An Investigation on Wear Process Parameter of Metal Matrix Composite Using Optimization Technique

S. Vignesh Kumar and N. V. Dhandapani

Abstract Aluminium-reinforced with SiC composition was produced by stir casting method, and their wear resistance and friction coefficient are investigated on different load conditions and different reinforcement percentages. Pin-on-disc wear test apparatus is used to study the dry sliding wear properties of single-reinforced composites, and the same was investigated at a constant sliding velocity of 1.05 m/s and sliding distance of 1774 m over different loads of 10, 20 and 30 N for particle weight percentage ranges from 10, 15 and 20%. The reinforcement addition up to a 20% weight reduces the wear rate. As a result, the wear rate of the specimens decreases with the increasing sliding distance, and the wear rate of the specimens increases with increase in load. Vickers hardness is used to measure the hardness of the specimen at room temperature. By increasing in percentage of reinforcements, the hardness of the composite test specimens increases. The uniform distribution of reinforcement in matrix is assessed using scanning electron microscope image. A plan of experiment done through RSM technique is used to conduct experiments based on L_{15} orthogonal array. The optimum wear under the influence of applied load, time and reinforcement percentage was identified by ANOVA and the regression equations.

Keywords Aluminium alloy · Stir casting · Response surface methodology · ANOVA

1 Introduction

For the past few decades, conventional material such as cast iron has played important role in automotive components. Grey cast iron, for instance, is used to produce

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automotive drum and disc brake, motor cylinders and pistons because of its low cost, good rigidity, good wear resistance, compressive strength, etc. However, grey cast iron is not a light material. The high density material will increase the fuel consumption in vehicle. The market price of the petrol is increasing continuously day to day. This study is based on the need to find an alternative material for automobile application. The alternative material should not only be lightweight but also must have properties—high strength, hardness, toughness and wear resistance. The superior properties aluminium-based MMCs make these materials attractive for automotive applications. Al–MMCs specimens with various particle sizes and weight percentage of SiC (10–15 μm) were tested to find the mechanical properties, tribological property and its characterization. By controlling the processing factors as well as the relative amount of the reinforcement material, it is possible to obtain a composite which satisfies the need [1].

2 Experimental Procedure

The production cost in preparing MMCs is high, so it is proposed to select alternate techniques which offer lower cost of production [2, 3]. Stir casting method is used in this study because its reinforcement distribution is uniform that leads to good mechanical and tribological properties and low production cost compared to other techniques as shown in Fig. 1b [4–8]. Pin-on-disc type wear tester as shown in Fig. 1a is used to check the dry sliding wear tests for different factors like load, sliding time and reinforcement percentage as shown in Table 1.

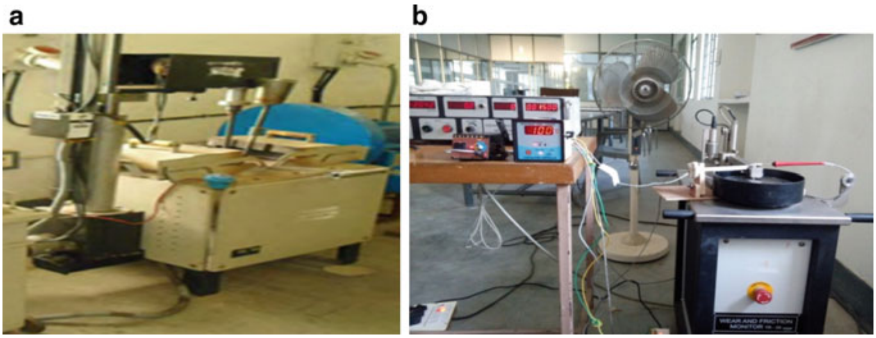


Fig. 1 **a** Stir casting setup. **b** Wear tester

Table 1 Process parameters and levels

Level	Load (N)	Time (min)	Reinforcement (%)
−1	10	5	10
0	20	10	15
+ 1	30	15	20

2.1 Optimization (Response Surface Methodology)

The experiments were conducted based on the standard orthogonal array [9–11]. In this article, an L_{15} orthogonal array was chosen, which has 15 rows corresponding to the number of tests and 03 columns at three levels and three factors, as shown in Table 2. This paper is focused only on response surface method approach by applying L_{15} orthogonal array from the obtained mechanical and tribological result. This approach is capable of determining significant factors which affect the properties of Al-MMC and determine the optimum conditions [9, 10, 12]. The objective of this present study is to optimize the minimum wear rate on Al 6061 metal matrix composite which depends on the process factors such as sliding time, load and percentage of the reinforcements using response surface method. The selected factor parameters for wear processing are (a) load, (b) sliding time and (c) reinforcement percentage of SiC. As the speed is set as constant, it is neglected for process factor. The experiments were conducted based on orthogonal array with level of parameters given in each row (Table 3).

