Application of full factorial design to study the tribological properties of AA6061-B_4C and AA6061-B_4C-MoS_2 composites

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Keywords: Hybrid composites; wear studies; full factorial studies

ABSTRACT – This study statistically analyzes the tribological properties of AA6061-10 wt. % B_4C mono composite and AA6061-10 wt. % B_4C-7.5 wt. % MoS_2 hybrid composite. The ANOVA analysis of the wear rate revealed that the three factors A (MoS_2 particles addition, wt. %), B (applied load, N), and D (sliding distance, m) presented the physical and statistical significance on the wear rate. The ANOVA analysis of the friction coefficient revealed that the factors B (applied load, N) and C (sliding speed, m/s) and interaction AB (interaction of MoS_2 particles addition in wt. % and applied load in N) presented the physical and statistical significance on the friction coefficient.

1. INTRODUCTION

Aluminum MMCs (AMMCs) reinforced with ceramic particles exhibited higher wear resistance compared to the wear resistance of unreinforced aluminum alloys [1]. However, hybrid AMMCs reinforced with both solid lubricant and ceramic particles exhibited anti-seizure and wear resistance properties. Literature makes it clear that the solid lubricant addition and the variation in their concentration influence the tribological behavior of the composites [2,3]. Also, studies on hybrid composites reinforced with B_4C particles (as ceramic phase) are limited. Furthermore, studies on statistical analysis of the tribological behavior of Al-B_4C-MoS_2 hybrid composites are lacking. Hence, in the present study, the tribological behavior of AA6061-10 wt. % B_4C and AA6061-10 wt. % B_4C-7.5 wt. % MoS_2 composites are statistically analyzed to understand the statistical significance of different tribo-test parameters and MoS_2 particles addition on the wear rate and friction coefficient.

2. EXPERIMENTATION SCHEME

The AA6061-10 wt. % B_4C mono composite and AA6061-10 wt. % B_4C-7.5 wt. % MoS_2 hybrid composite were fabricated using stir casting technique. FFD (full factorial design) was used to carry out the tribological experiments. The MoS_2 particles addition (factor A), applied load (factor B), sliding speed (factor C), and sliding distance (factor D) were varied for two levels of 0 and 7.5 wt. %, 10 and 50 N, 0.5 and 2.5 m/s, and 200 and 1000 m, respectively. The four factors (A, B, C, and D) were varied for two levels which constitute 2^4 FFD. The track radius was kept constant throughout the tests (150 mm). The composite pins were tested against the EN 31 bearing steel disk using a pin-on-disc tribo-tester as per ASTM G99-05 standard. The wear rate, W (mg/m) was obtained using the formula $W=\delta W/S$ where δW is the weight difference of the pin before and after the test in mg and S is the sliding distance in m. The coefficient of friction was computed as the ratio of tangential friction force to the applied normal force.

3. RESULTS AND DISCUSSION

The responses (wear rate and friction coefficient) obtained by performing the wear tests as per the experimental scheme are tabulated in Table 1.

Table 1 Experimental scheme and responses.

A	B	C	D	Wear rate (mg/m)	Friction coefficient
7.5	10	0.5	200	0.00317	0.409
0.0	50	2.5	200	0.00567	0.412
0.0	10	0.5	200	0.00433	0.401
0.0	10	0.5	1000	0.00767	0.418
0.0	10	2.5	200	0.00350	0.332
7.5	50	0.5	1000	0.00900	0.449
0.0	50	2.5	1000	0.01183	0.448
7.5	10	2.5	1000	0.00500	0.416
7.5	50	2.5	1000	0.01017	0.392
0.0	10	2.5	1000	0.00883	0.404
7.5	10	0.5	1000	0.00833	0.413
7.5	50	2.5	200	0.00550	0.403
7.5	10	2.5	200	0.00233	0.409
7.5	50	0.5	200	0.00433	0.419
0.0	50	0.5	1000	0.01283	0.487
0.0	50	0.5	200	0.00600	0.507

ANOVA is used to observe the effect of factors and the effect of interaction of factors on the responses. Tables 2 and 3 show the ANOVA of the wear rate and the friction coefficient, respectively. The level of significance (α) was selected as 0.05. Tables 2 and 3 show the standard error of the regression (S), R-Squared (R-Sq), adjusted R-Squared (R-Sq (adj)), source, degree of freedom (DF), sequential sum of squares (Seq SS), adjusted mean squares (Adj MS), F-ratio (F), and percentage of contribution P (%). The percentage of contribution was calculated with the formula, P (%) = (Seq SS_F/Seq SS_T) x 100 where Seq SS_F is the sequential sum of squares of the factors or the interactions and Seq SS_T is the total sum of squares. The factors and interactions having higher P (%) values than the P (%) value of error is considered as statistically and physically significant [4].

Table 2 ANOVA of wear rate.

