An Investigation of Wear Behavior on Phosphorus Bronze with SiC Composite

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Abstract: *Metal matrix composites are engineered materials with a combination of two or more dissimilar materials, (at least one of which is a metal) to obtain enhanced properties. Bronze/SiC metal matrix composite using stir casting method and various tests carried out and their outcomes. In the present investigation Bronze alloy was used as the matrix and silicon carbide (SiC) as reinforcements. The silicon carbide (SiC) was added in 6%, 9%, and 12% by weight (equal proportion) to the molten metal and experiment has been investigated by making the pins of material using stir casting process. The wear has been tested on tribometer Setup experimental setup. Various tests are conducted to evaluate the performance of the composite and the results obtained are discussed.*

Keywords: *Taguchi Method, tribometer Setup, SiC, Wear Rate, Bronze, Composite*

I. INTRODUCTION

Bronzes are commonly used for a variety of tribological applications. These alloys are used in journal and sleeve bearings, bushings and other heavy load supports in airframes, off-road construction equipment, mining equipment, and heavy manufacturing equipment. The alloys are known to be less susceptible to scuffing and galling under severe contact conditions in the boundary lubrication regime. In general, these alloys have a combination of properties such as adequate strength, excellent corrosion resistance, and high thermal conductivity that make them suitable for various challenging tribological applications. Bronze and brass alloys with a variety of compositions and microstructures are commercially available and are used for tribological applications. It is often necessary to enhance the properties and tribological performance attributes of the near-surface region which is exposed to mechanical and thermal stresses at the contact interface. For steel components, one of the most common means of enhancing surface properties is via deposition of thin-film coatings. Bronze is not a good candidate for hard coatings, in part because it is relatively soft and in part because of inherently poor adhesion of coatings onto copper-based materials.

Another approach that could be applicable for bronze material is near-surface region is microstructural modification. This can take the form of machining, mechanical peening, etc. Such operations can be used to cold work or refine the grain size and microstructure of the near-surface layer through recrystallization. This can be done by a variety of techniques such as near-surface melting and particle incorporation, for instance by laser. Of course, melting and re-solidification of the near-surface material can sometimes be accompanied by some undesirable defects such as microstructural and compositional heterogeneities, both of which can have detrimental effects on the properties and performance of the surface layer. A relatively new surface modification technique that can be used to enhance the near-surface material properties of bronze is friction stir processing (FSP).

II. EXPERIMENTATION

A. Methodology of Experiment

There are several optimization techniques to develop product, process or operation. Various techniques can be applied to optimize curing process. Sometimes different techniques are required integrate to get statistically significant results, which can lead to better conclusions and recommendations. Some extensively used methods in developing a process or a product are Build Test Fix (BTF), Design of Experiment (DOE) and One Variable at a Time (OVAT); BTF is very primitive and unorganized approach. It is iterative method of developing a process focused on improvement from last experiment. DOE is highly efficient method of investigating the effect of parameters as it varies multiple parameters at once. As more parameters are investigated, more number of new combinations is required. DOE cannot control individual parameters and more relies on statistical data. In one variable at a time (OVAT) approach, variation is done with one variable at a time and other parameters are kept constant until the effect of one parameter is studied.

It is highly precise method to study effect of each parameter at different levels. Reinforcement, load and frequency were identified as most predominant parameters affecting on wear rate. Based on the observation, Taguchi method has been used to optimize the process parameters. OVAT analysis has been conducted to find out effective range of parameters for optimization study. L9 orthogonal array (OA) has been selected from available designs. Standard notation for OA is given below

OA = Ln (Xm)

Where n= number of experiments, X= number of levels and m= number of parameters under study. From available designs for 3 levels 3 parameters, OA with least number of experiments required to conduct (L9) has been selected. ANOVA has been conducted to find out contribution of each parameter in the output. Minitab 19 software has been used for analysis.

B. Experimental Machine Selection

Table 1 states the specification of the Tribometer setup used in this study. All the experiments were conducted Government College of engineering, Aurangabad, M.S, India.

