International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

Dry Sliding Wear Characteristics of Fly Ash Reinforced AA2024 Based Stir Cast Composite

Shivaprakash.Y.M[*a], K.V.Sreenivasa Prasad[b] and Yadavalli Basavaraj[c]

[a]Department of Mechanical & Manufacturing Engineering , Manipal Institute of Technology, Manipal, Manipal University, Karnataka, India
[b]Department of Industrial & Production Engineering, Sri.Jayachamarajendra College of Engineering, Mysore, Visvesvaraya Technological University, Karnataka, India
[c]Department of Mechanical Engineering, Ballari Institute of Technology and Management, Bellary, Visvesvaraya Technological University, Karnataka, India

Accepted 25 July 2013, Available online 01 Aug. 2013, **Vol.3, No.3 (August 2013)**

Abstract

Of the many different types of particulate reinforcements tried out in the recent times for producing composite, fly ash is the cheapest and abundantly available waste by product from the combustion plants. Keeping in mind the environmental hazards of fly ash it has been used for producing composites besides for brick and cement manufacturing. Generally the physical and chemical nature of fly ash varies depending upon source. In the present investigation, Precipitator type fly ash having particle size below 45 µm is collected from JSW steels, Bellary, Karnataka, India at atmospheric temperature and composite were produced by reinforcing it in the wrought aluminium alloy AA2024.The motorized stir casting setup has been employed to fabricate the composite samples containing 2.5, 5, 7.5, 10 and 15 % by weight of fly ash. Non heat treated alloy and composite samples were tested for dry sliding wear behaviour in pin-on-disc machine. For each specimen the wear test is conducted by varying the speeds (200,300 and 400 rpm) and by applying different normal loads like 10, 25 and 35 N in the laboratory conditions. 60, 70 and 80 mm track diameters were selected for the entire test. For determining the wear mechanism of composite, the worn surfaces were examined using Inverted metallurgical microscope. Experimental results indicated a good improvement in the wear resistance as the content of fly ash reinforcement is increased in the matrix

Keywords: *stir casting, fly ash composite, pin-on-disc machine, dry sliding wear.*

1. Introduction

Among many types of matrix materials for composites aluminium and its alloys are the most favorite material for producing metal matrix material. Aluminium-alloy-based composites are very attractive on account of their processing flexibility, wide range, low density, high wear resistance, high thermal conductivity, heat-treatment capability, improved elastic modulus and strength, stiffness and dimensional stability.

To overcome the environmental hazards of fly ash and to take advantage of its low cost, low density and abundant availability as waste by product from the combustion plants it can be used as another reinforcement to widen the engineering applications of particulate composites.

Aluminum–fly ash composites have potential applications as covers, pans, shrouds, casings, pulleys, manifolds, valve covers, brake rotors, and engine blocks in automotive, small engine and the electromechanical industry sectors (T.P.D. Rajan *et al* 2007).

Incorporation of fly ash particles in aluminium metal/alloy will definitely promote the use of this low-cost waste by-product and, at the same time, has the potential for conserving energy intensive aluminium and thereby, reducing the cost of aluminium products.

The objective of present investigation is to study the wear performance of aluminium-fly ash composite. The results of this research can act as reference for exploring the new wear resistive applications.

In the last two decades many researchers have studied the wear behavior of aluminium and aluminium based composites, the summary of their work is as follows.

(M.K.Surappa *et al* 1982) have studied the wear and abrasion of composites with cast aluminium and Al-Si as matrix reinforced with γ-Al_2O_3 particles of size 100 µm dispersed up to 5% by wt in the matrix by stir casting technique. Their results indicate that adhesive wear rate of aluminium and Al-Si alloys decrease as Al_2O_3 particles are added and the abrasive wear rate of aluminium is less than that of Al-Si alloys. As the wear properties of matrix are improved they have proposed that Al_2O_3 can be a good substitute for expensive silicon. (Manish Narayan *et al* 1995) have fabricated the composite consisting of Al alloy

