Wear Characterization of Aluminium 6061-Fly ash Reinforced Composites

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Abstract—Aluminium 6061 alloy (Al6061) is most abundantly used matrix material due to its unique combination of low density, high strength, good mechanical properties, higher corrosion resistance, low electrical resistance and better machinability properties. However it's relatively poor resistance to wear has limited its use in certain tribological applications. In recent years, many of the fiber reinforced and particulate reinforced Al 6061composites have shown substantial enhancement in their mechanical as well as tribological properties. In view of the above, an attempt has been made to study the mechanical and tribological properties of fly ash reinforced Al 6061 composites, processed using the stir casting technique. Three sets of composite samples were prepared with 5, 10 and 15 weight percentage of fly ash with particle sizes in the ranges of 5-20, 25-30 and 50-60 µm in each set. Wear tests of these composites were conducted by using pin on disc apparatus. It was found that as the content of fly ash increased from 0 to 10%, wear rate decreased. With further increase in the content of fly ash up to 15 wt-%, wear rate increased. With the increase in particle size of the fly ash, wear rate decreased.

Keywords-*Al6061, Fly ash, Tribological properties, Microstructure*

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I. INTRODUCTION

Aluminium based metal matrix composites (MMCs) have combination of useful properties such as high specific strength, high specific stiffness and high hardness. At some stage in sliding against metals and abrasives, reinforced alloys show better wear resistance compared to un-reinforced alloys. Aluminium based MMCs are being used in various structural applications such as helicopter parts, rotor vanes in compressors and in aero-engines [1].

Due to higher cost of manufacturing of continuous fiber reinforced MMCs has led to the use of particle reinforced and whisker reinforced MMCs [2]. Particles such as mica, alumina (Al_2O_3), graphite, boron and silicon carbide (SiC) have been used as fillers with aluminium alloys. Fly ash generated from thermal power plants in India pose threat to surroundings causing health hazards. It is probable that, of 90mega tons (Mt) of coal combustion by-products generated per annum, only 25% is currently used, much of it is in the form of extenders in cement and in polymers; the remainder is ending up in land filling. It is expected that fly ash particles as reinforcement in aluminium alloys would promote yet another use of this by-product [3]. Tribological properties of components used in aircraft fittings, valves, pistons rings, brake drums, cam and follower play important role. Because light metal alloys usually have poor wear resistance, they require surface treatments like coating with oxides or nitrides.

II. TRIBOLOGICAL PROPERTIES

Considerable works have been found in literature that are aimed to improve tribological properties of aluminium alloys. Uyyuru et al. [4] studied tribological behavior of Al–Si–SiCp composites / automobile brake pad system under dry sliding conditions using pin-on-disc machine where the aluminium MMC was used as disc, whereas the brake pad material forms the pin. They found that both wear rate and friction coefficient varied with applied normal load and sliding speed. With increase in the applied normal load, the wear rate was observed to increase whereas the friction coefficient decreased. However, both the wear rate and friction coefficient were observed to vary proportionally with the sliding speed.

Anilkumar et al. [5] examined the wear behavior of aluminium fly ash composites, comprising fly ash in required quantities (10, 15, and 20 percent by weight) in weighed quantity of aluminium. They tested aluminium fly ash composite using a pin-on-disc wear testing machine with aluminium fly ash MMC as pin. They found that as the content of fly ash increased, the volumetric wear rate of the composite decreased.

Gurcan and Baker [6] studied the wear resistance of four AA6061 MMCs together with the monolithic AA6061 alloy, all in the T6 condition, using a pin-on-disc test. In addition to the widely studied 20 volume percent Saffil MMCs, their investigation considered a hybrid of 11% Saffil + 20% SiCp and a high volume fraction SiCp MMC, AA6061 + 60% SiCp. The wear behaviour against P400 SiC grit adhesive bonded paper and against BS817M40 (EN24) steel were explored under an applied load of 9.8 N with a nominal contact pressure of 0.5 MPa. It was found that after testing against SiC grit, AA6061 + Saffil showed little advantage over the monolithic alloy, but the other three composites had a significant improvement in wear resistance. The hybrid and the AA6061 + 60% SiC showed the best performance. Only small improvements were noted for AA6061 + Saffil and AA6061 + 20% SiC over the monolithic alloy, when tested against steel.

