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# Optimization of green sand mould process parameters using Taguchi approach in conjunction with Grey relational analysis

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***Abstract*— The condition of the mould cavity in sand casting is critical for foundrymen to achieve high-quality castings. Since the last few decades, optimization of green sand mixture has played a critical role in defect minimization. Experiments were carried out in this study using varying percentages (by weight) of sand additions such as water, molasses, bentonite, and fly ash. Green compression strength, permeability, compatibility, and mould hardness have all been tested as a result of the subsequent green sand mould qualities. To tackle this multi-response optimization issue, the Taguchi strategy was used, followed by Grey relational analysis (GRA). An attempt was made to achieve an ideal level of green sand combination process parameters in order to generate the best quality attributes of the green sand mould. The L18orthogonal array design by Taguchi, the Signal-to-Noise (S/N) ratio, and analysis of variance were used to evaluate the effect of chosen green sand mould process factors and their levels on the produced mould qualities. Among the other sand process factors, bentonite was determined to have the greatest effect. Through confirmation trials, a new experiment was undertaken at the ideal parametric combination to forecast and validate increase of quality features. As a result, GRA may be a complete decision-making tool for selecting the proper grade to improve the quality attributes of sand in the foundry business.**

***Keywords*—** Green sand mould; Molasses; Fly ash; Bentonite; Water; Orthogonal array; Grey relational analysis

## I. INTRODUCTION

Green sand casting remains one of the most commonly used casting processes today due to usage of cost-effective raw materials, with ample variety of castings with respect to complex size and composition, and the possibility of recycling the green sand moulding. The green sand combination is moistened, typically with water, and suitable bonding agents such as molasses, fly ash, dextrin, and starch etc. to improve the physical and mechanical properties of the green sand mould. Thus, it is vital for the foundry men to have the proper selection of the additives in green sand moulding to get the substantial increase in green sand mould properties which in turn lead to quality castings. Hence, suitable choice of the composition of a green sand moulding combination and their optimization are of crucial significance. The Taguchi method is very popular for solving optimization problems in the field of production engineering [1-4].

Few researchers made an attempt on the optimization of casting process parameters based on the Taguchi's method. Guharaja et al. [5] conducted a research to optimise the green sand-casting process using Taguchi's parameter design technique in order to provide the best

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quality attributes of spheroidal graphite cast iron rigid coupling castings. It was found that, the optimized parameter levels are moisture content–2.6%, green strength–950 g/cm$^2$, permeability number–235 and mould hardness number–80. Sushil Kumar et al. [6] implemented Taguchi method to optimize the process parameters of the sand castings. In order to minimize casting defects of differential housing cover castings, the optimized parameter levels are moisture content −4.0%, green strength −1,990 g/cm$^2$, pouring temperature −1410ºC and mould hardness number vertical −72 and horizontal −85. Karunakar and Datta [7] performed trials with varied grain fineness number, clay percentage, moisture percentage, mulling duration, and hardness with the goal of optimising the sand mixture formulation using a back propagation artificial neural network (ANN) and a micro genetic algorithm. Using the Taguchi approach and ANN Analysis, Lakshmanan Singaram [8] adjusted control elements of sand process characteristics such as green strength, moisture content, permeability, and mould hardness. It was discovered that the optimal level of control parameters include green strength of 1.2 Kg/cm2, moisture content of 2.0 percent, and mould hardness of 60. Rasik and Ishwar [9] attempted to capture the impacts of signal to noise ratio of the experimental subject based on orthogonal arrays employed, an analysis of variance, and optimal circumstances using the Taguchi technique. The results showed that the selected process parameters had a substantial impact on casting defects, and the improvement predicted in casting defect reduction was determined to be 37.66 percent in the foundry sector.

Karunakar and Datta [10] have applied back propagation neural networks for analysis and prediction of casting defects. It is concluded that neural network was the prominent optimization tool for prediction of casting defects such as cold shut, sand drop, slag inclusions and microstructure related defects. Vasudev et al. [11] recommended a methodology to foundry industry for the optimal layout of multi-cavity sand moulds based on an investigation of minimum gaps between the cavities and from cavity to mould wall in order to maximize the mould yield without compromising casting quality. Gadag et al. [12] has created nomograms which give optimum combination of active clay and chosen organic additive in order to get anticipated properties in the clay-bonded moulding sand containing given amounts of dead clay and moisture. Charnnarong Saikaew and Sermsak Wiengwiset [13] investigated the effects of variation in bentonite and water added to a recycled sand mold on the properties of the molding sand to achieve high quality iron castings. In three case studies in industrial applications, Al-Refaie et al. [14] developed a technique for optimising numerous answers in the Taguchi method utilising regression models and grey relational analysis. It was reported that that the formulated approach is efficient to obtain global optimal factor levels. In the current decade researchers were also inclined towards various other casting processes to achieve high quality castings [15-24].