*Corresponding author: Shivaprakash.Y.M

2024 as matrix with Al_2O_3 as reinforcements (average size, 18 µm) by stir casting. The quantity of reinforcement being 15% by volume. They have noticed that composites exhibited better seizure resistance than the unreinforced ones in peak aged conditions and in as extruded conditions the wear resistance of unreinforced alloy was better than the composite. (Rong Chen *et al* 1997) have also employed the stir casting technique to develop NiAlp/Al and SiCp/Al composites containing 5% and 10% volume fractions of reinforcement particles. The composites were tested for dry sliding wear behavior. Their results show that the wear rate is more for SiCp/Al composites compared to unreinforced aluminium alloy against a steel counter surface for the load range 3.5-82.7 N. Wear rate increased with increase in volume fraction of SiC particles. The wear rate is less for NiAlp/Al composites as compared to unreinforced aluminium alloy against the same counter surface.(X.Y. Li and K.N. Tandon 1997) casted composite by dispersing SiC particles (size 5-10µm, 20% by volume) in A356 matrix to study the subsurface microstructures produced by dry unidirectional sliding wear in non-heat treated and heat treated conditions. The findings of this group is that the wear resistance of as cast composite was slightly increased by heat treatment (T6).In situ precipitation was found to occur during the sliding wear of as cast aluminium composite and coarsening of age hardened precipitates was observed during the sliding wear of thermally aged composite.(Szu Ying Yu *et al* 1997) have produced SiC whisker and SiC particulate reinforced 6061 aluminum alloy composites by high pressure infiltration technique to study the temperature dependence of sliding wear behavior. The researchers observed that wear resistance of matrix was increased by reinforcing SiC both at room and elevated temperature with critical load being decreased with increase of temperature. (P.H. Shipway *et al* 1998) have studied the sliding wear phenomenon of three types of composites (with commercially pure aluminium, wrought Al-4Cu alloy and cast alloy, A356 as matrix) with TiC (average size, 10 µm) as reinforcements. The composites were produced by novel casting technique. The results shows that wear rate of all composites have decreased due to addition of TiC particles. These particles even delayed the transition with load from low wear coefficient to high wear coefficients. (M. Singh *et al* 1999,2001) have stir casted composite specimens by dispersing granite particles (size 50-150 µm and 10% weight) in LM6 aluminium alloy to study the abrasive wear and dry sliding wear characteristics. The results show that abrasive wear rate is less for composite as compared to unreinforced alloy when abraded against finer abrasive particles over the entire loading range. Similar trends were seen when abraded against coarse particles but at lower load. But at higher load and with coarse particles the trend was reverse. Abrasive Wear rate was decreased with sliding distance while wear rate increased as load is increased. The sliding wear rate has increased with applied pressure where as wear rate decreased with speed for composite except at maximum speed at high pressures. The seizure pressure of composites increased over the matrix alloy and it decreased with sliding speed. Friction heating and friction coefficient were more in matrix alloy than in composite. (Hülya Kaçar *et al* 2003) have carried out the sliding wear tests on wrought aluminium alloy 2024 to know the effect of precipitation hardening. The alloy specimens for wear test were aged in different temperatures and periods. SiC water proof emery papers of different abrasive grit sizes were employed to carry wear test at different sliding speeds and loads. The results show that maximum wear resistance is for natural aged specimen at room temperature for 1 week. The mass loss increased with increase in grit size, sliding speed and applied load. (Sug Won Kim *et al* 2003) developed Al–Si–Cu–Mg–(Ni)/SiCp composite by duplex method to know heat treatment and wear characteristics.3, 5 and 10 µm size of SiC particles were used for composite specimens. The composite with 10 µm is found to exhibit low wear rate as compared with composite containing 3 and 5 µm. The wear rate of composites of all the three particle size category of SiC was found to decrease with increase in sliding speed. The investigation of (C.S. Ramesh *et al* 2005) was to predict the wear coefficient of Al6061-TiO_2 composite produced by stir casting with TiO_2 being varied from 2 to 10% weight in matrix. Increased content of TiO_2 resulted in low wear coefficient of composite. At higher load and sliding distances the wear coefficient of all the composites decreases. (R.K. Uyyuru *et al* 2006) have studied the effect of reinforcement (SiC) volume fraction and size distribution on tribological behavior of Al-composite/brake pad tribo-couple. Their results show that wear rate increases with increase in normal load and decreases with increase in sliding speed. Friction coefficient decreases with increase in normal load and sliding speed. Wear rate and friction coefficients are higher when the reinforcement in the matrix has wide size distribution compared to the composite containing mono size reinforcement. (C.S. Ramesh and Mir Safiulla 2007) employed stir casting method to produce three different types of composites with matrix being Al6061.Three reinforcements like SiC(20-30µm),Al2O3(20-25µm) and cerium oxide(5µm) were used with variation in the range 4-8% by weight. The cast composites were hot extruded to carry out the dry sliding wear test. The results indicate that the wear rate decreases with increase in contents of reinforcements for both cast and extruded composites. The extruded composites exhibited lower wear rate as compared to the cast composites.Al6061-cerium oxide composites possessed lower wear rate as compared to other two composites. (M. Kok and K. Ozdin 2007) adapted the stir casting method to produce Al2024-Al_2O_3 composite. The weight percentage of reinforcement being 10, 20 and 30.The composites were tested for dry sliding with counter face being SiC abrasive paper of 600 grit, 320 grit and 240 grit under the applied normal loads of 2 and 5N.The researchers found that wear resistance of composites is higher than the unreinforced Al2024.Wear resistance increased with increase in Al_2O_3 particle content and size. The wear resistance decreased with increase in sliding distance, wear load and abrasive grit size. Particle size is found to effect wear resistance significantly than the content. (Shaoyang Zhang and Fuping Wang 2007) have made a comparative study of wear and friction properties of two types of Al alloy-SiC composite with that of same braking material. The size of SiC particles in two composites are 3.5 and 34 µm respectively with 25% by volume content in both. Composite with larger size of particles of reinforcements is found to exhibit better friction performance and wear resistance. With increase in load and speed friction coefficient decreased in both the cases .Also specific wear decreased as load and speed increased, but increased with temperature. (M. Ramachandra and K. Radhakrishna 2007) have reinforced fly ash particles (10µm,density 1.36 gm/cc added up to 15% by weight in steps of 5) in Al (12 wt% Si) by stir casting technique to study the two body sliding wear behavior in non-heat treated conditions. Their results show that as reinforcement content is increased the wear resistance increases and coefficient of friction reduces. Magnitude of wear and friction force increases as normal load sliding velocity is increased. Abrasion, oxidation, delamination, thermal softening and adhesion type wear mechanisms were observed as normal load, % fly ash and sliding velocity are varied during the test. (Ranjit Bauri and M.K. Surappa 2008) have studied dry sliding wear of as extruded and peak aged Al8090-SiCp composites. The conventional stir casting technique was used to cast composites containing 8, 12 and 18% volume of SiC particles of average size 40 µm. Compared to unreinforced alloy as extruded composites exhibited better wear resistance. But peak aged unreinforced alloy showed better wear resistance as compared to as extruded composite. Beyond 20 N a low wear resistance of peak aged composites is observed as compared to as extruded ones. (Sudarshan and M.K. Surappa 2008) fly ash of narrow size range (53-106 µm) and wide size range (0.5-400 µm) are used in 6 and 12% by volume to disperse in A356 alloy to produce composite by stir casting technique. Dry sliding wear behavior is studied for 10,20,50,65 and 80 N load. The findings of the researchers are that up to 80 N composites exhibited good wear resistance than the unreinforced alloy. The wear resistance of composite containing narrow size range of particles was superior as compared to the composite containing wide range of fly ash particles. (R.N. Rao *et al* 2009, 2010) fabricated composite using stir casting method by reinforcing SiC particles (size range of 20-40 µm ,content 10,15 and 25 % by weight) in aluminium alloy(Al-Zn-Mg).The dry sliding wear test results indicate that wear rate increased with the applied pressure, wear resistance of alloy improved with the addition of SiC particles, wear rate of composite is low as compared to alloy and wear rate of composite decreased with increase in SiC concentration. Further the same researchers extended their work and carried out dry sliding wear tests on the same alloy and composite in the heat treated condition. The alloy and composite aged for 6 hours shows peak hardness and hence maximum wear resistance. But materials aged for 4 hours exhibited lowest hardness. (Adel Mahamood Hassan *et al* 2009) adopted slurry casting method to produce aluminium alloy(Al-Mg-Cu) based matrix containing SiC particles (average particle size 75 µm , 5 and 10 % by volume) as reinforcements. The results show that volume loss for alloy decrease continuously up to 5% and dispersion of SiC particles played a major role in improving the wear resistance of composite system. (S. Suresha and B.K. Sridhara 2010) produced Al–SiC–Gr hybrid composite and Al–SiC composite by stir casting. Combined SiC and Gr % weight in hybrid composite was 2.5, 5, 7.5 and 10% where as for Al-SiC composite SiC % weight alone varied as 2.5, 5, 7.5 and 10%, LM25 is the matrix alloy. The both the types of composites were subjected to dry sliding wear test and the results show that hybrid composites exhibited better wear characteristics than the composite with SiC particles alone. The wear has increased due to increase in either load or sliding distance or both. But increase of speed caused decrease in wear. (R.N. Rao and S. Das 2010) have studied the sliding wear characteristics of alloy and composites prepared by reinforcing SiC particles (size range 20-40 µm, content range 0-25% weight) in AA7010, AA7009 and AA2024 using stir casting technique. Their results show that wear resistance of composites are higher than the alloys. Among matrix material AA7010 alloy exhibited maximum wear resistance than the other. (P.K.Rohatgi *et a*l 2010) have also employed stir casting technique and produced silica sand (9 and 13% by weight) dispersed A206 aluminium alloy based , A206+Mg-5% weight metal matrix composite to study the tribological characteristics. The test results show that friction coefficient of Mg modified A206 alloy decreased with the addition of silica particles. Wear rate of composites increase with increase in silica content from 0 to 13% by weight and also with increase in applied pressure. Heat treatment to T6 condition did not decrease the friction coefficient or the wear rate much in all the category of composite and A206 matrix alloy. (G. Naveen Kumar *et al* 2010) AA6351-xZrB_2 (x = 0, 3, 6 and 9 % weight) in situ composites prepared by reaction of mixture of K_2ZrF_6 and KBF_4 with molten aluminium alloy at a reaction temperature of 850^oC.The dry sliding wear test were carried at room temperature on composites in as-cast, the solutionized and the solutionized-aged conditions. The results show that wear rate was decreased with increase in weight % of ZrB2 and wear resistance was increased with increase in content of ZrB2 in composite before and after heat treatment. (R.N. Rao and S. Das 2010, 2011) synthesized composite with aluminium alloy (Al-Zn-Mg-Cu) as matrix and SiC particle (size range 20–40 µm, content 25% by weight) using stir casting technique. The composite is tested for dry sliding wear behavior in the heat treated condition. The results show that the wear coefficient decreases to minimum and then increases with increase in applied pressure. The measured wear rate data were compared with calculated wear rate at different loads and sliding speeds. A good agreement of calculated values with the theoretical values is seen implying the reliability of sliding wear test procedure. Further the same researchers studied the effect of variation of SiC content (10, 15 and 25% by weight) and sliding speed (0.52, 1.72, 3.35, 4.18 and 5.23 m/s) on the wear performance of alloy and composite. The results show that as content of SiC is increased the wear rate and temperature decreases, but for coefficient of friction reverse trend is seen.(V.S. Aigbodion and S.B. Hassan 2010) fabricated composite specimens by reinforcing 10% weight of bagasse ash particles(average size 63 µm) in Al-Cu-Mg alloy by double stir casting method. The results show that applied load affects the wear rate significantly than the sliding speed in both alloy and composite. But relative contribution of sliding speed in wear behavior of the alloy is higher than the applied load. (C.S. Ramesh *et al* 2010) used stir casting method to reinforce nickel coated alpha type silicon nitride particles(size 2-20 µm, content 4 to10% by weight in steps of 2% by weight) in Al6061 alloy matrix to obtain composites for wear and friction characteristics study. Their results show that Al6061-Ni-P-Si_3N_4 composite exhibited lower coefficient of friction and wear rate as compared to matrix alloy. For increase in sliding velocity coefficient of friction of both alloy and composite increase continuously. Wear rate of both alloy and composite increased with increase in both load and sliding velocity. (G.B. Veeresh Kumar *et al* 2012) studied the wear properties of SiC dispersed Al6061 alloy based composite. Content of SiC was 2-6% by weight with particle size 150 µm. The results show that wear resistance of composites has improved due to addition of SiC particles. The volumetric wear loss is found to be higher for increased applied load and sliding distances. (S. Gopalakrishnan and N. Murugan 2012) used enhanced stir casting method and reinforced TiC in AA6061 alloy matrix to produce Al-TiCp composites. These authors found that the wear loss increased linearly with the normal load and wear rate increased marginally with increase in content of reinforcement. Further it is proposed that the enhanced stir casting is the better method to produce such composites as wear in terms of volume loss is found to be lower than the earlier studies done by other researchers. (M. Uthayakumar *et al* 2013) synthesized hybrid composite by stir casting technique. The composite contained 1100 aluminum alloy matrix holding SiC (5 % by weight, average 10 µm size) and B_4C (5% by weight, average 65 µm size) particles. The wear tests are performed on such composites over a wide load range 20-100 N. The results indicate that wear resistance of composite was good up to a load of 60 N and sliding speed range 1-4 m/sec. (Xiaoliang Shi *et al* 2013) studied the friction and wear behavior of in situ NiAl–10 wt%Ti3SiC2 composites (NAT) and their results show that friction coefficient decreased and wear rates increased with increase in load but both decreased with increase in sliding speed. Transition from mild to severe wear mode is strongly influenced by sliding speed and load. (A. Devaraju *et al* 2013) have studied the influence of reinforcements (SiC and Al_2O_3) and rotational speed on wear and mechanical properties of aluminum alloy 6061-T6 based surface hybrid composites produced via friction stir processing. (C.A. Leon-Patino *et al* 2013) prepared Al–Ni/SiCp composite by directional infiltration and have studied for the dry sliding wear behavior in the applied load of 103 and 145 N, 0.3 and 0.9 m/sec sliding velocity for a total sliding distance of 2000 m. It is observed from the results that higher wear loss occurred at higher loads and on the other hand lower wear loss are seen for higher velocity. (K. Umanath *et al* 2013) produced Al6061/SiC/Al_2O_3 hybrid composites by stir casting and studied the dry sliding wear behavior. The results show that wear resistance of composite containing 15% hybrid composite is superior to 5% hybrid composite. (A. Baradeswaran and A. Elaya Perumal 2013) have dispersed 5, 10, 15 and 20 % volume of B_4C particles (16 µm to 20 µm) in 7075 aluminium alloy and produced the composite which were successively tested for tribological properties and their results indicated that wear rate of composites is less than that of unreinforced alloy this is because of increase in wear resistance with increase in the content of B_4C. (Naresh Prasad *et al* 2013) used pure aluminium (IE-07 grade) as matrix material and red mud particles (10, 15, 20, 30% by weight, size 150 µm) as reinforcements to produce composites by stir casting. The composite specimens were tested for dry sliding wear behavior in pin-on-disc machine. The results of this research show that an improvement in wear behavior because of dispersing the red mud particles. Co-efficient of friction decreases as load increases. At higher load and higher speed specific wear rate decreases as the content of red mud is increased. Wear coefficient tend to decrease with increase in particle volume content. Wear resistance is found to significantly improve because of addition of red mud particles.

