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RESEARCH

Optimisation of Dry Sliding Wear Process Parameters for Aluminium Hybrid Metal Matrix Composites

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A B S T R A C T

The advancement in today's technology calls for the usage of superior material. A metal matrix composite has a unique characteristics to combine the various properties of the different materials present in the matrix composition, which enables it to be used for various high temperature applications where constrains could be overcome. The present study investigates the influence of applied load, sliding velocity and temperature on wear rate of AlSi10Mg alloy reinforced with 3 wt-% graphite and 9 wt-% alumina which was fabricated through liquid metallurgy route. The wear rate of this hybrid composite was investigated by performing dry sliding wear test on a pin-on-disc wear tester. The experiment was conducted for a constant sliding distance of 1500m. The influence of the various parameters on the wear rate was studied using Taguchi's Design of Experiment. An L9 orthogonal array was used for analysis of data. Signal-to-Noise ratio and Analysis of Variance were used to determine the ranking and percentage effect of input process parameters on wear rate respectively. Results revealed that load has the highest contribution on wear rate followed by temperature and sliding velocity. Worn-out wear surfaces were analysed using scanning electron microscope.

1. INTRODUCTION

Today's technology demands materials which were light weight, having longer life span and cost effective. This led to the development of advanced materials which possesses excellent properties such as high stiffness, high specific strength along with superior wear resistance. Composites reasonable cost-performance relationship, resistance to fatigue strength, thermal shocks and wear behaviour has made it very popular among many industries. In automotive industry, it was used to make fibre reinforced pistons, aluminium crank shafts with strengthened cylinder surface and brake drums [1]. The production of metal matrix composite (MMC) materials by various casting methods was discussed to produce defect free components to meet customer's requirement [2]. There was always a compulsion to know about the wear behaviour of composite material. There were varieties of methods by which the wear can be analysed, like dry sliding wear, abrasion wear, and test of wear by ferrography method. Among these the most popular method was the dry sliding wear test. Aluminium was the most widely used metal because of its low density, high ductility and low cost. The Aluminium composites were well in demand, but because of its softness, it has a very low resistance to wear, and hence it has to be reinforced with some harder material [3,4].This calls for a study on the wear behaviour of the Aluminium Metal Matrix Composites (AMMCs). Relationship between thermal and sliding wear behaviour of Al6061/alumina metal matrix composites were discussed by Serdar and Soner [5], and observed that increase in alumina volume percentage decreased both thermal conductivity and friction coefficient and hence increased the transition temperature from mild to severe wear during dry sliding wear test. The studies done on the sliding wear behaviour of Al6061-garnet particulate composites, shows that the wear resistance was better when compared with unreinforced matrix alloy [6]. The investigation on dry sliding wear of aluminium composites reveals the effects of reinforcement size, volume fractions and morphology on wear behaviour of AMMCs [7]. Analysis made on the influence of load and temperature on the dry sliding wear behaviour of aluminium–Ni_3Al composite shows that the wear loss increased with unreinforced alloy and lower percentage reinforced alloys, with increase in load as well as with temperature [8]. The wear behaviour of aluminium metal matrix composite sliding against automobile friction material has been compared with the conventional grey cast iron. The wear of the lining material has been observed more when sliding against MMC disc because of the ploughing of the lining material by silicon carbide particles [9]. There have been many unique techniques in today’s world to bring out the optimised result on every experiment and analysis. One such was the Taguchi’s Technique which was widely used in the field of wear analysis to study the wear behaviour of the composites. The tribological behaviour of glass epoxy polymer composites with silicon carbide and graphite particles, as secondary fillers, was studied using a pin-on-disc wear tester under dry sliding conditions [10]. A plan of experiments based on the Taguchi technique showed that the inclusion of silicon carbide and graphite as filler materials will increase the wear resistance of the composite greatly. The studies done on simultaneous optimisation of multiple quality characteristics using fuzzy logic and Taguchi’s technique has proven to be an effective and simple method [11].The case study using Taguchi method on optimisation of Electrical Discharge Machining process parameters have been discussed [12].

