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OPTIMIZATION OF SAND PREPARATION TO IMPROVE CORE STRENGTH AND CASTING QUALITY

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ABSTRACT: Gravity die casting process is widely used for the manufacturing of hollow castings for automobile components, machine tool structures and mining and construction equipments. Cores are used to make most intricate internal cavities in castings. To have accurate dimensions and casting quality, cores must have resistance to erosion, resistance to thermal shock, resistance to metal penetration, higher strength, resistance to breakage, minimum gas evolution, higher permeability, etc. In this presented work, influence of binder content and shelf life on the foundry sand core properties is studied. Binder content and shelf life of core is optimized to get desired core properties affecting casting quality by two phase simplex method.
KEYWORDS : Gravity die casting, binder content, shelf life, two phase simplex method

I. INTRODUCTION

Cores are made of core sand mixture which consists of sand grains of base sand, binder to form bond between sand grains and catalyst to enhance bonding reaction. Cores are then obtained after compaction and baking of core sand mixture. Core wastes is having higher contribution to foundry wastes due to core rejection resulting from core defects like core damage while handling, core breakage due to low strength, low permeability,unfilling of cores resulting in reduced strength etc. Therefore it is important to study the effect of different process parameters related to sand preparation process and core making process on the core properties affecting casting quality and to optimize the process parameters to get desired core properties.

1.1Problem identification

For the identification of the problem ,rejection data is collected fromthe quality department and data analyzed. It is observed that number of defects like Core breakage, core shift, sand drop, blow hole and handling damage are commonly observed and have higher contribution to rejection of casting. All observed defects except core shift are related to the sand preparation, core making and core handling practices. Thus, it is important to understand what are the different causes related to these defects i.e. effect of different process parameters are studied to enhance core properties affecting casting quality.Cause and effect analysis diagram is studied for detail understanding of the parameters affecting core properties affecting casting quality and it helped to carry out root cause analysis of the defect. Literature survey is carried out to draw cause and effects analysis diagram and to understand the gravity die casting process, core making process and important process parameters affecting core and casting quality.

1.2 Cause and effect diagram for core properties

After going through literature survey, different process parameters affecting core properties are enlisted in cause and effect diagram in Fig. 1

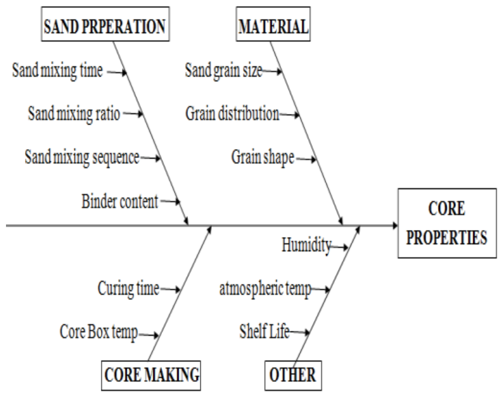

Fig. 1 Cause and Effect diagram for core properties

II. DESIGN OF EXPERIMENTS

2.1.1 Introduction to design of experiments

Experimental design is very important tool in engineering world for improving performance of manufacturing process. Statistical design of experiments refers to the process of planning the experiments so that collected data can be analyzed by statistical methods, resulting in valid and objective conclusion. The statistical approach to experimental design helps to find the meaningful conclusion from the experimental data. There are two aspects to anyexperimental problem, Design of experiments and Statistical analysis of the data[15].

2.1.2 Factorial Design

In general full factorial design, results of two factor factorial design may extended where there are *a* levels of factor A, *b* levels of factor B, *c* levels of factor C and So on. In general, there will be total *abc…n*observations if there are *n* replicates in complete experiment. Also, there must have at least 2 replicates (n>= 2) to determine the sum of squares due to error if all possible interactions are included in model[15]. Input variables along with their levels are defined in following Table 1.

Table 1. Levels and values of Input parameters

Parameters	Levels	Values
Binder content, Bc (% based on sand)	3	1.3, 1.6, 1.9
Shelf life, Ls (hrs)	5	0, 2, 4, 6, 8

3 replications are considered for present work i.e. n = 3 ... {(n>= 2)}

Therefore, total number of observation should be abn = 3x5x3 = 45.

III. EXPERIMENTAL RESULTS

3.1Experimental results for cold tensile strength(CTS), Traverse Strength(Ts)and gas evolution (Ge) of core for different combinations of Binder content (Bc) and Shelf life (Ls) Experimental trial according to design of experiment is carried out and observed results for cold tensile strength of core are shown in Table 2. and further graphs of main effects are plotted.

