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Investigation of Reinforcement Content, Load and Sliding Speed on the Tribological behaviour of Copper based Silicon Carbide Composite using Design of Experiments

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Abstract

Objectives: In this paper, the effect of reinforcement content, load and speed on the wear behaviour of Cu/SiC metal matrix composite are investigated using design of experiment. **Methods:** A statistical model is proposed to find the significant factor which affects the wear resistance properties of the prepared composite material. Three samples of composites were fabricated using different SiC content by stir casting. The wear behaviour of composites was evaluated for a variety of load and sliding speed at ambient temperature. **Findings:** It is found with the increase in SiC content the rate of wear of the composite decrease while with increase in load the wear rate increased. Also with increase of sliding speed wear rate is increased. Among the three variable parameters chosen for the study viz. reinforcement content, load and sliding speed, the load is the mainly prominent factor that affects the wear resistance of the composite. **Applications/Improvements:** This study can be enhanced further by using different reinforcement's combinations and parameters. Also the wear tests can be performed at elevated temperatures.

Keywords: DOE, Metal Matrix Composites, Wear

1. Introduction

Copper matrix composites with SiC particles as reinforcement is considered as capable material for electronics packaging industry due to their brilliant combination of good quality mechanical and electrical properties. Copper has high electrical conductivity, thermal conductivity and wear resistance. Therefore, Cu/SiC composite is widely investigated in recent years[1]. Akramifard et.al demonstrated in experimental work that Cu metal matrix reinforced with SiC particle resulted in enhancing wear resistance. The load distribution takes place between Cu and SiC particles. So direct load contact decreased between Copper and SiC composite as compare to pure Copper[2]. Sapate et.al. prepared Cu/SiC composites varying SiC %, on which Pin on Disc test was carried out and the modeling of dry sliding wear behavior of composites was reported. Powder metallurgy is used to fabricate the copper matrix composites with 10%, 20%, 30% and 40% SiC reinforcement. On Cu/SiC composites, dry sliding wear analysis is conducted using tribometer in which variation of load and sliding speed is in the defined range. With the help of dimensional analysis method experimental data was analyzed[3]. Prosviryakov investigated copper composites reinforced with SiC which showed the results in high wear resistance as well as a small coefficient of thermal expansion[4]. Addition of Sic in copper based composite showed an increase in its hardness and wear resistance[5]. The stir casting was mostly used to fabricate the Particulate Metal Matrix Composites (PMMCs) because it is found to be an extremely suitable for the development of net shape composites in an easy

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and cost effective manner. The main problem in this technology was to get adequate wetting of particle by the molten metal and to get a uniform dispersion of the ceramic particles[6]. Stir casting technique is used to manufacture Metal Matrix Composites (MMC) with an objective to develop a conventional low cost method and to obtain homogenous dispersion materials[7]. Stir casting is a technique in which dispersed phase is well mixed with molten metal by mean of mechanical stirring[8]. Fusion of aluminium based alloys and aluminium composite was done using TIG welding and regression equation was developed to predict the weld centre micro hardness of Al-8% SiC composite[9]. Factors influencing surface roughness, thrust force and ovality in drilling Al-Sic-Graphite hybrid composites disclose that in general performance of the drilling was improved when by means of carbide tipped tool than HSS[10]. Tribolayer was observed while enhancing the hardness and wear resistance of Al6061 reinforced with boron carbide particles of different weight percentage in peak aged condition during artificial aging due to the shift of material from revolving disc surface to the wear face of composite [11].

2. Experimental Procedure

2.1 Materials and Processing

Pure copper and silicon carbide are used to develop the composites. The description of the material is presented in Table 1. The composition of mixture is given in Table 2. These compositions are then taken into furnace where casting is performed at 1150° C in Argon atmosphere. When mixture is completely melted stirring is done for suitable duration to obtain homogenous distribution of SiC reinforcement throughout the composite.

Table 1. Material properties

	Cu	SiC
Density (g/cm^3)	8.96	3.21
Melting point temperature (°C)	1085	2730
Thermal conductivity (W/m.k)	401	120
Brinell hardness number	235-878	2800

Table 2. Chemical composition of metal matrix composite samples

Element (wt %)	Sample 1	Sample 2	Sample 3
Cu	98	96	94
SiC	2	4	6

2.2 Full Factorial Experimental Design

Design Of Experiment (DOE) or Statistically Design Experiment (SDE) helps in understanding the wear behaviour of composites. DOE allows better understanding of the process and it determines how the input factors affect the output or quality characteristics. The main objective of DOE is to get most information about a system with least number of designed experiments. The experiments are designed using full factorial method in which one factor is varied at a time, and experiments are performed for all levels of factors and all interactions are captured.

In this work total 27 experiments were performed based on full factorial design as shown in Figure 1. For every experiment three replications were made and average of three experimental values used to minimize any error during experiments. The factors and their levels are shown in Table 3. The treatment combinations and their response are shown in Table 4.

