Study of wear behavior on AMMC's (AA6061) with addition of MoS_2 Particles

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I. ABSTRACT

In the 21st century, the demand of manufacturing industries for light in weight of machines and machine parts is growing. In an industry sector, aluminium composite having advantage of light weight and high mechanical properties like hardness, tensile strength, flexural strength and wear rate etc. In this present investigation, Molybdenum disulphide (MoS_2) reinforced aluminium metal matrix composite was fabricated. The wear behavior was studied on AMMC's (AA6061) with addition of MoS_2 Particles. The test were carried on the basis of Taguchi's L_{25} orthogonal array taking five design factors, condition (C), Applied load (AL), speed (S), sliding distance (SD) and time (T). Using Taguchi optimization method, optimum combination of these five factors was found. Wear behavior was analyzed on ANOVA (Analysis Of Variance). In this analysis, outcome is that most dominating factor which affecting wear is speed followed by applied load. At last confirmation test was conducted to validate the optimized process parameters

***Keywords*— AA6061, MoS_2, Taguchi , Wear**

II. . INTRODUCTION

The aluminum based metal matrix composites provide excellent specific strength, stiffness, high hardness, wear resistance, stability at high elevated temperature [1] with additional advantages of three dimensional isotropy and affordability [2]. The Al–MoS_2 composites are used in the bicycle frame, bullet proof vests, armor tanks, nuclear waste, neutron absorber in nuclear power plant, transportation applications, etc. owing to their high hardness, low density and excellent thermal and chemical stability [2–4]. Al–MoS_2 composites are fabricated by various researchers in the past few years by stir casting [5–7], casting [8–10], squeeze casting [11] and mechanical alloying [12]

Many techniques had been reported for fabrication of aluminium metal matrix composites (AMMC), but stir casting has been identified as one of the most promising techniques.

Devaraju et al.[13]has fabricated a hybrid SC using Al6061 as parent material and reinforced the same with different mixture of the powder viz., SiC & Graphite (Gr) and Sic & Al2O3. Low wear rate has been observed in the Al–SiC/Gr surface hybrid composite due to mechanically mixed layer generated between the composite pin and steel disk surfaces which contained fractured SiC and Gr. It has been reported that the wear rate was 1/5th of the parent material.

In present work, Aluminium 6061 as being one of the stiffest and strongest aluminium alloy, has been used as matrix metal phase. Whereas Molybdenum disulphide (MoS_2), as being one of the hardest materials found on the earth has been used as reinforcement phase. Al 6061/ MoS_2 composite has been formed using various combination of As casting (AC), Cold rolled (CR), Heat treated (HT) and cold rolled followed by heat treatment (CR+HT). Investigation of microstructure, Micro hardness and wear properties had been done for the AMMC formed.

Before the experimentation is taken-up, the design of experiments, which is an important aspect to decide the number of experiments. Some times the number of experiments will be conducted without any need or without any scientific way of doing things. Therefore, many of the experts have proposed various techniques to decide the number of experiments to be carried out based on the input variable and process parameters. Such variable parameters influencing the experiments are considered based on the levels and suggested the optimum number of experiments need for experimentation. Out of them, the Taguchi Method is being widely used and it is explained in the following.

III. DESIGN OF EXPERIMENTS

Design of Experiments (DOE) is a structured, organized method for determining the relationship between factors affecting a process and the output of that process. Taguchi's approach was built on traditional concepts of design of experiments such as full factorial, fractional factorial designs and orthogonal arrays, based on some new DOE techniques such as signal to noise ratios, robust designs, and parameter and tolerance designs. Design of experiments is a power full statistical technique introduced by R.A. Fisher in England in the 1920s to study the effect of multiple variables. Taguchi method focuses on Robust Design through use of Signal-to-noise Ratio and Orthogonal Arrays. In signal-to-noise ration, signal represents the desirable value and noise represents the undesirable value. Therefore a method of calculating the signal –to-noise ratio has gone for quality characteristics. They are: (i) Smaller-the better (ii) Larger- the better and (iii) Nominal- the best.

Before selecting a particular Orthogonal Array (OA) to be used as a matrix for conducting the experiments, the following two points must be considered: 1) The number of parameters and interactions of interest; 2) The number of levels for the parameters of interest. As per Taguchi's method, the total DOF of selected OA must be greater than or equal to the total DOF required for the experiment. So an L_{25} OA having 24(=25−1) degrees of freedom were selected for the present analysis.

