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A FURAN NO-BAKE BINDER SYSTEM ANALYSIS FOR IMPROVED CASTING QUALITY

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Abstract

Traditional cast metal markets have been confronting incessant competition from overseas producers as their lower wage scales and environmental standards reduce their product cost. Many foundries have made changes in their processes reducing air and water emissions. One foundry, Krislur Castomech Pvt. Ltd., Bhavnagar, Gujarat, India, has adopted a newer furan no-bake binder system over a single-part binder system that offers an advantage in terms of strength and environmental concerns by reuse of the sand, which is discussed herein. In this work, grain fineness number and compressive tests are performed and the effect of temperature and resin is measured using the analysis of variance method. Sand topology and defect photographs were taken using a scanning electron microscope to identify sand size and shape. Investigation of the exact defect was performed using energy dispersive spectroscopy. In this work, progress was made in reducing casting defects and improving casting quality.

Keywords: *furan no-bake, FNB system, resin, catalyst*

Introduction

The metalcasting process is long standing and, at present, approximately 90 % of all metallic components are produced via some form of foundry casting process. However, the metalcasting process can affect the earth's ecosystem such as water pollution, air pollution and hazardous waste which could contribute to ozone depletion, acid rain, the greenhouse effect and global warming. As a result, foundries are implementing more environmentally friendly, energy-saving and efficient moulding and casting methods.

No-bake binders have targeted this issue by addressing casting quality, yield and ecological considerations through use of reclaimed sand. The no-bake furan resin-bonded sand with its self-setting mould and core qualities can be cured at room temperature. This is characterized by dimensional precision, a rapid hardening rate, production competence and an abundant source of raw material in a simple production process.[1]

This paper fundamentally deals with the no-bake furan-bonded system. It is basically used for producing cores, core moulds and moulds. Furan resin is made up of furfuryl alcohol. One of its most common applications is for foundry resins. No-bake furan moulds are used for producing steel, cast iron and nonferrous castings. The binder may be cured with a gas or a liquid catalyst. This process forms solid, firm cores and moulds which cast good dimensional tolerances. No-bake (self-setting) binders are either acid catalysed or ester cured.[2] The sand in a no-bake mould is blended with a liquid resin and catalyst hardens at room temperature.

Furan no-bake (FNB) binders offer a more sustainable solution (e.g. during mould preparation only 5 % new sand

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is required and 95 % reclaimed sand is used). This work was carried out at Krislur, which is an ISO 9001:2008 certified foundry that uses FNB binders for electrical applications as cast motor body housings and related components in grey cast iron.

Furan No-Bake Binder as Sustainable Solution

A comparison of single-part and two-part binders was carried out to identify the advantage of a two-part binder system over a single-part binder system. A furan no-bake two-part system is considered as a sustainable solution as it offers numerous advantages over a single-part binder system with increased productivity, augmented production rate, high-dimensional accuracy, reduced defect rate and is less labour intensive. The comparative merits of two-part furan no-bake binders to the single-part oil binder are shown in Table 1.

Table 2 shows the calculations of gas emission per second from the furan resin. In the given table, the amount of gas released from 1000 kg of sand was measured.

Identifying Defects

Rejection data for the month of January 2013 were collected and analysed with the help of Pareto chart as shown in Figure 1. This graph indicates sand inclusion as a major defect. Hence, our prime focus will be on sand inclusion defect (Figure 2).

There may be various causes for sand inclusion defect.

Identifying Important Parameters

The major parameters affecting inclusion defects are discussed below:

Table 1. Comparison of Single-Part Oil Binder and Two-Part FNB Binder (Courtesy: Krislur Castomech Pvt. Ltd.)