Bast et al. [25] has optimized the moulding parameters for sandcompaction by computer simulation and a new compaction measuring device and studied the effect of different moulding parameters. It was observed some agility to optimize the mould process. Few researchers also made an attempt on various properties of casting process [26-38]. Oji et al. [39] studied that the statistical multiple regression model for predicting the ultimate tensile strength of aluminium alloy castings under different sand-casting process parameters namely mould temperature, pouring temperature and runner size. The proposed multiple regression model was found to be useful for forecasting the ultimate tensile strength of aluminium alloy sand castings under typical circumstances. Kumaravadivel and Natarajan [40] made major efforts on minimizing the defects developed in the sand-casting process by process window approach. It was observed that the optimized parameters which obtained by using the Taguchi method and RSM were tested and validated the proposed process window approach. However, traditional Taguchi method cannot solve multiobjective optimization problem. To address this, the Taguchi technique, in combination with Grey relational analysis, has a wide variety of applications in many production processes [41-42].

In this present research investigation, the optimization of sand mould process parametersis considered with multiple quality characteristics of the sand properties using the Grey relational analysis.

## II. Taguchi based Grey Relational Analysis

Optimization of process parameters is the vital step in the Taguchi method to achieve perfection and cost effectiveness. The optimal process parameters are selected not only to progress quality, but also to be least profound to the deviation of environmental conditions and other noise factors. Basically, conventional process parameter design [42] is complex and very difficult to use. Several experiments need to be carried out when the number of process parameters increases. In order to resolve the task, the Taguchi has developed a method consisting of a special design of orthogonal arrays to study the total process parameter universe with a small number of experiments. Taguchi also recommended using the loss function to assess the quality characteristic that deviates from the target value, which is then turned into a signal-to-noise (S/N) ratio. Typically, there are three types of the quality characteristic in the analysis of the S/N ratio, that is, the lower-the-better, higher-the-better, and nominal-the-better. The larger S/N ratio corresponds to enhanced quality characteristic irrespective of the type of the quality characteristic. This is true for optimising a single quality feature. However, optimising many quality attributes differs from optimising a single quality feature. The higher S/N ratio for one response characteristic may equate to a lower S/N ratio for another. As a result, the overall estimation of the S/N ratio is necessary for the optimization of many quality aspects.

To solve this problem, the grey relational analysis is adopted in the present investigation. The first step of the grey relational analysis is the grey relational generation. During this step, the green compression strength, permeability, compatibility and mould hardness are normalized in the range between zero and one. Next, the grey relational coefficient is calculated from the normalized data to express the relationship between the desired and actual the green compression strength, permeability, compatibility and mould hardness. Then, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each quality characteristic. Following that, we may determine the many quality attributes based on the grey relational grade. As a consequence, optimising the complex numerous quality parameters may be reduced to optimising a single grey relational grade. Later, ANOVA analysis is performed to determine which process factors have a significant impact on quality features, and the matching best parametric combination may be predicted. Following that, a confirmation experiment is carried out to confirm the optimal process parameters determined by the analysis. Furthermore, the methods' specifics are discussed in the following sections.

## III. Methodology

### A. *Materials and Equipment's*

The materials were used in this research are green sand which has been used as basic moulding sand. Molasses is an organic additive which can be used as good surface finish purposes, and to achieve a specific sand mould properties the fly ash have been used in variable percentages with green sand and tests carried out for green compression strength, permeability, mould hardness and compatibility for moulding sand. The additive molasses is available commercially in Bhilai, Chhattisgarh. Fly ash was acquired from the Sepat Thermal Power Station, Chhattisgarh (India). Bentonite was purchased commercially from Nagpur, Maharashtra-India. The proportionate quantities of the green sand, fly ash and molasses were poured in the sand muller as shown in Fig. 1 and mixed according to the Taguchi orthogonal array matrix in the sand muller (Capacity at 5

Kg). The mixed sand combination was transferred into a precision specimen tube to make A.F.S. standard test specimens of diameter 50 mm x 50 mm. The sand was compressed by releasing a sliding weight at a fixed distance. The specimens of the sand mould were ready to be tested for their properties. The permeability test was done using a calibrated permeability meter as shown in Fig. 2. The green compression strength test was carried out using a universal sand strength testing machine as shown in Fig. 3.The mould hardness and compatibility were tested by mould hardness tester and compatibility scale respectively. The sample of the sand specimen for testing its respective properties is as shown in Fig. 4.

Fig. 1 Sand muller

Fig. 2 Permeability meter


Fig. 3 Universal sand strength machine

Fig. 4 Sand specimen sample 50 mm X 50 mm

*B. Steps for determining optimum green sand mould process parameters by GRA*

The usage of the design of experiments with grey relational analysis to optimize the green sand mould process parameters with multiple quality characteristics as given in Fig. 5.

