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Comparative Experimental Study of Friction and Wear Properties of MMC and Hybrid MMC

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Abstract - **This paper presents the experimental study on the friction and wear properties of MMC and Hybrid MMC. The MMC (Al/SiC, Al/C, Al/Al_2O_3) and Hybrid MMC (Al/SiC/C/Al_2O_3, Al/Al_2O_3/SiC, Al/Al_2O_3/C and Al/SiC/C) were fabricated by Squeeze Casting method. Wear test was done on a Pin on Disc machine at a constant track diameter of 60 mm, at varying speed of 300, 600 and 1200 rpm, at varying load of 4.91 N, 9.82 N and 14.72 N under dry sliding conditions. The wear properties of MMC and Hybrid MMC composite were evaluated in many respects. The effect of Al_2O_3, SiC, C particles on the wear behavior of composite was elucidated. Wear were analyzed by observing the worn surface of the composite. The variation of coefficient of friction (COF) during the wear process was recorded by using a computer under dry sliding condition. The total weight of the specimens for each type of composite was measured before and immediately after the wear test for calculating the mass loss. The hybrid MMC having composition (SiC-20%, C-7.5%, Al_2O_3-10%) shows the best wear resistance under high load and high speed. The MMC having composition (Al/C-10%) had the biggest weight loss under high load. As the percentage of SiC, C and Al_2O_3 increased in hybrid MMC under high load the wear rate reduced. The result indicates that hybrid MMC Al/SiC/C/Al_2O_3 showed the best wear resistance among them and its COF value was the smallest. The hybrid composites exhibit better wear characteristics compared to composite reinforced with SiC, Al_2O_3 & C alone.**

Keywords – Hybrid MMC, Squeeze Casting Method, Wear properties, Wear mechanism, Coefficient of friction

1. INTRODUCTION

Wear is common phenomenon of all metal having relative motion such as reciprocating and rotating motion of piston cylinder bores, connecting rods, drive shaft, brake rotors bearing etc. The performance advantage of metal matrix composites is their tailored mechanical, physical, and thermal properties that include low density, high specific strength, high specific modulus, high thermal conductivity, and high abrasion and wear resistance [Apasi et al., 2012, Goyal et al., 2014, Kumari et al., 2013]. The combination of hard ceramic particles, such as SiC ones, with self-lubricating reinforcements, such as carbon fibers, to produce a hybrid reinforcement system combines with the main used strategies to improve the wear resistance of aluminium alloys [Urena et al., 2009]. The widely used particles for reinforcing Al alloys are silicon carbide (SiC) and alumina (Al_2O_3) [Mahmoud et al., 2010, Sharma et al., 2014]. Besides their high hardness, low density and low cost comparing with other reinforcements. In the past two decades, the wear resistance of the aluminum alloys reinforced with SiC and Al_2O_3 in many forms (particles, whiskers and fibers) and sizes has been described by a huge body of publications [Sharifi et al., 2011]. Wear behavior of hybrid composite, which was reinforced with two different type of reinforcement, has also been studied [Ahlatcia et al., 2006 & Fu et al., 2004].

Carbon fibers have been considered as very important reinforcements for aluminum and its alloys in fabricating advanced composite materials. Carbon fiber (CF) reinforced metal matrix composites are widely used and studied due to the high specific strength, specific modulus, high thermal and electric conductivity, low expansion coefficient and good self-lubricant properties [Babu et al., 2011 & Lei et al., 2009]. It not only has advantages in preparation method and cost, but also could increase then abradability, dimensional stability and elevate temperature property of the composites.

The wear mechanism strongly dictated by the formation and stability of oxide layer, mechanically mixed layer (MML) and subsurface deformation and cracking. The overall results indicate that the aluminium alloy–silicon carbide particle composite could be considered as an excellent material where high strength and wear resistance are of prime importance [Rao et al., 2009]. The graphite particles are effective agent in increasing dry sliding wear resistance of Al/SiCp composites [Basavarajappa, et al., 2007]. Both mechanical strength and wear resistance of composites increase by adding SiC particulates to the matrix alloy. But the consequent increase in hardness makes the machining difficult. Thus, it is essential to look for ways to retain the advantageous influence of SiC and simultaneously attending the problem of machining of composites reinforced with SiC. Graphite particulates come handy in this direction, the addition of which improves the machining as well as wear resistance of Al–SiC composites. Al–SiC composites reinforced with Gr particulates are referred as Al–SiC–Gr hybrid composites [Suresha et al., 2010].

