TO ANALYZE THE EFFECT OF SILICON CARBIDE AND CARBON NANOTUBES ON WEAR BEHAVIOR OF ALUMINIUM

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ABSTRACT

Aluminum based metal matrix composites (MMCs) are appropriate materials for applications in the aircraft and automotive industries. Wear behavior of Aluminium with various weight percentage Multiwall carbon nanotubes and 20% Silicon Carbide reinforcement through Powder metallurgy method was investigated. The dry sliding wear tests were conducted on composite material using a pin-on-disc wear testing setup for varying Load, Sliding Velocity, Sliding Time and CNT content. Analytical modelling of composite material is carried out by Taguchi's design of experiments (DOE) using L_{27} orthogonal array. The experimental results were transformed into a signal-to-noise (S/N) ratios. Analysis of Variance (ANOVA) was used to determine the design parameters significantly influencing the wear rate of the composite material. Based on the experimental results, a multiple linear regression model was developed. A regression equation thus generated establishes correlation between the significant terms obtained from ANOVA. In order to validate the regression model, confirmation wear tests were conducted. The error associated with the relationship between the experimental values and the Predicted values of the regression model for composites was around ±9.5%. The results shows that, for dry sliding wear analysis CNT, Load and Sliding Velocity has great influence on the wear.

Key words: *MMC, Pin on Disc, Powder Metallurgy, Taguchi, ANOVA.*

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1. INTRODUCTION

Reinforced metal matrix composites (MMCs) have the potential to provide mechanical properties, for example, high specific stiffness, and specific strength and creep resistance. From which Aluminium based metal matrix composites (MMCs) are appropriate material for structural application in the aircraft and automotive industries because they are ductile, highly conductive, lightweight and have a high strength to weight ratio. Carbon nanotubes (CNTs), which were first discovered in 1991, have superior mechanical properties with a tensile strength up to 150 GPa and an elastic modulus up to 1 TPa, as well as excellent thermal stability and electrical conductivity, exceeding that of conventional fibers. All of these unimaginable characteristics render them potential reinforcement for the composite materials. Besides, the nano sized carbon tubes also provide superior dispersion strengthening to the composite structures. Al-MMCs reinforced by CNTs dispersion are an emerging area that is calling the attention of several research groups in the scientific community. However, agglomeration of the CNTs has been reported as a common problem which hinders the attainment of the desired properties and the large density gap between the metal and CNT. Efforts have thus been focused on finding effective dispersion techniques which can disperse the CNTs homogeneously within the matrix powders. The two techniques that have been investigated are sonication and high energy ball milling. Mechanical milling make CNTs uniformly distribute in the matrix. Whereas Silicon Carbide (SiC) having spherical microstructure are easy to impregnate into Aluminium particles and gets easily dispersed into metal matrix composite. So in this work, an attempt has been made to combine advantages of CNT and SiC, and disadvantage of CNT dispersion and agglomeration.

2. MATERIAL DISCRIPTION

2.1 Metal Matrix (Base Material)

Pure Aluminium is selected due to its following properties and applications. 50 mesh Aluminium powder (course) is purchased.

2.2 Multi Walled Carbon Nanotubes (MWCNT)

SWCNT is having high tensile strength and young's modulus. But MWCNT is more chemically stable and having low cost.

2.3 Silicon Carbide Powder

Silicon Carbide Powder was purchased from SRL, Thane. Powder was in nano form so that it can be easily impregnated.

3 EXPERIMENTAL PROCEDURE

3.1. MIXTURE PREPARATION

Required quantities of the metal powders were taken by weight balance. The weighing was done in a very precise weighing balance. 120 gm batches were prepared for each sample. Sample composition is shown below table-1.

Table-1: Composition

SAMPLE	COMPOSITION
A	Al-20%SiC-0.5%CNT
B	Al-20%SiC-01%CNT
C	Al-20%SiC-1.5%CNT

Aluminium is base material and 20 wt % SiC is used because, Al-SiC composite gives optimal wear rate at 20 wt % SiC, beyond which wear increases [4, 5]. Each samples is prepared as per above given composition. Selected Pin dimensions are 1 cm diameter and 2.5 cm Long. As per experimentation each sample required 9 pins and Hardness testing require 1 pin fir each sample hence total number of pins are 30.Disc material EN 32 Steel Disc having hardness 65 HRC [4,6,9].

3.2 BALL MILLING

Mixture of reinforcement and Aluminium is prepared and put into Jar of planetary Ball Mill machine. Also Balls of Tungstun Carbide were placed into Jar along with mixture powder. Ratio of Ball weight to powder weight was selected as 5:1. Jar was Closed and put into the Planetary Ball mill. Ball Milling Speed was selected as 250 rpm and ball milling time was set 30 min.

