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Influence of Wear Parameters on Dry Sliding Wear Behaviour of Al Alloy Hybrid Composites Using Taguchi Method

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Abstract: Aluminium Metal Matrix Composites (AlMMCs) are widely used in automotive components such as engine blocks, valves, piston and cylinder liners. Wear characteristics of hybrid composite significantly better compared to aluminium alloys. In this investigation AlSi7Mg reinforced with 3% graphite (Gr) (< 1micron) and varying weight fractions (3% 6% and 9%) tungsten carbide powder (WC) (size < 1micron) were prepared by stir casting method. Micro structural analysis revealed a uniform distribution of reinforcement particles in the aluminium alloy matrix. Wear tests were carried out using loads of 10N, 15N and 20N and sliding speeds of 1m/s, 1.5 m/s and 2 m/s at a constant sliding distance. For all the load conditions studied, wear rate of the composites showed a decrease with an increase in sliding speed. Wear rate of the composites decreased with an increase in WC content. Increasing the reinforcement content increased the hardness of the composites, thus leading to a reduction in wear rate. Design of Experiments (DoE) Taguchi method was used to maximize the process parameters. Analysis of Variance (ANOVA) method was employed to determine the process parameters (load, sliding speed and % reinforcement) which significantly influence the wear behaviour of the composites.

Key words: ANOVA · DoE · Graphite · Metal Matrix Composites · Tungsten Carbide · Wear

INTRODUCTION

AlMMCs are used in automobile applications because of their excellent strength to weight fraction coupled with increased efficiency as well as reliability of automotive components [1,2]. Al matrix composites exhibit high strength, stiffness, hardness, wear resistance and lower coefficient of thermal expansion. Aluminium alloys are being reinforced with SiC, B4C, WC, Al_2O_3, graphite and molybdenum disulfide particulates to enhance wear properties. Soft particulates such as graphite and molybdenum disulfide reinforced aluminium alloys show a lower wear rate and coefficient of friction, because of their lubricating action during service. Aluminium graphite piston and liners have been tested in race cars and found to lower the coefficient of friction and wear rates substantially [3]. A comparative study of research literature has shown that that reinforcement size influences the hardness and other mechanical properties [4]. In hybrid composites, graphite reduces wear through lubrication while SiCp provides wear resistance, thus lowering the wear rate. Similarly, influence of reinforcement content on hardness has been investigated [5,6]. By introducing a small volume fraction of graphite to SiCp reinforced Al alloy MMCs have been investigated to improve wear resistance through lubricating action [7]. Aluminium alloy graphite composites exhibits much lower coefficient of friction compared to that of matrix alloy [8]. Increasing the graphite reinforcement beyond 5%, fracture toughness was found to decrease due to the formation of a thick solid lubricant film which in turn affected the fracture toughness [9]. Highest wear resistance of composites was observed at higher reinforcement contents [10]. Aluminium composite rotors provide up to 60% weight reduction compared to cast iron [11]. The main aim of this study on AlSi7Mg alloy reinforced with tungsten carbide and graphite particles (less than one microns) to analyse the effect of various process parameters on wear rate. DoE and ANOVA was carried out to maximize the wear rate.

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MATERIALS AND METHODS

AlSi7Mg alloy, whose composition is given in Table 1, was chosen as the matrix alloy owing to its good corrosion resistance and mechanical properties. Graphite was chosen as a soft reinforcement for its lubricating effect which serves to lower both coefficient of friction as well as wear rate. WC was chosen as the hard reinforcement. Since limited work has been reported on Al alloy-WC composites. WC provides enhanced wear resistance at high temperature (melting point of WC 2870°C). Hybrid composites specimens were prepared by varying weight percentages of WC 3% 6% and 9% added with constant 3 wt % graphite.

