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Evaluation of Critical Parameters for Sand Inclusion Defect in FNB Casting

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Abstract

Casting covers major area of production all over the world. Resin bonded casting is widely used in today's manufacturing industries. Furan No bake casting is most widely accepted in indian foundries due to its excellent surface finish and dimensional stability. It is a self-setting binder and it has a lower work and strip times. Though the casting process is also known as process of uncertainty, in the present study, an attempt has been made to investigate the effect of Grain Fineness Number, Loss of Ignition, Potential of Hydrogen, % of Resin with respect to sand, Sand Temperature and Compressive strength of the mould on Sand Inclusion defect – one of the most dominating defect in the Krislur Castomech Pvt. Ltd. Industry situated at Bhavnagar, Gujarat, India. The experiments were conducted based on response surface methodology (RSM) and sequential approach using face centered central composite design. The results show that quadratic model with removal of some insignificant term is comparatively best fits for Sand Inclusion Defect.

Keywords: Furan, Grain fineness number, Loss of ignition, pH

1. Introduction

Foundry industries in developing countries suffer from poor quality and productivity due to involvement of number of process parameters in casting process. Even in a completely controlled process, defects in casting are observed and hence casting process is also known as process of uncertainty which challenges explanation about the cause of casting defects [1]. The production concerns must follow the quality control procedures correctly and perfectly to produce quality casting. With the passage of time the modified techniques based on the quality control research is became must to avoid defects in the products [2]. Sand is used by means of different processes: green molding, shell, No-bake, hot box, cold box and others. Each one of them presents its own particularities and advantages in relation to the needs of the products [3]. The difficulty with the green sand molding is that heated pattern plates and curing ovens are necessary; therefore it is mainly used for small castings [4]. Some of the resin bonded sand systems used are furan, phenolic urethane and sodium silicate. Casting furan resin is a new type of casting self-hardening adhesive [5]. No-bake binder system does not require a baking cycle to generate mechanical strength, so the furan binder has been acknowledged as the first true no-bake binder [6]. As the resin binders can be hardened by simply standing in air have found very useful application in the production of large moulds in the casting steel foundry. This means that stripping of cores and their consequent drying in stoves are eliminated resulting in a saving of labour and fuel cost [4]. It also offers advantages such as hardening speed, strength, collapsibility framing, high strength, high dimensional accuracy, fast hardening rate, high production efficiency and low labour intensity as well as abundant source of raw materials and simple production process to improving the quality of the piece of metal produced [7-8].

Furfuryl alcohol is the basic raw material for the furan family of acid-catalyzed no-bakes. It is produced from waste vegetable materials such as corn husks, rice hulls, etc. It is a simple two-part binder system made up of an acid catalyst and a reactive furan-type resin. The resin, which is dark coloured thin liquid acts as binder for sand particles and the catalyst or curing agent, is a solution of pure or mixture of organic, inorganic acids in varying concentration. The operating temperatures for this process range from 24 to 30 ºC. The sand, binder, and catalyst are continuously mixed and blown into the core box. The amount of furan no-bake binder used is usually 0.9-1.2%, based on sand weight. Catalyst levels generally are from 20-40% based on the weight of the binder [9].
After using the sand once, a lot of reacted products (binder and catalyst) are present in the sand, partly loose (Industrial Centre) and partly still attached to the sand grains. By re-using the sand, the "unburned" (organic) products will build up in the sand which is necessary to remove by reclamation process. Due to cost of dumping or re-using the "used sand" the necessity of reclaiming is increases. A lot of heat and energy produces during reclamation of sand as a result exposure to high temperature occurs [10]. By re-using the sand, the "unburned" (organic) products will build up in the sand. Also the sand grain will become finer. The consequences are as explained in Table 1.

