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PERFORMANCE OF AL-FLY ASH METAL MATRIX COMPOSITES

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ABSTRACT

Aluminum fly ash metal matrix composites (MMCs) find important applications in aerospace and automobiles where specific stiffness is important. Low cost fly ash and silicon carbide reinforcement are widely used in aluminium metal and matrix composite due to its low density, high young modulus and strength apart from good mechanical and chemical compatibility & thermal stability. However the MMCs often suffer from low ductility, toughness and fatigue crack growth resistance relative to the matrix alloy. Such applications require materials offering light weight, high strength to weight ratio with required mechanical properties. The applications of Al-Flyash-SiC MMCs are limited due to their poor machinability. In order to overcome the machining difficulty, Hybrid Al-Flyash- SiC composites are fabricated. The present study deals with the machining characteristics of Hybrid Al-Flyash-SiC MMC of different volume fractions (5%, & 10%) by weight.

Keywords: flyash, machinability, workability, hardness, metal matrix, composite.

INTRODUCTION

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties. Metal matrix composites (MMCs) are the forerunners amongst different classes of composites. Over the past two decades metal matrix composites (MMCs) have been transformed from a topic of scientific and intellectual interest to a material of broad technological and commercial significance (Miracle, 2005) Metal Matrix Composite consists of a metallic matrix combined with a reinforcing material. The matrix materials are Aluminium, Magnesium, and Titanium etc. The reinforcing materials can be Silicon Carbide, Flyash, Alumina, and Graphite. MMCs offer a unique balance of physical and mechanical properties. Aluminium based MMCs have received increasing attention in recent decades as engineering materials with most of them possessing the advantages of high strength, hardness and wear resistance. Charles and Arunachalam (2004) studied the properties of aluminium alloy hybrid (Al-alloy/Silicon carbide (SiC)/fly ash) composites. They reported that the wear and hardness were enhanced on increasing the volume fraction of SiC. Bernal, S., & Rodríguez, E. (2004) have studied the influence of reinforcement and thermal aging on the mechanical properties of Al 6061 based hybrid composites.

LITERATURE REVIEW

The dynamic power behind the development of metal matrix composites are their capability to design to provide needed types of material behaviour, such as their improved strength and stiffness, outstanding corrosion resistance (Chen 1997); friction resistance and wear resistance , high electrical and thermal conductivity and high temperature mechanical behavior . The fabrication and mechanical properties of metal matrix composites has been published in a general review R.K. Everett and R.J. Arsenault (1991). Basavarajappa et al. (2004) investigated the mechanical properties of aluminum alloy (Al2024) reinforced with SiC and graphite particles. Their results revealed that the mechanical properties such as ultimate tensile strength, yield strength, hardness and compressive strength of the composite increased predominantly with the increase in volume fraction of reinforcement. Mahendra K.V and Radhakrishna K. (2007) investigated the properties of Al-4.5% Cu alloy composite with fly ash as reinforcement. They reported the increase in hardness, tensile strength, compression strength and impact strength with increase in the fly ash content. Tomac N and Tonnessen (1992) investigated the effect of cutting speed when turning A1-SiC MMCs with PCD and coated tungsten carbide tools and found that high cutting speeds shorten tool life by causing excessive flank wear. They investigated the effect of feed rate and found that high feed rate setting can reduce the tool wear. At higher federates the temperature of the cutting zone increases. This leads to the softening of the metallic matrix enabling easier removal of the embedded SiC particle in the work piece. Yuan (1993) has shown that, when a PCD cutting tool is used, the depth of cut has no significant effect on the surface roughness of the machined work piece. Lane (1992) reported that the tool life of the PCD cutting tool was found to be inversely proportional to the depth of cut.

WORK MATERIAL

The base materials used for the fabrication of Aluminium Alloy is Al6061. Table-1 gives the composition of alloy Al6061. The basic elements present are Al, Si, Cu, Mn and Cr. Table-2 presents the various mechanical and chemical properties of A6061.

