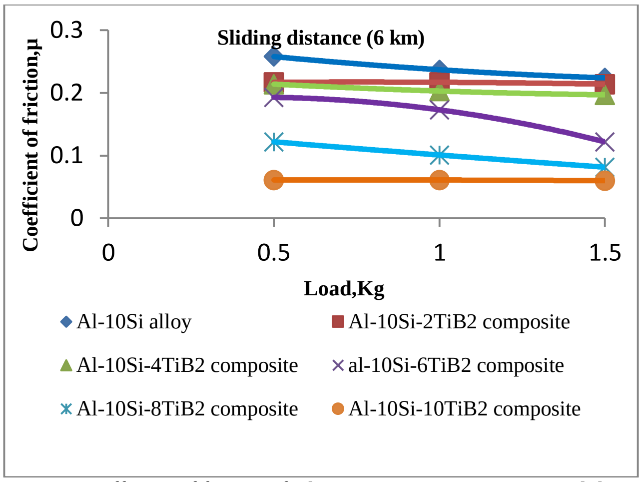
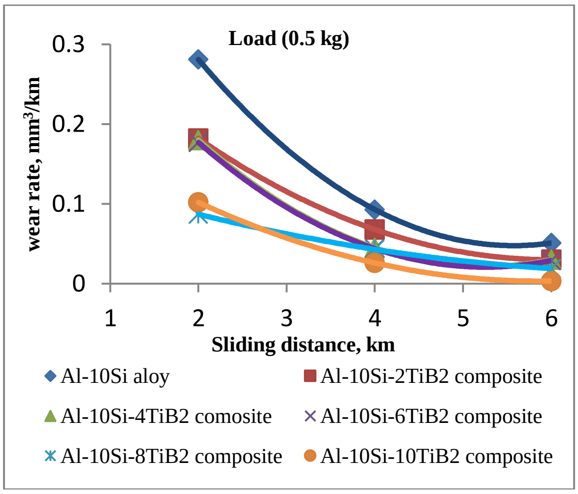


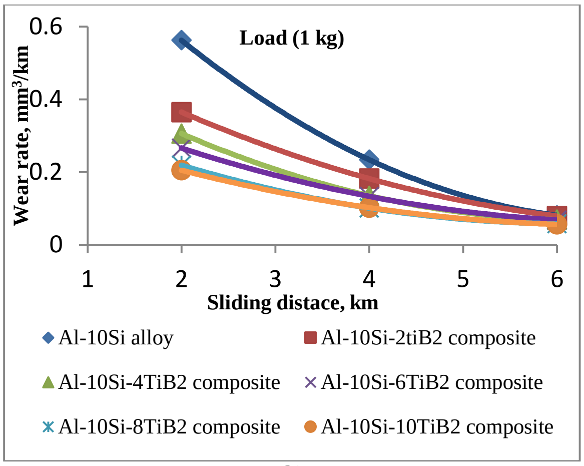
Fig.10 Coefficient of friction of Al-10Si-TiB_2 composites over a sliding distance of, 2km.

D. Effect of Sliding Distance on Wear Rate

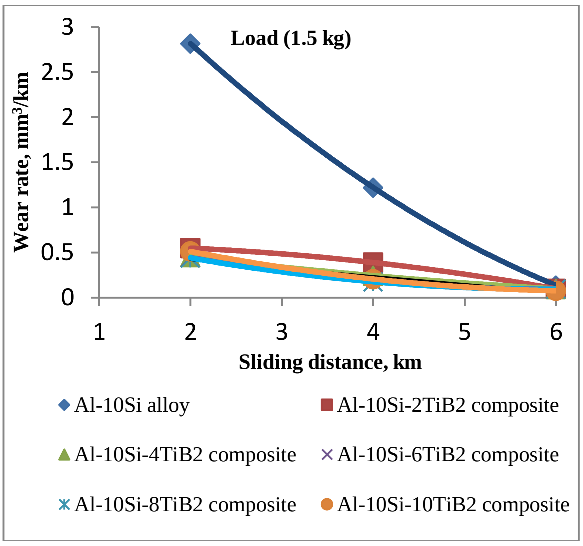
Fig.11 (a)-(c) shows the effect of sliding distance on wear rate of the Al-10Si alloy and TiB_2 composites. Wear rate decreased as a function of sliding Distance at 0.5 kg, 1 kg and 1.5 kg applied load for Al-10Si alloy and TiB_2composites. It was observed that wear rate decreased for Al-10Si alloy with increasing sliding distance from 2 km and 4 km and 6 km. Material under wear processes in materials are similar to the plastic deformation phenomenon which leads to cold working of the material. Hence the decrease in wear rate for the material under investigation is due to the strain hardening behaviour of soft - matrix in the presence of hard TiB_2 phase in the Al-10Si matrix. This lower wear rate phenomenon of the composites might be due to the presence of hard particles in the matrix alloy in addition to strain hardening phenomenon of matrix alloy. Though Al-10Si alloy shows a steady decrease in wear rate with increase in sliding distances. Since the alloy is soft (compared to the composite) and more heat conductive, the material soften at the contact area, whereas the TiB_2 composite shows a steady decrease in wear rate with increase in sliding distances.