Table 1.
List of consequences of reclaimed furan sand

a. build up of resin particles	-->	LOI increases
b. build up of catalyst	-->	pH decreases (needs less catalyst)
c. sand grain gets smaller	-->	AFS number increases
d. requires less binder	-->	because specific surface increases and the roundness of the grains gets better

The main components of any furan based system emit furfuryl and formaldehyde during mixing, processing and mould storage. Particularly, hazardous air pollutant emissions from the metal casting industry have attracted increasing attention. As per M Holtzer Application of synthetic resins as binding agents for moulding and core sands constitutes a threat for the natural and work environment. This is caused by generating, under an influence of high temperatures, highly toxic substances from the BTEX (benzene, toluene, ethylbenzene, xylenes) and PAHs group (polycyclic aromatic hydrocarbons), and others [11-14]. The harmful gases affect the health of workmen and nearby residents and cause public protests. The endangering factors are:

- The possibility of the migration of gases to the casting and degradation of the quality of its surface.
- Harmful condition at pouring station resulting from the chemical composition of gases affects the environment and health aspect of the industry.

For furan No-bake system, temperature is a primary consideration because the catalyst component must work in combination with temperature to initiate and sustain the chemical curing reaction. Hence Temperature must be monitored, controlled and, if possible, kept constant. The rate of cure increases as the temperature rises and slows as the temperature decreases. Catalyst adjustments can be made for temperature fluctuation, but it is better to control the sand temperature than to continually adjust the amount of catalyst [15].
As per Sarkar, in furan molding process silica sand should be used with approx 2 % binder and a catalyst addition of between 30 and 40 % by weight of the binder. The setting time of the cores is governed by the amount of catalyst and the sand temperature. He concluded that the amount of catalyst is increased, higher strengths are achieved at the early stages, but the ultimate strengths are lower with a higher amount of catalyst addition. Whether a faster curing rate and hence increased production or a higher ultimate strength is required or not, will be decided by the requirements of the individual foundry. As per him the rate of curing and hence stripping time will also be controlled by the sand temperature as it would vary between seasons.
The quality of the casting may be given by compressive strength of the mould and rejection rate/ casting defect. The temperature of the sand is depending on many parameters like storage location of sand hoppers, amount of catalyst which is responsible for reaction, Seasonal variation of temperature and humidity.

2. Methodology used in the present work

The main objective of this study is to evaluate Furan No Bake system in context with the strength and quality of the casting. Experiments were performed at Krislur Castomech Pvt. Ltd; one of the pioneer company in India for making motor body casting. The company started in 1985, initially using single part binder and gradually adopted FNB binder system for improving process efficiency and quality of casting. The methodology to study the influence of process parameters and to establish non-linear input-output relationships. The process parameters and results were analyzed using Design Expert software version 7. This software helps to optimize your product or process. It also provides highly efficient design of experiments (DOE). In this surface response methodology is used to analyze and measure the response. Even ANOVA was performed to analyse final results with help of in design expert software version 7 [16-17].
Before starting the experiment it is necesery to identify effective parameters affecting quality of mould.
To avoid consequences listed in Table 1, sand testing is essential. There are various tests available for sand testing, but particularly for furan no-bake sand following test are most significant, because it reveals property of sand and its performance as mentioned above.
List of test required to perform for furan no-bake binder system: [18]

- Sieve analysis test or Grain fines number test (as per AFS standard)
- Strength test – Compression test, Tensile test, Transverse test (as per BIS standard)
- Loss on ignition (LOI) test (as per BIS standard)
- To identify acidic and basic properties of sand – pH test

Apart from this as explained above sand temperature and amount of resin are also significant parameters affecting final strength of mould.

a)Identification of Important Process Parameters and Their Levels:

Table 2.
The process parameters and their chosen level

Parameter	Levels			In Coded Form		Standard Deviation
	Low	Medium	High	Low Code	High Code	
A-GFN*	44.1	49.5	54.9	-1	1	2.537834
B-LOI*	1	1.5	2	-1	1	0.135509
C-pH*	3	3.5	4	-1	1	0.10718
D-Resin (%)	0.8	0.875	0.95	-1	1	0.05045
E-Temp (^{o}C)	24	35.5	47	-1	1	5.116565
F-Comp strength (kg/cm^2)	12.15	19.515	26.88	-1	1	3.37538

*GFN – Grain fineness number, LOI – Loss on Ignition, pH – Acid demand value

The moulding/core sand mixture used consists of three ingredients, namely sand, resin – furfuryl alcohol and the hardener or catalyst – sulphonic acid. Along with that effects of various controllable parameters as given in the Table 2 are considered to find a role of their values behind Sand Inclusion defect.

