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Research Paper

DRY SLIDING WEAR BEHAVIOUR OF ALUMINIUM ALLOY REINFORCED WITH SIC METAL MATRIX COMPOSITES USING TAGUCHI METHOD

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The purpose of present work is to investigate the dry sliding wear behaviour of aluminium alloy reinforcing with varying in percentage of SiC. Dry sliding wear tests were conducted on samples using pin-on-disc machine for varying Normal pressure, speed and wt % of SIC. The design of experiment approach was employed to acquire data in controlled way using Taguchi method and analysis of variance were employed to optimize the wear rate and frictional force of Al-SiC composite. The mathematical model was obtained to determine the wear rate and frictional force of Al-SiC composite. The confirmation tests were conducted to verify the experimental results.

Keywords: ANOVA, MMC, Orthogonal array, Wear, etc.

INTRODUCTION

The challenge and demand for developing metal matrix composites for use in high performance structural and functional applications including aerospace industries, automobile sector, defence etc. have significantly increased in the recent times (Dinesh Kumar and Jasmeet Singh, 2014). Aluminium alloy (LM6) is used in Marine, Automobile, Aerospace industries. One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites (Mahendra Boopathi M *et al.*, 2013).Silicon carbide is a compound of silicon and carbon with a chemical formula SiC. Silicon carbide was originally produced by a high temperature electrochemical reaction of sand and carbon. Silicon carbide ceramics with little or no grain boundary

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impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. It is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics and numerous high-performance applications (Mahendra Boopathi M *et al.*, 2013). The effect of applied load on wear behaviour of Al- 5%SiC and Al-10%SiC was studied by Chen *et al*. (1997). The results suggested that with increase in volume fraction of reinforcement particle the wear rate increased but with gradual increase in applied load the wear rates decreased. Wear behaviour of Al-Mg-Cu alloy reinforced with SiC particle were studied by Hassan *et al.* (2009). The comparative study of alloy and alloy reinforced with SiC suggested that wear resistant property of the alloy increased considerably with addition of SiC particle. Another similar study of wear behaviour was performed by Kwok and Lim (1999) M. Ramachandra *et al*. studies the abrasive wear behaviour of Al-Si (12%) SiC metal matrix composite synthesized using vortex method. Wear behaviour was studied by using computerized pin on disc wear testing machine and was found that the abrasive wear resistance of MMC increased with increase in SiC content. But wear increased with increase in sliding velocity and normal load (Ramachandra M *et al.*, 2002). Veeresh Kumar *et al*. (2012) Conducted Dry-sliding wear test using a computer aided pin-on-disc wear-testing machine at constant sliding velocity (V = 2.62 m/s) and load on the pin was varied from 10 to 60 N while the sliding distance of 6 km was maintained and tests were conducted at room temperature in accordance with ASTM – G99 standard (diameter of the pin was 10 mm and 25 mm in length). It was found that the volumetric wear loss of the composites decreases with increased contents of SiC reinforcement in the matrix alloy.From the past review, it is apparent that many researches studies have been taken out on the wear behaviour of Al-SiC composite. For the present experimental study LM6 aluminium alloy is used as base metal and silicon carbide is used as reinforcement. The composite is prepared by stir casting process in an electric melting furnace. The tribological tests are carried out on LM6-SiC MMC using Taguchi orthogonal design with three parameters viz. SiC wt% (0, 5, and 15), normal pressure and sliding speed. A pin-on-disc testing machine is used for wear test. Furthermore, a statistical analysis of variance (ANOVA) is carried out to find the statistical significance of process parameters. Finally, a confirmation test is carried out to verify the optimal process parameters obtained from the parameter design.

TAGUCHI METHOD

The taguchi method was developed by Dr.Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels. This technique is carried out in a three stages approach such as system design, parameter design and tolerance design. System design reveals the usage of scientific and engineering information required for producing a part. Parameter design is used to obtain the optimum levels of process parameters for developing the quality characteristics and to determine the product parameter values. Tolerance deign is used to determine and analyze tolerance about the optimum combination suggested by parameter design. In the present study, parameter design is used to optimize the friction behaviour of LM-6/SiC composite.

