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MICROSTRUCTURE CHARACTERIZATION OF AA6061 ALLOY/SILICON CARBIDE /FLY ASH HYBRID METAL MATRIX COMPOSITE PRODUCED BY POWDER METALLURGY ROUTE

Muthukumar S.[1] and Mariappan R.[2]
[1]Vel Tech Multi Tech Dr.Rangarajan Dr. Sakunthala Engineering College, Avadi, Chennai, India
[2]Vel Tech Dr.Rangarajan Dr.Sakunthala Technical University, Avadi, Chennai, India
E-Mail: muthukumar@velltechmultitech.org

ABSTRACT

The influence of constant proportion of fly ash and varying proportions of silicon carbide on aluminum alloy /SiC/ fly ash composite processed through powder metallurgy route was investigated. Elemental composition of each constituents were calculated as per weight fractions in the hybrid metal matrix composite (HMMC) containing 5 wt. % to 15 wt. % silicon carbide with the addition of 7.5 wt. % fly ash as additional reinforcement. Powders were cold compacted under unidirectional pressing followed by sintering at 600°C in nitrogen atmosphere under controlled conditions. From micrograph images, the surfaces of the novel composite were studied for homogeneous mixture of silicon carbide and fly ash particles to identify dry sliding wear performance of hybrid metal matrix composite. Wear testing of the developed composite was carried out at different loads and sliding velocities for 3000m using Pin-on-disc setup. The result of experiments supports the fact that the wear resistance of AA6061/ SiC/Fly ash processed through powder metallurgy route was influenced by applied load, mass fraction of reinforcement while varying sliding velocity and keeping sliding distance constant. The analysis establishes chances of improved hardness and wear resistance with fly ash addition for silicon carbide reinforced AA6061 alloy hybrid metal matrix composite.

Keywords: hybrid metal matrix composite, silicon carbide, fly ash, micrograph, aluminum matrix composites.

INTRODUCTION

Aluminum alloy based composite materials are having desirable properties, which include low density, high specific stiffness, high specific strength, restricted thermal expansion co-efficient, increased fatigue resistance and superior dimensional stability at elevated temperatures etc. [1, 2]. The global consumption of the composite can be realized through outlook by application and segment. The various automotive parts produced by powder metallurgy are cams, nozzles, liner of cylinders, oil-less bearings, transmission gears, vanes and rotor of air conditioners etc. The composites are broadly classified to the types of reinforcement as particles reinforced, whiskers short fibre reinforced and continuous fibre reinforced. This work falls under the type of hybrid metal matrix composite in which aluminum alloy matrix is reinforced with particles of silicon carbide as well as Fly ash. Kumar et.al (2011) has found that increase of the strength coefficient value (K) with respect to the percentage of reinforcement content up to 16 wt. % with four dissimilar particle sizes, i.e. 60, 90, 120 and 150 µm for Al–Glass–SiC hybrid composite. Also it was observed that addition of Glass and SiC in Aluminum matrix affects the strain hardening index (n) of the hybrid composite[3].Sahin *et al.*(2011) predicted average volumetric wear rate as a function of applied load for the AA6061 matrix and its Silicon carbide reinforced composites when tested against 70 µm size of abrasive [4]. Mehdi Rahimian *et al.* (2010) made a study on variation of the wear rate of the composites as a function of Al_2O_3 particle content and Al_2O_3 particle size in different sliding distance [5]. Riahi *et al.* (2016) made comparison of the mild to severe wear transition boundaries of the Al–10% , SiC–4% Gr and A356 Al–5% /Al_2O_3 –3% Gr hybrid composites with those of the non graphitic composite of A356 Al with 20% SiC and the matrix A356 Al alloy [6]. Akhlaghi *et al.* (2009) observed the variation in the measured friction coefficient with the fractional content of graphite in the metal matrix composites for both dry sliding and sliding while smeared with oil, they found variation in the measured wear rate with the proportion of graphite reinforcement in the composites for dry sliding as well as oil impregnated sliding [7]. Ted Guo *et al.* (2000) found increase of friction coefficient with the percentage of graphite addition. Also an increase of wear rate of the composites and the counterparts during wear process for various graphite additions was observed by them [8]. Leng Jinfeng *et al.* (2009) computed the wear rate of the composites and counterfaces of worn surface specimen for SiC/Al and SiC/Gr/Al [9]. Mahdavi *et al.* (2011) showed that there is variation of the wear rates of Al/SiC and Al/SiC/Gr composites containing a range of SiC particle sizes at the sliding distances of 500 and 1000 m. They also gave the variation of the coefficient of friction in a range of composites with changes in the size of SiC particle [10]. Basavarajappa *et al.* (2006) experimentally found the deviation of wear rate with applied load at 3 m/s sliding speed run for 5000 m [11]. David Raja Selvam *et al.* (2013) has reported the Synthesis and characterization of AA6061-Fly Ash-SiCp composites by stir casting and compo casting methods. It is suggested that the mechanical properties like hardness and tensile strength will improve with the increase in weight percentage of SiC particulates and 7.5 weight percentage of Fly Ash particles in the aluminum matrix [12].

