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# Optimization of Wear Factors of Aluminium Hybrid Metal Matrix Composites Using Taguchi Method

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## Abstract

Hybrid metal matrix composites (Hmmc) are found to be more superior than the conventional composite materials because of their improved mechanical properties, which can be suited for an extensive range of engineering applications. Automobile and aerospace industries widely make use of hybrid composites as they possess excellent corrosion, wear resistance, low density, and high strength. This paper displays the strategy to build the hybrid composite utilizing Stir casting Method. Present investigation includes the creation of composites utilizing boron carbide (2%, 4%, 6% volume) and Red mud (2% volume) as the reinforcements and Structural aluminium as the matrix. Experimental investigation of wear analysis of the composites was carried out according to the L9 Taguchi method. The designated number of experiments was accomplished to probe the impact of control factors on the specific wear rate (SWR) of the developed composites. ANOVA was carried out and Wt%. Reinforcement was found to be the decisive factor on the SWR of the developed hybrid composite. The Confirmatory test was successfully carried out and the computed error was found to be varying from 0.878% to 2.58%.

## 1. Introduction

In recent years, a considerable rate of demand has been observed for hybrid composites across the globe. Hybrid metal matrix composites [Hmmc] synthesized using multiple reinforcements have excellent properties which suits appli-

cations in automobile and aerospace sector [1] [2] [3]. Appropriately selecting the specific matrix and reinforcements, it is practically possible to develop the tailored made composite. More consideration has been given to aluminium and its alloys because of their widespread application in automobile industry [4]. Reinforcements such as Fly ash, Graphite, Boron carbide, Red mud, Silicon carbide, titanium oxide etc., can be used successfully to develop the hybrid composites [5] [6] [7] [8]. Low cost, better intermolecular interactions between the matrix and reinforced particles and invariant distribution of reinforced particles can be produced through the liquid metallurgical technique [9] [10] [11]. Taguchi technique is a statistical experimental strategy for conducting a limited set of experiments as per the orthogonal array which adds new dimension to the conventional experimentation. Pin on disc has been used in large cases of wear studies considering parameters such as load, speed, percentage reinforcement, time and sliding distance [12]-[17]. ANNOVA reveals the most significant decisive factor which influences the wear characteristics of the composite. From the literature survey, it becomes obvious that many researchers have worked on wear behaviour of MMC's. Limited work has been carried out on optimizing the wear parameters of Aluminium reinforced with boron carbide and red mud.

In the present study, research is realized on composites that contain aluminium as the base matrix material, boron carbide having high hardness and stiffness and Red mud as the reinforcements. Present experimental work utilizes Genichi Taguchi Design of Experiments for the optimization of input control factors to obtain output in terms of minimum SWR Wt%. Reinforcement, Load and Speed are the input control parameters and SWR is the output response. L9 Orthogonal Arrays are used which limits the number of trials to be conducted and Signal-to-noise ratios (S/N) serve as objective functions for optimization. A Linear regression model was developed and validated through the confirmative test.

## 2. Experimental Details

### 2.1. Details of Matrix and Reinforced Materials

In the present research study, Structural aluminium containing 0.8% - 1.2% magnesium and 0.4% - 0.8% silicon as the major constituents is selected as it is widely applicable in the fields of construction and automotive. **Figure 1** shows the image of the structural aluminium.

Boron Carbide, a ceramic material and Red mud, a waste by product from the production of alumina are selected as reinforcements, shown in **Figure 2(a)** and **Figure 2(b)**. From the chemical analysis report, Composition of Structural aluminium, boron carbide and Red mud are shown in **Tables 1-3**.

Stir casting is an effortless and economical method, in which reinforcements are added along with the base matrix material with the aid of a mechanical stirrer to produce hybrid castings. Raw matrix materials were stacked first in the

Figure 1. Structural aluminium.



Figure 2. Boron carbide & red mud reinforcement.

