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DRY SLIDING WEAR BEHAVIOR OF SIC AND ZNO REINFORCED ALUMINIUM 6061 MATRIX COMPOSITE USING ROBUST DESIGN

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ABSTRACT

In the industrial world, the role and application of the aluminium metal matrix composite is extended to a greater level due to its superior properties, especially in aerospace and automobile fields. The main objective of the current work is to investigate the dry sliding wear behavior of an aluminium 6061 matrix reinforced with silicon carbide and zinc oxide particles. A aluminium matrix composite with 5 wt.%SiC and 2 wt.% ZnO particle reinforcement was prepared using stir casting method. The wear behavior of the Al/SiC/ZnO composite was investigated by carrying dry sliding tests using an oil-hardened non-shrinking steel disc on a pin-on-disc apparatus. Wear tests were carried for normal loads of 1, 1.5 and 2 kg at sliding velocities of 0.5, 1 and 1.5 m/s with the varied sliding distances of 500, 1000 and 1500 m at room temperature. The series of experiments were conducted by using Taguchi's L9 (3^3) orthogonal array as per Design of Experiments (DOE). The variations of the output responses such as wear rate and frictional coefficient for different loads, velocities and sliding distances were analyzed and the best condition of experiment is suggested by using robust design modelling.

Keywords: *Aluminium matrix composite, Stir casting method, L9 (3^3) orthogonal array.*

1. Introduction

Generally engineering materials have restrictions in attaining optimum levels of strength, density, toughness, stiffness and wear resistance. The composite materials provide engineers the chance to orient the material properties granting to their demands. Due to the contibution of hard reinforcements, these composites were indued with good tribological properties. AMMCs (Aluminium Metal Matrix Composites) attained grandness because of their raised tribological properties that substitutes their monolithic similitudes chiefly in aerospace, automotive and energy applications [1,2]. As well as the work on abrasive wear behavior, a wide review on dry sliding wear behaviour of aluminium alloy based composites was studied out. In this regard, various efforts were made to analyse the sliding wear behaviour of aluminium alloys and AMCs [3,4]. Reviews were proposing the tribology of AMMCs as a function of the reinforcement volume fraction, applied load, sliding velocity, sliding distance and nature of the reinforcing phase [5,6]. Several researchers reported the interactions between load and sliding velocity over wear of a composite material [7,8]. Due to the presence of ceramic particle content the wear resistance of particulate reinforced AMMCs was high, which defends the metal matrix from wear. Increased particle content in AMMCs enhances the wear resistance [9]. Investigating the influence of process parameters on hybrid AMMCs was fortunately performed using Taguchi's robust design technique [10]. Broad utilization of particle reinforced AMMCs in aircraft and automotive industries was found for brake pads, pistons, etc. where tribological properties of the material should be taken attentively [11]. The aluminium matrix acquires strengthened when it is reinforced with arduous ceramic particles like B_4C, SiC, Al_2O_3, ZnO, etc. ensuing in enhanced strength to weight ratio and wear resistance than the mainstream alloys [12]. The addition of the ZnO to the matrix increases its wear resistance significantly [13]. The another effective ceramic is silicon carbide (SiC), with the increase in reinforcement ratio, hardness, tensile strength, wear resistance and density to the base metal increases [14-17].

In this work an attempt has been made to enhance the wear properties for automotive and

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aerospace applications by aluminium 6061 alloy matrix reinforced with 5 wt% of SiC and 2 wt% ZnO particles by stir casting method. The composite was analyzed for its tribological behavior by valuating the wear rate and coefficient of friction using robust design as per Design of Experiments (DOE) rule.

2. EXPERIMENTAL DETAILS

2.1. Composite Fabrication

The matrix material used in this work is Al6061 and the reinforcements are zinc oxide and silicon carbide particles. The addition of silicon carbide increases the hardness and wear resistance of the matrix material and zinc oxide improves the compression strength. Such hybrid reinforcement improves the surface finishand slenderize the heat propagation during machining. By stir casting process the composite sample is prepared. The matrix material which is kept in a graphite crucible within the electric induction furnace. The matrix was melted to the super heating temperature of 750°C. The reinforcement particles with a quantity of 2 wt% zinc oxide and 5 wt% of silicon carbide with an average mesh size of 200 and 220 was preheated to the desired temperature of 400°C was introduced into the whirl of the molten alloy after efficient degassing. Graphite stirrer was used for the mechanical stirring of the molten reinforced alloy for a duration of 10mins and the stirrer was kept at a speed of 800rpm. The reinforced molten matrix was poured into a cast iron mould and was sustained in atmosphere to cool down to the desired room temperature with a desired dimension of 260 X ϕ25mm and shown in Figure 1.

