International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-4, Issue-3, March 2016

Wear Investigation of Al-SiC$_p$– Fly Ash Composites

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***Abstract*— Dry sliding wear tests of composites of aluminium, silicon carbide particles and fly ash in different weight percentages have been carried out on pin on disc machine considering a steel counterface. The weight percentage of SiC$_p$ has been kept constant at 5% where as the fly ash content was varied from 5 , 10 and 15 wt % to prepare the composites. Stir casting technique has been utilized for making samples of three different composites. Pins suitable for the pin on disc machine have been made by machining the cast cylindrical rods. Long run and short run wear tests have been conducted. The results show that for short frictional application the composite with 5 wt % of fly ash has exhibited least wear where as for long run applications the composite with 10 wt % of fly ash may be considered. At higher load and higher sliding speed composite with 5 wt % fly ash exhibited least wear. Optical micrographs of the worn surfaces have been carried out for all the specimens. This has revealed that at higher loads cavities have been formed might be due to chopping off the hard particles of reinforcements**

***Index Terms*— Aluminium- SiC$_p$-Fly Ash composites, Wear characterization**

I. INTRODUCTION

In the recent past lot of research has been carried out to replace the use of pure metal in various structures by light weight, high strength and high specific modulus, better wear and abrasion resistant composite materials. Metal matrix composites especially Aluminium composites is important in this regard due to its low density, higher corrosion resistance, durability and thermal conductivity properties etc. These composites are widely used in structural applications, automobile components; space, rocketry engineering and even house hold gadgets and interior/exterior decorations. Considering this, an attempt has been made to develop composites of aluminium utilizing the waste like fly ash. Materials like SiC$_p$ is also added to impart extra strength and hardness to the composite. A three system hybrid composite of Al-SiC$_p$ and Fly ash has been considered here as a better proposition. Further, the wear characteristics of these composites so developed may be studied for use in frictional applications. These materials can be utilized as brake linings in automobiles, railways, and engine components as fly ash will act as a solid lubricant. Therefore it has been thought proper to prepare composites by varying the percentage of fly ash and keeping the percentage of SiC$_p$ constant so that maximum utilization of thermal power plant waste can be made reducing the level of environmental pollution.

II. REVIEW OF LITERATURE

Deuis et al. [1] presented dry sliding wear theories and issues related to counter face wear and wear mechanisms of reinforcement phases in Al-SiC and Al composites. It was concluded that adhesive wear occurred due to the transfer of material from one surface to another during relative motion by a process of solid-phase welding or as a result of localized bonding between contacting surfaces. Zhiqiang et al. [2] studied the wear property of powder metallurgy aluminum matrix composites (9Si/Al–Cu–Mg). A ring on rock wear-testing machine was used to evaluate the wear properties of the composites in which a GCr15 steel ring was used as the counter face material. Silicon particle-reinforced composites exhibited reduced wear loss than the unreinforced alloy specimens. They reported that the wear loss of composites as well as the matrix alloy increased with the increase in applied load and sliding speed. The weak interface bond between silicon particle and aluminum matrix was the main reason of composite wear property change under different applied loads. Natarajan et al. [3] compared the wear behaviour of aluminium metal matrix composite sliding against automobile friction material with the conventional grey cast iron. Wear tests were carried out on a pin on disc machine using pin as brake shoe lining material and discs as Al356/25SiCp Al MMC and grey cast iron. It was observed that the friction coefficient of Al MMC is 25% more than the cast iron while sliding under identical conditions. Wear of the lining material was more when sliding against MMC disc due to the ploughing of the lining material by silicon carbide particles. Vieira et al. [4] studied the influence of centrifugal casting processing parameters on the wear of Al alloy/SiC$_p$ functionally graded composites. The wear behaviour was studied by using a ball-on-ring configuration with a high-carbon chromium steel ball as counter body. It was observed that the increase of SiC content upto 5% resulted in a fast decrease of the FGM composite wear coefficient followed by an additional, but much slow, decrease of the wear coefficient values with the incorporation of SiC particles above 5%. Further for SiC contents lower than 2% the severe wear regime was dominant, followed by a continuous transition to a mild wear regime when the highest content of SiC$_p$ is attained (36%). The dry friction and wear behaviour of 7075 Al alloy reinforced with SiC in 3D continuous ceramic network against Cr12 steel was studied by Dan et al. [5]. It was found that that the characteristic of abrasive wear and oxidation wear mechanisms were present for 3D continuous SiC/7075 Al composite. Under low load, the composite with low volume fraction of ceramic reinforcement exhibits better wear resistance due to the homogeneous reinforcement distribution with small pore size; on the contrary, under high load, the composite with high reinforcement volume fraction exhibits better wear resistance because of the coarse frame size. Radhika et al. [6] investigated tribological behaviour of aluminium alloy (Al-Si-10Mg) reinforced with alumina (9%) and graphite (3%) fabricated by stir casting process. The wear and frictional properties of the hybrid metal matrix composites were studied by performing dry sliding wear test using a pin-on-disc wear tester. Sliding distance seemed to have the highest influence on wear rate followed by applied