Table 3. Factors: Load, SiC weight percent, speed and their levels

Factors	Unit	Low level (-1)	Medium level (0)	High level (+1)
Load	Kg	2	4	6
SiC	Wt %	2	4	6
Sliding speed	m/s	2	6	10

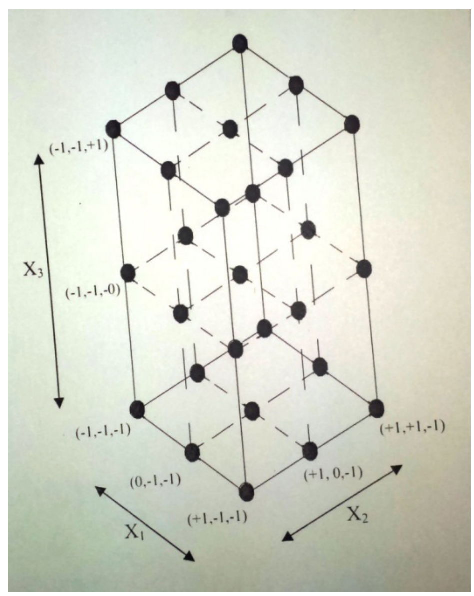

Figure 1. A 3^3 full factorial design model.

Table 4. Factors combination and experimental results

Run	Factor A:Load Kg	Factor B:SiC Weight %	Factor C:Sliding Speed m/s	Response: Wear mg
1	6	6	10	12.022
2	2	6	10	0.3812
3	6	2	10	39.375
4	6	4	2	7.563
5	4	4	10	3.3852
6	6	2	6	26.25
7	2	6	2	0.1722
8	4	4	6	2.604
9	2	4	6	0.426
10	6	6	6	9.774
11	6	4	6	15.8823
12	6	4	10	20.646
13	4	2	10	5.9625
14	2	2	10	0.9
15	4	4	2	1.24
16	2	4	2	0.2033
17	6	6	2	5.43
18	2	6	6	0.30996
19	4	2	6	3.975
20	2	2	6	0.6
21	6	2	2	10.533
22	2	4	10	0.5538
23	4	6	2	0.967
24	4	2	2	1.59
25	2	2	2	0.24
26	4	6	6	1.7406
27	4	6	10	2.1409

2.3. Wear Test

The wear test is performed at different normal loads and sliding speeds using tribometer wear testing machine. The tribometer requires two specimens, one a pin with radii tip which is positioned perpendicular to the other, and a flat circular disk. The stationary pin is pressed against the working material at required load and predefined speed. The friction forces are continuously recorded during its running using calibrated force transducers. The disk material used is made up of steel which has hardness value 400HBN. The specimens used for wear analysis are of diameter 10mm and height 15 mm. Prior to the testing the surface is cleaned using non chlorinated cleaning agents and then the weight of specimens are measured. The test is begun with specimens having different composition in contact under diverse normal loads and sliding speeds. The test is performed for 500 seconds. Following the test, the weight of the specimens is measured and compared with the initial weight and the wear loss in the specimens during the test was determined.

3. Results and Discussions

3.1 Wear Behaviour

The wear loss of composite material for different speeds and loads is shown in Figure 2. First the effect of load on composites is observed for a composite of 2% SiC. As the load increases wear rate of composites increases rapidly, and slope of the graph also increases with varying load. Composite having 4% SiC exhibit less wear rate as compared to composite having 2% SiC. Further composite having 6% SiC showed least wear rate. It is obvious from that with increase of SiC wt%, wear rate lowers down. The reason for lowering of wear rate is due to load distribution which takes place between Cu and SiC particles. As a result, direct load contact is decreased on Cu in Cu/Sic composites. The result of sliding speed on the wear loss of the composites is also observed. The wear loss of 2% SiC with sliding speed increases linearly. The different specimen of composites having 4 and 6% wt SiC show less wear rate. The 6% SiC composite material has smallest amount of wear loss among the sample composite materials for any grouping of load and sliding speed. It indicates SiC wt% plays an important role in controlling the wear rate.

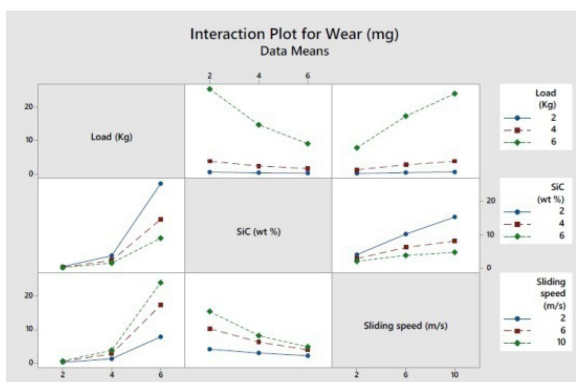

Figure 2. Interaction plots for wear..

