# Study of Factors Effecting Green Compression Strength and Shear Strength of Moulding Sand using Factorial Technique

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***Abstract***
*In sand casting process, the mould strength plays a major role as it has to withstand the stresses developed by the molten metal. The strength of the moulding sand depends on various parameters like grain size, moisture content, clay content, type of binder etc. In the present work the effect of various process parameters like grain size, moisture content, clay content and binder content on green compression strength and shear strength of the molding sand are investigated by using factorial technique. Four factor - two levels are used and total 16 experiments are performed. The coefficients are calculated by using regression analysis and the model is constructed. The adequacy of the developed model is checked using Analysis of Variance (ANOVA) technique. By using the mathematical model the main and interaction effect of various process parameters on green compression strength and shear strength of moulding sand is studied. The developed model helps in selection of accurate percentages of various parameters or composition of the sand and also helps in achieving the desired strength of the moulding sand.*

***Keywords:*** *Casting, moulding sand, green compressive strength, green tensile strength*

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## INTRODUCTION

Casting is one of the important manufacturing process in which a molten metal is poured in a die which consists of cavity of required shape. When molten metal is solidified, we will get the desired product. In sand casting the quality of the product produced in casting depends upon properties of mould. Proper selection of moulding materials leads to good strength mould and finally leads to good casting.

Many works are reported on properties of Moulding sand and it is understood that Researchers like Aman Jatale *et al*.[1] analyzed the effect on strength and mechanical properties of cement concrete by using fly ash. Rasik A Upadhye *et al.*[2] optimized the sand casting process parameters of the castings manufactured in iron foundry by maximizing the signal to noise ratios and minimizing the noise factors using Taguchi method. B. Surekha *et al*.[3] analyzed the forward mapping problem of cement bonded sand mould system using fuzzy logic (FL) based approaches. Wasiu Ajibola Ayoola *et al.*[4] analyzed the effect of using $CO_2$ process, metal mould, cement-bonded sand mould and naturally-bonded sand mould on the hardness, tensile and impact strengths of as-cast 6063 Aluminum alloy.

Atanda P. O *et al.*[5] investigated the effects of Bentonite and Cassava starch binders on foundry moulding sand. Adarsh Kumar, *et al*.[6] conducted an experiment to study the effect of 3 parameters, namely, moisture content of sand mould, the clay content of sand mixture and grain fineness number of sand on the tensile strength of the casting produced.

Dr. Hani Aziz Ameen *et al*.[7] targeted the study of influence of additives on sand mold's properties and, consequently, on that of carbon steel CK45 casts. J. Jakubski *et al*.[8] assessed the method of sands suitability by means of detecting correlations between their individual parameters. The presented investigations were aimed at the selection of the neural network able to predict the active Bentonite content in the moulding sand on the basis of these sand properties such as: permeability, compatibility and the compressive strength. Adeleke Victor Adedayo[9] studied the effects of additions of iron filings to green moulding sand on the microstructure of grey cast iron. Abdulkabir Raji[10] studied the comparison between the grain size of the microstructures of the cast products increased from those of squeeze casting through chill casting to sand casting.
Zong Qian *et al.*[11] investigated different contents of slag and moisture in the production of motor shell casting of sewing machine on the basis of the orthogonal test method. Process performances of molding sand such as strength, permeability were tested.

Alexander Brown[12] reviewed the interpretation of results and the action required to ensure control and more importantly consistent quality castings from Greensand systems with the emphasis on the understanding and control of carbonaceous additive on casting performance.
George J. Vingas *et al*.[13] studied the effects of heat on the behavior of sodium and calcium Bentonite in bonding foundry sands. M. Dawson[14] examined some of the processing routes along with grading and physical/chemical attributes of silica sand. Long Wei *et al*.[15] analyzed the reasons causing sand inclusion, blowhole, metal leakage and metal penetration defects in castings were described, and five main test items of properties of green moulding sand used for an air impact moulding line was introduced including compact-ability, moisture, permeability and hot-wet tensile strength. Chen Shiliang *et al*.[16] examined the influence of different compacting methods i.e. squeeze, ramming and impact compacting on the mechanical properties of moulding sands. Tests show that the strength of sand specimens (tensile, shear and compressive strength) is differential though the weight of standard specimens is kept equal.
From the literature review, it is understood that most of the works reported o sand casting are on analysis of moulding sand properties like permeability, clay content, moisture content etc. However, very few researchers used Design of Experiments to develop mathematical models. The objective of the present project is to study the green compressive strength and green shear strength of the moulding sand and developing mathematical models to predict the same.