From the reported studies, it can be concluded that the Hybrid MMC are engineering materials reinforced by combination of two or more different type or form of substances in order to achieve the combined advantage of both of them. Carbon, Al_2O_3 and SiC are usually used as reinforcement of aluminum alloys. But how do these reinforcement effect on the wear behavior of aluminum MMCs? The answer to this question would be very helpful in getting a general idea of the wear properties of hybrid MMCs for tribological use. By taking the references from the above literature the friction and wear properties of MMC (Al/SiC, Al/C, Al/Al_2O_3) and hybrid MMC (Al/SiC/C/Al_2O_3 % variation of composition SiC-10%-15%-20%, Al_2O_3-5%-7.5%-10% and C-3%-5%-7.5%, Al/Al_2O_3/SiC, Al/Al_2O_3/C and Al/SiC/C) Hybrid MMC were evaluated.

2. EXPERIMENTAL DETAILS

2.1 Material and Fabrication

The Squeeze casting technique will be used to prepare the workpiece samples. These workpiece samples will be utilized for testing on wear testing machine. There are following samples:-

Table 1: Test specimens and their compositions

Compositions Notation	Aluminum (gm)	SiC (gm)	Al_2O_3 (gm)	Carbon (gm)	Type of MMC
A	1310	164	82	50	SiC-10%, C-3%, Al_2O_3-5%
B	1200	247	123	82	SiC-15%, C-5%, $Al_2O_3$7.5%
C	1060	340	170	127	SiC-20%, C-7.5%, Al_2O_3-10%
D	1440	180	180	0	SiC-10%, Al_2O_3-10%
E	1445	170	0	85	SiC-10%, C-5%,
F	1445	0	170	85	C-5%, Al_2O_3-10%
G	1530	170	0	0	SiC-10%
H	1350	0	0	150	C-15%
I	1530	0	170	0	Al_2O_3-15%

The oil fired muffle furnace was used for preparing Al/Al_2O_3/SiC/C, Al/Al_2O_3/SiC, Al/Al_2O_3/C and Al/SiC/C, Al/SiC, Al/C, Al/ Al_2O_3 MMC and Hybrid MMC for experimentations by squeeze casting. The melting of matrix material aluminium was carried in a muffle furnace in a range of 760 ± 10^0C. The crucible material was graphite. A view of the furnaces has been shown in Fig.1.

Figure 1: Oil fired muffle furnace used for fabrication of MMC and hybrid MMC

The molten metal was poured into the mould. Subsequently, 80 MPa pressure was applied on the mixture. From the cast composites, Wear test specimens of length 35 mm and 8 mm diameter are machined. The end of specimens are polished with abrasive paper of grade 600 and 1000.

2.2 Wear behavior examinations

Wear test were performed using a pin on disc machine at room temperature. The specimens in the dimension of length 35 mm and 8 mm diameter were washed in acetone before test. The intial weight of the specimen was measured in electronic weighting machine with an accuracy of 0.001 gram. The friction coefficient was continuously measured during the test.The test were carried out at a normal loads of 4.91, 9.82 and 14.72 N. The sliding speed were 300, 600 and 1200 rpm and track diameter was 60 mm. Finally, the weight loss due to wearing of the pin i.e. the difference between the final and the initial weight was measured on the Digital Analytical Weight measuring machine and after that wear rate was calculated and analysis was done with the help of Taguchi design approach.

3. RESULTS AND DISCUSSION

For analyzing the wear rate, 27 specimens are taken for 1 min time intervals. The measured results were analyzed using the commercial software MINITAB 15 specifically used for design of experiment applications. The wear results at different parameter are given below in table 2.

Table 2: Wear result

S. No.	Material Compositions	Sliding Speed (rpm)	Load (N)	Track Dia. (mm)	Coefficient of friction	Wear (gm)	Wear Rate /60 (gm/sec)
1.1	SiC-10%, C 3%, Al_2O_3-5%	300	4.91	60	0.223	0.0004	0.00000667
1.2	SiC-10%, C-3%, Al_2O_3-5%	600	9.82	60	0.314	0.0007	0.00001167
1.3	SiC-10%, C-3%, Al_2O_3-5%	1200	14.72	60	0.326	0.0034	0.00005667
2.1	SiC-15%, C-5%, Al_2O_3-7.5%	600	4.91	60	0.397	0.0009	0.00001500
2.2	SiC-15%, C-5%, Al_2O_3-7.5%	1200	9.82	60	0.400	0.0014	0.00002333
2.3	SiC-15%, C-5%, Al_2O_3-7.5%	300	14.72	60	0.324	0.0015	0.00002500
3.1	SiC-20%, C-7.5%, Al_2O_3-10%	1200	4.91	60	0.321	0.0005	0.00000833
3.2	SiC-20%, C-7.5%, Al_2O_3-10%	300	9.82	60	0.260	0.0003	0.00000500
3.3	SiC-20%, C-7.5%, Al2o3-10%	600	14.72	60	0.281	0.0006	0.00001000
4.1	SiC-10%, Al_2O_3-10%	300	4.91	60	0.322	0.0004	0.00000667

