Jurnal Kejuruteraan 35(1) 2023: 179-190
https://doi.org/10.17576/jkukm-2023-35(1)-17

Gas Porosity Defect – What It Means and How to Respond

Manojkumar V. Sheladiyaa[a,b*], Shailee G. Acharya[c] & Ghanshyam D. Acharya[d]

[a]*Gujarat Technological University, Gujarat, India.*
[b]*Mech. Engg. Dept., FoET, Atmiya University, Rajkot, Gujarat, India.*
[c]*Mech. Eng. Dept., SVIT, Vasad, Affiliated to Gujarat Technological University, Gujarat, India.*
[d]*Atmiya University, Rajkot, Gujarat, India*

**Corresponding author: mvsheladiya@gmail.com*

Received 12 April 2022, Received in revised form 24 June 2022
Accepted 30 July 2022, Available online 30 January 2023

ABSTRACT

The foundries are facing problem-related to the selection of the parameter's value for minimum rejection and maximum productivity. The furan no-bake binders system guaranteed dimensional stability and a comparative good surface finish of the casting. Based on past data in the industry, it is found that gas porosity defect is one of the highest. The phenomenon of the formation of the bubble in the fissures of the mould-metal interface, and later on trapping during the solidification leads to gas porosity. The current research work is focused on the minimization of the defect by the selection of the optimum range of input variables. Based on rigorous literature survey and industrial expert's opinion, it is found that the parameters like grain fineness number (GFN) of the sand, loss on ignition (LoI) of the used sand, the sand temperature at the mixing time, potential of hydrogen (pH) are important parameters for gas porosity defect in the casting.Design-Expert software and particularly response surface methodology (RSM) and sequential approach using the face-centered central composite design is used for the experiments. The results show that a quadratic model with the removal of some insignificant term is a comparatively best fit for gas porosity defects. After analysis, various favorable levels of different parameters are obtained. The research work is based on realistic problems of the foundries and based on the experimental work. Thus, the provided solution is very much useful for foundries to reduce the rejection, particularly for furan no-bake with furfuryl alcohol as resin and sulphonic acid as catalyst. The research problem addressed in the paper is a genuine problem of the foundries and the sole work is based on experimental evidence.

Keywords: Furan no-bake; Loss on ignition; pH; Response surface methodology

INTRODUCTION

The casting technology which is the ancient manufacturing processes undergo quality and productivity issues considering several variables involved in the process. Even the fully controlled process does not give a guarantee of defect-free production that gives another name to the casting process as a 'process of uncertainty' (Guharaja et al. 2006; Kamble 2008). The quality control procedure needs to be followed in the appropriate way for quality casting. The innovative and novel practices need to be implemented immediately for taking the competitive benefits, particularly in developing countries (Chen & Yang 2009; Dańko 2010).

In the sand-casting process, sand is the main aggregate used in different processes including no-bake, shell molding, green molding, cold box, hot box, and others. There are unique features and limitations of different processes (Trinowski 2010) The usage of the excess energy by curing ovens and heated pattern plates and still no guarantee of quality products in green sand mold leads to usage of the novel binders namely phenolic urethane, sodium silicate, and furan no-bake binder systems (Trinowski 2010; Bobrowski & Grabowska 2012; Kassie & Assfaw 2013; Ghosh 2013)

In particular adhesion science, Furan No-Bake (FNB) is a self-hardening system (Riposan et al. 2013). As the name implies, FNB does not require any heat i.e. baking action for getting harden and produce require strength to withstand the forces of liquid metal (Gandini & Belgacem 2022; Qian et al. 2022). The self-setting phenomenon in the atmosphere only leads to making the binder suitable for the creation of large molds used in steel and gray cast iron foundries (Williams 2014).

The self-setting i.e. stripping of cores and complete elimination of subsequent drying in dryers leading to saving in fuel and labor costs. The other features of the process including dimensional accuracy andincreased hardening rate results in production efficiency and rapid quality production with economic justification (Acharya et al. 2016; Acharya et al. 2018; Kmita 2014).

The raw ingredient of the furan no-bake binder system is furfuryl alcohol which will get harden when acid-catalyst is mixed with it in appropriate proportion. Waste vegetable materials including rice hulls and corn husks are the main raw materials for its production. The FNB is a two-part system, one consisting of alcoholic resin and another of an acid catalyst. Figure 1 represents a classification of the foundry binder systems. The FNB binders along with the sand mixture achieve the required strength and scratch hardness within almost one hour when the sand temperature is in the range of 24 to 30 °C. If the temperature limit exceeds results in more consumption of the acid for its performance (Sheladiya et al. 2019). Figure 2 represents a bonding action of the FNB system and its polymerization action.

