Fabrication and Tribological Characteristics of Al6061-B_4C Metal Matrix Composites

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ABSTRACT: In the present day engineering design and development activites many Scientists, Researchers and Engineers are striving hard to develop new and better engineering materials, which accomplishes high strength, low weight and energy efficient materials since the problems of environment and energy are major threshold areas. The development of new materials is growing day by day to replace the conventional materials in aerospace, marine engineering, automobile engineering industries etc., Hence, composite materials are found to be an alternative. A variety of metals and their alloys such as Aluminium, Magnesium and Titanium are comprehensively used as matrix materials. Among these Aluminium alloys have been used extensively, because of their excellent strength, low density, corrosion resistance and toughness. Similarly, many researchers have attempted to develop aluminium based metal matrix composites using different reinforcements. Among these reinforcements, B_4C emerged as an exceptional reinforcement due to its high strength to density ratio, possesses high hardness and avoid the formation of interfacial reaction products with aluminium. Hence, in this paper attempts are made to fabricate Al 6061 - 3, 6, 9 and 12 wt. % B_4C metal matrix composites by stir casting process to study the wear loss and coefficient of friction using Pin on Disc (POD) as per the Design of Experiments (DOE). Wear loss and co-efficient of friction decreases with increase in the wt. % of hard B_4C particles and noticed form the ANOVA and regression analyses that reinforcement plays a vital role in the development of Al 6061- B_4C composite system.

Keywords*:* Al 6061- B_4C composite, POD, wear loss and COF

1. INTRODUCTION

In the present day engineering design and development activates many researchers are working towards the development of new materials to replace the conventional materials and found that composite materials are an alternative because to its high strength-to-weight ratio, higher stiffness, better fatigue, wear and corrosive resistance. Variety of aluminium alloys and different reinforcements such as SiC, B4C, TiC, TiO2, TiB2 etc. are comprehensively used to develop Aluminium Matrix Composites (AMC's) for aerospace, automobile brake pad, marine and lightweight engineering applications.

Brake is a very important part of an automobile which causes safe emergency stop with certain predetermined distance. Earlier, asbestos material was used to manufacture automobile brake pads due to various good properties. During 1986, the Environmental Protection Agency (EPA) and U.S. Federal Braking Regulations, USA announced a proposal to ban asbestos since it causes carcinogenic disorders in the human being [1]. Thenceforth, brake pad manufacturer started using various materials. Further, many researchers were worked to replace conventional cast iron brake pad to aluminium matrix composites (AMC) due its high thermal conductivity and low density. It was evident that AMC's improves the wear resistance when it slides against abrasives and metals [2]. Addition of reinforcements such as SiC, B_4C, TiC, TiO_2, TiB_2 along with soft lubricants and frictional additives to enhance wear resistance [3].

Hence in this paper attempts are made to develop Al6061- B4C AMC's by varying 3, 6, 9 and 12 wt.% B_4C to study the friction and wear characteristics using Pin on Disc (POD) as per the Design of Experiments.

2. FABRICATION OF AL 6061-B_4C ALUMINIUM MATRIX COMPOSITES

Several manufacturing techniques are used to synthesize metal matrix composites. The most commonly used techniques are liquid, solid and gaseous state [4], these processes includes Squeeze casting, Powder metallurgy, Spray forming, Diffusion bonding, Sinter-forging, Stir casting, In-Situ process. Due to ease of manufacturing stir casting was in this research work, to develop Al 6061-B_4C MMC's.

Stir casting process is an extensively used method to fabricate AMC's in liquid state in which molten metal is mixed in the furnace by means of mechanical stirring [5]. It is noticed that almost all the composites were manufactured by this process using up to 30% volume fraction of reinforcement [6,7]. It is evident from the literature that use of stir casting process enables better mixing of matrix and reinforcement in the AMC's. Different components of stir casting process are as shown in Fig.1 and Fig.2.

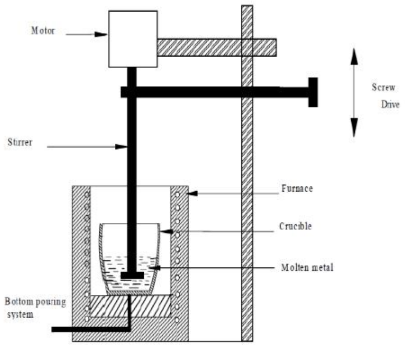


Fig. 1. Components of stir casting process

Fig. 2. Stir casting process Set-Up

Fig. 3. Pouring of molten metal into the cast iron molds

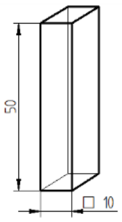
Fig. 4. Al 6061-Different wt. % of B4C MMC's.