Sr. no.	Parameters	Single-part oil binder	Two-part FNB binder
1	Technology	Single part	Two-part self-set binder system (resin + catalyst (acid hardener))
2	Ingredients	Cashew nut shell (oil binder)	Resin (furfuryl alcohol) + catalyst (acid hardener)
3	Strengthening/ drying cycle	4–8 h	4–12 h
4	Human body effect	Body and eye irritant	Reduces pollution by up to 10 % pollution compared to a single-part binder. Reduces skin and eye irritations
5	Cooling rate	Fast—3 min	Slow—4.5 min
6	Pouring method	Bottom poured due to fast cooling rate (top pouring not possible)	Top poured
7	Binders	5 % of total sand (e.g. for 2 t sand, 100 kg. Binder, yields 1 t casting)	1 % of total sand (e.g. for 2 t sand, 20 kg. Resin, yields 1 t casting)
8	Labour required	85/shift	21/shift
9	Rejection rate	18 % (ideal = 12 %)	7.5 % (ideal = 5 %)
10	Type of defects	Sand inclusion, shrinkage, moulding crack, blow holes	Distributed defects—mostly due to human error
11	Equipment required	Manual Muller	Continuous mixer
		Hand ramming	Compaction table
		Table	Rollover method
		Manual method	IR oven
		Drying naturally	
12	Capacity (land avail. 2500 m^2)	150 t/month	400 t/month
13	Sand to metal ratio	2:1, oil content 5 %	2:1 ratio, oil content 0.85 %
14	Surface finish	Poor	Good
15	Dimensional accuracy	Poor	Excellent

Table 2. Gas Emission from Furan Binder[3–6] (Courtesy: Krislur Castomech Pvt. Ltd.)

Sr. no.	Type of gas	Amount of gas released from the 1000 kg sand (9.88 kg of resin + Catalyst) gm	Amount of gas per unit volume gm/m^3	Gas emission per second μg m/m^3-sec	Gas emission limit standard[5, 6]
1	CO	2.37	0.0019	0.22	2000
2	SO_2	125.47	0.04387	5.08	50
3	Benzene	31.62	0.00907	1.05	5
4	Toluene	317.145	0.0771	8.92	20
5	Thiophene	6.92	0.00184	0.21	1

This table indicates that the FNB binder system is advantageous due to lower emission value

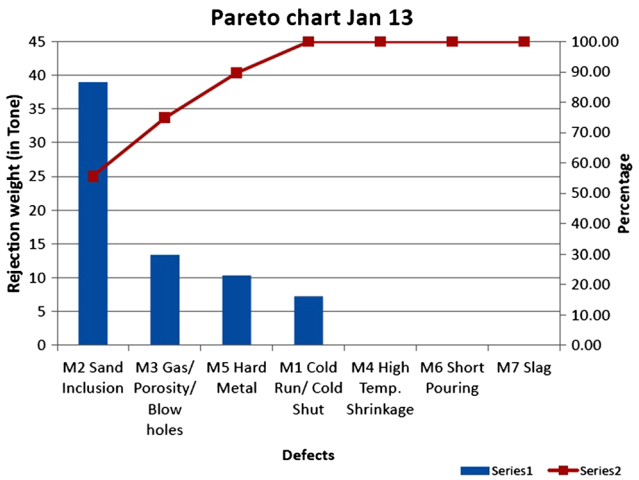


Figure 1. Pareto chart January 2013.

Figure 2. Sand inclusion in metalcasting.

Pouring method and related parameters—the design for the gating system consists of various elements such as pouring method, pouring time, average filling rate, ingate design, solidification time, relative freezing ratio, modulus of gating system, the casting and casting yield. Design parameters and calculated values for the existing casting design play a very significant role in defect prevention.[7]

Grain fineness number (GFN)—to produce high quality sand moulds, good grain distribution is needed. This grain distribution together with the grain surface (specific surface) determines the indispensable amount of resin and catalyst. Consequently, the "AFS-number" or "GFN-number" and the "Specific Surface" must be evaluated.[8]

Sand Temperature—as with all no-bake systems, sand temperature is a primary consideration for the catalyst component to initiate and sustain the chemical curing reaction. Catalyst adjustments can be made for temperature fluctuations, but it is better to control the sand temperature than to continually adjust the amount of catalyst.[9] Hence, during the process, the sand temperature must be monitored and controlled.