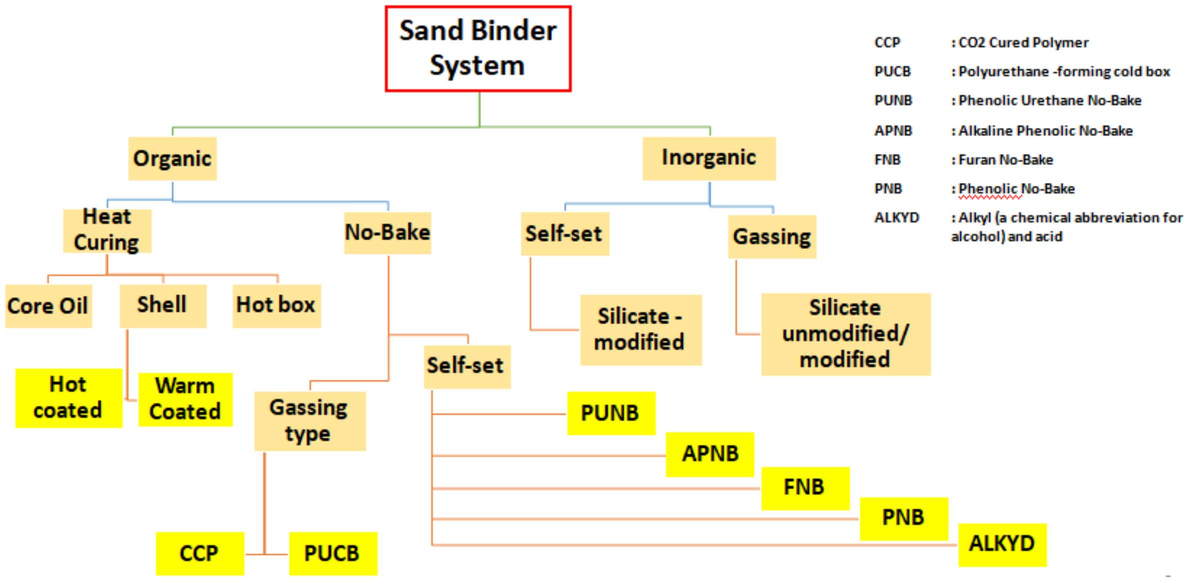

FIGURE 1. Classification of foundry binding system (Ghosh 2013)

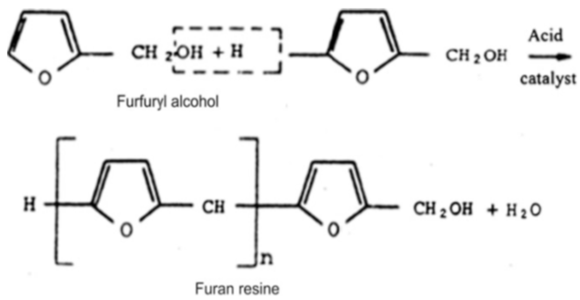

FIGURE 2. Chemistry of FNB System (Holtzer et al. 2015)

For addressing sustainable or green production and economic justification, industries are putting more emphasis on the usage of the used sand. For that, the layers of binders accumulated on the surface of the sand must be removed by the reclamation process. The measure for the successful reclamation is loss on ignition (LoI) and the minimum value is expectable (Consoli et al. 2019).

For any chemical reaction to be taken place, temperature and pressure will be the key properties for any reaction to initiate and/ or sustain. As, the process is being performed in an open atmosphere leading to a reaction at constant pressure,so the curing rate is a direct function of the mixing temperature of the sand, binder, and catalyst. The temperature needs to be carefully controlled and monitored for better results (Holtzer et al. 2020; Holtzer & Kmita 2020).

The requirement of the proportion of the binder and catalyst is decided by the industries based on the temperature and humidity of the ambient conditions based on seasonal variations. The general proportion of the resin which is being given in terms of the sand weight is in the range of 2 % and catalyst proportion is being given in terms of weight percentage of resin in the range of 40 %. American Foundry Society (AFS) has suggested various mold tests for its checking and fixing.

Considering the number of variables involved in the process of mold preparation, the current research focuses mainly on establishing a relationship between variables with the end goal of minimization of the gas porosity defect.

POURING PARAMETERS

The pouring-related quantitative information is given in Table 1. Few modifications in the gating design have been incorporated by the industry for achieving higher yield as shown in Table 2.

TABLE 1. Pouring parameters

Parameter	Value
Temperature	1350 – 1400 °C
Gross weight of the body	42 kg
Metal poured	45.5 kg
Mass flow rate	3.5 kg/s (0.5 litter/s)
Ladle and pouring cup distance	100 mm
Carbon	3.62 %
Silicon	2.14 %
Manganese	0.50 %
Sulphur	0.12 %
Pearlite	99.72 %

[Courtesy: KrislurCastomech Pvt. Ltd., Bhavnagar]

TABLE 2. Gating design modifications of motorbodycasting

Parameters	Value	
	Before Change	After Change
Gross Weight	47.08	46.12
Standard Weight	42.75 kg	42.75 kg
Yield	90 %	92.7 %
Runner Width	18 mm –16 mm	25 mm – 22 mm
In-gate thickness	2 mm	3 mm
Air-vent thickness	2 mm	3 mm
Pouring Cup location	Centre	Side
Pouring style	Top pouring	Top pouring
Equipment	Modern	Modern

[Courtesy: KrislurCastomech Pvt. Ltd., Bhavnagar]

IMPORTANT PROCESS PARAMETERS IDENTIFICATION AND THEIR RANGE

Based on the opinions of the industrial experts and their practices and available prior arts the input variables and their ranges are fixed. Three ingredients namely sand, resin (furfuryl alcohol), and catalyst or hardener (sulphonic acid) are involved in the process. Their combined proportion i.e. range is given in Table 3.

TABLE 3. Process parameters and their chosen level

Parameters	Levels			In Coded Form		Standard Deviation
	Lower	Moderate	Higher	Code (Lower)	Code (Higher)	
A-GFN	43.02	50.7	58.38	-1	1	3.123953
B-LoI	0.8	1.45	2.1	-1	1	0.183887
C-pH	3.5	3.75	4	-1	1	0.105996
D-Resin	0.8	0.875	0.95	-1	1	0.061233
E-Temp	24	34.5	45	-1	1	4.019747
F-Comp strength	11.96	18.82	25.68	-1	1	3.114096

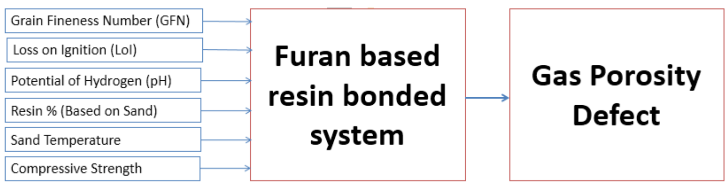

FIGURE 3. Design of Experiments of furan no-bake Binder System

Figure 3 shows a block diagram containing variable-response relationships of the FNB system. The data for the gas porosity defect is collected from the industry. The defect is identified by visual inspection through systemic and scientific methods performed by the team comprised of the quality assurance department and senior engineers. The data which is provided in table 5 contains the no. of the defective products (motor body) out of 100 products due to gas porosity defect.

