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# TRIBOLOGICAL PERFORMANCE OPTIMIZATION OF AL6061-RICE HUSK ASH COMPOSITES USING THE TAGUCHI METHOD AND GREY RELATIONAL ANALYSIS

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**ABSTRACT**

The study of the Tribological performance of Al6061-Rice Husk Ash MMCs and optimized the tribological control parameters using the Taguchi technique along with Grey Relational Analysis. To find the wear & friction values, Composite samples testing was conducted on a pin-on-disk machine under dry sliding conditions using the Taguchi technique. Factors like Volume fraction (V), Load (L), Sliding Speed (S) are selected at three levels. Therefore, $L_{27}$ Orthogonal array is selected. The experimental results data was used to calculate the grade value. A grey grade values were calculated using grey relational analysis is used as an output response to study the wear and Coefficient of friction of Al-RHA composite samples. To find the most important factors and their contribution to the performance of composite samples variance analysis is conducted. It was found out that the load factor has the highest contribution to the tribological performance of Al-RHA composite samples. Furthermore, all other interactions between the parameters have a significant influence on tribological performance. To validate the results of experiments and analysis, a confirmation test is carried out. The electron microscope was used to inspect the wear mechanism of the composite samples.

**KEYWORDS:** *wear; friction; Taguchi method; Grey relational analysis*

## 1. Introduction

In recent years there has been a rapid growth in the utilization of aluminum alloy in Industries due to its unique properties. There are different types of reinforcement materials that are used to improve the properties. They are broadly classified as Ceramic particles, Industry waste, and Agricultural waste. Stir casting technique is used widely for the fabrication of Aluminium metal matrix composites [1]. In the present paper, aluminum alloy as base metal and Rice husk ash particles as reinforcement developed AMMCs samples by varying the percentage of RHA and studied the wear and friction properties of the samples. Many researchers studied that Agro waste like maize stalk ash, corn cob ash, bean shell waste ash, rice husk ash, as reinforcement material which improved the tensile strength, hardness, wear and friction properties of AMCs. [2,3,4,5,6]. M Senthilkumar et. al. [7] studied the tribological characteristics of Al–RHA material using the Taguchi method. It found that the rate of wear and friction coefficient highly affected by the percentage of reinforcement followed by applied load and sliding speed. S. D. Saravanan et. al. [8] stir casting equipment was used for the development of composite samples and tribological properties evaluated using Pin on Disc machine. According to Taguchi Orthogonal array design, $L_{27}$ experiments were performed. Artificial Neural Network model was developed to predict the tribological behavior. odunrin et al. [9] Agrowaste material as reinforcement are believed to be assured materials for the development of Aluminium composites on a commercial scale. Furthermore, studies should be done on the optimization of the fabrication process to determine the optimum process parameters. Shouvik Ghosh et al. [10] Optimize the tribological performance of Al-SiCp composites material using the Taguchi and Grey relational technique. S Dharmalingam et. al. [11] Taguchi-grey relational technique used to optimize the hybrid metal matrix composites while considering the various process parameters as well as material characteristics for analysis. Prasanth Achuthamenon Sylajakumari et. al. [12] studied wear performance optimization of AA6063/SiC co-continuous composites using Taguchi and Grey relational analysis, find out the optimum set of parameters for wear performance of the composites.

## 2. Taguchi Method

Taguchi method [13-15] is a statistical design system based on different arrays of design experiments. Parameter design is very important as it optimizes the system design so that quality improves and reduces the cost. Taguchi uses signal-to-noise ratios as response variables. S/N ratios classified into various types according to desired output conditions. For all the materials, the wear rate should be minimum, therefore smaller the better will be considered. variance analysis (ANOVA) was carried out to find the parameters which are statistically notable. With the help of signal to noise ratio values and variance analysis, the optimal set of factors and their percentage contribution can be predicted.