b) Development of Design Matrix

In design matrix in Design Expert software for six input parameters consist of 44 sets of experiments. The 44 experimental runs allowed the estimation of linear, square, cubic and two way interaction effects of the input parameters.

c) Conducting Experiments

Experiments have been conducted to test the properties of Furan No Bake binder system. The cores are prepared with the help of sand, resin and hardener. The type of resin and hardener used in the present study is Furfuryl Alcohol and Sulphonic Acid respectively. The set of experiments are performed in January month (winter season in India), so effect of atmospheric humidity can be neglected. The grain fineness number (GFN) of the sand that was obtained from the sieve analysis test [19]. Standard procedure has been used to prepare the test specimens for compressive strength of standard size. A briefe descripsion of testing proceedure is as explained bellow:

- GFN: To calculate grain fineness number sieve analysis test is carried out by passing 50g of representatives and sample through 11 sieves. Weight out the sand retained on each sieve and the pan material individually & put the percentage of dried unwashed sand. Calculate fineness number as per IS 1918:1966.

Fig. 1. Standard sieve test equipment

- pH: The pH value is decided by pH scale. It is the standard representation of the degree of acidity or alkalinity on a scale from 1 to 14.
- LOI: Loss on ignition test is performed as per AFS standard. Employ a two hour ignition of 10g sand in muffle furnace at 1800 F (9820C). The resulting loss in weight from the sample is the LOI measurement.

Fig. 2. LOI test performed at Krislur Castomech. Pvt. Ltd.

- Compressive strength test: As per IS 1918:1966 Ram standard furan sand test specimen 50×50 and strip it from, the specimen container. Place the test specimen in the compression machine in such a manner that the top of the specimen as rammed in the specimen container rests against the upper head of the machine. Apply a uniform load against the plane faces ‘of the specimen until the specimen breaks. Record the load at rupture as shown in Figure 3.from universal testing equipment.

Fig. 3. Universal strength test equipment

Fig. 4. Laser gun to measure temperature of sand

d) Determining the Adequacy of the developed model
The non-linear regression model will be developed using the data collected as per design matrix. The effect of individual parameters and their interaction terms are examined by conducting a significance test. Contour plots are used to understand the relationships of process parameters and their interaction with responses. Further, they are utilized to study the contribution of process parameters. Design Expert software is used for the said purpose. The prediction accuracy of the models has been tested by passing 44 experimental test cases (See Appendix)

3. Results and discussions

This section discusses the non-linear regression models developed for Furan No Bake binder system using Design Expert software.

a) Mathematical model and statistical analysis
The experimental data obtained from Furan resin bonded sand core has been used to develop non-linear regression models. Further, the analysis of the models is contour plots for the responses – compressive strength and scratch hardness.
Response – Sand Inclusion

Equation (1) shows the non-linear model expressed as a function of input process parameters (in coded form), that represents the data in coded form for defective piece. By considering all the significant factors the response surface equation for compressive strength is as shown below:

Sand Inclusion= -321.4622 + 6.765017*A + 28.565601*B + 111.402314*C - 311.254560*D - 1.591869*E + 7.836696*F - 0.867510*A*B - 1.548489*A*C + 1.166523*A*D + 0.074962*A*E - 0.0563474*A*F - 19.521506*B*C + 77.262218*B*D - 0.120207*B*E - .340909*B*F - 17.977685*C*D + 0.167650*C*E - 1.178969*C*F + 1.961698*D*E + 1.423529*D*F + 0.0153309*E*F - 0.0190128*A^2 + 10.490369*B^2 + 4.526828*C^2 + 128.806571*D^2 - 0.01885715*E^2 - 0.040064*F^2 (Equation 1)

Table.3 shows that the model is significant and GFN, LOI, PH, % of Resin, Sand temperature and Compressive strength of the mould are the significant factors (terms) in the model. The lack of-fit is insignificant thereby indicates that the model fits well with the experimental data [9].