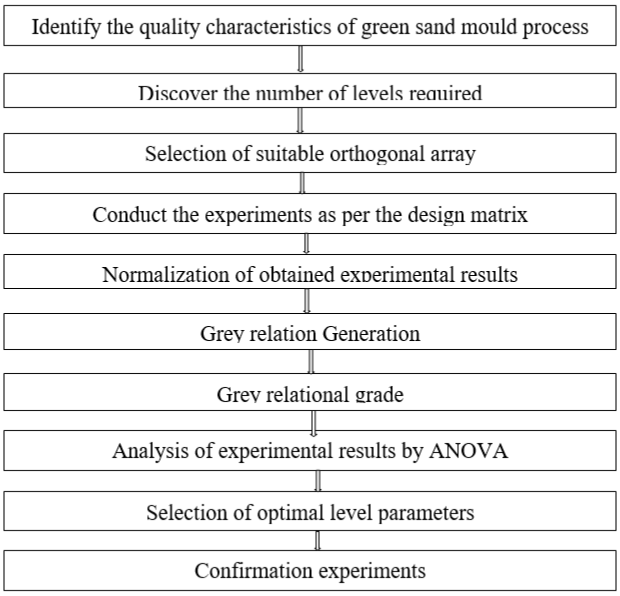


Fig.5 Process Layout of optimum green sand mould process parameters by GRA for present investigation

### *C. Process parameters of green sand mould*

An Ishikawa diagram (cause and effect diagram) was constructed as shown in Fig. 6 to identify the green sand mould process parameters that may influence green sand properties.

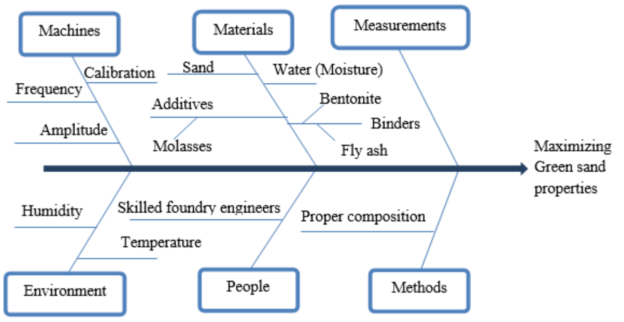


Fig.6 Cause and effect diagram

From Fig. 6, the most significant parameters are water (wt. %), molasses (wt. %), bentonite (wt. %) and fly ash (wt. %). The range of water was selected as 3.5-4.5 wt. %, molasses was selected as 1.25-3.25 wt. %, the bentonite was selected as 5-15 wt. % and the fly ash was selected as 5-15 wt. %. The selected green sand mould process parameters, along with their ranges, are given in Table 1.

TABLE 1

GREEN SAND MOULD CONTROL PROCESS PARAMETERS AND THEIR LIMITS

| Parameters | Range (wt. %) | Designation | Levels of factors | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| Water | 3.5-4.5 | A | 3.5 | 4.5 | --- |
| Molasses | 1.25-3.25 | B | 1.25 | 2.25 | 3.25 |
| Bentonite | 5-15 | C | 5 | 10 | 15 |
| Fly ash | 5-15 | D | 5 | 10 | 15 |

### *D. Selection of orthogonal array*

The selection of orthogonal array based on the earlier researchers and the present foundry industry needs concern number of parameters and their interaction and the significant number of levels for the parameters is considered. Therefore, each parameter was analyzed at different levels based on the performance of the process parameters. From the selected input parameters, the significant interactions between them are to be considered. As per the study conducted, it is observed that there is significant interaction between water with molasses (A*B) and bentonite (A*B) which ultimately affects quality characteristics. The total Degrees of Freedom (DOF) for four factors, one at two levels and three at three levels, and the interactions is 11. In the present investigation, the required Degrees of Freedom is 11 and the available Degrees of Freedom is 17. As a result, the $L_{18}$ orthogonal array is chosen. Taguchi has released two tools to help with factor and interaction assignment to arrays. The assigned $L_{18}$ orthogonal array is shown in Table 2. After the parameters and its interactions are assigned to a specific column in the chosen orthogonal array, the parameters at various levels are assigned for every test. The assigned experimental array is shown in Table 3. The green sand properties were found as per the trial conditions as given in Table 3. Using a single-repetition randomization approach, the trials were repeated three times for the same set of parameters [3].