III. EXPERIMENTAL DETAILS

Al6061 having good casting properties and strength is selected as matrix material having chemical composition mentioned in Table 3.1. Fly ash collected from Raichur thermal power plant was used as reinforcement and its composition is given in Table 3.2.

Table3.1: Chemical composition of Al6061 alloy (wt-%)

Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Al
0.91	0.76	0.24	0.21	0.08	0.11	0.05	0.04	balance

Table3.2: Chemical composition of Fly ash used in present study (wt-%)

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Loss of ignition
29,56	**59.8**	**4.99**	**3.1**	**1.44**

Tribological (wear) test was conducted on samples with fly ash of particle size 25-30 microns and 50-60 microns. A pin on disc apparatus (Fig. 3.8) was used to investigate the dry sliding wear behavior of Aluminium alloy and its composites as per ASTM G99-95 standards. The specimen of size 8 x 8 x 4 mm was cut from samples, machined and then polished metallographically. The tests were conducted with the load 1 kg (9.81 N) and 3 kg (29.43 N) sliding speed 1.11 m/s, 2.086 m/s and sliding distance 1000, 1500 and 2000 m.

IV. RESULTS AND DISCUSSION

4.1 Microstructure

The microstructure shows the important features relating to wear performance of the alloy and its composites. The microstructure of MMCs was analysed using scanning electron microscope (SEM) to study the distribution of fly ash in the matrix. The microstructure of as cast Al6061 and Al6061 with fly ash are shown in Figs. 4.1 a-j. The distribution of reinforced particles was found to be reasonably uniform in all the samples without voids and discontinuities.

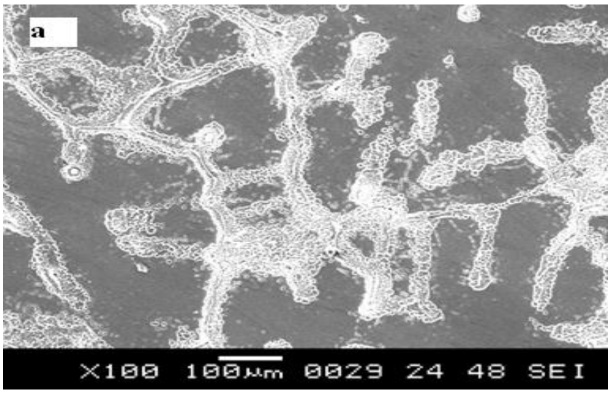

Figure 4.1(a) Microstructure of bare Al 6061

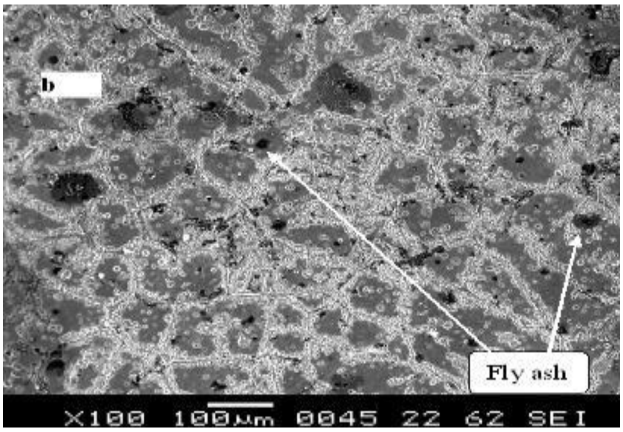

Figure 4.1(b) Microstructure of Al 6061 with 5 wt-% fly ash of particle size 5-20µm.