Fabrication of Hybrid Composites: AlMMCs was fabricated by stir casting method. Crucible furnace is used for melting the Al alloy bars and heated to a desired temperature of 750 °C. A small amount of Mg (2%) is added to a molten metal for improve the wettability. WC and Gr particulates were preheated to a temperature of 250°C. After the aluminium alloys was melted, calculated amount of graphite and tungsten carbide powders were added to the melt and continuously mixed using a mechanical stirrer rotates at a speed of 500 r.p.m to distribute the WC and graphite particles uniformly. Stir process was continuously done for 10-15 minutes for smooth mixing of matrix and reinforcement particles. The molten metal is poured into a cast iron mould to obtain a standard specimen size of 75mm length and 15mm diameter. Composite samples were carefully polished using standard metallographic practice and observed using a Carl-Zeiss make metallograph to confirm the uniform distribution of WC and graphite particles. Hardness tests were carried out a Vickers hardness tester using a load of 1Kg. For conducting wear tests, 20mm long and 8mm dia. specimen size were machined or the cast samples. Wear tests were conducted using a pin-on-disc apparatus consisting of a hardened EN31 steel disc (max. hardness 63 Rc). The specimens were cleaned with alcohol and carefully weighed using an electronic balance having an accuracy of 0.001 gm, both prior to and after the tests.

RESULTS AND DISCUSSIONS

Microstructure and Hardness of Hybrid Composites: Optical microscopic study of composite specimens (Fig. 1) revealed a uniform and random distribution of reinforcements in the matrix alloy.

Hardness test was carried out on Vickers hardness tester. It shows that the hardness of composite increases with increasing WC content listed in Table 2. This increasing in hardness can be attributed to the high hardness of WC particulates, which in turn will have a significant influence on the wear rate of composites.

Influence of Wear Parameters on Wear Behaviour Using Design of Experiments (DoE): DoE is an effective method to find both the individual and interaction effects of several factors influencing a given process. ANOVA is carried to perform the validity of proposed parameters and also to check the significant factors. In the present work, process parameters chosen were load, sliding speed and composition. Of these, first two are process variables, while composition is a material parameter. Sliding distance was kept constant at 3000m for all the experiments. Design of Experiments was used to determine the proper combination of process parameters and the number of specimens required for conduct of experiment. A L9 orthogonal factor design was selected for present study are presented in Table 3 and 4. analysis Signal to noise ratio analysis was carried out using smaller- the-better characteristics..

ANOVA is used to determine significance of the test parameters investigated (Table 5). Main effect plot for means and S/N ratios are shown in Figure 2 and 3.

Effect of Load on Wear Rate: During wear tests, three different loads, 10N, 15N and 20N were taken for evaluate the wear behaviour of the composites. It can be seen from the mean effect plot, that any increase in applied load leads to an increase in wear rate (Fig. 2). Due to increasing of load the interfacial temperature also showed an increase due to increased contact pressure, which in turn led to higher rate of material removal. A similar trend was reported in a study on Al-Sic composites [12]. Since more amount of energy gets.

Table 1: Chemical composition by weight % of AlSi7Mg

Si	Cu	Fe	Mg	Mn	Ni	Zn	Al
7.3	0.012	0.3	0.30	0.28	0.002	0.004	Remaining

Fig. 1: Uniform distribution of WC and Gr Content

Table 2: Hardness values of matrix alloy and Reinforcement

Sr.No	% of Reinforcement	Average VHN (Load 1kg)	Increase in percentage
1	AlSi7Mg	90.2	-
2	AlSi7Mg /3WC/3Gr	101.1	12
3	AlSi7Mg /6WC/3Gr	109.8	22
4	AlSi7Mg /9WC/3Gr	118.2	31

Table 3: Wear Parameters and Levels

Levels	Load (N)	Sliding Speed (m/s)	% (Wt) of Reinforcement (WC)
1	10	1	3
2	15	1.5	6
3	20	2	9

converted as heat energy as the applied load increases, adhesion takes place because of frictional heating, leading to enhanced material removal.

Effect of Sliding Speed on Wear Rate: From Fig. 2. It can be observed that with increasing sliding speed, the wear rate decreases. This is due to the formation of a protective oxide layer, which prevents direct contact between sliding interfaces and resulting in a reduction in the wear rate. Similar results have been reported in a previous study [13]. Highest wear rate was absorbed at a sliding speed of 1m/s.

Effect of Reinforcement on Wear Rate: Increasing in weight fraction of WC content, leads to a reduction in the wear rate (Fig. 2) due to the high hardness of WC and leads to significant enhancement in wear resistance. In addition, the load carrying capacity of the composite increases with WC content. This increased in hardness serves to reduces the wear rate of the matrix alloy. Similar effects have been reported in other hybrid metal matrix composites [14-16].

