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A Statistical Analysis of Wear Behaviour of Fly Ash Reinforced Al-Sic Hybrid Composites

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Abstract

The tribiological behaviour of aluminium hybrid composites reinforced with Silicon carbide (10 wt.%) and Fly ash (FA 0, 5, 10 and 15 wt.%) fabricated using powder metallurgy technique was investigated. Wear tests were performed on pin on disc machine to assess the tribiological behaviour of composites and to determine the optimum volume fraction of fly ash for its minimum wear. Wear loss reduces with increase in fly ash weight fraction and minimum wear rate was attained at 10 wt.% fly ash. The influences of sliding distance, sliding speed and applied load were studied with test based on full factorial design of experiments (DOE). Analysis of variance (ANOVA) was used to evaluate the percentage contribution of each sliding wear process parameters on wear loss. From the ANOVA approach, it was concluded that wear loss is mainly influenced by sliding distance followed by sliding speed and applied load.

Keywords: Aluminium; Silicon carbide; Wear; ANOVA; Regression; Fly ash; Load; Sliding speed

Introduction

Aluminium matrix composites (AMCs) are favourable materials due to its application in automobile, structural and aerospace industries because of their properties such as high strength to weight ratio, low density, and high stiffness and wear resistance along with relatively small fabrication cost [1]. The mechanical behaviour of the metal matrix composite depends upon fabrication technique, orientation as well as distribution of the reinforced particles. Various methods like mechanical alloying, casting and powder metallurgy are used for their fabrication. Amongst the different synthesis technique, powder metallurgy found more attention due to achievement of fair homogeneity of reinforcement in matrix along with producing near net shaped products [2].

Apart from the above, there was global need of reducing the wear in order to reduce the usage of material resources and wastage of energy. This controlling of wear should be considered carefully from the basis of selecting the alloy composition, reinforcement and also the processing methods [3].

Further, aluminium reinforced with two or more reinforcements i.e. a combination of hard ceramic particles and agricultural waste/industrial waste/natural minerals is more preferable because of improved mechanical and tribological behavior along with low production cost [4]. Amongst numerous ceramic reinforcements used in AMCs, SiC particle is most widely used because its density is very close to aluminium as well as it possesses higher stability, wear resistance and rigidity both at room and elevated temperature [5,6]. These enhancements in properties are achieved at the cost of ductility and fracture toughness. Further, addition of hard ceramic reinforcement enhances the hardness which makes machining difficult and uneconomical .In addition, fly ash particles are inexpensive, eco-friendly light weight and available in large quantities as an industrial waste. Therefore FA particles can be used as an economical reinforcement in comparison to conventionally used particles [1,7]. Previous works show an improvement in mechanical as well tribiological properties of AMCs reinforced with FA [7-10].

Further, tribiological characteristics of composites are governed by many factors like reinforcement percentage, sliding distance, sliding speed and applied load. Therefore, effect of each factor and its interaction is very important for sliding wear behaviour. For this, a statistical tool analysis of variance (ANOVA) can be used [11,12]. ANOVA method is simple, efficient and widely accepted to get quantitative measurement of each input variable on the response data.

From literature it has been noticed that no detailed findings are available on tribiological behaviour of FA reinforced Al-10%SiC hybrid composites using statistical approach. Therefore, in the current research work tribiological behaviour of Al-SiC-FA hybrid composites synthesized by powder metallurgy was explored. The effects of sliding speed, sliding distance and applied load on wear behaviour of hybrid composites were investigated using Taguchi DOE. The percentage contributions of input sliding wear parameters and their interactions were analysed using analysis of variance (ANOVA).

Materials and Experimental Details

Fabrication of composites

Pure aluminium (Al), silicon carbide (SiC) and fly ash (FA) powders were purchased. The scanning electron microscopy of as-received particles and processed FA are showed in Figure 1a-1c and Table 1.