Fig.1. Fabricated specimen

The stir casting process is made by SWAMEQUIP make bottom pouring stir casting machine and shown in Figure 2.

Fig.2. Bottom pouring stir casting machine

2.2. Pin and disc preparation

The fabricated sample was machined from 250 mm to 10 mm of diameter for a length of 28mm to create a wear pin (28mm X ϕ10mm) shown in Figure 3. The ends of the pin were asserted to be exempt of sharp corners andburrs. Using 600 grit SiC paper, the contact surface of the OHNS discs and pins were smoothened and then surfaces were cleaned with acetone. The surfaces were checked out to assure that the flatness of the pin are perfectly on the disc surface. The surface of the pin are polished by using various grit SiC paper in the order of 180, 320, 600 and 600 grit. Acetone was used to remove the debris found over the surface of the pin. Atlast the pin is rinsed off in ethanol and dried out in hot air.

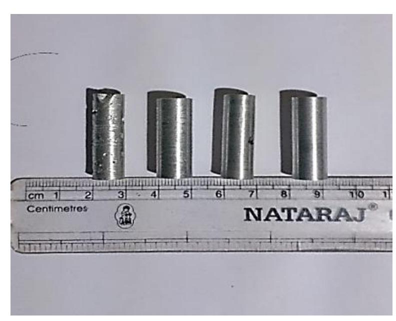

Fig.3. Prepared pins

2.3. Wear test

All the series of experiments were performed by Taguchi's L9 (33) orthogonal array using DUCOM pin on disc wear testing machine according to ASTM:

G99 in air at 28±1 °C. The DUCOM pin on disc machine used for this study is shown in Figure 4.

Table. 1 Experimental results and S/N ratios

Ex. No	Load (kg)	Sliding velocity (m/s)	Sliding distance (m)	Wear rate (mm^3/m)	Coefficient of friction	S/N ratio WR	S/N ratio COF
1.	1.0	0.5	300	0.010257	0.061698	39.77955	24.19456
2.	1.0	1.0	900	0.003747	0.030849	48.52567	30.21516
3.	1.0	1.5	600	0.004376	0.020523	47.17917	33.75518
4.	1.5	0.5	900	0.003794	0.092547	48.41899	20.67274
5.	1.5	1.0	600	0.005083	0.046274	45.87744	26.69334
6.	1.5	1.5	300	0.010622	0.030785	39.4761	30.23335
7.	2.0	0.5	600	0.005336	0.123396	45.45584	18.17396
8.	2.0	1.0	300	0.0102	0.061698	39.82803	24.19456
9.	2.0	1.5	900	0.003883	0.041046	48.21713	27.73458

The machined sample pin was set in a desired slot above the rotating disc. Zero error was maintained in respect of surface contact between sample pin and disc. The masses of the pin were measured by using GR202 digital weighing scale with an accuracy of ±0.1 mg. According to L9 (33) orthogonal array nine experiments were conducted, with the normal loads of 1.0, 1.5 and 2 kg and sliding velocities of 0.5, 1.0 and 1.5 m/s at a sliding distance of 300, 600 and 900 m.

After the termination of each experiment, the pins are removed carefully and rubs with acetone to remove the debris present over the contact surface of the pin. The exact mass loss losses were measured carefully after every experiment with different conditions. At the same time, 600 grit SiC was used to rub over the disc surface and cleaned with acetone to remove the debris burrs. By using the robust design, only main factors are studied along with the noise factors and the interactions are not included in the design. The parametric levels are tabulated in Table. 2.