4.2	SiC-10%, Al_2O_3-10%	600	9.82	60	0.284	0.0008	0.00001333
4.3	SiC-10%, Al_2O_3-10%	1200	14.72	60	0.310	0.0017	0.00002833
5.1	SiC-10%, C-5%,	600	4.91	60	0.441	0.0011	0.00001833
5.2	SiC-10%, C-5%,	1200	9.82	60	0.329	0.0005	0.00000833
5.3	SiC-10%, C-5%,	300	14.72	60	0.371	0.0008	0.00001333
6.1	C-5%, Al_2O_3-10%	1200	4.91	60	0.348	0.0021	0.00003500
6.2	C-5%, Al_2O_3-10%	300	9.82	60	0.414	0.0010	0.00001667
6.3	C-5%, Al_2O_3-10%	600	14.72	60	0.310	0.0034	0.00005667
7.1	SiC-10%	300	4.91	60	0.413	0.0020	0.00003333
7.2	SiC-10%	600	9.82	60	0.342	0.0035	0.00005833
7.3	SiC-10%	1200	14.72	60	0.447	0.0018	0.00003000
8.1	C-15%	600	4.91	60	0.427	0.0054	0.00009000
8.2	C-15%	1200	9.82	60	0.390	0.0052	0.00008667
8.3	C-15%	300	14.72	60	0.348	0.0091	0.00015167
9.1	Al_2O_3-15%	1200	4.91	60	0.345	0.0059	0.00009833
9.2	Al_2O_3-15%	300	9.82	60	0.303	0.0040	0.00006667
9.3	Al_2O_3-15%	600	14.72	60	0.351	0.0047	0.00007833

The effect of composition on the mean of means wear rate plotted for utilizing the wear rate results as shown in Fig.2. From the figure, it is observed that the mean value of wear is lower at the composition of C. As the percentage of composition increases the wear rate decreases. As the sliding speed increases from 300 to 600 rpm the wear rate remain almost constant. As the sliding speed increases from 600 to 1200 rpm, the wear rate also increases. From the graph, it is observed that the mean value of wear is lower at 4.91 N. The mean of wear rate rises continuously by increasing the value of load from 4.91 to 14.72 N.

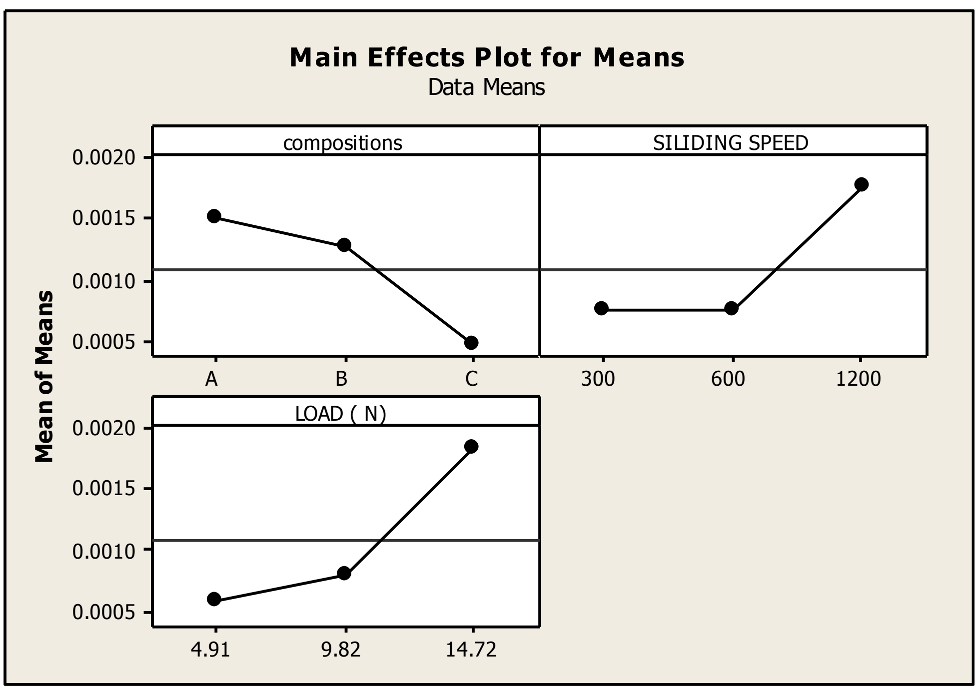

Figure 2: Showing the effect of load (N), composition and sliding speed (rpm) on mean wear rate