Compressive Strength—the most significant test to measure the strength of the mould is the compressive test, because the way in which the mould box is filled has a large influence on the final strength of the mould.[10] When the molten metal is poured into the mould, the sand in contact with the hot metal starts losing its strength. At this stage, the moulding sand must possess sufficient strength to retain the exact shape of the mould cavity and at the same time it must withstand the metallostatic pressure of the liquid metal. The principal feature in the testing of furan sand is the significance of the time factor in the development of properties; hence, the interval of the 1st, 4th and 24th hour was taken for compressive strength.[11]

The experimental procedure checks the compressive strength of the mould specimen. The dominating variables included in this experiment were resin percentage and temperature, but other variables such as catalyst type (e.g. sulphuric acid, sulphonic acid) or humidity may also play a role. As per preceding research, the amount of resin in the mould is restricted to 0.7–0.9 %, so in this experimental analysis three different amounts of resin were selected as 0.75, 0.80 and 0.85. The analysis was made with help of the analysis of variance (ANOVA) method.

Experimental Analysis of Different Parameters

The rationale of this study was to probe the effects of the mould's strength on the quality of the casting in general and the sand inclusions, in particular.

Pouring-Related Parameters and Metal Standard

The molten metal was poured at temperature in the range of 1350–1400 °C (2462–2552 °F). To achieve higher yields and reduce defects, the gating design was changed as

given in Table 3. The gross weight of the HX-160 motor body was 42 kg, and the corresponding metal poured was 45.5 kg including gating, sprue, runners and risers. The mass flow rate of poured metal from ladle was approximately 3.5 kg/s (0.5 L/s). The distance between the ladle and the pouring cup was measured as 100 mm. The metal used was grey cast iron (ASTM-A 247), with essentially 3.62 % C, 2.14 % Si, 0.50 % Mn, 0.12 % S and 0.16 % P. Pearlite and ferrite were observed 99.72 and 0.15 %, respectively.

Sieve Analysis

To find out the sand GFN, a sieve test was performed. Test data for one experiment for a given sand are shown in Table 4.

Table 3. Gating Design Data for HX-160 F Motor Body Casting

Parameter	Value	
	Before change	After change
Ingate thickness	2 mm	3 mm
Air-vent thickness	2 mm	3 mm
Runner width	18–16 mm	25–22 mm
Pouring cup location	Centre	Side
Standard weight	42.75 kg	42.75 kg
Gross weight	47.08	46.12
Yield	90 %	92.7 %
Equipment	Modern	Modern
Pouring style	Top pouring	Top pouring

The GFN values as per ABMI practices were made to stay within 40–60.[12] The graph of cumulative mass retained for each sieve number, shown in Figures 3 and 4, is analogous to the AFS standard and shows that the grain size distribution is acceptable.

SEM-EDS Analysis

The use of surface analysers, which is a micrographic analytical method, is especially effective for judging casting defects that are difficult to define visually.[13] Scanning

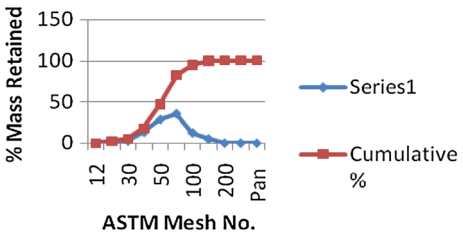


Figure 3. Mass retained on different mesh no.

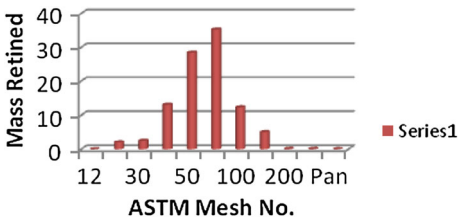


Figure 4. Column chart for mass retained on different mesh no.

