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Evaluation of Wear Behaviour for Al/B4C/Fly Ash Composites by Stir Casting Process

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In this study, the wear behaviors of aluminum matrix composites Al 6082 matrix reinforced with Boron carbide and Fly ash particles using Taguchi method were evaluated. Wear tests of unreinforced aluminum alloy and Al/5%B4C and Al/5%Flyash particles reinforced composites were carried out. The stir casting method was used to manufacture the aluminum and its composites. The wear tests were carried out at the sliding speeds of 0.5, 1.0 and 1.5 m/s with loads of 15, 30, 45 N. Type of the material, Sliding speed, Applied load are the input parameters and Specific wear rate is the output parameter for the conditions tested. Taguchi technique was applied for optimizing the selected composites. Analysis of variance (ANOVA) has been used to determine the significance of design parameters influencing the response. The influence of these parameters on the response has been evaluated using Signal to Noise (SN) ratio analysis. The experimental results proposed optimal combination of parameters which give the minimum specific wear rate. The microstructure examination was also done using Scanning electron microscope to assess the uniform distribution of reinforcement in aluminum composites.

Keywords: Aluminum Composites, B4C, Fly Ash, Stir Casting, Taguchi Method, Wear Behaviour

Introduction

The Metal Matrix Composite materials have limitations in achieving good combination of strength, stiffness, toughness, and density. Metal matrix composites are advanced materials resulting from a combination of two or more materials in which tailored improved properties including high specific strength, damping capacity, and good wear resistance as compared to unreinforced alloys[1]. Aluminum alloys with SiC and Rice husk to form hybrid composites, it is reported that to accelerate the precipitation kinetics of the composites[2]. Ceramic particles such as Al_2O_3, SiC are the most widely used materials for reinforcement of aluminum[3]. R.M. Mohanty *et al* suggested Boron carbide could be an alternative reinforcement material with properties like high strength, low density (2.52 g/cm^2), extremely high hardness; good wear resistance and good chemical stability[4]. ($Al_3Zr_{mp} + ZrB_{2np}$)/AA5052 composites have been synthesized by the direct melt reaction of AA5052 alloy and inorganic salts (K_2ZrF_6 and KBF_4). The results indicate the second phase reinforcement particles namely Al_3Zr and ZrB_2 in the AA5052 alloy matrix. Grain refinement of Al-rich phase observed in the composites, increases with increase in the vol.% of reinforcement particles[5]. Use of the precipitator fly ash in aluminum decreases the density of composites while it increases the wear resistance[6]. The microstructural investigation of Al 6061, SiC and Graphite hybrid metal matrix composite with varying percentage reinforcements 2.5%, 5%, 7.5% and 0% have been carried out. SEM analysis was done to accumulate the distribution of composites. Stir casting route was used to fabricate the composites[7]. Sathish kumar *et al* has carried out microstructural analysis on the monolithic alloy as well as cast composite samples[8]. The number of runs required for a full factorial design increases geometrically. Taguchi method is a statistical method to improve the quality of manufactured goods and more recently, it is also applied to engineering, biotechnology, marketing, and advertising[9]. MATLAB software package was used for the regression and graphical analysis of the experimental data and for analyzing the response surface and contour plots. ANOVA was used to estimate the statistical parameters[10]. Taguchi's robust design is an important tool for

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design of experiments which offers a simple and systematic approach to optimize design for performance, quality and cost[11]. The main objective of this work is to fabricate, an Aluminum (6082) metal matrix composite rods using B_4C and fly ash as reinforcements using stir casting technique. Taguchi's technique is employed to determine the influence of the input parameters (Type of the material, sliding speed, applied load) with respect to the Specific wear rate of the prepared composite. The influence of these parameters on the response has been evaluated using Signal to Noise (SN) ratio analysis.