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load and sliding speed. It is reported that incorporation of graphite as primary reinforcement increases the wear resistance of composites by forming a protective layer between pin and counter face. The inclusion of alumina as a secondary reinforcement also has a significant effect on the wear behaviour. Prashant et al. [7] compared the mechanical and wear properties of Al6061-Graphite and Al6061-SiC composites. Composites were prepared using stir casting method in which amount of reinforcement was varied from 6-12% in steps of 3wt%. The wear resistance of the Al6061-SiC composite was found to decrease with increased filler content whereas the wear resistance of the Al6061-graphite composite decreases up to 6wt% but thereafter tends to increase. Lokesh et al. [8] investigated mechanical characteristics of fly ash and SiC reinforced Al-4.5% Cu composites. Composites were made containing 2%fly ash with 2, 4,6% SiC and 4%fly ash with 2,4,6% SiC by direct squeeze casting technique. It was found that the hardness, tensile, compression, impact and wear resistance increases with increase in percentage of fly ash and SiC. Al-4.5wt. % Cu alloy reinforced fly ash and SiC composites showed lesser wear than other composites. Anil Kumar and Hebber [9] studied the effect of particle size of fly ash on mechanical and tribological properties of fly ash reinforced aluminium alloy (Al 6061) composite samples processed by stir casting route. The tensile strength, compressive strength and hardness of the aluminium alloy (Al 6061) composites decreased with the increase in particle size of reinforced fly ash. Increase in the weight fractions of the fly ash particles increases the ultimate tensile strength, compressive strength, hardness and decreases the ductility of the composite. The wear rate decreased with the increase in particle size of fly ash particles. Alaneme and Olubambi [10]] investigated the corrosion and wear behaviour Al–Mg–Si alloy matrix hybrid composites developed with the use of rice husk ash (RHA) and alumina as reinforcements. They utilized Alumina added with 2, 3, and 4 wt.% RHA to prepare 10 wt.% of the reinforcing phase with Al–Mg–Si alloy as matrix using double stir casting process. Fluctuating OCP values were obtained for Al–Mg–Si/2 wt.% RHA–8 wt.% Al_2O_3 hybrid composite and Al–Mg–Si/4 wt.% RHA–6 wt.% Al_2O_3 hybrid composite and less for single reinforced Al–Mg–Si/10 wt.% Al_2O_3 composite. This behaviour might have been attributed due to simultaneous corrosion products formation and breakdown. Senapati et al. [11] provided some of the aspects of mechanical and abrasive wear behaviour of aluminium alloys on treating it with various reinforcements like silicon, magnesium, fibres and fly ash. It reported that when aluminium alloy treated with different reinforcements like silicon, magnesium, fibres, ceramics and fly ash are tested with different wear tests, renders improved wear properties. Siddesh Kumar et al. [12] conducted dry sliding wear test on Al2219, Al2219/B_4C & Al2219/B_4C/MoS_2 hybrid composites as per ASTM G 99-95 standard on a pin on disc apparatus. The addition of B_4C slightly reduces wear rate of composites. It was observed that B_4C and MoS_2 reinforcements decrease the wear rate of the hybrid composites and increase the wear resistance of the composites. The wear rate decreases with increasing the % of MoS_2. At a lower sliding velocity the wear rate decreases and as the sliding velocity increases the wear rate increases. As the sliding distances and load increase the wear rate drastically increases. The wear rate was more for Al2219 and lesser for addition of B_4C and MoS_2 prepared composites. Admile et al. [13] provided an extensive literature review on the overall performance of fly ash reinforced composites fabricated by stir casting. It was concluded that up to 20% Fly Ash can be added to aluminium metal matrix for better performance. Also almost all properties like tensile, compression, hardness, wear etc. improved.