Table 4. Sieve Test Data Collection Sheet

Sr. no.	ASTM mesh no. (1)	Mass retained (gm.) (2)	Cumulative (3)	% Retained	Multiplication factor (5)	Product (6) = (2) * (5)
1	12	0	0	0	5	0
2	20	2.08	2.08	2.1	10	20.8
3	30	2.56	4.64	2.59	20	51.2
4	40	13.04	17.68	13.17	30	391.2
5	50	28.46	46.14	28.74	40	1138.4
6	70	35.27	81.41	35.62	50	1763.5
7	100	12.29	93.7	12.41	70	860.3
8	140	5.07	98.77	5.12	100	507
9	200	0.12	98.89	0.12	140	16.8
10	270	0.1	98.99	0.1	200	20
11	Pan	0.03	99.02	0.03	300	9
	Total	99.02		100	Total (T_p)	4778.2

Fineness no. $= T_p/T_{mm} = 48.25–50$

electron microscope (SEM)–energy dispersive spectroscopy (EDS) analysis reference data can greatly assist metalcasters in evaluating inclusion defects and thus help in creating countermeasures for decreasing the rate of inclusion defects. Figure 6 shows the SEM image of a major sand inclusion defect present in the cast piece in Figure 5. Figure 7 shows the EDS result of the sand inclusion defect in marked spectrum. Table 5 shows the value of different elements present during the SEM analysis.

Figure 7 and Table 5 show higher value of silicon content in the form of SiO_2 in the marked spectrum. This defect is believed to have been produced due to a loose sand particle present in the mould. It is believed that no other effects, such as sand erosion, could cause this during pouring (Table 6).

Compressive Strength

To overcome the sand inclusion defect, a detailed compressive strength analysis was carried out further by varying the amount of resin and catalyst along with available temperature range and ANOVA was performed using MINITAB software.

Figure 5. Sand inclusion defect.

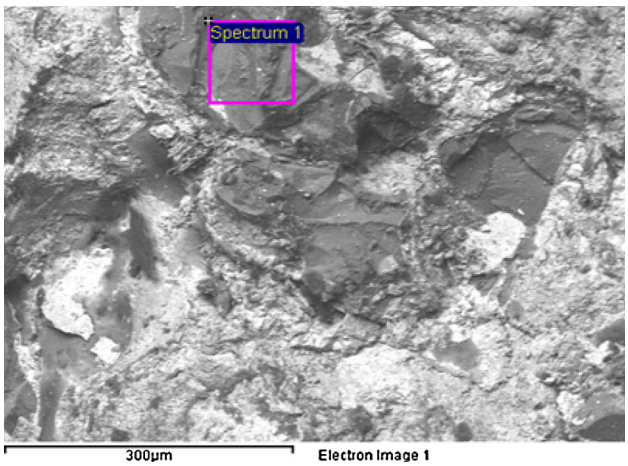


Figure 6. SEM image

Generally, the resin is given in terms of percentage of sand weight and the hardener (catalyst) is given in terms of percentage of resin. For this experiment, the catalyst level was selected arbitrarily for different combinations of resin as 30, 35 and 40 %. So the input parameters were sand temperature, resin %, catalyst % and sample weight.

The sand, resin and hardener were weighed using a digital scale and then mixed for 10 s. The sand mixture was compacted into a standard cylindrical shape with a 50 mm diameter and 50 mm height using a standard AFS mould as shown in Figure 8. The weight of the specimen was measured. After 7–10 min, the specimen was removed from the block and the weight of the sample was taken. The weight should be within 143 g as per the AFS Standard. Then, the standard sample was ready for testing.

The sample was placed between compression holders. A standard universal test machine (UTM) was used to perform compressive strength as shown in Figure 9. The sample was pressed and allowed to be broken, as shown in Figure 10. The compressive strength was noted in kg/cm^2 for every sample. This test was performed at the interval of 1st, 4th and 24th hour as prescribed by resin supplier. For the same method, once again samples were tested for compressive strength at 1st, 4th and 24th hour and the results are noted in Table 4.

