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# Wear Optimization of Al/Sic/Gr Hybrid MMC Using Taguchi and ANOVA

T. PratheepReddy[1], N. Amara Nageswara Rao[2]

P.G. Student, Department of Mechanical Engineering, N.I.S.T, Vijayawada, A.P, India.

Associate Professor, Department of Mechanical Engineering, N.I.S.T, Vijayawada, A.P, India.

**ABSTRACT:** In this paper, study is on preparing hybrid metal matrix composites of Al 6061 alloy as base material by incorporating 6% SiC and varying 2 to 4 % of graphite particulates varying insteps of 2 by vortex method. The dry sliding wear test is performed using pin on disc wear test apparatus as per ASTM standards G – 99 to study the wear and frictional properties of hybrid metal matrix composite. Taguchi's technique is implemented for designing of experiments. The analysis is performed using a L9 Orthogonal array, and Investigation to find the effect of applied load, sliding speed and track diameter on wear rate, during wear process was carried out using ANOVA technique. The wear rate was analysed using taguchi and the optimal parameters for minimizing the wear rate was determined.

**KEYWORDS:** Hybrid MMC, Stir casting, Wear analysis, Taguchi optimization.

## I.INTRODUCTION

Conventional materials has certain shortcomings in good combination of Strength, stiffness, toughness and density. In order to overcome these shortcomings and to meet the demand of modern day technology, composites are most important materials, Out of which Hybrid Metal Matrix Composites (HMMCs) possess high specific strength, toughness, impact strength and low sensitivity to temperature changes [1-3]. As a result, many of the current applications for HMMCs are widely used in the field of aerospace and automobile components,

Aluminium based MMCS are still the subjects of research studies, because of their low density makes more advantageous in many applications. Among the various useful aluminium alloys, aluminium alloy Al 6061 is typically characterized by properties such as fluidity, castability, corrosion resistance and high strength-weight ratio. Due to its high wear loss nature it will not be applicable for many tribological applications. AMCs can be reinforced with SiC, Al2O3, B4C, TiC, TiB2, MgO, TiO2 and BN. To avoid this limitations, Al alloySiC particulate composites are being spread for the mechanical and the tribological applications. Therefore, the investigation of tribological and mechanical behavior of aluminum based materials is becoming increasinglyimportant. Addition of a hard ceramic phase to a relatively soft matrix alloy, commonly aluminium, improves the strength, creep performance, and wear resistance of the alloy [4, 5].

Number of studies have been done on the Al/SiCp [6-8] and Al/Graphite [9, 10] individually. Normally, the external lubricant plays a vital role in wear behavior. The addition of naturallubricant like graphite enhances the self-lubricating capacity of the composites, though the wear behavior of Al/SiCp is good, which is essential in some of the applications where lubrication needs to be applied periodically, especially for wear parts which are difficult to access.

Metal matrix composite is fabricated by the Stir casting technique, because it is economical and good adhesion takes place between the matrix and reinforcement.

"Radhika et al. [11] found taguchi technique as a valuable technique to deal with responses influenced by multi variables. It is formulated for process optimization and detection of optimal combination of the parameters for a given response. This method significantly reduces the number of trials that are required to model the response function compared with the full factorial design of experiments. The most important benefit of this technique is to find out the possible interaction between the factors. Investigation of the experimental outcomes uses signal to noise ratio to support

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the determination of the finest process design. This method is effectively used to analysis of wear behaviour of composites materials [12]. In this various characteristics were taken to finding the minimum wear rate under various applied load and sliding distance conditions.

## II. MATERIALS AND METHOD OF FABRICATION

In the present study, Al 6061 used as matrix, SiC (37µ) and Gr(18µ) as reinforcement. The composites were prepared by using the stir casting technique.

## III.FABRICATION OF THE COMPOSITE

Firstly the Matrix is heated above its melting point and then temperature was decreasedgradually below the liquidus temperature to maintain the matrix alloy in the semi-solid state [9]. At this stage, reinforcement is introduced into the matrix. Degassing is to be done using solid hexachloroethane ($C_2Cl_6$),and then mixed thoroughly. To maintain wettability between the matrix and the reinforcement a small amount of Magnesium is introduced into the melt. The reinforcement was introduced into melt, and after introduction of reinforcement particles, mechanical stirring of the molten alloy for a period of 10 min was achieved by using Zirconia coated steel impeller. The stirrer is preheated before immersing into the melt, located approximately to a depth of 2/3 height of the molten metal from the bottom and run at a speed of 400 rpm. Again the alloy mixture was heated above its liquidus temperature to obtain fully liquid state, and stir for 15 minutes at an average speed of 600 rpm. A pouring temperature of $750^0$C was considered and the melt was poured into the cast iron mould. Hence composites containing 6 % of SiC and 2 - 4% Gr in terms of weight, were obtained in the form of cylindrical rods of dia 12 mm.