Firstly, a digital weighing machine (Made Precisa) with a least count of 0.1 mg. was used for measuring the weight of used powders. A predetermined amount of particles was mixed thoroughly using centrifugal type ball mill. While milling, stainless steel balls were adopted with 10:1 ball to powder ratio (BPR) for the minimization of clustering as well as mechanical alloying of composite powders. The rotation speed and milling time were fixed at 100 rpm and 30 min. respectively. Further, green pallets of dimensions 8mm and height 13 mm were fabricated at 400 MPa using uniaxial hydraulic pallet press. After every compaction process the die wall was cleaned and lubricated

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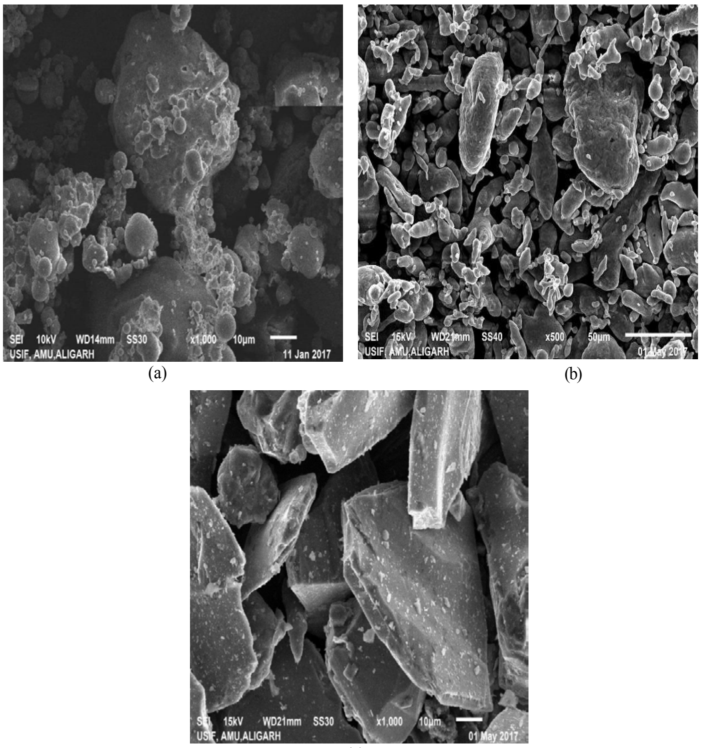

Figure 1: SEM images of as received: (a) Aluminium powder, (b) Fly Ash powder, and (c) SiC particles. For study following combination of hybrid composites are synthesized through powder metallurgy technique.

Sliding Speed (m/s)	Sliding Distance (m)	Load (N)	Wear loss (g)
1.5	300	10	0.00079
1.5	600	20	0.00101
1.5	900	30	0.00287
2	300	20	0.00165
2	600	30	0.00347
2	900	10	0.00231
2.5	300	30	0.00525
2.5	600	10	0.00412
2.5	900	20	0.00598

Table 1: Composition (wt. %) of different constituents of Al-based samples.

with zinc stearate manually to ensure proper functioning of the die. The green specimens were sintered in tubular electric furnace attached with controlled environment unit. The specimens were sintered at 425-450°C for 30 min. under the continuous flow of nitrogen gas for preventing the samples from oxidation. The specimens were cooled down to the room temperature in the furnace itself under controlled environment.

Wear analysis

A pin-on-disc set-up (Ducom, Bangalore, India) was used to study tribiological behaviour of synthesized hybrid composites according to ASTM standards. The wear control variables and their respective levels are provided in Table 2. The specimens and counter disc surfaces were cleaned with acetone to eliminate adhered wear particles. The wear loss is determined by measuring weight of specimens after every test run with electronic weighing balance.

Results and Discussion

Wear loss

The wear loss i.e. wear rate for Al/SiC/FA composite was lower as compared to Al/SiC composite (Table 3 and Figure 2).

Figure 2 shows that 10 wt% of FA was the lowest wear rate at load 20N, sliding speed 2m/s and 600m sliding distance. The wear resistance of the composite was increased as compared to base matrix [1,13,14]. The unreinforced aluminium was softer than SiC and Fly ash reinforced, as shown in Figure 2. This enhancement in the wear resistance can be attributed to the following reasons: (a) High hardness imparted by Fly ash particle which restricts plastic flow during sliding condition (b) strong interfacial bond between particle and matrix phase [3-17].