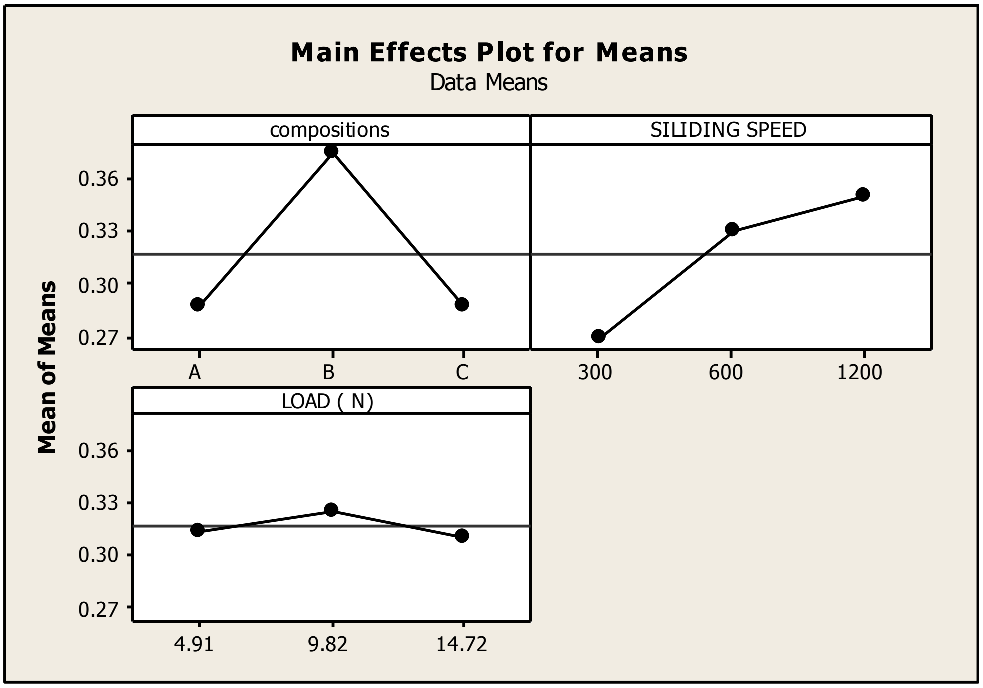

Figure 3: Showing the effect of load (N), composition and sliding speed (rpm) on mean of coefficient of friction

Figure 3 shows effect of composition on the mean of means of coefficient of friction plotted utilizing the coefficient of friction results obtained. From the figure, it is observed that the mean value of coefficient of friction is lower at composition A and C but mean value of coefficient of friction is higher at composition B. As the sliding speed increases from 300 to 1200 rpm the value of coefficient of friction increases. From the figure, it is observed that the mean value of coefficient of friction is lower at 4.91 N. The mean value of coefficient of friction increases by increasing the value of load from 4.91 to 9.82 N and then decreases by increasing load 9.82 to 14.72 N.