## METHODOLOGY

In the present paper the effect of moulding sand grain size, clay content, Binder and moisture content on green strength are studied. Four factor and two levels are selected and their values and levels are obtained by conducting trail experiments. Table 1 indicates the factors and their levels chosen.

***Table 1:*** *Process Variables.*

| Parameter | Minimum (–1) | Maximum (+1) |
|---|---|---|
| **Grain size (μm)** | 52 | 100 |
| **Clay content (%)** | 12 | 16 |
| **Binder (%)** | 1 | 2 |
| **Moisture content (%)** | 4 | 6 |

  

The numbers of levels to be included in the experiment were chosen for each factor as per the design. These numbers of levels were two for each so as per the definition it is a $2^n$ (2*2*2*2) factorial experiment. Where n is number of factors. In the present project work four factors and two levels were chosen. Hence the number of experiments to be conducted is $2^4$ =16 as per the design matrix shown in Table 2.

## EXPERIMENTAL PROCEDURE

Properties of moulding sand such as grain size, moisture content, clay content is calculated and their effect on green compressive strength and green shear strength are studied.

### Measurement Of Grain Size

Red soil of weight 15 kilo grams was taken and ground to powder using rammers.

The ground samples are poured into prearranged sieves of mesh size 8, 16, 32, 52, 100, 200 microns on a vibrator. The timer on the vibrator was set at 15 minutes and the motor was switched on as shown in Figure 1.

***Fig. 1:*** *Sieve Shaker.*

In the present work sand in sieves of size 52 and 100 microns are taken.

Experiment is repeated various times such that 7000 grams of sand having grain size 52 and 100 microns are collected as shown in Figure 2.


***Fig. 2****: Sand of Grain Size 52, 100μm.*

### Measurement of Clay Content

50 grams of 52 microns grain size sand is taken by weighing using digital weighing machine. 475 cc of distilled water and 25 cc of 3% NaOH are added to the sand. The mixture is agitated for about 10 minutes with the help of sand stirrer. The wash bottle is filled with water up to the marker as shown in Figure 3.

Once the sand is settled down at the bottom, siphon out the water from the wash bottle. Dry the settled down sand in muffle furnace for about 20 minutes until all the water molecules got evaporated. The remaining sand is weighed and found to be 47 grams. Thus the percentage of clay content is determined by the equation:

$$\text{Percentage clay contents} = \left[\frac{M_1 - M_2}{M_1}\right]100\%$$

where, $M_1$= Initial mass of the clay sample,
$M_2$= Final mass of the clay sample.

The percentage of clay content was found to be 6%. Similarly clay content test is performed for the grain size of 100 microns and was found to be 6%.


***Fig. 3:*** *Clay Content Test.*

**Sample Preparation**
Sand of grain size 52 microns was taken and using a measuring pan, 4 different samples of 1600 grams were prepared and sealed separately. Saw dust (additive) of 1% i.e., 16 grams was added to 2 samples each of 1600 grams. A clay content of 6% i.e., 96 grams was added to one of the sample and 10% i.e., 160 grams was added to the other sample.
For other 2 samples of grain size 52 microns, 2% of saw dust i.e., 32 grams was added to each sample. Again a clay content of 6% i.e., 96 grams was added to one sample and 10% i.e., 160 grams was added to the other. Each sample was mixed thoroughly.

The same procedure was repeated for the sand of grain size 100 microns. Thus 8 different samples of weight 1600 grams with different composition (difference in % of additive and clay content added) were obtained.

Firstly, a sample of grain size 52 microns, 1% saw dust and 12% clay content was taken and divided into two equal parts each of 800 grams. Each part was separately kept in the muffle furnace as represented in Figure 4 for about 15 minutes to nullify the moisture content.


***Fig. 4:*** *Muffle Furnace.*

Now 4% water, i.e., 32 ml was added to one part i.e., 800 grams and mixed thoroughly.

Using weighing pan, 4 different samples each of 200 grams was taken and pressed under Ram as shown in Figure 5 for 12 to 13 strokes to obtain a cake of 60 mm.

***Fig. 5:*** *Ramming Machine.*

**Measurement of Green Compression and Green Shear Strength**
The compression plates are placed in the Universal Strength Testing Machine shown in Figure 6 and green compression strength of 2 cakes were determined and their average values are recorded as indicated in Figure 7.

