Effect of Additives on Green Sand Molding Properties using Design of Experiments and Taguchi's Quality Loss Function – An Experimental Study

Bhagyashree Desai, Pavani Mokashi, Anand R L, Burli S B, Khandal S V

1, 2, 3, 4, 5 Department of Industrial and Production Engineering, B.V. Bhoomaraddi College of Engineering & Technology, Hubballi, Karnataka, India.

Corresponding author: khandal@bvb.edu

Abstract:- The experimental study aims to understand the effect of various additives on the green sand molding properties as a particular combination of additives could yield desired sand properties. The input parameters (factors) selected were water and powder (Fly ash, Coconut shell and Tamarind) in three levels. Experiments were planned using design of experiments (DOE). On the basis of plans, experiments were conducted to understand the behavior of sand mould properties such as compression strength, shear strength, permeability number with various additives. From the experimental results it could be concluded that the factors have significant effect on the sand properties as P-value found to be less than 0.05 for all the cases studied. The optimization based on quality loss function was also performed. The study revealed that the quality loss associated with the tamarind powder was lesser compared to other additives selected for the study. The optimization based on quality loss function and the parametric analysis using ANOVA suggested that the tamarind powder of 8 gm per Kg of molding sand and moisture content of 7% yield better properties to obtain sound castings.

Keywords: Green sand, design of experiments (DOE), compression strength, shear strength, permeability number.

1. Introduction
The foundry technique started as early as 3600 BC, has flourished very well and is likely to grow further. The foundry deals with casting techniques, which is one of the earliest metal shaping methods known to humans. It generally means pouring molten metal into a mould and allowing it to solidify. The solidified object is called casting. This forms the basis for manufacturing a product. Castings with additional features find applications in cylinder blocks, mill rolls, machine tool bed, piston rings, wheels, housings, automobile parts, train locomotives, water supply pipes, airplanes, etc [1]. Sand castings can be of various size ranging from small to large, bringing about variation in properties. Silica sand (SiO₂) is the most commonly used sand in molding. A green sand mold refers to the fact that the mold will contain moisture during the pouring of the casting [2]. The different types of refractory sands used for molding are silica sand, magnetite, zircon, silimanite, olivine, graphite. Green sand is composed of silica sand, about 10% bentonite clay and 2% to 5% water and around 5% sea coal [3]. Green sand is fine, soft, light and porous. Molds prepared out of green sand are not requiring backing. Green sand possesses ideal molding properties such as compression strength, shear strength, permeability number, mold ability etc, which makes it highly valuable sand that can be used in the production of ferrous and non-ferrous castings. Statistical approach is the most appropriate tool for studying green compression strength of green sand molds [12]. Green sand possess properties that are adjustable within a wide range.
which makes it suitable for all types of green sand molding equipment’s[13]. Green compression strength increases with increase in finesses of sand grains but decreases with coarse grains [15].

2. Literature review

There is a vital role played by the additives in inducing observable changes in the mold properties. The additives such as fly ash, wood flour, iron fillings, sea coal, coal dust, starch, husk etc., have been used to a limited level and have found to bring out beneficial products with higher resistance properties. In order to get good casting surface quality, easy casting cleaning, and decrease of sand adhesion to casting, reduce casting defects the mold properties are to be improved by using additives in molding sand. Properties such as refractoriness, cohesiveness, permeability, collapsibility, green strength dry strength, etc, are the basic requirements that molding sand should possess in order to get defects free castings [4]. Without the use of additives the molding sand fails to impart certain important properties [5]. Due to involvement of additives in sand, several properties including high temperature plasticity, metal penetration property and surface finish were enhanced [6]. Additives are mixed during sand preparation based on the requirement of molten metal to obtain specific characteristics in the sand [7]. Fly ash it is one of the residues of thermal power station and it is waste material it contents silica this can be utilized as an additives for molding sands. Coconut shell powder, tamarind powder is agricultural wastes and can be used as additives in sand molding to improve the castings surface finish. Among Coconut shell powder, Fly ash, Tamarind powder, the coconut shell powder shows the higher compression strength. Fly ash shows the good permeability number for molding sand [8]. Bentonite possesses special properties such as swelling index, colloidal properties, water absorption ability, viscosity and thixiotropy etc which makes bentonite to be used as binder material in the molding sand preparation for production of steel and non-ferrous casting. Very high green and dry sand strengths were obtained when both cassava and bentonite powder were combined. The sand strength was minimum when cassava starch alone was used [9]. Among fly ash, coconut shell powder, and tamarind powder it is tamarind powder which gives highest sand strength [10]. Clay content and moisture content have positive effect on green compression strength [12]. Compression strength and moisture content are the control factors which has significant effect on quality control [14].