2.1. Experiment Design

Design of Experiment is the important step in the Taguchi technique, according to the factors and testing levels a suitable orthogonal array selection is to be carried out. As well as the experiments were performed according to the orthogonal array design. Orthogonal design enables us to find out the outcome of each factor on the wear depth and friction coefficient responses independent of all remaining factors. Table 1. Shows design factors and their levels, where three design factors considered are, Volume Fraction (V), Load (L) and Sliding speed (S) as well as their values at different levels. According to factors and their levels, two orthogonal arrays are available in Minitab software that is $L_9$ AND $l_{27}$. But in case $L_9$ factors interaction results not possible therefore L27 orthogonal array was preferred as well as array consist of 27 rows and 13 columns.
Here, the First column is volume fraction (V), the second column is Load (L) and the fifth column is Sliding speed (S). The remaining all other columns are two-factors interaction and error terms. According to the orthogonal array, the total number of trails is 27, it means that 27 experiments as to perform as per set values of factors in each row. The system's output to be studied was the wear and COF.

Table 1**.** Design factors and their levels

| Levels | Design Factors | | |
|---|---|---|---|
| | Volume fraction (V) (% wt.) | Load (L) (N) | Sliding speed (S) (m/s) |
| 1 | 4 | 9.81 | 2 |
| 2 | 8 | 19.62 | 3 |
| 3 | 12 | 29.43 | 4 |

**3. Wear & Friction Test**

The wear & friction test was performed on Pin on disk tribotester setup. To study the wear & COF behavior of Al6061-Rice husk ash under normal sliding conditions at normal temperature (28$^0$C). The Al- Rice husk ash samples with specific sizes were pressed against the rotating steel Disk which is made up of material EN8 steel with hardness 55 HRc. The tribological test was performed as trails no. of orthogonal array settings Table 2. and track diameter of disk varied from 60 to 130 mm for each set of experiments. During the tests, wear depth and friction coefficient were recorded by the computer system which is enabled with sensors. The following are the experimental results of wear & COF Table 2.

Table 2. Experimental results

| Experiment no. | Volume fraction (V) (% wt.) | Load (L) (N) | Sliding speed (S) (m/s) | COF | Wear (µm) |
|---|---|---|---|---|---|
| 1 | 4 | 9.81 | 2 | 0.198 | 35.189 |
| 2 | 4 | 9.81 | 3 | 0.176 | 54.110 |
| 3 | 4 | 9.81 | 4 | 0.806 | 23.654 |
| 4 | 4 | 19.62 | 2 | 0.486 | 44.707 |
| 5 | 4 | 19.62 | 3 | 0.477 | 81.161 |
| 6 | 4 | 19.62 | 4 | 0.944 | 53.739 |
| 7 | 4 | 29.43 | 2 | 0.222 | 27.461 |
| 8 | 4 | 29.43 | 3 | 0.805 | 26.417 |
| 9 | 4 | 29.43 | 4 | 0.159 | 20.242 |
| 10 | 8 | 9.81 | 2 | 0.353 | 18.203 |
| 11 | 8 | 9.81 | 3 | 0.508 | 20.016 |

| | | | | | |
|---|---|---|---|---|---|
| 12 | 8 | 9.81 | 4 | 0.284 | 14.451 |
| 13 | 8 | 19.62 | 2 | 0.72 | 31.040 |
| 14 | 8 | 19.62 | 3 | 0.824 | 53.945 |
| 15 | 8 | 19.62 | 4 | 0.835 | 45.322 |
| 16 | 8 | 29.43 | 2 | 0.52 | 16.556 |
| 17 | 8 | 29.43 | 3 | 0.262 | 60.292 |
| 18 | 8 | 29.43 | 4 | 0.708 | 35.088 |
| 19 | 12 | 9.81 | 2 | 0.111 | 20.683 |
| 20 | 12 | 9.81 | 3 | 0.806 | 39.573 |
| 21 | 12 | 9.81 | 4 | 0.724 | 72.828 |
| 22 | 12 | 19.62 | 2 | 0.276 | 34.998 |
| 23 | 12 | 19.62 | 3 | 0.505 | 21.925 |
| 24 | 12 | 19.62 | 4 | 0.618 | 26.660 |
| 25 | 12 | 29.43 | 2 | 0.364 | 21.669 |
| 26 | 12 | 29.43 | 3 | 0.352 | 10.367 |
| 27 | 12 | 29.43 | 4 | 0.538 | 90.552 |