Experimental details

Materials and methods

The matrix material used in this investigation was Aluminum 6082 with chemical composition of Mg- 0.8-1.2%, Si- 0.4-0.8%, Cu- 0.15%, Zinc- 0.25%, Fe- 0.30%, Iron- 0.7%, Others- 0.05%, Al- Balance. Boron Carbide and Fly ash have been used as reinforcements. The details of fly ash are: Al_2O_3 -30.40%, Fe_2O_3 -8.44%, TiO_2 -2.75%, LOI - 1.43%. The particle size of B_4C and fly ash were 25 µm and 10 µm respectively. Stir casting method was used to manufacture aluminum and its composites. B_4C particles were preheated at 800^0C for 2 hours by removing the absorbed hydroxide and other gases. Fly ash was preheated at 400^0C for 1 hour by removing the moisture content and other gases. The furnace temperature was raised to 750^0C to melt the matrix completely. At this stage both reinforcement materials were added slowly and mixed. The stirring was carried out for 10 minutes at a speed of 350rpm. 1 % of magnesium is added to the molten metal to ensure good wettability of particles with the molten metal. The molten metal was stirred to create a vortex and the particulates were introduced. The molten metal is poured into the mould by gravity casting. The dimensions of the specimens were 50mm in diameter and 500mm in length.

Wear test

Wear tests of the cylindrical components 8 mm diameter and 50 mm length, versus AISI316L stainless steel were carried out for dry sliding condition using a pin-on-disc arrangement. Tests were observed at sliding speeds of 0.5, 1, 1.5 m/s and under the loads of 15, 30, and 45N. Sliding wear data are reported as an average of atleast 3 runs.

Scanning electron microscope

The microstructure of Al/B_4C/Fly ash MMCs of different compositions were obtained using Scanning Electron Microscope. Figure 1 (a, b, c) shows the SEM images of Pure Al, Al with 5%B_4C and Al with 5%Fly ash composites. The micro structural analysis proves the presence of B_4C and Fly ash reinforcements and its uniform distribution in the metal matrix, and it clearly shows that there were no voids and discontinuities. It also shows a good

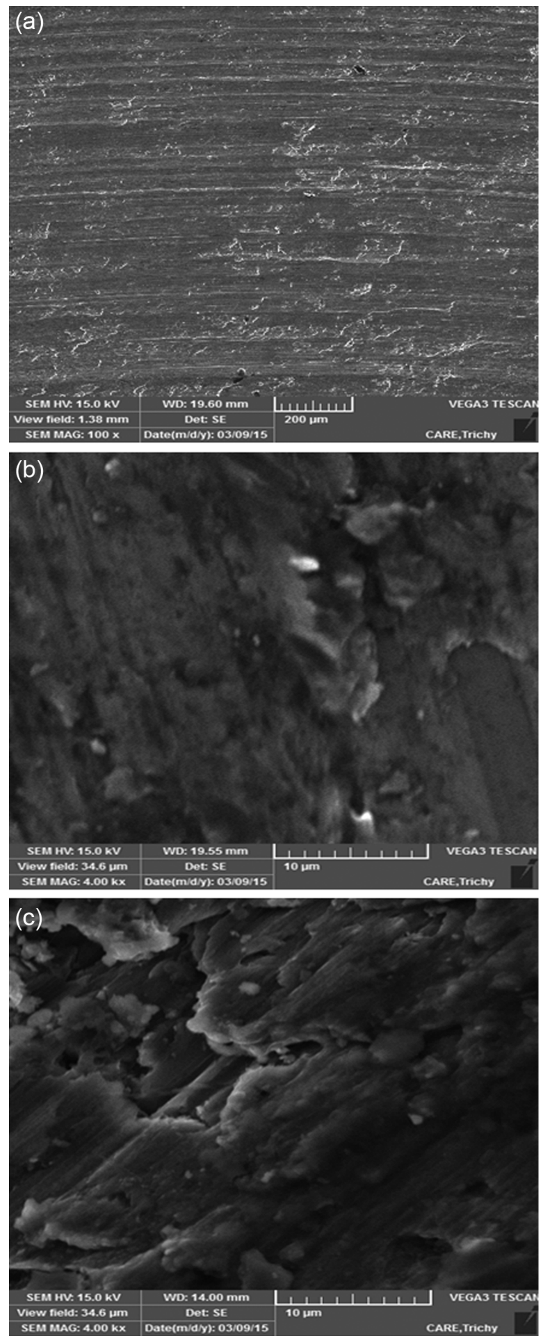

Fig. 1 — SEM Image of a)Pure Al b) Al/5%Fly ash, c)Al/5%B_4C

interfacial bonding between the particles and the matrix material.

