Wear Characteristics of Hybrid Aluminium Metal Matrix Composites Produced by Stir Casting Technique

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Abstract.* Aluminium Metal Matrix Composites with multiple reinforcements i.e. hybrid MMCs are finding increased application because of improved mechanical and tribological properties and hence are better substitutes for single reinforced composites. Few investigations have been reported on the tribological properties of these composites with % reinforcement above 10%. This work investigated the influence of addition of graphite particulates as a second reinforcement on the wear behaviour of Aluminium matrix composites reinforced with Al_2O_3 particulates. The conventional liquid casting technique i.e. stir casting technique was used for the fabrication of composite material. Ceramic particles along with solid lubricating materials were incorporated into aluminium alloy matrix to accomplish reduction in both wear resistance and co-efficient of friction. The Al7075/Al_2O_3 /Graphite hybrid composite was prepared with 3 wt% graphite particles addition and 3, 6, and 9 wt % of Al_2O_3. Dry sliding wear tests have been conducted by using pin on disc apparatus to study the influence of graphite particulates, load, sliding distance and sliding speed on the wear characteristics of hybrid MMCs. The wear properties of the hybrid composites containing graphite exhibited the superior wear resistance properties.

Keywords: Hybrid Composite, Casting, Particle reinforcement, wear

I.INTRODUCTION

Wear may be defined as the progressive loss of materials from contacting surfaces in relative motion. Wear takes place at a materials interface of metal matrix composites (MMCs) with reinforcement of ceramic particles which gives better wear resistance. Aluminium based metal matrix composites have been a very major role in the field of newer advanced materials for high performance tribological applications. Aluminium based composites are being highly used in automobile sector, aircraft industry, marine, electronic and mineral processing industries owing to their high stiffness to weight ratio, high specific strength, high wear resistance, higher thermal conductivity and lower coefficient of thermal expansion [1, 2].

Generally, silicon carbide *(SiC)*, aluminium oxide *(Al_2O_3)*, and graphite which is in the form of particulates are widely used for making this type of composite. Liquid casting processing technique or powder metallurgy technique is used for the fabrication of aluminium matrix composites. In the liquid casting processing technique, the ceramic particulates are reinforced into the molten matrix which is followed by mechanical stirring for the uniform distribution of particles. This Processing technique is quiet cheaper than other techniques of fabrication. Aluminum based MMCs reinforced with ceramic particles shows better mechanical properties than unreinforced aluminium alloys and are most widely used for tribological parts due to their high strength to weight ratio and improved wear resistance [3, 4].

In 1940 Holm [5] starting from the atomic mechanism of wear, calculated the volume of substance worn over unit sliding path. Barewell and Strangin 1952: Archard in 1953 and Archard and Hirst [6] in 1956 developed the adhesion theory of wear and proposed a theoretical equation identical in structure with Holm's equation. In 1957, Kragelski [7] developed the fatigue theory of wear. Evans et al. [8] studied the abrasion wear behavior for 18 polymers and they noticed that low density polyethylene (LDPE) showed the lowest wear rate in abrasion against rough mild steel, but a higher wear rate in abrasion with coarse corundum paper. Bardeswaran et al. [9] investigated the wear properties of Al 7075/Al2O3/Graphite fabricated with stir casting method and concluded that hybrid composites shows better wear resistance than the base metal. Y.Sahin [10] studied the wear behaviour of composites reinforced with SiC produced by the molten metal mixing method and also done the statistical analysis and found that wear rate is increased with increasing applied load and sliding distance. Stojanovic [11] investigated the tribological behaviour of aluminium hybrid composite reinforced with SiC and graphite and concluded that load, sliding speed, sliding distance, volume fraction and size of particles influence the wear and co-efficient of friction of hybrid composite.

Generally graphite which is also known as solid lubricant is externally added to reduce the wear because it acts as self lubricating material. Many researchers investigated on aluminium graphite composite which contains less amount of graphite which shows better wear properties over the base alloys but found decrease in strength of composite.

II. EXPERIMENTAL PROCEDURE

Materials. Aluminium alloy Al 7075 was purchased from Bharat Aerospace metals, Mumbai. Graphite and Al_2O_3 particles were purchased from N.B. Enterprises, Bilaspur. The chemical composition of Al 7075 alloy is given in Table 1.