Aluminum matrix composites have been reported for its success and failure in service much superior to that of the unreinforced alloy. The additions of reinforcing phase considerably improve the tribological properties of AA6061 alloy. The purpose of this development of hybrid metal matrix composites is to combine the desirable properties of aluminum alloy, fly ash and silicon carbide. As stated by Shanmughasundara (2011), Aluminum alloys encompass useful properties such as high strength, ductility, high thermal and good electrical conductivity but have inconsiderable stiffness while silicon carbide and fly ash are stiffer and stronger and have excellent resistance at elevated temperature but feeble brittle nature [13].

Rohatgi *et al.* (1994) has reported that the addition of fly ash particles to the AA6061 alloy significantly enhances its wear resistance by abrasion [14]. The various methods reported to be suitable for the processing of Metal Matrix Composites are spray deposition, squeeze-casting, liquid metal infiltration, stir-casting and powder metallurgy [15]. Powder metallurgy route is reported apt for processing of particulate or discontinuous reinforced metal matrix composites [16]. This route is most suitable due to its simple methods, flexible ways and ease of fabrication for nearly all automobile and aeronautical components [17], [18].

Literature dealing with the effect of fly ash percentage on the wear resistance of AA6061/SiC_p/Fly ash composites processed through powder metallurgy is not available. The present research is an attempt to evaluate the effect of the varying percentage of Silicon carbide reinforcement on the wear resistance property in dry sliding condition in AA6061/SiC/Fly ash composite processed by powder metallurgy route. The relationship between the various applied load and the relative density and its effect on the various percentage of silicon carbide particles keeping a constant percentage of fly ash particles are discussed. We investigated whether addition of fly ash improves the desirable properties acting as secondary reinforcement in AA6061 alloy with SiC particulates as primary reinforcement or fly ash just acts towards reduction of weight of the hybrid composite. We investigated the effects of Fly ash addition on the hardness and wear resistance of novel hybrid composite.

Experimental procedure

The AA6061 alloy-SiC- Fly ash hybrid composite composition was developed from elemental composition. The elemental Aluminum, Chromium, Copper, Iron, Magnesium, Silicon, Titanium, Zinc and Manganese with a purity of 99.5% were procured from Alfa Aesar. The respective compositions such as Al-96.45 Cr- 0.08 Cu-0.4 Fe- 0.7 Mg-0.3 Si-0.8 Ti-0.15 Zn- 0.25 Mn-0.1 were blended in pot mill for 12 hours with a rotation speed 45rpm. Prior to cold compaction, a lubricant coating of Zinc stearate was applied on outer surface of punch, inner surface of the die (Figure-1) and on the top of the butt so as to reduce the particle-die friction.