For the experimental plan, the Taguchi method is used for five levels with careful understanding of the parameters. Table-1 indicates the factors to be studied and the assignment of corresponding levels.

Table 1 Process Parameters with their values at corresponding levels

Factors	symbol	Levels				
		1	2	3	4	5
Condition	C	MM	AC	HT	CR	CR+HT
Applied Load(N)	AL	10	20	30	40	50
Speed(rpm)	S	200	300	400	500	600
Sliding Distance(m)	SD	500	1000	1500	2000	2500
Time(min)	T	9	12	14	15	16

IV. MATERIALS AND METHODS

Al alloy of AA6061 matrix material was used. The chemical composition is presented in Table 2. The micron sized MoS_2 particles with a purity of 99% having an average particle size of 20 microns were used as reinforcement materials.

Table 2 Chemical composition of AA6061

Ele	Cu	Mg	Si	Fe	Mn
%	0.19	0.82	0.67	0.19	0.06
Ele	**Zn**	**Ti**	**Cr**	**Al**	
%	0.03	0.07	0.08	Rem	

The following procedure is adopted to obtain raw composite specimens from which actual test specimens were machined. The compositions are cast by the 4wt. % of MoS_2. Estimated amount of matrix metal is preheated at 450°C for 3 hours before melting. The preheated matrix metal is fed into the furnace and first heated above the liquidus temperature to melt completely (700°C). It is then slightly cooled below the liquidus temperature to maintain the slurry in the semi solid state. Magnesium is added to the molten metal to improve the wettability of the reinforced particles in the metal matrix. MoS_2 particles which are preheated at 350°C were then added to the molten metal slowly and stirring is performed at a constant speed of 300 rpm for 15 min. The setup used for melting along with the stirrer is shown if Fig. 1.

Fig. 1 – Stirring mechanism of composite melt

The molten metal is then poured into the cast iron moulds which are also preheated to 400°C to minimize the casting defects. The die is left few hours for solidification. Then the cast specimens are detached from the metallic die and cleaned.

Each fabricated composite plate was marked equally into four parts (150 x 150 x 6 mm) and was cut by power hand saw and these four pieces are further used for four case studies like As Cast (AC), Cold Rolling (CR), Heat Treatment(HT) and combination of Cold rolling & Heat treatment (CR&HT).

V. WEAR ANALYSIS

The wear behavior of the Al 6061 alloy with reinforcement particle (micro sized MoS_2 particle were evaluated by a pin on disc tribometer as shown in the fig.2.

Fig. 2 – DUCOM TR-20M-106 pin-on disc wear test apparatus

Cylindrical specimens of 4 mm diameter and 40 mm length were cut from the AMMC's material as shown in fig. 3 and have been analyzed for wear testing on wear track diameter 80mm based on taguchi's experimental plan.

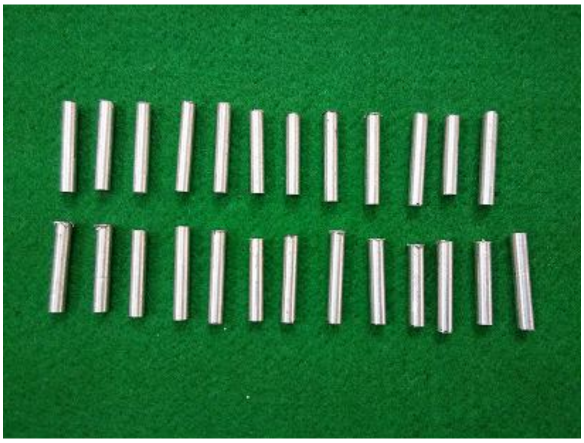


Fig. 3 –pin-on disc wear test specimens

The variation of wear loss in terms of S/N ratio influenced by different condition, speeds and applied loads combination along with the sliding distance and time using minitab.15 software is presented in the Table-3.

Table 3 Response table for S/N ratios of Wear Loss

Level	Condition	Load	Speed	Distance	Time
1	-58.53	-37.52	-39.72	-44.37	-43.87
2	-46.21	-41.85	-44.46	-42.46	-43.15
3	-39.35	-40.75	-43.09	-44.10	-40.81
4	-38.70	-47.88	-41.75	-40.98	-43.92
5	-32.67	-47.45	-46.43	-43.55	-43.92
Delta	25.86	10.36	6.71	3.39	3.12
Rank	1	2	3	4	5

It indicates the S/N ratio at each level of control factor and how it is changed when settings of each control factor were changed from level one to level five.