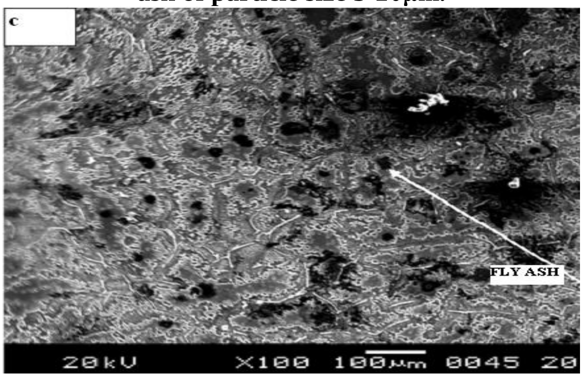

Figure 4.1(c) Microstructure of Al 6061with 10 wt-% of fly ash of particle size 5-20µm.

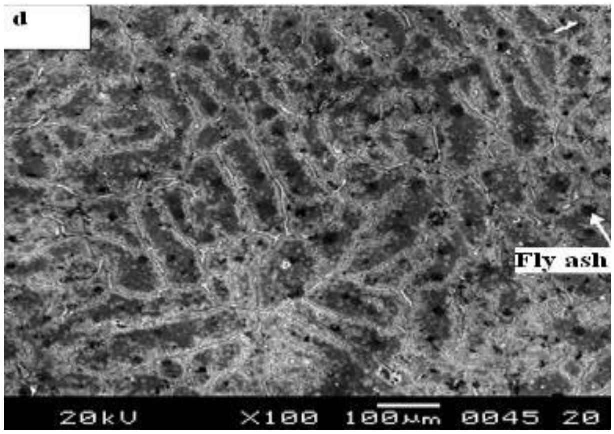

Figure 4.1(d) Microstructure of Al 6061with 15% weight fraction of fly ash of particle size 5-20µm.

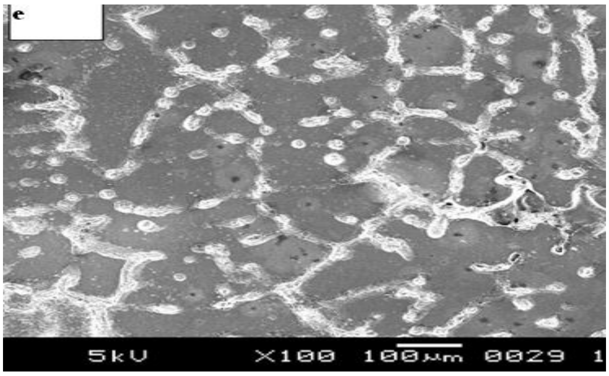

Figure 4.1(e) Microstructure of Al 6061with 5% weight fraction of fly ash of particle size 25-30µm.

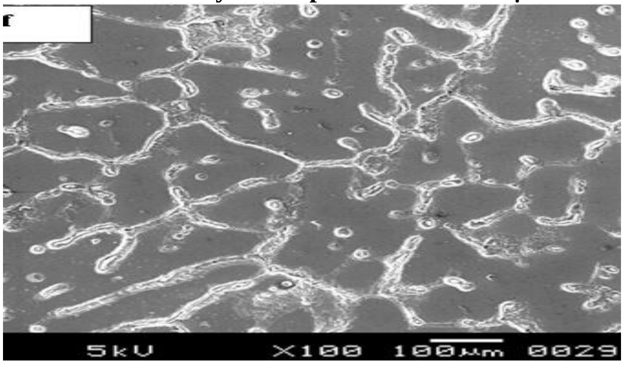

Figure 4.1(f) Microstructure of Al 6061with 10% weight fraction of fly ash of particle size 25-30µm.

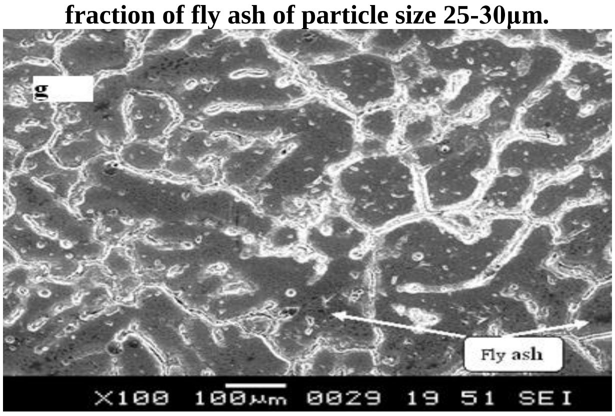

Figure 4.1(g) Microstructure of Al 6061with 15% weight fraction of fly ash of particle size 25-30µm.