TABLE 2

TAGUCHI'S L18 ORTHOGONAL ARRAY DESIGN

| Expt. No. | A | B | A*B | A*B$^2$ | C | A*C | A*C$^2$ | D |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| 3 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 |
| 4 | 1 | 2 | 1 | 1 | 2 | 2 | 3 | 3 |
| 5 | 1 | 2 | 2 | 2 | 3 | 3 | 1 | 1 |
| 6 | 1 | 2 | 3 | 3 | 1 | 1 | 2 | 2 |
| 7 | 1 | 3 | 1 | 2 | 1 | 3 | 2 | 3 |
| 8 | 1 | 3 | 2 | 3 | 2 | 1 | 3 | 1 |
| 9 | 1 | 3 | 3 | 1 | 3 | 2 | 1 | 2 |
| 10 | 2 | 1 | 1 | 3 | 3 | 2 | 2 | 1 |
| 11 | 2 | 1 | 2 | 1 | 1 | 3 | 3 | 2 |
| 12 | 2 | 1 | 3 | 2 | 2 | 1 | 1 | 3 |
| 13 | 2 | 2 | 1 | 2 | 3 | 1 | 3 | 2 |
| 14 | 2 | 2 | 2 | 3 | 1 | 2 | 1 | 3 |
| 15 | 2 | 2 | 3 | 1 | 2 | 3 | 2 | 1 |
| 16 | 2 | 3 | 1 | 3 | 2 | 3 | 1 | 2 |
| 17 | 2 | 3 | 2 | 1 | 3 | 1 | 2 | 3 |
| 18 | 2 | 3 | 3 | 2 | 1 | 2 | 3 | 1 |

TABLE 3
EXPERIMENTAL DATA OF GREEN SAND PROPERTIES

| Expt. No. | GCS[a] (kPa) | Permeability[a] (mmws) | Compatibility[a] (%) | Mould hardnessa (nu.) |
|---|---|---|---|---|
| 1 | 145 | 250 | 70 | 70 |
| 2 | 155 | 255 | 85 | 75 |
| 3 | 170 | 240 | 95 | 88 |
| 4 | 175 | 255 | 80 | 78 |
| 5 | 170 | 258 | 78 | 75 |
| 6 | 165 | 265 | 75 | 80 |
| 7 | 158 | 260 | 80 | 80 |
| 8 | 155 | 268 | 78 | 78 |
| 9 | 165 | 265 | 85 | 85 |
| 10 | 170 | 260 | 80 | 75 |
| 11 | 165 | 265 | 75 | 80 |
| 12 | 175 | 255 | 80 | 78 |
| 13 | 165 | 265 | 80 | 85 |
| 14 | 158 | 260 | 78 | 80 |
| 15 | 155 | 268 | 75 | 78 |
| 16 | 160 | 270 | 80 | 80 |
| 17 | 180 | 285 | 92 | 92 |
| 18 | 140 | 280 | 75 | 75 |

[a]Averaged of three experiment results

## IV. DATA PRE-PROCESSING

In GRA, data pre-processing is required since the range and unit in one data sequence may differ from the others. It is also necessary when the scatter range sequence is too large. For this purpose, the experimental results are normalized in the range between zero and one. Depending on the characteristics of data sequence, there are various methodologies of Data pre-processing available for the GRA. To obtain optimal green sand properties, the "larger-the-better" quality characteristic has been used for maximizing green compression strength, permeability, mould hardness and compatibility. When the "larger-the-better" is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x_i^*(k)=\frac{x_i(k)-\min x_i(k)}{\max x_i(k)-\min x_i(k)} \quad (1)$$

Where, $x_i^*(k)$ and $x_i(k)$are the sequence after the Data pre-processing and comparability sequence respectively, $k=1$ for green sand properties; i=1, 2, 3……, 18 for experiment numbers 1 to 18. The $x_i^*(k)$ for green compression strength is calculated for Expt. No. 2 using Equation (1) as shown below.

$$x_i^*(k)=\frac{155\text{-}140}{180\text{-}140}=\frac{15}{40}=0.375$$

Similarly, the subsequent calculations are also made and all the sequences after Data pre-processing (Grey relational generation) using Equation (1) are depicted in Table 4.

Now, $\Delta_{0i}(k)$is the deviation sequence of the reference sequence $x_0^*(k)$ and the comparability sequence $x_i^*(k)$, i.e.

$$\Delta_{0i}(k)=\left|x_0^*(k)-x_i^*(k)\right| \quad (2)$$

The deviation sequence $\Delta_{0i}$can be calculated for Expt. No. 2 using Equation (2) as follows;

$$\Delta_{01}(2)=\left|x_0^*(2)-x_1^*(2)\right|=|1-0.375|=0.625$$

$$\Delta_{01}(3)=\left|x_0^*(3)-x_1^*(3)\right|=|1-0.333|=0.667$$

$$\Delta_{01}(4)=\left|x_0^*(4)-x_1^*(4)\right|=|1-0.600|=0.4$$

$$\Delta_{01}(5)=\left|x_0^*(5)-x_1^*(5)\right|=|1-0.227|=0.773$$

So, $$\Delta_{0i}=\Delta_{02}=(0.625, 0.667, 0.4, 0.773) \quad (3)$$

Similar calculation is performed for i= 1 to 18 and the results of all $\Delta_{0i}$ for i=1 to 18 are presented in Table 5.