DEVELOPMENT OF DESIGN MATRIX

Six input parameters consist of forty-four experiments in the commercial non-linear design matrix.

CONDUCTING EXPERIMENTS

The experiments are performed in the winter season having the least humidity in the atmosphere. The sieve analysis test gives the value of grain fineness number (GFN) (IS: 1918). After that, as shown in figure 4, Scanning Electron Microscopy (SEM) analysis is performed and found that from each sieve the topology of the sand is either round or sub-round which is a favorable condition. The compressive strength test specimens are prepared as per the standard test procedure of AFS, in the compressive strength testing equipment (figure 5).

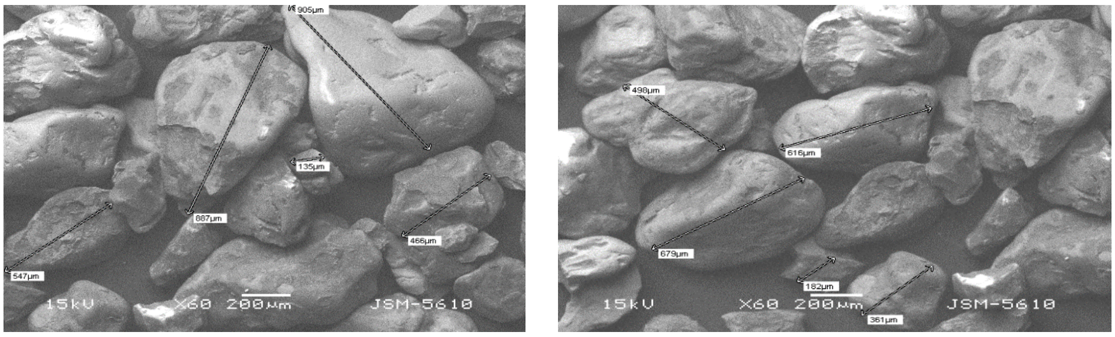

FIGURE 4.SEM image of Sand

FIGURE 5. Compressive test performed with help of standard test piece

DETERMINATION OF THE ADEQUACY OF THE DEVELOPED MODEL

With the help of a set of data as per the design matrix, a non-linear regression model has been developed. The significance test is performed and contour plots are constructed to identify the effect of individual elements and their interactions (Shunmugasundaram, M. et al. 2020; Delarami, A. et al. 2021)

RESULTS AND DISCUSSION

The section discusses the application of the non-linear regression analysis software for the non-linear regression model development.

Mathematical modeling and statistical analysis

Response – Gas Porosity

Equation (1) is the response surface equation in coded form with consideration of all significant parameters involved in the expression.

$$\boldsymbol{GasPorosity} = -25.0736 + 4.145 * A + 23.8788 * B + 1.8276 * C - 261.5534 * D + 1.165 * E - 2.4235 * F - 0.1861 * A * B - 1.17 * A * C - 0.0722 * A * D + 0.00096 * A * E - 0.0032 * A * F - 9.7008 * B * C + 27.7823 * B * D + 0.0892 * B * E - 0.957 * B * F + 14.5985 * C * D - 0.8381 * C * E + 0.4099 * C * F + 0.6773 * D * E + 2.1607 * D * F\ 0.0106 * E * F + 0.0098 * A2 + 0.0074 * B2 + 10.9591 * C2 + 52.3311 * D2 + 0.0239 * E2 - 0.0030 * F2$$

(Equation 1)

Table 4 is the indicator of the significance of process parameters i.e. GFN, LoI, pH, resin (%), the temperature of the sand and mould compressive strength. The insignificance of lack-of-fit indicates that the model is fit with experimental data. The negative sign indicates that compressive strength and temperature are having an opposite relationship with gas porosity.

From Table 4, the value of $R^2 = 0.5711$ for gas porosity defect indicates that 57.1% of the total variations can bedescribed by the model. The value of the R^2Adj = 0.2953 specifies that 29.53% of the total variability is described by the model after consideration of the significant factors.

TABLE 4. ANOVA partial sum of square for compressive strength

	Sum of Squares	df	Mean Square	F-Value	p-value Prob.> F	Contribution%	
Source						95% CI	
Model	67.8843	27	2.5142	2.0711	0.0166	3.5110	Significant
A-A-GFN	2.5109	1	2.5109	2.0683	0.1578	7.3375	
B-B-LoI	0.8800	1	0.8800	0.7249	0.3994	8.0401	
C-C-pH	0.3313	1	0.3313	0.2729	0.6042	2.6836	
D-D-Resin	1.3363	1	1.3363	1.1008	0.3001	1.0095	
E-E-Temp	2.5861	1	2.5861	2.1302	0.1519	6.1794	
F-F-Comp str	1.3185	1	1.3185	1.0861	0.3033	4.3526	
AB	0.0877	1	0.0877	0.0722	0.7894	6.0494	
AC	2.9255	1	2.9255	2.4098	0.1281	0.6740	
AD	0.0026	1	0.0026	0.0021	0.9635	1.7843	
AE	0.0011	1	0.0011	0.0009	0.9761	5.3089	
AF	0.0092	1	0.0092	0.0076	0.9309	3.8190	
BC	0.4417	1	0.4417	0.3638	0.5496	3.6977	
BD	0.7526	1	0.7526	0.6200	0.4355	4.8258	
BE	0.0536	1	0.0536	0.0441	0.8346	6.4594	
BF	0.0422	1	0.0422	0.0348	0.8530	4.1923	
CD	0.2089	1	0.2089	0.1720	0.6804	1.6055	
CE	1.7732	1	1.7732	1.4607	0.2336	1.4736	
CF	0.4985	1	0.4985	0.4106	0.5251	2.9171	
DE	0.3775	1	0.3775	0.3110	0.5800	2.4637	
DF	2.6963	1	2.6963	2.2211	0.1436	2.6171	
EF	0.2525	1	0.2525	0.2080	0.6507	2.6307	
A^2	0.2177	1	0.2177	0.1793	0.6741	3.3594	
B^2	0.0000	1	0.0000	0.0000	0.9981	2.6083	
C^2	0.7022	1	0.7022	0.5784	0.4512	2.5024	
D^2	0.4443	1	0.4443	0.3660	0.5484	1.2763	
E^2	7.7726	1	7.7726	6.4026	0.0152	4.7516	
F^2	0.0278	1	0.0278	0.0229	0.8804	1.7838	
Residual	50.9871	42	1.2140				
Cor Total	118.8714	69					
Std. Dev.	1.1018		R-Squared	0.5711			
Mean	3.0429		Adj. R-Squared	0.2953			
C.V. %	36.2096		Pred. R-Squared	-2.0674			
PRESS	364.6262		Adeq. Precision	6.7870			