Al 6061 rods and 3, 6, 9 and 12 wt.% of B4C are weighed as per the wt.% of the reinforcement and fed into the graphite crucible and heated using an electrical During stirring preheated B4C is gradually poured into the molten metal and stirring was continued about 10-12 minutes the melt was poured into a preheated cast iron molds shown in Fig.3. After solidification process castings were obtained as shown in Fig.4 and machining of different wt. % of B4C composites using wire cut EDM, CNC turning and milling was carried out as per different ASTM standards to POD experiments to determine wear loss and coefficient of friction.

3. ABRASIVE WEAR OF AL 6061-B_4C AMC'S

Wear is a metal removal process in which two interacting surfaces are rubbing each other. In the present work pin on disc (POD) experiments were conducted for 3, 6, 9 and 12 wt.% of B_4C reinforcement as per ASTM **G 99-95** standard to determine the coefficient of friction and wear loss by sliding distance, varying load and sliding speed. The test specimen (10 x 10 x 50) mm shown in Fig:5. Were machined as per holder of POD apparatus.

A. Specimen Preparation



ASTM G 99-95

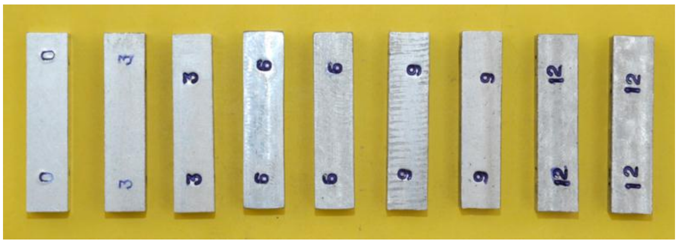


Fig: 5. Wear Test Specimens

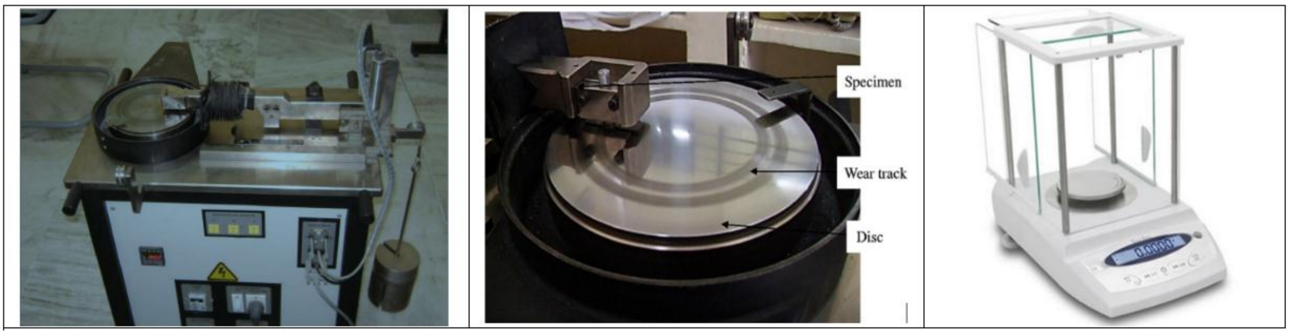


Fig: 6. POD Test Setup

B. Optimization Technique

Optimization is a technique/process of finding the "best available" solution among the variety of solution functions and domains. Design of Experiments (DOE), Taguchi Technique, ANOVA and Regression Analysis are adopted in the present study.

C. Plan of Experiments

The experimental plan was formulated by considering factors and levels based on the Taguchi technique. The levels of variables chosen for design of experiments are listed in Table: 1. Dry sliding wear tests were conducted as per L_{25} orthogonal array to study the effect of wear parameters.