From the detailed literature survey it is found that no literature is available for optimization of input parameters to yield better sand properties using DOE and Quality loss function. Therefore this is an attempt to use DOE and Quality loss function for the optimization of input parameters to yield better sand properties that provide sound castings.

3. Experimental set up and methodology

Various experimental set ups used for the current study are universal testing machine, sand rammer and permeability meter which are shown in Figs 1 to 3. The input parameters (factors) selected for the study and there level is provided in table 1. The experimental plan based on DOE is provided in table 2 based on complete factorial designs. The experiments were conducted as per the plan. One Kg of moulding sand was used for all possible combinations. The green sand and powder are weighed using an electrical weighing balance shown in Fig. 4 and mixing was done using sand muller shown in Fig. 5. The moisture content of the sand was found using moisture content test apparatus which is shown in Fig. 6. All the experiments were repeated 5 times to minimize the possible errors. Once the desired moisture content was achieved, the standard specimens (50mm height × 50mm diameter) were prepared using sand ramming machine. Then they were tested on universal testing machine and permeability meter. The
experimental results recorded for coconut shell powder, Fly ash powder and Tamarind powder are shown in tables 3, 7 and 11 respectively.

Table 1 Input parameters setting and their levels [11]

| Parameters          | Levels |
|---------------------|--------|
|                     | -1     | 0 | +1   |
| Moisture Content (%)| 4      | 8 | 12   |
| Powder (gm)         | 5      | 7 | 9    |

Table 2 Experimental plan as per 3² complete factorial designs [11]

| Trial no. | Powder (in gms) | Moisture percentage |
|-----------|-----------------|---------------------|
| 1         | 4               | 5                   |
| 2         | 4               | 7                   |
| 3         | 4               | 9                   |
| 4         | 8               | 5                   |
| 5         | 8               | 7                   |
| 6         | 8               | 9                   |
The data recorded in Table 3 were analyzed to identify the significance of input parameters on the compressive strength, shear strength and permeability number using statistical software MINITAB. Table 4 shows the ANOVA (analysis of variance) chart for the Compressive strength, Table 5 shows the ANOVA chart for the shear strength and table 6 depicts ANOVA chart for permeability number with respect to the input parameters (% Coconut shell powder and % moisture) for 95% of confidence interval. Similarly the tables 8 to 10 and tables 12 to 14 show the results of ANOVA for other selected additive types. Further the main effect plots were drawn which are shown in figures 7 to 15 to understand the effect of each control parameter on the responses. The analysis of variance is performed on the experimentally obtained data to check the statistical significance of each control parameter on the each response variable.

Further the Taguchi’s quality loss function (Quadratic loss function) is used to optimize the input parameters to recommend the best settings of each parameter levels where the quality loss minimum.

4. Results and Discussions

The experimental results for coconut shell powder, fly ash powder, and tamarind powder are shown in Table 3, 7 and 11 respectively.

4.1 Coconut shell powder

The experimentally obtained data for coconut shell powder are analyzed using ANOVA and the results are shown in tables 4, 5 and 6. From the ANOVA it can be concluded that the coconut shell powder and moisture % are statistically significant on the responses. The main effect plot shown in figure 7 indicates the drop in permeability number from level 1 with change in levels of amounts of coconut shell powder and % moisture. From figures 8 and 9 it is observed that the compression strength and shear strength are found increased when both control factors are at level 2.