## IV.WEAR ANALYSIS

The objective of the study is to achieve the minimum wear rate. A pin-on-disc test machine is used to perform the wear experiment at Ducom Instruments, Bangalore. Specimens of size 10 mm diameter and 20mm length were cut from the cast samples, machined and then polished. The tests were conducted at room temperature under unlubricated conditions. A digital weighing machine is used to weigh each specimen having an accuracy of ±0.0001 gm. During the test, the sample is held pressed against a rotating EN32 steel disc (hardness of 65HRC) by applying load that acts as counter weight and balances the pin. The parameters such as the load, sliding speed and sliding distance were varied in the range given in Table-1. A LVDT (load cell) on the lever arm helps in determining the wear at any point of time by monitoring the movement of the arm. Once the surface in contact wears out, the load pushes the arm to remain in contact with the disc. This movement of the arm generates a signal which is used to determine the maximum wear. Weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of .0001g after thorough cleaning with acetone solution.

a b

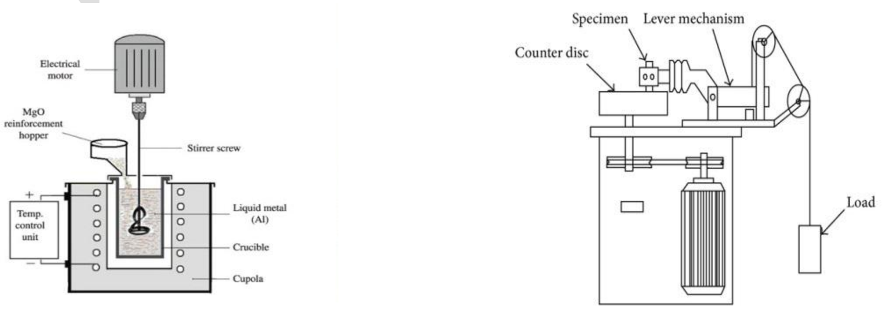


Fig. 1. (a) Stir Casting Furnace (b) Pin on Disc Apparatus

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**Table 1** Process parameters and their levels

| Parameter | Level - 1 | Level - 2 | Level - 3 |
|---|---|---|---|
| **Load (N)** | 10 | 30 | 50 |
| **Speed (rpm)** | 200 | 600 | 1000 |
| **Track Dia (mm)** | 50 | 80 | 110 |

## V. DESIGN OF EXPERIMENTS

In the study, applied load, speed and track diameter were chosen as the independent variables and wear rate, was selected as response variables for the alloy and composites. Commercial statistical software MINITAB 16 was specifically used for design of experiment and L9 orthogonal array and the selection of Orthogonal array depends on three items in order of priority, viz., the number of factors and their interactions, number of levels for the factors and the desired experimental resolution or cost limitations. A total of 9 experiments were performed based on the run order generated by the Taguchi model. The response for the model is wear rate. Plan of experiments were listed in the table 2.

**Table 2.** Design of Experiments

| S.No | Load | Speed | Track Dia |
|---|---|---|---|
| **1** | 10 | 200 | 50 |
| **2** | 10 | 600 | 80 |
| **3** | 10 | 1000 | 110 |
| **4** | 30 | 200 | 80 |
| **5** | 30 | 600 | 110 |
| **6** | 30 | 1000 | 50 |
| **7** | 50 | 200 | 110 |
| **8** | 50 | 600 | 50 |
| **9** | 50 | 1000 | 80 |

The model objective is to minimize the wear rate. The Signal to Noise (S/N) ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. The S/N ratio characteristics is categorised into three viz. „nominal is the best", „larger the better" and „smaller the better „characteristics. In this work, "smaller the better" characteristics is opted to analyse the dry sliding wear resistance. The smaller the better S/N ratio characteristic given by Taguchi, is as follows:

$$S/N = -10 log \frac{1}{n}\sum_{i=1}^{n} y_i^2$$

Where y1, y2...yn are the sliding wear and response of friction and n being the number of observations. The response table for signal to noise ratios represents the average of selected characteristics for each level of the factor. This table includes the ranks based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. Analysis of variance of the S/N ratio is performed to identify the statistically significant parameters.

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In order to the combined effects of the independent variables on the responses, L9 orthogonal array experiments with no repetition were carried out. The observed responses were fitted to a first order polynomial equation. From this the regression equation was derived for the composites and the taguchi technique was applied to evaluate the optimum composite and condition. The investigational results and calculated values were obtained based on the plan of experiment and then the results were analyzed with the help of commercial software MINITAB 16 as specially utilized for the Design of Experiment and statistical analysis of experiment applications.