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III. EXPERIMENTAL DETAILS

Sample preparation

The Stir casting method (also called liquid state method) was used for the hybrid composite materials fabrication in which a dispersed phase was mixed with a molten matrix metal by means of mechanical stirring. This has been carried out at IMMT, Bhubaneswar. The casting process was done in the following steps:

a. Pure Aluminium ingot(in proper wt%) was placed in the crucible and melted at 800°C. The reinforcements Fly Ash (11µm size) and SiCp (42 µm size) of proper wt% were preheated to 500°C and maintained at that temperature for 20 minutes in the tube furnace to remove moisture content. The weight percentages are indicated in Table1.
b. The molten metal was stirred to create vortex and the preheated reinforcements were slowly added to the molten metal maintained at 800°C, with continuous stirring at a speed of 350 rpm for 6 minutes.
c. Then the melt with the reinforcements were poured in to the mould to get castings of 20 mm diameter and 150 mm long.
d. It was left for 3 hrs. to get solidified before withdrawing it from the mould.

Three nos. of samples were manufactured in the stir casting process having different composition (wt %) as listed in the Table 1.

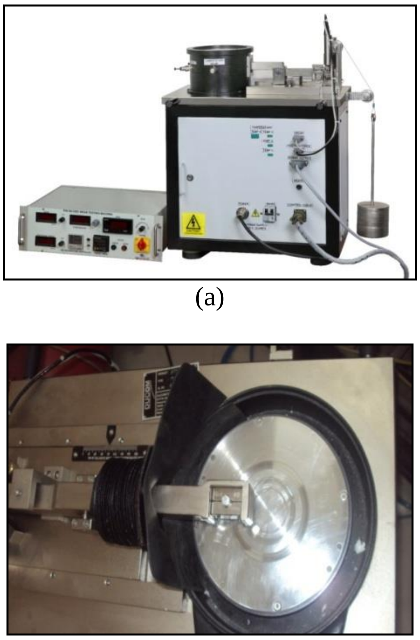
Table 1 Samples and their compositions

Samples	Composition
C1	Al + Fly Ash (5 wt %) + SiC_p (5 wt %)
C2	Al + Fly Ash (10 wt %) + SiC_p (5 wt %)
C3	Al + Fly Ash (15 wt%) + SiC_p (5 wt%)

Wear Tests

To study the wear characteristics of the composite, samples of 8 mm diameter and 30 mm length were used (Fig.1) prepared by machining the cast samples. The wear tests were performed in the Pin-on-disc type friction and wear monitor (DUCOM; TL-20, Fig 2 a&b) with data acquisition system, The disc was hardened ground steel (EN-32) having hardness 65HRC and surface roughness (Ra) 0.5 µm. Load was applied on pin (specimen) by dead weight through pulley string arrangement. Weight loss principle was adopted for calculation of wear.

Fig.1 Samples for wear test



(a)

(b)

Fig.2 (a) Pin on disc apparatus, (b) Magnified view of pin on disc

IV RESULTS AND DISCUSSION

At first the coefficient of friction for each sample (C1,C2 and C3) was found by varying the load from 10 N to 50 N with sliding speed of 400 rpm of the steel disc. The different values obtained are plotted in Fig.3. It is observed that the coefficient of friction for all the composites initially decrease and then increase with increase in load. Further wear tests were carried out to study the dry abrasive wear behaviour of the composites. Different plots like wear vs time, wear rate vs load,sliding distance vs load and wear rate vs speed etc. were drawn.