Based on the above literature, to improve the dry sliding wear resistance for automotive applications and to produce better alternative to other metals especially for cast iron made automotive components where light weight and wear resistance was under major consideration, aluminium hybrid metal matrix composites have been fabricated with alumina and graphite as reinforcements. The 9 wt-% of alumina and 3 wt-% of graphite particles have been added in the matrix through liquid metallurgy route. The dry sliding wear experiments were conducted based on the plan generated by Taguchi technique. The influence of various parameters on the wear rate was analysed using Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA).

2. TAGUCHI TECHNIQUE

Design of Experiments (DOE) was used for analyzing the impact of various input parameters on a given output. DOE approach uses Taguchi technique to find the optimal combination of parameters for a given set of response [13]. It provides an optimised picture to improve the performance, efficiency and cost. This technique was used for evaluating systems based on orthogonal arrays. The technique was widely used because of its ability to analyze and interpret data based on the responses. A standard orthogonal array was chosen based on the number of parameters, and the effect of parameters on the target value. Based on this, experiments were conducted to study the impact of various factors on the response. The variations were identified by means of a signal-to-noise ratio. This S/N ratio gives the effect of noise on various characteristics. ANOVA was used to determine the percentage of influence of various parameters on the response [14]. It was a quantitative measurement to determine the contribution of each parameter on the response.

3. EXPERIMENTAL DETAILS

The dry sliding wear test was conducted on a pin-on-disc tester as shown in Fig. 1. Size of the specimen used for the wear test was of 25 mm in length and 10 mm in diameter. They were machined and polished as per ASTM standards. A radius of 5 mm was given to one end of the specimen and the other side was made flat. The rounded end (pin) was made in contact with the disc.

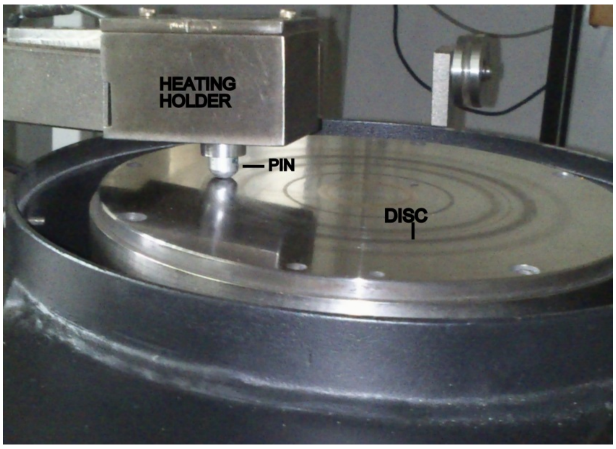

Fig. 1. Pin-on-disc wear tester.

The experiment was conducted by holding the pin against a rotating disc (EN32 steel) and by adding weights on the left arm of the apparatus. The track diameter was kept constant as 100 mm. The sliding distance was also kept constant as 1500 m. The experiment was then conducted by varying the applied load, temperature and sliding velocity for three levels as shown in Table 1.

Table 1. Parameters and their levels.

Level	Load [N]	Sliding velocity [m/s]	Temperature [°C]
1	10	1	50
2	20	2	100
3	30	3	150

A Linear Variable Differential Transformer monitors the motion of the left arm thereby helping to determine wear at any given point of time. Once the surface in contact wears out, the load pushes out the arm to remain in contact with the disc. This generates a signal by means of which it monitors the maximum wear on a continuous scale. The weight loss was found by measuring the specimen before and after the experiment on an electronic weighing pan with accuracy of 0.0001g.

4. PLAN OF EXPERIMENTS

Experiments were conducted by considering three parameters namely: load applied, the sliding velocity and temperature, by varying them for three levels. The degree of freedom for an orthogonal array was selected as 9, based on the rule that it should be greater than the wear parameters considered (Table 2). The selection for the array depends on the number of factors involved, the number of levels and their responses. The first column was taken as the load applied, the second taken as the sliding velocity and third as the temperature .The S/N ratio consolidates all multiple data and evaluates them based on the characteristics of the data. The S/N ratio was generally classified into three types: “smaller the better”, “larger the better” and “nominal the best”. “Smaller the better” characteristic of S/N ratio was considered for minimum wear rate and was given by:

$$S/N = -10 \log 1/n \left(y_1^2 + y_2^2 + \dots y_n^2\right) \qquad (1)$$

Where y_1, y_2...y_n were the response and n is the number of observations. ANOVA was performed to determine the percentage effect of each parameter.