Table 3.
ANOVA partial sum of square for compressive strength

	Sum of Square	df	Mean Square	F Value	p-value Prob > F	% Contribution
Model	28.20	27	1.04	2.56	0.027	4.43
A-A-GFN	1.08	1	1.08	2.65	0.12	9.24
B-B-LOI	0.12	1	0.12	0.30	0.59	13.2
C-C-PH	0.12	1	0.12	0.31	0.59	10.4
D-D-Resin	0.12	1	0.12	0.31	0.58	3.54
E-E-Temp	0.30	1	0.3 0	0.75	0.40	3.80
F-F-Comp strength	1.49	1	1.49	3.67	0.07	9.86
AB	0.23	1	0.23	0.58	0.45	4.13
AC	0.81	1	0.81	1.99	0.18	2.09
AD	0.06	1	0.06	0.15	0.70	3.03
AE	6.90	1	6.90	16.9	0.00	7.05
AF	1.46	1	1.46	3.58	0.07	0.26
BC	0.46	1	0.46	1.13	0.30	4.81
BD	0.64	1	0.64	1.57	0.22	7.78
BE	0.03	1	0.03	0.08	0.77	4.38
BF	0.33	1	0.33	0.81	0.38	1.69
CD	0.04	1	0.04	0.11	0.74	3.59
CE	0.04	1	0.04	0.11	0.74	6.92
CF	1.06	1	1.06	2.61	0.13	1.35
DE	1.75	1	1.75	4.29	0.05	0.03
DF	0.26	1	0.26	0.65	0.43	2.84
EF	0.32	1	0.32	0.79	0.38	4.38
A^2	0.10	1	0.10	0.24	0.62	1.80
B^2	0.33	1	0.33	0.83	0.37	8.71
C^2	0.03	1	0.03	0.09	0.76	8.92
D^2	0.68	1	0.68	1.66	0.21	1.91
E^2	7.06	1	7.06	17.3	0.00	-1.22
F^2	4.13	1	4.13	10.1	0.00	-0.72
Residual	6.52	16	0.40			
Cor Total	34.72	43				
Std. Dev.	0.63		**R-Squared**		0.81	
Mean	1.72		**Adj R-Squared**		0.49	
C.V. %	36.97		**Pred R-Squared**		-8.89	
PRESS	343.65		**Adeq Precision**		5.81	

LOI, PH and Compressive Strength Sand temperature is the dominant contributor to the compressive strength compared to other parameters resin and catalyst. Negative sign indicates that temperature and compressive strength having inverse relationship. It even shows that strength is better to be higher value while sand temperature is better at lower.

The various R^2 statistics (i.e. R^2, adjusted R^2 (R^2 Adj) and predicted R^2 (R^2 Pred)) of the compressive strength are given in Table.3. The value of R^2 = 0.8120 for sand inclusion defect indicates that 81.2% of the total variations are explained by the model. The value of the R^2 Adj =0.4950 indicates that 49.50% of the total variability is explained by the model after considering the significant factors [9]. 'C.V.' stands for the coefficient of variation of the model and it is the error expressed as a percentage of the mean ((S.D./Mean) ×100). Lower value of the coefficient of variation (C.V. = 36.97%) indicates improved precision and reliability of the conducted experiments.

Figure 5 shows effect of compressive strength on sand inclusion defect at stated level of GFN, Loss on ignition (LOI), pH, Resin and Temperature. It shows as compressive strength increase defect may decrease. Figure 6 shows effect of temperature on sand inclusion. Figure 7 shows effect of resin on defect. At given level of parameter if resin is more than required chances of defect may increase. From Figure 8 we can say pH value doesn't give significant effect on sand inclusion defect. Respectively Figure 9 and 10 shows effect of GFN and LOI on sand inclusion defect. All these figure shows effect of one single component on sand inclusion defect, but the warning shows that more number of parameters are affecting on final result. Hence further interaction plot results were observed as shown in Figure 11-13

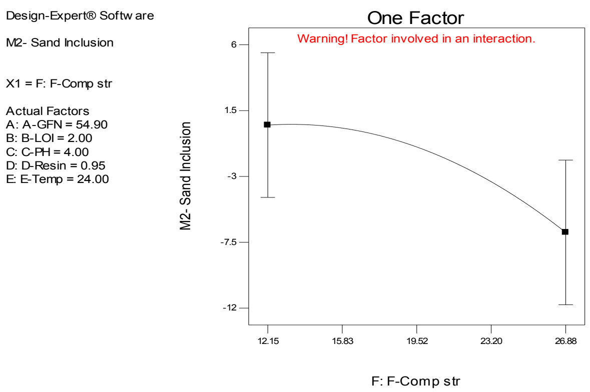

Fig. 5. Compressive strength as a single variable for sand inclusion defect at a stated design point