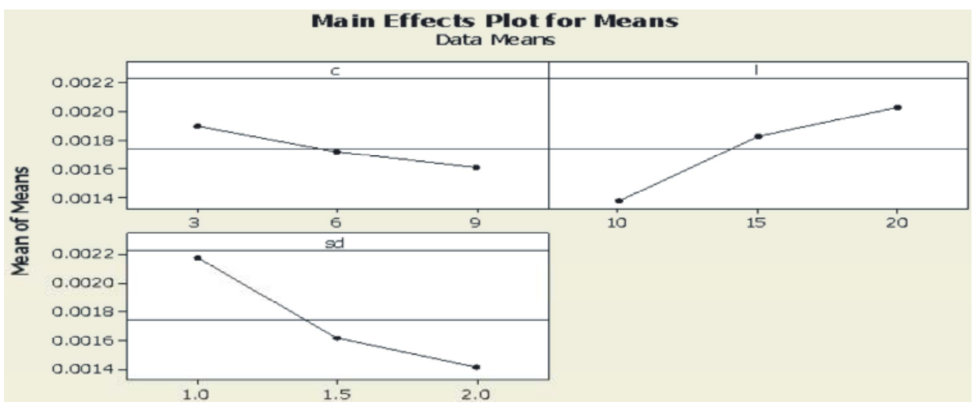

Fig. 2: Main effects of significant parameters for means in wear rate

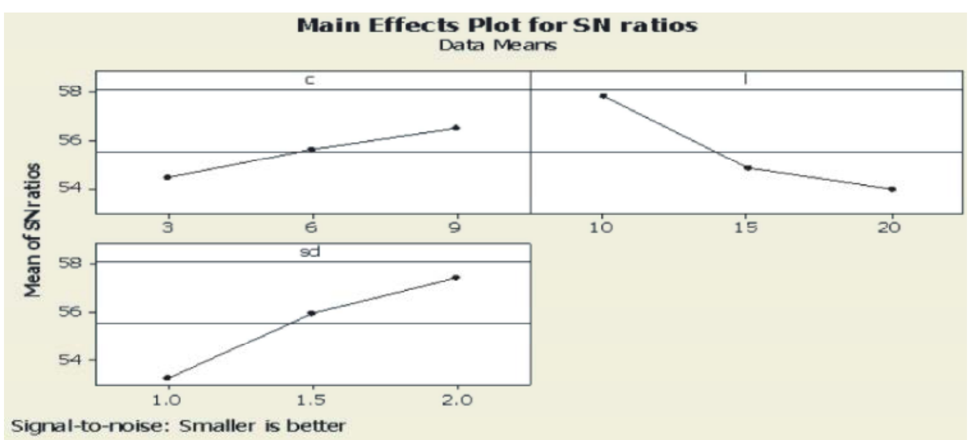

Fig. 3: Main effects of significant parameters for S/N ratio in wear rate

Table 4: Design of Experiments using L9 Orthogonal array for study on wear rate

No of Runs	% (Wt) of Reinforcement (WC)	Load (N)	Sliding Speed (m/s)	Wear Rate (mm^3/m)
1	3	10	1	0.0020458
2	3	15	1.5	0.0017957
3	3	20	2	0.0018458
4	6	10	1.5	0.0012243
5	6	15	2	0.0015541
6	6	20	1	0.0023764
7	9	10	2	0.0008513
8	9	15	1	0.0021154
9	9	20	1.5	0.0018463

Table 5: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	F	P
Reinforcement(%)	2	0.000000	0.000000	4.27	0.190
Load(N)	2	0.000001	0.000001	21.83	0.044
Sliding speed(m/s)	2	0.000001	0.000001	30.77	0.031
Residual Error	2	0.000000	0.000000		
Total	8	0.000001			

CONCLUSION

Major conclusions of the present investigation are:

- Hardness of the hybrid composites show an increase with increasing percentage of WC
- Wear rate of the composites decreased with an increase in sliding speed up to 2m/s.
- For all the load conditions tested, wear rate of the composite increased with an increase in load.
- An increase in WC content from 3 %weight to 9% weight resulted in a decrease in wear rate of the hybrid composites.

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