Table 2. Orthogonal array.

Ex.No	Load [N]	Sliding velocity [m/s]	Temperature [°C]
1	10	1	50
2	10	2	100
3	10	3	150
4	20	1	100
5	20	2	150
6	20	3	50
7	30	1	150
8	30	2	50
9	30	3	100

5. RESULTS AND DISCUSSION

The wear process parameters were analysed using Minitab software, especially designed for this purpose. S/N ratio and ANOVA were found out.

Table 3. Orthogonal array with experimental result.

Ex. No	Load [N]	Sliding velocity [m/s]	Temperature [°C]	Wear Rate [mm^3/m]	S/N ratio [dB]
1	10	1	50	0.001403	57.0619
2	10	2	100	0.001853	54.642
3	10	3	150	0.0021	53.5556
4	20	1	100	0.002557	51.8457
5	20	2	150	0.002381	52.4648
6	20	3	50	0.001805	54.8705
7	30	1	150	0.004762	46.4442
8	30	2	50	0.002508	52.0148
9	30	3	100	0.0028	51.0568

5.1 Analysis using S/N ratio

Experiments were conducted accordance to the orthogonal array and the corresponding values of wear rate was shown in Table 3.The influence of input process parameters on wear rate were determined using S/N ratio. The parameter with the highest S/N ratio gives minimum wear rate [15].

The response table for S/N ratio was shown in Table 4. The difference between the maximum and minimum values of S/N ratio gives delta. Ranking of parameter were done according to the delta value. The parameter with the highest value of delta has the greatest influence on wear rate. From Table 4, it was found that load has the significant impact on wear rate followed by temperature and sliding velocity.

Table 4. Response table for S/N ratio-Wear Rate.

Level	Load [N]	Sliding velocity [m/s]	Temperature [°C]
1	55.09	51.78	54.65
2	53.06	53.04	52.51
3	49.84	53.16	50.82
Delta	5.25	1.38	3.83
Rank	1	3	2

The main effects plot for mean was shown in Fig. 2. From the plot (Fig. 2), it was inferred that wear rate increases with increase in applied load and temperature. Conversely, the wear rate decreases with increase in sliding velocity. As the temperature increases, the material becomes softer and hence more material has been removed from the wear surface. As sliding velocity increases, the contact time between the disc and pin decreases, hence decreased wear rate.

The main effects plot for S/N ratio was shown in Fig. 3. The input process parameter value which has the highest S/N ratio gives the optimum wear rate. From the Figure, it was found that L=10 N, S=3 m/s and T=50 °C gives the optimum condition.

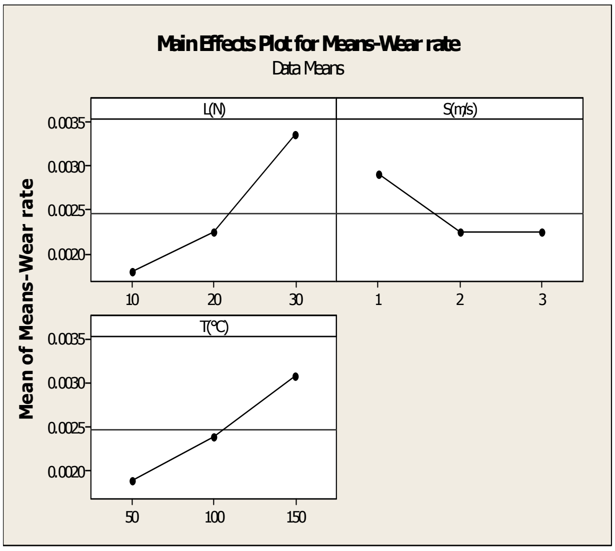

Fig. 2. Main effects plot for Means-Wear rate.