Table 1.Chemical composition of Al 7075

Element	Zn	Cu	Mg	Si	Fe
Wt.%	5.8	1.5	2.4	0.09	0.36
Element	Fe	Mn	Cr	Ti	Al
Wt%	0.36	0.07	0.21	0.05	89.52

Fabrication Method. A stir casting setup consists of an electric resistance furnace and a stirrer assembly, was used to synthesize the composite. The stirrer assembly consists of a four blade graphite stirrer, which was connected to a variable speed electric motor with range of 800 to 900 rpm by means of a steel shaft.

Approximately 1 Kg of aluminium alloy in solid form (circular rod) was melted at 800°C in the resistance furnace. Preheating of reinforcement particles was done at 800°C for 2 hour to remove moisture, gases and other organic contaminants from the surface of the particles which will improve the wettability between matrix and the reinforcement particles. Once the Al alloy is in full liquid condition 1% Mg is added into the molten metal for increasing the wettability. After that 0.3% hexachloro ethane (C_2Cl_6) is added for the degassing purpose. The stirrer was then lowered vertically up to 3 cm from the bottom of the crucible (total height of the melt was 9 cm).

The speed of the stirrer was gradually raised to 900 rpm and the preheated particles were added into the melt through a steel pipe and funnel at the rate of 10- 20 g/min. The speed controller maintained a constant speed of the stirrer, as the stirrer speed got reduced by 50-60 rpm due to the increase in viscosity of the melt when particulates were added into the melt. After the addition of particles, stirring was continued for approximately 10 minutes for proper mixing of particles in the matrix. The melt was kept in the crucible for approximate half minute in static condition and then it was poured in the metallic mould.

Wear Test

From cast plate, a small portion of dimension 2×2×10 cm^3 were cut and then it was machined to make the cylindrical pin of having dimension 6mm diameter and 35 mm length Fig.1. The wear and frictional tests were carried out on pin on disc apparatus (Model: TR-20LM-M5) Fig.2.

Before conducting the test, the pin and the disc surfaces were polished with emery papers, so that the contact will be a smooth one. The test pieces were cleaned with tetra-chloro-ethylene solution before each test. All the wear tests were carried out as per ASTM G-99 standard under dry condition at room temperature. The wear in specimen after each test was noted by an electronic display.

Fig.1. Pin for wear test

Fig.2. Pin on Disc wear testing machine

Calculation of sliding distance.

Sliding Speed (V_S) = (πDN/60000) m/s, Sliding distance (D_S) in meter= (πDNT /60000) m

Where, π = 3.14, D = Dia. of wear track in mm, N = Disc speed in RPM, T = Test duration in sec

Calculation of the disc speed for the sample of 10 kg load.

Sliding speed = 1m/s, track diameter = 120mm, N = ($V_S \times 60000/\pi D$) = 159.23 RPM

Results and Discussion

The wear characteristics of the hybrid composites Al 7075/Al_2O_3/Graphite is as shown in Table 2-5 and the corresponding graph is drawn which is as shown in Graph 1-4. The wear decreases with the addition of Al_2O_3 and reaches a minimum at 6 wt. % Al_2O_3/3 wt.% graphite and it is less than that of the matrix material Al 7075, whereas the wear of the hybrid composite decreases with increasing sliding speed. At a higher sliding distance, rise of temperature of the sliding surfaces is inevitable and heavy deformation at a higher sliding distance, but the reduction in wear rate of the hybrid composite relative to the matrix material can be one of the reasons which is beneficial for the effect of the graphite addition in reducing the wear of the composites due to the formation of a thin lubricating graphite film on the tribo surface.

The wear increases with increasing applied load and at all the load condition; the minimum wear was at 3 wt. % Al_2O_3/3 wt. % graphite hybrid composites. The Al_2O_3 particles act as load bearing elements in the hybrid composites and also it results in the formation of a more stable lubricating film on the tribo surface of the hybrid composites. The decreased wear rate of hybrid composite with graphite content can be ascribed to the collective effects of graphite and Al_2O_3 particles in the formation of a more resistant tribo layer on the contact surface. The graphite tribo film minimizes the degree of shear stress transferred to the sliding material underneath the sliding contact area which results in less plastic deformation in the subsurface region and reduces the wear rate in the hybrid composites.