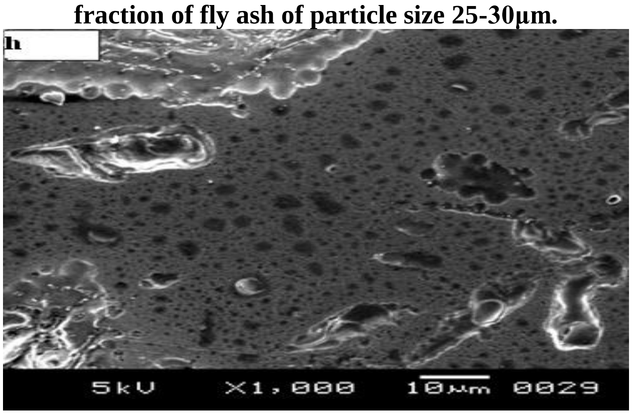

Figure 4.1(h) Microstructure of Al 6061with 5% weight fraction of fly ash of particle size 50-60µm.

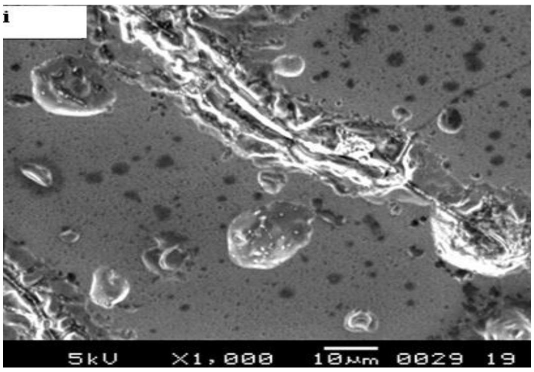

Figure 4.1(i) Microstructure of Al 6061with 10% weight fraction of fly ash of particle size 50-60µm.

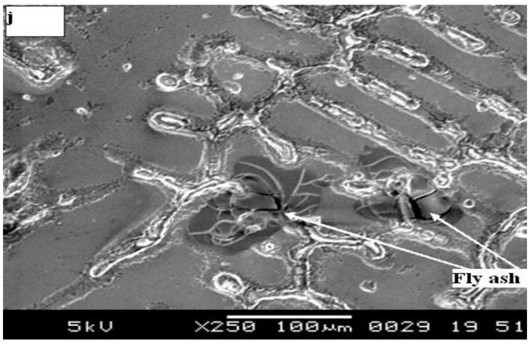

Figure 4.1(j) Microstructure of Al 6061with 15% weight fraction of fly ash of particle size 50-60µm.

Tribological tests were conducted on samples with fly ash of particle size 25-30 microns and 50-60 microns. The results of the variation of wear rate with the content of fly ash are shown in Figs. 4.6 - 4.13. Tables 4.5- 4.12 show the percentage improvement in wear rate of Al6061 alloy matrix by reinforcements. The percentage improvements with different weight fractions of reinforcements are also given. From the Figure 4.6 to 4.13 it is clear that as the weight fraction increases from 0% (pure Aluminium) to 10% wear rate decreases, having a minimum value at 10 wt-%, then it again increases. This may be due to the fact that strength and hardness of the composite increases till 10 wt-% and decreases afterwards, attaining the maximum value at 10 wt-%. This is due to the higher bonding between fly ash particles and Al alloy matrix.