The below figures show an effect of the single variable at stated other variable levels. Following the values or range of different single parameter lead to minimum gas porosity defect. As per figure 6GFN should be minimum. The significance of grain fineness number is the sand becomes coarser at low GFN value and becomes finer at high GFN value. As per Figure 7, the LoI value should be nearly about 1.47. Figure 8 suggests the value of pH of sand should be 3.70, the higher value will increase the defect. Figure 9 favors a higher percentage of resin. Loss of Ignition value directly proportional to % resin. Figure 10 favors a temperature of 29° C. Figure 11 shows the compressive strength of mould should be minimum considering sufficient space for gases produced during molten metal pouring to escape.

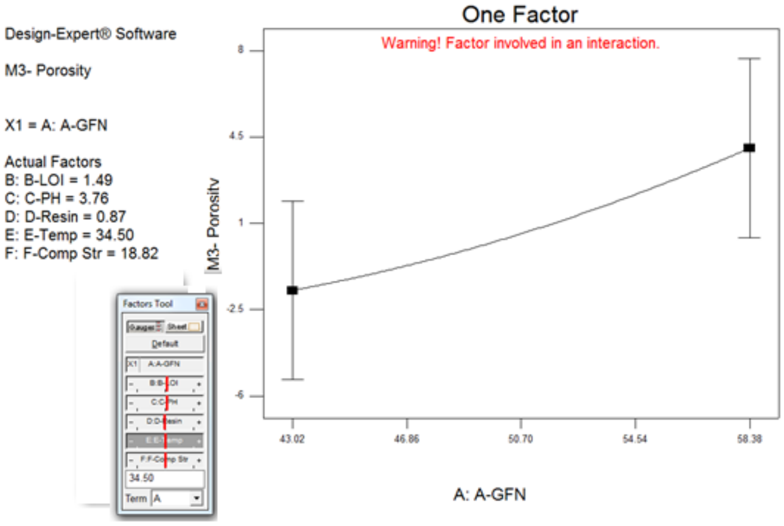

FIGURE 6. Grain fineness number as a single variable for gas porosity defect at the marked design point

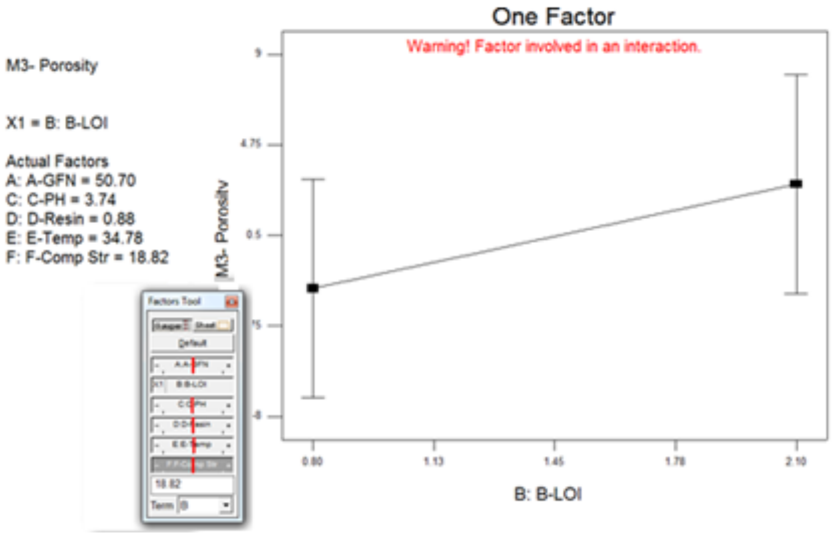

FIGURE 7. Loss of Ignition as a single variable for gas porosity defect at the marked design point

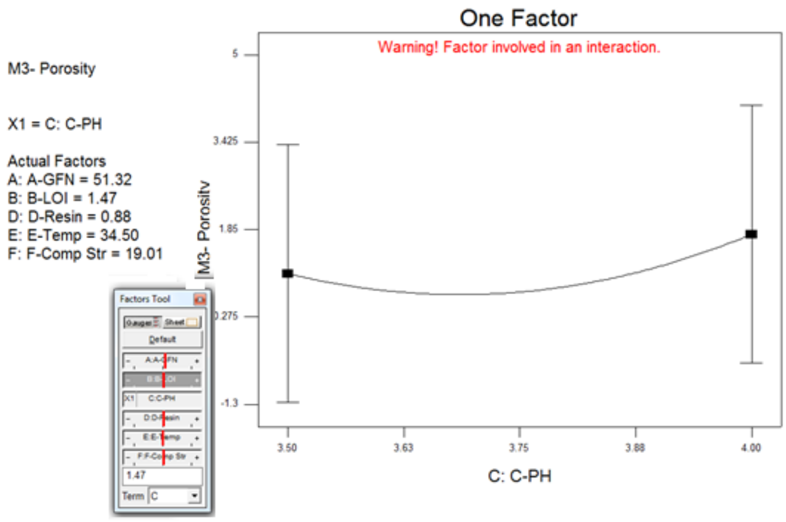

FIGURE 8. pH as a single variable for gas porosity defect at the marked design point

