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# INVESTIGATION OF THE MECHANICAL PROPERTIES ON RED MUD FILLED POLYESTER BANANA COMPOSITES USING GREY RELATIONAL TECHNIQUE

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**Abstract.** Red mud is an industrial waste generated during the production of alumina by Bayer's process. General purpose polyester resin is used as a matrix and banana fiber as reinforcement. This paper presents a new approach for the optimization of fabrication parameters on red mud filled banana fiber treated and untreated polyester composite with multiple response based on orthogonal array with grey relational analysis in order to save the initial experimental cost on number of specimen and experimental duration. In this study, fabrication parameters namely red mud percentage, fiber treatment, length of fiber, weight fraction of fiber are optimized with consideration of multi response such as impact strength, flexural strength, and tensile strength. A grey relational grade is obtained from the grey analysis. Based on the grey relational grade, optimum level of parameters has been identified and significant parameters are determined by analysis of variance (ANOVA). Experimental result has shown that the responses in the fabrication process can be improved effectively through the new approach.

## 1. Introduction

In the present days the usage of fillers along with the fibres increases gradually because of the improved mechanical properties and also cheap cost which is useful for producing low cost composite products. Natural fibres such as jute, coir, sisal, etc. which are all found to be environmental friendly and enhanced property make these as for making composite products along with fillers. Red mud used as filler is an industrial waste which causing environmental problems reinforced along with natural fibre enhances the properties. A comparative evaluation using Artificial Neural Network and Taguchi approach carried out by Siba Sankar Mahapatra and Saurav Data [1] for studying the wear rate of red mud filled pure polyester composites without fibres. Wear tests are carried out by using pin on disc wear tester machine for different weight percentages of red mud and for different variables such as sliding velocity, red mud content and load using grey Taguchi method the optimal parameter is obtained. It is found that red mud has very good wear resistance properties which make it as suitable potential filler. Erosion studies on glass fibre reinforced polyester composites along with Taguchi experimental design and genetic algorithm approach were carried out by S.S. Mahapatra et al [2] material loss due to erosion is minimized by means of obtained optimal parameter combination. S.S. Mahapatra and Amar Patnaik [3] further suggested the preparation of composites along with ceramic particulates and determine their erosion rate by using Taguchi approach, here again the same polyester resin is used along with E-glass fibre and ceramic particulate. They also concluded that the addition of ceramic particulates along with glass fibre improves the performance due to its high wear resistance performances glass fibre reinforced polyester composites attract the researchers interest towards and by the addition of fly ash an industrial waste along with glass fibre and its response on wear resistance were studied by Amar Patnaik and Alok Satapathy [4]. Taguchi approach and genetic algorithm involved here also to find the optimal parameter combination. Studies on glass fibre reinforced epoxy composites along with red mud filler were done by Sandhyarani Biswas and Alok Satapathy [5]; banana fibre reinforced polyester and epoxy composites which were employed for automotive applications and studied by Lina Herrera-Estrada et al [6] along with this fibre with surface modifications and treatment were done and the flexural, compressive and water absorption properties were carried out. It is noted that fibre with treatment produces low strength values in comparison with untreated fibre.

The present work deals with analysis of mechanical properties such as impact, flexural, and tensile properties of banana fibre filled red mud polyester composites of different fibre length, weight percentages and red mud weight composition and a new approach for the optimization of various parameters with multiresponses based on orthogonal array with grey relational analysis.

## 2. Experiment details

The reinforcement used is red mud an industrial waste of particle size 70-100 microns obtained from Madras Aluminium Company (MALCO), Salem. Unsaturated polyester resin is used as matrix obtained from Vasavibala Resins Private Limited, Chennai, INDIA. The materials and methodology used in this work are given below in Table 1.

Table 1. Materials and methodology used in this work.

| | |
|---|---|
| Resin | Unsaturated polyester |
| Reinforcement | Red mud |
| Accelerator | Cobalt napthanate |
| Catalyst | Methy ethyl ketone peroxide |
| Releasing agent | Wax |
| Methodology | Grey relational Taguchi |

### 2.1 Mechanical testing

**2.1.1 Impact Strength.** The tests are done as per ASTM D 256 using an impact tester. The standard specimen for ASTM D 256 is 65 x 13 x 3 mm. The Charpy test is used to evaluate the relative toughness or impact toughness of materials. The impact energy (J) is calculated from the digital display, which is fitted on the machine. Five samples are taken for each test and the results are averaged.

**2.1.2 Flexural strength.** A three point bend test is conducted for finding out this material property. The flexural test is performed in UTM (capacity-3T). Flexural test was performed on all the three samples as per ASTM D 790 is 127 x 13 x 3 mm test standards. A span of 50 mm was taken and cross head speed was maintained at 2 mm/min. The five samples are taken from each test and the results are averaged.