TABLE 4
GREY RELATIONAL GENERATION OF SAND QUALITY CHARACTERISTICS

| Expt. No. | GCS[a] (kPa) | Permeability[a] (mmws) | Compatibility[a] (%) | Mould hardness (nu.) |
|---|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 | 1 |
| 1 | 0.125 | 0.222 | 0.000 | 0.000 |
| 2 | 0.375 | 0.333 | 0.600 | 0.227 |
| 3 | 0.750 | 0.000 | 1.000 | 0.818 |
| 4 | 0.875 | 0.333 | 0.400 | 0.364 |
| 5 | 0.750 | 0.400 | 0.320 | 0.227 |
| 6 | 0.625 | 0.556 | 0.200 | 0.455 |
| 7 | 0.450 | 0.444 | 0.400 | 0.455 |
| 8 | 0.375 | 0.622 | 0.320 | 0.364 |
| 9 | 0.625 | 0.556 | 0.600 | 0.682 |
| 10 | 0.750 | 0.444 | 0.400 | 0.227 |
| 11 | 0.625 | 0.556 | 0.200 | 0.455 |
| 12 | 0.875 | 0.333 | 0.400 | 0.364 |
| 13 | 0.625 | 0.556 | 0.400 | 0.682 |
| 14 | 0.450 | 0.444 | 0.320 | 0.455 |
| 15 | 0.375 | 0.622 | 0.200 | 0.364 |
| 16 | 0.500 | 0.667 | 0.400 | 0.455 |
| 17 | 1.000 | 1.000 | 0.880 | 1.000 |
| 18 | 0.000 | 0.889 | 0.200 | 0.227 |

Investigating the data presented in Table 5, $\Delta_{max}(k)$ and $\Delta_{min}(k)$ is obtained and are as follow:

$$\Delta_{max} = \Delta_{18}\ (1) = \Delta_{03}\ (2) = \Delta_{01}\ (3) = \Delta_{01}\ (4)$$

$$\Delta_{min} = \Delta_{17}\ (1) = \Delta_{17}\ (2) = \Delta_{03}\ (3) = \Delta_{17}\ (4)$$

TABLE 5

EVALUATION OF $\Delta_{0i}$ FOR EACH OF THE RESPONSES

| Expt. No. | GCS[a] (kPa) | Permeability[a] (mmws) | Compatibility[a] (%) | Mould hardnessa (nu.) |
|---|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 | 1 |
| 1 | 0.875 | 0.778 | 1.000 | 1.000 |
| 2 | 0.625 | 0.667 | 0.400 | 0.773 |
| 3 | 0.250 | 1.000 | 0.000 | 0.182 |
| 4 | 0.125 | 0.667 | 0.600 | 0.636 |
| 5 | 0.250 | 0.600 | 0.680 | 0.773 |
| 6 | 0.375 | 0.444 | 0.800 | 0.545 |
| 7 | 0.550 | 0.556 | 0.600 | 0.545 |
| 8 | 0.625 | 0.378 | 0.680 | 0.636 |
| 9 | 0.375 | 0.444 | 0.400 | 0.318 |
| 10 | 0.250 | 0.556 | 0.600 | 0.773 |
| 11 | 0.375 | 0.444 | 0.800 | 0.545 |
| 12 | 0.125 | 0.667 | 0.600 | 0.636 |
| 13 | 0.375 | 0.444 | 0.600 | 0.318 |
| 14 | 0.550 | 0.556 | 0.680 | 0.545 |
| 15 | 0.625 | 0.378 | 0.800 | 0.636 |
| 16 | 0.500 | 0.333 | 0.600 | 0.545 |
| 17 | 0.000 | 0.000 | 0.120 | 0.000 |
| 18 | 1.000 | 0.111 | 0.800 | 0.773 |

TABLE 6

GREY RELATIONAL COEFFICIENT OF EACH PERFORMANCE CHARACTERISTICS (WITH $\zeta$=0.5)

| Expt. No. | GCS[a] (kPa) | Permeability[a] (mmws) | Compatibility[a] (%) | Mould hardnessa (nu.) |
|---|---|---|---|---|
| Ideal sequence | 1 | 1 | 1 | 1 |
| 1 | 0.364 | 0.391 | 0.333 | 0.333 |
| 2 | 0.444 | 0.429 | 0.600 | 0.393 |
| 3 | 0.667 | 0.333 | 0.943 | 0.733 |
| 4 | 0.800 | 0.429 | 0.440 | 0.440 |
| 5 | 0.667 | 0.455 | 0.623 | 0.393 |
| 6 | 0.571 | 0.529 | 0.673 | 0.478 |
| 7 | 0.476 | 0.474 | 0.600 | 0.478 |
| 8 | 0.444 | 0.570 | 0.702 | 0.440 |
| 9 | 0.571 | 0.529 | 0.733 | 0.611 |
| 10 | 0.667 | 0.474 | 0.673 | 0.393 |
| 11 | 0.571 | 0.529 | 0.805 | 0.478 |
| 12 | 0.800 | 0.429 | 0.892 | 0.440 |
| 13 | 0.571 | 0.529 | 0.846 | 0.611 |
| 14 | 0.476 | 0.474 | 0.733 | 0.478 |
| 15 | 0.444 | 0.570 | 1.000 | 0.440 |
| 16 | 0.500 | 0.600 | 0.733 | 0.478 |
| 17 | 1.000 | 1.000 | 0.805 | 1.000 |
| 18 | 0.333 | 0.818 | 0.733 | 0.393 |

Table 7 displays the grey relational grade for each experiment performed with $L_{18}$ OA. Because it receives the highest grey relationship grade, Experiment 17 has the best multiple quality features out of the eighteen experiments. According to the findings of the research, optimising the many quality features of green sand mould attributes has been translated into optimising a single grey relational grade.