3.3 Die Manufacturing

As abrasion wear rate test was to be performed on compacts, so die of circular cross-section is prepared. The die design is shown in Fig-1. Material used for manufacturing of die is D-2, (hardness 60 HRC with sand blasting).

3.4. Powder Compaction

Thus ball milled powder is measured approximately. Die and Punch are properly lubricated with paraffin so that powder will not affect the sliding motion of punch inside Die. Approximately 12gm of Powder is then placed inside Die and punch is fitted. Assembly of punch and die is placed on testing platform of Compression Testing Machine (CTM). Load of 300N was applied on punch using CTM [1, 2]. Thus powder gets compacted inside Die.

Then removing Base plate again load is applied to remove pin from Die. Fig-2 shows Compression Testing Machine used for powder compaction. Thus compaction is very low cost manufacturing method to fabricate powder metallurgy products. Die and Punch are inexpensive tools and can be repetitively used for continuous production unlike casting.

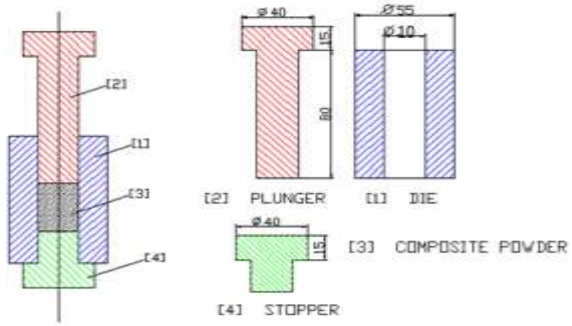

Fig-01: Die Set

Fig-2: Compression Testing Machine

3.5 SINTERING

Sintering of powder is sequentially involves the establishment and growth of bonds between the particles of powder at their areas of contact and migration of the grain boundaries formed at the bonds. The coated compacts were sintered in an electric muffle furnace at a closely regulated temperature of 530^0C for 02 hrs and allowed to get cooled to room temperature in the furnace itself. At last, in order to reach to the proper shape and size, all the compacts were trimmed to the exact size with a diameter of 10 mm and a height of 25 mm. The ends of the specimens were sequentially polished with abrasive paper of grades 600, 800 and 1000.

4 SAMPLE TESTING

4.1 Hardness

In this study, to measure Hardness of composite Brinell Hardness Testing method is used. Hardened Steel ball of 10 mm is used as indenter. Load used for indentation is 500 kg. Holding time is 15 seconds. Hardness is measured at 3 different places of specimen and average hardness is calculated. Hardness values of composite fabricated are tabulated in table-2. With addition of CNT and SiC hardness of Composite gets increased. This increment in Hardness is due to addition of carbon in the form CNT and SiC. Maximum hardness obtained is 53 BHN with 1.5 % reinforcement.

4.2 Wear Test Experimental Setup

The friction and wear tests were carried out using single pin type “Pin-on-disc set up. Tests were carried out at the room temperature and dry operating condition. The cylindrical Pin flat ended specimens of size 10 mm diameter and 25mm length were tested against EN-32 steel disc.

[**Table-2**: Hardness Values]

Sample wt% Reinforcement	Position	Hardness BHN	Avg. Hardness BHN

0.5	Top	43	42
	Middle	40	
	Bottom	42	
1	Top	48	47
	Middle	46	
	Bottom	47	
1.5	Top	52	53
	Middle	54	
	Bottom	54	

5 DESIGN OF EXPERIMENT

It is methodology based on statistics and other discipline for arriving at an efficient and effective planning of experiments with a view to obtain valid conclusion from the analysis of experimental data. Design of experiments determines the pattern of observations to be made with a minimum of experimental efforts.The Taguchi method, which is best to deal with responses, that responses influenced by multi-variables. This method drastically reduces the number of experiments that are required to model the response function compared with the full factorial design of experiments. The major advantage of this technique is to find out the possible interaction between the parameters. The Taguchi technique is devised for process optimization and identification of optimal combination of the factors for a given response. This technique is divided into three main phases, which encompasses all experimentation approaches. The three phases are (1) the planning phase (2) the conducting phase and (3) the analysis phase. Planning phase is the most important phase of the experiment. This technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiments. The experimental results are analyzed using analysis of means and variance to study the influence of factors.

In this investigation work, which is carried out for 4 factors (Load, sliding velocity, sliding time, percentage of CNT), each factor has 3 levels, L_{27} orthogonal array is chosen for conducting the experiments. Table-3 shows process parameter and their levels.