Table.1 Input parameters and their levels

Levels	Load (kg)	Sliding velocity (m/s)	Sliding distance (m)
1	1.0	0.5	300
2	1.5	1.0	600
3	2.0	1.5	900

3. Results and discussion

3.1 Tribological Behavior

Tribological behavior of the prepared composite, i.e. wear rate and coefficient of friction was valuated. Table 2 shows the results and their corresponding S/N ratios. Both the output responses comes under smaller-the-better category for calculating the S/N ratios

3.2 Analysis of signal-to-noise ratio

S/N ratio which proposes the ranking of parameters based on their influence. Mean response performance index (MRPI) table for S/N ratios of wear rate and coefficient of friction is shown in Table 3 & 4. ‘Smaller-the-better’ characteristic was taken for the analysis of S/N ratio. The remainder between the peak values gives the delta value of representing parameter. Ranking was assigned in the descending range of the delta value. Regarding the wear rate, sliding distance was the major parameter which had its influence followed by load and sliding velocity

Fig.4. DUCOM pin on disc machine

(Table 3). Contribution of hard reinforcements could be the cause for the rank of distance. As the distance increases, the reinforced particles which bulge out of the surface get fractured, thus enhancing the contact area among the sliding surfaces which in turn reduces the wear consecutively. From the MRPI, suggests that A1B3C3 is the suitable optimum level for getting the lesser wear rate which is 1 kg of load, 1.5 m/s of velocity and 900 m of sliding distance.Last row Tables 3 & 4 points the corresponding ranking of parameters.

Table. 3 Response table-Wear rate

Level	A-Load (kg)	B-Sliding velocity (m/s)	C-Sliding distance (m)
1	45.1615	44.5515	39.6946
2	44.5904	44.7437	46.1708
3	44.5003	44.9575	48.3873
Delta	0.6612	0.406	8.6927
Rank	2	3	1

On the account of coefficient of friction, sliding velocity was ranked foremost for its influence on it, pursued by applied load and the sliding distance (Table 4). Due to the contribution of the reinforcements, it withstands the load with high velocity. From the MRPI, provides the best condition for the lesser coefficient of friction which is also alike of previous response A1B3C3 (load of 1kg, sliding velocity of 1.5 m/s and sliding distance of 900 m).

Table 4 Response table-coefficient of friction

Level	Load (kg)	Sliding velocity (m/s)	Sliding distance (m)
1	29.3849	22.3437	26.5375
2	26.5664	27.0677	26.2408
3	23.701	30.241	26.8741
Delta	5.6839	7.8973	0.6333
Rank	2	1	3

3.3 Regression equation

The regression equation for wear rate and coefficient of friction was shown in shown in Equations. 1 & 2.

Wear rate=0.01257+0.00035A-0.00017B-0.000011C 1

Coefficient of friction=0.0583+0.0377A-0.0618B+0.000006C 2

The value of R^2 and adjusted $R^2$for both wear rate and coefficient of friction are above 85%, which clearly indicates that the developed linear model provides a standard relation between the input and output parameters. The p-value for both the responses are less than 0.05, thus the linear model are statistically significant.

3.4 Effect of load

From the Figures. 5 & 6, it was noticed that both wear rate and coefficient of friction increases when applied load increases. For 2 kg, marginal enhancement of wear rate was noticed, whereas drastic increase for 1.5 kg. This trend can be assigned due to the plastic deformation of the composite. At low loads (1 kg), temperature develop over the sliding surface caused less effect on the plastic deformation. Enhanced load on the specimen results to increase in temperature over the sliding surface still at low sliding velocities. Plastic deformation of the surface occurred which contribute the adhesion of pin surface onto the disc due to this high temperature. This adhesion ensues in more material removal, therefore it drastically increasing the wear rate. Similarly increased coefficient of friction also due to the increased number of loads applied. Lower coefficient of friction occurs for the initiative load of 1 kg and it drastically increases from 1.5 to 2 kg.

3.5 Effect of velocity

From the Figures. 5 & 6, the responses were noticed to be decreasing with increasing velocity. This can be due to the establishment of tribo-layer. Aluminium has an integral property of forming an oxide layer on its outer periphery layer. When it slides at high velocity, the increase in temperature over the contact surface, makes the material to oxidize. This developments leads to the transmitting of materials, forming Mechanically Mixed Layer (MML), which is also called tribo layer. This tribo layer will play as a barrier between the two contact surfaces decreasing the wear rate and the coefficient of friction when the sliding velocity increases.