Table 4.5 Results of variation of wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 9.81 N; Sliding velocity: 1.11 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	3.0
	5	2.7
	10	2.9
	15	3.0
1500	0	3.6
	5	3.1
	10	3.0

	15	3.6
2000	0	3.6
	5	3.5
	10	2.5
	15	4.5

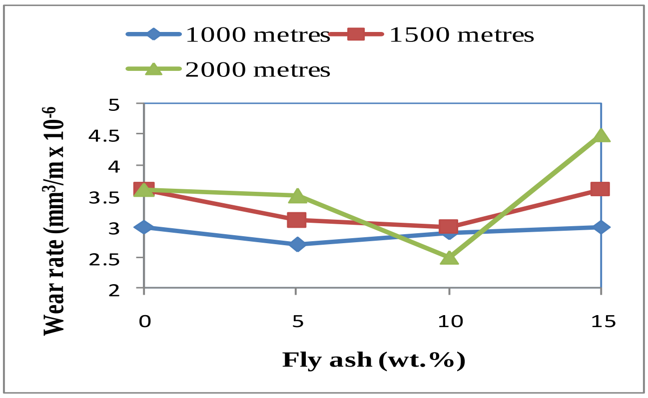

Fig.4.6 Variation of Wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 9.81 N; Sliding velocity: 1.11 m/s

Table 4.6 Results of variation of wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 9.81 N; Sliding velocity: 2.086 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	3.3
	5	2.9
	10	3.1
	15	3.5
1500	0	3.7
	5	3.2
	10	3.4
	15	3.8
2000	0	4.8
	5	4.3
	10	2.2
	15	2.8

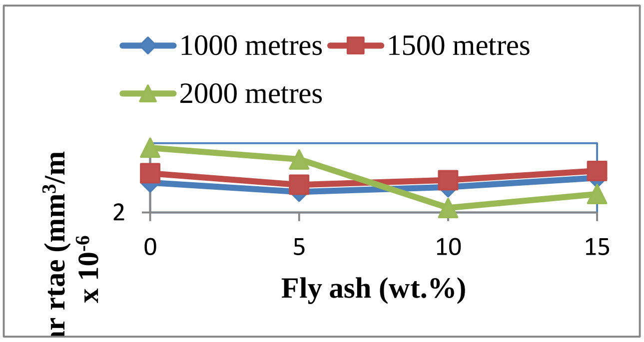

Fig.4.7 Variation of Wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 9.81 N; Sliding velocity: 2.086 m/s

Table 4.7 Results of variation of wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 29.43 N; Sliding velocity: 1.11 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	5.4
	5	4.8
	10	4.2
	15	5.4
1500	0	5.3
	5	4.6
	10	4.5
	15	5.7
2000	0	6.4
	5	5.3
	10	4.4
	15	4.7

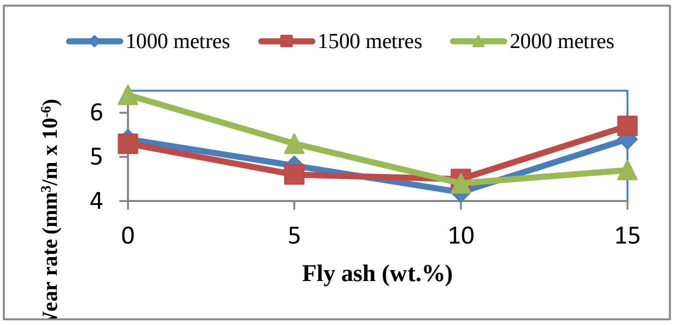

Fig.4.8 Variation of Wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 29.43 N; Sliding velocity: 1.11 m/s

Table 4.8 Results of variation of wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 29.43 N; Sliding velocity: 2.086 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	6.4
	5	4.3
	10	4.8
	15	6.8
1500	0	5.4
	5	4.9
	10	4.9
	15	5.5
2000	0	7.4
	5	5.5
	10	4.5
	15	5.5

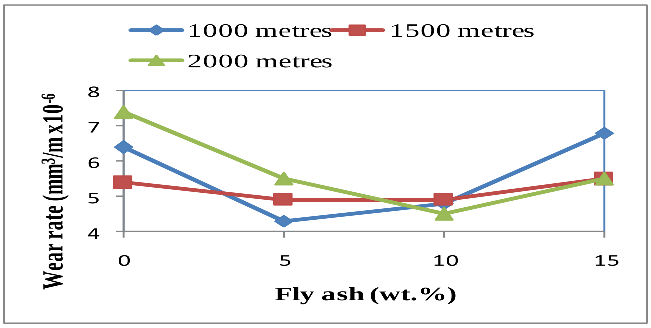

Fig.4.9 Variation of Wear rate with weight percent of fly ash of particle size 25-30 µm; Load: 29.43 N; Sliding velocity: 2.086 m/s