***Fig. 6:*** *Universal Strength Testing Machine.*

***Fig. 7:*** *Holders for Green Compression Strength.*

Other 2 cakes were tested for shear strength by re-placing the compression plates with shear plates and the average value of green shear strength are recorded as represented in Figure 8.

***Fig. 8:*** *Holders for Green Shear Strength.*

The other part of 800 grams was mixed thoroughly with 6% i.e., 48 ml of water. Four different samples of 200 grams each were taken and the procedure was repeated. The average green compression strength and green shear strength for all the sixteen samples as per design matrix.

Similarly, the procedure is repeated for every other sample of 1600 grams and their average values were tabulated.

## MATHEMATICAL MODELING AND ANALYSIS

By performing the experiments as discussed above, the values of Green Compression Strength (GCS) and Green Shear Strength (GSS) are measured and presented in Table 2.

### Development of Mathematical Model

Using MINITAB 14 statistical software package, the significant coefficients are determined and final model is developed using significant coefficients to estimate green compression strength and green shear strength of the moulding sand.

**Green Compression Strength (GCS)**

$$Y = 0.24344 - 0.04031X_1 + 0.05719X_2 + 0.01219X_3 + 0.00781X_4 + 0.00219X_1X_2 - 0.00781X_1X_3 - 0.01469X_1X_4 - 0.00781X_2X_3 - 0.00594X_2X_4 - 0.00906X_3X_4 - 0.00656X_1X_2X_3 - 0.02219X_1X_2X_4 + 0.007816X_1X_3X_4 + 0.01406X_2X_3X_4$$

**Green Shear strength (GSS)**

$$Y = 0.10938 - 0.01375X_1 - 0.02437X_2 + 0.00250X_3 + 0.00750X_4 - 0.00250X_1X_2 - 0.00312X_1X_3 - 0.00312X_1X_4 - 0.00375X_2X_3 + 0.00125X_2X_4 + 0.000188X_3X_4 - 0.00563X_1X_2X_3 - 0.00562X_1X_2X_4 - 0.00125X_1X_3X_4 + 0.00438X_2X_3X_4$$

*Table 2: Experimental Results.*

| Experiment No. | Moisture (%) | Clay (%) | Binder (%) | Sieve Size (Microns) | GCS (Kg/cm$^2$) | GSS (Kg/cm$^2$) |
|---|---|---|---|---|---|---|
| **1** | 4 | 12 | 1 | 52 | 0.195 | 0.09 |
| **2** | 6 | 12 | 1 | 52 | 0.1 | 0.05 |
| **3** | 4 | 16 | 1 | 52 | 0.29 | 0.13 |
| **4** | 6 | 16 | 1 | 52 | 0.345 | 0.135 |
| **5** | 4 | 12 | 2 | 52 | 0.25 | 0.095 |
| **6** | 6 | 12 | 2 | 52 | 0.145 | 0.08 |
| **7** | 4 | 16 | 2 | 52 | 0.31 | 0.135 |
| **8** | 6 | 16 | 2 | 52 | 0.25 | 0.1 |
| **9** | 4 | 12 | 1 | 100 | 0.22 | 0.095 |
| **10** | 6 | 12 | 1 | 100 | 0.15 | 0.08 |
| **11** | 4 | 16 | 1 | 100 | 0.35 | 0.155 |
| **12** | 6 | 16 | 1 | 100 | 0.2 | 0.12 |
| **13** | 4 | 12 | 2 | 100 | 0.25 | 0.105 |
| **14** | 6 | 12 | 2 | 100 | 0.18 | 0.085 |
| **15** | 4 | 16 | 2 | 100 | 0.405 | 0.18 |
| **16** | 6 | 16 | 2 | 100 | 0.255 | 0.115 |

Where, $X_1$, X2, $X_3$ and $X_4$ are the coded values of clay (%), binder (%), sieve size and moisture (%).

**Checking the Adequacy of the Developed Model**

The adequacy of the developed model was tested using the Analysis of Variance technique (ANOVA). As per this technique, if the calculated value of the F-ratio of the developed model is less than the standard F-ratio (from F-table) value at a desired level of confidence (say 95%), then the model is said to be adequate within the confidence limit. ANOVA test results presented in Table 3 and 4 are found to be adequate at 95% confidence level.