The experimental results are analyzed also with Analysis of variance (ANOVA). By performing ANOVA, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. This analysis is carried out at a significance level of 0.05 viz. for a confidence level of 95 wt. %.

It is observed from Table 4 that the condition has the highest influence (P=70.16%) on wear. Hence condition is the important control factor to be taken into consideration during wear process followed by applied load (P=14.38 %), speed (P=4.70 %), sliding distance (P=1.38%) and time (P=1.24 wt.%). The pooled error is very accounting for only 9.19 %. The effect of process parameters was also seen from the Fig. 4 graphically. The plot in Fig.6.56 clearly indicate that increase in condition levels from level 1 to 5 decreased the wear and wear increased in load and speed from level 1 to 5, sliding distance from level 1 to 3 decreased, from level 3 to 5 increased. For time from level 1 to 3 wear increased and decreased, and from level 3 to 5 it is increased.

Table 4 Analysis of variance for wear

Source	Seq.ss	DF	Adj MS	F-calculated	% contribution
Condition	1949.93	4	487.483	8.65	70.16
Load	399.78	4	99.946	1.77	14.38
Speed	130.89	4	32.723	0.58	4.70
Distance	38.53	4	9.634	0.17	1.38
Time	34.49	4	8.624	0.15	1.24
Error	255.52	4	56.380		9.19
Total	2779.16	24			

DF-Degrees of freedom, SeqSS-Sequencial sum of squares, AdjSS—Adjusted sum of square, Adj MS-Adjusted mean square, F-Fisher ratio, P-probability that exceeds the 95 % confidence level.

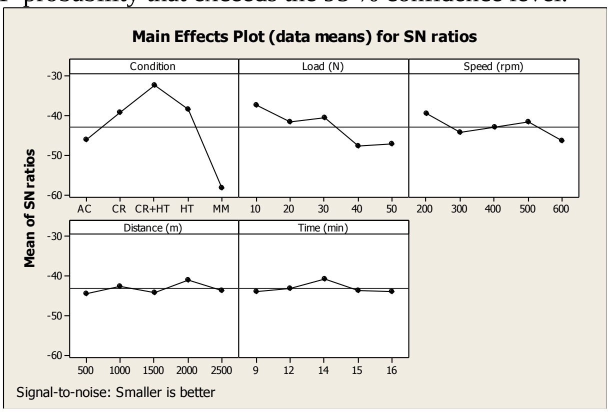


Fig. 4 – Main effects plot for S/N ratios-Wear

. The optimum condition for wear and coefficient of friction were found to be C5AL1S1D4T3 (i.e. at condition 4wt.% MoS_2 CR&HT condition, applied load 10N, speed 200rpm, sliding distance 2000m and time of 14min).

The confirmation test was conducted to validate the optimized process parameters.

VI. RESULTS AND DISCUSSION

A. Wear analysis of AA6061-MoS_2 composites at optimized conditions

Fig. 5 shows the variation of wear with sliding distance of the AA6061+4wt.%MoS_2 composite samples at various conditions. The wear of the as received matrix material is higher than the AA6061+4wt.%MoS_2 at optimized parameters (applied load 10N, speed 200rpm, sliding distance 2000 m and time 14 min).

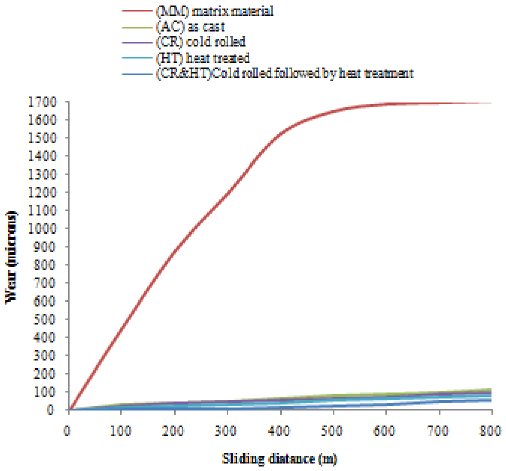


Fig. 5 Variations of wear with the sliding distance for AA6061+4wt.% MoS_2
(a) MM (b) AC (c) CR (d) HT (e) CR&HT

From the table 5 the wear of the AA6061+4wt.%MoS_2 in CR&HT condition has less as compared to the other conditions, this is because of the dispersion of hard MoS_2 particles and Mg_2Si precipitates in uniform manner and fine grain size in AA6061+4wt.%MoS_2 due to CR&HT.