Table 2. Wear properties of material at different sliding distance

Load: 20N, Sliding speed: 0.8 m/s, RPM: 170

Material	Sliding distance (m)	Time (sec)	W1 (μm)	W2 (μm)	Wmean (μm)
Al 7075	250	312	332	340	336
	500	624	198	216	207
	750	936	143	149	146
	1000	1248	91	87	89
Al 7075 + 3% Al2O3+ 3%Graphite	250	312	184	196	190
	500	624	122	136	129
	750	936	104	98	101
	1000	1248	63	73	68
Al 7075 + 6% Al2O3+ 3%Graphite	250	312	168	174	171
	500	624	116	122	119
	750	936	85	79	82
	1000	1248	47	53	50
Al 7075 + 9% Al2O3+ 3%Graphite	250	312	187	177	182
	500	624	131	143	137
	750	936	119	105	112
	1000	1248	69	69	69

The effect of graphite on friction coefficient is as shown in Graph 4. The coefficient of friction of hybrid composite decreases due to the presence of graphite. The reduction in the coefficient of friction is due to the release of graphite during their wear process which acts as the solid lubricant.

However it is observed that in all cases wear decreases with respect to increase in percentage addition of reinforcement up to 7 %. The subsequent marginal increasing trend of these hybrid composites at 9 wt. % of reinforcement overshooting the wear rate can be the negative effect of the hard particle addition together with the increasing tendency of crack initiation and propagation at the reinforcement/metal interface.

Table 3. Wear properties of material at different sliding speed

Load: 20N, Sliding distance: 250 m

Material	Sliding speed (m/s)	W1 (μm)	W2 (μm)	Wmean (μm)
Al 7075	0.6	440	436	438
	0.8	332	336	334
	1	480	490	485
Al 7075 + 3% Al_2O_3 + 3% Graphite	0.6	253	249	251
	0.8	174	178	176
	1	302	300	301
Al 7075 + 6% Al_2O_3 + 3% Graphite	0.6	265	273	269
	0.8	168	162	165
	1	290	274	282
Al 7075 + 9% Al_2O_3 + 3% Graphite	0.6	290	296	293
	0.8	187	183	185
	1	313	321	317

Table 4. Wear properties of material at different load

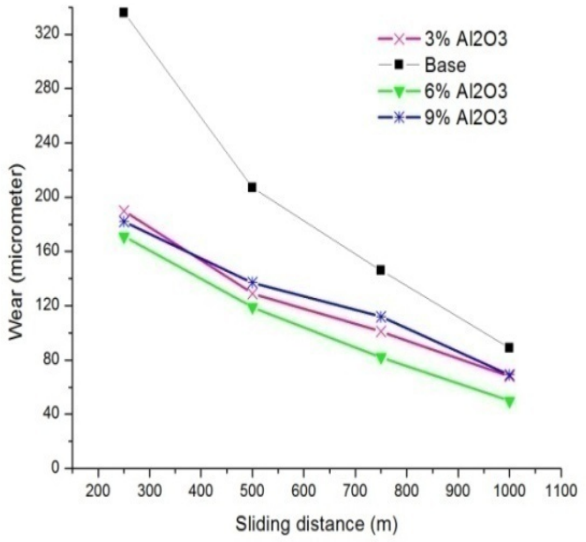
Sliding speed: 0.8 m/s, sliding distance: 250 m

Material	Load (N)	W1 (μm)	W2 (μm)	Wmean (μm)
Al 7075	10	44	50	47
	20	71	73	72
	30	81	77	79
Al 7075 + 3% Al_2O_3 + 3% Graphite	10	23	33	28
	20	45	33	39
	30	54	60	57
Al 7075 + 6% Al_2O_3 + 3% Graphite	10	26	20	23
	20	36	34	35
	30	55	47	51
Al 7075 + 9% Al_2O_3 + 3% Graphite	10	30	42	36
	20	41	41	41
	30	59	77	68