Plan of experiments

Taguchi approach was used for designing the experiments, L27 orthogonal array was applied which composed of three columns and 27 rows, which mean that 27 experiments were carried out. DOE was selected based on a three different parameters with 3 levels each. The selected parameters for this study are: Material Type, sliding speed, applied load. Taguchi method was applied to the experimental data using statistical software MINITAB 15. The SN ratio for each level of process parameters is computed based on the SN analysis. Regardless of the category of the quality characteristic; a lower SN ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameter is the level with the lower SN ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed for each response individually to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted.

Results and Discussion

In this study, Twenty seven experiments were required to study the parameters using L_{27} orthogonal array. The experimental layout for the parameters using the L_{27} orthogonal array and the responses for signal-to-noise ratio are presented in Table 1. Design expert 7 software was used for analyzing the measured responses.

The signal-to-noise (SN) ratio analysis

In order to evaluate the influence of each selected factor on the responses, the signal-to-noise ratios SN for each factor is to be calculated. The signals have

Table 1 — Response methodology parameters

Exp No	Input Parameters						Response Value	
	A	B	C	Material Type	Sliding Speed (m/s)	Applied load (N)	Specific wear rate ($mm^3 N^{-1} m^{-1}$) x 10^{-13}	S/N ratios
1	1	1	1	Al	0.5	15	9.77	-19.7979
2	1	2	2	Al	1	15	10.12	-20.1036
3	1	3	3	Al	1.5	15	15.71	-23.9235
4	2	1	1	Al	0.5	30	4.96	-13.9096
5	2	2	2	Al	1	30	5.58	-14.9327
6	2	3	3	Al	1.5	30	8.7	-18.7904
7	3	1	1	Al	0.5	45	4.67	-13.3863
8	3	2	2	Al	1	45	4.07	-12.1919
9	3	3	3	Al	1.5	45	6.66	-16.4695
10	3	1	2	Al/5%B_4C	0.5	15	2.55	-8.1308
11	3	2	3	Al/5%B_4C	1	15	3.58	-11.0777
12	3	3	1	Al/5%B_4C	1.5	15	4.31	-12.6895
13	1	1	2	Al/5%B_4C	0.5	30	1.4	-2.9226
14	1	2	3	Al/5%B_4C	1	30	1.62	-4.1903
15	1	3	1	Al/5%B_4C	1.5	30	2.06	-6.2773
16	2	1	2	Al/5%B_4C	0.5	45	1.07	-0.5877
17	2	2	3	Al/5%B_4C	1	45	1.21	-1.6557
18	2	3	1	Al/5%B_4C	1.5	45	1.39	-2.8603
19	2	1	3	Al/5%Flyash	0.5	15	5.89	-15.402
20	2	2	1	Al/5%Flyash	1	15	6.13	-15.749
21	2	3	2	Al/5%Flyash	1.5	15	8.98	-19.0655
22	3	1	3	Al/5%Flyash	0.5	30	3.06	-9.7144
23	3	2	1	Al/5%Flyash	1	30	3.44	-10.7312
24	3	3	2	Al/5%Flyash	1.5	30	4.87	-13.7506
25	1	1	3	Al/5%Flyash	0.5	45	2.47	-7.8539
26	1	2	1	Al/5%Flyash	1	45	2.82	-9.005
27	1	3	2	Al/5%Flyash	1.5	45	3.18	-10.0485

indicated that the effect on the average responses and the noises were measured by the influence on the deviations from the average responses, which would indicate the sensitiveness of the experiment output to the noise factors. The appropriate SN ratio must be chosen using previous knowledge, expertise, and understanding of the process. When the target is fixed and there is a trivial or absent signal factor (static design), it is possible to choose the SN ratio depending on the goal of the design. In present work, the SN ratio was chosen according to the criterion the 'Smaller is better', in order to minimize the responses. The SN ratio for the 'Smaller is better' target for all the responses was used in this work[11].The specific wear rate of the aluminum and its composites decreases with the increase in load and increases with the increment of sliding speed and loads varying from 10 to 40 N and sliding distances of 500 t and 1000 m with constant sliding speed of 1m per second with the studies of Thirumalai *et al*[13] and Straffelini *et al*[14]. In the present work, unreinforced aluminum has the highest specific wear rate value of 1.07 x $10\text{-}^{13}m^2N^{-1}$. In general, the applied load has a stronger effect on the specific wear rate of aluminum and its composites than the sliding speed.