Source	DF	Seq SS	Adj MS	F	P (%)
A	1	0.1E-4	0.1E-4	7.11	6.75
B	1	0.31E-4	0.31E-4	21.24	20.94
C	1	0.1E-5	0.1E-5	0.35	0.67
D	1	0.94E-4	0.94E-4	65.15	63.51
AB	1	0	0	0.14	0
AC	1	0	0	0.03	0
AD	1	0.1E-5	0.1E-5	0.87	0.67
BC	1	0.1E-5	0.1E-5	1.02	0.67
BD	1	0.2E-5	0.2E-5	1.47	1.35
CD	1	0	0	0.06	0
Error	5	0.7E-5	0.1E-5		4.72
Total	15	0.148E-3			
S = 0.0012, R-Sq = 95.12 %, & R-Sq (adj) = 85.36 %					

Table 3 ANOVA of friction coefficient.

Source	DF	Seq SS	Adj MS	F	P (%)
A	1	0.000613	0.000613	1.47	2.60
B	1	0.006202	0.006202	14.92	26.39
C	1	0.005148	0.005148	12.38	21.91
D	1	0.001139	0.001139	2.74	4.84
AB	1	0.005006	0.005006	12.04	21.30
AC	1	0.001351	0.001351	3.25	5.75
AD	1	0.000352	0.000352	0.85	1.49
BC	1	0.001008	0.001008	2.42	4.29
BD	1	0.000264	0.000264	0.64	1.12
CD	1	0.000333	0.000333	0.80	1.41
Error	5	0.002079	0.000416		8.84
Total	15	0.023493			
S = 0.0203, R-Sq = 91.15 %, & R-Sq (adj) = 73.45 %					

It is observed from Table 2 that the P (%) values of the factors A (6.75 %), B (20.94 %), and D (63.51 %) are higher than the P (%) value of the error (4.72 %). The P (%) value of factor C and the P (%) values of all interactions are lower than the P (%) value of the error. Hence, the factors A, B, and D are statistically and physically significant as their P (%) values are higher than the P (%) value of the error. These factors (A, B, and D) presented the statistical and physical significance on the wear rate. Factor C and all the interactions are not statistically and physically significant to influence the wear rate. Furthermore, the factor D that has the highest P (%) value of 63.51 % provided the strongest statistical and physical significance on the wear rate. In the case of friction coefficient, Table 3 shows that the P (%) values of factors B (26.39 %) and C (21.91 %) and interaction AB (21.30 %) are higher than the P (%) value of the error (8.84 %). Hence, the factors B and C and the interaction AB are taken as statistically and physically significant. Meanwhile, the P (%) value of factor D and the P (%) values of all the other interactions are less than that of the error. Hence, it is evident that the factors B and C and the interaction AB presented the statistical and physical significance on the friction coefficient. Furthermore, the factor B with its highest P (%) value of 26.39 % provided the strongest statistical and physical significance on the friction coefficient. It is understood from Tables 2 and 3 that the R-Sq values are more than 90 %. Therefore, it is clear that the linear model explains more than 90 % of the variability in the responses. Also, the S values are low which indicate that the distance between the observed values and fitted values are small.

The interaction plot shows the effect of interaction of factors on the response. The continuous and dotted lines in Figure 1 represent the mean of the friction coefficient of the mono and hybrid composites respectively. The friction coefficient increased with increase in applied load (factor B) for both the mono and hybrid composites. However, in the case of hybrid composites, the MoS_2 particles (factor A) reduced the degree of increase of the friction coefficient. Hence, it is clear that factor A also influenced the response. This phenomenon (influence of the factors A and B on the friction coefficient) is suggestive of the interaction between the factors A and B.

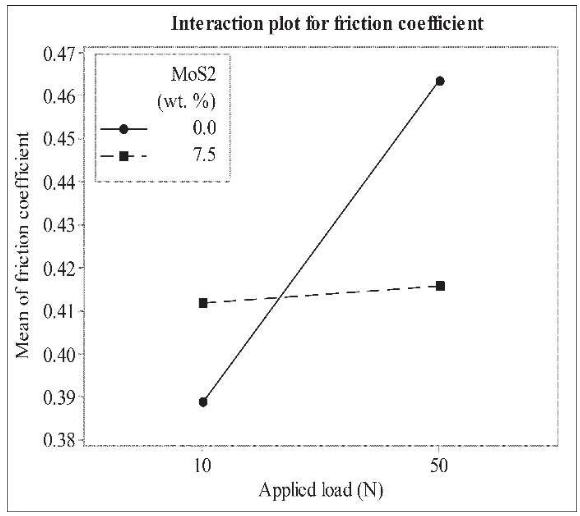

Figure 1 Interaction plot of friction coefficient.

4. CONCLUSIONS

ANOVA analysis of the wear rate revealed that the factors A (MoS_2 particles addition, wt. %), B (applied load, N), and D (sliding distance, m) presented physical and statistical significance on the wear rate. In the case of friction coefficient, statistically and physically significant interaction existed among the factors A and B as revealed by the interaction plot.

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