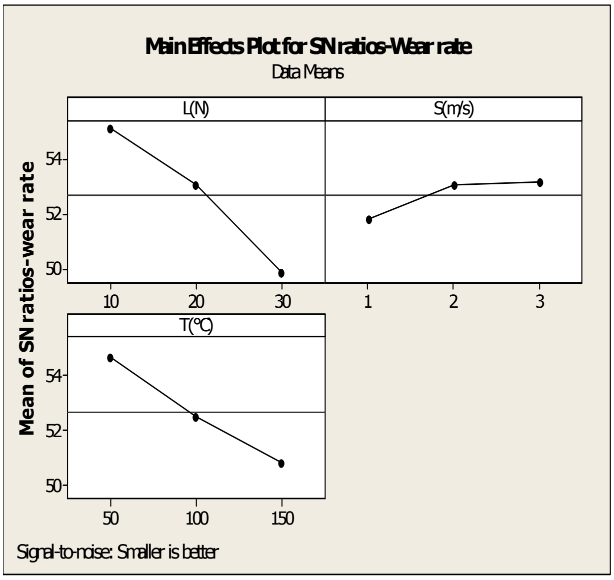

Fig. 3. Main Effects Plot for S/N ratio-Wear rate.

5.2. Analysis of Variance

ANOVA was used to analyse the effect of control parameters like applied load, sliding velocity and temperature on wear rate. The analysis was performed for a level of significance, α=0.05.

Table 5. Analysis of Variance.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P %
L	1	0.0000037	0.0000004	0.0000004	3.53	0.201	49.33
S	1	0.0000007	0.0000003	0.0000003	2.23	0.274	9.33
T	1	0.0000021	0.0000001	0.0000001	1.01	0.421	28
L*S	1	0.0000003	0.0000005	0.0000005	4.21	0.177	4
L*T	1	0.0000004	0.0000004	0.0000004	3.07	0.222	5.33
S*T	1	0.0000001	0.0000001	0.0000001	0.44	0.575	1.33
Error	2	0.0000003	0.0000003	0.0000003			
Total	8	0.0000075					

(Notes: DF, Degrees of freedom; Seq SS, Sequential sum of squares; Adj SS, Adjusted sum of squares; Adj MS, Adjusted mean squares; P, Percentage of contribution.)

The ANOVA was shown in Table 5. The last column in the table shows the percentage contribution of each input process parameter on the wear rate.

It shows that load (49.33 %) has the greatest contribution on wear rate followed by temperature (28 %) and sliding velocity (9.33 %). Further, it was found that interaction of factors also have significant effect on the wear rate.

5.3 Regression Analysis and Confirmation Test

A regression model was developed based on the experimental results and this establishes a correlation between the significant parameters.

The regression equation developed for wear rate was:

$$\text{Wear rate} = 0.000389 + 0.000079\,L - 0.000336\,S + 0.000012\,T$$

From the above relation, it was observed that the coefficient associated with load and temperature was positive. This clearly reveals that as load and temperature increases, wear rate of the hybrid composite also increases. The negative coefficient of sliding speed reveals that increase in speed decreases the wear rate.

To validate the conclusions obtained from the analysis, confirmation experiment was conducted and comparison was made between the experimental values and computed values developed from regression model. Table 6 and Table 7 show the confirmation experiment and its results.

Based on the confirmation experiment, it was observed that the error associated with experimental values and computed values was minimal and hence this regression model obtained from L9 array can be used effectively to predict the wear rate of the composites with good accuracy.

Table 6. Confirmation experiment.

Ex. No	L [N]	S [m/s]	T [°C]
1	15	1.5	70
2	22	1.8	90
3	25	2.5	130

Table 7. Results of confirmation experiment.

Ex. No	Exp. Wear rate [mm^3/m]	Reg.model wear rate [mm^3/m]	Error [%]
1	0.00199	0.00191	4.02
2	0.00245	0.00260	5.76
3	0.00314	0.00308	1.91

5.4 Scanning Electron Microscopy Analysis

The worn-out surfaces for various conditions were analysed using Scanning Electron Microscope (SEM) and the same was discussed (Figs. 4, 5 and 6).