Table: 1 Parameters and their levels

Factors	**Levels**				
	1	2	3	4	5
Wt. % of B4C	0	3	6	9	12
Load, N	10	20	30	40	50

Sliding Velocity, m/sec	1	2	3	4	5
Sliding Distance, m	500	1000	1500	2000	2500

4. RESULTS AND DISCUSSIONS

Wear tests were conducted using POD machine to predict the wear behavior of Al 6061 and 3, 6, 9 and 12 wt.% of B_4C composites as per the DOE using L_{25} orthogonal array by varying percentage of Reinforcement, Load, sliding distance and Sliding velocity to determine wear loss and coefficient of friction. Wear loss and coefficient of friction for different wt.% of B_4C were tabulated in the Table 2.

Results obtained from the POD experiments are used to develop ANOVA, Taguchi analysis and regression analyses. It was evident from the results obtained from the model are established good correlation between various terms obtained from ANOVA analyses based on reinforcement, applied load, sliding velocity and sliding distance [8, 9].

Table: 2. Wear behavior of Al 6061-B_4C AMC's

L25 Tests	Factors				Results	
	Wt. % of Reinforcement	Load, N	Sliding Velocity, m/s	Sliding Distance, m	Wear Loss, gm	COF
1	0	10	0.5	300	0.0093	0.198
2	0	20	1	600	0.0111	0.206
3	0	30	1.5	900	0.0127	0.209
4	0	40	2	1200	0.0140	0.212
5	0	50	2.5	1500	0.0151	0.216
6	3	10	1	900	0.0082	0.323
7	3	20	1.5	1200	0.0086	0.327
8	3	30	2	1500	0.0087	0.329
9	3	40	2.5	300	0.0089	0.331
10	3	50	0.5	600	0.0091	0.341
11	6	10	1.5	1500	0.007	0.498
12	6	20	2	300	0.0071	0.453
13	6	30	2.5	600	0.0074	0.469
14	6	40	0.5	900	0.0078	0.478
15	6	50	1	1200	0.0081	0.489
16	9	10	2	600	0.0061	0.513

17	9	20	2.5	900	0.0064	0.597
18	9	30	0.5	1200	0.0068	0.522
19	9	40	1	1500	0.007	0.527
20	9	50	1.5	300	0.0071	0.531
21	12	10	2.5	1200	0.0048	0.583
22	12	20	0.5	1500	0.0051	0.589
23	12	30	1	300	0.0053	0.592
24	12	40	1.5	600	0.0055	0.600
25	12	50	2	900	0.0057	0.604

A. Optimization Technique for Wear loss

Figure.7 shows the means of means and S/N ratio plots for Al 6061-B_4C AMC's based on the wear loss. It is evident from the plots that wt. % of the reinforcement is most significant wear parameter while load, sliding distance and sliding velocity also has considerable effect [10]. Further, it is observed from the response tables for single to noise ratio (Table 3) and means of means table (Table 4) that the reinforcement has significant effect on wear loss. Hence increase in the addition of B_4C plays a vital role to control the wear loss of Al 6061 composites.

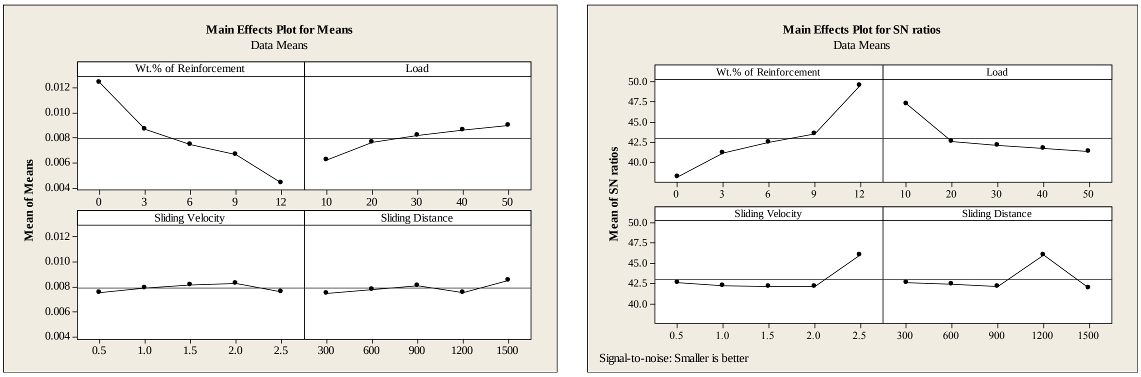


Figure: 7 Means of Means and S/N ratio plots for wear loss of Al 6061 - - with different wt.% of B_4C composites.