Table-3: Process Parameters and their levels

SR. No.	**Level**	**Velocity (m/s)**	**Load(N)**	**Sliding Time(min)**	**% CNT**
1	1	0.6	10	30	0.5
2	2	1.0	20	60	1.0
3	3	1.6	30	90	1.5

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6. RESULTS AND DISCUSSION

6.1 S/N Ratio:

Following table-4 represent the S/N Ratio which is obtained from software Minitab 17 by substituting wear rate values (i.e. Experimental Values).

Table-4: Wear Rate and S/N Ratio

Exp.No.	Velocity (m/s)	Load (N)	Sliding Time (min)	CNT (wt%)	S/N Ratio
1	0.6	10	30	0.5	-35.8478
2	0.6	20	60	0.5	-38.1697
3	0.6	30	90	0.5	-38.69
4	1	10	60	0.5	-37.5012
5	1	20	90	0.5	-38.69
6	1	30	30	0.5	-38.8897
7	1.6	10	90	0.5	-38.69
8	1.6	20	30	0.5	-39.1808
9	1.6	30	60	0.5	-40.6685
10	0.6	10	30	1	-34.1514
11	0.6	20	60	1	-36.1236
12	0.6	30	90	1	-37.7298
13	1	10	60	1	-36.5215
14	1	20	90	1	-38.0618
15	1	30	30	1	-38.4856
16	1.6	10	90	1	-37.2665
17	1.6	20	30	1	-38.5884
18	1.6	30	60	1	-39.5545
19	0.6	10	30	1.5	-31.8213
20	0.6	20	60	1.5	-33.9794
21	0.6	30	90	1.5	-35.9868
22	1	10	60	1.5	-33.2552
23	1	20	90	1.5	-35.2686
24	1	30	30	1.5	-36.902
25	1.6	10	90	1.5	-34.9638
26	1.6	20	30	1.5	-37.0252
27	1.6	30	60	1.5	-38.2763

6.2 S/N Ratio Analysis

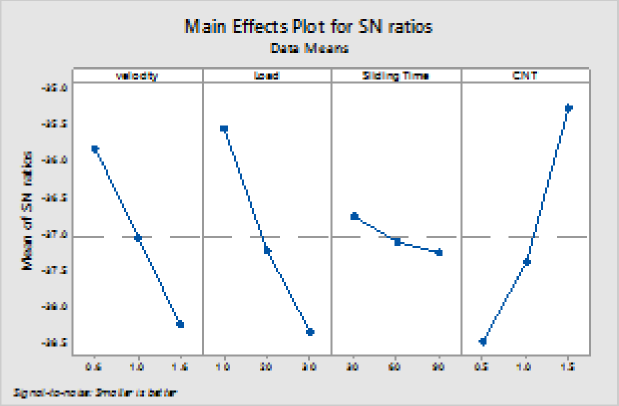
The normal method of calculating the desirable factors levels is to look at simple averages of the results. But the variability of results within a trial condition cannot be judged by this method.The analysis is carried out using smaller-is-better criterion and the same is expressed as:

$$S/N= -10\log (\Sigma y^2/n) \qquad [1]$$

Here, y is the experimental data and n is the number of experiments [13]. Table no.4 shows corresponding S/N ratio for each experiment. The experimental design being orthogonal, it is possible to separate out the effect of each control factor at different levels. The influence of control parameters such as velocity, load, sliding time and CNT content on wear rate has been evaluated using S/N ratio response analysis. The S/N ratio response analysis, presented in Table-5, shows that among all the factors, CNT was the most influential and significant parameter followed by Load, velocity, Sliding time.

Graph-1 shows the mean of wear rate graphically and graph-2, depicts the main effects plot for means of S/N ratio for wear rate. From the analysis of these results, it is clear that minimum wear at the highest S/N ratio values in the response graph. The optimal wear parameters were at velocity 0.6 m/s (level 1),Load 10N (level 1),Sliding Time 30 min(level 1) and CNT 1.5%(level 3).From response table it is concluded that CNT is most significant parameter on wear followed by Load, Velocity and Sliding time is less significant parameter on wear.

Graph-1 : Main effect plot for means



Graph-2 :Main effect plot for S/N ratios

6.3 Response table for S/N ratio

Table-5 :Response Table for S/N Ratio

Level	Velocity (m/s)	Load (N)	Sliding Time(min)	CNT (wt %)
1	-35.83	-35.56	-36.777	-38.48
2	-37.06	-37.23	-37.12	-37.39
3	-38.25	-38.35	-37.26	-35.28
Delta	2.41	2.80	0.50	3.21
Rank	3	2	4	1

6.4 ANOVA :

Analysis of Variance (ANOVA) was used to determine the design parameters significantly influencing the wear rate (response). The Table-6 shows the results of ANOVA for wear rate. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05[13]. The last column of Table-6 shows the percentage of contribution of each parameter in the response, indicating the degree of influence on the result. When the P-value for this model was less than 0.05, then the parameter or interaction can be considered as statistically significant [11, 12, 13]. It can be observed from the results obtained in the Table-6, CNT was the most significant parameter having the highest statistical influence (41.99%) on the dry sliding wear of composites followed by Load (31.24%) and Velocity (24.04%) and less significant parameter is Sliding time (0.69%). In case of interaction Sliding time and CNT (0.029%) has highest influence on wear.