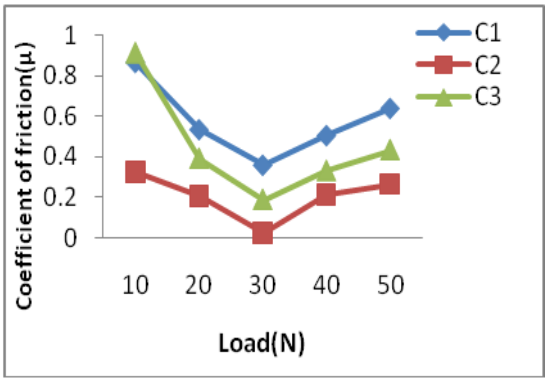
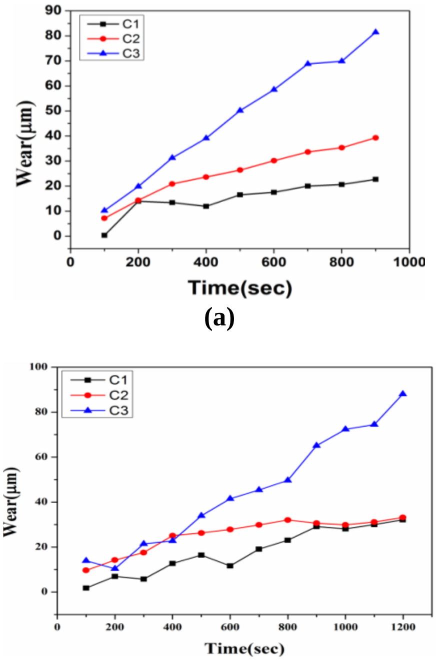


Fig.3 Variation of coefficient of friction with load

Variation of Wear (μm) against Time (sec)

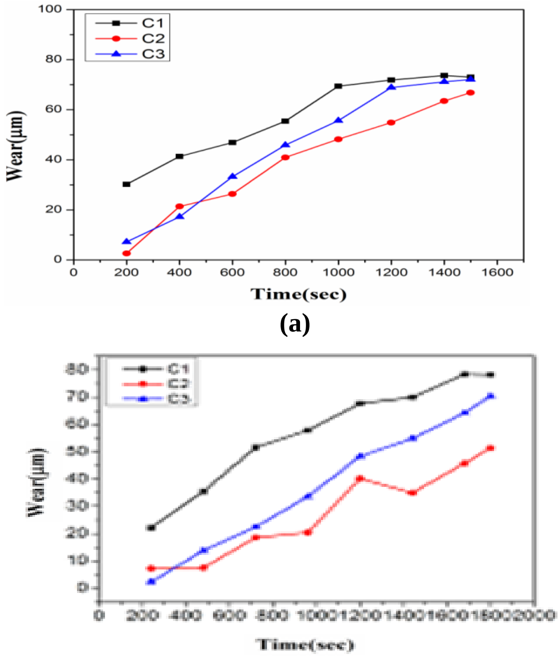


(a)

(b)

Fig. 4 (a) Short run wear tests (Load -20 N, Time -15 min) and (b) Load-30 N, time-20 minutes

From the graph of short run wear tests (Fig. 4 a and b) it is clear that the composite(Al-SiC$_P$5wt%-Fly ash15wt%) shows higher wear as compared to two other composites. It can be attributed to the presence of more wt% of fly ash or may be due to poor bonding of the reinforcements with the matrix.



(a)

(b)

Fig. 5 (a) Long run wear tests (Load- 40 N, Time-25 min) and (b) Load-50 N, time-30 minutes

In case of long run wear tests (Fig. 5 a and b), the composite C1 (Al-SiC$_P$5wt%-Fly ash 5 wt%) shows higher wear where as the composite C2 (Al-SiC$_P$5wt%-Fly ash10wt%) shows least wear.

Variation of wear rate against load

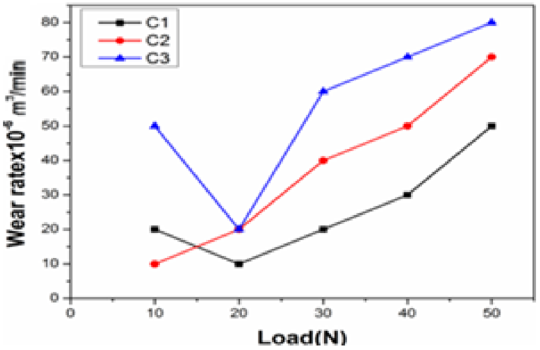


Fig. 6 Wear rate against Load

From the plot (Fig.6) it is evident that at lower load the composite C3 (Al-SiC$_P$5wt%-Fly ash 15wt%) shows higher wear rate as compared to other two composites. However the composites C1 and C2 (Al-SiC$_P$5wt%-Fly ash5wt% and Al-SiC$_P$5wt%-Fly ash 10 wt%) show nearly equal wear rate at initial conditions. When load increases, wear rate increases for all the three composites in a proportion with fly ash contents of the composites. Least wear rate was observed with sample C1.