| Trial no. | Coconut shell powder (in gms) | Moisture Percentage | Permeability no | Compression strength x 0.1MPa | Shear strength x 0.1MPa |
|-----------|-------------------------------|---------------------|----------------|-------------------------------|-------------------------|
| 1         | 4                             | 5                   | 87             | 31.6                          | 9.4                     |
| 2         | 4                             | 7                   | 83             | 31.9                          | 9.6                     |
| 3         | 4                             | 9                   | 80             | 31.8                          | 9.5                     |
| 4         | 8                             | 5                   | 83             | 33.0                          | 9.6                     |
| 5         | 8                             | 7                   | 79             | 33.3                          | 9.8                     |
| 6         | 8                             | 9                   | 76             | 33.1                          | 9.7                     |
| 7         | 12                            | 5                   | 78             | 32.0                          | 9.4                     |
| 8         | 12                            | 7                   | 74             | 32.3                          | 9.5                     |
| 9         | 12                            | 9                   | 72             | 32.2                          | 9.4                     |
Table 4 Analysis of variance for Permeability Number

| Source                  | DF | Sum of the squares | Variance | F     | P     |
|-------------------------|----|--------------------|----------|-------|-------|
| Coconut shell powder    | 2  | 112.889            | 56.444   | 508.00| 0.000 |
| % Moisture              | 2  | 67.556             | 33.778   | 304.00| 0.000 |
| Residual error          | 4  | 0.444              | 0.111    |       |       |
| Total                   | 8  | 180.889            |          |       |       |

Fig. 7 Main effect plot for permeability number

Table 5 Analysis of variance for Compression strength

| Source                  | DF | Sum of the squares | Variance | F      | P     |
|-------------------------|----|--------------------|----------|--------|-------|
| Coconut shell powder    | 2  | 2.96222            | 1.48111  | 1333.00| 0.000 |
| % Moisture              | 2  | 0.13556            | 0.06778  | 61.00  | 0.001 |
| Residual error          | 4  | 0.00444            | 0.00111  |        |       |
| Total                   | 8  | 3.10222            |          |        |       |
Fig. 8 Main effect plot for compression strength

Table 6 Analysis of variance for Shear strength

| Source                 | DF  | Sum of the squares | Variance | F     | P    |
|------------------------|-----|--------------------|----------|-------|------|
| Coconut shell powder   | 2   | 0.115556           | 0.057778 | 52.00 | 0.001|
| % Moisture             | 2   | 0.042222           | 0.021111 | 19.00 | 0.009|
| Residual error         | 4   | 0.004444           | 0.001111 |      |      |
| Total                  | 8   | 0.162222           |          |       |      |
4.2 Fly ash powder
The experimentally obtained data for coconut shell powder are analyzed using ANOVA and the results are shown in tables 8, 9 and 10. From the ANOVA it can be concluded that the fly ash powder and moisture % are statistically significant on the responses.

The main effect plot shown in figure 10 indicates the drop in permeability number from level 1 with change in levels of amounts of coconut shell powder and % moisture. From figures 11 and 12 it is observed that the compression strength and shear strength are found to be increased when both control factors are at level 2.

| Trial no. | Fly ash powder (in gms) | Moisture Percentage | Permeability no. | Compression strength x 0.1MPa | Shear strength x 0.1MPa |
|-----------|-------------------------|---------------------|------------------|-----------------------------|------------------------|
| 1         | 4                       | 5                   | 91               | 31.8                        | 9.7                    |
| 2         | 4                       | 7                   | 87               | 32.0                        | 9.8                    |
| 3         | 4                       | 9                   | 83               | 31.9                        | 9.7                    |
| 4         | 8                       | 5                   | 87               | 33.5                        | 10.0                   |
| 5         | 8                       | 7                   | 83               | 33.8                        | 10.1                   |
| 6         | 8                       | 9                   | 80               | 33.6                        | 10.0                   |
| 7         | 12                      | 5                   | 82               | 32.5                        | 9.6                    |
| 8         | 12                      | 7                   | 79               | 32.7                        | 9.8                    |
| 9         | 12                      | 9                   | 76               | 32.6                        | 9.7                    |
Table 8 Analysis of variance for Permeability no

| Source             | DF | Sum of the squares | Variance | F     | P    |
|--------------------|----|--------------------|----------|-------|------|
| Fly ash powder     | 2  | 96.222             | 48.111   | 173.20| 0.000|
| % Moisture         | 2  | 73.556             | 36.778   | 132.40| 0.000|
| Residual error     | 4  | 1.111              | 0.278    |       |      |
| Total              | 8  | 170.889            |          |       |      |

