Tribological behavior of diamond-reinforced Fe-Co composite by Taguchi method

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Abstract. Tribological behavior of diamond-reinforced Fe-Co composites was studied. SN ratio and ANOVA were employed to investigate the influence of parameters like, abrasive size, load, distance and hardness. The load factor was the major parameter, followed by abrasive size. The percent contributions are abrasive size (32.17 %), hardness (11.30 %).

Keywords: *Fe-Co matrix; Diamond tool; Powder metallurgy; Tribological behavior*

1. Introduction

Diamond has the highest thermal conductivity and low coefficient of friction, and shows superior mechanical properties such as bulk modulus, tensile stress and hardness. High hardness and wear resistance result in good surface finish and long tool life [1]. Therefore, diamond tools are widely used for difficult-to-cut materials like Al-Si alloys, fiber reinforced composite or stone, concrete. The matrix used in the most diamond tool, is a cobalt alloy since it combines with diamond grits good chemical compatibility at the processing temperature. However, the price of Co is subjected to great variations [2]. This is the main reason behind efforts to replace Co with other metals such as Co-bronze, Fe-bronze, Tin-Co, Fe-Co, Fe-Cu, Fe-Co-Cu materials [3, 4]. The properties of diamond abrasive and the adhesion between the diamond grits and bond determine properties of diamond tools [5]. This also depends upon composition of metal powders, their sizes and distributions, processing temperature and times [6]. The aim of the present study is thus, to investigate the wear behavior of diamond impregnated composite by changing the matrix composition based on Fe/Co ratio and B_4C powder addition.

2. Experimental study

Fe-Co-Bronze based diamond with and without B_4C reinforcement composites were produced by hot pressing method. Diamonds were used as reinforcement in the production of metal matrix composite while Co metal was a binder with a good wet ability. Fe is also used as a filling material because of its lower-cost. The concentration of diamond grits in the composite was kept at about 20%. Fe-(15-35-55wt. %Co)-bronze 10wt. %-diamond 20wt. %. A Co, Fe powder and diamond grits with an average particles size of 400 mesh, 85/15 mesh and -40/+50 mesh powders were selected as the starting material. Hereafter, these are denoted by C1 (Fe-15Co-10bronze-20diamond), C3 (Fe-35Co-10bronze-20diamond), and C5 (Fe-55Co-10bronze-20diamond).

In the production of composites, Fe-Co-bronze-diamond- was blended in T2 turbula mixture at about 45 min. The mixture per composition was put in carbon moulds 24X10X10 mm dimension were cold compacted, and then hot zone was evacuated to remove the air from the chamber atmosphere, and sintered by hot pressing of Fritsch DSP 510 type machine under nitrogen atmosphere. The sintering temperature was about 800 ^{o}C under a compression of 25 MPa. Total sintering time was about 15 min.

The wear parameters were abrasive size (A), material hardness (B), load (C) and sliding distance (D) and their levels indicated in Table 1. An L18 orthogonal array was chosen.

Table 1. Control factors and their levels for diamond reinforced MMCs.

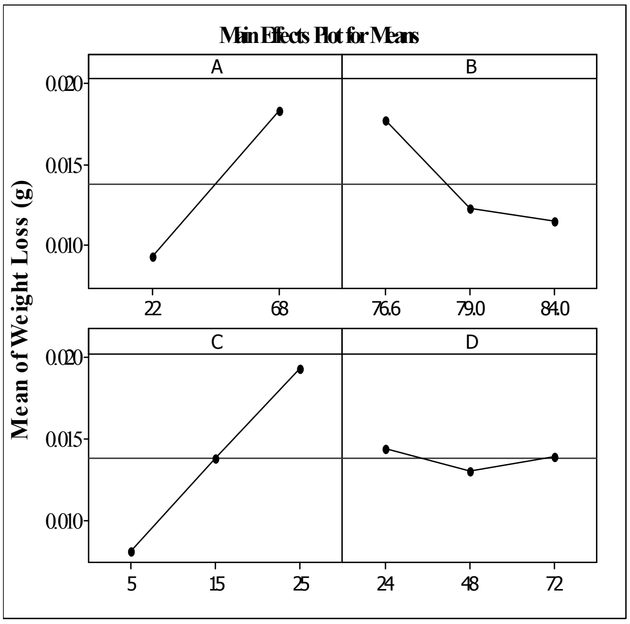
Levels	Abras. size, μm	Hardness, BHN	Applied load, N	Sliding dist., m
1	22 μm	76.6	5	24
2	68 μm	79	15	48
3	-	84	25	72

