Development of factorial model for green compression strength of moulding sand

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ABSTRACT

Keywords:
Green Compression Strength,
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DOE,
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Sand casting process is one of the most versatile process in manufacturing process where molten metal is poured into the expendable sand mould cavity to get complex shapes. In this process green compression strength is considered to be one of the important mechanical property for mould preparation in sand casting. These moulding sand properties play a vital role in determining the optimum moisture content for making green sand casting mould.

To optimize green compression strength the process variables like clay, moisture and sand composition are varied by selecting design of experiments (DOE) technique to find out effect of input parameters on green compression strength.

The present work aims to determination of green compression strength by varying silica sand, clay and water. Using factorial method number of experiments to be conducted is determined and design matrix is created. Using design matrix regression coefficients are calculated and student's t-test is carried out to check significance of each regression coefficient. Contribution of each factor on output is determined by analysis of variance (ANOVA).

1. Introduction

In metal casting process Sand casting is one of the oldest and fastest method. Casting is a manufacturing process where metallic components are made. In this process molten metal is usually poured into a mould of desired shape and then allowed to solidify. The solidified part is known as casting, which is broken out of the mould to complete the process. Casting materials are usually metals or various time setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster and clay. Sand castings are produced in specialized factories called foundries. Sand casting is one of the earliest forms of casting practiced due to the simplicity of materials involved. It still remains one of the cheapest ways to cast metals because of that same simplicity. Green sand is usually housed in what foundry workers refer to as "flask", which are nothing other than boxes without a bottom or lid. The box is split into two halves which are stacked together in use. The halves are referred to as the cope and drag flask respectively. For sand casting, green sand is used as a moulding material which is a mixture of silica sand, binding material and water. So to hold the mould firmly while pouring hot molten metal the green sand should have high compression strength because compressive forces will be exerted on the mould. This property is called as Green Compression Strength. This experiment aims at finding the Green Compression Strength of green sand and finding a appropriate model using three parameters weight of silica sand, binder and amount of water.

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2. Factorial Design of Experiments

The factorial design of an experiment is the procedure of selecting the number of trials and conditions for running them, essential and sufficient for solving the problems that has been set with the required precision. Factorial designs are widely used in experiments involving several factors where it is necessary to study the joint effect of the factors on a response. However there are several special cases of the general factorial design that are important because they are widely used in research work and also because they form the basis of other designs of considerable practical value.

2.1 Objective & Methodology

The mathematical model is developed by using factorial design of experiments to predict the green compression strength of the given mould. The three factors, namely, weight of sand, clay and water content are analyzed simultaneously by the main effects with two and three factor interactions. The developed model is tested for its adequacy and significance of each coefficient is checked by student's t-test at 5% significance level.

The investigation study is planned with the following objectives

1. Postulation of mathematical model for green compression strength
2. Adoption of two level factorial design of experiments and selection of test regions for the variables (factors).
3. Conducting the experiments as per design matrix.
4. Estimation of coefficients of postulated model.
5. Analysis of results
   - Checking the adequacy of the postulated model by 'F-test'
   - Testing the significance of each coefficient of the model by 't-test'
   - Determination of percentage contribution of each factor.

2.2 Postulation of model for green compression strength

Objectives and Scope of work

Objectives:-

- To study the effect of weight of sand, binder and water content on green compression strength of mould
- To find optimal weights of sand, binder and water and their corresponding process parameters

Scope:-

The mould sand properties are identified to develop the mathematical model to predict the green compression strength. These include weight of sand, clay and water content. The first order model is assumed with two and three factor interactions which can be expressed as,

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_{12} X_1 X_2 + a_{13} X_1 X_2 + a_{23} X_2 X_3 + a_{123} X_1 X_2 X_3$$

where 'Y' represents Green Compression strength X_1, X_2, X_3 represent the coded values of weight of sand, clay and water content respectively; $a_0, a_1, \ldots, a_{123}$ are the regression coefficients of polynomial to be determined. A two level full factorial design of experiments is adopted for calculating the main and the interaction effects of the three factors at two levels; $2^3 = 8$ experiments are conducted to fit an equation. The design plan with high and low limits as indicated Table -1

Table 1
Factors and levels

Factors	Units	Designation		Test levels	
		Natural form	Coded form	Low	High
Weight of sand	g	S	X_1	475	575
Weight of clay	g	C	X_2	30	45
Water content	ml	W	X_3	25	35

3. Model Development

In the present work, sequences of steps followed in development of model are

3.1 Calculation of regression coefficients

Here the number of replications for the response are two i.e., y1 and y2 and average of these is 'y'. Regression coefficients a_0, a_1, a_2, a_{12} etc., are calculated by using the formula given below

$b_j = [\sum x_{ij} y_i]/N$

Where N = number of trails (N=8)

Fisher test for adequacy of model (f-test for 5% significance level)

Variance for reproducibility

$= S_y^2 = [2\sum(\text{dely})^2]/N$

N=number of trails, dely = (y1-y)

Variance of adequacy,

$S_{ad}^2 = [2\sum(y-y_p)^2]/DOF$

y_p = predicted response.