2. Experimental

2.1. Materials

2.1.1 Fly ash Reinforcement

The precipitator type fly ash is used as reinforcement for the present investigation which is a gray colored fine powder with the particle size below 45 µm and with density 1.1902 gm/cc. The fly ash samples were subjected to chemical analysis as per IS: 1727-1967 RA 2004 and the detailed chemical composition is as shown in Table-1.

Table 1 Chemical composition of fly ash

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI*
% Wt	26.73	24.94	18.10	7.43	2.075	2.81	0.0648	0.0493	2.62

*LOI=Loss On Ignition

2.1.2 Aluminium alloy Matrix

The aluminium alloy selected for the matrix material is AA2024 whose chemical composition is as shown in Table-2.The density of as received alloy was 2.77 gm/cc.

The alloy ingots were supplied by Manufacturing Metallurgy & Management Training Institute, Materials Research Centre, Bangalore, Karnataka, India.

Table 2 Chemical composition of wrought AA2024 alloy

Element	Si	Mg	Cu	Mn	Fe	Ni	Ti	Zn	Pb	Sn	Al
% Wt	0.5	0.066	4.51	0.13	0.663	0.075	0.013	0.118	0.029	0.021	Rest

2.2. Casting of composites

About 3000 grams of blocks of AA2024 was melted in a graphite crucible by electric resistance furnace of 5 kW rating. The melt temperature was raised to 850^{o}C and the scum powder in small quantities is added to the melt to remove the slag or flux. The total melt is then degassed by adding dry hexa chloroethane tablet weighing 10 grams (C_2Cl_6, 0.3 % by weight). The fly ash particles were preheated to 400^{o}C for 1 hour to remove the moisture before adding into the melt. After degassing, preheated fly ash particles with different % by weight were added to the vortex formed in the melt by stirring. A mild steel stirrer with vertical axis was used. The rpm of the stirrer was maintained at 350-400 and stirring is continued for about 10 minutes to allow for proper mixing of the fly ash in the melt. During stirring small pieces of magnesium (0.5 % by weight) were added to molten metal to improve the wettability of fly ash particles with the melt. The melt temperature was maintained at 800-850^{o}C during the addition of the particles. The pouring temperature was kept at 850^{o}C and the time of pouring was 5 minutes. The melt was poured in the grey cast iron molds which were preheated to 300^{o}C.The aluminium-fly ash composites were produced by varying amount of fly ash from 2.5 to 15 % by weight. The cast aluminium-fly ash composite specimens were obtained after solidification in air for about 2 hours. To ascertain the uniform distribution of fly ash particles the casted specimens were cut and were observed in scanning electron microscope. The photographs Fig.1 clearly indicate a fairly uniform distribution of fly ash particles in the matrix material.

2.3 Wear test

To evaluate the sliding wear behaviour of aluminium alloy and composite specimens, experiments were conducted in Pin-on-Disc type wear and friction monitor [DUCOM, India make; Model: TR-201CL] supplied with data acquisition system as shown in Fig.2 This tribometer is specifically suitable for fundamental wear and friction characterization.

The wear tests were conducted as per ASTM G-99 standards in air under the laboratory condition having a relative humidity of 80 to 85% and temperature ranging between 25 to 29^{o}C.The duration of single test was 6 hours. The test specimen contact surface and disc surface were polished with silicon carbide emery paper of 600 grit for smooth contact between them prior to the conduction of each test. The specimens were cleaned with ethanol solution before and after each test. After each 1hour during the test the specimen mass was measured to know the mass loss by using a high precision electronic weighing machine (Infra digital balance, Model: IN2011) having a resolution of 0.001mg. Also the track of disc and specimen surface was regularly cleaned by soft cotton cloth to avoid the entrapment of wear debris.

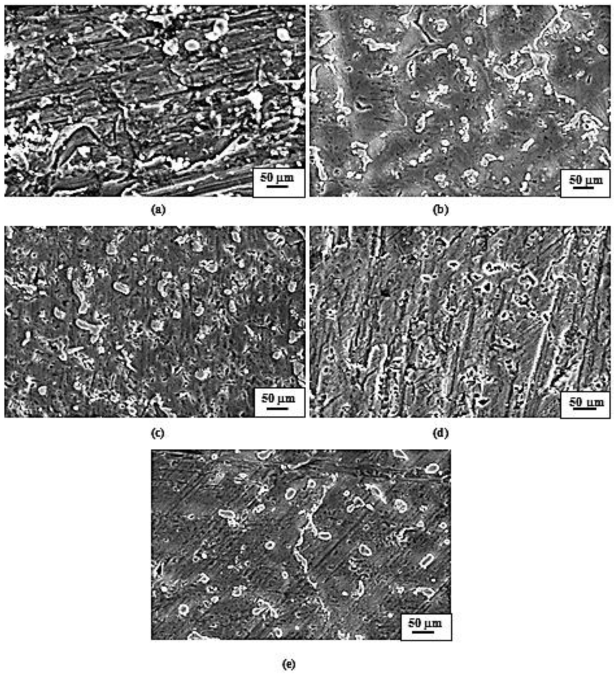
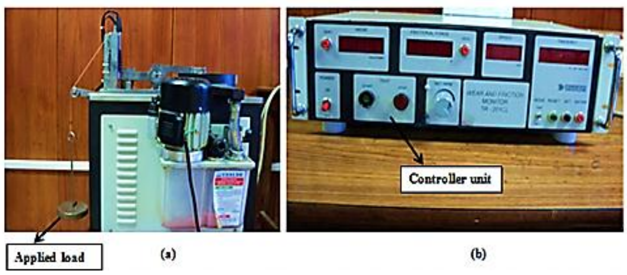