Table 1. Composition of structural aluminium.

| Fe | Si | Mg | Cr | Cu | Zn | Mn | Ti | Al |
|------|------|-----|------|------|------|------|------|-----------|
| 0.7 | 0.65 | 0.8 | 0.07 | 0.25 | 0.25 | 0.15 | 0.15 | Remaining |

Table 2. Percentage of composition of boron carbide particles.

| B | $Fe_2O_3$ | Si | C |
|-----|------|----|-----------|
| 70% | 0.10 | 1% | Remaining |

Table 3. Percentage composition of redmud particles.

| $Al_2O_3$ | $Fe_2O_3$ | $SiO_2$ | $TiO_2$ | $Na_2O$ | CaO | LOI |
|---------|---------|-------|--------|--------|---------|-----|
| 17 - 20 | 44 - 47 | 7 - 9 | 8 - 11 | 17 - 20 | 44 - 47 | 7 - 9 |

graphite crucible as per the calculations and then melted in an electrical induction furnace, which is shown in Figure 3. Once the melt temperature reaches 750°C the degassing of molten metal was administered using hexachloro ethane tablets. At the same instant boron carbide (2%, 4%, 6%, volume) and Red mud particles (2% volume) were heated in a separate muffle furnace at 1000°C to remove water content. The added reinforcements were blended continuously by using a mechanical stirrer for about 10 - 12 minutes at an impeller speed of 300 rpm. The melted metal is then spouted into the preheated die. Test specimens are displayed in Figure 4.

## 2.2. Wear Test Procedure

Wear is an essential factor in deciding the life span and consistency of the

**Figure 3.** Electrical induction furnace with stirrer.



**Figure 4.** Test specimens.

engineering systems. Frictional resistance between the contact surfaces causes wear on the surfaces which results in the cumulative loss and deformation of the material. Pin-on-disk tribometer, as shown in Figure 5 is the standard test instrument (VER02 Computerized Pin on Disc Wear Testing Machine, Bangalore) for the assessment of friction, wear rate and wear resistance. Wear samples (10 mm × 10 mm) and testing were carried out according to ASTM G99 standard. A pin is loaded against a flat revolving EN31 steel disc and the wear track diameter is set to 60 mm.

The specific wear rate of 2% $B_4C$ and 2% Red mud aluminium hybrid composite, 4% $B_4C$ and 2% Red mud aluminium hybrid composite, 6% $B_4C$ and 2% Red mud aluminium hybrid composites were investigated. Tests were realized with different values of Speed at 600, 1200 and 1500 rpm, under normal loads of 10 N, 20 N, and 30 N.

## 3. Experimental Results and Discussion

### 3.1. Taguchi's Design of Experiments

The Genichi Taguchi's Design of Experiments utilizes orthogonal array (OA), signal-to-noise (S/N) ratios, main effects, and Analysis of Variance (ANOVA). L-9 orthogonal array which is more efficient than other statistical methods is selected, which has 9 rows and 3 columns. The Input control factors considered here are Wt%. Reinforcement, Load and Speed, each at three different levels, represented in Table 4. Experiments were carried out for 9 tests according to the

**Figure 5.** Pin on disc tribometer.

**Table 4.** Control factors and levels of the experiment.

| Control factors | Units | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Wt%. Reinforcements (M) ($B_4C$ + 2% RM) | Wt% | 2 | 4 | 6 |
| Load (L) | N | 10 | 20 | 30 |
| Speed (S) | rpm | 600 | 1200 | 1500 |

standard Taguchi method. SWR is considered as the output response in the present investigation. The well-balanced experiments were implemented for the distinct combinations of input control parameters and SWR is tabulated as the output response. Minitab-17 is employed to measure the standard characteristics of S/N quantitative, which is then remodeled from the experimental value. The specific wear rate is studied as the output response to S/N ratio, considering the smaller the better-quality characteristic. The focus of the present investigation is to obtain minimal SWR. The input and output factors and the respective S/N ratios are shown in Table 5.

The investigation of S/N ratio reveals the most significant statistic decisive factor.

Table 6 shows the response for S/N ratios and according to it the most influential decisive Control factor and the optimal factor for SWR is determined.

Main effect of control factors will be directly represented by examining how each individual factor affects the SWR and is shown in Figure 6. SWR found to decrease with increase in the% of Reinforcement and Load.