Variation of volumetric wear against load

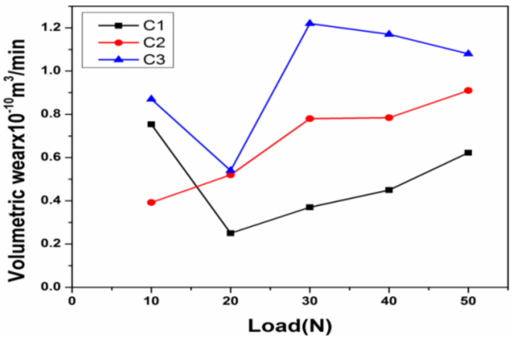


Fig. 7 Variation of volumetric wear against load

The variation of volumetric wear rate vrs load (Fig.7) shows that volumetric wear rate increases in direct proportion with load. The composite C3 (Al-SiC$_P$5wt%-Fly ash 15 wt%) has higher volumetric wear rate at higher load as compared to other composites.

Variation of wear rate against sliding distace

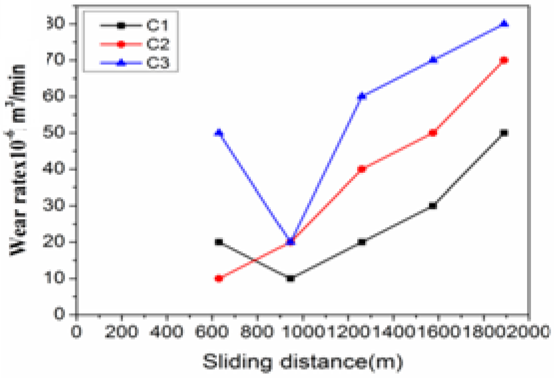


Fig. 8 Variation of wear rate against sliding distace

The plot for wear rate vrs sliding distance (Fig.8) indicates that the wear rate increases with increase in sliding distance. The composite C1 (Al-SiC$_P$5wt%-Fly ash5wt%) shows least wear rate and the composite C3 (Al-SiC$_P$5wt%-Fly ash 15wt%) shows higher wear rate at higher sliding distance.

Variation of wear rate against speed

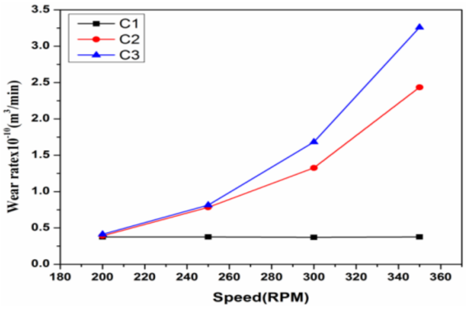
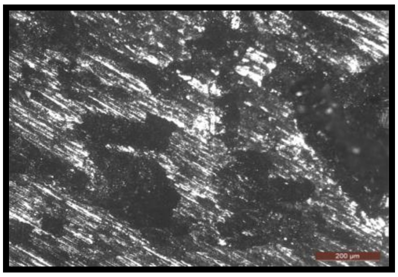


Fig. 9 Variation of wear rate against speed

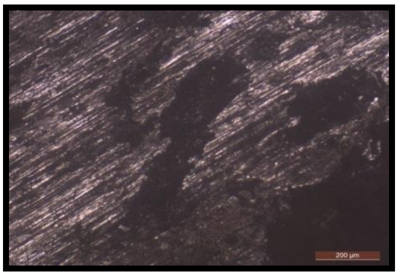
As the speed increases at constant load (Fig.9) , the composite C1 shows constant wear rate against speed. But the composite C3 shows higher wear rate as compared to other composite. The results obtained from short run wear tests (Fig. 4 a and b) indicate that composite with 5 % fly ash is having least wear in comparison to others when slid against steel disc for 15 minutes and 20 minutes under constant load and speed. However during long run tests of 30 minutes or so composite with 10 % fly ash exhibited least wear (Fig.5, a,b). From the plot of variation of wear rate and volumetric wear against load at constant speed it is evident that the composite with 5 % fly ash is having minimum wear (Fig. 6 and Fig.7). At higher sliding distances around 2 km (Fig. 8) the same composite is showing wear behaviour better than others and expected to attain steady state beyond this distance. In any case at higher speeds (Fig. 9) the composite with 5% fly ash is also having least wear rate.