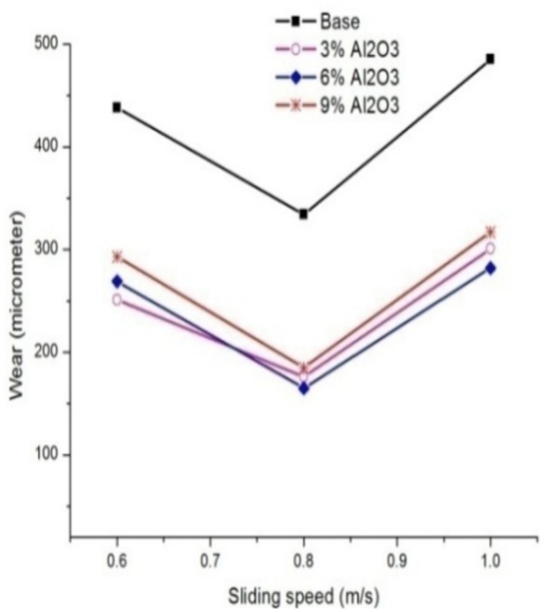
Table 5. Coefficient of friction of different material

Load: 20N, Sliding speed: 0.8 m/s, sliding distance: 250 m

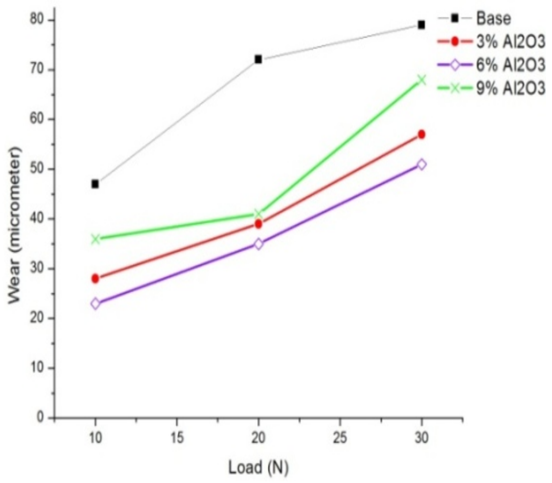
Material	$(cof)_1$	$(cof)_2$	$(cof)_{mean}$
Al 7075	0.255	0.285	0.27
Al 7075 + 3% Al_2O_3 + 3% Graphite	0.24	0.26	0.25
Al 7075 + 6% Al_2O_3 + 3% Graphite	0.135	0.125	0.13
Al 7075 + 9% Al_2O_3 + 3% Graphite	0.08	0.086	0.083



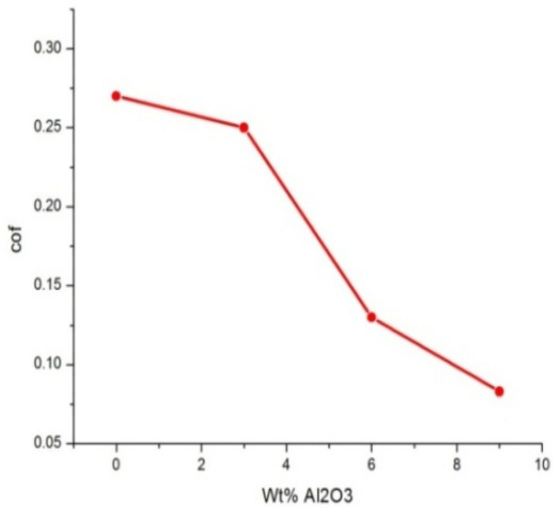
Graph.1. Sliding distance Vs wear



Graph.2. Sliding speed Vs wear



Graph.3. Load Vs Wear



Graph.4. Wt. % Vs Coefficient of Friction

CONCLUSION

In the Present research, hybrid metal matrix composites i.e. Al 7075/Al_2O_3/Graphite has been successfully fabricated using stir cast method. Increase in load increases the wear while it is observed that wear decreases with respect to increase in sliding distance. In case of sliding velocity as it increases the nature of graph shows that wear first decreases then it suddenly increases.

Wear tends to decrease with increasing particle volume content. It also indicates that Al_2O_3 and graphite addition is beneficial in reducing wear of the aluminium composite. Wear in reinforced alloy is less compare to unreinforced alloy. Coefficient of friction decreases with respect to increase in particle volume content.

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