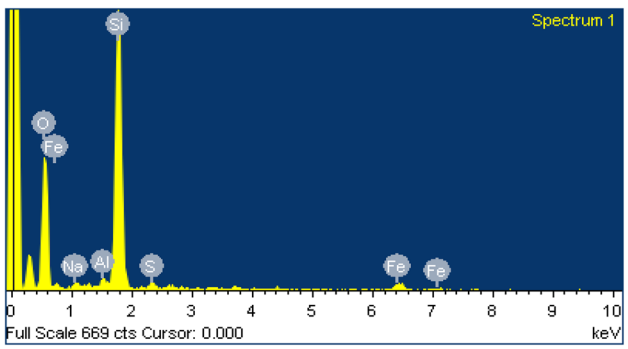


Figure 7. EDS image

Table 5. Result Table of Energy Dispersive Spectroscopy (Andrade et al.)

Element	Standard	Weight %	Atomic %
O	SiO_2	50.93	66.0
Na	Albite	1.19	1.08
Al	Al_2O_3	0.76	0.58
Si	SiO_2	39.57	29.21
S	FeS_2	1.19	0.77
Fe	Fe	6.37	2.36
Total		100	

Table 6. Results of Compressive Test for January 2014 with (Courtesy: Krislur Castomech Pvt. Ltd.)

Sr. no.	Compressive strength in kg/cm^2			Resin %	Catalyst %	Temp. (At mixing)		Sr. no.	Compressive strength in kg/cm^2			Resin %	Catalyst %	Temp. (at mixing)	
	1st hour 7–12	4th hour 15–25	24th hour >30			°C	°F		1st hour 7–12	4th hour 15–25	24th hour >30			°C	°F
1	8.91	20.2	29.1	0.85	30	22	71.6	14	16.26	19.68	30.79	0.8	30	27.5	81.5
2	10.97	19.9	34.21	0.85	30	28	82.4	15	13.84	18.34	28.13	0.75	35	22.5	72.5
3	16.84	21.4	30.71	0.85	35	24.5	76.1	16	10.27	19	27.81	0.75	30	21	69.8
4	15.49	19.5	32.72	0.85	40	22	71.6	17	10.81	18.24	28.73	0.75	40	21.5	70.7
5	12.32	20.9	29.11	0.8	35	21.5	70.7	18	13.69	17.87	28.24	0.75	35	25.5	77.9
6	12.83	18.4	*29.15*	0.8	30	21.5	70.7	19	13.08	17.72	28.66	0.75	30	22.5	72.5
7	12.23	22	*29.74*	0.85	30	23	73.4	20	13.18	18.97	27.68	0.75	35	24.5	76.1
8	14.05	20.3	33.92	0.8	35	23.5	74.3	21	12.27	15.38	29.32	0.75	30	25	77
9	18.64	21.1	27.81	0.8	30	20.5	68.9	22	13.49	20.02	27.59	0.75	30	26	78.8
10	15.25	20.9	30.27	0.8	30	20.5	68.9	23	8.55	19.96	26.81	0.75	30	26.5	79.7
11	10.95	19.9	29.88	0.8	35	28.5	83.3	24	14.76	20.11	28.42	0.75	40	28.5	83.3
12	13.9	19.2	28.73	0.8	40	17.2	62.9	25	13.92	19.39	25.9	0.75	30	28	82.4
13	15.3	17.3	30.2	0.8	35	26	78.8	26	13.54	22.91	29.21	0.75	30	36.3	97.3

Figure 8. Standard test specimen (as per IS: 1918).