Table-1. Composition of A6061.

Element	Al	Si	Cu	Mg	Cr
Weight%	97.90	0.60	0.28	1.00	0.20

Table-2. Properties of A6061.

Properties	Values	Conditions T (ºC)
Density (× 1000 kg/m^3)	2.7	25
Poisson's Ratio	0.33	25
Elastic Modulus (GPa)	70-80	25
Tensile Strength (Mpa)	115	25
Yield Strength (Mpa)	48	25
Elongation (%)	25	25
Hardness (HB500)	30	25
Shear Strength (MPa)	83	25
Fatigue strength (MPa)	62	25
Thermal Expansion (10^{-6}/^{o}C)	23.4	20-100
Thermal Conductivity (W/m-K)	180	25
Electric Resistivity (10^{-9}W-m)	37	25

Properties of flyash

The presence of flyash in a work piece helps a lot in machinability.

a) Flyash can be used as Lubricants.
b) It has low thermal conductivity.
c) The size is less than 250 micrometers.
d) Melting point is above 1000 ^{o}C.
e) It is chemically inert.

Table-3 presents the properties of different constituent used for the fabrication of composites. The melting points of flyash, SiC, A6061 are presented in Table-3 for easy comparison.

Table -3. Properties of the composite material.

Material	Form	Formula	Melting point (°C)	Density g/cm³
Flyash	Powder	Combination of elements	>1000	0.8
Silicon Carbide	Powder	SiC	2730	3.22
Aluminium A6061	Chip	Al	660	2.70

Fly ash composition

SiO_2 = 60.62%
Al_2O_3 = 21.93%
$Fe_2O_3 + Fe_3O_4$ = 7.12%
CaO = 2.28%
MgO = 0.85%
SO_4 = Traces
Loss on ignition = 0.72%
Bulk Density = 0.86gm/cc
Fine ness = 0.075mm in m^2 / kg

Melting point of aluminium is about 660°C Casting periods is about 2 ½ hrs Stirring period is about 20 minutes.

Pit Furnace was used for melting, by coke fire method. Dry sand moulding is used. Pattern material was teak wood. Type of pattern used is solid pattern. Speed of three blade stirrer is 7000 rpm. This speed is reduced to 60 rpm by auto transformer or dimmer stat.

Method for the preparation of Cast Hybrid Al-SiC MMC with 5% volume fraction

The A6061 Aluminium in the form of Chip by weight 90 % is placed in the Flyash crucible and is heated to a temperature higher than the melting temperature 660^{o}C of Aluminium. The reinforcement's like Silicon Carbide by weight 5% and Flyash by weight 5% are preheated for three hours in a separate furnace and after preheating it is poured into the Flyash crucible. The motor with stirrer set up is made on and the stirrer is made to rotate with high speed in order to mix the reinforcements uniformly with A6061. After thorough mixing is done, the liquid MMC is poured to the mould kept at the bottom of the furnace, through the Argon gas chamber with a pressure of 2 bars to cool the hybrid MMC. Thus the solid hybrid Al- SiC-Flyash MMC rod with dia 50 mm and length 250 mm is fabricated.

MACHINING PERFORMANCE EVALUATION

Turning was carried out for the combination of different speeds, feeds and depths of cuts, using a fresh cutting edge. The ranges of cutting conditions were decided for progressive wear f the tool. For each cutting condition, the three components of cutting forces F_x, F_y and F_z, were measured. Measurements were made at different intervals of time. Depending on the length of cut, machining was stopped after every 60-80 seconds, and V_b was measured. Static forces were recorded at two or three intermediate points between two V_b measurements. The set of measurements were taken immediately prior to a wear measurement. One hundred sets of data were collected. During re-insertion of tool inserts after every V_b measurement, inserts were slugged into the slot made out in the tool holder, so that there was no change in the tool overhang.

Table- 4. Data collected during turning.