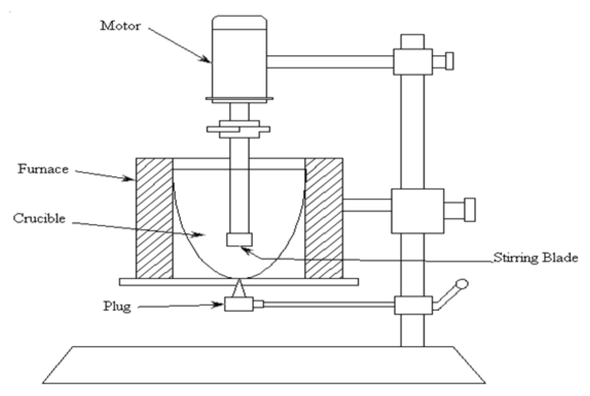
EXPERIMENTAL DETAILS

Materials and Methods

For the fabrication process aluminium alloy, LM6 is used as matrix metal that has been reinforced with SiC particles of 400 mesh size (size ~ 37 ìm). The reinforcement percentage (herein termed as volume fraction of reinforcement) is varied in the range 5% - 15% by weight.

The fabrication of LM6-SiC composites were carried out by stir casting process. The line diagram of the experimental set up used for making of these composites was shown in Figure 1. Silicon carbide particles were preheated at around 850^{0}C to 900^{0}C for 2-3 hrs to make their surfaces oxidized. LM6 Al alloy ingots were taken into a graphite crucible and melted in an electrical furnace. They were then slightly cooled to below the liquids, to maintain the slurry in the semi-solid state. The preheated silicon carbide particulates were added and mixed manually. The composite slurry was then reheated to a fully liquid state and mechanical mixing was carried out about 20 min at an average mixing speed of 400-500 rpm. The final temperature was controlled to be around 750^{0}C. The melt is then poured into a green silica sand mould. The material is then cooled and samples for wear testing are prepared by different machining processes.

Figure 1: Line Diagram of the Stir Casting Process



Design of Experiment

The experimental plan was formulated considering three parameters (variables) and three levels based on the Taguchi technique. SIC wt %(A), Normal Pressure (B) and Sliding Speed(C), these are process parameters is considered for the study. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance [8]. The levels of these variables chosen for experimentation are given in the Table 1.

In the present investigation an L9 orthogonal array was chosen as shown in Table 2. The selected of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than, or equal to, the sum of the variables. The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. This analysis includes the rank based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. The experimental results were transformed into signal-to-noise ratio (S/N) ratios. An S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio for the wear rate and frictional force using 'smaller the better' characteristics, which can be calculated as logarithmic transformation of the loss function is given as

$$S/N = -10 \log_{10} (MSD) \quad \ldots (1)$$

Where MSD = Mean Square Deviation

For the smaller the better characteristic,

$$MSD = (Y_1^2 + Y_2^2 + Y_3^2 + \ldots) \times 1/n$$

where Y_1, Y_2, Y_3 are the responses and 'n' is the number of tests in a trial.