Table 4.9 Results of variation of wear rate with weight percent of fly ash of particle size 50-60µm; Load: 9.81 N; Sliding velocity: 1.11 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	3
	5	2.6
	10	3
	15	2.8
1500	0	3.6
	5	3.1
	10	2.8
	15	2.9
2000	0	3.6
	5	2.9
	10	2.4
	15	3.6

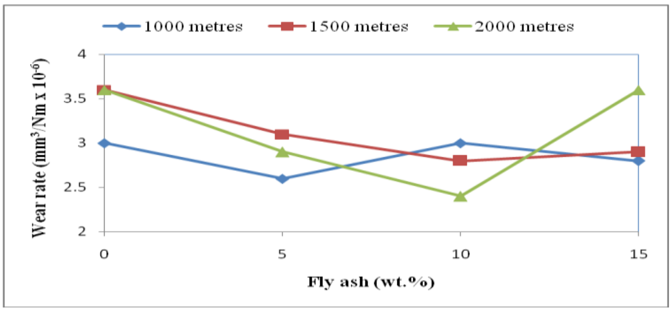

Fig.4.10 Variation of Wear rate with weight percent of fly ash of particle size 50-60µm; Load: 9.81 N; Sliding velocity: 1.11 m/s

Table 4.10 Results of variation of wear rate with weight percent of fly ash of particle size 50-60µm; Load: 9.81 N; sliding velocity: 2.086 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	3.3
	5	2.7
	10	2.6
	15	2.9
1500	0	3.7
	5	3.5
	10	3.3
	15	3.4
2000	0	4.8
	5	2.7
	10	2.2
	15	3.5

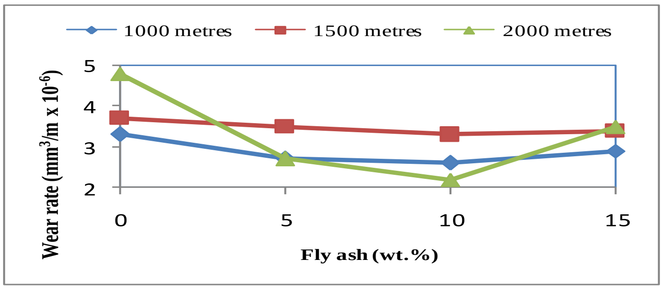

Fig.4.11 Variation of Wear rate with weight percent of fly ash of particle size 50-60µm; Load: 9.81 N; sliding velocity: 2.086 m/s

Table 4.11 Results of variation of wear rate with weight percent of fly ash of particle size 50-60µm; Load: 29.43 N; sliding velocity: 1.11 m/s

Sliding distance (meters)	Weight percent of reinforcement	Wear rate
1000	0	5.4
	5	4.2
	10	3.2
	15	4.4

1500	**0**	**5.3**
	5	**4.5**
	10	**4.6**
	15	**5.4**
2000	**0**	**6.4**
	5	**6**
	10	**5**
	15	**4.5**

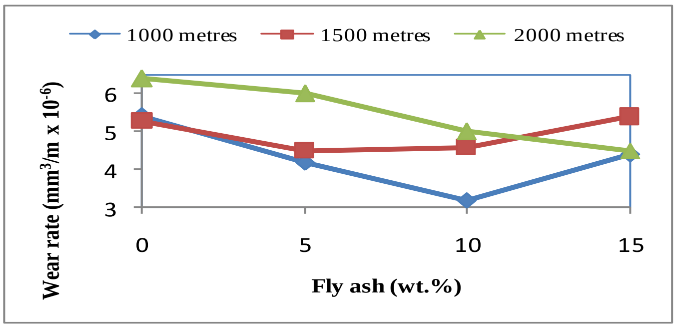

Fig.4.12 Variation of Wear rate with weight percent of fly ash of particle size 50-60 μm; Load: 29.43 N; Sliding velocity: 1.11 m/s