3.2 Statistical Analysis

Analysis of variance method is used to investigate the influence of load, SiC wt% and sliding speed on wear resistance of the composite material. The ANOVA

Table 5. Analysis of variance (ANOVA) for Wear

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1942.28	6	323.71	17.73	< 0.0001	Significant
A-Load	1147.03	1	1147.03	62.84	< 0.0001	Significant
B-SiC Weight	177.27	1	177.27	9.71	0.0054	
C-Sliding Speed	183.22	1	183.22	10.04	0.0048	
AB	192.44	1	192.44	10.54	0.0040	
AC	186.42	1	186.42	10.21	0.0045	
BC	55.90	1	55.90	3.06	0.0954	
Residual	365.06	20	18.25			
Total	**2307.34**	**26**				

results presented in Table 5 shows the load is relatively a significant factor in this process. These results also suggest that the model is significant and can be used for further analysis.

The following ANOVA model assumptions must be validated for further analysis;

1. 1. The resultant wear data must be independent and normally distributed and the residuals are not usual,
2. 2. For all input variables the response data must have constant variance and the errors occurred are impartial.

To confirm the first assumption, normal probability of wear output data is plotted in which it is observed that for the most part, data appears very close to the straight line fit which confirms the normality assumption. The residuals are plotted with respect to the input variables and the fitted values, to confirm the second assumption. The different observations of arbitrary distribution of the residuals are about to zero as observed in Figure 3 and, there is no orderly pattern in the residuals as seen in Figure 4 which confirm the second assumption of constant variance.

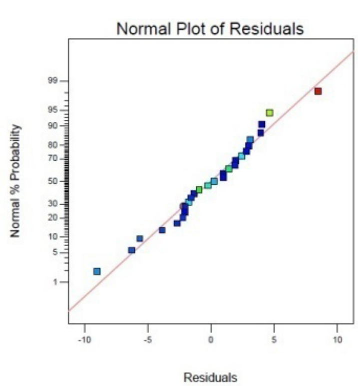

Figure 3. Normal probability plot of residuals of the wear loss data.

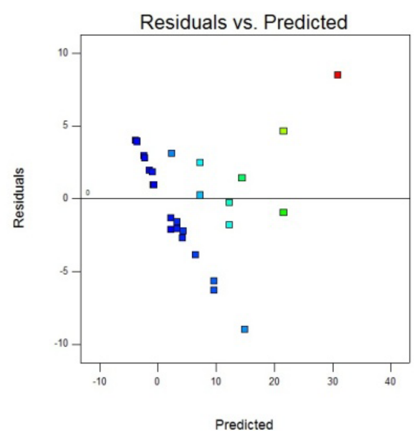

Figure 4. Variation of the residuals with predicted values of the wear loss data.

Table 5 indicates the statistically important factors that affect the wear resistance based on their P (probability of significance) values. The factors whose P values are having 95% confidence levels indicate model term is statistically important. In this case, it is established that load (A), SiC wt% (B), sliding speed (C), interaction of A and B, and interaction of A and C are statistically important. Amongst these factors, load is the most influencing factors which affect the wear. The response surface analysis is also done to compare the model results. The three dimensional surface plots indicate the interaction effect of load, SiC wt% and sliding speed as shown in Figure 5. It is apparent from the slope of the plane that applied load influences considerably wear resistance of the composite material. The slope of the sliding speed and SiC wt% interaction is comparatively lower representing its less importance than load.

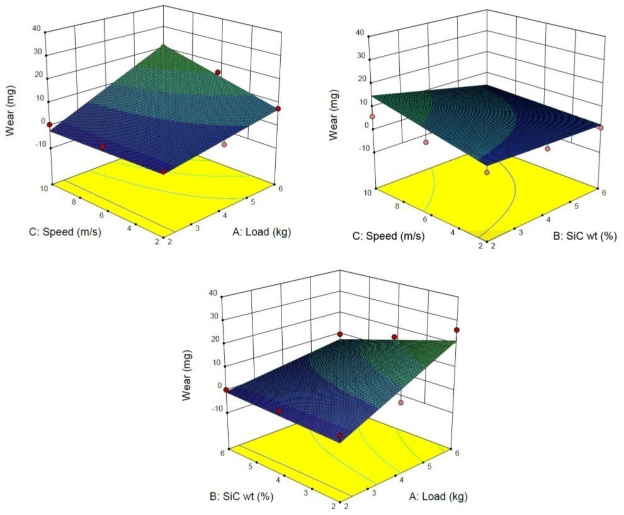

Figure 5. Response surface plots for the wear loss of the composites.

4. Conclusion

Different types of Copper/SiC composites are fabricated using the stir casting method. The composite material was tested to study the influence of load, SiC wt% and sliding speed on the wear behaviour of the Copper/SiC composites.

- 6% SiC wt% is the most useful content in getting better the wear resistance of the composite at any load and sliding speed combination among the prepared samples.
- The statistical analysis which is based on the ANOVA explains well the investigational outcomes with a practical accuracy. The analysis shows that the applied load is the most leading factor deciding the wear resistance of the composite material.
- F value for the composite material decides the implication of the factors controlling the wear loss in the subsequent falling order: normal applied load, sliding speed and SiC wt%.

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