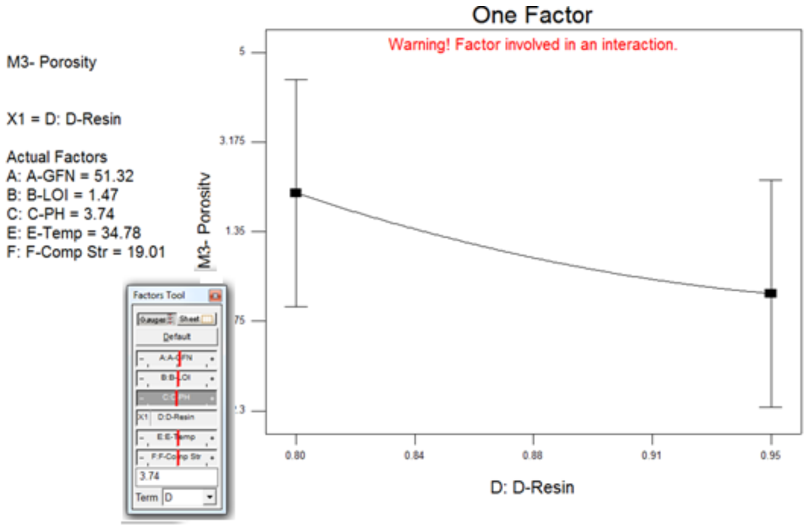

FIGURE 9. Resin percentage as a single variable for gas porosity defect at the marked design point

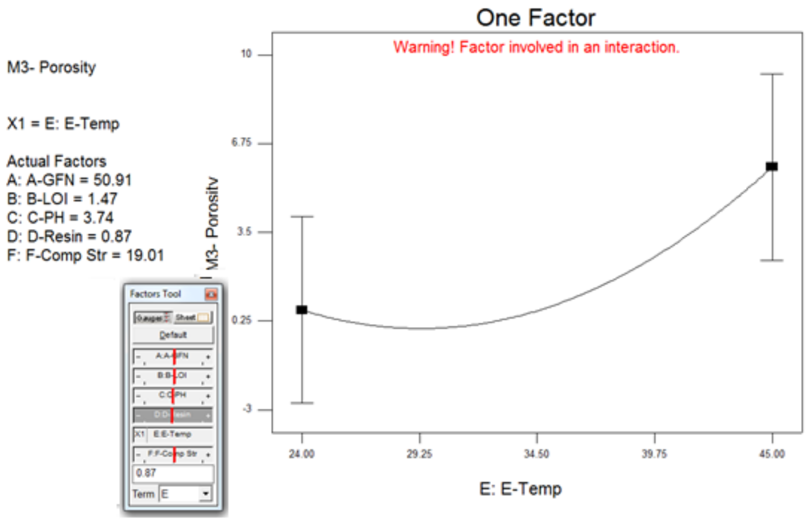

FIGURE 10. Temperature as a single variable for gas porosity defect at the marked design point

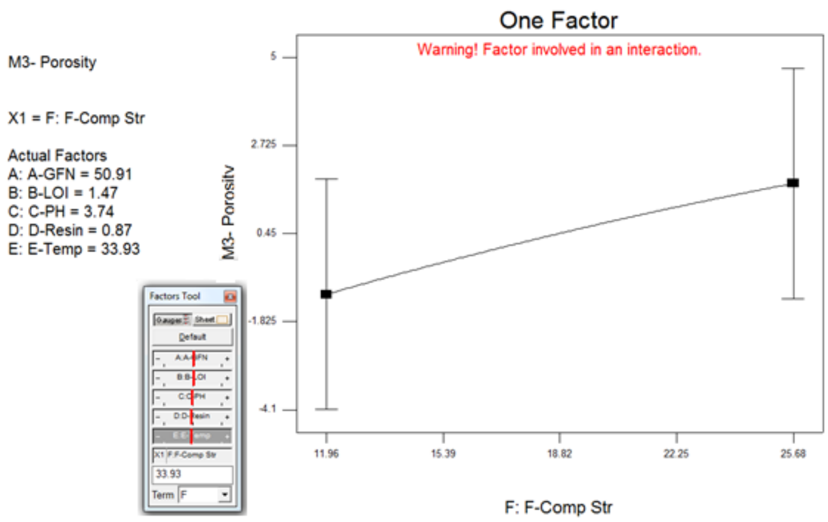

FIGURE 11. Compressive strength as a single variable for gas porosity defect at the marked design point

Figure 12, 13 and 14 show contour plots for identification of the effect of two variables at a time for minimum gas porosity defect. As per the ANOVA table, only three parameters i.e. GFN, LoI, and temperature are important. Figure 10 recommended GFN and LoI combination as 46.86 and 1.13 respectively. Figure 11 recommended LoI and temperature of 1.13 and 34°C respectively. As sown in Figure 12 the favorable GFN and temperature values as mentioned above only.