***Table 3:*** *ANOVA Table for Green Compression Strength.*

| Source | Seq SS | Adj SS | Adj MS | F |
|---|---|---|---|---|
| **Main effects** | 0.081681 | 0.0816813 | 0.0204203 | 29.63 |
| **2-Way Interactions** | 0.007359 | 0.0073594 | 0.0012266 | 1.78 |
| **3-Way Interactions** | 0.012706 | 0.0127063 | 0.0031766 | 4.61 |
| **Residual Error** | 0.000689 | 0.0006891 | 0.0006891 | |
| **Total** | 0.102436 | | | |

***Table 4:*** *ANOVA Table for Green Shear Strength.*

| Source | Seq SS | Adj SS | Adj MS | F |
|---|---|---|---|---|
| **Main effects** | 0.0135312 | 0.0135312 | 0.0033828 | 33.83 |
| **2-Way Interactions** | 0.0007187 | 0.0007187 | 0.0001198 | 1.20 |
| **3-Way Interactions** | 0.0013437 | 0.0013437 | 0.0003359 | 3.36 |

| | | | | |
|---|---|---|---|---|
| **Residual Error** | 0.0001000 | 0.0001000 | 0.0001000 | |
| **Total** | 0.0156937 | | | |

where, DF=Degrees of Freedom, SS=Sum of Squares, MS=Mean Square, F=Fishers Ratio.

Figure 9 and 10 indicates the scatter plot for green compression strength and green shear strength of the moulding sand and reveal that the experimental and predicted values are close to each other with in the specified limits.

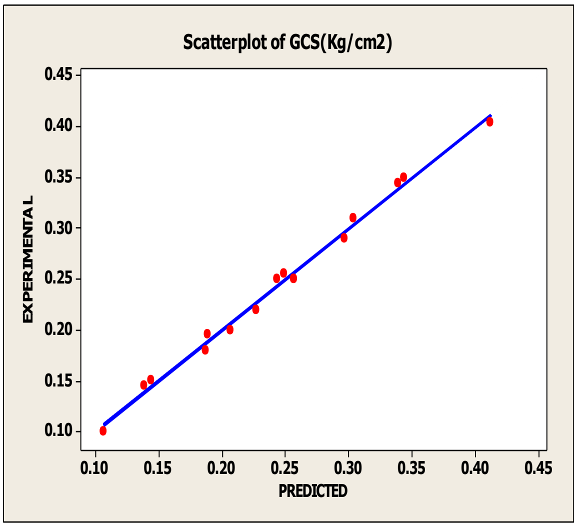


***Fig. 9**: Scatter Plot for GCS.*

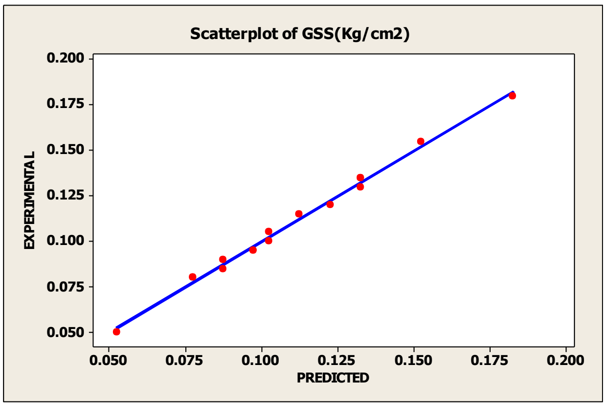


***Fig. 10:** Scatter Plot for GSS.*

## Effect of Input Parameters on GCS and GSS

### *Main effects on GCS*

Graphs are drawn as represented in Figure 11 and the following observations are made:

1. As the moisture content increases GCS value decreases.
2. As the clay content (%) increases GCS value increases.
3. As the binder content (%) increases GCS value increases.
4. As the sand grain size (Sieve size) increases GCS value increases.