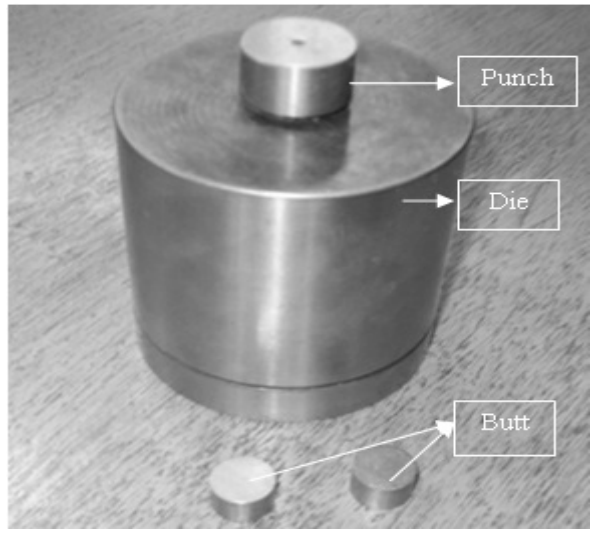

Figure-1. Photograph of the die setup arrangement.

Figure-2. Photograph showing the hydraulic press arrangement for cold compaction.

The milled powder was subjected to cold compaction in hydrostatic press (Figure-2) with pressure of 280 MPa in to specimen of 20 mm diameter and 20 mm height. Then the specimens were sintered in vacuum hot press furnace (Figure-3) at the temperature of 600°C in Nitrogen atmosphere with a flow rate of 2000 ml/ min. The photographic view of sintered AA6061 alloy specimen and AA6061 alloy/ SiC/ Fly ash hybrid composites is given in Figure-4.

Figure-3. Photograph showing vacuum hot press equipment used for sintering the compacted powders.

Sintered cylindrical billets were subjected to microscopic examination (METSCOPE-1) supplied from Chennai Metco Pvt. Ltd. The specimens were ground sequentially on different grit size papers to cylinders of size diameter 20 mm and height 10 mm. After grinding the specimen were mechanically polished by 0.5 µm alumina paste. Then the specimen was polished in velvet cloth in the presence of aerosol with diamond paste of particle size 0.5 µm to obtain a smooth surface finish. The specimens were etched by hydro fluoric acid and they were visualized on magnifications of 200 X and 500X.

The Pin-on-Disc machine (DUCOM) was used to evaluate wear response to the sliding contact surface of the specimen. Wear tests were conducted under dry sliding conditions as per ASTM G 99- 95 standards. At the start of each test the pin was cleaned with acetone and weighed using a high accuracy digital electronic balance. The test was carried out by applying load of 9.81 N, 19.62 N, and 29.43 N, run for a sliding distance of 3000 meters at different sliding velocities of 1 m/s, 2 m/s, and 3 m/s. The counterpart chosen was a heat treated EN-32 steel disc with hardness of 65 HRC. At the end of each test the final weight of the specimen was noted to get loss of material with respect to with initial weight.

Hardness measurements were carried out by Vickers's Hardness Tester (Akashi MVK-H2). The Vickers micro-hardness of AA6061 alloy/SiCp/Fly ash HMMC was evaluated using diamond indenter at an applied load of 100g for a time of 15 seconds.

RESULTS AND DISCUSSIONS

Our first finding was an improvement in hardness of AA6061/SiC/Fly ash hybrid metal matrix composite is possible due to addition of fly ash particles. The obtained hardness value for unreinforced AA6061 alloy was found to be 50 HV. The optical micrograph of unreinforced alloy is shown in Figure-4 and 5. The microstructure is observed to have uniform distribution of alloy particles. The obtained hardness of AA6061 alloy/5 Wt. % SiCp/7.5 Wt.% Fly ash and AA6061 alloy/10 Wt. % SiCp/7.5 Wt.% Fly ash composites was obtained as 72 HV and 98 HV respectively. The maximum hardness obtained for 15 Wt. % SiCp reinforcement with 7.5 Wt. % Fly ash was 115 HV. This is attributed to the fact that as the percentage of primary reinforcement silicon carbide increases the area fraction occupied by reinforcements also increases.