Figure 1. *Tribometer Setup*

Table 1*. Tribometer Specification.*

Make Model	**Ducom Ltd., Banglore, India**
Upper Specification	Pin(dia. × 1)- Φ4×15mm, Φ6×15mm, Φ8×15mm, Φ10×15mm. Pin Rectangular (l×b×h)-4×6×15 Pin Square (l×b×h)- 4×4×15mm, 6×6×15mm, 8×8×15mm. Ball- Φ10mm
Lower Specification	Rectangular Block (l×b×h)- 40×40×5, 30×30×5, 20×20×5mm
Lower Specification	EN-31 Steel
Lower Specification Hardness	60 HRC
Stroke Length Range	10, 20 30 fixed.
Load Range	5 to 100 N (In step of 5N)
Temperature Range	Ambient 200 to 200° C, Ambient 200 to 200° C (For Both Lubrication). Least count..-0.21°C, Sensor: PT-100

Frequency (Speed) Range1	1-20Hz(1200rpm) Least count: 1rpm, Sensor, Proximity Sensor
Power	230 V× 1 Φ×50Hz,8A(For Tester)

C. Selection of material

Phosphorous Bronze

The chemical composition Bronze is an alloy consisting primarily of copper, commonly with about 12–12.5% tin and often with the addition of other metals (such as aluminum, manganese, nickel or zinc) following tableis done at S.N.Metallurgy Pvt Ltd. Aurangabad.

***Figure 2** Bronze*

Table 2 *Chemical Composition of Bronze material*

Composition	[illegible]	[illegible]	[illegible]	Pb	P	Fe	Cu
Percentage	[illegible]	[illegible]	[illegible]	0.010	0.21	0.035	94.34

III. RESULTS AND DISCUSSION

To get complete understanding of effects of input parameters Reinforcement, load and frequency on output Wear Rate, you usually assess signal to noise ratio or main effects plot for means. For this purpose, Minitab 18 statistical software has been used. Wear rare have been done. ANOVA has been conducted to find out effect of each parameter on the wear rate and linear regression model has been established to predict the values of wear rate.

A. Experimental Result

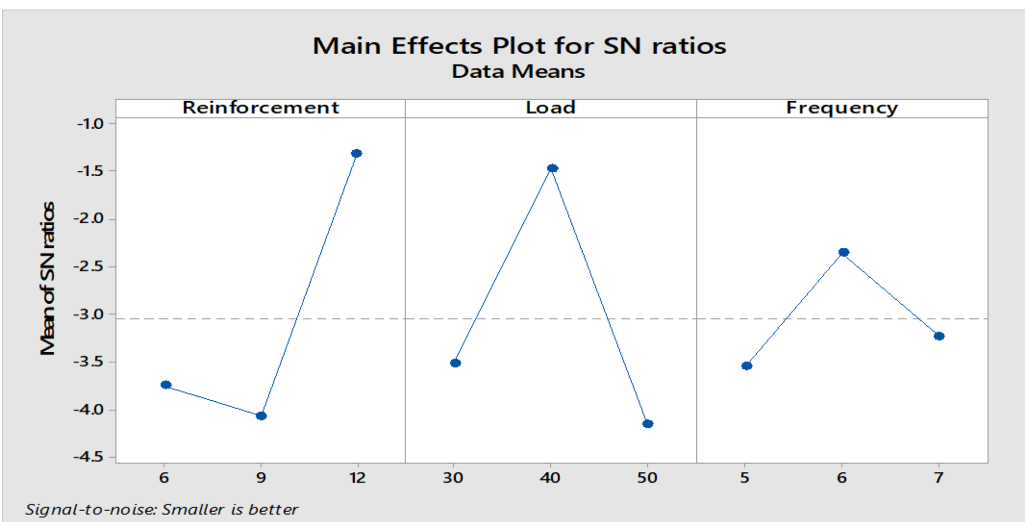
Table 3 shows the L9 orthogonal array with measurement of wear rate for runs one to nine. It also shows S/N ratio for all nine experiments.

***Table 3** L9 orthogonal array with response characteristic.*

Experiments	**Input Factors**			**Output Responses**	
Trial No.	**Reinforcement (%)**	**Load (N)**	**Frequency (Hz)**	**Wear rate (mm^3/Nm)**	**S/N Ratio**
1	6	30	5	1.755	-4.88554
2	6	40	6	1.528	-1.42291
3	6	50	7	1.768	-4.94965
4	9	30	6	1.538	-3.73913
5	9	40	7	1.387	-2.84153
6	9	50	5	1.712	-5.62976
7	12	30	7	1.246	-1.91036
8	12	40	5	1.016	-0.13787
9	12	50	6	1.246	-1.91036

The S/N ratio values are calculated with help of Minitab 18 software. It can be seen that variation in S/N ratio is minimum for all experiment.