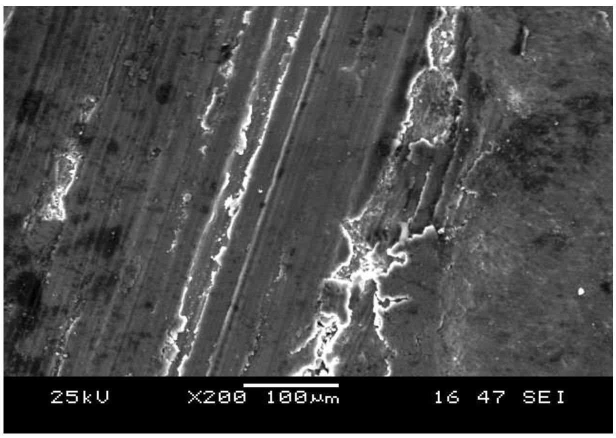

Fig. 4. SEM Micrograph for L=10 N, S=1 m/s, T=50 °C.

From the SEM Micrograph (Fig. 4), it was found that at low applied load, sliding velocity and temperature, the worn pin surface shows shallow grooves in the direction of sliding [17].The phenomenon indicates the mild wear regime.

At higher loads (Fig. 5), the alumina particle gets fractured and these particles acts as sharp asperities to remove more material from the wear surface [16].

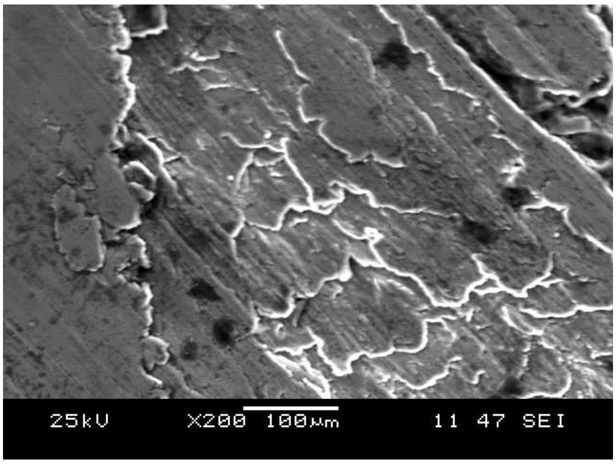

Fig. 5. SEM Micrograph for L=30 N, S=1 m/s, T=150 °C.

Fig. 6. SEM Micrograph for L=20 N, S=1 m/s, T=100 °C.

Also at high temperature, the material becomes soft and gets easily removed. Thus wear rate was more at this condition and indicates severe wear regime. Delamination was maximum at this condition. The graphite particle in general acts as self-lubricant and reduces the severity in the wear rate. At intermediate load and temperature (Fig. 6), deep grooves were observed along with graphitic film. The transition from mild wear to severe wear reduces because of the presence of graphite particles in the matrix.

6. CONCLUSION

Optimal conditions for minimum wear rate were obtained using S/N ratio analysis and ANOVA. The analysis shows that wear rate increases with increase in applied load and temperature, and decrease in sliding velocity. From the Main effects plot for means and S/N ratio, it was found that L=10 N, S=3 m/s and T=50 °C gives minimum wear rate. The ANOVA shows the percentage contribution of each control parameter on wear rate. From the S/N ratio and ANOVA analysis, it was found that applied load has the highest significance on wear rate followed by temperature and sliding velocity. The regression model generated was effectively used to predict the wear rate. Scanning Electron Microscopy analysis of the worn-out surfaces shows narrow grooves in the direction of sliding, which widens with increase in applied load and temperature. Thus the optimized condition can be well utilized to improve the wear resistance of the components and these components can be used in automotive and aerospace industry for wear resistance applications.