## 4. Grey Relational Analysis

The main objective is to reduce both wear depth and friction coefficient of Al6061-RHA and to find the optimum the test parameters. Thus, it is a Dual response optimization case. Therefore, it is required to evaluate the overall $S/N$
the ratio for both the characteristics for optimization purposes. Grey relational analysis [16] is a very efficient tool for the dual response or multiresponse analysis. For GR analysis, it involves various steps i) Develop the Normalized data within the range of 0 and 1 using experimental results. For that three standard formulas are available based on condition- bigger, smaller and nominal is the best. For wear and friction minimization smaller, the better formula will be used. (k influence factor)

$$Normalized\ value\ = \frac{max\, x_i - x_i}{max\, x_i - min\, x_i}$$

ii) find the grey relational degree (Δ) using normalized data. It is calculated as the maximum minus minimum. iii) calculate the grey coefficient, coefficient constant k is usually set to 0.5. iv) grade value is average the grey relational coefficients. Find out the single grade value for multiple output responses

*4.1 Procedure to find out the Grey relational grade*

To find the grey relational grade first we have to evaluate the values of normalized data, grey degree and grey coefficient from experimental results as per the formulas mentioned in the above paragraph. Here, Table 3. Shows the step by step procedure to calculate the grey relational grade for each experiment.

Table 3. Evaluated values of Grey Relational Grade.

| Exp. No. | Experimental Results | | Normalized data Generated | | Degree Value of Δ | | Grey relational coefficient | | Grey relational grade |
|---|---|---|---|---|---|---|---|---|---|
| | COF | Wear (µm) | Normalized COF | Normalized WEAR | Δ COF | Δ wear | K value COF | K value wear | |
| 1 | 0.198 | 35.18922 | 0.896 | 0.690 | 0.104 | 0.310 | 0.827 | 0.618 | 0.722 |
| 2 | 0.176 | 54.10991 | 0.922 | 0.454 | 0.078 | 0.546 | 0.865 | 0.478 | 0.672 |
| 3 | 0.806 | 23.65433 | 0.166 | 0.834 | 0.834 | 0.166 | 0.375 | 0.751 | 0.563 |
| 4 | 0.486 | 44.70727 | 0.550 | 0.572 | 0.450 | 0.428 | 0.526 | 0.539 | 0.532 |
| 5 | 0.477 | 81.16067 | 0.561 | 0.117 | 0.439 | 0.883 | 0.532 | 0.362 | 0.447 |
| 6 | 0.944 | 53.73891 | 0.000 | 0.459 | 1.000 | 0.541 | 0.333 | 0.480 | 0.407 |
| 7 | 0.222 | 27.46072 | 0.867 | 0.787 | 0.133 | 0.213 | 0.790 | 0.701 | 0.745 |
| 8 | 0.805 | 26.41707 | 0.167 | 0.800 | 0.833 | 0.200 | 0.375 | 0.714 | 0.545 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 0.159 | 20.24154 | 0.942 | 0.877 | 0.058 | 0.123 | 0.897 | 0.802 | 0.850 |
| 10 | 0.353 | 18.20301 | 0.709 | 0.902 | 0.291 | 0.098 | 0.632 | 0.837 | 0.735 |
| 11 | 0.508 | 20.01585 | 0.523 | 0.880 | 0.477 | 0.120 | 0.512 | 0.806 | 0.659 |
| 12 | 0.284 | 14.45135 | 0.792 | 0.949 | 0.208 | 0.051 | 0.707 | 0.908 | 0.807 |
| 13 | 0.72 | 31.03992 | 0.269 | 0.742 | 0.731 | 0.258 | 0.406 | 0.660 | 0.533 |
| 14 | 0.824 | 53.9449 | 0.144 | 0.457 | 0.856 | 0.543 | 0.369 | 0.479 | 0.424 |
| 15 | 0.835 | 45.32189 | 0.131 | 0.564 | 0.869 | 0.436 | 0.365 | 0.534 | 0.450 |
| 16 | 0.52 | 16.55613 | 0.509 | 0.923 | 0.491 | 0.077 | 0.505 | 0.866 | 0.685 |
| 17 | 0.262 | 60.2922 | 0.819 | 0.377 | 0.181 | 0.623 | 0.734 | 0.445 | 0.590 |
| 18 | 0.708 | 35.08826 | 0.283 | 0.692 | 0.717 | 0.308 | 0.411 | 0.619 | 0.515 |
| 19 | 0.111 | 20.68342 | 1.000 | 0.871 | 0.000 | 0.129 | 1.000 | 0.795 | 0.898 |
| 20 | 0.806 | 39.57324 | 0.166 | 0.636 | 0.834 | 0.364 | 0.375 | 0.579 | 0.477 |
| 21 | 0.724 | 72.82764 | 0.264 | 0.221 | 0.736 | 0.779 | 0.405 | 0.391 | 0.398 |
| 22 | 0.276 | 34.99779 | 0.802 | 0.693 | 0.198 | 0.307 | 0.716 | 0.619 | 0.668 |
| 23 | 0.505 | 21.92496 | 0.527 | 0.856 | 0.473 | 0.144 | 0.514 | 0.776 | 0.645 |
| 24 | 0.618 | 26.66022 | 0.391 | 0.797 | 0.609 | 0.203 | 0.451 | 0.711 | 0.581 |
| 25 | 0.364 | 21.66869 | 0.696 | 0.859 | 0.304 | 0.141 | 0.622 | 0.780 | 0.701 |
| 26 | 0.352 | 10.36704 | 0.711 | 1.000 | 0.289 | 0.000 | 0.633 | 1.000 | 0.817 |
| 27 | 0.538 | 90.55236 | 0.487 | 0.000 | 0.513 | 1.000 | 0.494 | 0.333 | 0.414 |