Sl. No.	Input patterns								Target values	
	Workpiece Composition	Values of the machine setting during turning			Values collected from dynamometer during turning				Values to be monitored during online implementation	
	Volume fraction %	Speed rpm	Feed mm/rev	Depth of cut, mm	Fx N	Fy N	Fz, N	Machining time, min	Flank wear Vb, mm Diagnostics	Ra µm
1	5	325	0.102	0.5	114.98	81.55	228.93	2	0.030	1.71
2	5	325	0.205	0.5	138.43	126.27	290.26	5	0.140	3.83
3	5	325	0.286	0.5	165.8	173.22	354.48	8	0.310	5.48
4	5	325	0.102	1	120	85	236	2	0.050	1.74
5	5	325	0.205	1	141	130	307	5	0.170	5.8
6	5	325	0.286	1	171	179	359	8	0.360	5.6
7	5	325	0.102	1.5	125	91	241	2	0.080	1.79
8	5	325	0.205	1.5	144	132	310	5	0.190	4.3
9	5	325	0.286	1.5	175	180	362	8	0.390	5.8
10	10	325	0.102	0.5	75	32	144	2	0.120	1.1
11	10	325	0.205	0.5	37	22	190	5	0.320	3.1
12	10	325	0.286	0.5	75	33	71	8	0.010	1.89
13	10	325	0.102	1	78.57	35.72	149.37	2	0.150	1.85
14	10	325	0.205	1	41.45	26.85	193.06	5	0.350	3.12
15	10	325	0.286	1	79.5	35.63	74.36	8	0.040	2.65
16	10	325	0.102	1.5	81	39	151	2	0.180	1.9
17	10	325	0.205	1.5	43	28	197	5	0.380	3.19
18	10	325	0.286	1.5	83	37	81	8	0.070	3.12
19	5	500	0.102	0.5	124.94	82.26	241.03	2	0.231	2.11
20	5	500	0.205	0.5	166.98	144.7	323.14	5	0.244	2.75
21	5	500	0.286	0.5	227.28	231.82	416.95	8	0.225	3.17
22	5	500	0.102	1	127	85	249	2	0.242	2.13
23	5	500	0.205	1	170	150	330	5	0.255	2.6
24	5	500	0.286	1	230	235	417	8	0.239	3.4
25	5	500	0.102	1.5	130	90	255	2	0.256	2.5
26	5	500	0.205	1.5	172	160	341	5	0.269	3.1
27	5	500	0.286	1.5	232	240	422	8	0.254	4.2
28	10	500	0.102	0.5	71	34	161	2	0.270	1.32
29	10	500	0.205	0.5	75	42	185	5	0.283	1.79
30	10	500	0.286	0.5	74	47	200	8	0.237	2.2
31	10	500	0.102	1	73.2	37.2	164.32	2	0.253	1.34
32	10	500	0.205	1	76.39	43.43	189.77	5	0.266	1.81
33	10	500	0.286	1	78.84	48.17	207.19	8	0.251	2.78
34	10	500	0.102	1.5	77	38	167	2	0.267	1.37
35	10	500	0.205	1.5	77	44	190	5	0.281	1.82
36	10	500	0.286	1.5	80	52	210	8	0.295	2.79