Fig. 10 Main effect plot for permeability number

Table 9 Analysis of variance for Compression strength

| Source             | DF | Sum of the squares | Variance | F     | P    |
|--------------------|----|--------------------|----------|-------|------|
| Fly ash powder     | 2  | 4.5622             | 2.2811   | 2053.00| 0.000|
| % Moisture         | 2  | 0.0822             | 0.0411   | 37.00 | 0.003|
| Residual error     | 4  | 0.0044             | 0.0011   |       |      |
| Total              | 8  | 4.6489             |          |       |      |
Fig. 11 Main effect plot for compression strength

Table 10 Analysis of variance for Shear strength

| Source            | DF | Sum of the squares | Variance | F     | P     |
|-------------------|----|--------------------|----------|-------|-------|
| Fly ash powder    | 2  | 0.202222           | 0.101111 | 91.00 | 0.000 |
| % Moisture        | 2  | 0.028889           | 0.014444 | 13.00 | 0.018 |
| Residual error    | 4  | 0.004444           | 0.001111 |       |       |
| Total             | 8  | 0.235556           |          |       |       |
The experimentally obtained data for coconut shell powder are analyzed using ANOVA and the results are shown in tables 12, 13 and 14. From the ANOVA it can be concluded that the tamarind powder and moisture % are statistically significant on the responses.

The main effect plot shown in figure 13 indicates the drop in permeability number from level 1 with change in levels of amounts of coconut shell powder and % moisture. From figures 14 and 15 it is observed that the compression strength and shear strength are found increased when both control factors are at level 2.

| Trial no. | Tamarind Powder (in gms) | Moisture Percentage | Permeability. no | Compression strength x 0.1MPa | Shear strength x 0.1MPa |
|-----------|--------------------------|---------------------|-----------------|-------------------------------|------------------------|
| 1         | 4                        | 5                   | 85              | 32.0                          | 9.8                    |
| 2         | 4                        | 7                   | 81              | 32.2                          | 9.9                    |
| 3         | 4                        | 9                   | 78              | 32.1                          | 9.8                    |
| 4         | 8                        | 5                   | 80              | 34.0                          | 10.1                   |
| 5         | 8                        | 7                   | 76              | 34.3                          | 10.2                   |
| 6         | 8                        | 9                   | 73              | 34.1                          | 10.1                   |
| 7         | 12                       | 5                   | 75              | 33.0                          | 9.7                    |
| 8         | 12                       | 7                   | 71              | 33.2                          | 9.9                    |
| 9         | 12                       | 9                   | 69              | 33.1                          | 9.8                    |
Table 12 Analysis of variance for Permeability number

| Source                        | DF | Sum of the squares | Variance | F     | P     |
|-------------------------------|----|--------------------|----------|-------|-------|
| Tamarind Powder (in gms)      | 2  | 140.222            | 70.111   | 631.00| 0.000 |
| % Moisture                    | 2  | 67.556             | 33.778   | 304.00| 0.000 |
| Residual error                | 4  | 0.444              | 0.111    |       |       |
| Total                         | 8  | 208.222            |          |       |       |

Fig. 13 Main effect plot for permeability number

Table 13 Analysis of variance for Compression strength

| Source                        | DF | Sum of the squares | Variance | F     | P     |
|-------------------------------|----|--------------------|----------|-------|-------|
| Tamarind Powder (in gms)      | 2  | 6.2022             | 3.1011   | 2791.00| 0.000 |
| % Moisture                    | 2  | 0.0822             | 0.0411   | 37.00  | 0.003 |
| Residual error                | 4  | 0.0044             | 0.0011   |       |       |
| Total                         | 8  | 6.2889             |          |       |       |
Fig. 14 Main effect plot for compression strength

Table 14 Analysis of variance for Shear strength

| Source                      | DF | Sum of the squares | Variance | F      | P      |
|-----------------------------|----|--------------------|----------|--------|--------|
| Tamarind Powder (in gms)    | 2  | 0.202222           | 0.101111 | 91.00  | 0.000  |
| % Moisture                  | 2  | 0.028889           | 0.014444 | 13.00  | 0.018  |
| Residual error              | 4  | 0.004444           | 0.001111 |        |        |
| Total                       | 8  | 0.235556           |          |        |        |
4.4 Optimization of parameters using Taguchi’s quadratic loss function.