Table2. Effect of binder content & shelf life on CTS, TS and Ge of core

Sr.No.	I/P parameters		Avg. CTS (kg/cm2)	Avg. TS (kg/cm2)	avg. Ge (cc)
	Bc (%BOS)	Ls (hrs)			
1	1.3	0	5.16	8	7.9
2	1.3	2	7.5	7	8.3
3	1.3	4	8.43	9	8.6
4	1.3	6	8.89	9	8.4
5	1.3	8	8.29	8	8.7
6	1.6	0	8.11	14	8.7
7	1.6	2	8.94	15	8.9
8	1.6	4	9.46	18	9.2
9	1.6	6	9.89	17	9.5
10	1.6	8	9.43	18	9.1
11	1.9	0	11.92	26	10.7
12	1.9	2	12.1	26	11.7
13	1.9	4	12.8	27	11.2
14	1.9	6	13.12	28	11.5
15	1.9	8	13.03	27	11.9

Fig 2 shows the main effect plot for CTS and it is observed that CTS of core increases as binder content and shelf life of core increases. Higher value of CTS is desired to avoid core breakage.

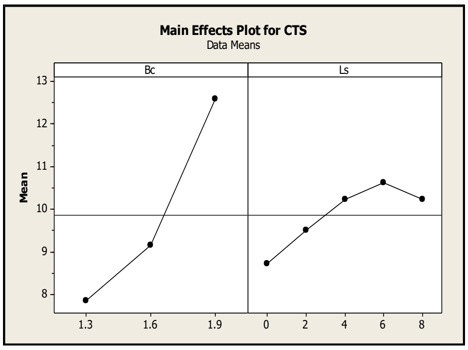

Fig. 2 Graph shows main effects plot for CTS of core

Fig. 3 the main effect plot for transverse strength and it is observed that transverse strength of core increases as binder content and shelf life of core increases. Higher value of transverse strength is desired to avoid core breakage.

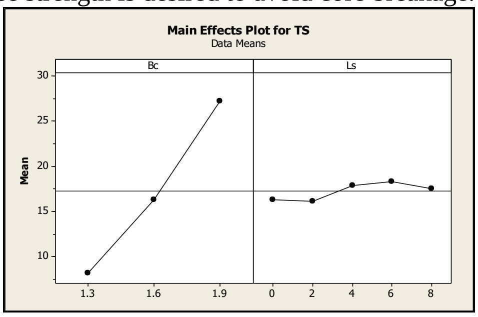

Fig. 3 Graph shows main effects plot for transverse strength (TS) of core

Fig. 4shows the main effects plot for Gas evolution and it is observed that Gas evolution increases as binder content and shelf life increases, but lower value of gas evolution is desired to avoid defects like blow hole and porosity.

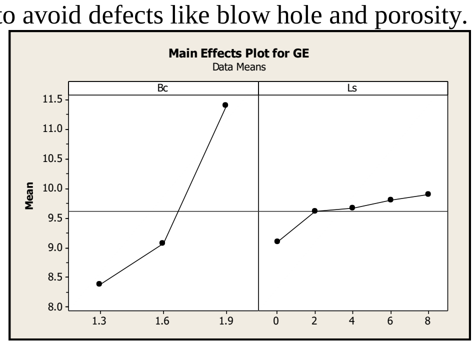

Fig. 4 Graph shows main effects plot for gas evolution (GE) of core

IV. EXPERIMENTAL DATA ANALYSIS

4.1Postulation of regression model for response

The observations in factorial experiment can be described by regression model. Here regression model has been established to get entire range of values used, particularly response from a subsequent run at an intermediate factor level

4.2 Linear regression model

In factorial design, it is easy to express the results of experiment in terms of a regression model. The linear regression model with two independent variables can be given by,

$Y = \beta_0 + \beta_1 Bc + \beta_2 Ls$

Where, $\beta_0, \beta_1, \beta_2$ are constant regression coefficient.
The values of regression coefficients are found out & the final linear regression model for cold tensile strength (CTS), Traverse Strength (Ts) and gas evolution (Ge) can be given as,
CTS = -4.334 + 8.2333 Bc + 0.2403 Ls
TS = -34.311 + 31.55 Bs + 0.277 Ls
GE = 1.1333 + 5.0333Bc + 0.0983Ls

4.3Two phase simplex method – L.P. problem (minimization type)

Linear programming method is used to find out intermediate optimized values of parameters. Linear programming is an optimization method applicable for the solution of problems in which the objective function and the constraints appear as linear functions of the decision variables. The constraint equations in a linear programming problem may be in the form of equalities or inequalities. The simplex method developed by Prof. George B. Dantzing can be used to solve any L.P. problem (for which the solution exists) involving any number of variables and constraints[11].
The general guidelines for formulation of L.P. problem are explained below[l]:
Step1: Express the problem in scalar form.
Scalar form of the problem is shown below,
MinimizeZ
$f(x_1, x_2 \ldots x_n) = c_1x_1 + c_2x_2 + \cdots + c_n$………...(I)
subject to the constraints :
$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1$
$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = b_2$
………
$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = b_m$…......(II)
$x_1 \geq 0, x_2 \geq 0, x_n \geq 0$ ...……..…….(III)
where,
Z = Objective function
c_j, b_j, a_{ij} = Constants… (i = 1, 2, . . . ,m; j = 1, 2, . .. , n)
And x_j = Decision variables.

