STUDY ON HIGH TEMPERATURE WEAR AND FRICTION PROPERTIES OF LM13/SIC/MOS2 HYBRID COMPOSITES

Mukunda B. Pote[1], S.Y.Pawar[2]
[1]P.G. Student (Mechanical Design Engineering), [2]Assistant Professor
Department of Mechanical Engineering, NDMVP'S KABGT COE, Nasik, Maharashtra, India
Savitribai Phule Pune University, Pune, Maharashtra, India

Abstract: In these paper the wear behavior of hybrid composites of LM13 alloy reinforced with Sic & Mos_2 was investigated at ambient & elevated temperature. The specimens were fabricated by stir casting method. The pin on disc equipment was used to evaluate the wear behavior of specimen. Taguchi technique was used for optimization. An orthogonal L 27 array was formed. The influence of various parameters like applied load, sliding velocity, temperature & percentages of reinforcement were investigated by means of ANOVA. MINITAB software was used for analysis. Further, correlation between the parameters was determined by regression equations. Signal to noise ratios were used to find out most influencing parameters. It was found that applied load & temperature was dominant factor in coefficient of friction. Reinforcement shows negative influence on wear loss. As reinforcement increases wear decreases.

Keywords: hybrid composites, Minitab, orthogonal array, Taguchi, temperature

I. INTRODUCTION

Durability of any machine part is important design consideration. There are many factors that directly affect the life of machine component. So careful material selection for particular application is the big challenge in front of design engineer. Hybrid metal matrix composites are now extensively used for many applications of automobile and process industries due to their high strength to weight ratio. Reinforcing aluminum alloy with other materials increases its temperature range in wear limited application such as gear, crankshaft, piston. Many times at higher temperature sliding or rotating component like bearing lubricating conditions may eventually ends up in semi-lubricated or dry conditions. The temperature accelerates the wear rate and there will be quicker replacement of machine component. Many industries face this problem that they have to replace the bearing frequently while working in high temperature area. So present work focuses on development of hybrid composites for high temperature bearing application and investigate the tribological properties of hybrid composites for bearing application.

II. LITERATURE REVIEW

T.S.Kiran [1] et al had studied dry sliding wear behavior of zinc based alloy and composite reinforced with sic (9% wt). I It was observed that applied load significantly influences the wear volume loss. Rajaram et al [2] had studied wear behavior of aluminum silicon alloy at ambient and elevated temperatures. They have studied that due to addition of graphite particle metal matrix composite offers better wear resistance at high temperature. S. Basavarajappa et al [3] had studied application of taguchi for developing aluminum metal matrix composite reinforced with sic. Orthogonal array and ANOVA was employed to investigate the influence of wear parameter like as normal load, sliding speed and sliding distance on dry sliding wear of the composite. N. Natarajan et al [4] recommended Sic particulate reinforcement of metal matrix is more appropriate aspirant material for automobile purpose but new friction material is to be developed. V. D. Londhe et al [5] studied tribological behavior of LM13-sic composite under ambient and elevated temperature. They found that for semi metallic lining material frictional forces increases with increase in load & speed. It was observed that for composite material at ambient temperature wear was less and at elevated temperature wear was negative. Ranjit Kumar et al [6] presented optimization of tribological properties of molybdenum disulphide reinforced with aluminum composites. The result reveals that with increase in applied load wear rate also increases. The Mos2 showed less wear compared to conventional material. N. Radhika et al [7] have studied tribological behavior of aluminum matrix. The signal to noise ratio and analysis of variance reveals that load has the highest significance on the wear rate followed by percentages of reinforcement. P. Shanmughasundaram et al [8] studied the effect of wear behavior of AA7075-sic composites. In this experiment they revealed that wear resistance of composite decreases with increase in temperature, load and sliding velocity within the observed range. It was found that load was most dominant factor influencing the wear followed by temperature and sliding velocity. V. C. Uvaraja et al [9] investigated optimization on friction and wear process parameter using taguchi design. They showed that load and sliding speed was the most dominant factor in wear loss of LM24 material. The result also reveals that as reinforcement increases wear loss decreases. Belete shirabizu et al[10] done experiment on Al-12% / Si / Tic with different parameters such as load, sliding velocity. They showed ANOVA and regression analysis to find out most influencing factor in parameter. P. Ravindran et al [11] have studied tribological behavior of Al / sic hybrid composite. In this experiment they performed wear test on pin on disc tribometer. They tested different parameter and analyzed most dominant factor with the help of MINITAB software. Pruthvi serrao et al [12] predicted abrasive behavior of Cp titanium using Taguchi method. They concluded that there was increment in wear properties