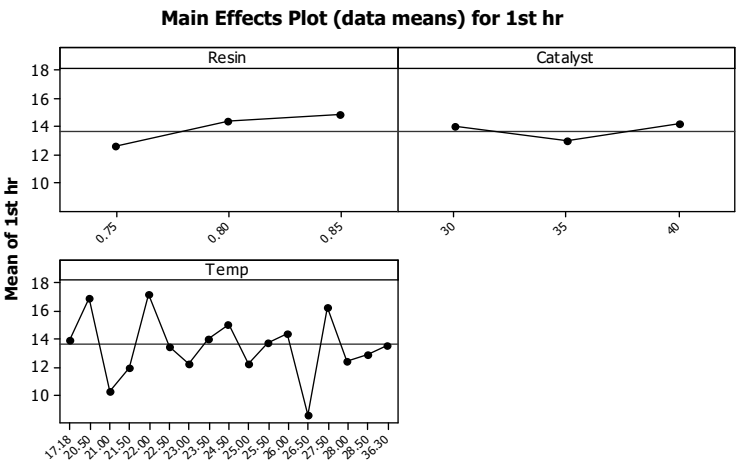
Figure 9. Universal sand testing machine.

Result and Discussion

The data were analysed with the ANOVA method using MINITAB software as shown in Figure 11.[14] The graphs

Figure 10. Broken specimen.

show that different amalgamation of these three parameters (resin, catalyst and temperature) yield altered values of compressive strength as the graph keeps on fluctuating at diverse level of temperature. From the graph, it can be observed that at the 4th hour (at 36 °C/96.8 °F), the maximum compressive strength was achieved. At the 24th hour, one pattern graph is formed which signifies that if the range of temperature increases, compressive strength slightly decreases. It has been observed that during the 1st, 4th and 24th hour, initially the compressive strength increases with an increase in resin–catalyst amount, but after reaching the peak value, it starts decreasing. The behaviour of graphs indicates that the amount of resin and catalyst plays very imperative functions in achieving higher moulding strength. It can also be said that the reaction time, resin amount and sand temperature may be potential causes of the sand inclusion defect when considering polymerization of the resin when mixed with the



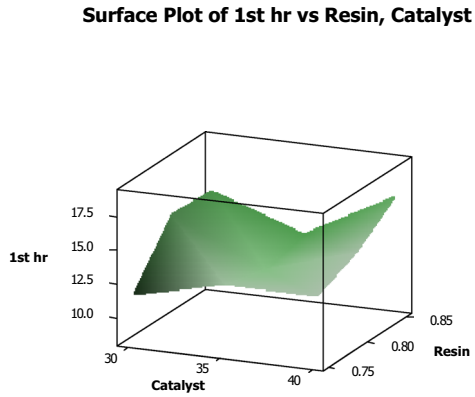
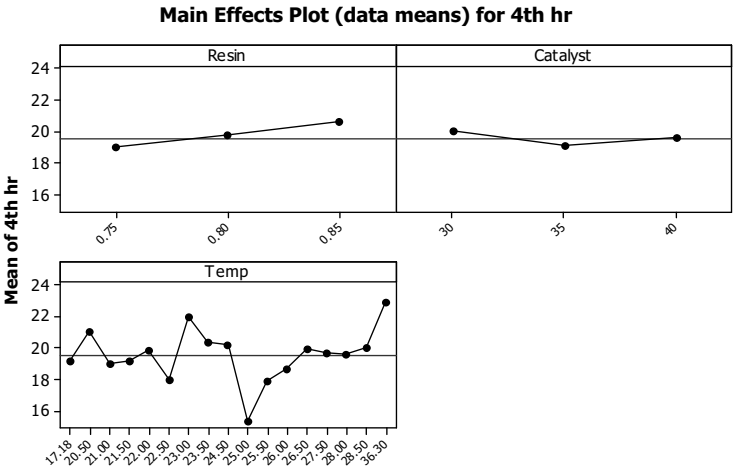


Figure 11. Surface plot and main effect plot at 1st hour.