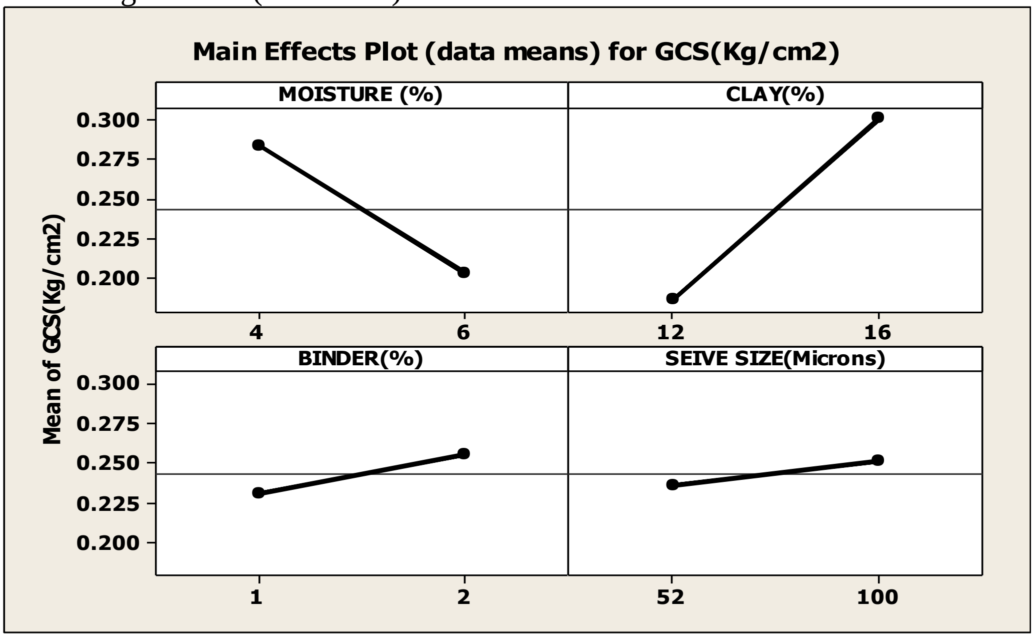


***Fig. 11:** Main Effects on GCS.*

***Main effects on GSS***

Graphs are drawn as represented in Figure 12 and the following observations are made:

1. As the moisture content increases GSS value decreases.
2. As the clay content (%) increases GSS value increases.
3. As the binder content (%) increases GSS value increases.
4. As the sand grain size (Sieve size) increases GSS value increases.

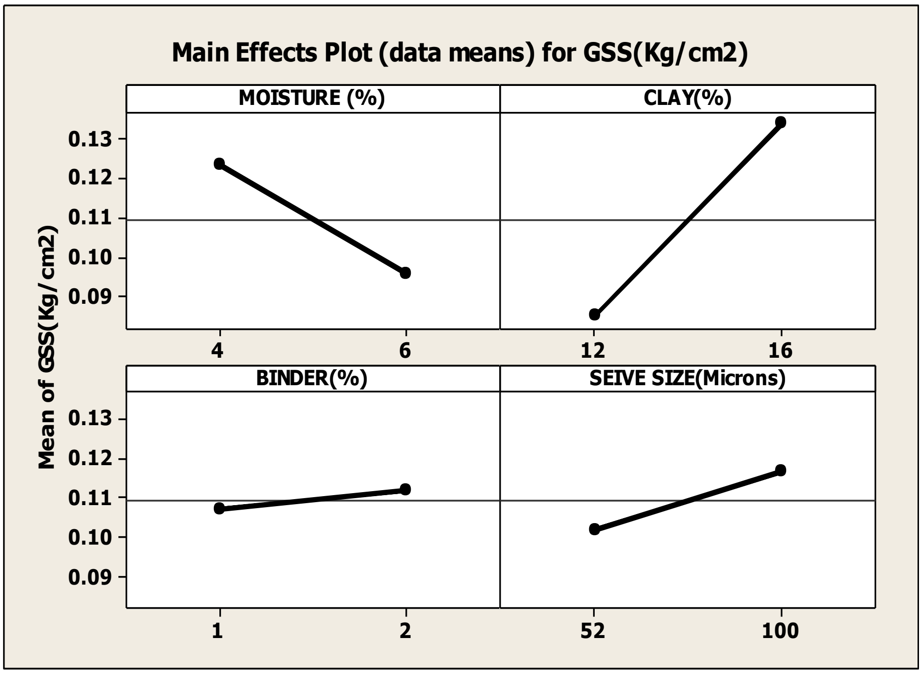


***Fig. 12:*** *Main Effects on GSS.*

***Interaction effects on surface roughness***

Interaction plots are drawn in order to the study the effect of input parameters at a time on GCS and GSS as shown in Figure 13 and 14.