## VI. RESULTS AND DISCUSSIONS

### a) Wear behavior

The wear rate of composites decreases compared to unreinforced alloy. Increase in wt% of Gr wear rate decreases compared with the lower weight percentages of reinforcement. Gr reduces the wear rate because of its lubricant property. The unreinforced aluminium alloy was softer than the hybrid composites and because of this the base alloy undergoes high wear rate. The wear rate for base alloy and composites were shown in fig 2

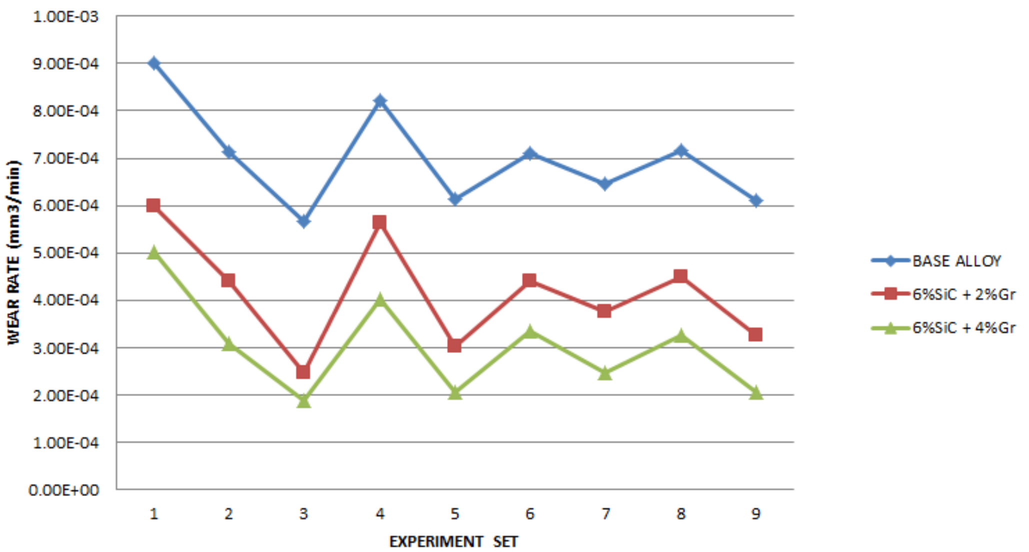


**Fig. 2**. Wear rate Vs. experimental sets

### b) ANOVA Results for Wear Test:

The experimental results were analysed with Analysis of Variance (ANOVA) which is used to investigate the effect of the considered wear parameters namely, applied load, sliding speed, and track diameter that significantly affect the performance measures. By performing analysis of variance, 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 for a significance level of $\alpha=0.05$, i.e. for a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures.

### c) Regression model

A multiple linear regression model is fitted using "MINITAB 16". This model gives the relationship between input and output by fitting a linear equation. Regression equation thus generated establishes correlation between the significant terms obtained from ANOVA analysis namely applied load, sliding speed & track dia.

The regression equation developed for wear rate for base alloy and composites are as follows:

Y (base alloy) = 0.0010948 - 0.0000018*Load - 0.0000002*Speed - 0.0000028*Dia……(1)

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Y(Al+6%SiC+2%Gr,) = 0.0008317 - 0.0000011* Load - 0.0000002* Speed - 0.0000031* Dia (2)

Y(Al+6%SiC+4%Gr,) = 0.0006969 - 0.0000018* Load - 0.0000002* Speed - 0.0000029*Dia (3)

From the above eq's (1- 3) it indicates that load, speed and track dia, increases or decreases the wear rate and coefficient of friction at any parametric value. the positive sign indicates that increase in load increases the wear rate and coefficient of friction and negative sign indicates that increase in speed and track dia decreases the wear rate and coefficient of friction. Confirmation experiment for wear rate was conducted as in the table 2 and compared with the regression equation results and found to be varied slightly in terms of percentages. For base alloy, Al+6%SiC+2%Gr, Al+6%SiC+4%Gr, the wear rate 2- 5% , 2-10%, 1– 7%, compared with the experimental values respectively.

**d) Optimal parameters:**

The optimal parameters for minimum wear rate for different composites was analysed using smaller the better analysis and the optimal parameters are tabulated below in the table 3 and shown in fig 3,4 and 5.