**2.1.3 Tensile strength.** The tensile test is generally performed in universal testing machine. The tensile test is performed in UTM (capacity-2T) crosshead of 1 mm/min and result is analyzed. ASTM D638 is 165 x10 x 3 mm. A uniaxial load is applied through the ends. Five samples are taken from each test and the results are averaged.

Using Taguchi design of experiment orthogonal array is prepared based on the following control factors and levels.

Table 2. Control factors and levels.

| Parameters | | Levels | | |
|---|---|---|---|---|
| | | L1 | L2 | L3 |
| A | Red mud, % | 5 | 10 | 15 |
| B | Fiber treatment | Untreated | NAOH | Silane |
| C | Length of fiber, mm | 5 | 10 | 15 |
| D | Weight fraction of fiber, % | 15 | 20 | 25 |

**3. Optimization of impact, flexural and tensile strength using grey relational analysis**

**Step 1**. For each experiment in the orthogonal array, calculate the value of signal to noise ratio (S/N) at experiment *i* for each response *j* ($y_{ij}$) using an appropriate equation from the following formulas [7]:

$$\text{Signal to noise ratio S/N} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^{2}}\right),$$

where $n$ is a number of replication; $y_{ij}$ is observed response value; $i$=1,2,..$n$; $j$=1,2,…$k$.

Table 3. L9 orthogonal array with factors and responses.

| Trial no | Control factors | | | | Responses | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | | | |
| | Red mud, % | Fiber treatment | Length of fiber, mm | Weight fraction of fiber, % | Impact energy, KJ/m$^2$ | Flexural strength, MPa | Tensile strength, MPa |
| 1 | 5 | Untreated | 5 | 15 | 136.396 | 31.68 | 19.88 |
| 2 | 5 | NAOH | 10 | 20 | 31.86 | 53 | 35.3 |
| 3 | 5 | Silane | 15 | 25 | 46.171 | 58.06 | 38.86 |
| 4 | 10 | Untreated | 10 | 25 | 222.76 | 37.95 | 28.18 |
| 5 | 10 | NAOH | 15 | 15 | 25.37 | 38.41 | 30.24 |
| 6 | 10 | Silane | 5 | 20 | 45.28 | 53.01 | 28.54 |
| 7 | 15 | Untreated | 15 | 20 | 252.054 | 41.1 | 28.97 |
| 8 | 15 | NAOH | 5 | 25 | 121.688 | 37.12 | 25.5 |
| 9 | 15 | Silane | 10 | 10 | 33.374 | 40 | 28 |

**Step 2**. Value $y_{ij}$ is normalized as $Z_{ij}$ ($0 \le Z_{ij} \le 1$) by the formula shown below to avoid the effect of adopting different units and to reduce and to normalize the original data before analyzing them with grey relation theory or any other methodologies. An appropriate value is deducted from the values in the same array approximate to 1 since the normalization affect the rank, it is also analyze the sensitivity of the normalization

process on the sequencing of result.

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij},\ i = 1, 2 \ldots n)}{\max(y_{ij},\ i = 1, 2 \ldots n) - \min(y_{ij},\ i = 1, 2 \ldots n)}$$

(to be used for S/N ratio with larger the better manner).

**Step 3**. Calculate the grey relational co-efficient for the normalized S/N ratio values:

$$\gamma(y_0(k), y_j(k)) = \frac{\Delta_{\min} + \xi\,\Delta_{\max}}{\Delta_{0j}(k) + \xi\,\Delta_{\max}},$$

where
$j = 1, 2 \ldots n$; $k = 1, 2, \ldots m$, $n$ is the number of experimental data items and $m$ is the number of responses;
$\Delta_{0j} = \left\| y_0(k) - y_j(k) \right\|$ is the absolute value of the difference between $y_0(k)$ and $y_j(k)$;
$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left\| y_0(k) - y_j(k) \right\|$ is the smallest value of $y_j(k)$;
$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left\| y_0(k) - y_j(k) \right\|$ is the largest value of $y_j(k)$;
$\xi$ is the distinguishing coefficient which is defined in the range $0 \le \xi \le 1$ (the value may adjusted based on the practical need of the system).

**Step 4**. Generate grey relational grade:

$$\bar{\gamma}_j = \frac{1}{k} \sum_{i=1}^{k} \gamma_{ij},$$

where $\bar{\gamma}_j$ is the grey relational grade for the $j^{th}$ experiment; $k$ is the number of performance characteristics.

Then use average of grade values for each level $j$, denoted by $AGV_{ij}$, then the effect $E_i$ is defined as per following equation:

$$\gamma_i = \frac{1}{q} \sum_{j=1}^{q} \xi_{ij},$$ $\xi_{ij}$ is the distinguishing coefficient,

$E_i = \max(AGV_{ij}) - \min(AGV_{ij})$,

J*= $\max(AGV_{ij})$, where J* is the best level determined by this equation.