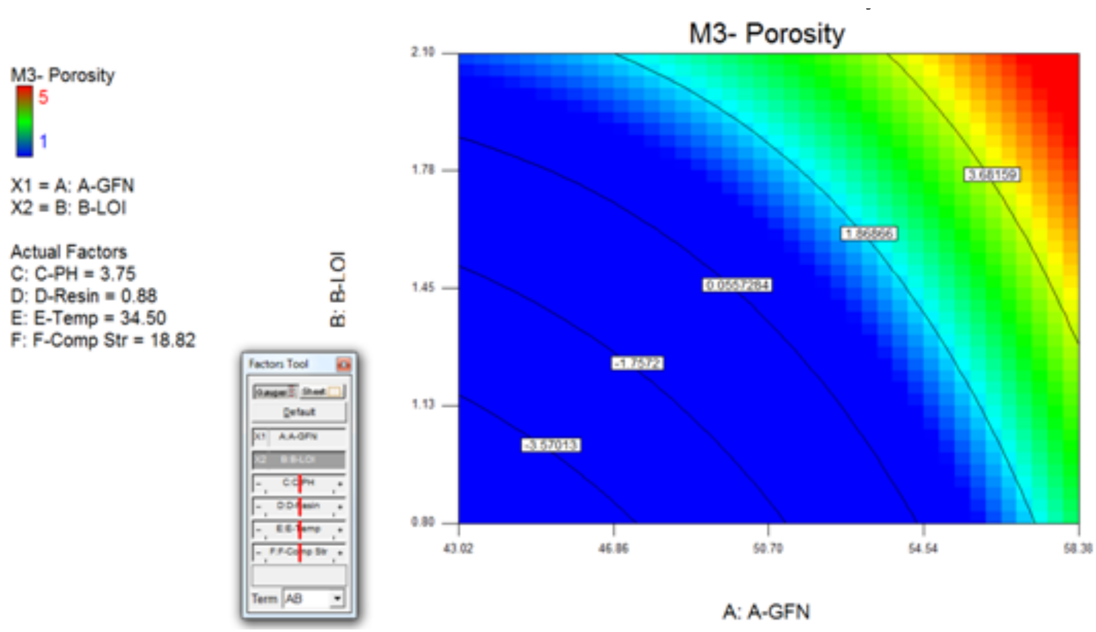

FIGURE 12. LoI and GFN at the marked design point

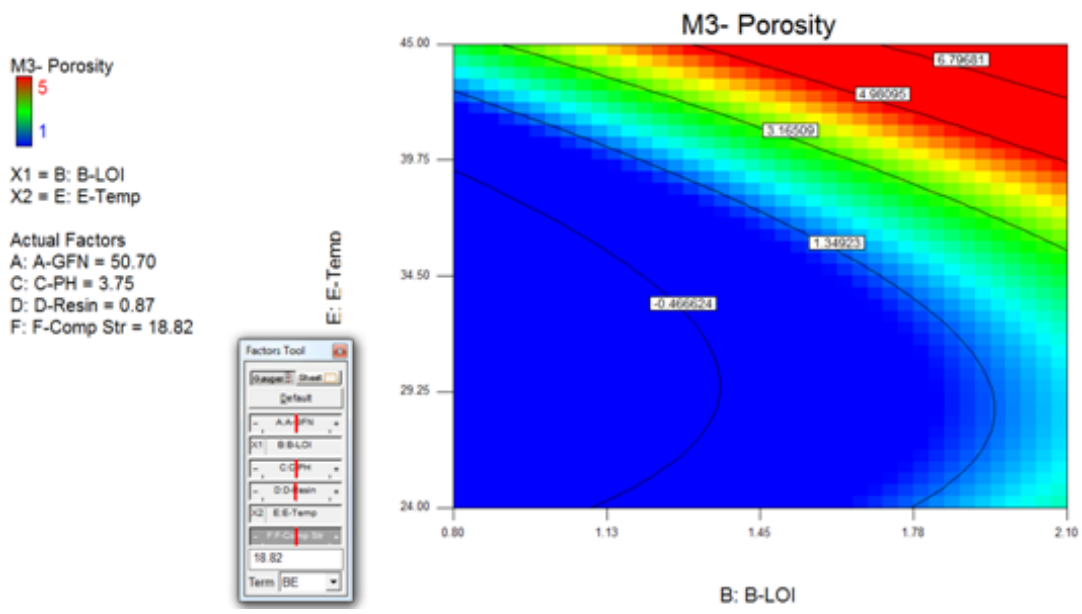

FIGURE 13. LoI and temperature at the marked design point

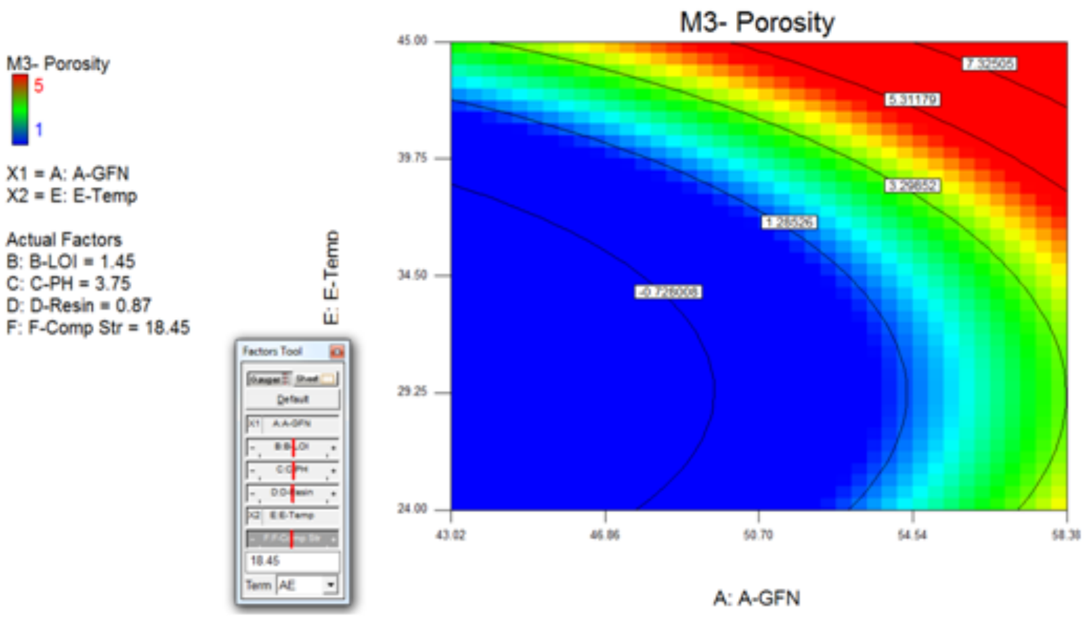

FIGURE 14. GFN and temperature at the marked design point

CONCLUSION

After the experimental study, the parameters for minimum gas porosity defect with possible reasons are as below.