$$\text{Smaller the better: S/N ratio} = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$$

where, n = number of variables y1= the value of the response

Using the above presented data with the selected formula above for calculating SN ratio, the Taguchi experiment results were obtained using MINITAB 15 statistical software. The response values for SN ratio and means are noted in Table 2. In SN ratio plot, the material type is the most important influence factor on specific wear rate, followed by applied load and sliding speed. And the main effects plot for means, the material type is also the most important factor which influences the specific wear rate, followed by applied load and sliding speed.

Interaction plot for SN ratio

From the interaction plots shown in Figure 2, it is observed, that the sliding speed value increases with respect to applying load.The SN ratio value also increases with the increase in applied load for sliding speed.It is observed that the 'type of material' is the most significant factor and the sliding speed (m/s) is an insignificant factor for the specific wear rate of the Al 6082 metal matrix composites.

Analysis of variance (ANOVA)

The purpose of the ANOVA is to determine the parameters that significantly affect the quality characteristic. This is accomplished by separating the total variability of the SN ratios, measured by the sum of the squared deviations from the total mean of the SN ratio, contributions by each composite parameter and the error. The percentage contribution by each of the process parameter is the total sum of the squared deviations which is used to evaluate the importance of the process parameter change on the quality characteristic. In addition, the F test can also be used to determine, which of the composite parameters have a significant effect on the quality characteristic. Usually, the change of the composite parameters has a significant effect on the quality characteristic when the F value is large.

Analysis of variance for specific wear rate

The purpose of ANOVA is to find the significant factor statistically. It gives a clear picture as to how far the process parameter affects the response and the level of significance of the factor considered. The ANOVA table for mean and signal to noise ratio is calculated and listed in Table 3. The F test is carried out to study the significance of the process parameter. The high F value indicates that the factor is highly significant in affecting the response of the process. In this work, the material type is a highly significant factor and plays a major role in affecting the specific wear rate of the composites.

Table 2 — Response table for SN ratios and Means

	Response for S/N Ratio			Response for Means		
Level	Material Type	Sliding Speed (m/s)	Applied Load (N)	Material Type	Sliding Speed (m/s)	Applied Load (N)
1	7.804	3.982	7.449	-17.056	-10.19	-16.216
2	2.132	4.286	3.966	-5.599	-11.071	-10.58
3	4.538	6.207	3.06	-12.369	-13.764	-8.229
Delta	5.672	2.224	4.389	11.457	3.574	7.987
Rank	1	3	2	1	3	2