**Step 5**. Determine the optimal factor and its level combination.

The higher the grey relational grade implies the better combination; factor can also be determined therefore, on the basis of grey relational grade, the factor effect can be estimated and the optimal level for each controllable.

**Step 6**. Perform ANOVA for identifying the significant factors.

Calculate the analysis of variance to identify the effect of individual factor. Result from ANOVA can determine the contribution ratio of each factor. The percentage of contribution is used to conduct main effect plot for grey grade.

**4. Results and discussion**

**Step 1.** Calculate the S/N ratio for a given response.

**Step 2**. Calculate normalize the S/N ratio value. The results are in Table 4.

**Step 3**. Perform the grey relational analysis from the data in Table 4 and calculate the grey relational co-efficient GRCO for the normalized S/N ratio value. The results are given in the Table 5.

**Step 4.** Next, the grey relational grade can be computed using equations. Finally, they are considered for optimizing the multi response parameter design problem. The results are given in Table 5.

Table 4. S/N ratio values and normalized S/N ratio value.

| Trial no | GR CO Impact | GR CO Flexural | GR CO Tensile | GRADE |
|---|---|---|---|---|
| 1 | 0.494943231 | 0.333333333 | 0.333333333 | 0.3872033 |
| 2 | 0.33981939 | 0.722739726 | 0.727203065 | 0.59658739 |
| 3 | 0.355053646 | 1 | 1 | 0.78501788 |
| 4 | 0.794624078 | 0.396096096 | 0.470500744 | 0.55374031 |
| 5 | 0.333333333 | 0.401644336 | 0.524019879 | 0.41966585 |
| 6 | 0.354065401 | 0.723135965 | 0.479050984 | 0.51875078 |
| 7 | 1 | 0.43747927 | 0.489680083 | 0.64238645 |
| 8 | 0.465072956 | 0.386463522 | 0.415317287 | 0.42228459 |
| 9 | 0.341368945 | 0.42208 | 0.466339066 | 0.40992934 |

Table 5. Grey relational co-efficient and grey grade values.

| Trial no | S/N ratios | | | Normalized values of S/N ratios | | |
|---|---|---|---|---|---|---|
| | Impact | Flexural | Tensile | Impact | Flexural | Tensile |
| 1 | 42.6960327 | 30.01570346 | 25.9683276 | 0.510216866 | 1 | 1 |
| 2 | 30.0649154 | 34.48551739 | 30.95549411 | 0.971369836 | 0.191811979 | 0.187565859 |
| 3 | 33.2873856 | 35.27754063 | 31.79005593 | 0.908237899 | 0 | 0 |
| 4 | 46.9567442 | 31.5842356 | 28.99881978 | 0.129228353 | 0.762319939 | 0.562697576 |
| 5 | 28.0864093 | 31.68888614 | 29.61163574 | 1 | 0.744882487 | 0.454162276 |
| 6 | 33.1181284 | 34.48715608 | 29.10907938 | 0.912168481 | 0.191432904 | 0.543730242 |
| 7 | 48.0298719 | 32.27683644 | 29.2389699 | 0 | 0.642911296 | 0.521074816 |
| 8 | 41.7049551 | 31.39215935 | 28.13080361 | 0.575100139 | 0.793783169 | 0.703898841 |
| 9 | 30.4681652 | 32.04119983 | 28.94316063 | 0.964690935 | 0.684609553 | 0.572181243 |

**Step 5**. From the value of grey relational grade in table using the main effect are tabulated in table and the factors effect are plotted.

**Step 6**. Considering maximization of the grade values, we can obtain the optimal parameter conditions.

Table 6. Result of ANOVA on grey grade.

| FACTOR | DOF | SOS | MEAN | CONTRIBUTION | PERCENTAGE |
|---|---|---|---|---|---|
| Red mud, % | 2 | 0.0181559 | 0.00907793 | 0.128545121 | 12.85451205 |
| Fiber treatment | 2 | 0.0126304 | 0.00631521 | 0.089424411 | 8.9424411 |
| Length of fiber, mm | 2 | 0.0450312 | 0.02251558 | 0.318824509 | 31.88245088 |
| Weight fraction of fiber, % | 2 | 0.0654238 | 0.03271189 | 0.46320596 | 46.32059596 |
| TOTAL | 8 | | 0.07062061 | 1 | 100 |

From Fig. 1 the optimum control factors for the impact, flexural, and tensile strength were found to be the 5% red mud along with fiber treated with silane of 15 mm fiber length and 25% weight fraction of fiber. Also calculate the analysis of variance for the above combination.