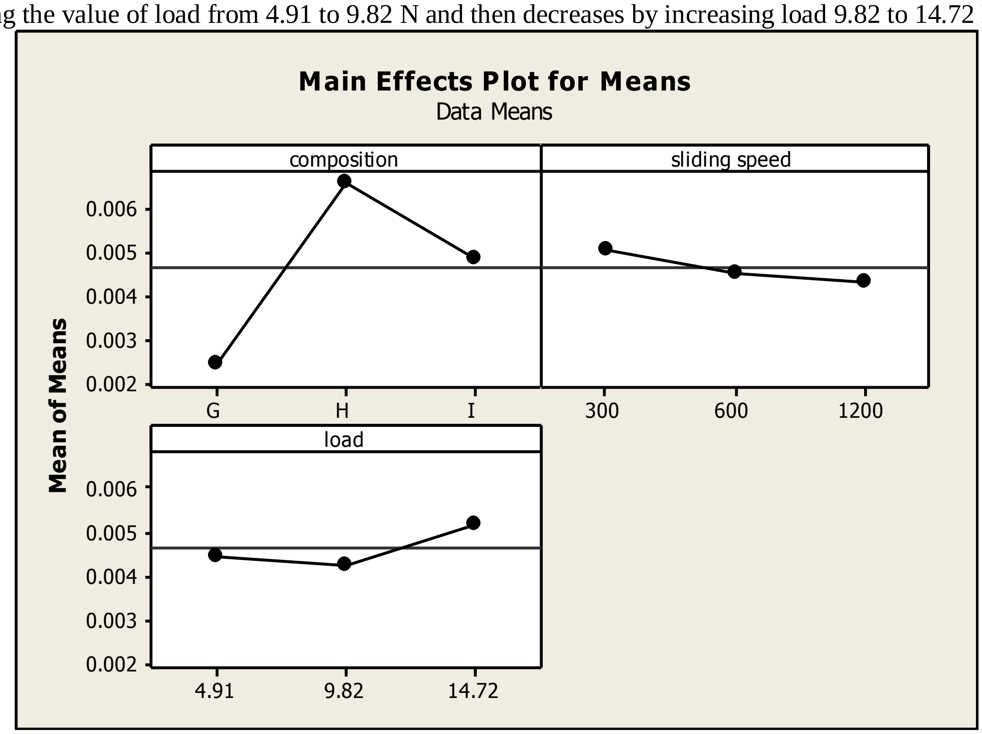

Figure 4: Showing the effect of load (N), composition and sliding speed (rpm) on mean wear rate

The effect of composition on the mean of means wear rate plotted for utilizing the wear rate obtained as shown in Fig.4. It is observed that the mean value of wear is higher at composition value of H and lower at composition value of G. As the sliding speed increases from 300 to 1200 rpm the wear rate decreases. It is observed that the wear rate slightly decreases as the load increases from 4.91 to 9.82 N and wear rate increases as the load increases from 9.82 to 14.72 N.

The results show that at load 4.91 hybrid composite having composition (SiC-10%, C-3%, Al_2O_3-5%) have minimum wear rate but hybrid composite having composition (SiC-20%, C-7.5%, Al_2O_3-10%) have minimum wear rate at maximum load at 14.72 N and 9.82 N. Wear rate is maximum at composition (Al_2O_3-15%) at load 4.91 N. The results also show that minimum wear rate at composition (SiC-20%, C-7.5%, Al_2O_3-10%) at speed 300 rpm and maximum wear rate at composition (C-15%). At speed 600 rpm minimum wear rate at composition (SiC-20%, C-7.5%, Al_2O_3-10%) and maximum at (C-15%). At 1200 rpm the minimum wear rate at composition (SiC-20%, C-7.5%, Al_2O_3-10 and maximum at composition (Al_2O_3-15%).

4. CONCLUSIONS

On the basis of the wear test experimentation on MMC and hybrid MMC materials by using the Taguchi's technique, the following conclusions are drawn which influences the contribution to analyzed the momentous friction and wear properties.

1. The lowest wear rate of hybrid MMC at the composition of C (Al, SiC-20%, C-7.5%, Al_2O_3 -10%) is 0.00000500 gm/sec noted at applied load of 9.82 N, 300 rpm sliding speed and 60 mm track diameter.
2. Under dry sliding condition hybrid MMC Al/SiC/C/Al_2O_3 of composition SiC-20%, C-7.5%, Al_2O_3 -10% showed the best wear resistance under high load and speed.
3. In Al/SiC/C/Al_2O_3 hybrid MMC wear resistance increased with increasing of SiC, C and Al_2O_3 addition.
4. In Al/SiC/C/Al_2O_3 hybrid MMC, from 300 to 600 rpm the wear rate almost constant by supporting mechanically mixed tribolayer and increase of load increases wear by reducing the role of tribolayer.
5. As the percentage of SiC, C and Al_2O_3 increased in Al/SiC/C/Al_2O_3 hybrid MMC under high load the wear rate reduced.
6. The highest wear rate of MMC (Al/C- 10%) is 0.00015167 gm/sec noted at applied load of 14.72N, sliding speed of 300 rpm and 60 mm track diameter.
7. The result indicates that hybrid MMC had better tribological properties than MMC. The hybrid composites exhibit better wear characteristics compared to composite reinforced with SiC, Al_2O_3 and C alone.

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