Optical micrograph of worn surface

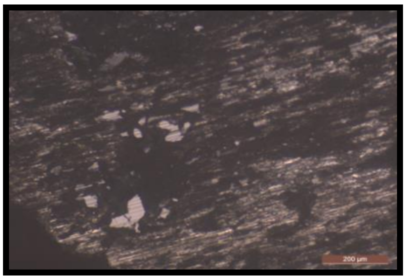
The optical micrographs were taken for three composites sliding at constant speed of 400 rpm with varying load and time. The micrographs have been shown as under.



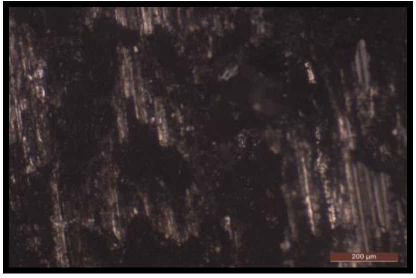
(a) C1-10N,10 min.



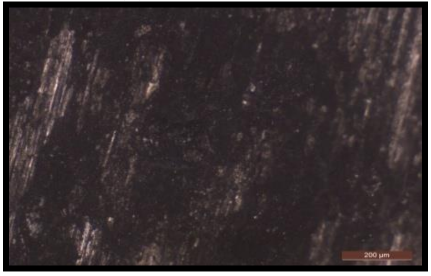
(b) C1- 20N,15 min



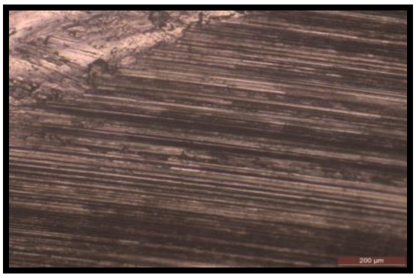
(c) C1- 30N, 20 min.



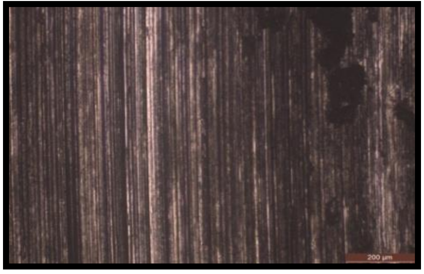
(d) C1- 40N,25 min.



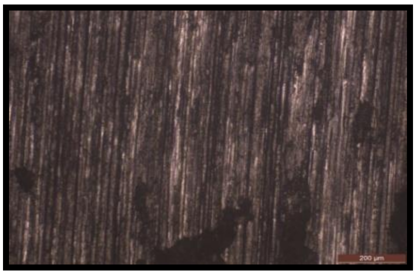
(e) C1-50N,30 min.



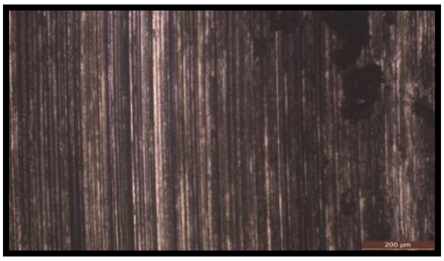
(f) C2-10N,10 min.



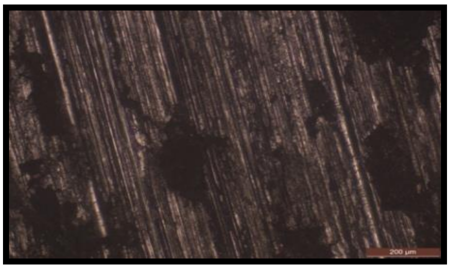
(g) C2-20N,15 min.



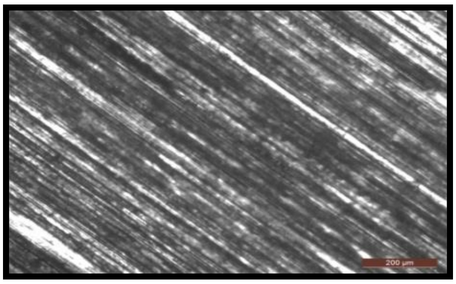
(h) C2- 30N,20 min.