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compared with conventional alloy. Michal Rajan et al [13] investigated aluminum alloy reinforced with TiB2 composites. The effect of TiB2 was evaluated using pin on disc at different temperature ranging from 30 to 2400 c on wear rate was studied. The wear rate increases when applied temperature increases. Mahadiar valefi eat al [14] conducted wear test using an alumina ball with 5% wt of copper oxide at a temperature of 7000c. They reported that wear rate and coefficient of friction were strongly depend on temperature. Dheerendra kumar et al [15] conducted friction test on pin on disc apparatus. It was observed that initially wear rate was constant but beyond critical temperature coefficient of friction and wear rate increases rapidly with increase in temperature. In view of above article, it was understood that there is no clear understanding in the literature regarding the contribution of temperature, load, reinforcement & sliding velocity. Hence this work aims to find the influence of the parameters on the wear resistance of the composites under three different temperatures (30 0C, 60 0C, 90 0C), three different load, percentages of reinforcement & three different velocities against steel disc using Taguchi and analysis of variance.

III. SPECIMEN PREPARATION

A. Material Selection

In this paper, dry sliding wear test were performed on LM13 alloy by varying (5%, 10%) sic and adding constant weight percentages of Mos2 (3%). The pins are basically made up of LM13 alloy & reinforced with silicon carbide particles of size 25 micrometer. The pins are circular in cross section 10mm in diameter and 30mm of length. Disc is made up of steel EN31 grade with surface roughness of 1.57 micrometer.

Table 1 Chemical composition of LM13 alloy

Material	Si	Ni	Cu	Mg
Wt%	12%	2.5%	0.9%	1.2%

B. Manufacturing Hybrid Metal Matrix Composite

The LM13 alloy reinforced with (5% 10% wt) of Sic and (3% wt) of Mos_2 were fabricated by using stir casting method.
The stir casting set up consist of muffle furnace. There are 2 thermocouples available which controls the temperature of electric furnace precisely. LM13 alloy was melted at a temperature of (700-800^{0}c) in muffle furnace. Silicon carbide particle of 25 micrometer are melted into electric furnace upto 900^{0}c. The molten slurry was stirred continuously by Stirrer which is most commonly made up of mild steel because of its high temperature sustaining capability. The stirrer was moved clockwise and anticlockwise by an electric motor to ensure the uniformity of reinforcing material. To avoid blowholes, the molten metal was degassed by nitrogen gas. Then slurry was poured into mould and casting was prepared.

IV. TAGUCHI TECHNIQUE

The objective of taguchi technique is to reduce the number of experiment (trial) that is required to find the response function. Taguchi technique finds out how different factor affect the mean and variance of given process. Taguchi designs orthogonal arrays according to number of test variables. In case of conventional method of experimentation it tests only one factor at a time, while other factors remain constant. Therefore in conventional experimentation one can have to test all possible combination of testing factors. Taguchi reduces these drawbacks. Taguchi test only pair of combination and gives rise to the factor that affect most in the given experiment thus it saves time and resources.

A. Plan of experiment

In this wear experiment, to consider the effect of all factors orthogonal arrays are generated. There are 3 levels of design namely low, medium, high denoted by 1, 2, 3.The wear parameter selected for the experiment are applied load, sliding velocity, percentages of reinforcement of silicon carbide and Mos2. The control factors for the test and 3 levels are shown in table 2. Taguchi calculated minimum number of experiment for 3 level and 4 control factors as 27. Hence we selected L27 orthogonal array for our wear testing.

Table 2 Control factors and levels for given experiment

Level	Load (N)	Sliding velocity (m/s)	Percentages of reinforcement	Temperature (^{0}c)
1	5	1	0	30
2	10	2	5	60
3	15	3	10	90

B. Wear Experiment

The experiment was conducted on pin on disc tribometer (TR20PHM400) at ambient and elevated temperature. The experiment was done according to ASTM G99 standard. The specimen are circular in cross section of size 10mm x 30mm made up LM13 alloy reinforced with (5% 10%) sic and (3% wt) of Mos2. The circular disc made up of mild steel EN31 grade which was having same composition as that of shaft of bearing. In this experiment pin was pressed against rotating disc under application of load. The test were carried out under three different loads (5, 10, 15N), three sliding velocities(1, 2, 3 m/s), three percentages of Sic reinforcement(0, 5 & 10 wt %) & three different temperatures(30, 60, 90 0c).The sliding distance kept constant at 500m. The pins were made flat from bottom and cleaned with emery paper after each trial. The chamber heating mode was used for this test. Pins were fixed in the fixture in given chamber surrounded by heating coil. The different parameters were feed in Winducom software. Disc was set to given rpm. Once rpm was set loads were applied to it. Wear value on screen was adjusted by screw. After all this conditions test was started. Wear loss, tangential friction force and coefficient of friction were recorded on screen. The responses obtained in this experiment were used to developed mathematical equation by ANOVA. Further regression equations were formed that gives correlations between wear loss and coefficient of friction with other parameter. All this statistical analysis was done with the help of MINITAB software.