TABLE 7

GREY RELATIONAL GRADE AND RANK

| Expt. No. | Grey relational grade (Yi) | Rank |
|---|---|---|
| 1 | 0.355 | 18 |
| 2 | 0.466 | 17 |
| 3 | 0.669 | 2 |
| 4 | 0.527 | 15 |
| 5 | 0.534 | 14 |
| 6 | 0.563 | 10 |
| 7 | 0.507 | 16 |
| 8 | 0.539 | 13 |
| 9 | 0.611 | 6 |
| 10 | 0.552 | 11 |
| 11 | 0.596 | 7 |
| 12 | 0.640 | 3 |
| 13 | 0.640 | 4 |
| 14 | 0.540 | 12 |
| 15 | 0.614 | 5 |
| 16 | 0.578 | 8 |
| 17 | 0.951 | 1 |
| 18 | 0.569 | 9 |

Figure 7 depicts the grey relational grade for several process parameters. A vertical line represents the mean of grey relationship grade for each attribute. The greater grey relationship grade is generally recognised to be required for best quality. Using the same procedure, the mean of the grey relational grade values for each level of the green sand mould parameters was computed. The higher the value of the grey relational grade, the stronger the association between the two series. [43]. As a result, Table 8 depicts the appropriate amounts of green sand mould parameters setting for better green sand qualities (A2, B3, C3, and D3). The level with the highest grey relational grade is the best level of the green sand mould characteristics. The presence of an asterisk (*) indicates that the level value signifies a higher quality of green sand mould. Based on the grey relational grade values in Table 7, the optimal green sand mould control parameters for maximum sand characteristics are water 4.5 wt. percent (level 2), molasses 3.5 wt. percent (level 3), bentonite 15 wt. percent (level 3), and fly ash 15 wt. percent (level 3). (level 3). The higher the numbers in Fig. 7 are, the better the green sand characteristics and mould quality. Therefore, experiment 17, as shown in Table 7 and Fig. 7, may be considered as very close to fit the optimal process conditions. As shown in Table 8, the difference between the maximum and the minimum value of the grey relational grade of the sand mould process parameters: 0.1008 for water, 0.0795 for molasses, 0.1376 for bentonite, and 0.1119 for fly ash material. The most effective factor affecting quality characteristics is determined by comparing these values. This comparison will give the level of significance of the controllable factors over the multi-quality characteristics.

TABLE 8

MEAN RESPONSES FOR OVERALL GREY RELATIONAL GRADE

| Symbol | Green sand mould process parameters | Grey relational grade | | | Main effect (Max-Min) | Rank |
|---|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | | |
| A | Water | 0.5303 | 0.6311* | --- | 0.1008 | 3 |
| B | Molasses | 0.5464 | 0.5696 | 0.6260* | 0.0795 | 4 |
| C | Bentonite | 0.5219 | 0.5607 | 0.6595* | 0.1376 | 1 |
| D | Fly Ash | 0.5272 | 0.5757 | 0.6392* | 0.1119 | 2 |

Total mean value of the grey relational grade = 0.5807

* Levels for optimum grey relational grade

The most effective controllable factor was the maximum of these values. Here, the maximum value among 0.6311, 0.6260, 0.6595, and 0.6392 is 0.6595. The value indicates that the bentonite is influenced on the multi-quality characteristics among the other sand mould process parameters. Examining these data, on the other hand, reveals the major significance that each controllable parameter plays over the multi-quality features. The order of importance of the controllable parameters to the multi-quality characteristics in the sand mould process parameters, in sequence, such as: parameter C (bentonite), D (fly ash), A (water), and B (molasses) (i.e., 0.6595>0.6392>0.631> 0.6260). The most efficient parameter for influencing the qualitative attributes of the green sand mould was parameter C (bentonite). Similarly, a few researchers attempted to optimise casting process parameters [44].