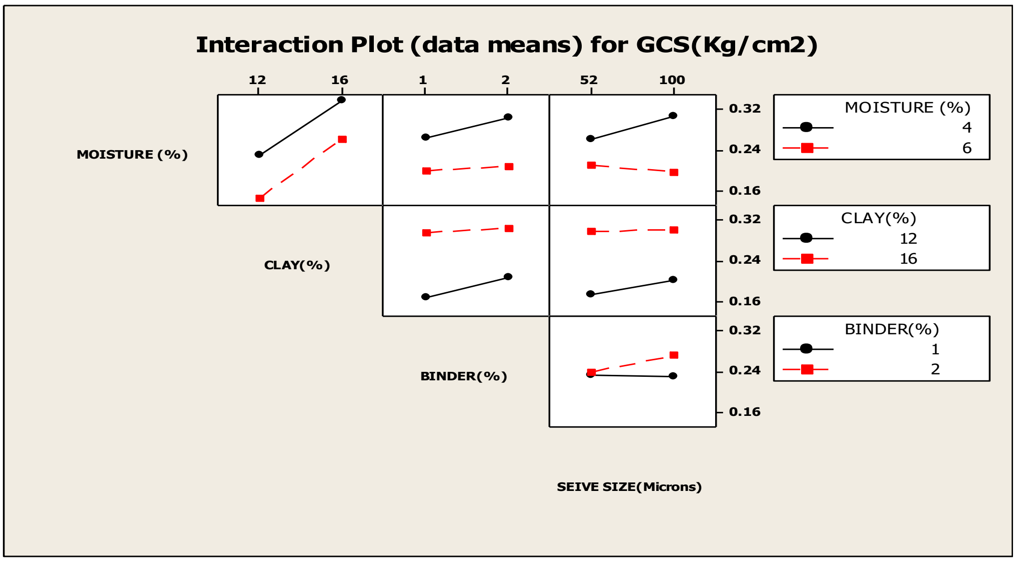


***Fig. 13:*** *Interaction Plot for GCS.*

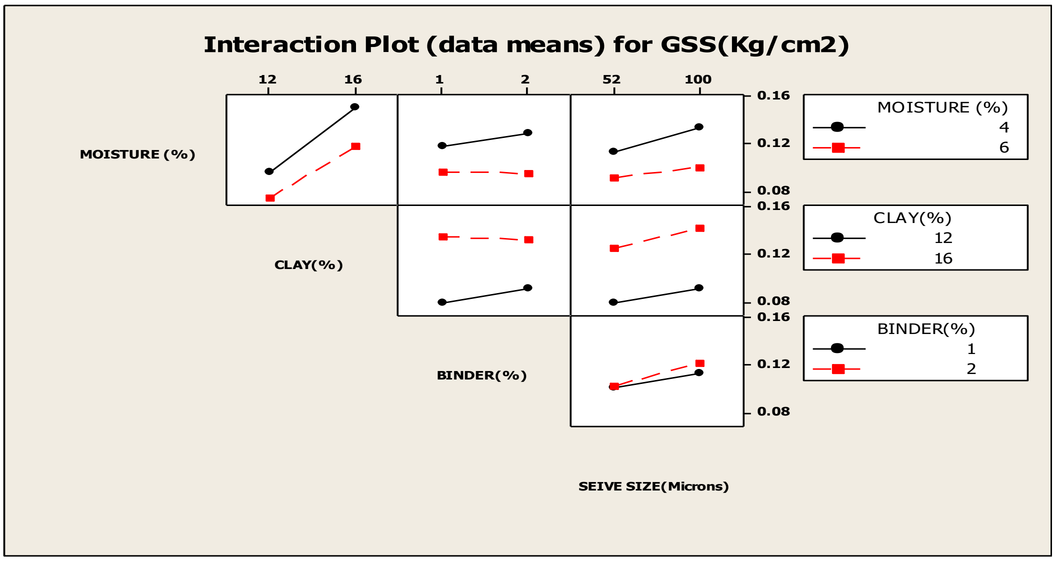


*Fig. 14: Interaction Plot for GSS.*

## Contour Plots for GCS and GSS

The simultaneous effect of two parameters at a time on the output response is generally studied using contour plots. By generating contour plots using statistical software (MINITAB14) for response surface analysis, the most influencing parameter can be identified based on the orientation of contour lines. If the counter patterning of circular shaped counters occurs, it suggests the equal influence of both the factors; while elliptical contours indicate the interaction of the factors. Figure 15 and 16 indicates the contour plots for GCS and GSS respectively.