*4.2. find the S/N ratio values for Grey Relational Grade*

To find the S/N ratio values we should consider the wear and coefficient of friction as the output response. Criteria used for calculation should be smaller is the better as we are dealing to reduce the wear depth and friction, the formula is written below as [17]

$$S/N = -10 * log\left(\sum (Y^2)/n\right)$$

where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

Table 4: - Response for grey relational grade

| Level | Volume Fraction (V) | Load (L) | Sliding Speed (S) |
|---|---|---|---|
| 1 | 0.609 | 0.6588 | 0.6911 |
| 2 | 0.600 | 0.5207 | 0.586 |
| 3 | 0.6219 | 0.6512 | 0.5537 |
| Delta | 0.0223 | 0.1381 | 0.1374 |
| Rank | 3 | 1 | 2 |

Total mean grey relational grade = 0.610

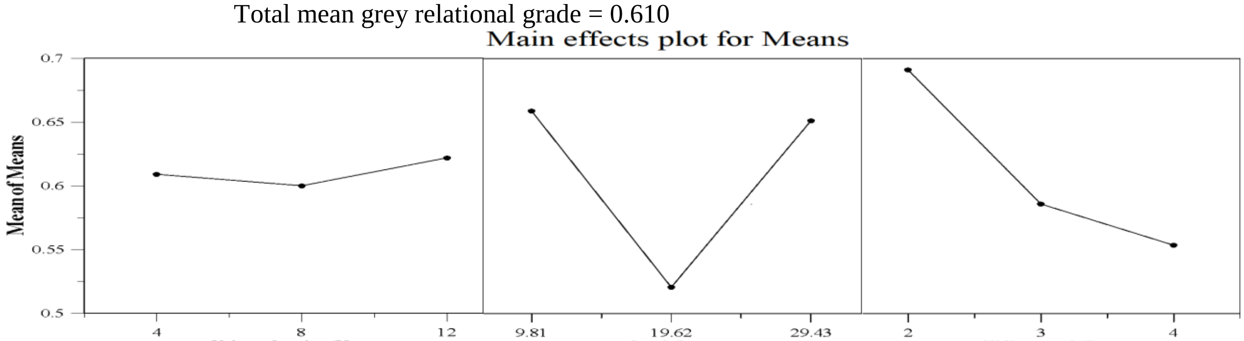


Fig.1. Main effects plot for the grey relational grade.