Table-6 : ANOVA Result

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
Velocity	2	1684.47	1684.67	842.33	303.24	0.000	24.04%
Load	2	2188.67	2188.67	1094.33	393.96	0.000	31.24%

Sliding Time	2	48.67	48.67	24.33	8.76	0.017	0.69%
CNT	2	2942.00	2942.00	1471.00	529.56	0.000	41.99%
Velocity*CNT	4	39.33	39.33	9.83	3.54	0.082	0.56%
Load*CNT	4	22.00	22.00	5.50	1.98	0.217	0.31%
Sliding	4	64.67	64.67	16.17	5.82	0.029	0.92%
Error	6		16.67	2.78			0.24%
Total	26	7006.67					100%

The coefficient of determination (R^2) is defined as the ratio of the explained variation to the total variation.

Table-7 : Model Summary

S	R-sq	R-sq (adj)	PRESS	R-sq(pred)
2.81530	97.96 %	97.06%	321	95.42%

It is a measure of the degree of fit. When R^2 approaches unity, a better response model results and it fits the actual data [8]. From table-7 it is seen that the value of R^2 calculated for this model was 97.96%, i.e., very close to unity, and thus acceptable. It demonstrates that 97.96% of the variability in the data can be explained by this model. Thus, it is confirmed that this model provides reasonably good explanation of the relationship between the independent factors and the response.

6.5 Multiple Linear Regression Model

To establish the correlation between the wear parameters (1) sliding velocity, (2) Load, (3)Sliding time, (4) weight percentage of CNT and the dry sliding wear loss the wear multiple linear regression model was obtained using statistical software “MINITAB 17”.The terms that are statistically significant are included in the model. Final Equation obtained is as follows:

Wear = 53.33 + 19.17 velocity + 1.1000 Load + 0.0444 Sliding Time - 25.33 CNT ….. (2)

The above equation no.2 can be used to predict the wear rate. The constant in the equation is the residue. The regression coefficient (R^2) obtained for the model was 0.9796 and this indicates that wear data was not scattered. The coefficient associated with velocity in the regression equations is positive and it indicates that as the velocity increases, the wear rate of the composite also increases. The coefficient associated with the Load in the regression equations is also positive and this suggests that the wear rate of the composite increases with increasing increase in the load. The coefficient associated with the Sliding time in the regression equations is also positive and this suggests that the wear rate of the composite increases with increasing increase in the Sliding Time. It can be inferred from the negative value of the coefficient associated with CNT in the regression equations that as the weight percentage of CNT content increases, wear rate of the composite reduces. The wear resistance of composite has increased due to the increase in the weight fraction of the CNT.

7 CONFIRMATION PROCESS

A confirmation experiment is the final step in the Design process. A dry sliding wear test was conducted using a specific combination of the parameters and levels to validate the statistical analysis.

7.1 Comparison Between Experimental and Software Value

%Deviation= (Experimental value-Predicted value)/Experimental value x 100

It can be observed that the calculated error/deviation varies from -9.89 % to +9.39 %. Therefore the multiple regression equation derived above correlate the evaluation of wear in the composite with the degree of approximation. Graph-3 shows the comparison of both values of wear i.e. Predicted Wear and Experimental Wear.

Graph-3: Comparison between Predicted and Exp.Wear

8. CONCLUSION

After conducting above experimentation the following conclusions are drawn:

- The present work shows that successful fabrication of Al-SiC-CNT composites with different composition is possible by powder metallurgy technique.
- Hardness of the composite is increases with increase in CNT percentage.
- From S/N ratio result it is seen that, Sliding Velocity 0.6 m/s (Level 1), Load 10 N (Level 1), Sliding Time 30 min (Level 1) and CNT 1.5 wt % (Level 3), gives minimum wear rate.
- For dry sliding wear condition, CNT (41.99%), Load (31.24%), Velocity (24.04%) has great influence on wear and Sliding time (0.69%) has less influence on wear. In case of interaction, Sliding time and CNT (0.029%) has highest influence on wear.
- From regression equation it is also clear that, as the wt% CNT increases wear decreases and as sliding velocity, load, sliding time increases wear also increases.
- Confirmation experiment was carried out and made a comparison between experimental values and predicted values showing an error associated with dry sliding wear of composites varying from -9.89% to 9.39% Thus, Design of experiments by Taguchi method was successfully used to predict the tribological behavior of composites.

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