Table 5 wear test results

Condition	MM	AC	CR	HT	CR&HT
Wear (Microns)	1700	53	30	50	28

B. Wear surface analysis of AA6061-MoS_2 composites at optimized conditions

Fig.6(a) shows SEM images for matrix material, which is much softer than the disc material, and during sliding the counter body (steel disc) penetrates into the matrix material producing deep grooves and causing extensive plastic deformation of the surface results in great material loss and significant wear.

Fig.6(b) It indicates formation of the continuous wear grooves, relatively smooth layer and some damaged regions. However, the degree of crack formation on the wear surface is not much. The wear surface is characterized by the formation of parallel lips along the continuous groove marking.

The worn surface shown in Fig.6.(c) depicts the wear in CR comparatively the grooves are reduced. It may be due to uniform distribution of precipitates (Mg_2Si) and MoS_2 particles throughout the matrix material due to CR.

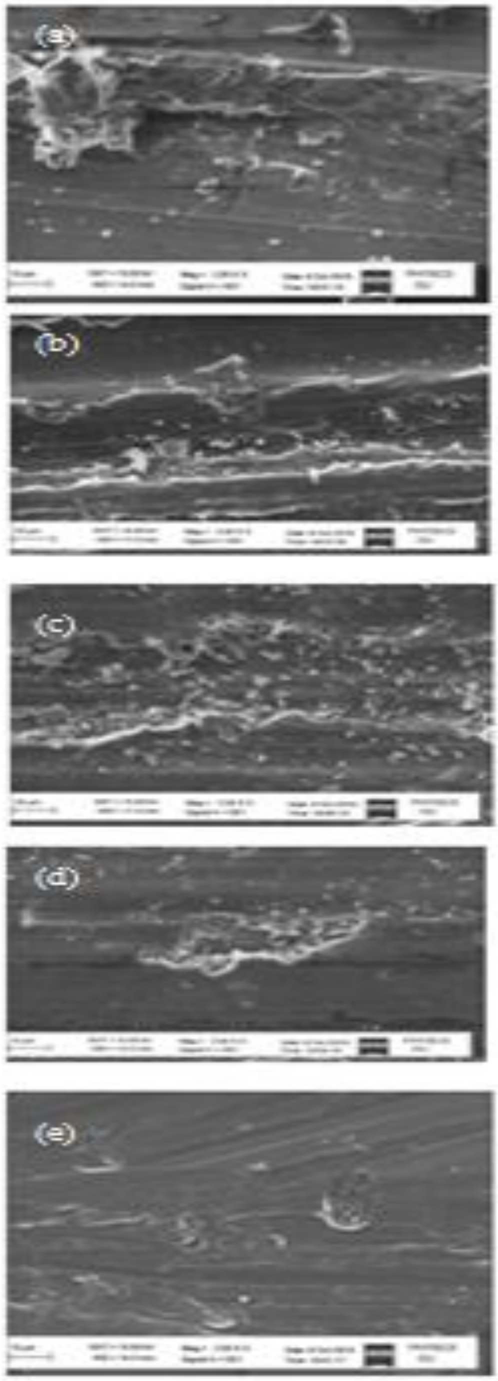
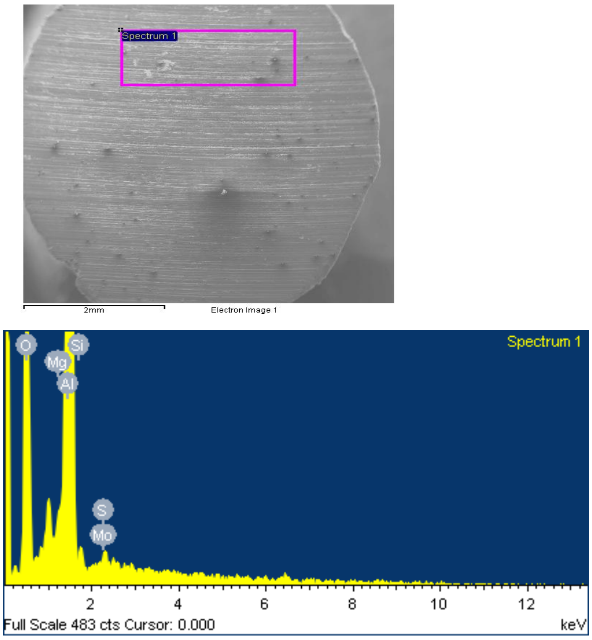