Fig.1 SEM photographs showing distribution of fly ash particles in the matrix(a)2.5%(b)5%(c)7.5%(d)10%(e)15%

The test specimen used was a cylindrical pin (8 mm diameter and 27 mm length) that was held with its axis perpendicular to the surface of the disc, and one end of pin slid against the disc in a dry friction condition, under a constant axial load applied with a dead weight. For testing specimens of each type a track diameter of 60, 70 and 80 mm were selected. The applied normal load was 10, 25 and 35 N with variable speed of 200, 300 and 400 rpm. In total 8 sets of test specimens were tested for dry sliding wear. Each set contained 9 pieces of specimens of a particular type of composition. After each test duration of 6 hours the micrograph of worn surface was taken by using an Inverted metallurgical microscope (IM 7000 series).



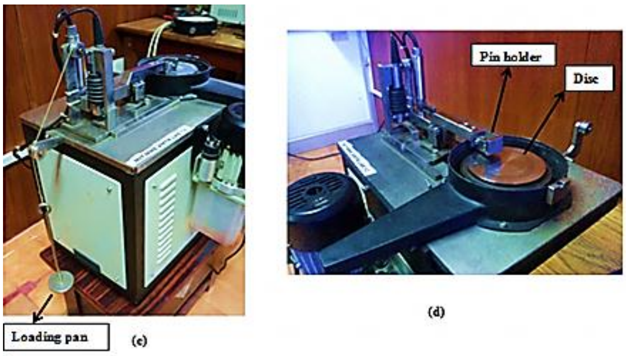


Fig.2 Pin-on-Disc type wear and friction monitor

3. Results and Discussion

Based on the wear test data various graphs have been plotted for different testing conditions that are shown in Fig: 3-9.

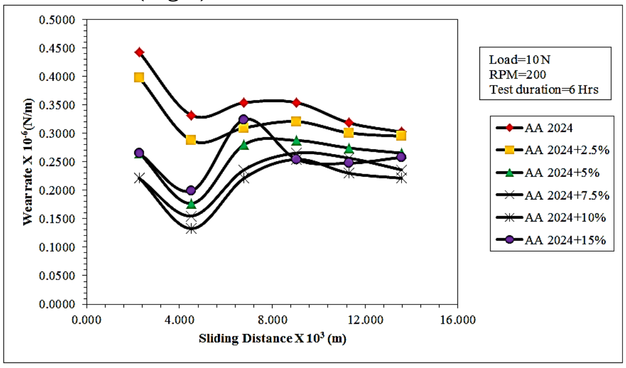
Fig 1 to 3 shows the variation of wear rate with the sliding distance. From Fig 3 it can be seen that wear rate has decreased as percentage of fly ash was increased up to 10% .But composite containing 15% showed a slight increase in wear rate for all the speeds. At lower sliding distance wear rate decreases and then increases by small amount and remains constant for higher sliding distance during the entire test. Even the similar behavior is noticed for applied normal load of 25 N which is clear from the Fig 4. Interestingly wear rate decreased much for 2.5% and higher weight percentages as compared to unreinforced ones for all speeds. This decrement is more for 400 rpm than 200 and 300 rpm. At 35 N, 400 rpm a higher decrement in wear rate is observed for 2.5%.Slight deviation in variation is seen for this load as wear rate keeps increasing with increase in sliding distance after a small initial dip for higher speeds (Fig 5).

The effect of variation of sliding velocity on the specific wear rate is plotted in Fig 6.The specific wear rate decreases as percentage of fly ash is increased up to 10% but there after increases by small amount for 15%.At 10 and 25 N, there is decrease in specific wear rate up to 1.099 m/sec sliding velocity and it again picked up for further increase in sliding velocity and also the load (Fig 7).

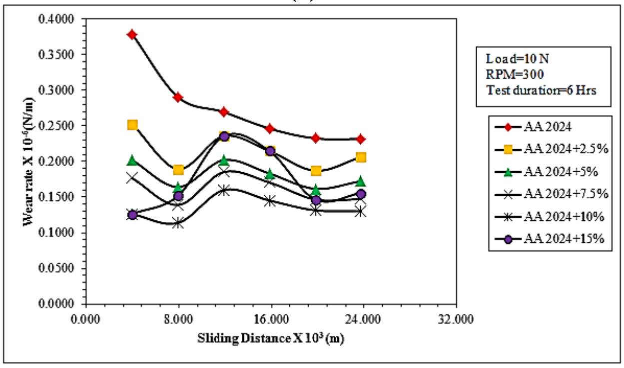
As depicted in Fig 7 as the filler volume percentage increases the specific wear rate decreases for all the sliding velocities (0.628, 1.099 and 1.675 m/sec) and loads (10, 25 and 35 N).After decrease in specific wear rate up to 23 % by volume (equivalent to 10% by weight) an increasing trend is observed up to 35 % by volume (equivalent to 15% by weight) indicating the optimum filler volume falling between 23 to 35%.

Fig 8 shows the nature of variation of volumetric wear rate with the increase in normal load. Volumetric wear rate keeps on increasing as the normal load is increased for all the speeds. This is because of the fact that at higher load, frictional thrust increases which results in increased debonding and fracture (Naresh Prasad *et al* 2013). Also a sudden increase in volumetric wear rate is found for 15% by weight sample compared with the smaller amount of reinforcement.

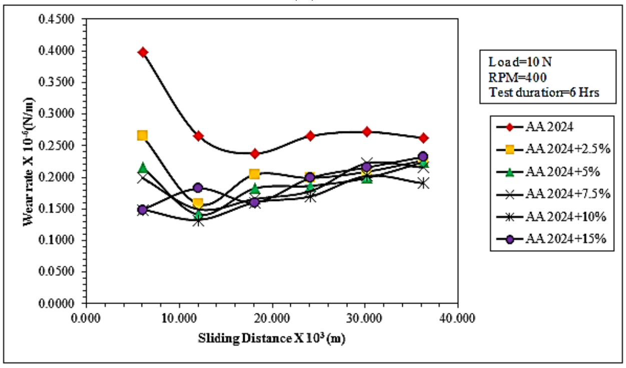
The co-efficient of friction is found to decrease as the percentage of fly ash is increased in the matrix but it showed an increasing and decreasing nature for increase in normal load (Fig 9)



(a)

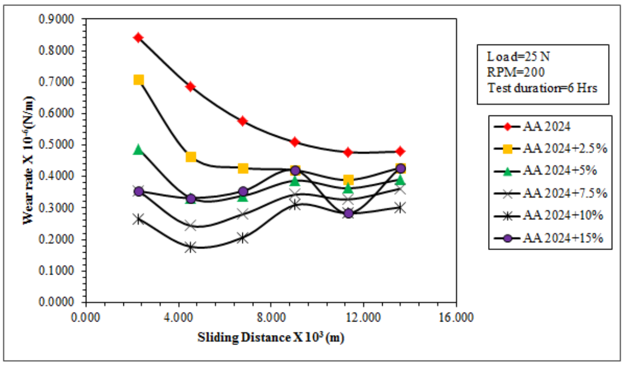


(b)

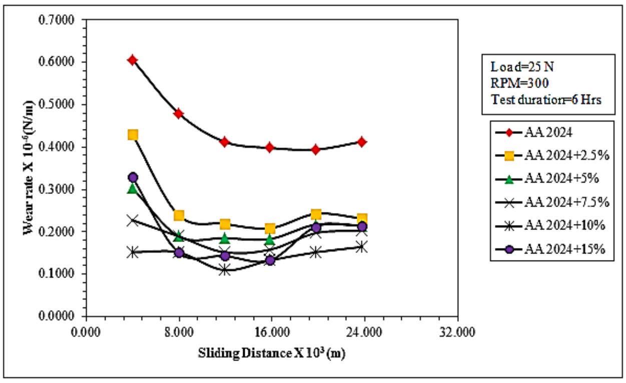


(c)