- The value of Temperature should be up to 29° C and the analysis favor minimum compressive strength but it should be enough i.e. 12 kg/cm^2 to withstand molten metal forces as per the standard as per IS: 1918-1966.
- Moderate compressive strength is favorable considering sufficient space for gases produced due to molten metal contact with no-bake binders to escape from the mould.
- As an effect of a single variable pH value should be 3.7 and the grain fineness number should be nearly 46. Loss of Ignition value should be minimum and nearly 1.47.
- Along with that, a few of the techniques, one can apply for minimization of the gas porosity defect are redesign the core to artificial venting or improving the permeability of the core to reduce its internal gas pressure, quick filling to cover the core with liquid metal before its internal pressure rises results into force a bubble into the melt and raising the casting temperature.

ACKNOWLEDGMENTS

The authors are very grateful to the management of KrislurCastomech Pvt Ltd., Bhavnagar, Gujarat, India, and show our indebtedness to Atmiya University, Rajkot for all obligatory assistance.

DECLARATION OF COMPETING INTEREST

None

TABLE. 5 Experimental data for gasporosity defect

GFN	LoI	pH	% Resin Based on Sand	Temperature °C	C.S. kg/cm^2	Gas porosity defective products percentage
47.66	1.60	3.90	0.80	45.00	16.90	33.33%
49.00	1.50	3.50	0.80	36.00	22.39	6.67%
49.34	1.70	3.80	0.80	24.00	21.90	20.00%
48.47	1.70	3.90	0.80	35.00	20.71	26.67%
46.72	1.50	3.90	0.80	26.00	22.30	33.33%
48.65	1.50	3.80	0.80	24.00	24.44	26.67%
48.58	1.80	3.90	0.80	44.00	19.1	6.67%
51.89	1.80	3.90	0.80	32.00	12.15	6.67%
49.46	1.80	3.90	0.80	38.00	20.15	13.33%
47.51	1.90	4.00	0.80	31.00	17.88	40.00%
50.08	1.80	3.90	0.80	34.00	14.9	40.00%
47.12	2.00	3.90	0.80	38.00	16.1	33.33%
49.83	1.70	3.80	0.80	42.00	20.88	33.33%
50.99	1.80	4.00	0.80	38.00	23.42	6.67%
50.19	0.80	3.90	0.80	45.00	21.49	33.33%
49.24	1.70	4.00	0.80	42.00	24.9	20.00%
52.57	2.00	4.00	0.80	42.00	20.2	33.33%
53.30	2.00	3.90	0.80	42.00	20.5	13.33%
50.77	1.90	4.00	0.80	34.00	22.5	6.67%
50.90	1.80	4.00	0.80	40.00	17.95	20.00%
50.31	1.90	3.80	0.80	41.00	20.88	26.67%
45.83	1.80	4.00	0.80	40.00	16.70	20.00%
46.38	2.00	3.90	0.80	40.00	16.62	53.33%
46.59	1.90	4.00	0.80	40.00	20.40	33.33%
46.11	2.00	4.00	0.80	42.00	25.52	33.33%
46.37	1.90	4.00	0.80	43.00	25.68	46.67%
43.02	2.00	3.90	0.80	40.00	17.85	53.33%
45.13	2.00	4.00	0.80	40.00	17.35	53.33%
46.96	2.00	4.00	0.80	40.00	18.58	40.00%
46.22	1.70	3.80	0.80	40.00	24.29	20.00%
47.91	1.80	3.90	0.80	40.00	24.77	26.67%
48.03	2.00	4.00	0.80	40.00	24.80	6.67%
48.19	1.80	4.00	0.80	40.00	21.08	33.33%
46.65	2.00	3.95	0.80	40.00	15.12	20.00%
47.50	1.60	3.80	0.80	40.00	17.90	13.33%
47.38	1.70	4.00	0.80	40.00	15.25	20.00%
45.24	1.90	3.80	0.80	40.00	18.01	20.00%
45.59	1.80	3.70	0.80	40.00	15.01	6.67%
44.26	1.90	3.90	0.80	40.00	16.10	13.33%
44.80	2.00	3.90	0.80	38.00	15.20	20.00%
49.37	1.90	4.00	0.80	38.00	15.02	6.67%

continue ...

... continued

50.31	1.90	3.80	0.85	38.00	15.94	13.33%
49.21	1.90	3.90	0.90	35.00	20.80	33.33%
55.08	2.10	4.00	0.90	40.00	20.30	33.33%
47.55	2.00	4.00	0.95	38.00	16.10	26.67%
46.40	2.00	3.90	0.95	37.00	19.61	20.00%
47.83	1.90	4.00	0.90	38.00	18.32	6.67%
48.18	1.80	3.80	0.90	38.00	18.54	6.67%
47.36	1.90	3.80	0.90	35.00	17.68	6.67%
51.27	1.80	4.00	0.90	35.00	14.13	6.67%
44.89	2.00	3.80	0.90	37.00	18.15	6.67%
51.66	1.90	3.90	0.90	38.00	19.22	13.33%
51.65	2.00	3.80	0.90	38.00	15.16	33.33%
49.54	1.90	3.70	0.95	38.00	11.96	53.33%
53.81	1.70	4.00	0.95	38.00	16.28	6.67%
51.05	1.70	3.80	0.95	39.00	19.28	13.33%
53.79	1.90	3.90	0.95	38.00	18.55	26.67%
44.10	2.00	3.70	0.95	39.00	18.50	33.33%
49.00	1.80	3.80	0.95	37.00	17.70	40.00%
52.77	1.90	4.00	0.90	39.00	15.29	13.33%
56.92	1.80	4.00	0.90	38.00	19.49	26.67%
58.38	1.70	3.90	0.90	37.00	18.89	26.67%
49.43	1.80	3.70	0.90	39.00	20.66	33.33%
51.24	1.60	4.00	0.90	38.00	21.80	26.67%
53.93	1.80	3.90	0.90	42.00	20.24	33.33%
52.71	2.00	3.90	0.90	34.00	20.86	6.67%
53.56	1.90	3.80	0.95	32.00	18.74	20.00%
55.08	1.80	3.70	0.95	35.00	18.73	26.67%
50.00	1.90	3.90	0.95	33.00	18.25	6.67%
52.07	1.80	3.70	0.95	35.00	16.15	6.67%