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Fig. 1. Shows the main effects plot, the optimal parameter set is the highest mean value. it is clear that the mean value is higher at level 3 for Volume fraction (V), at level 1 for Load (L) and at level 1 for Sliding speed (S) parameters. Therefore, the optimum condition set is V3, L1 and S1. the optimal setting of control parameters to reduce wear and coefficient of friction of Al-RHA are V3L1S1 (i.e. Volume fraction = 12%, Load= 9.81 N, and sliding speed =2 m/s).

### *4.3. Analysis of Variance for Grey Relational Grade*

Analysis of variance test was performed to find out the important factors and interrelation factors affect on the composite samples. The contribution of each factor and interrelation factors on Al-RHA samples can be calculated in percentage. It is identified that the important factor is Load (L) which has the maximum contribution of 19.67% followed by Sliding speed (S) with the contribution of 16.85% and volume fraction (V) has the least contribution of 0.41%. The among interactions, significant factors were Volume fraction (V) * Load (L) which has a contribution of 18.91% followed by Volume Fraction (%) *Speed (m/s) with the contribution of 12.62%. Table 5. Shows the detail contribution in percentage for each factor and interaction factors.

Table 5. Results of Variance Analysis for Wear & COF

| Source | DF | Seq SS | Adj MS | F ratio | Contribution (%) |
|---|---|---|---|---|---|
| V (%) | 2 | 0.002246 | 0.001123 | 0.06 | 0.41 |
| L (N) | 2 | 0.108419 | 0.054209 | 2.74 | 19.67 |
| S (m/s) | 2 | 0.092882 | 0.046441 | 2.34 | 16.85 |
| V (%) * L (N) | 4 | 0.104236 | 0.026059 | 1.32 | 18.91 |
| V (%) * S (m/s) | 4 | 0.069591 | 0.017398 | 0.88 | 12.62 |
| L (N)* S (m/s) | 4 | 0.015382 | 0.003846 | 0.19 | 2.79 |
| Total | 26 | 0.551266 | | | 100 |

## 5. Scanning Electron Microscopy (SEM)

The electron microscope was used to capture images of the wear surface area of tested samples. Fig. 2 (a, b, c) shows an SEM image of wear traces on Al-RHA composites.