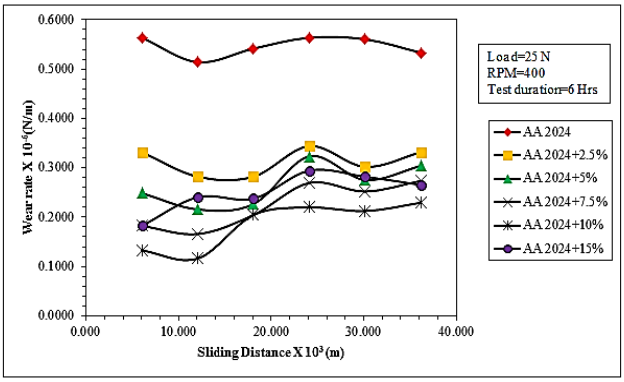
Fig.3 Variation of wear rate with sliding distance for 10 N Load



(a)

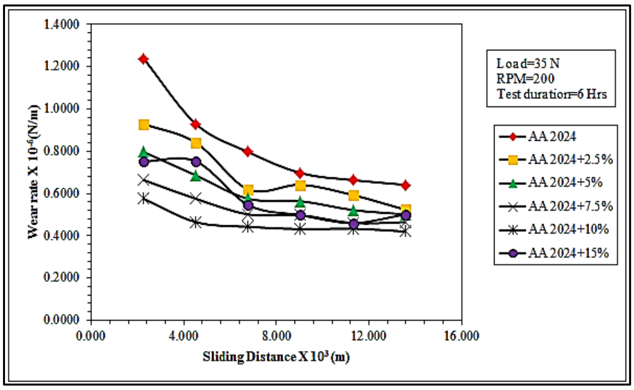


(b)

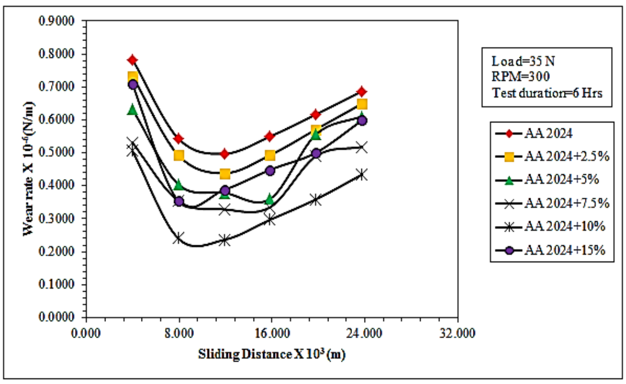


(c)

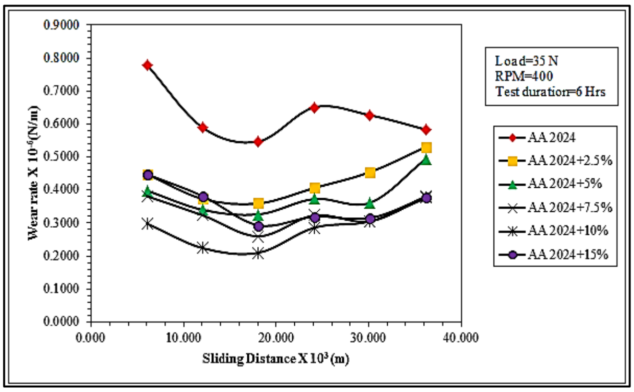
Fig.4 Variation of wear rate with sliding distance for 25 N Load



(a)

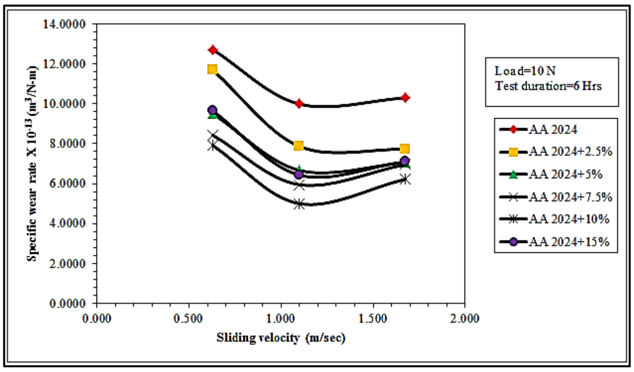


(b)

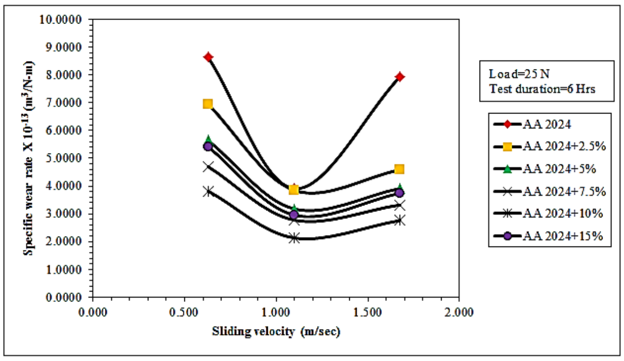


(c)

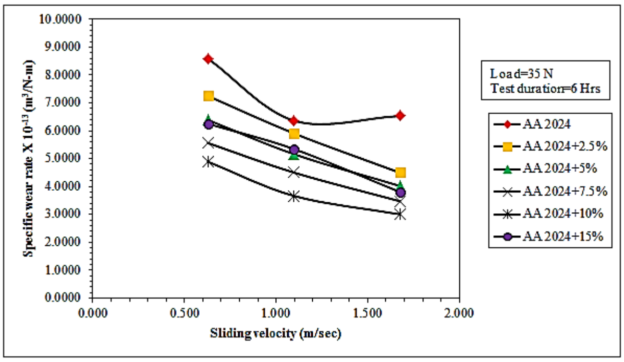
Fig.5 Variation of wear rate with sliding distance for 35 N Load



(a)

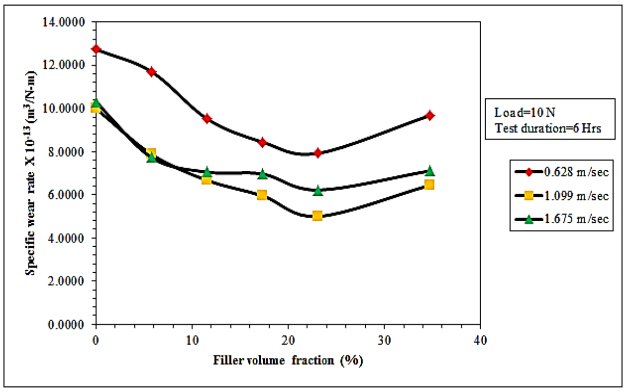


(b)

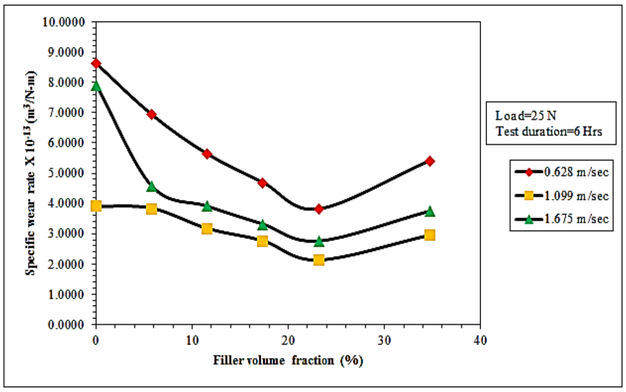


(c)