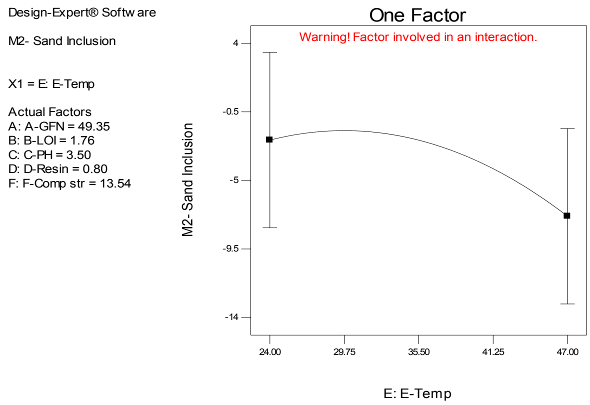

Fig. 6. Sand Temperature as a single variable for sand inclusion defect at a stated design point

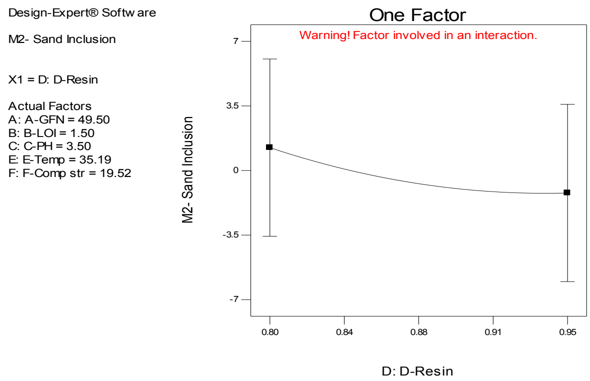

Fig. 7. Resin as a single variable for sand inclusion defect at a stated design point

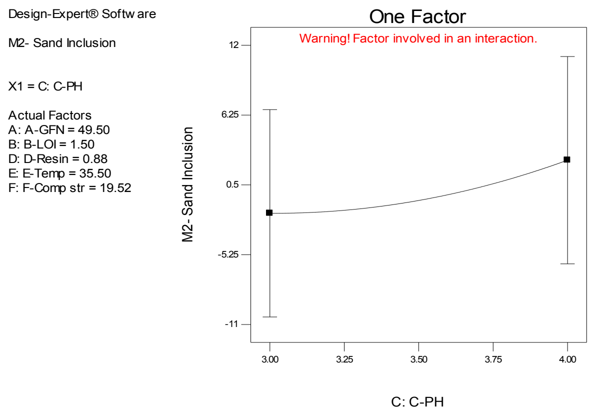

Fig. 8. pH as a single variable for sand inclusion defect at a stated design point

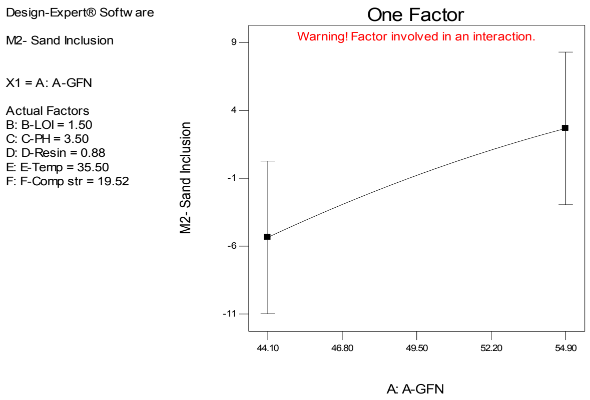

Fig. 9. GFN as a single variable for sand inclusion defect at a stated design point