Experimental design and ANOVA analysis

The experiments were performed according to Taguchi design for the Al/10% SiC/10% FA. The various control factors and their respective levels for the experiment are shown in Table 2. The Taguchi design having 9 rows and 3 columns is shown in Table 4. The results of all 9 set of experiments were subjected to analysis of variance (ANOVA). All the result tables and plots are calculated with the help of Minitab-18 software (Tables 4 and 5).

To find influence of each process parameter on wear behaviour of synthesized composites ANOVA have been performed and shown in Table 5. The sliding speed is showing highest effect on wear loss and contributing 74.07% while applied load (11.11%) and sliding distance (7.4%) contributed a lesser amount to the wear loss. The error contribution is 3.7% only. Since interaction effect contributed a very lesser amount so it is not shown in the table (Figure 3).

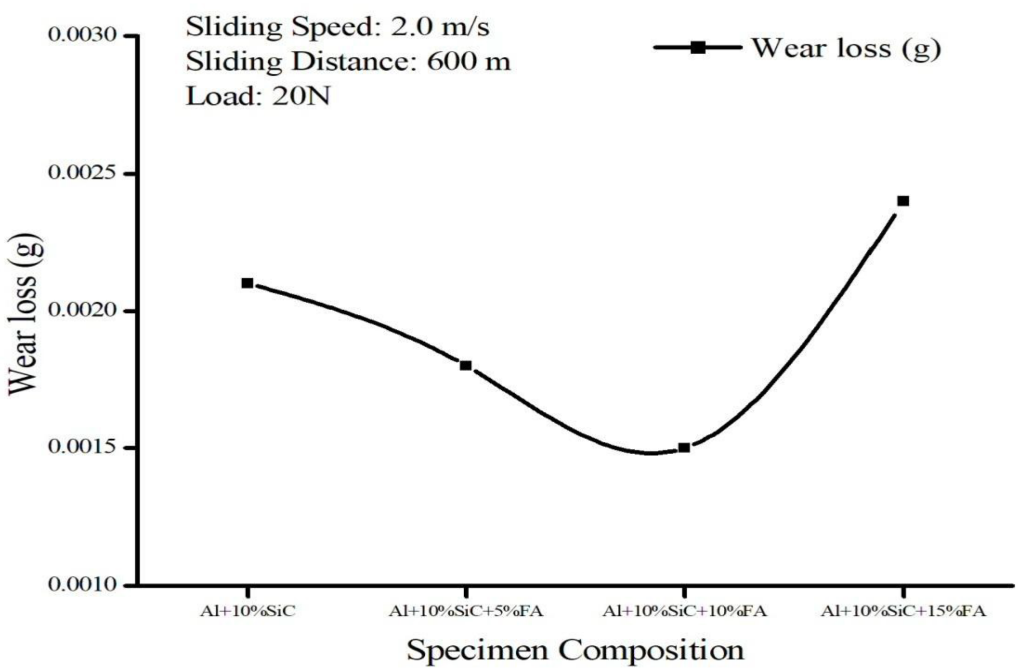

Figure 2: Variation of wear loss of Al/SiC/FA composites with different weight% of FA.