(a)



(b)

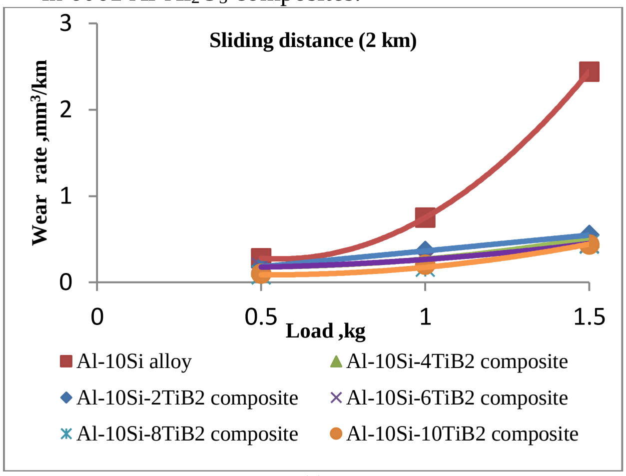


(c)

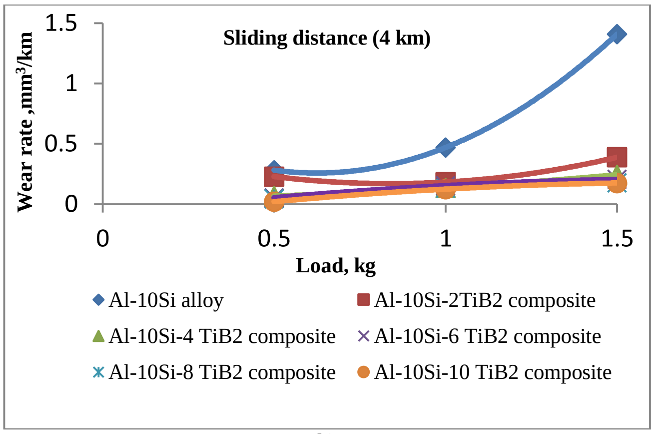
Fig.11. Variation of wear rate as a function of sliding distances of Al-10Si alloy and Al-10Si alloy-TiB_2 composites for applied loads of: (a) 0.5 kg (b) 1.0 kg and (c) 1.5 kg.

E. Effect of load on wear rate

In addition to the amount of the TiB_2 particles, the wear rate is also dependent on the applied load. Figs.12 (a)-(c) shows the variation of wear rate as a function of load for Al-10Si alloy and TiB_2 composites with loads of 0.5 kg, 1 kg and 1.5 kg at sliding distances 2 km, 4 km and 6 km. It was observed that the wear rate increases with increasing load at all sliding distances. This is due to increase in the deformation of the matrix with increase in applied load. However, the extent of deformation due to applied load is reduced with increase in the TiB_2 content. Similarly the wear rate is much lower for the composites at all sliding distances in comparison to the base alloy. This improvement is attributed to the improved strength/hardness of the composites due to grain refinement. Prasada Rao et al. [18] clearly demonstrated the improvement in wear resistance and load bearing capacity with grain refinement. At 2km, Al-10Si alloy reaches the severe wear condition at 1.5kg (Fig 12(a), (b)). In severe wear the bulk metal gets transferred from the pin to the steel counter face during sliding, the transition from mild to severe wear of Al-10Si alloy can be controlled by the increase in the weight percent of TiB_2 particles. Singh and Alpas [19] also reported similar type of transition behaviour in 6061 Al-Al_2O_3 composites.