**Table 3.**Optimal parameters

| S.No | Type of composite | Load (N) | Speed (rpm) | Track Dia (mm) |
|---|---|---|---|---|
| 1 | Base alloy – Al 6061 | Level – 3 ,50N | Level -3,1000 rpm | Level -3,110 mm |
| 2 | Al 6061 + 6%SiC + 2%Gr | Level – 3 ,50N | Level -3, 1000 rpm | Level -3,110 mm |
| 3 | Al 6061 + 6%SiC + 4%Gr | Level – 3 ,50N | Level -3,1000 rpm | Level -3,110 mm |

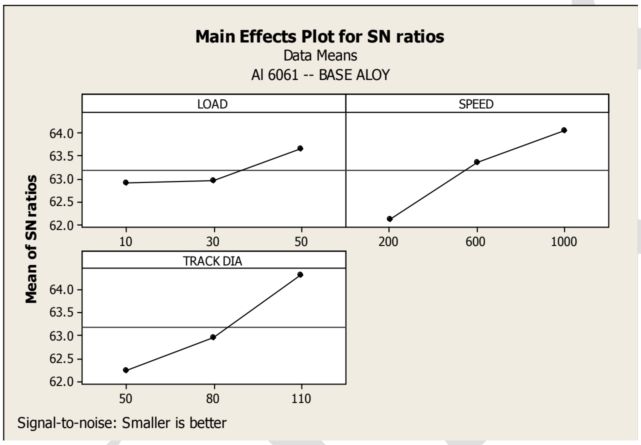


**Fig 3. Optimal parameters of Al 6061**

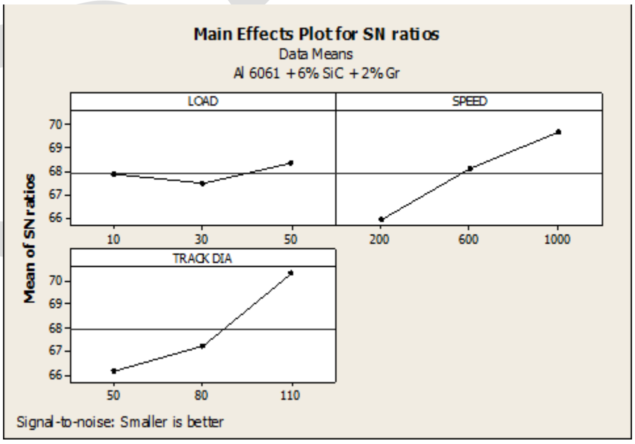


**Fig 4. Optimal parameters of Al 6061 + 6% SiC + 2% Gr**

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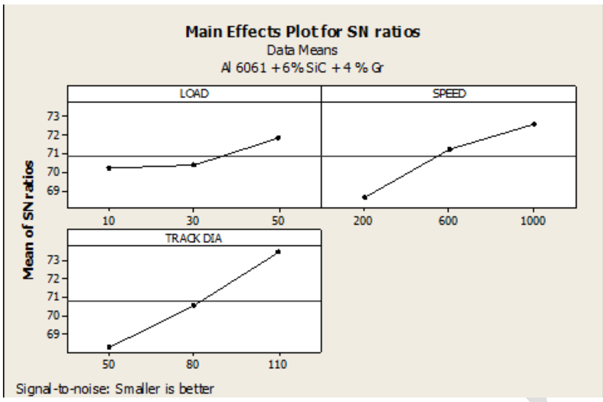


**Fig 5. Optimal parameters of Al 6061 + 6% SiC + 4% Gr**

From the fig 3,it shows that base alloy exhibits the minimumwear ratei.e; 4.97E-04 mm3/N-m at load 50N, 1000 rpm and trackdia 110 mm. and from the fig 4,it shows that Al/SiC(6%)/Gr(2%) composite exhibits the minimum wear ratei.e; 2.36E-04 mm3/N-m at load 50N, 1000 rpm and trackdia 110 mm, and from the fig 5,it shows that Al/SiC(6%)/Gr(4%) exhibits the minimum wear ratei.e; 8.79E-05mm3/N-m at load 50N, 1000 rpm and trackdia 110 mm.

## VI. CONCLUSIONS

- The hybrid composites have been successfully fabricated by stir casting route for the study of tribological properties.
- The wear resistance of the composites increases with addition of the SiC and Gr particle content. The wear rate is comparatively less for the composites compared to pure matrix material.
- The wear rate at 6 wt. % SiC/ and 4% Gr is very less compared with the wear rate for the pure matrix material.
- The analytical results of taguchi shows the speed,load and track dia influences the wear rate and coefficient of friction.
- The optimal parameters for minimum wear rate of base alloy and composites are load 50N, speed 1000 rpm and Track dia 110 mm.
- The confirmation test was done using the optimal parameters and the results are agreed.

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