Table 2 L_{15} orthogonal array

Standard order	Run order	Load (N)	Time (min)	Reinforcement (%)
15	1	0	0	0
6	2	1	0	−1
3	3	−1	1	0
14	4	0	0	0
9	5	0	−1	−1
4	6	1	1	0
12	7	0	1	1
5	8	−1	0	−1
1	9	−1	−1	0
13	10	0	0	0
8	11	1	0	1
10	12	0	1	−1
11	13	0	−1	1
7	14	−1	0	1
2	15	1	−1	0

Table 3 Experimental data

Standard order	Run order	Load (N)	Time (min)	Reinforcement (%)	Wear rate (μm)
15	1	20	10	15	199.8
6	2	30	10	10	385.0
3	3	10	15	15	161.1
14	4	20	10	15	199.8
9	5	20	5	10	247
4	6	30	15	15	298.3
12	7	20	15	20	186.6
5	8	10	10	10	230.2
1	9	10	5	15	158
13	10	20	10	15	199.8
8	11	30	10	20	240.2
10	12	20	15	10	289.5
11	13	20	5	20	159.8
7	14	10	10	20	123.1
2	15	30	5	15	278.6

3 Result and Discussion

3.1 Contour Plot of Wear Rate (Akima's Polynomial Method)

With respect to the plan of experiment, the investigated results and calculated values were obtained, and MINITAB® 16 a commercial software for DOE is used to analyse the results. The influence of dominant factors such as load, sliding time and reinforcement percentage was analysed based on contour. In the listed factor, percentage of reinforcement is primary dominating factor on the wear rate followed by load. The influence of conquered process parameters on wear rate is shown graphically in Figs. 2, 3 and 4

Figure 2 clearly shows that increase in percentage of reinforcement leads to less wear rate, where the reinforcement strengthens the material and increase in load tends to gradual increase of wear rate which is suitable for the application. The application like clutch plate requires high friction but less wear rate, so this composition will meet the demand of such application [10, 13–15]. Figure 3 states that increase in sliding time causes increase in wear, but after some duration of continuous operation (increased time), wear rate gets reduced, in which material gets naturally wear up to some extent and fitted for the application. Figure 4 satisfies the basic science concept that at 15 N of load wear rate lies in the range of 150–200 μm, as the load increased from 15 to 30 N, the wear rate also increases to the range of 300–350 μm, so the optimum load and time are chosen based on the application.

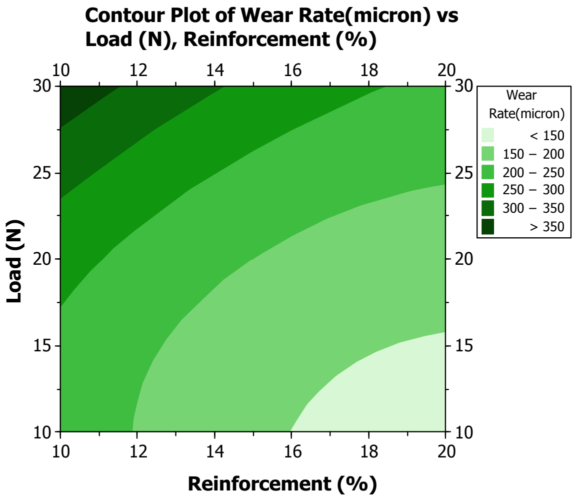


Fig. 2 Contour plot of load (N) versus reinforcement (wt%)

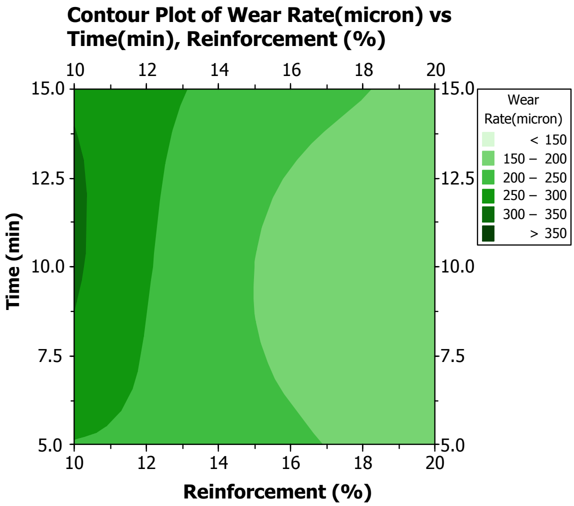


Fig. 3 Contour plot of time (min) versus reinforcement

3.2 Surface Plot of Wear Rate (Akima's Polynomial Method)

The influencing factors like load, sliding time and reinforcement percentage were analysed based on surface plot. The above surface plot graph satisfies the basic science concept. For strengthening the values in three-dimensional form, Figs. 5, 6 and 7 have been included. Among these parameters, percentage of reinforcement is primary dominating factor on the wear rate followed by load.