3. Results and discussion

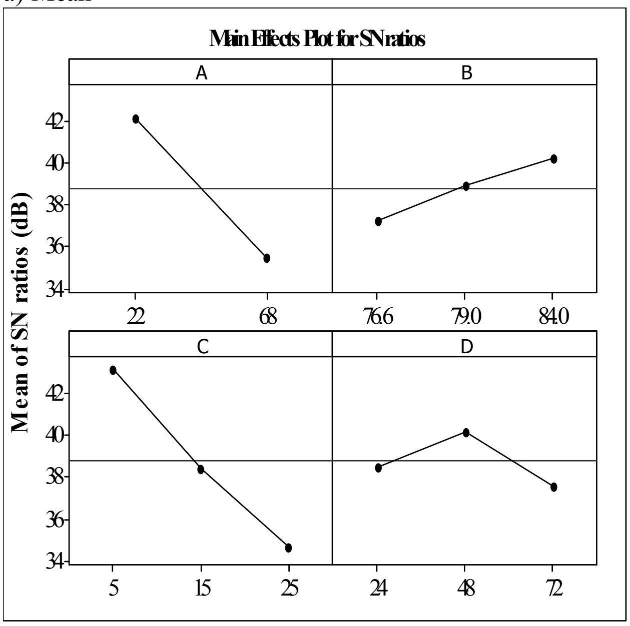
3.1. Main effects plot

Fig.1a indicates the main effects plots of the weight loss of composites for the means. The average values of weight loss for each parameter at levels 1, 2 and 3 were calculated and were shown in Fig.1. Optimal testing conditions of these control factors could be determined from this graph. The best weight loss value was at the lower mean value in the response graph. It was clear from Fig.1 that the weight loss was minimum at the 1st level of parameter A, 3rd level of parameter B, 1st level of parameter C and lastly 1st level of parameter D. It was evident that the load (C) had the greatest effect on the optimal testing conditions. This might be because SiC abrasive did not have an ability to dig out of diamond powders in its place to remove it. On the other hand, the level of a factor with highest S/N ratio is the optimum level, as shown in Fig.1b. Hence, the optimum levels of the factors are A_1, B_3, C_1 and D_2.

Table 2 shows experimental lay out and results with calculated S/N ratios for weight loss of the composites. The control factor with the strongest influence is detected by difference value. It can be seen in Table 2 that the strongest influence is exerted by C and A, respectively. The weight loss obviously increases as load increases from 5N to 25N, followed by the abrasive particle size from 400 mesh (≈22μm) to 180 mesh ((≈68μm). In addition, weight loss increases slightly with the B and D factor. These effects, however, much lower compare to those of C and A factor. The results are good agreement with Mondal et al. [7], Prasad et al. [8] and Basavarajappa et al. [9]. However, previous works by Fernandez et al. [10], Sahin [11] indicated that abrasive size was the more effective on wear rate of the samples. Basavarajappa et al. [9] also found that the sliding distance was the most effective parameter for Al/SiCp and Al/Gr matrix composites, which is followed by the load. The least weight loss is recorded during 7th test run when the process parameters were at first level of A, 3rd level of B, first level of C and D factor. It is followed by 8th, 4th and 1st run.



a) Mean



b) S/N ratio

Fig.1. Effects of main parameters on the weight loss of diamond-reinforced MMCs. a) Abrasive size, b) Hardness, c) Load, d) Sliding distance.

The wear performance of the tested samples was estimated from Eq.(1) using the optimal testing factors.

$$\bar{Yi} = \sum_{i=0}^{n}(Y_i - Ym) + Ym \quad (1)$$

The average performance of S/N ratios was found to be about 49.376dB. It could be noted that the optimum condition for the "smaller is better" quality characteristic was A_1 B_3 C_1 D_2. Optimal settings of control factors for the tested samples were: load (5N), abrasive size (22 µm), hardness (84HB) and sliding distance (48m).

Table 2. Experimental lay out and results with calculated S/N ratios for weight loss of MMCs.

Exp. no.	Abr. size, µm (A)	Mater. hardn., HB (B)	Load ,N (C)	Slid. dist., m (D)	Weight loss (g)	S/N ratio (dB)
1	22	76.5	5	24	0.004	47.958
2	22	76.5	15	48	0.0082	41.723
3	22	76.5	25	72	0.020	33.979
4	22	79	5	24	0.0068	43.349
5	22	79	15	48	0.0077	42.270
6	22	79	25	72	0.0145	36.772
7	22	84	5	48	0.0027	51.372
8	22	84	15	72	0.0065	43.741
9	68	84	25	24	0.0132	37.588
10	68	76.5	5	72	0.0106	39.493
11	68	76.5	15	24	0.030	30.457
12	68	76.5	25	48	0.0333	29.551
13	68	79	5	48	0.0091	40.819
14	68	79	15	72	0.0169	35.442
15	68	79	25	24	0.0184	34.703
16	68	84	5	72	0.0154	36.249
17	68	84	15	24	0.014	37.077
18	68	84	25	48	0.0172	35.239

The response table of the weight loss is presented in Table 3. It indicates that the mean S/N ratios at each level of control factor and how it is changed when settings of each control factor are changed from level 1 to level 2. The influence of interactions between control factors is ignored. The control factor with the strongest influence is detected by difference value. The higher the difference, the more influential is the control factor. It can be seen that the strongest influence is expected by factor C and factor A, respectively.