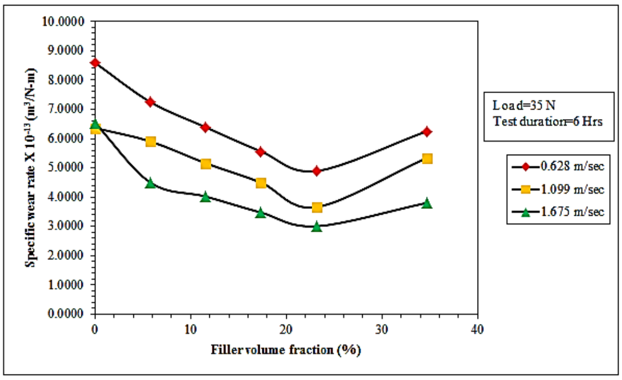
Fig.6 Variation of specific wear rate with sliding velocity at different loads for same test duration



(a)

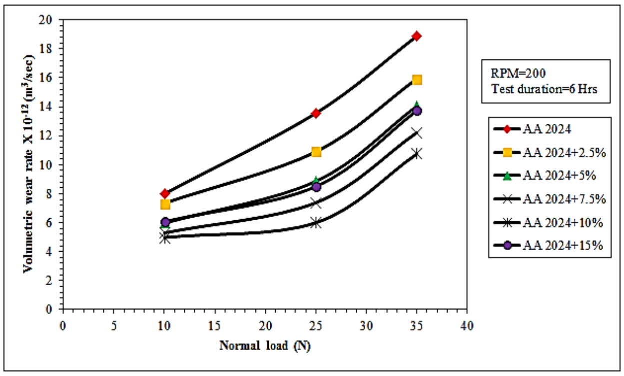


(b)

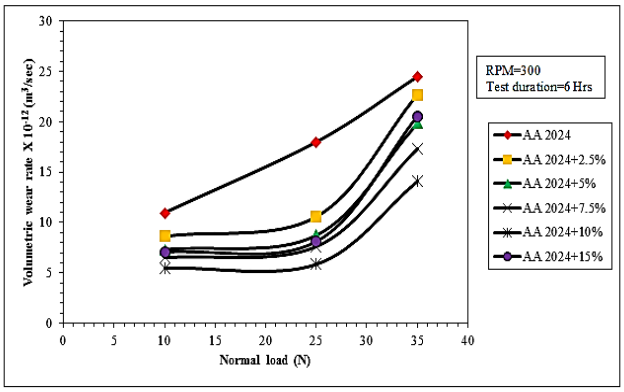


(c)

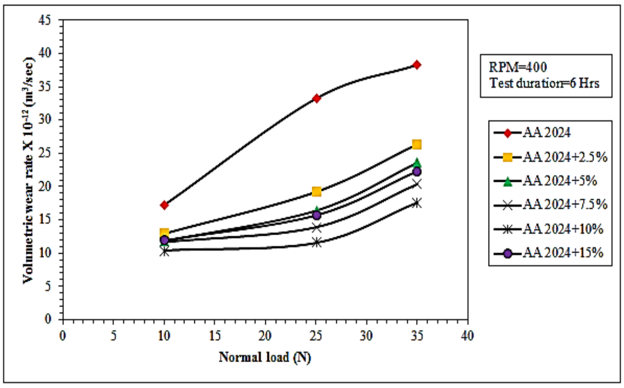
Fig.7 Variation of specific wear rate with filler volume fraction at different loads for same test duration



(a)

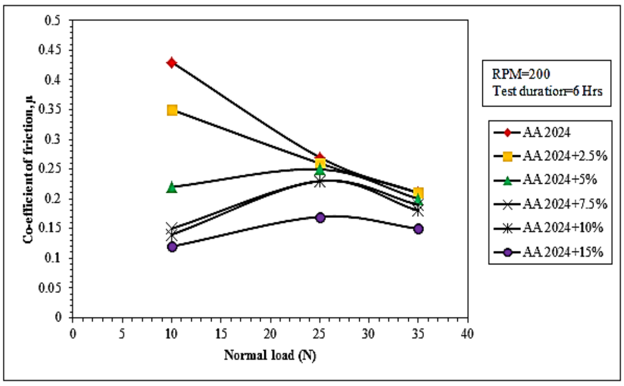


(b)

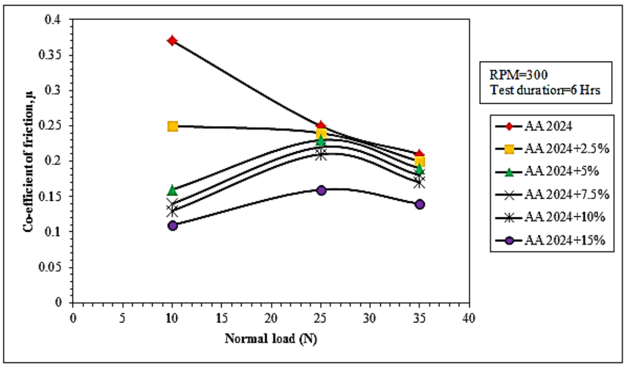


(c)

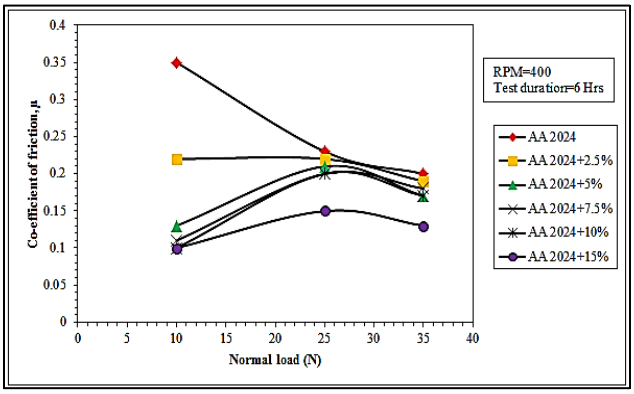
Fig.8 Variation of volumetric wear rate with normal load at different disc speeds for same test duration



(a)



(b)

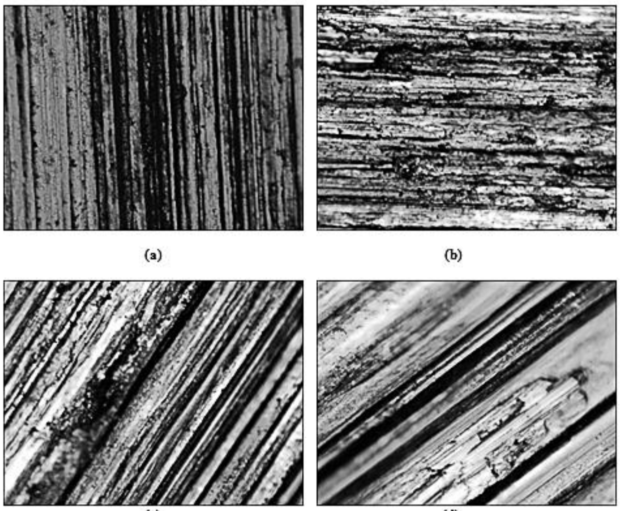


(c)

Fig.9 Variation of co-efficient of friction with normal load at different disc speeds for same test duration

The micrographs of the worn surfaces were taken at 200X magnification in an inverted metallurgical microscope. Some typical micrographs are as shown in Fig 10-14.

Long and continuous grooves aligned in the direction of sliding can be seen with chopped off hard flyash particles deposited in the grooves at lower load and speed [Fig 10(a)].Small cavities are formed that are aligned in the direction of sliding as load is increased at lower speed [Fig 10(b)] but as speed is increased for same load(25 N) the amount of cavitation have reduced and deep groves are formed to some extent [Fig 10(c)].As both load and speed are increased the grooves have grown wider and deeper with some matrix area smeared along the direction of sliding.