Previous researchers have stated that the increase in hardness of aluminum matrix composite can be attributed to the increase in interfacial bonding of reinforcement with the aluminum alloy matrix. The dispersion of reinforcement particles in the matrix material for another reinforcement of titanium oxide were studied by microstructure observations for clear interfacial bonding in Aluminium Metal Matrix Composite [19]. Basavaraju (2012) made studies on Mechanical Properties and Tribological Characteristics of LM25- Graphite-Silicon Carbide and LM25-Flyash- Silicon Carbide - Hybrid MMC's and insisted on the interfacial bonding among constituents[20]. It is clear from the Figure-6(a), 7(a) and 8(a) that the distributions of the silicon carbide particles and fly ash particles in the matrix alloy is uniform throughout the specimen surfaces. . It was found that at some places there were clusters of fly ash present.

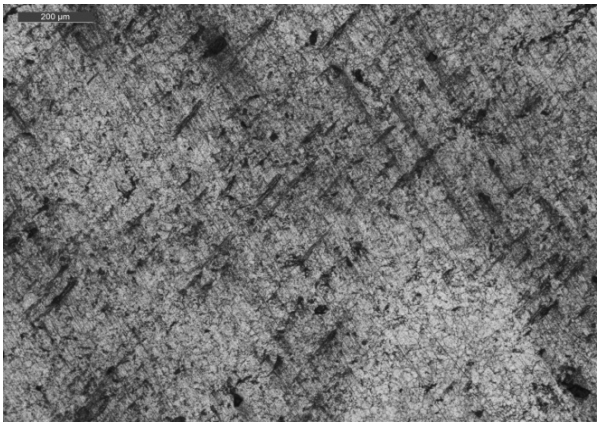

Figure-4. Optical micrograph of sintered AA6061 alloy at 100 X.

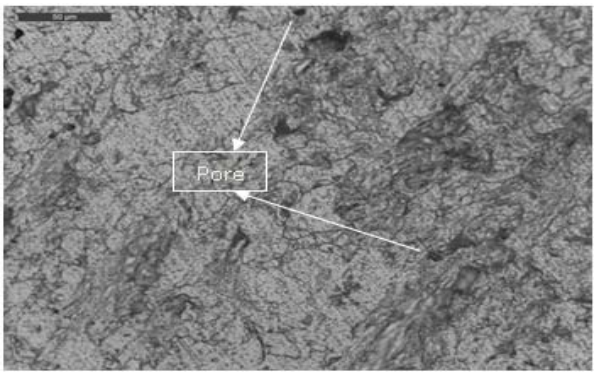

Figure-5. Optical micrograph of sintered AA6061 alloy at 500 X.

At higher magnification the micrograph also reveals pores on some places as shown in Figure-6(b), Figure-7(b) and Figure-8(b). The particle size of the silicon carbide is 15-20 µm while the size of fly ash particles lies in the range from 25µm to 50µm. The shape of the fly ash particles is irregular in nature while the shape of the most fly ash particles is round in nature. The irregular shape of the silicon carbide may be due to the breakage of particles during milling The shape of fly ash particles observed in micrograph images of sintered AA6061/ SiC/Fly ash hybrid composite are agglomerated spheres in the micrographs for various composites having silicon carbide content of 5 Wt. % to 15 Wt. %.The uniform distribution of fly ash particles was still evident other than the places where localization of the fly ash particles was seen. Some of the agglomerated spheres were seen to create pores in the places where these particles were closer enough to be seen as larger particles as observed by earlier researchers [21], [22].