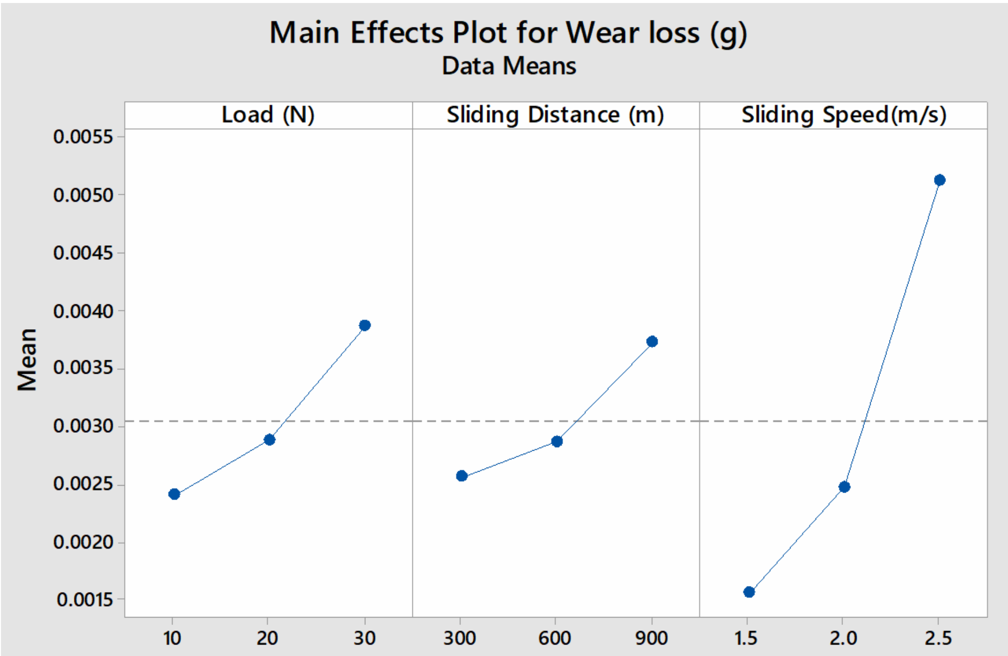

Figure 3: Main effect plot for process parameters on wear loss of Al-SiC-FA hybrid composites.

Effect of different process parameters on wear loss

The effect of each process parameter (sliding speed, sliding distance and applied load) on wear behaviour can be analysed with the help of main effect plot and interaction plot. Figure 3 is main effect plot and is showing the effect of process parameters on the wear loss. According to the ANOVA, if the slope of any process parameter in the main effect plot is lower to the mean value, then it concludes that the given process parameter has no significant effect. On the other hand, process parameter whose plot has the highest slope is most significant. So, it is clear from the main effect plot that the sliding speed is the most Influential parameter followed applied load and sliding distance. The main effect plot also shows that as there is increase in sliding speed, sliding distance and applied load aluminium composites its wear resistance decreases (Figure 4) [12-19].

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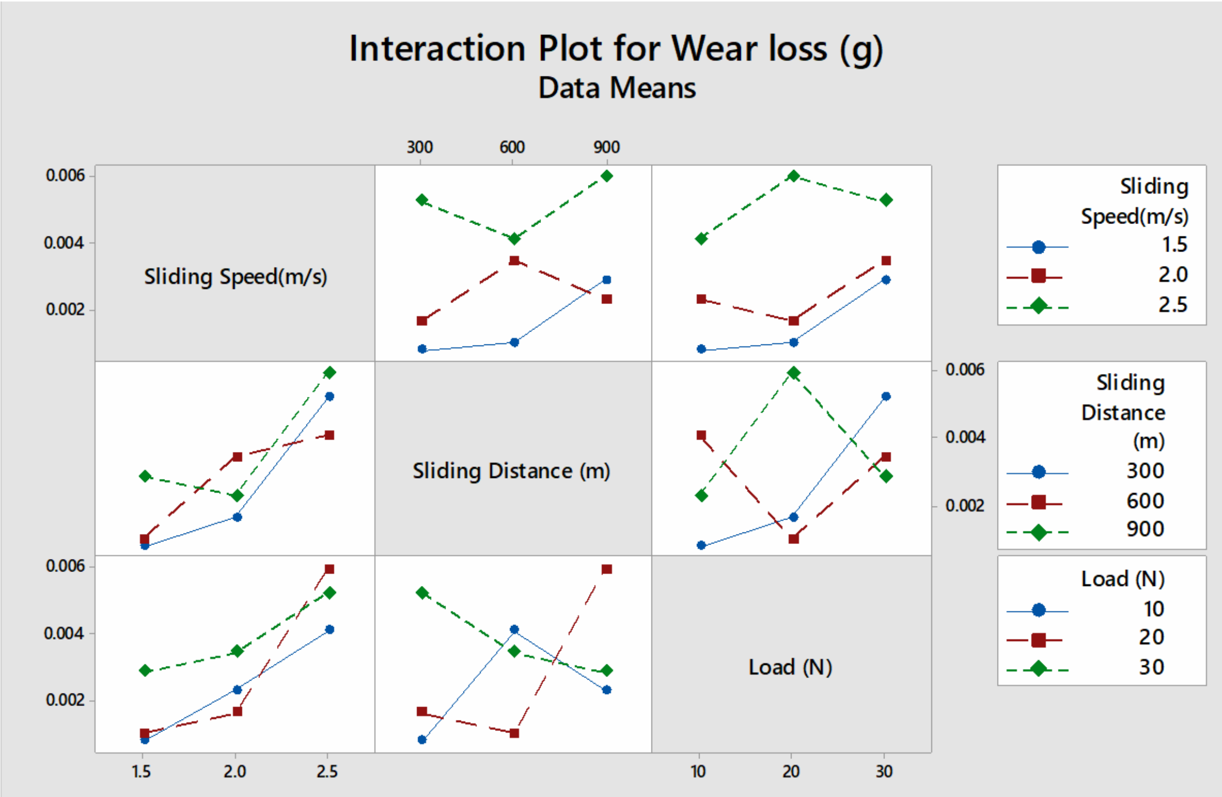