37	5	770	0.102	0.5	153.67	99.72	267.85	2	0.339	1.48
38	5	770	0.205	0.5	240	194.78	385.36	5	0.355	1.91
39	5	770	0.286	0.5	309.28	255.38	479.03	8	0.368	2.27
40	5	770	0.102	1	156	102	270	2	0.353	1.5
41	5	770	0.205	1	246	205	400	5	0.370	1.94
42	5	770	0.286	1	310	260	480	8	0.383	2.28
43	5	770	0.102	1.5	157	107	272	2	0.367	1.55
44	5	770	0.205	1.5	250	210	403	5	0.384	1.95
45	5	770	0.286	1.5	312	265	490	8	0.397	2.29
46	10	770	0.102	0.5	73	36	166	2	0.350	0.92
47	10	770	0.205	0.5	75	40	185	5	0.367	1.35
48	10	770	0.286	0.5	77	43	192	8	0.380	1.9
49	10	770	0.102	1	75.32	38.35	168.56	2	0.364	0.93
50	10	770	0.205	1	77.03	41.82	186.6	5	0.381	1.3
51	10	770	0.286	1	78.46	44.71	196.5	8	0.394	1.95
52	10	770	0.102	1.5	76	40	170	2	0.378	0.94
53	10	770	0.205	1.5	79	42	190	5	0.395	1.3
54	10	770	0.286	1.5	79	45	196	8	0.408	1.95
55	5	325	0.102	0.5	114.98	81.55	228.93	10	0.152	1.73
56	5	325	0.205	0.5	138.43	126.27	290.26	10	0.168	3.87
57	5	325	0.286	0.5	165.8	173.22	354.48	10	0.182	5.5
58	10	325	0.102	0.5	75	32	144	10	0.163	1.25
59	10	325	0.205	0.5	37	22	190	10	0.180	3.17
60	10	325	0.286	0.5	75	33	71	10	0.193	1.95
61	5	500	0.102	0.5	124.94	82.26	241.03	10	0.225	2.17
62	5	500	0.205	0.5	166.98	144.7	323.14	10	0.242	2.79
63	5	500	0.286	0.5	227.28	231.82	416.95	10	0.255	3.22
64	10	500	0.102	0.5	71	34	161	10	0.237	1.39
65	10	500	0.205	0.5	75	42	185	10	0.253	1.82
66	10	500	0.286	0.5	74	47	200	10	0.266	2.31

During machining of hybrid Al -Flyash-SiC MMC, large amount of cutting forces are generated between the contact of tool tip and work piece surface. Three components of cutting forces: F_x, F_y and F_z are generated. The tangential force is responsible for removal of material from the work piece surface. Cutting forces are acquired from the three axes kistler dynamometer.

Turning data

Table-4 presents the experimental data obtained during turning. The second column represents volume percent by weight of the work piece. The third column represents speed of the work spindle in revolution per minute. The fourth column represents axial feed of the cutting tool along the axis of the job in mm per revolution. The fifth column represents the depth of cut into the work piece surface by the tool. The values mentioned above were constant for a particular cutting condition. However, the cutting force F_x (sixth column), F_y (seventh column) and F_z (eighth column) continuously varies depending upon the hardness of the work piece material and the wear of the tool surfaces as the machining time increases (ninth column). Normally, flank wear of the PCD tool and the surface roughness of the work piece are measured. A total of 100 patterns are measured.

RESULTS AND DISCUSSIONS

Hardness test

The hardness have been evaluated for A6061/fly ash composites with Brinell hardness tester and the hardness values of the base alloy and composites are listed in Table-5. The hardness of the aluminum fly ash composites increase with the fly ash reinforcement The Brinell hardness number is calculated by dividing the load applied by the surface area in the indentation (Table-5).The specimen diameter is 40 mm. Brinell hardness test specimen diameter = 30mm. diameter of indenter=10mm . Applied load = 1000kg.

Where,

P = applied force

D = diameter of indenter (mm)

d = diameter of indentation (mm)

Table- 5. Hardness test performances.

	5% flyash		10% flyash	
S. No.	**D**	**(BHN)**	**D**	**(BHN)**
1	5.8	34.3581	5.7	35.7120
2	5.65	36.4156	5.65	36.4156
3	5.7	35.7120	5.71	35.5735
4	5.7	35.7120	5.55	37.8795
5	5.81	34.2265	5.58	37.4322
6	5.8	34.3581	5.6	37.1379
7	5.75	35.0264	5.7	35.7120
8	5.7	35.7120	5.66	36.2734
9	5.75	35.0264	5.6	37.1379
10	5.8	34.3581	5.7	35.7120

Table-5 shows the hardness measurements of 10 specimen cut at different portions of the case specimen of 5%, 10% flyash composition.