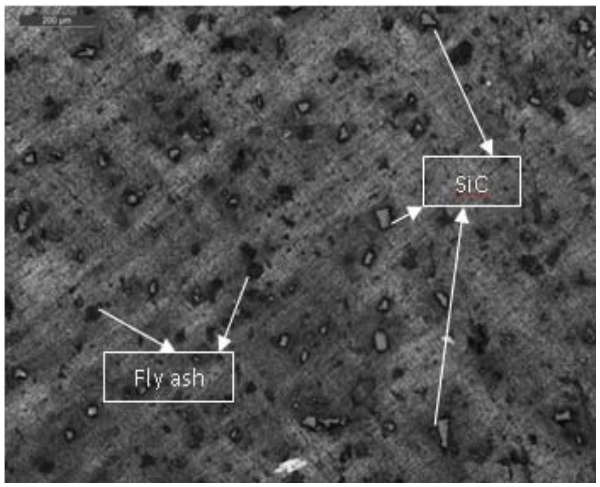

Figure-6. (a) Optical micrographs of HMMC with 5 wt.% SiC and 7.5 wt. Fly ash% at 100X.

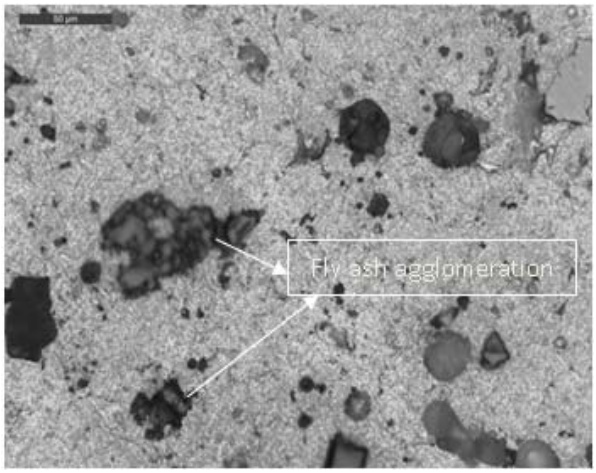

Figure-6(b). Optical micrographs of HMMC with 10 wt.% SiC and 7.5 wt. Fly ash% at 500X.

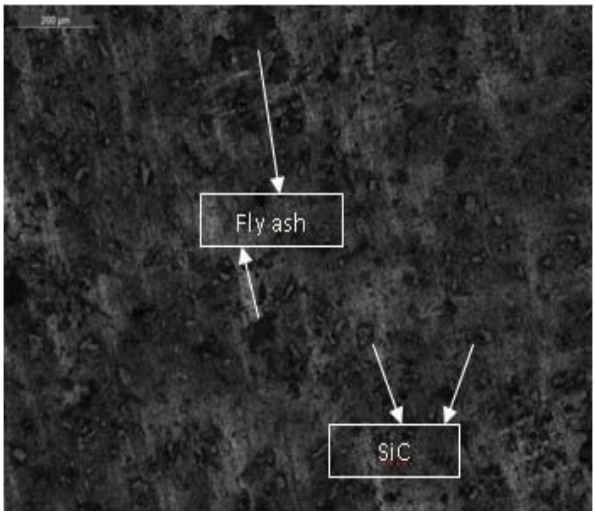

Figure-7(a). Optical micrographs of HMMC with 15 wt.% SiC and 7.5 wt. Fly ash% at 100X.

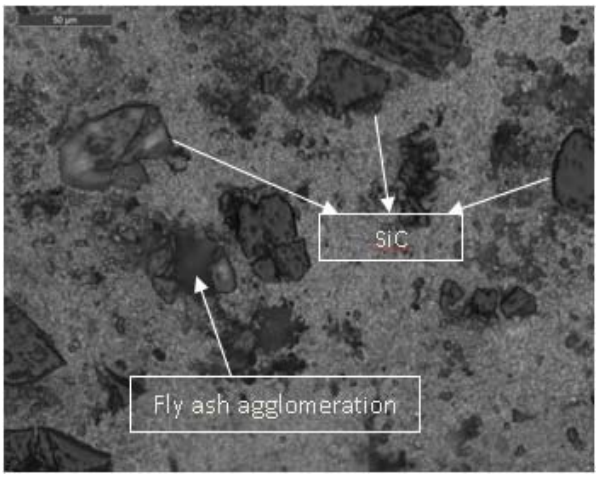

Figure-7(b). Optical micrographs of HMMC with 5 wt.% SiC and 7.5 wt. Fly ash% at 500X.