Wear Tests

Sliding wear tests as shown in the Figure 2 were conducted in pin-on-disc wear testing apparatus (model: TR20-LE, Wear and Friction Monitor, Ducom Make, Bangalore, India as per ASTM: G99 – 05) under normal pressure, varying sliding speed against EN32 steel disc of hardness 500HV. The pin samples were 08mm in diameter and 24mm in length. The track diameter of 80mm enabled the rotational speeds of 238, 716 and 1190 rpm to attain linear sliding speeds of 1, 3 and 5 m/s respectively. Load on the specimen was increased in steps until the specimen seized before traversing a fixed sliding distance of 1000m.The surfaces of the pin sample and the steel disc were ground using emery paper prior to each test. In ordered to ensure effective contact of fresh surface with the steel disc, the fresh samples were subjected to sliding on emery paper of 240grit size fixed on the steel disc. During sliding, the load is applied on the specimen through cantilever mechanism and the specimens brought in intimate contact with the rotating disc at a track radius of 80mm.Before each test the disc was cleaned with organic solvents to remove contaminants. The wear losses of sample pins were recorded using an electronic microbalance having an accuracy of ± 0.01mg. After wear test specimens were cleaned thoroughly and weighed again. The wear rate was calculated by a weight-loss method.

RESULTS AND DISCUSSION

The experiments were conducted based on the run order generated by Taguchi model, with

Table 1: Control and Noise Factors

S.No.	Process Parameters	Level 1	Level 2	Level 3
1	SIC (wt%),A	0	5	15
2	Normal Pressure (MPa),B	0.19	0.59	0.990
3	Sliding Speed (m/s.), C	1	3	5

Figure 2: Wear Testing Machine

Table 2: L9 Orthogonal Array (OA)

S. No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

the aim of relating the influence sliding speed (m/s), Normal pressure (MPa) and percentage of SiC for the wear test. The result obtained for various combinations of parameters was obtained and was shown in Table 3.

Analysis of S/N Ratio

In Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristics and the term 'noise' represents the undesirable value for the output characteristics. Taguchi uses S/N ratio to measure the quality characteristics deviating from the desired value. The influence of control parameters such as Normal pressure, Sliding speed and wt% of reinforcement content has been analyzed and the rank of involved factors like wear rate of composite materials which supports S/N ratio response is given in the Table 4. It is evident from the table that among these process parameters, normal pressure is a dominant factor on the wear rate. The influence of controlled process parameters on wear rate are graphically represented in Figures 3 and 4.

Analysis of Variance

Analysis of variance (ANOVA) was introduced by Sir Ronald Fisher. This analysis was carried out for a level of significance of 5%, i.e., for 95% level of confidence. The purpose of ANOVA is to investigate the percentage of contribution of variance over the response parameter and to find the influence of wear parameters. The ANOVA is also needed for estimating the error of variance and variance of the prediction error. The Table 5 shows analysis of variance for wear rate of the composite material. From the table 5, it is observed that the normal pressure, sliding speed and wt% of reinforcement have the influence on wear of composite material. The last column of the table 5 indicates the percentage contribution of each other on the total variation indicating their degree of influence on the result. It can be observed from the ANOVA table that the normal pressure (49.66) was the most significant parameter on the dry sliding wear of composites followed by sliding speed (22.31) and SiC wt% (17.83). When the P-value for this model was less than

Table 3: Combination of parameters in (L9) Orthogonal Array

S.No.	Process Parameters			Wear Rate (mm^3/m)	S/N Ratio for Wear (db)
	SiC (wt %)	Normal Pressure (MPa)	Sliding Speed (m/s)		
1	0	0.19	1	0.00268	51.4373
2	0	0.58	3	0.01295	37.7546
3	0	0.97	5	0.03705	28.6242
4	5	0.19	3	0.00268	51.4373
5	5	0.58	5	0.000893	60.9830
6	5	0.97	1	0.00402	47.9155
7	15	0.19	5	0.00357	48.9466
8	15	0.58	1	0.00179	54.9429
9	15	0.97	3	0.06696	23.4837

Table 4: Response Table for S/N Ratio

Level	SiC (wt %)	Normal Pressure	Sliding Speed
1	39.27	50.61	51.43
2	53.45	51.23	37.56
3	42.46	33.34	46.18
Delta	14.17	17.89	13.87
Rank	2	1	3

0.05, then the parameter can be considered as statistically significant. The pooled error associated in the ANOVA table was approximately about 10.20%. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable.