Step 2: Express problem in standard form:

In presented work, Binder Content (% BOS) and Shelf life (hrs) are the decision variables and objective function is to minimize the cost incurred with use of binder and core storage.
Cost of binder = Rs. 280 / kg.
In presented work, all trials are carried out on the batch of 20 kgs sand. Thus cost of binder per %BOS can be calculated as,
Cost of binder = $\frac{20 \text{ X } 280 \text{ X } 1}{100}$ = Rs. 56 per % bindeR and
Cost of core storage = approx. Rs. 50 per hour.
Thus objective function can be written as,
Minimize Z : 56X1 + 50X2 … (say Binder content = X1 & Shelf life = X2)….. (IV)
And these values of X1 and X2 are subjected to constraints of core properties which can be written from equation IV, VI, VII as,
CTS : -4.334 +8.2333 Bc+0.2403Ls>= 7 …(V)
TS : -34.311 + 31.55 Bs + 0.277 Ls>= 7 ...(VI)
GE:1.1333+5.0333Bc+0.0983Ls<=8.5 …(VII)
It has been observed that optimized value for shelf life is 0 hours, it means core should be utilized immediately for die casting, but in actual practice for first 15 to 20 cores it requires around 1 hour for pouring at die casting stage. So remaining cores need wait at least for 1 hour because of casting process limitations, thus constraint of minimum 1 hour of shelf life is provided.
i.e.X2 >= 1…(VIII)
Rewrite above equations to standard form, we get,
Minimize: 56 X1 + 50 X2 … (IX)
Subject to:
CTS:8.2333X1+0.2403X2>= 11.334…(X)
TS: 31.55X1 + 0.277 X2 >= 41.311…(XI)
GE:5.0333 X1+0.0983X2 <= 9.6333 ….(XII)
X2 >= 1 ……(XIII)
X1, X2 >0
In this problem, three constraints are of (>=) type. So we introduce artificial variables. Two phase method is used to solve this problem.

Step 3: Phase I

The new objective function is,
Minimize W = A1 + A2 + A3
Now the simplex method requires that variables appear in one equation must appear in all equations. This is done by proper placement of a zero coefficient in equation (XVII), (XVIII), (XIX), (XX), (XXI). Thus the problem of Phase I in standard form can be written as:
Minimize
W=0*X1+0*X2+0*S1+0*S2+0*S3+0*S4+1*A1+1*A2+1*A3…………(XIV)
Subject to
CTS:8.2333X1+ 0.2403X2–S1+ A1>= 11.334 TS: 31.55X1+0.277X2 – S2 + A2 >= 41.311 GE: 5.0333 X1 + 0.0983 X2 – S3 <= 9.6333 X2 – S4 + A3 >= 1
X1, X2 >0
By using the method of Two phase simplex method and performing 4 iterations, Optimum values which are obtained for binder content and shelf life are1.35% BOS and 1 hour respectively.

V. CONCLUSIONS

1) The value of cold tensile strength (CTS), Transverse strength (TS) and Gas Evolution (GE) can be predicted by following equations for gravity die casting process for predefined material, environmental conditions and remaining process parameters:

Table 3. Linear Regression Equations for Responses

Sr. no.	Predicted Equations	Units
1	CTS =-4.334 + 8.2333 Bc + 0.2403 Ls	Kg/cm^2
2	TS =-34.311 + 31.55 Bs + 0.277 Ls	Kg/cm^2
3	GE =1.1333 + 5.0333Bc + 0.0983Ls	Cc

2) As binder content increases values of CTS, TS and GE increases.

3) Optimum values obtained for binder content and shelf life are1.35% BOS and 1 hour respectively.
4) Core sand mixture with 1.3% of binder based on sand shows very good flowability than that of 1.6% of binder.
5) Core sand mixture with 1.3% of binder shows fewer blockages of shooting nozzles due good flowability which results in elimination of core unfilling.
6) Core with 1.3% of binder has low residual strength because of minimum amount of binder thus help in easy decoring after casting solidification.
7) Also, Cores with 1.3% of binder shows less amount of gas evolution compared to 1.6% of binder which minimizes porosity defect in casting.
8) Shifting from 1.6% to 1.3% of binder based on sand, results into huge amount of binder saving around approximately 150 kg based on 50 ton sand per year which is equal to cost saving of Rs. 42000 / year.

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