It is observed from the ANOVA Table 5 that the reinforcement (Pr.%=48.57%), load (Pr.%=16.09%) sliding velocity (Pr.%=8.21%) and sliding distance (Pr.%=7.93%) have great impact on wear. The pooled error associate in the ANOVA Table is 19.17%. This clearly indicates that addition of the reinforcement with increase in load, the wear loss due to applied load which intern increases the friction between contact surface. It is evident from ANOVA Table 5. that, reinforcement has major contribution towards wear loss in comparison with other parameters.

Table: 3 Response table for Signal to Noise Ratios for wear loss (Smaller is better)

Level	Wt.% of Reinforcement	Load	Sliding Velocity	Sliding Distance
1	38.23	47.22	42.56	42.62

2	41.21	42.62	42.25	42.4
3	42.54	42.12	42.1	42.11
4	43.52	41.71	42.09	45.99
5	49.56	41.39	46.06	41.93
Delta	11.33	5.84	3.97	4.05
Rank	1	2	4	3

Table: 4 Response Table for Means of Means for wear loss

Level	Wt.% of Reinforcement	Load	Sliding Velocity	Sliding Distance
1	0.01244	0.00622	0.00762	0.00754
2	0.0087	0.00766	0.00794	0.00784
3	0.00748	0.00818	0.00818	0.00816
4	0.00668	0.00864	0.00832	0.0076
5	0.00442	0.00902	0.00766	0.00858
Delta	0.00802	0.0028	0.0007	0.00104
Rank	1	2	4	3

Table: 5. Analysis of Variance (ANOVA) table for Al 6061 with different wt. % of B_4C composites for wear loss.

Source	Df	Seq. SS	Adj. SS	Adj. MS	F	P	Pr. %
Wt.% of Reinforcement	4	347.5	347.5	86.88	5.07	0.025	48.57
Load	4	115.17	115.17	28.79	1.68	0.247	16.09
Sliding Velocity	4	58.79	58.79	14.7	0.86	0.528	8.21
Sliding Distance	4	56.76	56.76	14.19	0.83	0.543	7.93
Error	8	137.19	137.19	17.15			19.17
Total	24	715.4					100

Further, Linear regression analyses of Al6061 with different wt.% of B_4C composite was conducted and regression equation was developed using MINITAB software to study the wear weight loss of the composite system.

Wear Loss = 0.00889-0.000602 Wt. % of Reinforcement +0.000066 Load + 0.000090 Sliding Velocity + 0.000001 Sliding Distance 1

It is noticed from the Equation.1 that the co-efficient of load, sliding velocity and sliding distance are positive whereas co-efficient of wt.% of reinforcement is negative. Further, it is evident from the Equation.1 that wt.% of reinforcement has more effect on wear of the composite which is followed by the load, sliding velocity and sliding distance.

B. Optimization Technique for Coefficient of Friction (COF)

Similarly, optimization procedure for COF is adopted for Al6061-B4C composite system. It is noticed that wt. % of the reinforcement is most significant wear parameter. Further, it is evident from the results that COF decreases with the addition of reinforcement while load, sliding distance and sliding velocity also has considerable effect. Similar observations are noticed from the response tables for single to noise ratio (Table 6) and means of means table (Table 7).