Tension test

The test provides information on proof stress, yield point, tensile strength, elongation and reduction in area Table-6.

Table-6. Tension test performances.

Aluminium with	Maximum Ultimate Load, Kn	Deflection at Maximum Load, mm	Maximum Displacement at fracture, mm	Percentage of Elongation, %
5% flyash	15.94	9.9	7.5	8.3
10% flyash	16.14	11.7	9.2	10.2

Figure-1 represents the tension test performance carried out with 5% and 10% fly ash. The yield strength, tensile strength of AA6061 fly ash metal matrix composites increases with the increase in reinforcement, however % elongation decreases with the increase in reinforcement.

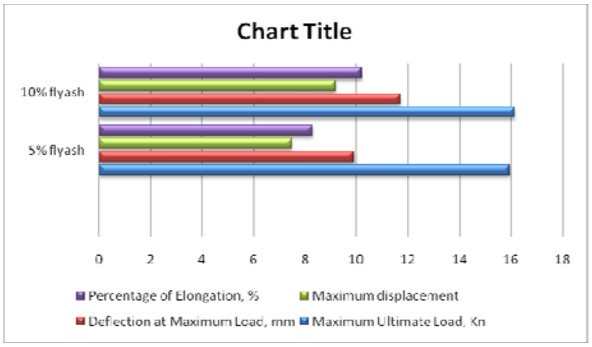

Figure-1. Tension test performance.

Toughness test (CHARPY)

Table-7 presents the toughness values for all three combinations of Flyash.

Table -7. Toughness (j/m)^{3} test values.

S..No.	5% Flyash	10% Fly ash
1	60	120
2	65	115
3	62	117
4	58	121
5	60	122
6	63	120
7	61	119
8	65	120
9	62	120
10	63	121

COMPOSITE WORKABILITY DATA

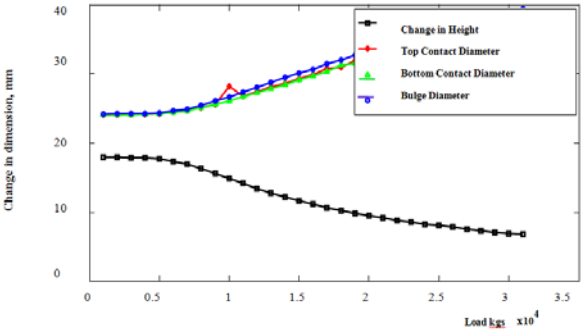

Figure-2. Deformation plot for Aluminium 5% flyash with Aspect ratio: 0.75.

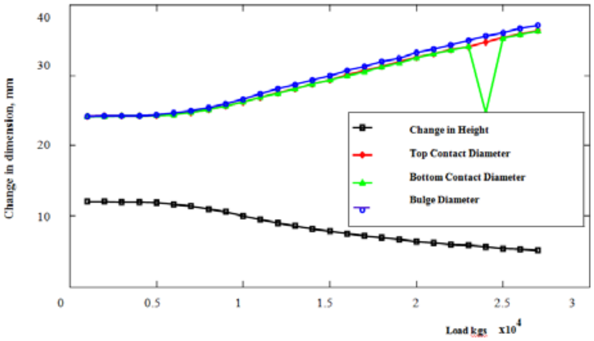

Figure-3. Deformation plot for Aluminium 10% flyash with Aspect ratio: 0.5.

CONCLUSIONS

From the above literature review, it can be concluded that in order to study the influence of the particle size of fly ash as reinforcement on the aluminium alloy (Al6061) composite and to study its effect on mechanical properties different sizes of fly ash have been selected in the present study. Gradually the percentage of flyash content In of Al-Flyash-SiC MMCs was increased and was subjected to various hardness tests and with the help of techniques such as it is clear that the machinability property of Al-Flyash-SiC increases significantly. Thus the new combinations of hybrid Al Flyash SI MMC with increased volume percentage helps in improving machinability, reducing PCD tool wear and reducing surface roughness of the work piece.

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