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V. RESULT AND DISCUSSION

Experimental values of wear loss and coefficient of friction for given responses are listed in table

Table 3 L27 orthogonal array

Test no	Load (N)	Sliding velocity (m/s)	Percenteges of reinforcement	Temperature (^{0}C)	Coefficient of friction	Wear loss (mm^3)
1	5	1	0	30	0.390	0.00193
2	5	1	0	30	0.380	0.00196
3	5	1	0	30	0.370	0.00195
4	5	2	5	60	0.380	0.00191
5	5	2	5	60	0.382	0.00193
6	5	2	5	60	0.390	0.00195
7	5	3	10	90	0.400	0.00193
8	5	3	10	90	0.410	0.00194
9	5	3	10	90	0.390	0.00195
10	10	1	5	90	0.396	0.00198
11	10	1	5	90	0.410	0.00200
12	10	1	5	90	0.420	0.00210
13	10	2	10	30	0.380	0.00191
14	10	2	10	30	0.381	0.00190
15	10	2	10	30	0.370	0.00185
16	10	3	0	60	0.390	0.00195
17	10	3	0	60	0.410	0.00230
18	10	3	0	60	0.420	0.00220
19	15	1	10	60	0.421	0.00200
20	15	1	10	60	0.420	0.00198
21	15	1	10	60	0.390	0.00196
22	15	2	0	90	0.440	0.00221
23	15	2	0	90	0.450	0.00223
24	15	2	0	90	0.430	0.00215
25	15	3	5	30	0.400	0.00200
26	15	3	5	30	0.410	0.00210
27	15	3	5	30	0.420	0.00211

A. Analysis of variance for wear loss

Table 4 shows the result of analysis of variance of wear loss Sic and Mos_2 particles reinforced with LM13 Alloy hybrid matrix composite. To understand the combined effect of all parameters ANOVA was performed. The analysis was carried out at a level of 5% significance that is up to confidence level of 95%. The table indicating percentages of contribution (Pr) of each factor shows degree of influence of each factor on wear loss. From ANOVA most influencing factor were denoted on the basis of P value. It should be noted that P value for percentages of reinforcement & load is approximately zero. It should be observed that percentage of reinforcement has greater influence on wear loss (33.25%). Following to percentage of reinforcement applied load (26.07%), temperature (9.59%) & sliding velocities (6.33%) were less dominant factors respectively. The main effect plot for coefficient of friction shows that

B. Analysis of variance for coefficient of friction

From table it was observed that P value for load and temperature were nearly zero. Applied load (42.45%) was most dominating factor in coefficient of friction. Temperature (29.14%), percentages of reinforcement (6.81%) and sliding velocity (1.62%) were less dominating factors respectively.

Table 4 Anova for coefficient of friction

Source	Degree of freedom	Sum of squares	Percentages of Contribution	Adjusted Sum of squares	Adjusted Mean of squares	F Value	P Value
L	2	0.004902	42.45%	0.004902	0.002451	19.12	0.001
V	2	0.000187	3.62%	0.000187	0.000094	0.73	0.496
S	2	0.000786	6.81%	0.000786	0.000393	3.07	0.072
T	2	0.003366	29.14%	0.003366	0.001683	13.13	0.001
L*T	4	0.000214	5.14%	0.000214	0.000120	0.89	0.574
L*S	4	0.00157	2.08%	0.00157	0.00785	0.67	0.421
Error	10	0.02308	10.76%	0.02308	0.01154		
Total	26	0.34105	100%				

Table 5 ANOVA for wear loss

Source	Degree of freedom	Sum of squares	Percentages of contribution	Adjusted sum of squares	Adjusted Mean of squares	F value	P value
L	2	0.001743	26.07%	0.001743	0.000871	9.47	0.002
V	2	0.000814	6.33%	0.000814	0.000407	2.30	0.129
S	2	0.001202	33.25%	0.001202	0.000601	12.08	0.001
T	2	0.001106	9.59%	0.001106	0.000530	3.49	0.052
L*S	4	0.000934	8.07%	0.000934	0.000467	2.66	0.671
S*T	4	0.000865	7.29%	0.000865	0.000432	2.40	0.654
Error	10	0.001021	9.4%	0.001021	0.000510		
Total	26	0.007685	100%				