From the contour plots it is understood that binder is the most dominating parameter effecting GCS and GSS followed by clay, sand grain size and moisture.

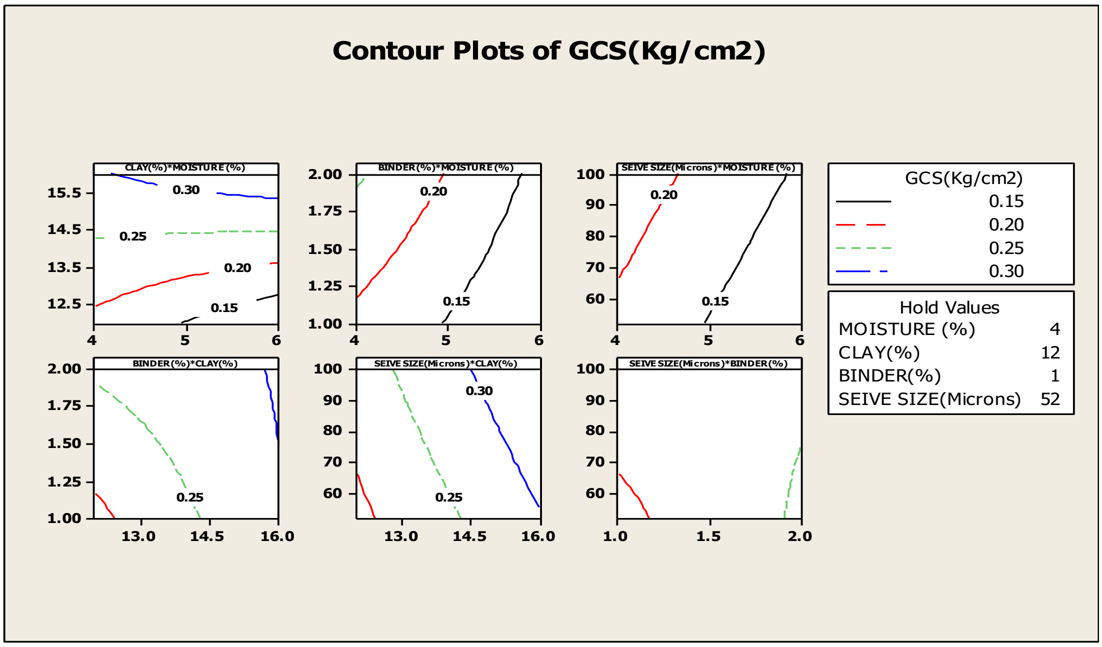


*Fig. 15: Contour Plots for GCS.*

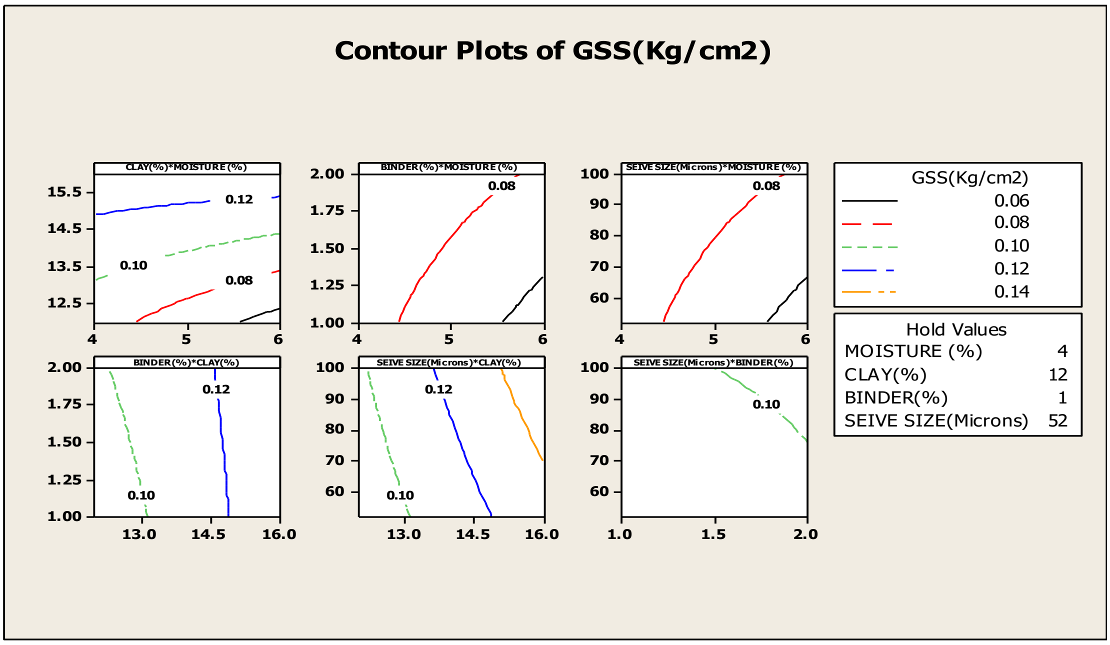


***Fig. 16:*** *Contour Plots for GSS.*

## Comparison of Experimental and Predicted Strength Values of GCS and GSS

From the experiments performed, the experimental and predicted values are in Table 5. From the developed model, the values of GCS and GSS are predicted by substituting the coded values of the input parameters in the developed empirical mathematical model. Table 5 indicates the experimental and predicted values of GCS and GSS for all the 16 combination of experiments performed.

***Table 5:*** *Comparison of Experimental and Predicted Values.*

| Experiment No. | Green Compression Strength (Kg/cm$^2$) | | Green Shear Strength (Kg/cm$^2$) | |
|---|---|---|---|---|
| | Experimental | Predicted | Experimental | Predicted |
| **1** | 0.195 | 0.188437 | 0.09 | 0.0875 |
| **2** | 0.1 | 0.106563 | 0.05 | 0.0525 |
| **3** | 0.29 | 0.296563 | 0.13 | 0.1325 |
| **4** | 0.345 | 0.338438 | 0.135 | 0.1325 |
| **5** | 0.25 | 0.256562 | 0.095 | 0.0975 |
| **6** | 0.145 | 0.138437 | 0.08 | 0.0775 |
| **7** | 0.31 | 0.303437 | 0.135 | 0.1325 |
| **8** | 0.25 | 0.256563 | 0.1 | 0.1025 |
| **9** | 0.22 | 0.226563 | 0.095 | 0.0975 |
| **10** | 0.15 | 0.143438 | 0.08 | 0.0775 |
| **11** | 0.35 | 0.343438 | 0.155 | 0.1525 |
| **12** | 0.2 | 0.206563 | 0.12 | 0.1225 |
| **13** | 0.25 | 0.243437 | 0.105 | 0.1025 |
| **14** | 0.18 | 0.186563 | 0.085 | 0.0875 |

| | | | | |
|---|---|---|---|---|
| **15** | 0.405 | 0.411562 | 0.18 | 0.1825 |
| **16** | 0.255 | 0.248438 | 0.115 | 0.1125 |

## RESULTS AND DISCUSSION

From the experiments performed the following results are drawn.

1. Empirical mathematical model are developed for predicted Green Compression Strength and Green Shear Strength of the moulding sand using full factorial method.