3.6 Effect of distance

As distance increases, the wear rate and were noticed to be decreasing. From the Figures. 5 & 6, clearly indicates the wear rate reduced to a broad extent for travelling a distance of 300 m to 600 m when compared with the wear rate between 600 m to 900 m. This behavior was due to the presence of hard reinforcements that act as acuate rigours on the surface of the composite specimen.

At low distance reinforcement particles which emerge out from the composite surface decreases the contact area between the specimen and the disc, which in turn decreases the wear rate. Whereas for coefficient of friction, the friction drastically increases for 600 m and marginal increase for 900 m when compare with the sliding distance of 300 m. Sliding velocity and applied loads contribution make the friction decreases at lesser travelling of distance.

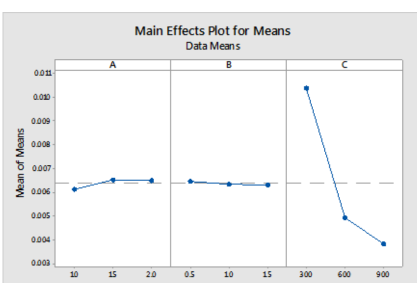

Fig.5. Main effect plot for means-wear

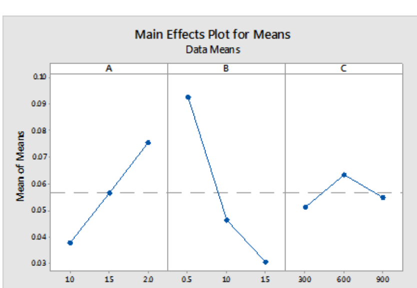

Fig.6. Main effect plot for means-coefficient of friction

3.7 Machine vision evaluation

From the Figures. 7 & 8, it is observed that the usual effects occurred for the specimen such as groove, plough and delamination. These are effects which has been seen from the machine vision scale. The machine vision which shows the worn surfaces of the specimen while analysing. The adhesive wear formed over the surface which leads to the occurance of delamination. The grooves are the usual defect formed over the surface. It is the removal of the material from the pin during the experiments. The series condition of grooves which leads the major defect of ploughing of the pin's surfaces. The formation of the oxidation layer (MML) over the surface which decreases the defects gradually.

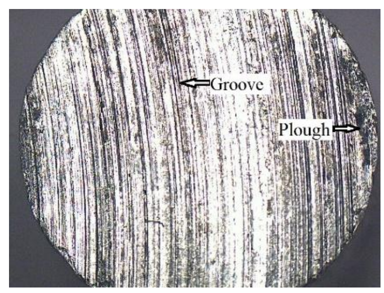

Fig.7. Worn surface of the pin of A3B1C1

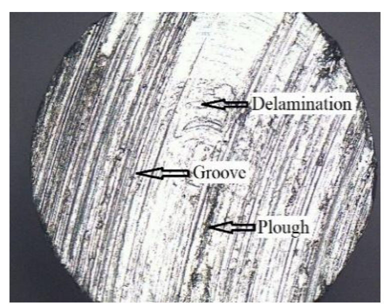

Fig.8. Worn surface of the pin A3B1C2

The Figure. 8 which clearly shows the defects of A3B1C2 (1 kg load, 1.5 m/s sliding velocity and 600 m sliding distance) has some severe defect when compared to other pins surfaces, which is illustrated from MRPI tables of both wear rate and coefficient of friction.

4. Conclusions

The aluminium (6061) alloy reinforced with 5 wt% SiC and 2 wt% ZnO particles was successfully fabricated by the stir casting path and the tribological behavior was noticed.

- Experiments are successfully done by using L9 orthogonal array as per DOE rule.
- Robust design is used to analyse the responses successfully by using S/N ratios and predicting the mean response performance index for both wear rate and coefficient of friction.
- As per MRPI of wear rate which illustrates the best condition of A1B3C3.
- Similar to wear rate, MRPI of coefficient of friction also illustrates the same condition (A1B3C3) as best for low coefficient of friction.
- The linear regression model created for the responses are statistically significant.
- Effects of loads, velocity and sliding distance according to the mean responses are analysed successfully.
- By using machine vision, the defects arised on the specimen's surface are investigated successfully.