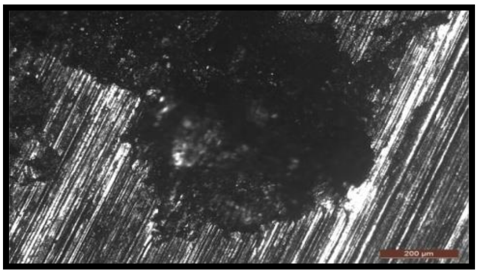
(i) C2-40N,25 min.



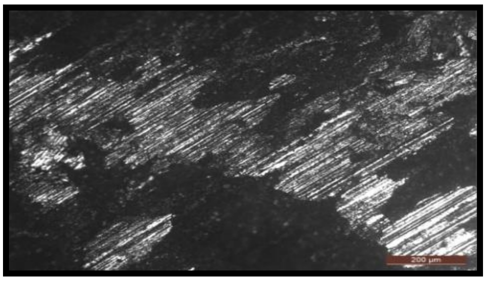
(j) C2-50N,30 min.



(k) C3 -20 min,30 N



(l) C3- 25 min,40 N



(m) C3- 30 min,50 N

Fig. 10, (a)-(m) Optical micrographs of worn surfaces.

The worn surfaces of all the three specimens (C1, C2 and C3 respectively) were observed under optical microscope. Figure 10, (a)-(e) show the worn surfaces of the composite C1 (Al+5%SiC$_P$+5%Fly Ash) under load conditions of 10N, 20N, 30N, 40N and 50N. The worn surface of the composite (C1) under 20N load seems clear and somewhat parallel to the sliding direction. Under other load conditions, the worn surfaces of the composite (C1) shows the formation of cavities. This may be due to the fact that, some reinforcement particles might have been chopped off during sliding. The worn surfaces of the composite C2 (Al+5%SiC$_P$+10%Fly Ash) show {Fig.10 (f)-(j)} that under load 10N wear is parallel to the sliding direction and there is no cavities formed. With increase in loads from 20N to 50N, more cavities were found. There are more cavities at load of 50N and aligned parallel to the sliding direction. Figure 10,(k)–(m) show the worn surfaces of the composite C3 (Al+5%SiC$_P$+15%Fly Ash) under loads of 30N,40N,50N. From the micrographs it is clear that the worn surface of the composite (C3) under 30N is parallel to the sliding direction and under loads of 40N and 50N, cavities were found. There are more number of cavities at load of 50N, and this might be due to the chopping off of hard particles during sliding.

V. CONCLUSIONS

Different wear tests were carried out to study the dry abrasive wear behavior of the composites. Different plots like wear vs time, frictional force vs time, wear rate vs load, volumetric wear rate vs load, wear rate vs sliding distance, volumetric wear rate vs speed were drawn. The composite with 5wt% Fly Ash exhibits least wear in comparison to other composites when slid against steel disc for 15 and 20 minutes under constant load and speed. On the other hand the composite with 10wt% Fly Ash exhibits least wear when run for 20 and 30 minutes. From the plots of wear rate (N/m) and volumetric wear rate (N/m^3) vs load, it is clear that the composite with 5wt% Fly Ash is having least wear. For higher speeds, the same composite is showing better wear behavior. Frictional force at higher load of 50N is much less for composite with 10wt% Fly Ash in comparison to other composites. The optical micrographs reveal that, the composite with 10wt% Fly Ash has less cavities as compared to other composites. It is concluded that for short frictional application the composite with 5 wt % of fly ash i.e sample C1 is suitable where as for long run applications the composite with 10 wt % of fly ash (sample C2) may be considered. At higher load and higher sliding speed composite with 5 wt % fly ash (C1) exhibited least wear. Optical micrographs of the worn surfaces have been carried out for all the specimens. This has revealed that at higher loads cavities have been formed might be due to chopping off of the hard particles of reinforcements.

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(Biomedical and Natural), Machine Design, Entrepreneurship management, Manufacturing, ANN etc.
Membership – LMISTE, MIE, LMSBAOI, Senior Member IACSIT
Achievements – Former Director of Indira Gandhi Institute of Technology, Nine years of industry experience in M/s Larsen and Toubro Ltd., Best Engineering College Principal of Odisha- 2010 by ISTE, Rajiv Gandhi Sadbhavna award, Rashtriya Vidya Saraswati Puraskar and Adarsh Odia. Delivered lectures at various engineering colleges, Expert member AICTE, NBA, UPSC and OPSC etc