Dr. Taguchi defined the term quality as the Deviation from target performance. According to Taguchi, quality of manufactured products is the total loss generated by the product to the society from the time it is shipped. Taguchi proposed a quadratic loss function of nominal-the-best type, which is used to quantify the loss.

The average quality loss for the nominal-the-best type of quality characteristic is obtained by an expression

\[ Q = (\mu - m)^2 + \sigma^2 \] .......................... (2)

Where \( Q \) = the average quality loss  
\( \mu \) = the mean of performance characteristic  
\( m \) = the target performance  
\( \sigma^2 \) = the variance

In the proposed work it is assumed that the properties of green molding sand required for obtaining the sound casting are of nominal-the-best quality characteristic. The target performances for these quality characteristic are obtained through the literatures existing in the field of foundry technology.
The determination of quality loss is accomplished by the quadratic loss function. Assuming quality \( K = 1 \)
in quality loss equation.

### 4.4.1 Estimation of quality loss

The estimation of quality loss for the different additives at different levels of is computed and the results of quality loss are tabulated in the table 15.

| Property          | Additive type    | Target | Level | Quality loss (\( Q_a \)) |
|-------------------|------------------|--------|-------|--------------------------|
| Compression strength | Coconut Powder  | 34     | 1     | 5.01111 4.42666 3.62666 |
|                   |                  |        | 2     | 0.77444 0.17333 0.05666 |
|                   |                  |        | 3     | 2.67135 1.97666 0.82666 |
| Permeability no    | Fly ash Powder   | 80     | 1     | 31.6666 75.6666 22.3333 |
|                   |                  |        | 2     | 21 31.6666 34 |
|                   |                  |        | 3     | 44 16 130.333 |
| Shear strength     | Tamarind Powder  | 10     | 1     | 0.26666 0.07666 0.03333 |
|                   |                  |        | 2     | 0.10666 0.00666 0.02333 |
|                   |                  |        | 3     | 0.32444 0.10666 0.05666 |

The figures 16 to 18 have been obtained for the estimated quality loss in different levels for each additive type, which reveals the information that there is a strong interaction between the additives type. Quality loss distribution also indicates that the average quality loss is decreasing at the level 2 for all the additives type, whereas for the tamarind powder, it is observed that the loss quantity found less than compared to all other additives types such as coconut powder and fly ash. Therefore from the analyses it can be evidence that the tamarind powder shows less quality loss for achieving optimum properties of molding sand.
Fig. 17 Quality loss for Compression strength with parameter levels

Fig. 18 Quality loss for Permeability number with parameter levels
Conclusions

The experiments were conducted to examine the effect of changes in additives on the sand properties. From the detailed experimental results using DOE and quality loss function following conclusion were drawn:

- The experimental investigation and the statistical analysis revealed that the both factors such as additive type and % moisture are most significant factors that decide the optimal properties of green molding sand.

- Taguchi’s quality loss is found effective approach for selecting the best settings of control factors, in the current studies it is observed that the tamarind powder is found with less quality loss when compared with other additives. Therefore the tamarind powder which is found experimentally suitable choice of additive material that can be utilized for obtaining the sound casting requirements.

- The optimization based on quality loss function and the parametric analysis using ANOVA this is suggested that the tamarind powder of 8gms/kg , moisture of 7% gives optimum properties for green molding sand to obtain sound castings.

- From the experimental study it is also concluded that the DOE and Taguchi’s quality loss functions can be used for the optimization of control parameters which further to inculcate in the manufacturing process to minimize the loss to the society in terms reducing the variations in the manufactured components and also to achieve the target for the selected target.

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