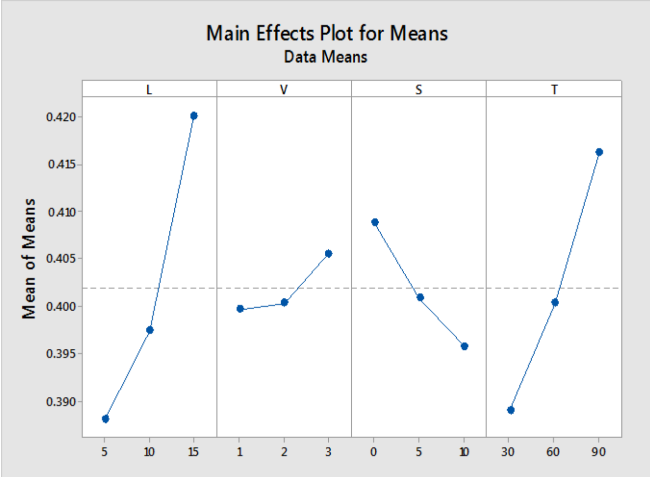

Fig 1 Main efeect plot for means for coefficient of friction

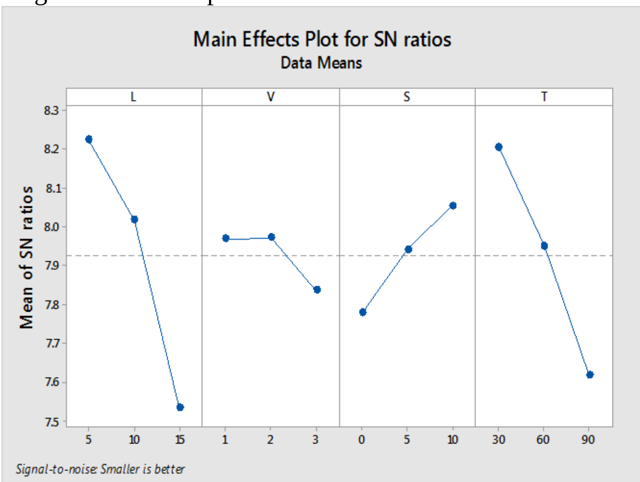

Fig 2 Main effect plot for S/N ratios of coefficient of friction

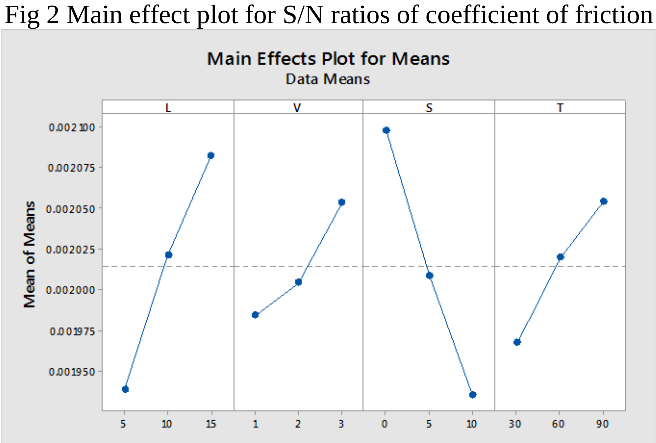

Fig 3 Main effect plot for means for wear loss

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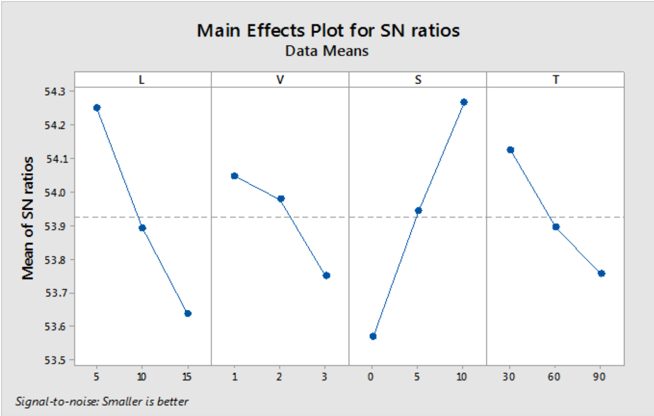