2. The experimental and predicted values are very close to each other, which indicate the accuracy of the developed model.
3. The adequacy of the developed model is checked using ANOVA at 95% confidence level ad found to be adequate.
4. From the scatter plot it is understood that experimental and predicted values are close to each other.
5. From the main effect plots, it is clear that Green Compression Strength decreases with increasing moisture (%) and increases with increase in binder (%), clay (%) and sand grain size (Sieve size).
6. From the main effect plots, it is observed that Green Shear Strength decreases with increasing moisture (%) and increases with increase in binder (%), clay (%) and sand grain size (Sieve size).
7. From the contour plots it is understood that binder (%) is the most dominating parameter effecting Green Compression Strength and Green Shear Strength followed by clay (%), sand grain size and moisture (%).
8. The developed models are valid within the range of the selected input parameters.

## CONCLUSIONS

The following conclusions are drawn based on the experimental results. Empirical mathematical model is developed for predicting Green Compression Strength and Green Shear Strength by using factorial method.

The adequacy of the developed model is checked at 95% confidence level using ANOVA. The effect of input parameters are studied and understood that Green Compression Strength and Green Shear Strength decrease with increase in moisture (%) and increases with increase in binder (%), clay (%) and sand grain size (Sieve size).

From the contour plots it is understood that binder (%) is the most dominating parameter effecting Green Compression Strength and Green Shear Strength followed by clay (%), sand grain size and moisture (%). The model is valid within the specified range of the selected parameters; however the accuracy can be improved by considering more number of factors and their levels.

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