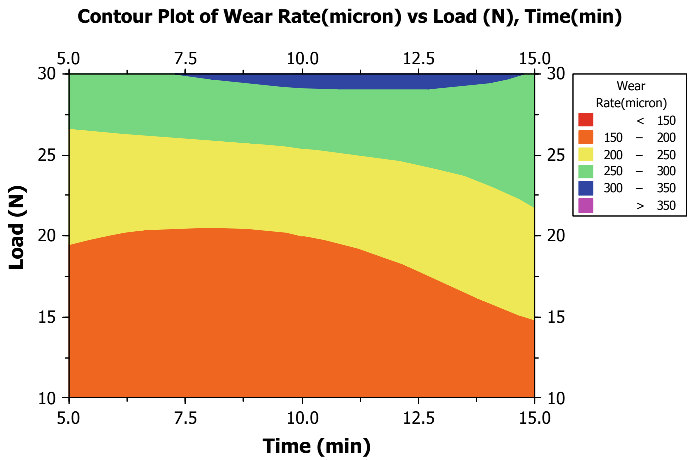


Fig. 4 Contour plot of load (N) versus time (min)

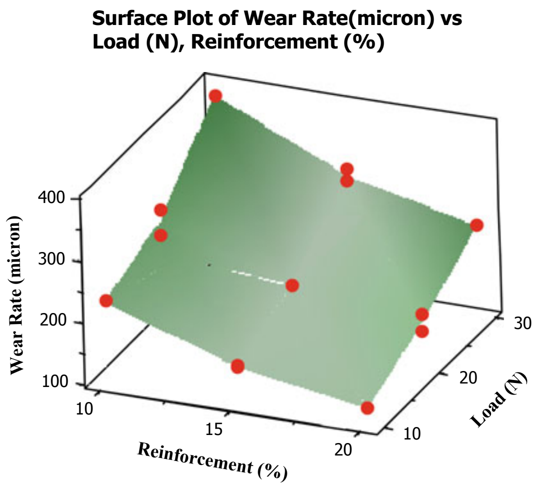


Fig. 5 Surface plot of wear rate (micron) versus load (N) and reinforcement (wt%)

3.3 Residual Plots for Wear Rate

Normality of the Data

This graph shows the residuals on the vertical axis and the independent variable on the horizontal axis. Linear regression model is appropriate for the data if the points in a residual plot are randomly dispersed around the independent variable; otherwise, a nonlinear model is more appropriate. Normality of the data was done by means of normal probability plot. The normal probability plot of the residuals for specific wear rate is shown in Fig. 8.

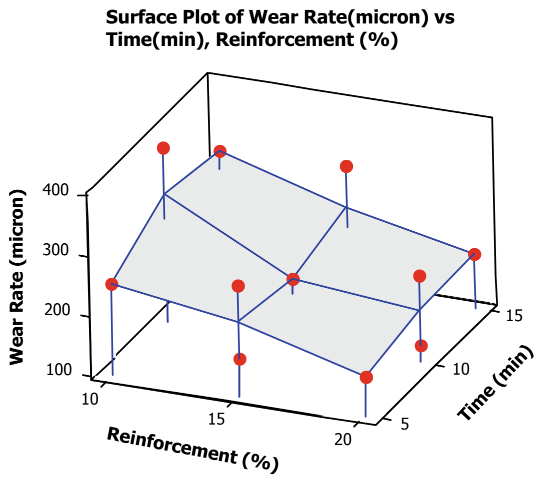


Fig. 6 Surface plot of wear rate (micron) versus time (min) and reinforcement

Fig. 7 Surface plot of wear rate (micron) versus time (min) and load (N)