Table 4.12 Results of variation of wear rate with weight percent of fly ash of particle size 75-100 μm; Load: 29.43 N; Sliding velocity: 2.086 m/s

Sliding distance (m)	Content of reinforcement (wt-%)	Wear rate
1000	**0**	**6.4**
	5	**6.2**
	10	**3.5**
	15	**4.9**
1500	**0**	**5.4**
	5	**4.5**
	10	**4.3**
	15	**5.7**
2000	**0**	**7.4**
	5	**6.6**
	10	**5.3**
	15	**5.9**

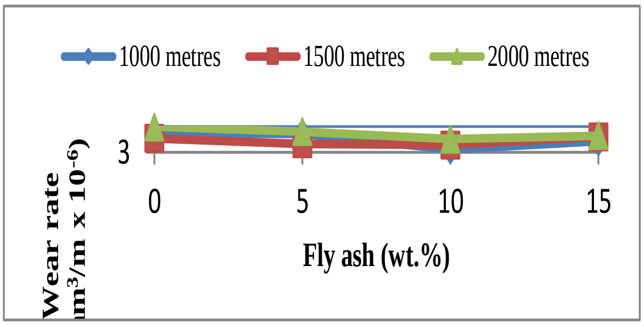

Fig. 4.13 Variation of wear rate with content of fly ash of particle size 50-60 μm; load 29.43 N; sliding velocity 2.086 m/s

Wear properties conducted at room temperature are presented in Figs. 4.6-4.13. Assessment of wear properties of the fly ash as well as matrix in the interface region is important on these counts. These properties help to assess the integrity of the material, and to understand the material behavior under the condition of wear in critical components used in various applications. A normal load of 1kg and 3kg were used for all samples and they registered a gradual decrease in wear rate as the content of fly ash increased up to 10 wt-%. During wear test, thermal stress gradient may be generated within the sample and this gradient may produce cracks. Reinforcements in the form of fly ash can stop these cracks hence higher content of fly ash will lead to higher probability of stopping of cracks. Therefore, higher contents of fly ash show lower wear rate. During friction and wear process a significant heat is generated between any two sliding surfaces. If the surface contains more content of fly ash i.e. 10 wt-%, the amount of heat generated will be less compared to material with lower fly ash.

If the sample contains more content of fly ash i.e. 15wt-% the amount of small cracks will be more and more of matrix is easy to break. In the present study, it is concluded that matrix worns out faster than fly ash. Hence, wear loss is caused mainly by matrix wear but fly ash only gets removed when matrix completely worns out. This could be revealed from SEM micrograph shown in Fig. 4.14.

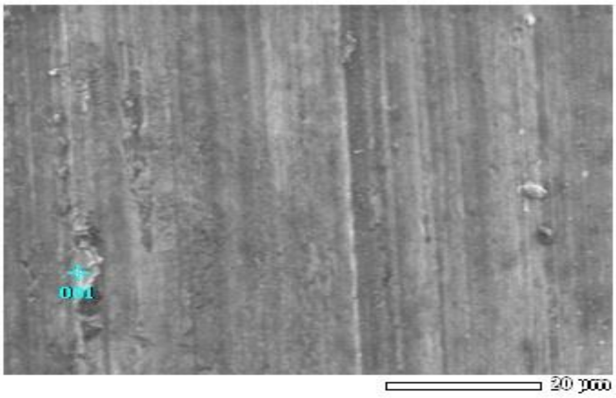

Fig. 4.14 Micrograph of worn surface of fly ash 50-60 µm and 15 wt-% at sliding velocity 2.086m/s, load 29.43 N, sliding distance 2000m

V. CONCLUSIONS

1. As the fly ash content increases from 0% (pure Aluminium) to 10% wear rate decreases, having a minimum value at 10%, then it again increases.
2. Increasing the grain size of fly ash particle wear rate of composite decreases in most of the working conditions.
3. From the SEM analysis it has been concluded that as the fly as content increases the distribution of fly as much uniform throughout the specimen.

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