Our second finding is improvement of the wear resistance with incorporation of Fly ash by 7.5 Wt.% in 5 Wt.% , 10Wt.% and 15 Wt.% silicon carbide reinforced Aluminum alloy metal matrix composite. To support this the theoretical green density of composite was determined by equating the sum of weight percentage to density ratio of alloy and reinforcements. The theoretical green density of AA6061 alloy- 5 wt. % SiCp composites with 7.5 wt. % of Fly ash was determined as 2.3071 g cm^{-3}, similarly the theoretical green density of AA6061 alloy –10 Wt. % SiCp-7.5 Wt.% Fly ash and AA6061 alloy –15 Wt. % SiCp-7.5 Wt.% Fly ash composites was determined as 2.3232 g $cm^{-3}$and 2.3951 g cm^{-3} respectively. Since the density considerably increased the increase in number of reinforcement particles while the fraction of matrix material decreased in total composite material the increase in green density could be a reason for increased wear resistance.

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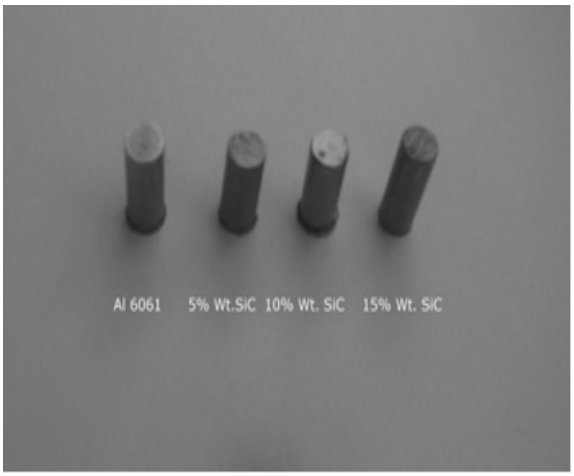

Figure-8. Photograph of Specimen for Pin-on-disc test.

The process parameters (Table-1) selected were applied load, sliding velocity and sliding distance towards investigation of wear resistance of the test specimen. The results obtained during this work have been presented in terms of sliding wear and specific wear rate. The various test conditions and observations are given in Table-2, Table-3 and Table-4 for the AA6061/SiC/Fly ash composites with 5 Wt.% Silicon carbide reinforcement and 7.5 Wt.% Fly ash.

Table-1. Process parameters for wear test.

Material Designation	Load	Sliding Speed	Percentage of SiC content
	(N)	(m/s)	
Composite A	9.81	1	5%
Composite B	19.62	2	10%
Composite C	39.43	3	15%

Table-2. Details of wear test at 1 m/s and 3000 m condition.

S. No	Load	Initial wt.	Final wt.	Wt. Loss	Specific wear rate
	(N)	(gm)	(gm)	(gm)	(10^{-5} mm^3/Nm)
1	9.81	8.144	8.1229	0.0211	3.864
2	19.62	8.1133	8.1074	0.0059	4.321
3	29.43	8.132	8.1133	0.0187	4.566

Table-3. Details of wear test at 2 m/s and 3000 m condition.

S. No	Load	Initial wt.	Final wt.	Wt. Loss	Specific wear rate
	(N)	(gm)	(gm)	(gm)	(10^{-5} mm^3/Nm)
1	9.81	8.27122	8.246	0.02522	4.045
2	19.62	8.09076	8.073	0.01776	4.364
3	29.43	8.16358	8.1494	0.01285	6.689

Table-4. Details of wear test at 3 m/s and 3000 m condition.