B. Main Effects of Wear Rate



***Graph 1** Main Effects Plot for S/N Ratio*

From main effects plot for S/N ratio, parametric effect on response characteristic i.e The optimal input parameters were Reinforcement 12% (level 3), Load 40 N (level 2) and Frequency 6 Hz (level 2). The graph shows the effect of the control factors on Bronze material

C. ANOVA Result

ANOVA, the ratio between the variance of the welding parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the operating parameter is considered significant. Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). ANOVA table shown the result of the ANOVA analysis. ANOVA analysis makes it possible to observe that the value of P is less than 0.05 in the three parametric sources. It is therefore clear that rotational speed, welding speed and tool tilt angle of the material have an influence on the bronze material. The last column of cumulative ANOVA showed the percentage of each factor in the total variance that indicates the degree of impact on the outcome. Table 4 shows results obtained from analysis of variance

Table 4 *ANOVA Result.*

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Reinforcement	2	0.356443	0.178221	442.11	0.002	46.60
Load	2	0.319618	0.159809	396.44	0.003	41.78
Frequency	2	0.088010	0.044005	109.16	0.009	11.50
Error	2	0.000806	0.000403			
Total	8	0.764876				

It shows table 4 that the Reinforcement (46.60%), the Load (41.78%) and the Frequency (11.50%) have major influence on the Wear Rate. Contribution of Reinforcement (46.60%) is highest among all three parameters hence it is most dominating parameter while Frequency is least affecting parameter.

D. Development of Regression Model for Wear Rate

Regression model has been developed using Minitab software. Substituting the experimental values of the parameters in regression equation, values for Wear rate have been predicted for all levels of study parameters.

Graphical representation also shows that a predicted and experimental value of Wear rate correlates with each other.

Regression Equation –

Wear rate = 2.07 - 0.0663 [Reinforcement]+ 0.0064 [Load] - 0.047 [Frequency]

Table number 5 gives comparison between experimentally measured and predicted wear rate by developed mathematical equation

Table 5 *Experimental and Predicted Values of Wear rate*

Sr. No.	Experimental value	Predicted value	Error %
1	1.755	1.629	7.73
2	1.528	1.646	7.16
3	1.768	1.663	6.31
4	1.538	1.383	9.20
5	1.387	1.400	0.92
6	1.712	1.558	9.88
7	1.246	1.137	9.58
8	1.216	1.295	6.80
9	1.246	1.312	5.03

Difference between wear rate values calculated using regression equation and experimental values for each experience found less than 10%. Hence, we can say that the regression equation developed is valid.

E. Confirmation Experiment Result

Table 5 shows the difference between value of Wear rate of confirmation experiment and value predicted from regression model developed.

Table 6 Confirmation Experiment Result

Parameter	Predicted value	Experimental value	Error %
Wear Rate (mm^3/Nm)	1.295	1.198	7.49

Confirmation experiment is conducted by keeping parameters at optimum levels suggested by Taguchi method and the wear rate value obtained has been compared with value predicted by the regression model keeping the parameters at same levels. It can be seen that the difference between experimental result and the predicted result is 7.49%. This indicates that the experimental value correlates to the estimated value.

IV. CONCLUSIONS

In this study the influence of operating parameters such as Reinforcement, Load, Frequency and their optimization for Bronze with SiC has been studied by using Taguchi Method. Following conclusions are drawn.

- The optimal solution obtained for Wear Rate based on the combination of operating parameters and their levels is Reinforcement 12% (level 3), Load 40N (level 2) and Frequency 6 (level 2)
- ANOVA results indicate that Load plays prominent role in determining the Wear Rate. The contribution of Reinforcement, Load and Frequency to the quality characteristics Wear Rate is 46.60%, 41.48% and 11.50% respectively.
- ANOVA results indicate that contribution of Frequency on Wear Rate is lower followed by Reinforcement and Load. Reinforcement is most dominant factor.
- Value of Wear Rate is lower obtained in confirmation experiment. Hence, good quality of bronze with SiC can be achieved using suggested level of parameters by Taguchi method.
- Values of Wear Rate calculated using regression model correlates with experimental values with error less than 10%. Hence the model developed is valid and experimental results of Wear Rate with any combination of operating parameters can be estimated within selected levels.

ACKNOWLEDGMENT

I would like to express my deepest gratitude and sincere thanks to my guide **Dr. M. S. Kadam**, Department of Mechanical Engineering, MGM's Jawaharlal Neharu Engineering College, Aurangabad for his valuable time and keen interest in my review work. His intellectual advice has helped me in every step of my review work and motivated my efforts.

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