$y_p = a_0 x_0[i] + a_1 x_1[i] + a_2 x_2[i] + \ldots\ldots$

where DOF = degree of freedom

= [N-(k+1)]

where N = number of trails

k = number of factors

F-model = S_{ad}^2 / S_y^2

For given values of f1 and f2, F-table value is found from fisher table.

Here f1=N-(k+1), f2=N

If F-model ≤ F-table, model is adequate in linear form otherwise it is not adequate.

3.2 Student's t-test (for 5% significance level)

When the model is adequate in linear form, then t-test is to be conducted to test the significance of each Regression coefficient.

Standard deviation of each coefficient,

$$S_{bj}=\sqrt{(S_y^2/N)}$$

$$\text{t-ratio} = |a_j| / (S_{aj})$$

for f = N, t value is to be taken from t-table and compared with t-ratio of each regression coefficient. If t-ratio ≥ t-table corresponding regression coefficient is significant. Non-significant coefficients are to be eliminated from the model to arrive the final form of mathematical model in linear form as

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_{12} X_1 X_2 + a_{13} X_1 X_2 + a_{23} X_2 X_3 + a_{123} X_1 X_2 X_3$$

4. Experimentation

The experiment was carried out by thorough mixing of silica sand, binder and water in certain proportions. Then some amount of mixture is weighed and rammed to make it hard.

Then this rammed mould is put in a compression strength testing machine. Pressure is applied slowly and readings were noted when a sudden crack was observed in the mould.

The column of each variable X_1, X_2 and X_3 are arranged in standard order. The values of regression coefficients a_0, a_1, a_2…a_{123} are calculated by regression analysis.

The values of regression coefficients a_0, a_1, a_2…a_{123} are calculated for cutting force and surface roughness is given below.

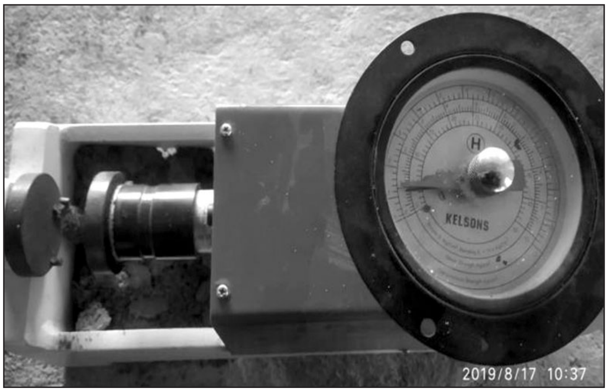


Fig. 1. Compression Strength testing device

Fig. 2. Rammed mould

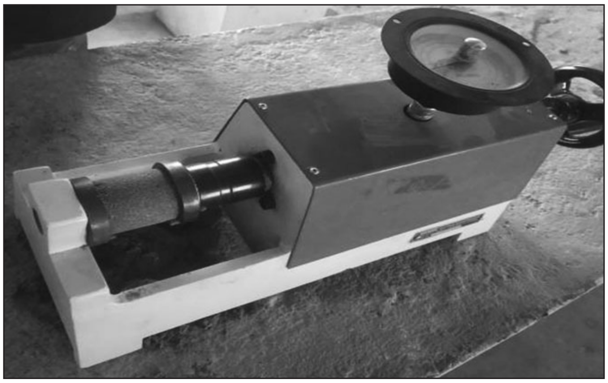


Fig. 3. Applying pressure on the mould

Fig. 4. Crack in the mould

Table 2
Design Matrix

Trial No.	DESIGN MATRIX				Green Compression Strength (Kgf/cm^2)		
	X_0	X_1	X_2	X_3	Y_1	Y_2	Y
1	1	-1(475)	-1(30)	-1(25)	0.10	0.10	0.10
2	1	+1(575)	-1(30)	-1(25)	0.30	0.30	0.30
3	1	-1(475)	+1(45)	-1(25)	0.40	0.40	0.40
4	1	+1(575)	+1(45)	-1(25)	0.30	0.25	0.28
5	1	-1(475)	-1(30)	+1(35)	0.20	0.20	0.20
6	1	+1(575)	-1(30)	+1(35)	0.10	0.10	0.10
7	1	-1(475)	+1(45)	+1(35)	0.20	0.20	0.20
8	1	+1(575)	+1(45)	+1(35)	0.10	0.10	0.10