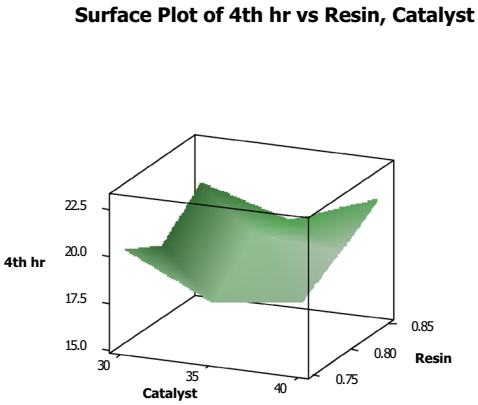
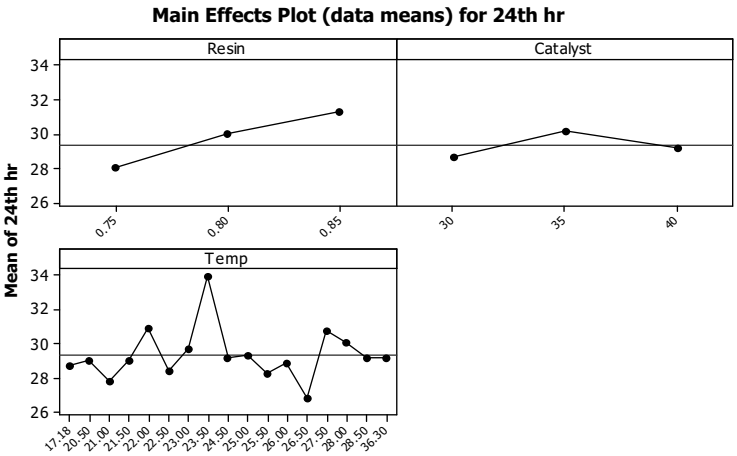


Figure 12. Surface plot and main effect plot at 4th hour.



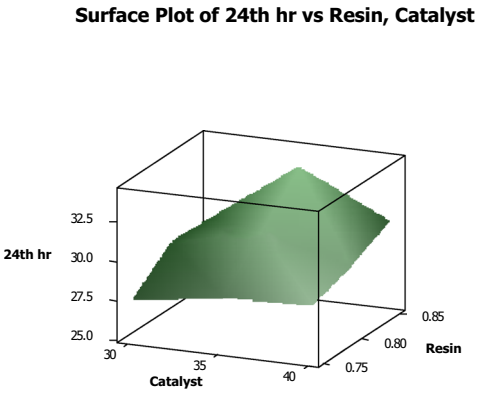


Figure 13. Surface plot and main effect plot at 24th hour.

acid catalyst. The control of sand temperature is also advantageous in terms of consumption of furan resin (Figures 12, 13).

For finding interaction of these parameters on compressive strength, three interaction graphs are plotted as shown in Figures 14, 15 and 16.

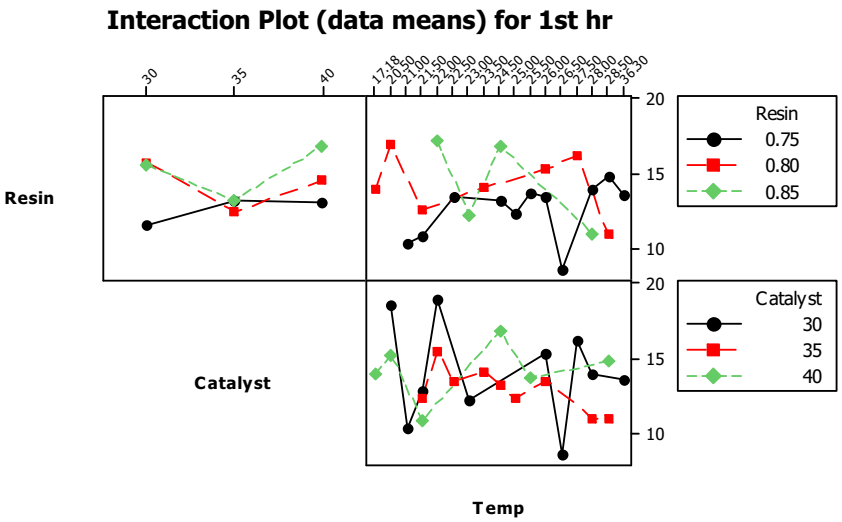


Figure 14. Interaction plot for 1st hour between resin, catalyst and temp.