(a)



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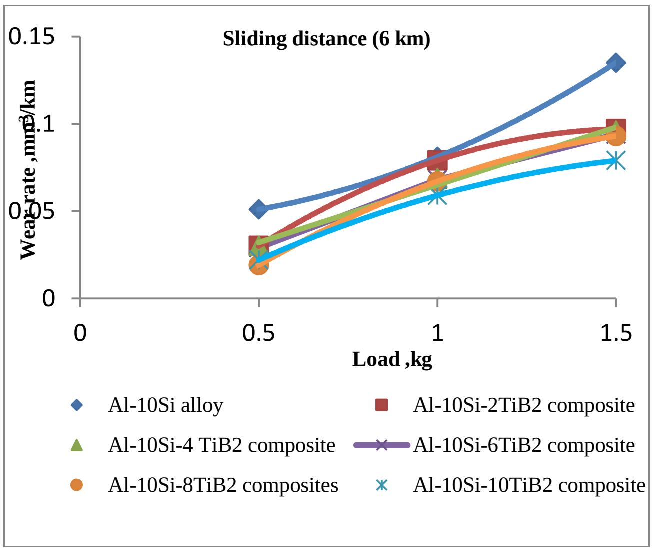

(c)

Fig.12. Variation of wear rate as a function of sliding distances of Al-10Si alloy and Al-10Si alloy-TiB_2 composites for applied loads of: (a) 2 km (b) 4 km and (c) 6 km.

F. Microscopic examination

Scanning Electron Microscopic examinations of the worn pin surfaces were carried out to determine wear mechanism.

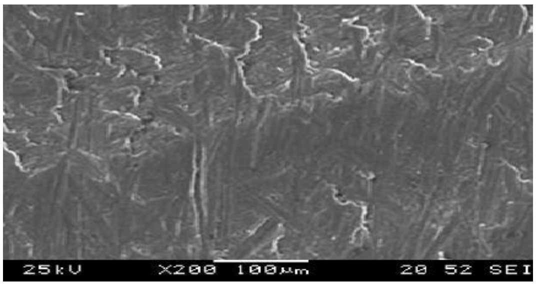

Fig.13 The worn surface of the Al-10Si- wt 2%TiB_2 with a normal load of 4.9N with 3.35m/s Sliding velocity.

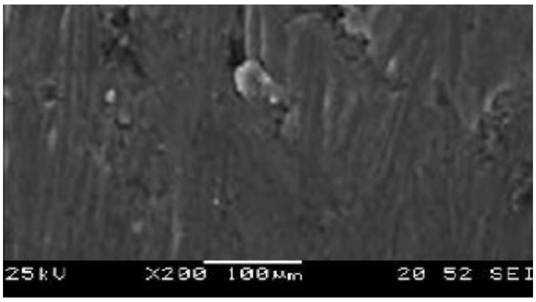

Fig.14 The worn surface of the Al-10Si-wt 10%TiB_2 composite with a normal load of 14.7N and 3.35m/s Sliding velocity.

Wear grooves and scratches along the sliding direction were smaller due to the presence of TiB_2 particulates. This shows that the presence of TiB_2 in the matrix improves resistance to wear. Applied load affects the wear behaviour of composites and is the most dominating factor in controlling the wear rate.

Since the Al-10Si alloy matrix is much softer than the stainless steel disc, the steel penetrates to larger depth into the surface and cuts severely, causing plastic deformation of the surface resulting in a great amount of material loss. The worn surface of the Al-10Si-wt 2%TiB_2 shows little plastic deformation as shown in Fig.13.

Worn surface of the Al-10Si alloy composite with 10 wt% TiB_2 was characterized by many pull-out and exposures of the TiB_2 particles and more wear debris was observed which indicated the poor interfacial strength between the Al-10Si alloy matrix and TiB_2 particles. Large grooves and scratches appeared on the worn surfaces as shown in Fig.14 and there was no indication of plastic deformation

IV. CONCLUSIONS

The following conclusions have been drawn from the above study

1. Dispersion of TiB_2 particles in aluminium alloy matrix improves the hardness of the matrix material and also the wear behaviour of the composite.
2. The resistance to wear increases with increasing TiB_2 content in all the composites..
3. With increasing TiB_2 content, the amount of particles present strengthens the matrix and hence more wear resistance was observed.
4. The metal matrix composites (MMCs) with lower weight fraction of TiB_2 underwent large wears, and the wear increased almost linearly with time.
5. The base alloy exhibits higher wear and the MMCs with 10% TiB_2 showed lower wear. The presence of hard TiB_2 particles in Al-10Si alloy matrix might be reason for the lower wear losses for composites compared to base Al-10Si base alloy.
6. Increase in the applied load as well as TiB_2 content results in the decrease in coefficient of friction (µ) for both the Al-10Si base alloy and TiB_2 composites.
7. The decrease in coefficient of friction (µ) was more for higher 10%TiB_2 content.

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