(a) (b) (c) (d)

(a) NHT_10N_200RPM_2.5% (b) NHT_25N_200RPM_2.5%

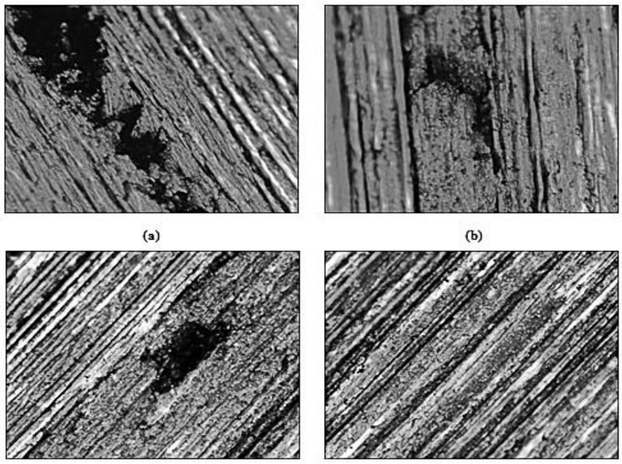
(c) NHT_25N_300RPM_2.5% (d) NHT_35N_400RPM_2.5%

[200X]

Fig 10 Micrographs showing worn surface composite with 2.5% fly ash

Deep crack was observed which is slightly aligned at an angle with respect to direction of sliding. Also the chipped off particles are entrapped in the crack with no evidence of deep grooves [Fig 11(a)].Increase in speed has reduced the length and depth of crack. Some areas show the presence of scars formed because of chip off of hard particles [Fig 11(b)].An increase in load at low speed have created patches of high particle removal with a heavy scar observed at a point [Fig 11(c)].Increase in load and speed have led to the formation of fine grooves aligned in the direction of sliding with no cracks on the surface [Fig 11(d)].

The chopped off fly ash particles have spread over the entire area filling the spaces in the narrow grooves. Some broken fine grooved area is also visible in Fig 12(a).Some grooves have grown slightly wide as the speed is increased to 300rpm [Fig 12(b)].Fig 12(c) indicates a small pit like structure formed as a result of chop off of hard particles and some uneven surface damage also resulted because of increase in load to 25 N.As the speed is increased to 300 rpm the grooves size has increased and some patches of smeared off matrix were seen along the direction of sliding [Fig 12(d)].At higher load and speed (35 N,400 rpm) the grooves became still fine and have aligned in the direction of sliding. Some grooves have undergone damage partly with deposit of hard particles observed in the damaged areas of grooves [Fig 12(e)].



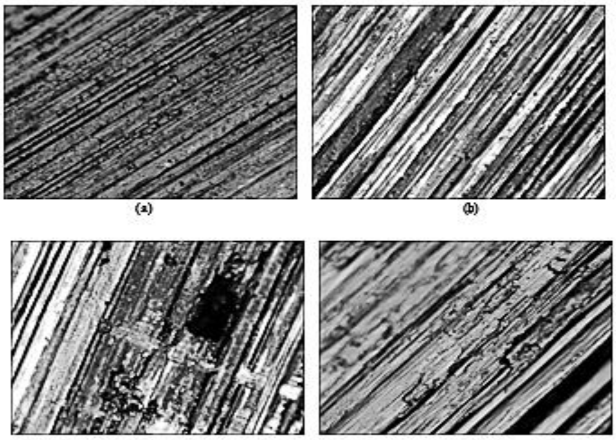
(a) (b) (c) (d)

(a) NHT_10N_200RPM_5% (b) NHT_10N_300RPM_5%

(c)NHT_25N_200RPM_5% (d) NHT_35N_400RPM_5%

[200X]

Fig 11Micrographs showing worn surface composite with 5% fly ash



(a) (b) (c) (d)

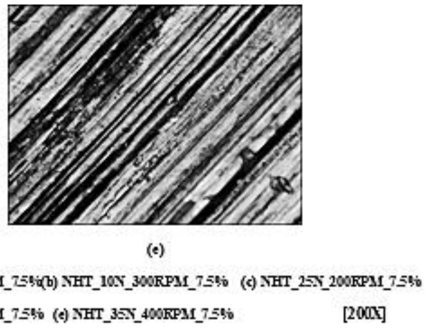
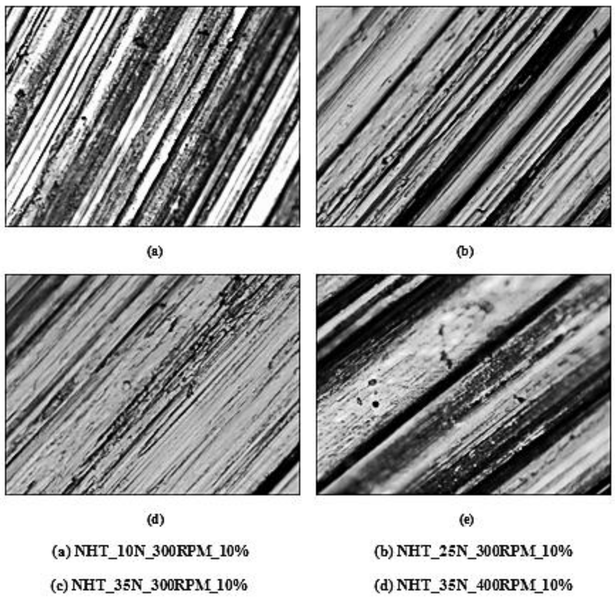


Fig 12 Micrographs showing worn surface composite with 7.5% fly ash

Fig 13(a) shows the micrograph of 10 weight % at 10 N and 300 rpm. As seen from this micrograph long continuous fine grooves are present on the wear surface with fly ash particles entrapped only in few grooves. As the load is increased to 25 N at same speed some groves underwent damage and some grooves have grown wider and deeper [Fig 13(b)].There is a slight tendency to grooving because of high percentage of fly ash in the matrix with some scars at few points [Fig 13(c)].At 35 N, 400 rpm the amount of surface damage has reduced with only few grooves having fly ash embedded in them [Fig 13(d)].



[200X]

Fig 13 Micrographs showing worn surface composite with 10% fly ash

In Fig 14(a) we can see the presence of agglomeration of wear debris with a little tendency to grooving. There is a heavy surface damage with the matrix material smeared at maximum points. Some broken and discontinuous grooves can also be visualized in Fig 14(b).At 35 N, 200 rpm few hard particles were found around the small surface cavities with presence of combined continuous and discontinuous grooves [Fig 14(c)].Worn surfaces are smoother with a low magnitude of surface damage at higher speed as compared to the lower speed [Fig 14(d)].

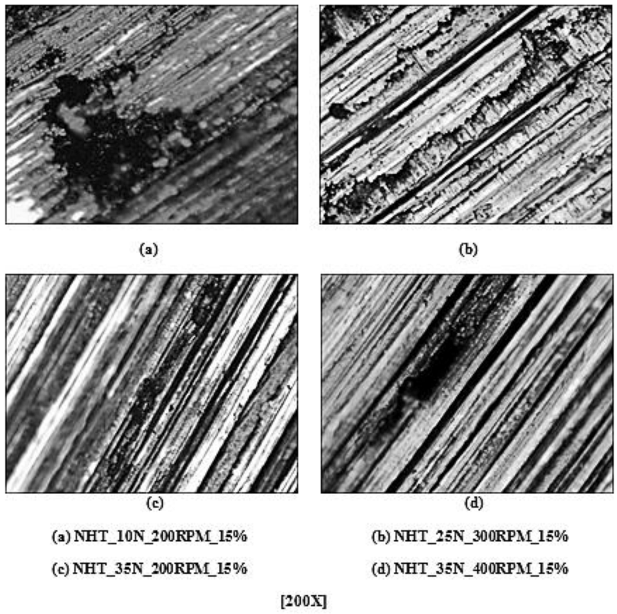


Fig 14 Micrographs showing worn surface composite with 15% fly ash

Conclusions

Fly ash reinforced AA 2024 alloy based composite are successfully developed by motorized stir casting method with fairly uniform distribution of fly ash particles in the matrix. As fly ash content is increased the matrix hardness of composite has increased and this in turn has contributed to increase in the wear resistance of composite as compared to the un reinforced alloy. Co-efficient of friction is found to decrease as the content of fly ash is increased but it showed an increasing and decreasing trend for increase in normal load for all the speeds. As the filler volume percentage increases the specific wear rate decreases for all the sliding velocities (0.628, 1.099 and 1.675 m/sec) and loads (10, 25 and 35 N).After decrease in specific wear rate up to 23 % by volume (equivalent to 10% by weight) an increasing trend is observed up to 35 % by volume (equivalent to 15% by weight) indicating the optimum filler volume falling between 23 to 35% which can give maximum wear resistance to the composite.

References

T.P.D. Rajan, R.M. Pillai, B.C. Pai , K.G. Satyanarayana and P.K. Rohatgi.(2007), Fabrication and characterisation of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes, *Composites Science and Technology*, 67,3369–3377.

