

Performance Analysis of Defect-Free Sand Casting by Optimizing Various Process Parameters

Chhajed R. V.¹, Gavkhare Vaibhav², Gavkhare Ashutosh³, Salunke Abhijeet⁴, Jare Atharva⁵

¹Guide, Department of Mechanical Engineering, Sau. Sundarbai Manik Adsul Polytechnic, Chas, Ahilyanagar, India

²Student, Department of Mechanical Engineering, Sau. Sundarbai Manik Adsul Polytechnic, Chas, Ahilyanagar, India

³Student, Department of Mechanical Engineering, Sau. Sundarbai Manik Adsul Polytechnic, Chas, Ahilyanagar, India

⁴Student, Department of Mechanical Engineering, Sau. Sundarbai Manik Adsul Polytechnic, Chas, Ahilyanagar, India

⁵Student, Department of Mechanical Engineering, Sau. Sundarbai Manik Adsul Polytechnic, Chas, Ahilyanagar, India

Emails: rahulchhajed46@gmail.com

Abstract-

The primary objective of this research is to identify and optimize the most influential parameters of the green sand-casting process to minimize defects in valve body components. Common defects such as shrinkage porosity, blowholes, sand inclusion, and low hardness significantly impact productivity and quality. This study employs the Taguchi approach to parameter design, utilizing Minitab 18 for Design of Experiments (DoE) and AutoCAST software for simulation. By selecting optimal levels for parameters like filling temperature and pouring time, the study aims to reduce casting rejections and achieve a "zero defect" concept in manual foundry operations.

I. INTRODUCTION

In the current globalized manufacturing landscape, foundries serve as a fundamental pillar, acting as the primary source of metallic components for diverse industrial sectors. Metal casting is a highly versatile and direct manufacturing method capable of transforming raw materials into complex geometries through a sequence of integrated processes, including pattern making, core insertion, and the pouring of molten metal into sand-mould cavities. Despite its efficiency and widespread use in automotive and industrial applications, casting is often viewed as an "artwork" that requires high professional expertise to yield quality results.

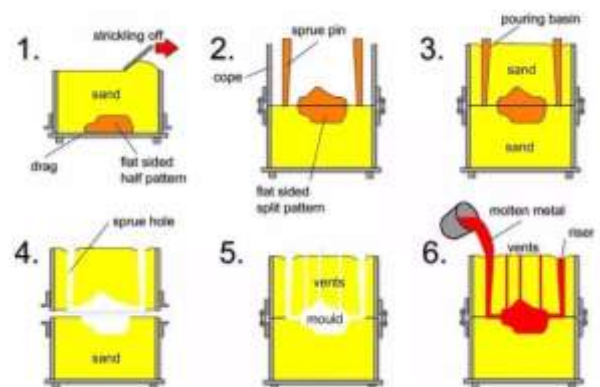


FIGURE 1. Sand casting process

In many regions, particularly in India, a significant number of foundries still rely on manual and conventional operations for casting

Keywords: Sand Casting, Taguchi Method, Optimization, Casting Defects, Valve Body, AutoCAST.

production. These manual processes, while simple and cost-effective for small-scale production, are frequently susceptible to high rejection rates. Common irregularities such as mould shifting, shrinkage, porosity, cold shuts, and surface finish issues are prevalent in these environments. Such defects directly undermine the productivity, profitability, and overall quality standards of an organization.

Today's competitive market demands a "zero defect" concept, requiring foundrymen to achieve higher productivity in less time while significantly reducing manufacturing costs. A foundry's performance is gauged by its ability to maintain high production levels with a minimum number of rejections. Therefore, identifying and minimizing the root causes of casting challenges is essential for effective manufacturing

This research provides an in-depth analysis of critical casting defects, specifically focusing on a valve body component manufactured through the green sand-casting process. The study aims to establish technically feasible remedies by identifying the most influential process parameters such as filling temperature, pouring time, and mould hardness that contribute to persisting defects like shrinkage porosity and blowholes. By utilizing simulation tools like AutoCAST and the Taguchi Method for optimization, this work serves as a control measure for quality professionals to improve casting yield and achieve defect-free operations.

II. FUNDAMENTALS OF SAND CASTING

A. Basic Steps and Sand Types

The sand casting process generally involves six fundamental steps: pattern placement, gating system integration, pattern removal, mold filling with molten metal, cooling, and final shakeout. Sand is the primary mold material, accounting for

over 60% of all metal castings worldwide due to its refractory properties and cost-effectiveness. Various types of molding sand are employed based on specific requirements, including:

Green Sand: A natural mixture of silica, 15-30% clay, and approximately 8% water.

Dry Sand: Green sand with moisture removed for greater strength and rigidity, typically used for heavy castings.

Specialty Sands: Including Core sand for internal cavities, Loam sand for large hoppers, and Facing sand for improved surface finish.