S. No	Load	Initial wt.	Final wt.	Wt. Loss	Specific wear rate
	(N)	(gm)	(gm)	(gm)	(10^{-5} mm^3/Nm)
1	9.81	8.27122	8.2422	0.02922	5.065
2	19.62	8.09076	8.067	0.02376	6.546
3	29.43	8.16358	8.14182	0.02176	8.562

The observation of wear testing under dry sliding conditions at 9.81 N and 19.62 N loads shows the increase in wear resistance with various sliding speeds for 5% SiC reinforcement in AA 6061/SiC/Fly ash composite. The wear testing machine is shown in Figure-9.

Figure-9. Components of pin-on-disk test apparatus.

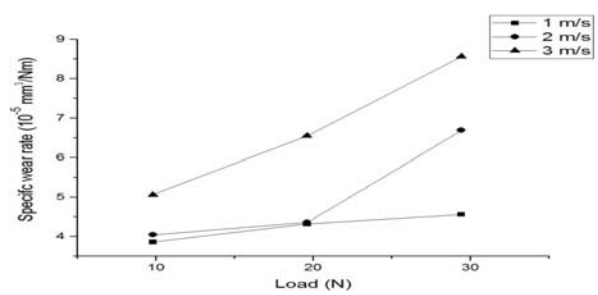

Figure-10. Variation of Load against Specific wear rate for 5% SiC reinforced AA6061-SiC-Fly ash Composite for various sliding velocities and 3000 m.

The mechanisms for the increasing wear resistance may be due to particle pull out, particle fracture, debonding of particles or micro mechanics during the tests reported by earlier by researchers[23], [24]. The influence of the particle fracture is a predominant mechanism than other mechanisms. This is evident from the microstructure of the elemental alloy and HMMC in higher magnifications. The increase in the applied load from 9.81 n to 19.62 N increased the wear rate, as shown in figure 10, this indicates change of wear mechanism from abrasion to particle cracking. At much higher load of 39.43 N the increased hardness attribute adhesion as a dominating mechanism for increase in wear resistance [25].

The possible topics that have been not discussed by the authors here are effect of friction, effect of coating on the reinforcements, formation of built up edges, thermal softening and tool wear. As the occurrence of wear is accompanied by friction it is assumed to be covered. Since it is a novel attempt to incorporate the fly ash particles as strengthening agents in HMMC by powder metallurgy route with silicon carbide as primary reinforcement, the effect of coating is not considered for determining the fundamental properties of novel HMMC. The formation of build up edges is evident from the fractured Silicon carbide particles. As there was no heat treatment done during the synthesis of HMMC thermal softening in HMMC is ruled out. Tool wear along with, tool particle interactions, surface roughness and surface morphology may be taken up during the evaluation of machining parameters of the novel HMMC.

CONCLUSIONS

Fly ash can be used as additional reinforcement material to improve the properties of the AA6061 alloy/SiC composite processed under powder metallurgy route. The AA6061 alloy/5 wt.% SiC/ 7.5 wt.% Fly ash, AA6061 alloy/10 wt.% SiC/ 7.5 wt.% Fly ash and AA6061 alloy/15 wt.% SiC/ 7.5 wt.% Fly ash hybrid composites upon investigation revealed that

- The micro hardness of the hybrid composite specimen increases with the increase in content of the Silicon carbide particles up to 15 wt% while adding another reinforcement in the form of 7.5 Wt % fly ash.
- Incorporation of 7.5 Wt. % of fly ash particles in AA6061 alloy/10 wt. % SiC and AA6061 alloy/15 wt. % SiC composites results in increase of dry sliding wear resistance for different sliding speeds at low load of 9.81 N.
- AA6061 alloy/15 wt.% SiC/ 7.5 wt.% Fly ash composites show highest wear resistance compared to AA6061 alloy- 5wt % SiC/7.5 wt.% Fly ash and AA6061 alloy- 10 wt %/7.5 wt.% Fly ash for different sliding speeds at a higher load 19.62 N.
- In AA6061 alloy/SiC/Fly ash composites wear decreases with increase in weight fraction of reinforcements, for the 7.5 Wt. % Fly ash and increasing weight fraction of SiC particulates up to 15 Wt.% for different sliding speeds.

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