Table 3
Contribution of input parameters on output

Factor	% contribution
X_1(Weight of sand)	2.28
X_2(Weight of clay)	11.05
X_3(Water content)	32.97
X_1X_2	15.43
X_1X_3	11.05
X_2X_3	11.05
$X_1X_2X_3$	15.43

Regression coefficients for cutting force are

a_0=0.21 a_{12}=0.04
a_1= -0.02 a_{13}= -0.03
a_2= 0.03 a_{23}= -0.03
a_3= -0.06 a_{123}=0.04

The adequacy of the model was then tested by Fisher test. As per this technique, F-ratio of the model developed does not exceed the standard tabulated value of f-ratio for a 95% confidence level. Hence the model was adequate. The significance of the coefficients was checked by using student's t-test and only the significant coefficients were used to develop final mathematical model.

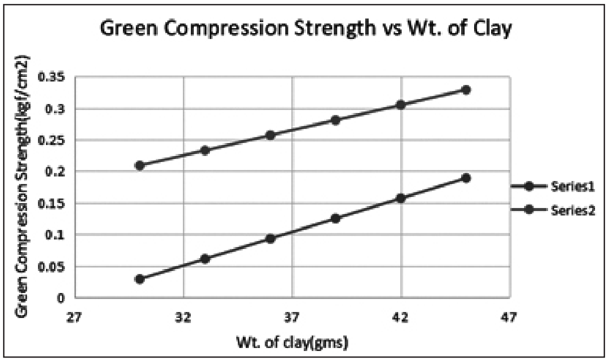
The final model in coded form for green compression strength is

$$Yp = 0.219\, X_0 - 0.02\, X_1 + 0.03\, X_2 - 0.06\, X_3 + 0.04\, X_1X_2 - 0.03\, X_1X_3 - 0.03\, X_2X_3 + 0.04\, X_1X_2X_3$$

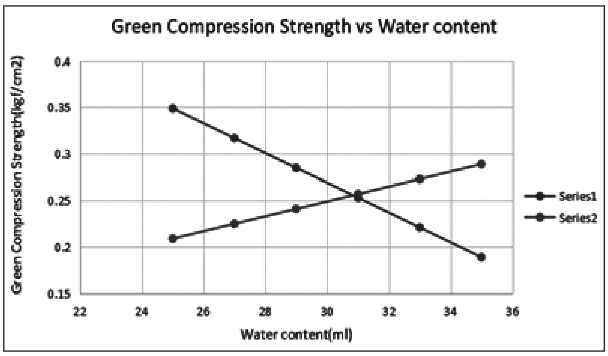
5. Analysis of Variance

Analysis of variance is done to find out the percentage contribution of each factor and relative significance of each factor for cutting force & surface roughness.
Percentage contribution of the Factors and their Interactions for Green Compression Strength.

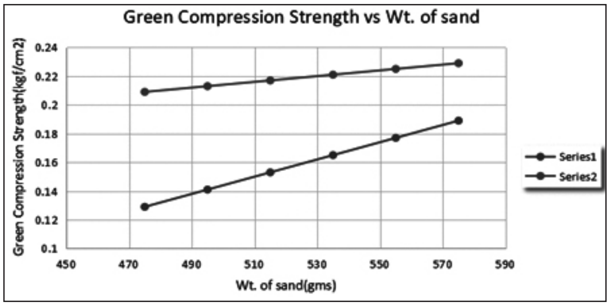
6. Graphical Representation



Series 1 represents graph for 575gms of sand and 35ml of water
Series 2 represents graph for 475gms of sand and 25ml of water



Series 1 represents graph for 575gms of sand and 45gms of clay
Series 2 represents graph for 475gms of sand and 30gms of clay



Series 1 represents graph for 45gms of clay and 35ml of water
Series 2 represents graph for 30gms of clay and 25ml of water

7. Results & Conclusion

It is clear that, percentage contribution of sand X_1, is 2.28% on the green compression strength, contribution of clay X_2, is 11.05%, contribution of water X_3, is 32.97%, and remaining percent is contributed by other interactions. From table-2, it is observed that influence of water content is more compared to clay and sand. Determination of contribution of factors helps the operator to set the parameters at required values in order to get desired quality of sand mould.

8. References

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