M. K. Surappa, S.V.Prasad and P. K. Rohatgi.(1982),Wear and abrasion of cast Al-Alumina particle composites, *Wear*, 77,295 – 302.

Manish Narayan , M.K. Surappa and B.N. Pramila Bai.(1995), Dry sliding wear of Al alloy 2024-Al2O3 particle metal matrix composites,*Wear*, 181-183,563-570.

Rong Chen, Akira Iwabuchi , Tomoharu Shimizu , Hyung Seop Shin and Hidenobu Mifue.(1997), The sliding wear resistance behavior of NiAl and SiC particles reinforced aluminum alloy matrix composites,*Wear*,213,175-184.

X.Y. Li, K.N. Tandon(1997), Subsurface microstructures generated by dry sliding wear on as-cast and heat treated Al metal matrix composites,*Wear*,203-204,703-708.

Szu Ying Yu , Hitoshi Ishii, Keiichiro Tohgo, Young Tae Cho and Dongfeng Diao.(1997), Temperature dependence of sliding wear behavior in SiC whisker or SiC particulate reinforced 6061 aluminum alloy composite,*Wear*,213,21-28.

P.H. Shipway, A.R. Kennedy and A.J. Wilkes.(1998), Sliding wear behaviour of aluminium-based metal matrix composites produced by a novel liquid route,*Wear*,216,160-171.

M. Singh, O.P. Modi, Rupa Dasgupta and A.K. Jha.(1999), High stress abrasive wear behaviour of aluminium alloy-granite particle composite,*Wear*,233-235,455-461.

M. Singh, B.K. Prasad, D.P. Mondal and A.K. Jha.(2001), Dry sliding wear behaviour of an aluminium alloy–granite particle composite, *Tribology International*,34,557–567.

Hülya Kaçar, Enver Atik and Cevdet Meriç.(2003), The effect of precipitation-hardening conditions on wear behaviours at 2024 aluminium wrought alloy, *Journal of Materials Processing Technology*,142,762–766.

Sug Won Kima, Ui Jong Leea, Sang Won Hana, Dong Keun Kima and K. Ogib.(2003), Heat treatment and wear characteristics of Al/SiCp composites fabricated by duplex process, *Composites*: Part B, 34, 737–745.

C.S. Ramesha, A.R. Anwar Khanb, N. Ravikumar and P. Savanprabhu.(2005), Prediction of wear coefficient of Al6061–TiO2 composites, *Wear*,259,602–608.

R.K. Uyyuru, M.K. Surappa and S. Brusethaug.(2006), Effect of reinforcement volume fraction and size distribution on the tribological behavior of Al-composite/brake pad tribo-couple, *Wear* 260,1248–1255.

C.S. Ramesha and Mir Safiulla.(2007),Wear behavior of hot extruded Al6061 based composites, Wear 263,629–635.

M. Kok and K. Ozdin.(2007), Wear resistance of aluminium alloy and its composites reinforced by Al2O3 particles, *Journal of Materials Processing Technology*,183,301–309.

Shaoyang Zhang and Fuping Wang.(2007), Comparison of friction and wear performances of brake material dry sliding against two aluminum matrix composites reinforced with different SiC particles,*Journal of Materials Processing Technology*,182,122–127.

M. Ramachandra and K. Radhakrishna.(2007), Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite,*Wear*,262,1450-1462.

Ranjit Bauri and M.K. Surappa.(2008), Sliding wear behavior of Al–Li–SiCp composites, *Wear* 265,1756–1766.

Sudarshan and M.K. Surappa.(2008), Dry sliding wear of fly ash particle reinforced A356 Al composites,Wear,265,349-360.

R.N. Rao, S. Das, D.P. Mondal and G. Dixit.(2009), Dry sliding wear behaviour of cast high strength aluminium alloy (Al–Zn–Mg) and hard particle composites,*Wear*,267,1688–1695.

R.N. Rao , S.Das, D.P.Mondal and G.Dixit.(2010), Effect of heat treatment on the sliding wear behaviour of aluminium alloy (Al–Zn–Mg) hard particle composite, *Tribology International*,43,330–339.

Adel Mahamood Hassan , Abdalla Alrashdan, Mohammed T.Hayajneh, Ahmad Turki Mayyas.(2009), Wear behavior of Al-Mg-Cu-based composites containing SiC particles, *Tribology International*,42,1230–1238.

S. Suresha and B.K. Sridhara.(2010), Effect of addition of graphite particulates on the wear behaviour in aluminium-silicon carbide-graphite composites, *Materials and Design*,31,1804-1812.

R.N. Rao and S. Das.(2010), Effect of matrix alloy and influence of SiC particle on the sliding wear characteristics of aluminium alloy composites, *Materials and Design*,31,1200–1207.

P.K.Rohatgi, B.F.Schultz, A.Daoud and W.W.Zhang.(2010), Tribological performance of A206 aluminum alloy containing silica sand particles, *Tribology International*,43,455–466.

G. Naveen Kumar, R. Narayanasamy, S. Natarajan, S.P. Kumaresh Babu,K. Sivaprasad and S. Sivasankaran.(2010), Dry sliding wear behaviour of AA 6351-ZrB2 in situ composite at room temperature, *Materials and Design*,31,1526–1532.

R.N. Rao and S. Das.(2010), Wear coefficient and reliability of sliding wear test procedure for high strength aluminium alloy and composite, *Materials and Design*,31,3227–3233.

R.N. Rao and S. Das.(2011), Effect of SiC content and sliding speed on the wear behaviour of aluminium matrix composites, *Materials and Design*,32,1066–1071.

V.S. Aigbodion and S.B. Hassan.(2010), Experimental correlations between wear rate and wear parameter of Al–Cu–Mg/bagasse ash particulate composite, *Materials and Design*,31,2177-2180.

C.S. Ramesh, R.Keshavamurthy, B.H.Channabasappa and S.Pramod.(2010), Friction and wear behavior of Ni–PcoatedSi3N4 reinforced Al6061composites, *Tribology International*, 43, 623–634.

G.B. Veeresh Kumar, C.S.P. Rao and N. Selvaraj.(2012), Studies on mechanical and dry sliding wear of Al6061–SiC composites, *Composites:* Part B, 43, 1185–1191.

S. Gopalakrishnan and N. Murugan.(2012), Production and wear characterisation of AA 6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method, *Composites*: Part B, 43, 302-308.

M. Uthayakumar, S. Aravindan and K. Rajkumar.(2013), Wear performance of Al–SiC–B4C hybrid composites under dry sliding conditions, Materials and Design, 47, 456–464.

Xiaoliang Shi, Mang Wang, Wenzheng Zhai, Zhiwei Zhu, Zengshi Xu, Qiaoxin Zhang, Siyuan Song, Jie Yao and Abid Qamar ud Din.(2013), Friction and wear behavior of NiAl-10 wt % Ti3SiC2 composites, *Wear*,303, 9-20.

Devaraju, A. Kumar, A. Kumaraswamy, B. Kotiveerachari.(2013), Influence of reinforcements (SiC and Al2O3) and rotational speed on wear and mechanical properties of aluminum alloy 6061-T6 based surface hybrid composites produced via friction stir processing, *Materials and Design*,51,331–341.

C.A.Leon-Patin, E.A.Aguilar-Reyes, E.Bedolla-Becerril, A.Bedolla-Jacuinde and S.Mendez-Dıaz.(2013), Dry slidingwearofgradientAl–Ni/SiCcomposites, Wear, 301,688–694.

K. Umanath , K. Palanikumar and S.T. Selvamani.(2013), Analysis of dry sliding wear behaviour of Al6061/SiC/Al2O3 hybrid metal matrix composites, *Composites:* Part B,53, 159-168.

Baradeswaran and A. Elaya Perumal.(2013), Influence of B4C on the tribological and mechanical properties of Al 7075–B4C composites, *Composites*: Part B, 54, 146–152.

Naresh Prasad, Harekrushna Sutar, Subash Chandra Mishra, Santosh Kumar Sahoo and Samir Kumar Acharya.(2013), Dry Sliding Wear Behavior of Aluminium Matrix Composite Using Red Mud an Industrial Waste, *International Research Journal of Pure & Applied Chemistry*,3(1),59-74.