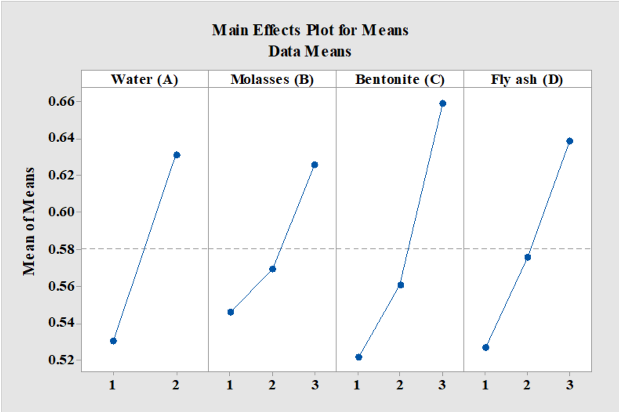


Fig. 7. Mean plot for overall Grey relational grade

*A. Analysis of Variance (ANOVA) of experimental results*

ANOVA is a statistical technique, which can infer some important conclusions based on analysis of the experimental data. The method is customized to reveal the level of significance of influence of parameter(s) or interaction of parameters on a particular response. It deconstructs the entire variability of the response (the sum of squared departures from the grand mean) into contributions from each parameter and the error. Thus

$$SS_T=SS_F+SS_E \tag{4}$$

$SS_E=SS_F- SS_T$

$SS_E= SS_A +SS_B+SS_{A*B} +SS_{A*B^2}+SS_C+SS_{A*C}+SS_{A*C^2}+SS_D$

$SS_E= 0.046 +0.020+0.027+0.008 +0.060+0.0015+0.014+0.3238$

$SS_E= 0.006$

Total degrees of freedom= 17

Where $SS_T = \sum_{j=1}^{p}(Y_j\text{-}Y_m)^2$

$SS_T$:Total sum of squared deviations about the mean

$Y_j$:Mean response for j[th] experiment

$\gamma_m$:Grand mean of the response

P: Number of experiments in the orthogonal array

$SS_F$ :Sum of squared deviations due to each factor

$SS_E$ : Sum of squared deviations due to error

In ANOVA table mean square deviation is defined as:

$$MS=\frac{SS\text{ (Sum of squared deviations)}}{DOF\text{ (Degree of Freedom)}}$$

F-value of Fisher's F ratio (Variance ratio) is defined as:

$$F=\frac{MS\text{ for a term}}{MS\text{ for the error term}}$$

Depending on F-value, P-value (probability of significance) is calculated. According to the present analysis, the most effective parameters with respect to green compression strength, Permeability, Compatibly, and Mould hardness are Bentonite, Fly ash, water, and Molasses respectively. Percent contribution indicates the relative power of a factor to reduce variation. For a factor with a high percent contribution, has a great influence on the performance. The percent contributions of the green sand mould parameters on the green sand properties are shown in Table 9 and Fig.8. Bentonite (26 wt. %) was found to be the major parameters affecting green sand properties, whereas water (20 wt. %) and fly ash (16 wt. %) were found to be the second and third ranking parameters respectively.

TABLE 9

RESULTS OF ANOVA USING ADJUSTED SS FOR TEST

| Source | DF | SS | MS | F-Value | Percentage contribution |
|---|---|---|---|---|---|
| A | 1 | 0.046 | 0.046 | 14.784 | 20% |
| B | 2 | 0.020 | 0.010 | 3.248 | 9% |
| A*B | 2 | 0.027 | 0.013 | 4.305 | 11% |
| A*B² | 2 | 0.008 | 0.004 | 1.271 | 3% |
| C | 2 | 0.060 | 0.030 | 9.770 | 26% |
| A*C | 2 | 0.015 | 0.007 | 2.409 | 6% |
| A*C² | 2 | 0.014 | 0.007 | 2.217 | 6% |
| D | 2 | 0.038 | 0.019 | 6.118 | 16% |
| Error | 2 | 0.006 | 0.003 | -- | 3% |
| Total | 17 | 0.233 | 0.014 | -- | -- |

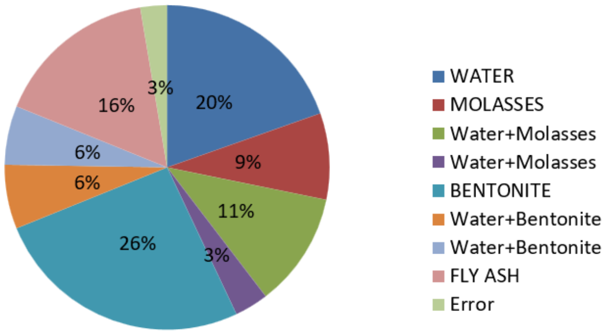


Fig.8 Contributed percentage of the green sand mould parameter

The sand properties are the "larger the better" type of quality characteristics. Larger the better S/N ratios of grey relational grade were computed for each of the 18 trials and the values are depicted in Table 10.

$$S/N\text{ ratio (Larger the better)}= -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]$$