Table 3. The response table for signal to noise ratios of MMCs.

	Weight loss of MMCs (dB)			
Level	A	B	C	D
1	42.08	37.19	43.21	38.52
2	35.45	38.89	38.45	40.17
3	-	40.22	34.65	37.61
Differ	6.63	3.03	8.56	2.56
Rank	2	3	1	4

3.2. Confirmation test

The confirmation tests are performed by selecting the set of parameters. Table 4 shows the confirmation test results and a comparison of the predicted weight loss using the optimal testing parameters. The values obtained experimentally, the values obtained from the optimal settings were compared, and some differences were found between experimental and theoretical values. A good agreement between the predicted and actual weight loss was observed. It can be seen in Table 4 that the predicted error of S/N ratio was in the reasonable limit. The confirmation tests showed that error associated with abrasive wear of the composite was about 3, 35%. The deviation is found to be less from the predicted values.

Table 4. The confirmation test results.

Performance measure	Results
Levels (A,B,C,D)	1,3,1,2
S/N observed, dB	46.020
S/N predicted, dB	49.370
Prediction of /N ratio, dB	3.35

3.3. Analysis of Variance (ANOVA)

Table 5 shows the mean results of analysis of variance (ANOVA) for the wear of the samples. This analysis is performed with a level of significance of 5%. The last column of the table shows the contribution % (p) of each variable in the total variation indicating the influence degree on the abrasive wear of sample. If the "Test F" value is greater than the F (5%) column value, then the assigned variable is statistically significant. It can be observed from the ANOVA table that the applied load (p=33.04%) and the abrasive size (p=32.17%) has great influence on the wear. However, hardness

(11.30%) and sliding distance (0.52%) does not have a significant effect on the abrasive wear for both physical and statistical point of view. The residual error associated in the ANOVA table is approximately about 22.97%. This shows clearly as the applied load and abrasive size increases the wear rate also increases in the most of the cases. From this table, it indicates that applied load has the major contribution for the weight loss compare to other parameters.

Table 5. Results of the mean-ANOVA for diamond reinforced Fe-Co matrix composite.

Sour. of var.	DOF	SS	Variance	Test F	F	P,%
A	1	0.00037	0.00037	14.4	4.96	32.1
B	2	0.00013	0.00006	2.70	4.10	11.3
C	2	0.00038	0.00019	7.59	4.10	33.0
D	2	0.000006	0.000003	0.12	4.10	0.5
Res. error	10	0.00025	0.000025			22.9
Tot.	17	0.00115				100

In order to study the significance of the parameters in affecting the quality characteristic of interest for wear data, ANOVA in terms of S/N ratio was performed. The S/N ANOVA version is given in Table 6. It is clear from this table that the parameter C significantly affects the wear of the composite, which is followed by the parameter A, again.

Table 6. Results of the S/N-ANOVA for diamond reinforced Fe-Co matrix composite.

So.	DF	SS	Varian.	Test F	F	P,%
A	1	197.83	197.83	24.82	4.96	36.2
B	2	27.61	13.80	1.73	4.10	5.05
C	2	220.7	220.7	13.85	4.10	40.4
D	2	20.17	20.17	1.27	4.10	3.69
Res err.	10	79.69	7.969			14.6
Tot.	17	546.01				100

It can be observed from the ANOVA table that the applied load (p=40.42%) and the abrasive size (p=36.23%) have great influence on the wear, but hardness (p=5.05%) and sliding distance (p=3.69%) do not have a significant effect on the abrasive wear.

Optimal setting of control parameters for the abrasive wear of MMCs against SiC abrasives are: load (5N), abrasive size (22 µm), hardness (84HB) and sliding distance (48m). The percent contribution of parameters based on mean weight loss in affecting variation for abrasive wear of MMCs are: abrasive size (32.17 %), hardness (11.30 %), load %33.04 %), and sliding distance (0.52 %). The percent contribution of parameter in terms of S/N ratio is also confirmed by the ANOVA.

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