Figure 4: Interactions of various process parameters on wear loss.

S.No	Factor	Type	Levels	Values
1.	Sliding Speed (m/s)	Fixed	3	1.5, 2.0, 2.5
2.	Sliding Distance (m)	Fixed	3	300, 600, 900
3.	Load (N)	Fixed	3	10, 20, 30

Table 2: Wear variables and process parameters.

S.No.	Composition	Wear loss (g)
1	Al-10%SiC	0.0021
2	Al-10%SiC-5%RHA	0.0018
3	Al-10%SiC-10%RHA	0.0015
4	Al-10%SiC-15%RHA	0.0024

Table 3: Wear loss for different composition of Al/SiC/FA.

Sliding Speed (m/s)	Sliding Distance (m)	Load (N)	Wear loss (g)
1.5	300	10	0.00079
1.5	600	20	0.00101
1.5	900	30	0.00287
2	300	20	0.00165
2	600	30	0.00347
2	900	10	0.00231
2.5	300	30	0.00525
2.5	600	10	0.00412
2.5	900	20	0.00598

Table 4: Taguchi based design for wear experiment for Al/SiC/10%FA.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage
Sliding Speed (m/s)	2	0.00002	0.00001	34.44	0.028	74.07
Sliding Distance (m)	2	0.000002	0.000001	3.63	0.216	7.4
Load (N)	2	0.000003	0.000002	5.57	0.152	11.11
Error	2	0.000001	0			3.7
Total	8	0.000027				

Table 5: Results of ANOVA for wear loss (g).

Figure 4 presents the two way interaction plot for coefficient of friction. If the lines are non-parallel then it shows an interaction between the factors while the line crossing each other shows a strong interaction between the factors. Hence, in Figure 4, plot depicts that lines are non-parallel and crossing each other. It can be stated that interaction takes place but overall effect is little as compared to the main effects [1,20].

Conclusion

The following major conclusions can be drawn by using statistical approach on Fly ash reinforced Al-10%SiC hybrid composites fabricated by powder metallurgy technique.

1. The Al/SiC/FA composites have been successfully fabricated by the powder metallurgy route for study on the tribiological properties.
2. The wear resistance of the composites increased with addition of the Fly ash particle content. The wear rate at 10 wt.% FA reinforced Al/SiC is lowered by 28% of the wear rate for the Al/SiC material.
3. The wear behaviour increases with increasing velocity, sliding distance and load during sliding.
4. ANOVA analysis provided the exact amount of percentage contribution of each factor on wear loss: Sliding speed (74.07%), applied load (11.11%) and sliding distance (7.4%) in the composites.

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