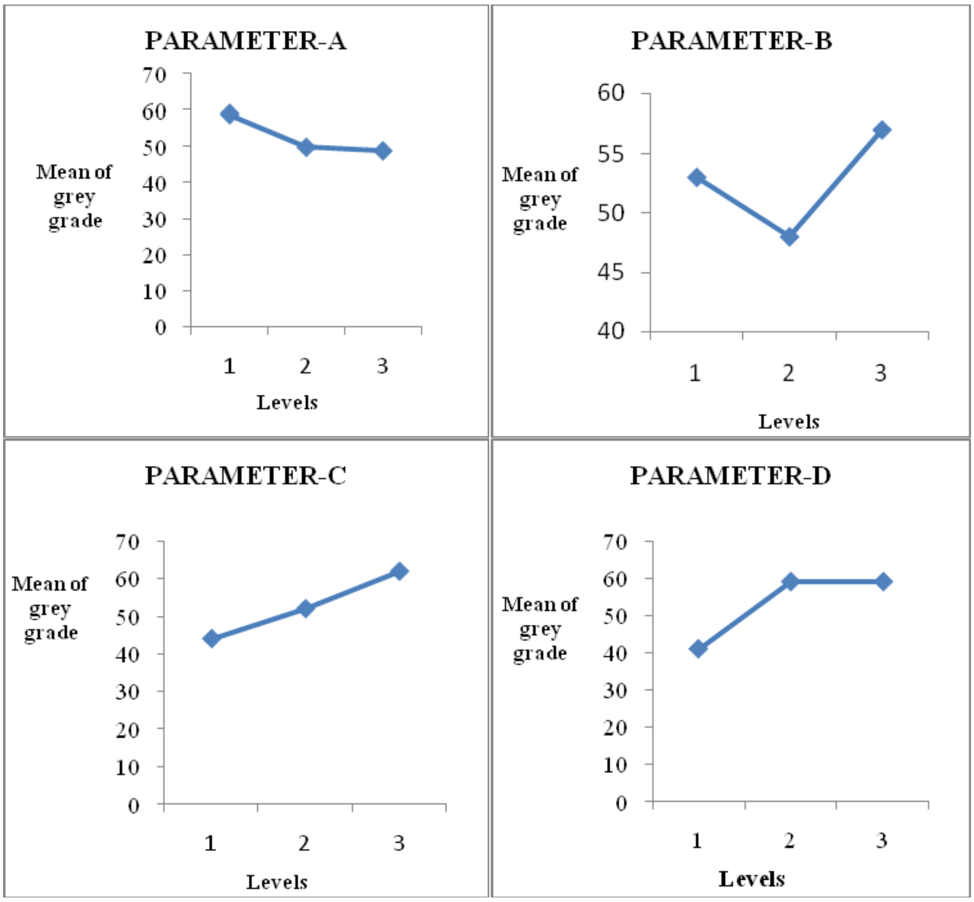


**Fig. 1.** Main effect plot for grey grade.

From the Table 5 to plot the contribution ratio for individual parameters in the experiments.

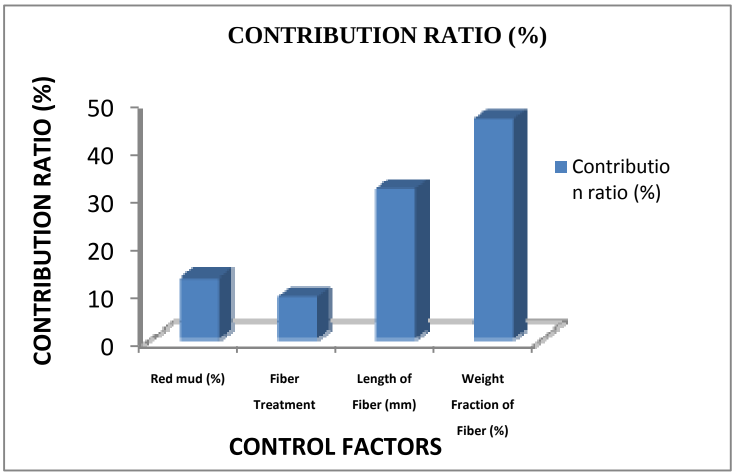


**Fig. 2.** Contribution ratio for control factors.

## 5. Conclusions

The polymer matrix composites with red mud filled is prepared successfully

From the response table of the average grey relational grade, it was found that the largest value of grey relational grade for 5 % red mud, fiber treated with silane with 15 mm fiber length and 25 % weight fraction of fiber respectively.

The weight fraction of fiber showed the strongest comparability sequence among the four important parameters investigated in this study. It means that the weight fraction of fiber had the strongest correlation to improved mechanical properties.

Improved impact, flexural, tensile strength were observed at the optimum level.

## References

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