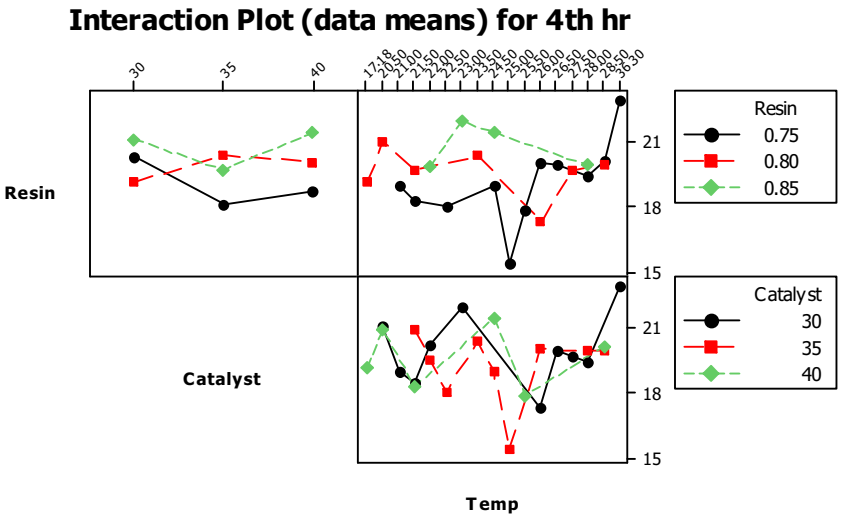


Figure 15. Interaction plot for 4th hour between resin, catalyst and temp.

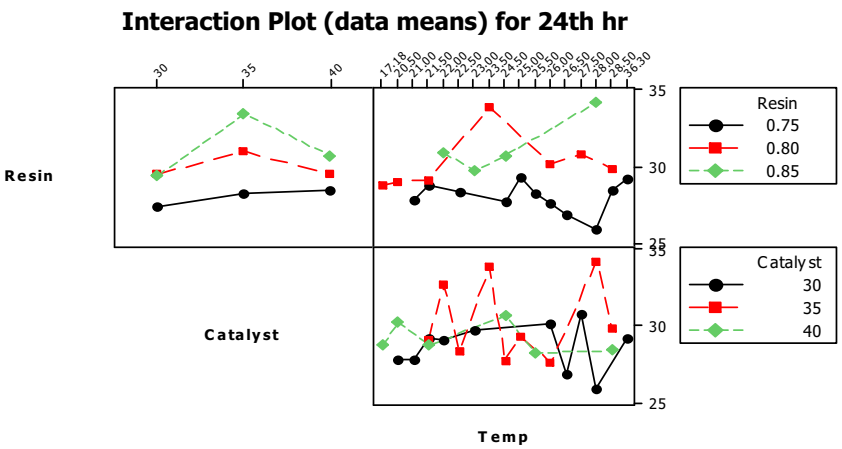


Figure 16. Interaction plot for 24th hour between resin, catalyst and temp.

As the sand temperature is not a controllable parameter in this experiment, due to atmospheric effect, a graph of compressive strength kept fluctuating. Figures 14, 15 and 16 of the interaction plot show that with the increase in atmospheric temperature, most resin and catalyst were required. It was observed from Figures 15 and 16 that with 0.80 % resin and 35 % catalyst a good compressive strength was attained, when the temperature was lower.

Conclusions

The inference of the work and the articulations of industrial experts uniformly concluded that temperature is one of the significant parameters to control sand inclusion defects. We can reduce these defects by optimizing the amount of furan resin and catalyst for the desired compressive strength. After the 4th hour, the compressive strength fell within the specified range given by the resin supplier. So, the best result was obtained at the 4th hour after mixing of the sand and resin. This short self-baking period compared to a single-part binder system leads to reduced cycle time and eventually escalating the productivity. Sand grain sieve analysis implied that there was no issue of grain distribution. The SEM-EDS analysis of defect gives scientific verification of the sand inclusion defect in the casting.

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