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References

1. *AnandhaMoorthy, Natarajan N, Sivakumar R, Manojkumar M and Suresh M (2012), "Dry sliding wear and mechanical behavior of aluminium/fly ash/graphite hybrid metal matrix composite using taguchi method", Int. J. Modern. Eng. Vol..2, 1224-1230.*

2. *Clifford F. Lewis (1998), 'Processing makes the difference in thermal spray coating', Mater. Eng. (May) (1988),pp. 1.*

3. *Roy M, Venkataraman B, Bhanuprasad V V, Mahajan Y R and, Sundararajan G, Metall. Trans. Vol. 23A (1992), pp. 2833.*

4. *Baradeswaran A and ElayaPerumal A (2014), "Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites", Compos.56, 464–471.M.*

5. *Singh D P and Mondal S Das (2006), "Abrasive wear response of aluminium alloy–sillimanite particle reinforced composite under low stress condition", Mater. Sci. Eng., Vol. 419, 59–68.*

6. *Jerome S, Ravisankar B, Kumar Mahato P and Natarajan S (2010), "Synthesis and evaluation of mechanical and high temperature tribological properties of in-situ Al–TiC composites", Tribology International, Vol. 43, 2029-2036.*

7. *Venkataraman B and Sundararajan G (2000), "Correlation between the characteristics of the mechanically mixed layer and wear behaviour of aluminium Al-7075 alloy and Al-MMCs", Wear. 245, 22–38.*

8. *Perrin C and RainforthW.M (1995), 'Work hardening behaviour at the worn surface of Al Cu and Al Si alloys', Wear, Vol 181–183, pp.312.*

9. *Chen R, Iwabuchi A, Shimuzu T, Seop Shin H and Mifune H (1997), 'The sliding wear resistance behavior of NiAl and SiC particles reinforced aluminium alloy matrix composites', Wear, Vol. 213, pp. 175.*

10. *Radhika N, Subramanian R and VenkataPrasat S (2011), "Tribologicalbehaviour of aluminium/alumina/graphite hybrid metal matrix composite using Taguchi's techniques", J. Miner. Mater. Charact. Eng., Vol. 10, 427-443.*

11. *Birol Y (2006), "Grain refining efficiency of Al–Ti–C alloys', Journal of alloys and Compounds", Vol. 422 (1-2), 128-131.*

12. *Ramesh C S, Kesharamurthey R, Channabasappa B H and Abrar Ahmed (2009), "Microstructure and mechanical properties of Ni-P coated Si3N4 reinforced Al6061 composites", Mater Science Engg A, Vol. 502, 99-106.*

13. *Selvam B (2014), "Dry sliding wear behaviour of zinc oxide reinforced magnesium matrix nano-composites", Materials and Design, Vol. 58, 475–481.*

14. *Tamer Ozben, ErolKilickap and Orhan Cakir (2008),'Investigation of mechanical and machinability properties of SiC particlereinforced Al-MMC', Journal of Materials Processing Technology, Vol.198, pp. 220-225.*

15. *Sandeep sharma, Tarunnanda and Pandey O S (2018), "Effect of particle size on dry sliding wear behaviour of sillimanite reinforced aluminium matrix composites", Ceramics International, Vol.44 (1), 104-114.*

16. *Allwyn Kingsly Gladston, Dhinaharan I, Mohamed Sherif N and David Raja Selvam J (2017), "Dry sliding wear behavior of AA6061 aluminum alloy composites reinforced rice husk ash particulates produced using compocasting", Journal of Asian Ceramic Societies, Vol. 5 (2), 127-135.*

17. *Kalyan Kumar Singh and Saurabh Singh Anil Kumar Shrivastava (2017), "Comparison of Wear and Friction Behavior of Aluminum Matrix Alloy (Al 7075) and Silicon Carbide based Aluminum Metal Matrix Composite under Dry Condition at Different Sliding Distance", Materials today, Vol. 4(8), 8960-8970.*

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