REFERENCES

Acharya, S. G., Sheladiya, M. V., Kanjariya, P. V. & Acharya, G. D. 2018. An investigation into the release of air pollutant gases during thermal degradation of Furan Sand. *IUP Journal of Mechanical Engineering* 11(2): 27-37.

Acharya, S. G., Vadher, J. A. & Sheladiya, M. 2016. A furan no-bake binder system analysis for improved casting quality. *International Journal of Metalcasting* 10(4): 491-499.

Bobrowski, A. & Grabowska, B. 2012. The impact of temperature on furan resin and binders structure. *Metallurgy and Foundry Engineering 38*, 73-80.

Chen, Y. & Yang, X. J. 2009. Numerical simulation and experimental investigation for sand casting of exhaust manifold based on AnyCasting [J]. *Foundry*, 58(3): 249-252.

Consoli, N. C., Leon, H. B., da Silva Carretta, M., Daronco, J. V. L. & Lourenço, D. E. 2019. The effects of curing time and temperature on stiffness, strength and durability of sand-environment friendly binder blends. *Soils and Foundations* 59(5): 1428-1439.

Dańko, J., Holtzer, M. & Dańko, R. 2010. Problems of scientific and development research concerning the reclamation of used foundry sands. *Archives of Foundry Engineering* 10(4): 29-34.

Delarami, A., Moghaddam, A. M., Yazadani, M. R. & Najjar, S. 2021. Investigation of the main and interactive effects of mix design factors on the properties of cement emulsified asphalt mortars using Mixture Design of experiment. *Construction and Building Materials* 266: 120975.

Gandini, A. &Belgacem, M. N. 2022. Furan resins. In *Handbook of Thermoset Plastics* (pp. 83-95). William Andrew Publishing.

Ghosh, D. 2013. Modern furan for modern castings. In *Transactions of 61st Indian Foundry Congress*, 1-4.

Guharaja, S., Haq, A. N. & Karuppannan, K. M. 2006. Optimization of green sand casting process parameters by using Taguchi's method. *The International Journal of Advanced Manufacturing Technology* 30(11): 1040-1048.

Holtzer, M. & Kmita, A. 2020. Division of the Molding and Core Sands: Criteria. In *Mold and Core Sands in Metalcasting: Chemistry and Ecology*. Springer, Cham., 129-144.

Holtzer, M., Dańko, R., Kmita, A., Drożyński, D., Kubecki, M.,Skrzyński, M. & Roczniak, A. 2020. Environmental impact of the reclaimed sand addition to molding sand with furan and phenol-formaldehyde resin—A comparison. *Materials*, 13(19): 4395.

Holtzer, M., Górny, M. & Dańko, R. 2015. *Microstructure and properties of ductile iron and compacted graphite iron castings: the effects of mold sand/metal interface phenomena*. Springer International Publishing.

IS: 1918:1966, *Indian Standard, Methods of physical tests for foundry sands*, Bureau of Indian Standards.

Kamble, B. S. 2008. Analysis of different sand casting defects in a medium-scale foundry industry-A review. *International Journal of Innovative Research in Science, Engineering and Technology,* 5.

Kassie, A. A. &Assfaw, S. B. 2013. Minimization of casting defects. *IOSR Journal of Engineering (IOSRJEN)*, 3(5): 31-38.

Kmita, A., Fischer, C., Hodor, K., Holtzer, M., &Roczniak, A. 2018. Thermal decomposition of foundry resins: a determination of organic products by thermogravimetry–gas chromatography–mass spectrometry (TG–GC–MS). *Arabian journal of Chemistry* 11(3): 380-387.

Qian, X. W., Wan, P., Yin, Y. J., Qi, Y. Y., Ji, X. Y., Shen, X. & Zhou, J. X. 2022. Gas evolution characteristics of three kinds of no-bake resin-bonded sands for foundry in production. *China Foundry*, *19*(2): 140-148.

Riposan, I., Chisamera, M. & Stan, S. 2013. Control of surface graphite degeneration in ductile iron for windmill applications. *International Journal of Metalcasting*, 7(1): 9-20.

Sheladiya, M. V., Acharya, S. G., Mehta, K., & Acharya, G. D. 2019. Evaluate Sulphur Diffusion at Mould-Metal Interface in No-Bake Mould System. *Archives of Foundry Engineering* 11(1): 63-70.

Shunmugasundaram, M., Kumar, A. P., Sankar, L. P. & Sivasankar, S. 2020. Experimental investigation and process parameters optimization of stir cast aluminium metal matrix composites to improve material removal rate. *Materials Today: Proceedings*, 27: 883-888.

Trinowski, D. M. 2010. Foundry. Phenolic Resins: A Century of Progress. *Foundry*, Springer, Berlin, Heidelberg, 401-502.

Williams, I. D. M. 2014. The environmental performance of biobased resin within phenolic-urethane nobake binders: A feasibility study.

Xia, L., Huang, J. & Zhang, Y. S. 2011. Performance Comparison and Mechanism Analysis of Several No-Bake Sand. In *Advanced Materials Research*, *Trans Tech Publications Ltd.,*189: 3828-3831.