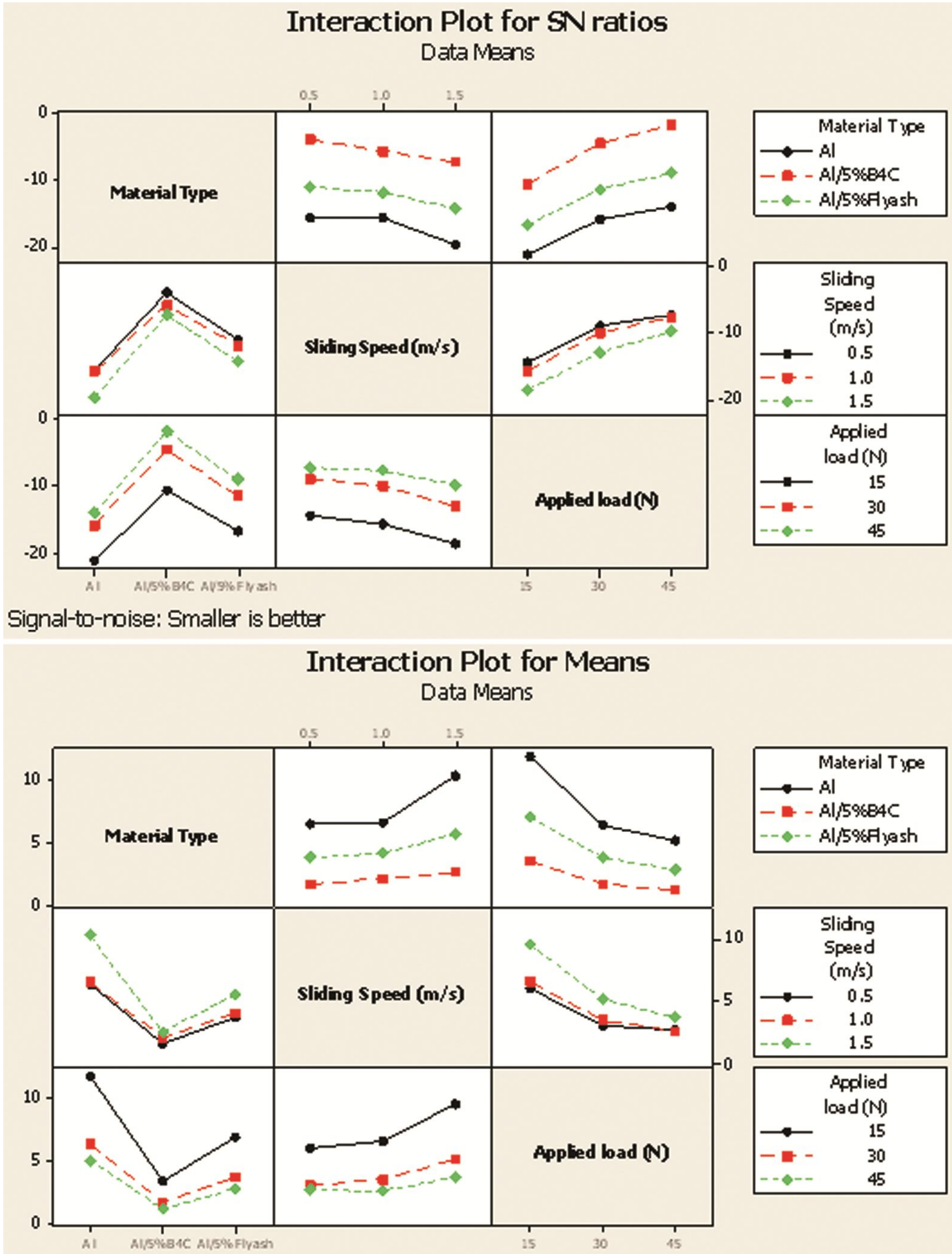

Fig. 2 — Interaction plot for SN ratios and means

Table 3 — Analysis of variance for Specific wear rate

Source	DOF	SS	MS	F	P
Material Type	2	0.008245	0.004122	1.44	0.406
Sliding Speed	2	0.03521	0.017605	4.96	0.03
Applied Load	2	0.000086	0.000043	0.05	0.885
Error	20	0.045621	0.02281		
Total	26	0.089215			

S-0.0560323 R-Sq – 37.12 % R Sq (adj) – 16.58%

Conclusions

Al (6082grade)/B_4C/Fly ash composites were produced by stir casting method successfully. There was a uniform distribution of B_4C/Fly ash particles in the matrix phase and also exhibited a good bonding between matrix and fly ash reinforcements. The specific wear rate of the unreinforced aluminum alloy and Al/5% B_4C and Al/5% Fly ash composites decreases with the increase in load, and it increases with the increment in sliding speed. Taguchi's design method can be effectively used for optimizing the parameters. Taguchi's robust orthogonal array design method is suitable to analyze the wear sliding behavior problem as described in this work. The material type has the most influence on the specific wear rate of the composites among the selected parameters; the applied load has a stronger effect on the specific wear rate of aluminum and its composites than the sliding speed.

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