Multiple Linear Regression Models

Statistical software MINITAB R17 is used for developing a multiple linear regression equation. This developed model gives the relationship between independent/predictor variable and a response variable using by fitting a linear equation to the measured data.

The regression equation developed for wear rate is,

$$\text{Wear rate} = 0.01473 - 0.01220\,A - 0.00952\,B - 0.00089\,C \quad ...(2)$$

$R\text{-sq} = 89.80\%$

Confirmation Experiment

Finally, confirmation test was performed for composite material by selecting the set of parameters as shown in table 6. The table 7 shows the results obtained using regression equation and the experimental results. From the analysis, the actual wear rate is found to be varying from the calculated one using regression equation and the error percentage ranges between 7.01% to 9.59% for wear rate.

Figure 3: Main Effects Plot for SN ratios - wear rate

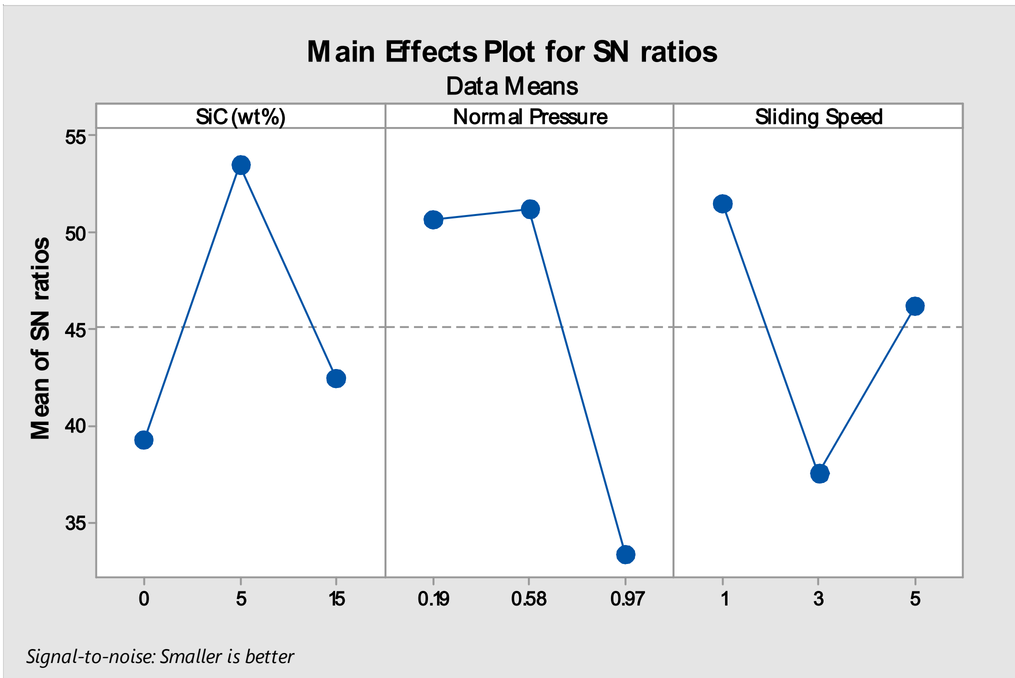


Figure 4: Main Effects Plot for Means- wear rate

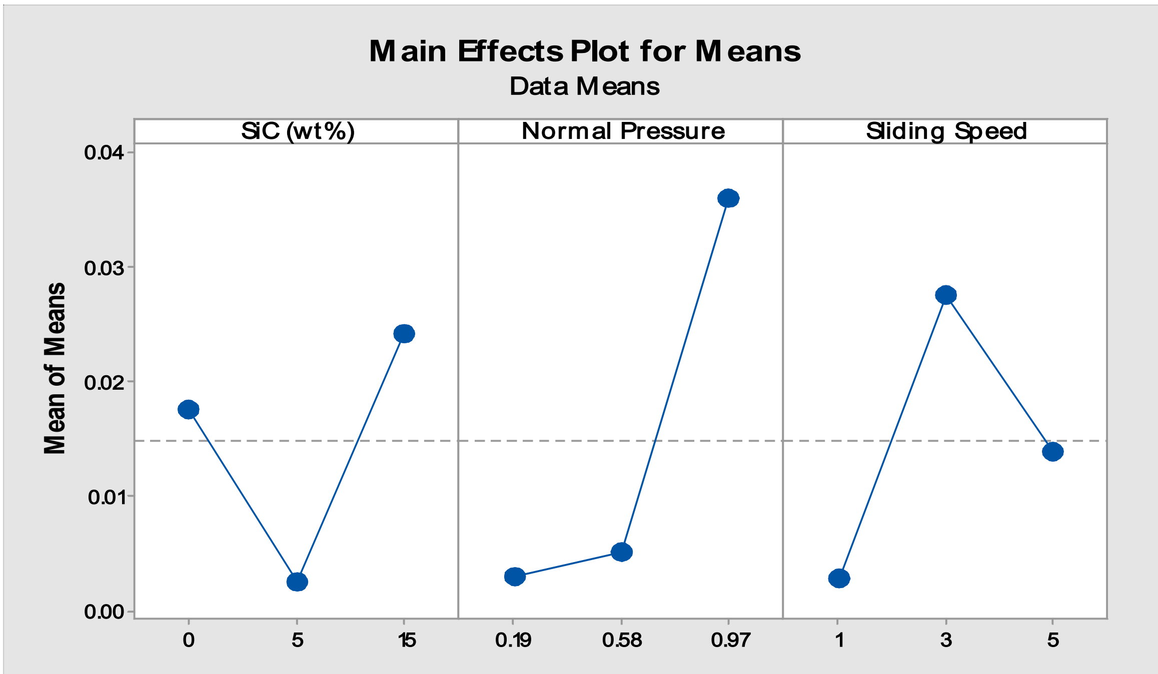


Table 5: Analysis of Variance for Wear Rate (mm^3/m)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Pr%
SiC (wt %)	2	0.000734	0.000367	1.75	0.364	17.83
Normal Pressure	2	0.002045	0.001022	4.87	0.170	49.66
Sliding Speed	2	0.000919	0.000459	2.19	0.314	22.31
Error	2	0.000420	0.000210			10.20
Total	8	0.004118				

Table 6: Confirmation Experiment for Wear Rate

Level	SiC (wt %)	Normal Pressure	Sliding Speed
1	0	0.2927	1.5
2	5	0.4879	2.5
3	15	0.8782	4.5

Table 7: Result of Confirmation Experiment and their Comparison with Regression Model