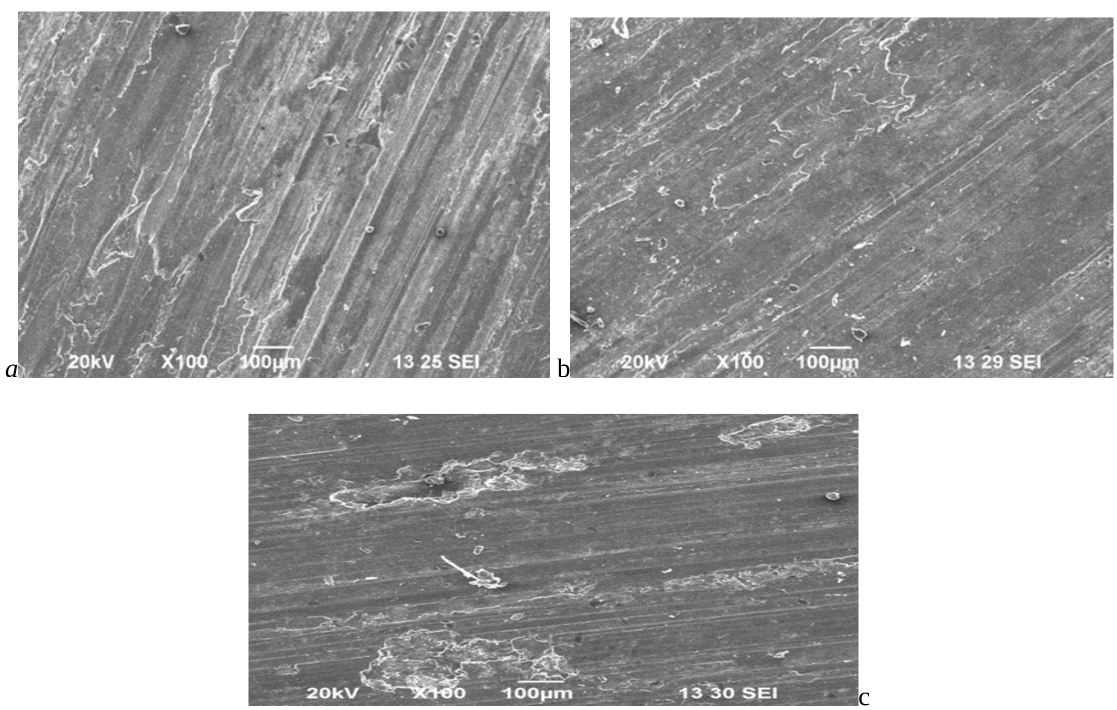


Fig. 2. (a) SEM of wear traces of AL+ 4% RHA; (b) SEM of wear traces of AL+ 8% RHA; (c) SEM of wear traces of AL+ 12% RHA.

From SEM images, the long grooves and irregular pits that indicating the adhesive wear and few other traces of micro-cuts and Micro-ploughing areas are also observed which indicates the abrasive wear mechanism. Thus, it can be concluded that both abrasive wear and adhesive wear are observed but abrasive wear being more in nature.

*5.4. Confirmation Test*

After testing at various optimal levels, it is required to carry out the verification test to evaluate the efficiency of the analysis and experimental work results. Therefore, find the Signal to noise ratio at an optimum level using optimum testing parameters using a formula as written below

$$\hat{S} = S_m + \sum_{i=1}^{0} (\bar{S}_i - S_m)$$

where $S_m$ = Mean of total $S/N$ ratio, $S_i$ = mean of S/N ratio at the optimum level with optimum testing parameters, $o$ = Total number of control parameters which affect the tribological performance of Al-RHA composites samples.

Table 6. Results of confirmation tests

| | Initial condition Parameter | Optimal condition Parameter | Experimented Parameters |
|---|---|---|---|
| Level | V2L2S2 | V3L1S1 | V3L1S1 |
| COF | 0.824 | | 0.111 |
| Wear | 53.945 | | 20.683 |
| Grade | 0.424 | 0.469 | 0.898 |
| Improvement in grade | | 0.045 | 0.474 |

Table 6. shows the improvement in grade values of the initial condition using initial parameters and grade values at an optimum level using optimum parameters is improved by 0.045. from the experiment it also found that at the optimal condition parameters coefficient of friction and wear values were also improved.

**6. Conclusions**

Taguchi Method and grey relational grade analysis of Al-RHA composite samples following conclusions can be written

- It was found that Load (L) is the most important factor affecting the Tribological performance of the Al-RHA composite samples. among the interaction factors, volume fraction and load is the most important.
- From an analysis, it is found that the optimum combination for minimum wear & friction of Al-RHA is (V3L1S1) volume fraction at level 3, Load at level 1and Sliding speed at level 1.
- It is also observed that the Wear depth is decreased by nearly 61% from initial to optimum process parameter condition, and friction is decreased by 86%.
- From the analysis and optimization process, it is observed that using proper control of process parameters can result in the improved design of Al-RHA MMCs for wear and friction applications.
- From the SEM test, it can be seen that the abrasive wear mechanism has occurred on the wear surfaces with few traces of adhesive wear mechanism.

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