TABLE 1

SIGNAL TO NOISE RATIO OF GREY RELATIONAL GRADE

| Expt. No. | Grey relational grade ($\gamma_i$) | S/N ratio |
|---|---|---|
| 1 | 0.355 | -8.986 |
| 2 | 0.466 | -6.624 |
| 3 | 0.669 | -3.491 |
| 4 | 0.527 | -5.561 |
| 5 | 0.534 | -5.446 |
| 6 | 0.563 | -4.988 |
| 7 | 0.507 | -5.899 |
| 8 | 0.539 | -5.367 |
| 9 | 0.611 | -4.275 |
| 10 | 0.552 | -5.166 |
| 11 | 0.596 | -4.495 |
| 12 | 0.640 | -3.875 |
| 13 | 0.640 | -3.883 |
| 14 | 0.540 | -5.346 |
| 15 | 0.614 | -4.243 |
| 16 | 0.578 | -4.763 |
| 17 | 0.951 | -0.434 |
| 18 | 0.569 | -4.891 |

ANOVA on grey relational grade was used to determine the impact of each process parameter affecting the qualitative attributes of the green sand mould. Figure 9 depicts the S/N ratio of the grey relational grade produced for various process settings. A vertical line represents the S/N ratio of grey relational grade for each parameter. The S/N ratio is likewise greatest at the same parameter levels (A2, B3, C3, and D3) as the ideal values for obtaining maximum green sand qualities of the green sand mould process parameters.

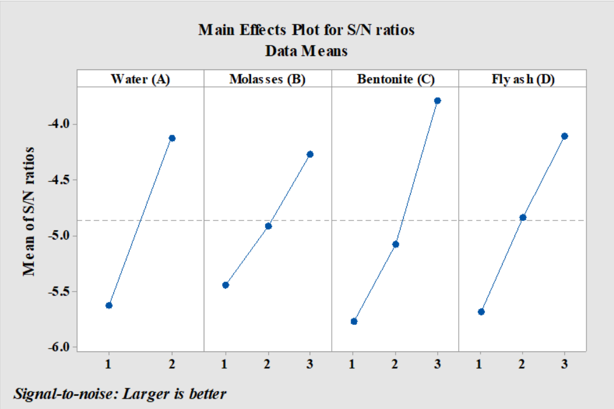


Fig. 9 Effect of green sand mould parameters on the multi-quality characteristics

## V. Confirmation Experiment

Once the optimal level of green sand mould process parameters is selected the final step is to predict and verify the improvement of the quality characteristics using the optimal level of thegreen sand mould process parameters. The estimated Grey relational grade $\hat{\gamma}$ usingthe optimum level of the green sand mould process parameters can be calculated as

$$\hat{\gamma}=\gamma_m+\sum_{i=1}^{q}(\bar{\gamma}_j-\gamma_m) \quad (5)$$

Where $\gamma_m$ is the overall mean of the Grey relational grade, $\bar{\gamma}_j$ is the optimal mean of the Grey relational grade, and q is the number of green sand mould process factors that have a substantial impact on the numerous quality features. The estimated Grey relational grade utilising the optimal green sand mould process parameters may therefore be determined using Equation (5). The findings of the confirmation experiment employing the optimal green sand mould process parameters are shown in Table 11. As a result, the grey relation grade of quality features increases from 0.355 to 0.951. This study clearly shows that many quality attributes in the green sand mould process are considerably improved.

Table 11

Results of the Confirmatory Experiment

| | Initial GS process parameters | Optimal GS process parameters | |
|---|---|---|---|
| | | Prediction | Experiment |
| Factors levels | $A_1B_1C_1D_1$ | -- | $A_2B_3C_3D_3$ |
| GCS | 145 | -- | 185 |
| Permeability | 250 | -- | 265 |
| Compatibility | 70 | -- | 95 |
| Mould hardness | 70 | -- | 90 |
| S/N ratio of overall Grey relational grade | -8.986 | -- | -0.434 |
| Overall, Grey relational grade | 0.355 | 0.8136 | 0.951 |
| Improvement in Grey relational grade =0.596 | | | |

## VI. Conclusions

Based on the present investigation following conclusions were made.

1. It was discovered that bentonite had the greatest impact on the multi-quality features of the other parameters tested. Bentonite, fly ash, water, and molasses are the order of significance of the controllable elements to the multi-quality features. The experimental findings clearly indicate that the suggested technique may successfully improve the characteristics of green sand. As a result of this strategy, optimising the challenging numerous quality parameters may be substantially simplified.
2. The optimal green sand mould management parameters for maximum sand qualities are water 4.5 wt. percent, molasses 3.5 wt. percent, bentonite 15 wt. percent, and fly ash 15 wt. percent. At the best combination of settings, the improvement in grey relational grade for sand attributes is 0.596. Confirmation experiments have effectively demonstrated the efficacy of this strategy. As a result, the answers obtained from this approach may be employed by foundrymen and production engineers who are looking for an ideal solution of sand mould process parameters for sand casting.

It is proposed that this method is an approach for optimization and control parameters analysis of the green sand mould parameters based on $L_{18}$ orthogonal array design matrix table.

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