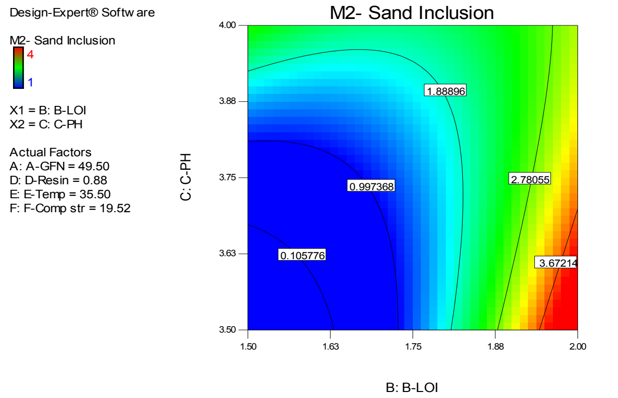

Fig. 11. Ph and LOI level for sand inclusion defect at a stated design point

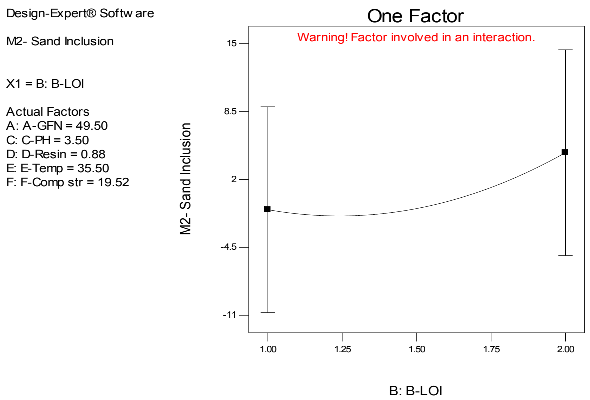

Fig. 10. LOI as a single variable for sand inclusion defect at a stated design point

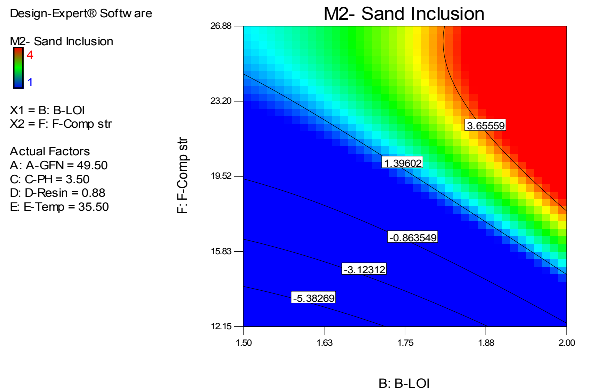

Fig. 12. Compressive Strength and LOI level for sand inclusion defect at a stated design point

Figure 11, 12 and 13 shows Contour plot for finding the effect of two variables at a time for minimum sand inclusion defect. As per ANOVA results shown in table 3, only 3 parameters i.e. LOI, ph, Compressive strength are important parameters. Figure 11 Suggested combination of ph is up to 3.63 and LOI as 1.63. Figure 12 shows that the combination of LOI and Compressive strength as 3.63 and 15.83. Figure 13shows the favourable ph and compressive strength.

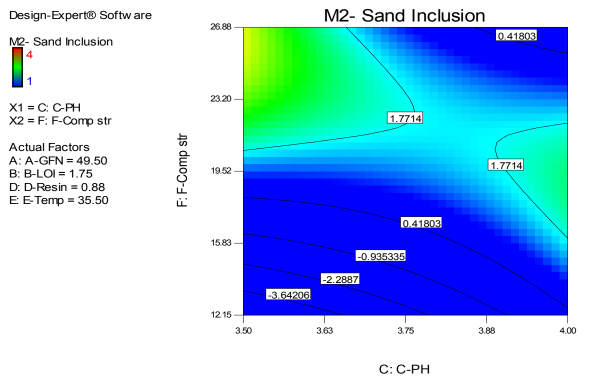

Fig. 13. Compressive Strength and PH level for sand inclusion defect at a stated design point

4. Conclusions

The critical parameters affecting the sand inclusion defect in FNB casting are GFN, LOI, percentage of resin, Temperature, pH and compressive strength of FNB mould system. % of resin is directly related to the strength of FNB mould system as shown in Table 5. Moreover, lowering the temperature makes the sand/ binder mixture more viscous, this makes it unfavourable to coat the sand grains. Also higher temperature lowers the compressive strength of the mould and ultimately raises the sand inclusion defect. Experimental Analysis show that optimum consumption of resin is 0.84% based on sand for economical production. Grain fineness number should be kept near 44. LOI should be less than 1.5 and pH should be 3.5 as shown in Table 5 bellow:

Table 5.
Critical value of parameters

Parameter	Critical value to reduce defect
GFN	44
LOI	< 1.5
pH	3.5
% Resin	0.84% based on sand
Temperature of processed sand	36 ‘C
Compressive strength	15 to 25 kg/cm^2 after 4 hours

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Appendix (See next page)

Std.	Run	Block 1	GFN	LOI	pH	Resin (%)	Sand temperature (°C)	Comp. strength (Kg/cm^2)	No of defect found
1	1	Block 1	49.25	1.8	3.8	0.8	40	20.3	1
2	2	Block 1	47.36	1.7	3.8	0.8	40	25.08	2
3	3	Block 1	47.03	1.7	3.9	0.8	34	16.8	3
4	4	Block 1	46.96	1.8	3.7	0.8	34	17.9	2
5	5	Block 1	48.77	1.7	3.9	0.8	38	17.9	2
6	6	Block 1	51.12	1.7	3.8	0.8	47	23.02	1
7	7	Block 1	49.46	1.8	3.8	0.8	34	26.88	1
8	8	Block 1	49	1.5	3.5	0.8	36	22.39	2
9	9	Block 1	49.34	1.7	3.8	0.8	24	21.9	1
10	10	Block 1	48.47	1.7	3.9	0.8	35	20.71	3
11	11	Block 1	47.21	1.8	3.8	0.8	24	20.9	2
12	12	Block 1	46.96	1.9	3.9	0.8	32	15.9	4
13	13	Block 1	48.65	1.5	3.8	0.8	24	24.44	1
14	14	Block 1	47.6	2	4	0.8	38	19.15	4
15	15	Block 1	48.58	1.8	3.9	0.8	44	19.1	1
16	16	Block 1	51.89	1.8	3.9	0.8	32	12.15	1
17	17	Block 1	50.46	1.9	4	0.8	32	19.61	2
18	18	Block 1	49.46	1.8	3.9	0.8	38	20.15	2
19	19	Block 1	49.25	1.7	4	0.8	38	20.15	4
20	20	Block 1	48.9	1.9	3.8	0.8	36	16.98	2
21	21	Block 1	48.06	2	4	0.8	40	14.9	1
22	22	Block 1	51.45	1.8	4	0.8	29	17.9	1
23	23	Block 1	50.99	1.8	4	0.8	38	23.42	1
24	24	Block 1	49.24	1.7	4	0.8	42	24.9	1
25	25	Block 1	49.47	1.8	3.9	0.8	34	18.1	3
26	26	Block 1	45.83	1.8	4	0.8	40	16.7	2
27	27	Block 1	46.78	2	3.9	0.8	40	25.56	1
28	28	Block 1	45.13	2	4	0.8	40	17.35	2
29	29	Block 1	46.96	2	4	0.8	40	18.58	3
30	30	Block 1	46.22	1.7	3.8	0.8	40	24.29	1
31	31	Block 1	47.92	1.7	3.8	0.8	40	17.9	1
32	32	Block 1	44.83	1.9	3.9	0.8	38	16.15	1
33	33	Block 1	54.9	1.7	4	0.85	34	16.1	1
34	34	Block 1	52.02	2	4	0.85	38	14.94	2
35	35	Block 1	48.33	2	3.8	0.85	38	17.05	2
36	36	Block 1	49.05	1.9	3.8	0.9	38	18.25	1
37	37	Block 1	51.65	2	3.8	0.9	38	15.16	2
38	38	Block 1	53.81	1.7	4	0.95	38	16.28	1
39	39	Block 1	44.1	2	3.7	0.95	39	18.5	1
40	40	Block 1	51.24	1.6	4	0.9	38	21.8	1
41	41	Block 1	53.93	1.8	3.9	0.9	42	20.24	1
42	42	Block 1	52.71	2	3.9	0.9	34	20.86	2
43	43	Block 1	54.88	1.7	3.8	0.95	37	18.75	2
44	44	Block 1	50.14	1.7	3.9	0.95	24	25.72	1