In Figure 6, the effect of the three factors, which are Wt%. Reinforcement, Load & Speed for S/N ratio for the SWR is represented. From Table 6 & Figure 5, optimization of factor variant is obtained by considering the highest S/N ratio among the control factors.

From the study of the results, the lowest SWR is obtained from the factor combination having a load value of 30 N, Speed at 1200 rpm, and 6 Wt%. Reinforcement.

According to the ranking from Response table (Table 7), the most influential factors can be determined, which are in the order of Wt%. Reinforcement, Load, and

(a)
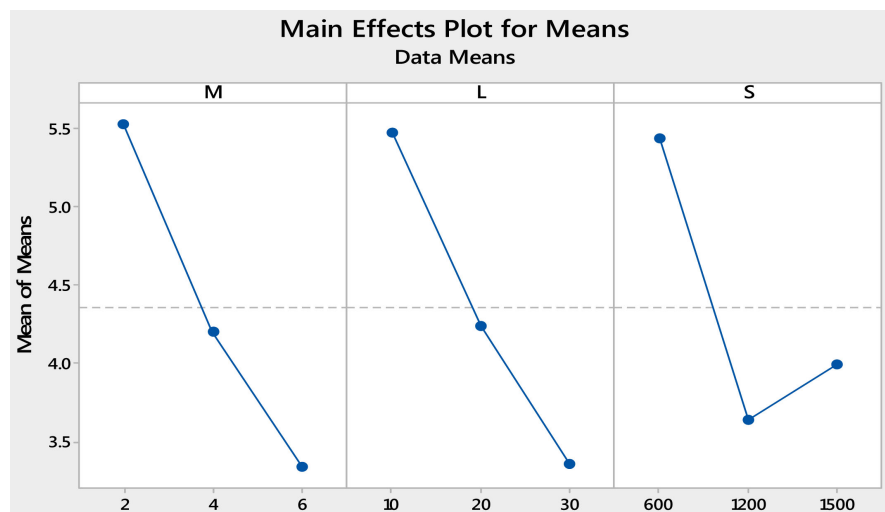


(b)

**Figure 6.** (a) and (b): Effect of control factors on SWR.

**Table 5.** L-9 OA experimental design.

| Ex No | Wt%. Reinforcements (M) | Load (L) N | Speed (S) rpm | Specific wear rate (SWR) (mm³ × 10⁻⁵/Nm) | S/N Ratio SWR |
|---|---|---|---|---|---|
| 1 | 2 | 10 | 600 | 8.10000 | −18.1697 |
| 2 | 2 | 20 | 1200 | 4.32676 | −12.7232 |
| 3 | 2 | 30 | 1500 | 4.17243 | −12.4078 |
| 4 | 4 | 10 | 1200 | 4.60780 | −13.2699 |
| 5 | 4 | 20 | 1500 | 4.10000 | −12.2557 |
| 6 | 4 | 30 | 600 | 3.91992 | −11.8655 |
| 7 | 6 | 10 | 1500 | 3.71858 | −11.4075 |
| 8 | 6 | 20 | 600 | 4.30000 | −12.6694 |
| 9 | 6 | 30 | 1200 | 2.00000 | −6.02060 |

Table 6. Response table for S/N ratio.

| Level | M | L | S |
|---|---|---|---|
| 1 | −14.43 | −14.28 | −14.23 |
| 2 | −12.46 | −12.55 | **−10.67** |
| 3 | **−10.03** | **−10.10** | −12.02 |
| Delta | 4.40 | 4.18 | 3.56 |
| **Rank** | **1** | **2** | **3** |

Table 7. Reponse table mean.

| Level | M | L | S |
|---|---|---|---|
| 1 | 5.533 | 5.475 | 5.440 |
| 2 | 4.209 | 4.242 | 3.645 |
| 3 | 3.340 | 3.364 | 3.997 |
| Delta | 2.194 | 2.111 | 1.795 |
| **Rank** | **1** | **2** | **3** |

then Speed. Levels of the optimal parameter variant are M3L3S2, which means that the Wt%. Reinforcement and Load are on the third level and the Speed is on the second level.