REFERENCES

[1] H.B. Bhaskarand, Abdul Sharief: *Dry sliding wear behaviour of aluminium/Be3Al2(Sio3)6 composite using taguchi method,* Journal of Minerals and Materials Characterization and Engineering, Vol. 11, No. 7, pp. 679-684, 2012.

[2] W. Kaczmar, K. Pietrzak, W. Wlosinski: *The production and application of metal matrix composites materials,* Journal of Materials Processing Technology, Vol. 106, No. 1-3, pp. 58–67, 2000.

[3] Rajesh Siriyala, Gopala Krishna Alluru, Rama Murthy Raju Penmetsa, Muthukannan Duraiselvam: *Applications of grey taguchi method for optimization of dry sliding wear properties of aluminium MMCs,* Frontiers of Mechanical Engineering, Vol. 7, No. 3, pp. 279-287, 2012.

[4] M.O. Shabani, A. Mazahery: *Development of an extrusion process to ameliorate the tribological properties of heat treated Al Mg Si (Cu) system alloys matrix composites in consolidated state*, Tribology in Industry, Vol. 34, No. 3, pp. 166-173, 2012.

[5] O.Y. Serdar, Soner Buytoz: *Relationship between thermal and sliding wear behaviour of Al6061/Al2o3 metal matrix composite,* Journal of Materials Science, Vol. 42, No. 12, pp. 4485-4493, 2007.

[6] S.C. Sharma: *The sliding wear behaviour of Al6061-garnate particulate composite,* Wear, Vol. 249, No. 12, pp. 1036-1045, 2001.

[7] R.L. Deuis, C. Subramanian, J.M. Yellup: *Dry sliding wear of aluminium composites- A Review,*

Composites Science and Technology, Vol. 57, pp. 415–435, 1997.

[8] Mehtap Demirel, Mehtap Mouratoglu: *Influence of load and temperature on the dry sliding wear behaviour of aluminium-Ni3Al composites,* Indian Journal of Engineering & Material Science, Vol. 18, No. 4, pp. 268-282, 2011.

[9] N. Natarajan, S. Vijayarangan, I. Rajendran: *Wear behaviour of A356/25SiCp aluminium matrix composites sliding against automobile friction material*, Wear, Vol. 261, No. 7-8, pp. 812–822, 2006.

[10] S. Basavarajappa, K.V. Arun, J. Paulo Davim: *Effect of filler materials on dry sliding wear behaviour of polymer matrix composite-taguchi approach,* Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No. 5, pp. 379-391, 2009.

[11] Y.N. Puri, N.V. Deshpandae: *Simultaneous optimisation of multiple quality characteristics using fuzzy logic and taguchi technique,* in*: Proceedings of the fifth asia pacific Industrial Engineering and Management Conference*, 2004.

[12] P.R. Apte: *Optimisation of EDM using taguchi technique,* Methods workshop using UNIMAP, 2012.

[13] A. Dolata-Grosz, J. Wieczorek: *Tribological properties of composite working under dry technically friction condition,* Journal of Achievements in Material Manufacturing Engineering, Vol. 18, No. 1-2, pp. 83-86, 2006.

[14] N.M. Rajneesh, S. Kanakuppi: *Dry sliding wear behaviour of Sic particles reinforced Zn-Aluminium (ZA43) alloy metal matrix composite,* Journal of Minerals & Material characterisation & Engineering, Vol. 10, No. 5, pp. 419-425, 2011.

[15] Nofal Al-Araji, Hussein Sarhan: *Effect of temperature on sliding wear mechanism under lubricated conditions,* International Journal of Engineering, Vol. 5, 2011.

[16] S. Venkat Prasat, R. Subramanian, N. Radhika, B. Anandavel, L. Arun, N. Praveen: *Influence of parameters on the dry sliding wear behaviour of aluminium/fly ash/graphite hybrid metal matrix composite,* European Journal of Scientific Research, Vol. 53, No. 2, pp. 280-290, 2011.

[17] K. Hokkirigawa, K. Kato: *An experimental and theoretical investigation of ploughing, cutting and wedge formation during abrasive wear,* Tribology International, Vol. 21, No. 1, pp. 51-57, 1988.