Expt. No.	Expt. Wear rate (mm^3/m)	Reg. Model Eqn(1), Wear rate (mm^3/m)	% Error
1	0.0114	0.0106	7.01
2	0.00451	0.00414	8.20
3	0.00771	0.00697	9.59

The mathematical model obtained from the multiple linear regression models evaluates the wear of the composite materials with reasonable degree of approximation.

CONCLUSION

Based on the above analysis the following conclusions are drawn from the present study.

1. Taguchi method provides a systematic and efficient methodology for the design and optimization of wear rate parameters with far less effort than would be required for most optimization techniques.
2. For Al-SiC the optimal tribological testing combination for minimum wear rate is found to be A2B2C1. All the factors % of SiC (A), Nr. Pressure (B) and sliding speed(C) are found to affect the friction significantly.
3. The analysis of variance shows that the Normal pressure (49.66) is the wear factor that has the highest statistical influence on the dry sliding wear of composites followed by sliding speed (22.31) and reinforcement (17.83).
4. The pooled error associated with the ANOVA analysis was 10.20% for the factors and the correlation between the wear parameters was obtained by multiple linear regression model.
5. From confirmation tests, the errors associated with wear rate ranges between 7.01% to 9.59% resulting in the conclusion

that the design of experiments by Taguchi method was successful for calculating wear rate from the regression equation.

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