## 3.2. Analysis of Variance

Statistical parametric ANOVA test was employed for the inference of the experimental results. ANOVA was used to review the combination of control factors which considerably affects the output response, *i.e.*, SWR, without lubrication. ANNOVA for specific wear rate is represented in Table 8. Analysis was conducted at a level of significance of 5% (*i.e.*, confidence interval of 95%). The factor is highly statistically significant when the corresponding p-value is lower than the significance level of 0.05.

From the results it can be discerned that Wt%. Reinforcement was the most substantial factor having the highest statistical effect (38.3%) followed by Load (34.83%) and then Speed (25.50%). Outcomes of ANOVA for SWR obtained by using the MINITAB 17 software indicates that Wt%. Reinforcement is the most significant factor that influences the SWR, as the p value for the obtained model was less than 0.05.

## 3.3. Regression Analysis and Confirmatory Tests

### 3.3.1. Regression Analysis

Linear Regression equation was built using the MINITAB 17 software. An interrelationship was established between the significant control factors and the SWR.

The linear regression equation developed for SWR is:

$$SWR = 10.65 - 0.548M - 0.1056L - 0.001802S$$

Table 8. ANOVA for the transformed response.

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | p-Value |
|--------|----|--------|--------------|--------|--------|---------|---------|
| M | 2 | 0.38652 | 38.30% | 0.38652 | 0.193258 | 28.09 | 0.034 |
| L | 2 | 0.35154 | 34.83% | 0.35154 | 0.175771 | 25.55 | 0.038 |
| S | 2 | 0.25738 | 25.51% | 0.25738 | 0.128690 | 18.71 | 0.051 |
| Error | 2 | 0.01376 | 1.36% | 0.01376 | 0.006879 | | |
| Total | 8 | 1.00920 | 100.00% | | | | |

Table 9. Experimental and predicted values.

| S N | Wt%. Reinforcements | Load | Speed | Experimental | Predicted | Error |
|-----|---------------------|------|-------|--------------|-----------|-------|
| 1 | 6 | 30 | 1200 | −6.02060 | −6.18187 | 2.58 |
| 2 | 4 | 30 | 600 | −11.8655 | −12.1767 | 2.54 |
| 3 | 2 | 10 | 600 | −18.1697 | −18.3310 | 0.878 |

### 3.3.2. Confirmatory Tests

The confirmatory test is the culminating step in the verification of advancement of performances of characteristics on the base of achieved optimal control factors. The outcome of the confirmatory test is compared with the result of the orthogonal series.

S/N Ratio of the experimental values are compared with their predicted values and the outcomes are shown in Table 9. It is observed that the computed error associated with the experimental values and the predicted values was found to be minimum. The computed error varies from 0.878% to 2.58% and the regression model can be effectively used to calculate the SWR obtained from the L-9 Orthogonal array.

## 4. Conclusions

The main purpose of the present study was to develop hybrid composites and obtain the optimal set of control factor which affect the wear performance of hybrid composites.

1) Hybrid composite was successfully developed by combining various proportions (2, 4, 6 Wt%) of boron carbide and 2% Red Mud reinforcements using Stir casting methodology.

2) Initially, the outcome of varying three factors—namely, Wt% Reinforcement, Load and Speed on the Specific wear rate was studied using a Genichi Taguchi L9 Orthogonal array.

3) From the response table of S/N ratio and Mean, the optimal set of parameters for improved wear behaviour of the hybrid composite were identified to be 6 Wt%. Reinforcement, 30 N Load and Speed at 1200 rpm.

4) SWR was found to decrease with an increase in Load and percentage of reinforcement.

5) The ANOVA indicated that Wt%. Reinforcement was the most influencing

factor having a contribution of 38.3%, followed by load having a contribution of 34.83% and then speed having a contribution of 25.50%.

6) Regression model was successfully developed to determine the SWR.

7) The Confirmatory test was successfully carried out and the computed error was found to be varying from 0.878% to 2.58%.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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