Fig 4 Main effect plot for S/N ratios of wear loss

C. Signal to noise ratio

For design parameter optimization signal to noise ratios were used in taguchi design. The control factors which affects more in given process were measured by signal to noise ratio. There are three type of approaches smaller is the better, nominal is the best, larger is the better. In this case smaller is the better approach was used. Smaller is the better reduces the undesirable effect or defects. In this case we want to reduce the wear loss and coefficient of friction. The S/N ratios were calculated for both wear loss and coefficient of friction. The S/N ratio graph and main effect graphs were plotted with the help of MINITAB 17 software. In S/N ratio plot, the factor which lies far away from horizontal line has most significant effect. The factor which lies near to horizontal line has less significant effect. From the main effect plot it indicates that applied load and temperature lies far away from horizontal line and hence most significant factor in coefficient of friction. Main effect plot for wear loss shows that as percentages of reinforcement increases wear loss decreases. The response table for S/N ratio was calculated in MINITAB 17. Ranking of each factor was computed on the basis of delta value which is the difference between maximum and minimum values of S/N ratio. The parameter which has highest value of delta is the most influencing factor for wear. It can be noted from table that load was most significant factor in coefficient of friction. Similarly percentage of reinforcement was most influencing factor in wear loss.

Table 6 Response table for signal to noise ratio for coefficient of friction considering smaller is better

Level	L	V	S	T
1	8.224	7.968	7.781	8.206
2	8.018	7.972	7.942	7.952
3	7.535	7.837	8.051	7.619
Delta	0.689	0.135	0.273	0.587
Rank	1	4	3	2

Table 7 Response table for signal to noise ratio for wear loss considering smaller is better

Level	L	V	S	T
1	54.25	54.05	53.57	54.13
2	53.89	53.98	53.94	53.90
3	53.64	53.75	54.27	53.76
Delta	0.61	0.30	0.70	0.37
Rank	2	4	1	3

D. Regression analysis

The factors such as applied load, temperature, sliding velocity, percentages of reinforcement were correlated to the quality characteristics through the employment of regression equations in linear form. The regression equations give effect of all factor combinations in given experiment. The regression equation for wear loss and coefficient of friction is given as below.

Wear loss= 0.001796 + 0.000014L + 0.000034V - 0.000016Wt + 0.000001T

COF= 0.34319 + 0.003211L + 0.00294V -0.001311wt + 0.000454T

The positive sign for factor indicates that wear loss & coefficient of friction of the material increases with that factor & negative sign indicate that wear or the coefficient of friction decreases with the increase in that factor.

E. Conformation experiment

Conformation experiment was performed to find out the efficiency of statistical model. At first values were calculated from regression equations. In confirmation experiment experimental and calculated values were compared and the error is calculated. The factors tested in confirmation test were given in following table.

Table 8 Factors for confirmation test

Level	L	V	S	T
1	5	2	10	30
2	10	1	0	60
3	15	3	5	90

Table 9 confirmation test for wear loss

Experiment No	Experimental value	Regression value	% Error
1	0.00184	0.00180	2.17%
2	0.00214	0.00203	5.14%
3	0.00232	0.00211	9.05%

Table10 confirmation test for coefficient of friction

Experiment No	Experimental Value	Regression value	% Error
1	0.381	0.365	4.19%
2	0.431	0.405	5.97%
3	0.462	0.434	6.06%

From the confirmation experiment, the actual wear loss and coefficient of friction is found to be varying using regression equations. The error percentages ranges between 2.17% to 9.05% for wear loss & the error percentages for coefficient of friction ranges between 4.19% to 6.06%. As these values closely resemble with actual data with minimum error, design of experiment by Taguchi method was successful for calculating wear loss and coefficient of friction for hybrid composite.

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VI. CONCLUSION

Taguchi method was used to find out the optimum conditions for wear test. It was found that applied load was dominant factor in coefficient of friction & percentages of reinforcement were dominant factor in wear loss. As reinforcement increases wear loss decreases and hence hybrid metal matrix composite is more efficient than conventional alloy.

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AUTHOR BOBLIOGRAPHY

Mr. Mukunda B. Pote Completed Bachelor's Degree in Mechanical Engineering from NDMVPS's KBT College of Engineering, Nasik-13 in 2013. And currently pursuing Master Degree in Mechanical Design Engineering from Savitribai Phule Pune University.
Email ID:
mukunda.pote@gmail.com

Prof. S. Y. Pawar
Asst. Professor in NDMVPS's KBT College of Engineering, Nashik-13
Education Qualification :M.E(Design) Ph.D. (Pursuing)
Experience :12 Years
Specialization : Tribology and Design Engineering
Email ID:
suyashyp@gmail.com

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