FIGURE 2. 3D view of Valve body

B. Classification of Defects Basic Steps and Sand Types

Undesired irregularities in the casting process are classified into several major categories:

- **Gas Porosity:** Trapped gas bubbles caused by insufficient mold permeability.
- **Shrinkage Defects:** Interior holes or distorted shapes occurring during uneven cooling.
- **Mold Material Defects:** Issues arising from improper mold design or material composition, forming the largest category of casting failures.
- **Pouring and Metallurgical Defects:** Resulting from inadequate melting temperatures or improper metal composition.

III. METHODOLOGY

The study adopts the Taguchi Method, which uses "Orthogonal Arrays" (OA) to provide a balanced set of experiments with minimal variance.

A. Quality Characteristics

The Signal-to-Noise (S/N) ratio is used as the objective function for optimization. For casting defects, the "Smaller-the-Better" characteristic is chosen, as the ideal value for defects is zero.

B. Process Parameters

Four key parameters were selected for optimization based on foundry standards:

- Filling Temperature: 1580°C to 1630°C.
- Pouring Time: 13 to 15 seconds.
- Mould Hardness: 65 to 75 BHN.
- Cooling Time: 35 to 45 minutes

IV. SIMULATION AND ANALYSIS

Analysis was conducted using AutoCAST software. Simulation of the existing gating system revealed critical thermal concentrations.

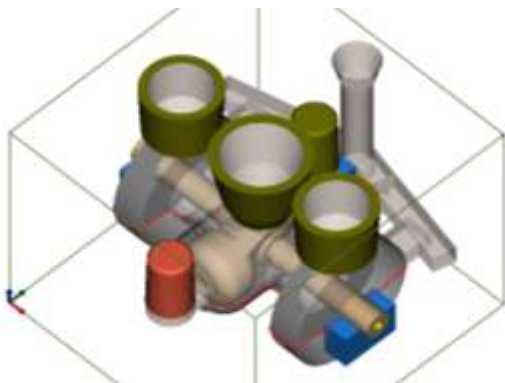


FIGURE 3. *Our existing layout*

Solidification: Blue indicates room temperature, while red indicates liquid state.

Defect Identification: The software identified "cracks" as the primary defect, specifically shrinkage porosity at the center of the valve body.

Optimization: By altering the gating system and riser, the simulation showed the crack shifting from

structural failures.

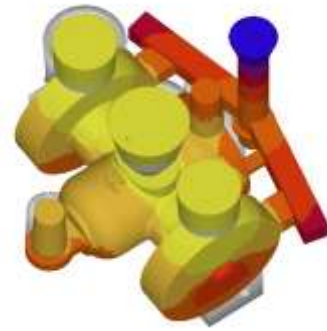


FIGURE 4. *Solidification (Temperature Range)*



FIGURE 5. *Defect after Solidification*

V. EXPERIMENTATION AND RESULTS

Using a Taguchi L9 orthogonal array, experiments were planned to observe the effects of the chosen parameters. The primary quality characteristic measured was the occurrence of cracks

The experimental phase was designed to identify the optimal settings for green sand-casting parameters to minimize the occurrence of cracks in the valve body. The investigation utilized the Taguchi method to systematically vary process parameters and analyze their impact on the final quality.

A. Selection of Process Parameters and Levels

Based on foundry standards and professional experience, four critical process parameters were selected. Each parameter was tested at three distinct levels to define the experimental region:

the center to one end, effectively reducing major

Table 2. Control factors of process parameters and their levels

Parameter	Range	Level 1	Level 2	Level 3
Filling Temp. (°C)	1580 - 1630	1580	1605	1630
Pouring Time (Sec)	13 - 15	13	14	15
Mould Hardness (BHN)	65 - 75	65	70	75
Cooling Time (Min)	35 - 45	35	40	45

B. Orthogonal Array and Experimental Design

To reduce the number of required experiments while maintaining statistical integrity, a Taguchi L9 Orthogonal Array (OA) was employed. This matrix allows for the evaluation of four factors at three levels with only nine experimental runs, significantly improving efficiency over traditional trial-and-error methods.

Table 3. Orthogonal array L9 (control factors assigned)

Trail No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3

C. Quality Characteristics and S/N Ratio

The primary quality characteristic measured was the presence of "cracks," which are identified as geometrical discontinuities caused by high thermal concentration and stress localization during cooling.

Objective Function: The "Smaller-the-Better" Signal-to-Noise (S/N) ratio was chosen because the ideal value for casting defects is zero.

- **Formula:** $n = -10 \text{Log}_{10} [\text{square of slope or beta of the I/O characteristics}]$

D. Results and Discussion

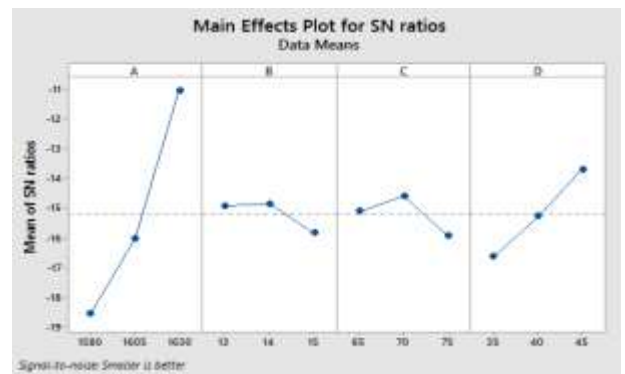


Image 1 : Main Effect Plot for SN Ratio

The results of the L9 array experiments were processed using MINITAB 18 software to generate Main Effect Plots for both S/N Ratios and Means:

- **Defect Identification:** Software-aided simulation (AutoCAST) confirmed that the primary defect was shrinkage porosity at the center of the valve body.
- **Optimization Strategy:** Analysis of the S/N ratio plots helped determine the preferred level for each parameter. By identifying the most influential parameters, the study establishes a "zero defect" control measure.
- **Simulation Improvements:** Initial simulations showed cracks occurring at the center; however, after modifying the gating system and riser based on the experimental

9	3	3	2	1
---	---	---	---	---

- results, these defects were shifted to the non-critical ends of the component, effectively reducing the impact of the flaw.

E. Confirmation Run

A final verification experiment was conducted using the newly identified optimum settings. The outcome indicated a significant reduction in persisting defects (shrinkage porosity and cracks), confirming that the Taguchi approach effectively "tuned" the manual casting process for superior results.

VI. CONCLUSION

The optimum conditions for the parameters computed are given below as

Filling Temp (°C)	Level 3	1630
Pouring Time (Sec)	Level 2	14
Mould Hardness (BHN)	Level 1	65
Cooling Time (Min)	Level 3	45

Using Taguchi method, the factor levels when optimized will result in reduction of casting defects and increase the yield percentage of the accepted casting without any additional investment.

A usage of quality tools like pareto charts is useful for finding the major defects in the daily operations of foundry.

Quality of casting can be improved by aesthetic look, dimensional accuracy, better understanding of noise factor and interaction between variables, quality cost system based on individual product, scrap reduction, reworking of casting and process control.

sand system using design of experiments and back propagation neural network. *Journal of Materials Processing Technology*, 180, 167–173(2006).

VII. REFERENCES

1. ASM International Committee, Metal’s handbook for castings. ASM International, 10th edn, vol 15. Materials Park, OH (1990)
2. A Mandal, and P. Roy, Modeling the compressive strength of molasses–cement
3. S. Guharaja, Noorul Haq, A. K. M. Karuppanan Optimization of green sand-casting process parameters by using Taguchi’s method. *Int J Adv Manuf Technol* 30:1040–1048(2006).
4. D.B. Karunakar and G. L. and Datta, Prevention of defects using back propagation neural Networks. *International Journal of Advanced Manufacturing Technology*, 39, 1111-1124(2008).
5. M. B. Parappagoudar et al. Neural Forward and reverse mappings in green sand mould system using neural networks. *Applied Soft Computing* 8:239–260(2008).
6. A. Noorul Haq, S. Guharaja, K.M. Karuppanan, Parameter optimization of CO2 casting process by using Taguchi method. *Int J Interact Des Manuf* 3:41–50(2006).
7. B. Senthilkumar, S.G. Ponnambalam, Process factor optimization for controlling pull-down defects in iron castings, *Journal of Materials Processing Technology* 209:554-560. (2009).
8. Sushil Kumar, P. S. Satsangi, D. R. Prajapati, Optimization of green sand-casting process parameters of a foundry by using Taguchi’s method. *International Journal of Advanced Manufacturing Technology* 55:23-34(2011).
9. Charnnarong Saikaew, Sermsak Wiengwiset, Optimization of moulding sand composition for quality improvement of iron castings, *Applied Clay Science* 67-68:26-31(2012).
9. R. A. Upadhye and I. P. Keswani, Optimization of Sand-Casting Process

Parameter Using Taguchi Method in Foundry. International Journal of Engineering Research and Technology, 1(7), 1-11(2012).

10. U. A. Dabade and R.C. Bhedasgaonkar, Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique, Procedia CIRP Science Direct 00:000-000(2013).

11. A. Kumaravadivel et.al. Optimization of sand-casting process variables—a process window approach, International Journal of Advanced Manufacturing Technology 66:695-709(2013).

12. Ganesh G. Patil, Dr. K. H. Inamdar, Optimization of Casting Process Parameters using Taguchi Method, International Journal of Engineering Development and Research Vol.1: Issue1(2014).

13. Manjunath Patel G, Prasad Krishna and Mahesh B. Parappagoudar, Optimization of squeeze cast process parameters using Taguchi and grey relational analysis, Procidia Technology 14:157-164(2014).

14. S.K.Tiwari,R.K.Singh,S.C.Srivastava,Optimisation of green sand-casting process parameters for enhancing quality of mild steel castings', Int. J. Productivity and Quality Management, Vol. 17, No. 2, pp.127–141(2016).

15. Johnson Santhosh and A. R. Lakshmanan, Investigation of ductile iron casting process parameters using Taguchi approach and response surface methodology, China Foundry 13:352-360(2016).

16. Yao, Y., Huang, Z., Li, Y., & Zhang, Y. (2024). An experimental study on the impact fatigue behavior of basalt fiber reinforced polymer composites. *Composites Science and Technology*, 254, 110688. <https://doi.org/10.1016/j.compscitech.2024.110688>