Fig. 6 SEM Images worn out surface of for AA6061+4wt.% MoS_2 (a) MM (b) AC (c) CR (d) HT (e) CR&HT

Fig.6.(d) and Fig.6.(e) shows the SEM Images worn out surface in HT and CR+HT conditions respectively at optimal The wear damage is the lowest for the AA6061- 4wt.% MoS_2 composites at CR+HT condition among the tested composites in other conditions and matrix material.

a)



b)

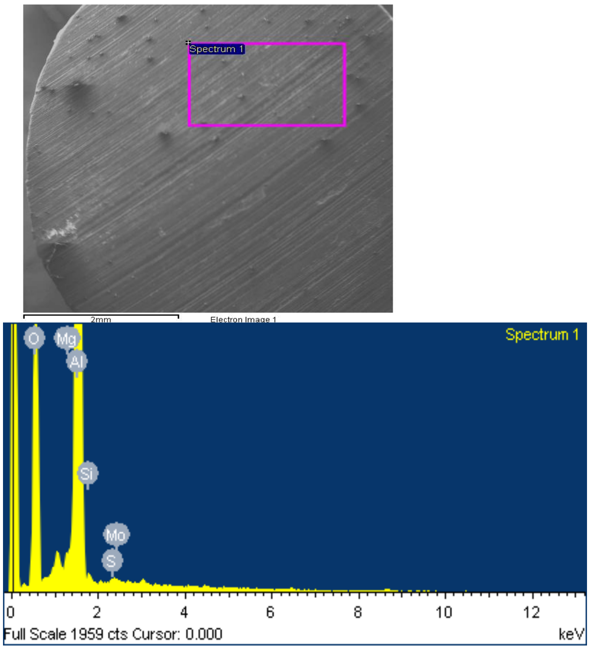


FIG. 7 SEM EDAX Images of 4wt.% MoS_2
(a) MM (b) CR&HT

Fig. 7 (a-b) shows the SEM EDS of worn surface of AA6061+ 4wt.% MoS_2 of different conditions at applied load 10N, speed 200rpm, sliding distance 2000m and time 14 min. The results of the surface analysis of the AA6061+ 4wt.% MoS_2 after wear obtained from EDS are shown in Fig. 7(b) The location selected for EDS analysis from the test specimen was random. EDS spectrum shows the presence of six elements on the surface of the composite. These elements are oxygen (O), magnesium (Mg), aluminium (Al) , Silicon (Si), Sulphur (S) and Molybdenum (Mo). This indicates no contamination of the surface.

Moreover, it is evident from the Fig. 7(a-b) that composite-2 exhibits a slight gradual wear from CR+HT to matrix material. EDS analysis of AA6061+ 4wt.% MoS_2, after wear test, shows only compositional elements of AA6061+ 4wt.% MoS_2 and it can be confirmed that debris produced during wear test on the surface are free from contamination.

VII. CONCLUSIONS

Dry sliding experiments are conducted on AA6061- 4wt.% MoS_2 in all conditions using pin-on-disc experimental set up. The signal to noise ratio analysis based on the Taguchi method is applied successfully in order to identify the dominant parameter that contributes for wear.

i. It is observed that the condition had the highest significant effect followed by applied load, speed, sliding distance, and time on the wear and the speed had the highest significant effect followed by condition, sliding distance, applied load and time on the coefficient of friction.
ii. The optimum condition for wear and coefficient of friction were found to be C5AL1S1D4T3 (i.e. at condition 4wt.% MoS_2 CR&HT, applied load 10N, speed 200rpm, sliding distance 2000m and time of 14min).
iii. Based on the SEM results of the wear tracks, it is concluded that the wear is less for the MoS_2 reinforced composite at CR&HT condition when compared to that of other conditions and unreinforced matrix material. The wear properties of the matrix material was improved by addition of 4wt.% MoS_2 particles in CR&HT condition when comparison with addition of 4wt.% MoS_2 particle for other

conditions and the wear resistance of the composite-2 in CR&HT condition was higher than that of the matrix material and all other composites.

VIII. FUTURE SCOPE OF THE WORK

The present work can be extended to carry out SEM testing, SEM EDAX, factrography and X-ray analysis to study the detailed micrograph analysis of the optimized parameters on CC and PC GMAW of AA5083.

The addition of alloying elements in AA5083 in order to improve the mechanical properties.

IX. BIOGRAPHIES

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