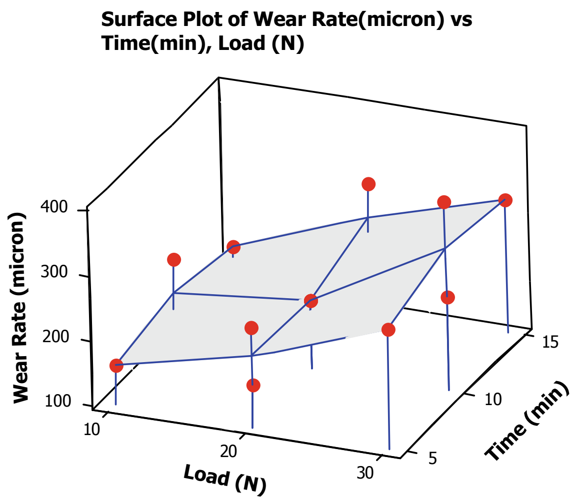
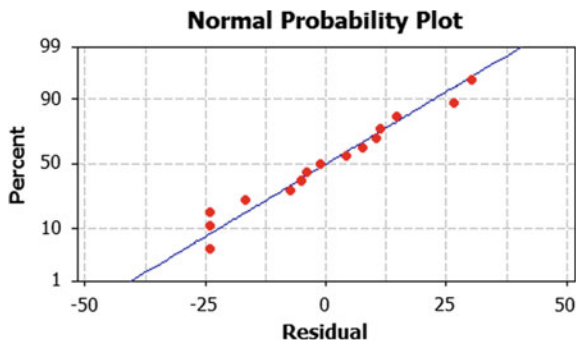


Fig. 8 Normality of wear



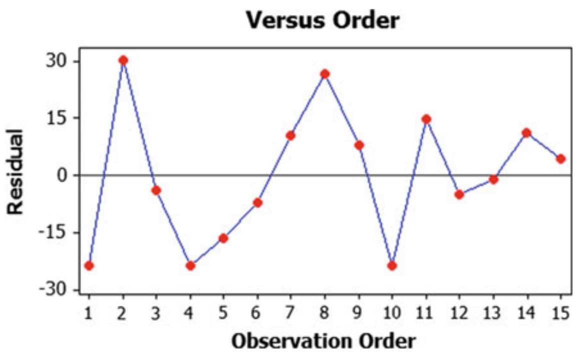


Fig. 9 Residual plot of wear

Table 4 Optimum level process parameter for wear rate

S. No.	Speed (rpm)	Load (N)	Time (Min)	Percentage of reinforcement (wt%)	Wear rate (μm)
1	400	20	15	20	186.6

Independency of the Data

Independency of the data was tested by plotting a graph between the residuals and the observation order. The residual plot for specific wear rate is shown in Fig. 9, which reveals that there was no predictable pattern observed because all the run residues lay on or between the levels of −30 to 30.

Analysis of Variance

Based on the analysis of these experimental results, the optimum conditions resulting in wear rate are shown in Table 4.

Table 5 shows the ANOVA result on the wear rate for SiC-reinforced composite. This analysis is done for 5% significance that is up to a confidence level of 95%. The linear regression model is shown in Eq. (1).

The regression equation is

$$\text{Wear Rate(micron)} = 234 + 6.62\,\text{Load(N)} + 2.30\,\text{Time(min)} - 11.0\,\text{Reinforcement}\,(\%) \tag{1}$$

$$R - \text{Sq(adj)} = 90.7\%$$

4 Conclusion

- Aluminium alloy with SiC reinforcement was prepared by stir casting setup, and required mechanical and tribological test was conducted.

Table 5 Analysis of variance for wear rate (μm)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	61,039.4	61,039.4	10,173.2	19.05	0.000
Linear	3	60,553.6	60,553.6	20,184.5	37.79	0.000
Load (N)	1	35,072.8	35,072.8	35,072.8	65.66	0.000
Time (min)	1	1060.3	1060.3	1060.3	1.99	0.197
Reinforcement (%)	1	24,420.5	24,420.5	24,420.5	45.72	0.000
Interaction	3	485.8	485.8	161.9	0.30	0.822
Load (N) * time(min)	1	68.9	68.9	68.9	0.13	0.729
Load (N) * reinforcement (%)	1	355.3	355.3	355.3	0.67	0.438
Time (min) * reinforcement (%)	1	61.6	61.6	61.6	0.12	0.743
Residual error	8	4273.2	4273.2	534.2		
Lack-of-fit	6	4273.2	4273.2	712.2		
Pure error	2	0.0	0.0	0.0		
Total	14	65,312.6				

- The obtained result is optimized using RSM technique of L_{15} orthogonal array.
- As per this experiment result, 20% of reinforcement at 20 N of load gives the optimum result in wear which meets the need.
- The contour plot and surface plot show that increase in reinforcement and optimal load has less wear rate over other combinations.
- The dominant parameter in this paper is the load followed by percentage of reinforcement.
- The ANOVA test provides the optimal value which will be suitable for the application.

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