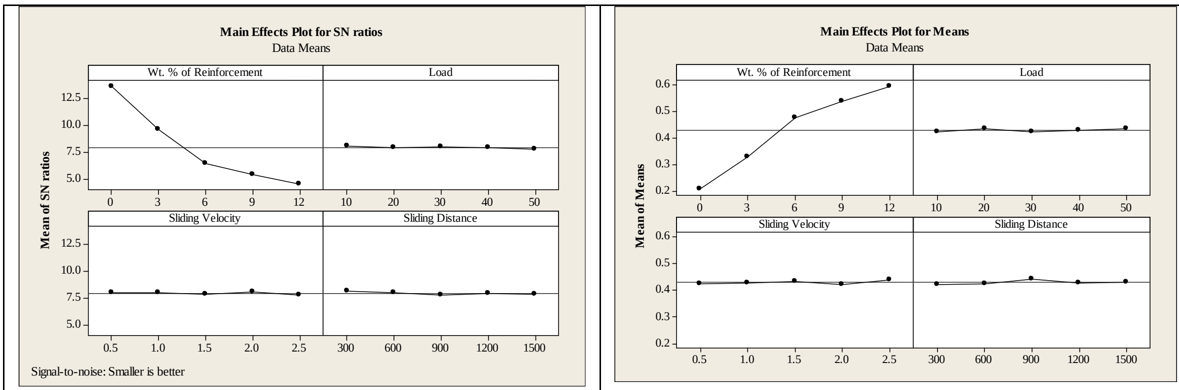


Figure: 8 Means of Means and S/N ratio plots for Coefficient of Friction of Al 6061 with different wt.% of B_4C composites.

Table: 6 Response table for Signal to Noise Ratios for COF (Smaller is better)

Level	Wt. % of Reinforcement	Load	Sliding Velocity	Sliding Distance
1	13.634	8.084	8.013	8.12
2	9.626	7.878	7.974	7.976
3	6.427	8.006	7.859	7.737
4	5.397	7.898	8.037	7.946
5	4.531	7.749	7.732	7.837
Delta	9.103	0.335	0.305	0.383
Rank	1	3	4	2

Table: 7 Response Table for Means of Means for COF

Level	Wt. % of Reinforcement	Load	Sliding Velocity	Sliding Distance
1	0.2082	0.423	0.4256	0.421
2	0.3302	0.4344	0.4274	0.4258
3	0.4774	0.4242	0.433	0.4422
4	0.538	0.4296	0.4222	0.4266
5	0.5936	0.4362	0.4392	0.4318
Delta	0.3854	0.0132	0.017	0.0212
Rank	1	4	3	2

Table: 8 ANOVA table for Al 6061 -with different wt.% of B_4C composites for COF.

Source	D_f	Seq. SS	Adj. SS	Adj. MS	F	P	Pr. %
Wt.% of Reinforcement	4	278.203	278.203	69.551	586.04	0.0	99.28
Load	4	0.329	0.329	0.082	0.69	0.617	0.117
Sliding Velocity	4	0.322	0.322	0.081	0.68	0.626	0.114
Sliding Distance	4	0.421	0.421	0.105	0.89	0.514	0.15
Error	8	0.949	0.949	0.119			0.338
Total	24	280.224					100

It is observed from the ANOVA Table 8 for COF that the reinforcement (Pr.%=99.28%) is the highest significant influencing parameter. Load (Pr.%=0.117%), sliding velocity (Pr.%=0.114%) and sliding distance (Pr.%=0.15%) has minimum influence on COF. The pooled error associate in the ANOVA Table is 0.338%. This clearly indicates that addition of the reinforcement enhances the COF.

Further, Linear regression analyses of Al6061 with different wt.% of B_4C composite was conducted and regression equation was developed using MINITAB software to study the coefficient of friction of the composite system.

COF = 0.214 + 0.0326 Wt. % of Reinforcement + 0.000216 Load + 0.0044 Sliding Velocity + 0.000007 Sliding Distance 2

It is noticed from the Equation.2 that the co-efficient of load, sliding velocity, sliding distance and wt.% of reinforcement are positive. The positive values of the coefficients suggest that COF of material increases with their associated variables. Further, it is evident from the Equation 2 that wt.% of reinforcement has more effect on COF. Further, it is found that Errors associated with B_4C reinforced composites using POD experiments were in good agreement with the regression model and error associate with it is 0.6% to 6.27% which are in good agreement with the published results.

5. CONCLUSIONS

Based on the POD experiments and optimization using mathematical models the following conclusions were drawn:

- Al 6061 - 3, 6, 9 and 12 wt. % of B_4C AMC's were Fabricated using stir casting process.
- Wear behavior of Al 6061 and 3, 6, 9 and 12 wt.% of B_4C composites were conducted using Pin-On-Disc (POD) apparatus as per the design of experiments using L_{25} orthogonal array by considering different influencing factors.
- It is evident from the experimental results that wear loss decreases with increase in the wt.% of the B_4C reinforcement.
- It is observed from the design of experiments that the reinforcement has great influence on wear loss and coefficient of friction.
- Presence of hard B_4C particles in the composite increases coefficient of friction. Hence Al6061-B_4C composite material can be used as brake friction material for automotive brake pads applications.

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