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# Assessment of Sand Casting Defects and Corrective Actions Carried Out: A Review

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**Abstract:- Casting is an especially flexible process that can be utilized by foundries for production on a large scale. Due to their importance as a source of castings, foundries now play a significant role in the industrial sector. The production of excellent castings at the lowest possible cost is the ultimate aim of the manufacturing sector. Undesirable imperfections in the metal casting process are known as defects. A number of issues that are process-related are the reason for the defects. A few defects can be tolerated while others can be fixed, or they can even be eliminated with good moulding technique. These imperfections develop as a result of a few production cycle processes that are not effectively monitored. Sand casting company efficiency is negatively affected by poor casting. For strong castings, the challenging casting defect conditions must be identified and reduced. By reducing casting defects throughout manufacturing, the foundry sector can improve its level of quality. The primary objectives of this study are to identify the significant sand casting defects and analyze the preventative measures to reduce the defects. In this work, efforts are undertaken to identify technically feasible remedies for minimizing a variety of casting weaknesses and improving casting quality.**

***Keywords:-*** *Casting; Casting Defects; Cause and Remedies; Defect Analysis; Quality Improvement.*

## I. INTRODUCTION

One of the earliest human-developed techniques for shaping metal is casting. Typically, it involves pouring molten metal in a refractory mould that has a hollow in the desired shape and allowing it to solidify. When the metal has formed, the refractory mould is broken or disassembled to release the desired metal product [1]. The earliest and one of the most adaptable methods of casting metal is by using sand. Sand casting was used for the first time in literature around 1540 [2]. The sand casting process would not be entirely mechanized until the increasing demand for automobiles and machinery. Sand casting technology has advanced as a result of this increase in demand, including faster moulding and stronger moulds [3].

A typical casting process involves creating a pattern with the required modifications, using that pattern to create a mould, melting metal or alloy in a furnace, pouring molten metal into the cavity of the mould, breaking the mould to remove the casting, cleaning the casting and removing risers, runners, etc. (also known as "fettling"), and inspecting the casting [4].

Even though the term "quality" is a lot more complex than it originally appears, this paper defines quality as conformity to specification. Defects are thus defined as any casting imperfections brought on by one or more molding process mistakes or any non-conformance to specification [4].

The costs associated with these defects are a major concern for most foundries, since they result in what is known as quality cost. The price of unacceptable products or services is the cost of quality. Cost of prevention, Cost of Appraisal, Cost of Internal Failures (or Cost of Non-Conformance), and Cost of External Failures are typically included [5].

Even though casting technology is improving in accuracy and precision, casting uncertainty continues to provide challenges to the foundry sector. Higher losses are attributed to defective casting in the sand casting business. Therefore, the defects can be fixed by doing extensive research.

The objective of this article is to review the various factors that contribute to the formation of common sand casting defects with suggested remedial actions to help foundry shops reduce their quality costs and identify a significant research gap in the area.

This article was prepared from reviews of many works on the subject. The original researchers performed their research using techniques such as industrial case studies, reviews, simulations, and experimental validation. The chosen papers' quality and relevancy are given plenty of consideration.

## II. OVER-VIEW OF SAND CASTING TECHNOLOGY

In sand casting, molten metal is poured into a cavity-shaped sand mould, where it solidifies. Sand particles are used to create the mould, and an inorganic bind is used to keep them together. The sand mould is split open to release the casting after the metal has cooled to room temperature. The schematic illustration of sand casting is shown in Fig. 1[6].

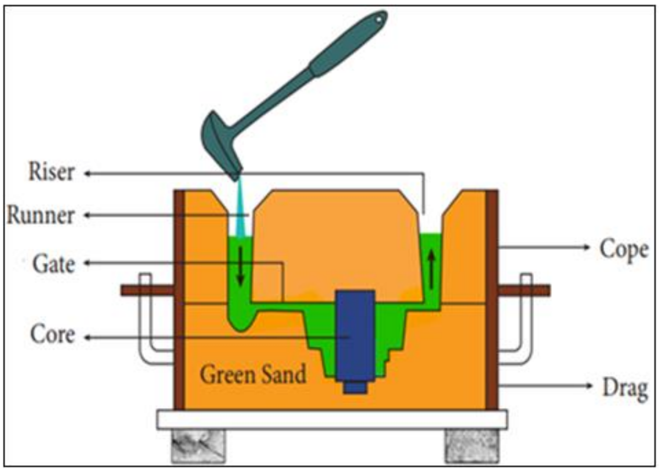

Fig 1 Typical Sand Casting Process Mould Setup

*A. Basics for Defect Free Quality Casting*

A sound casting should be produced by a properly designed casting, a properly prepared mould, and suitably melted metal. However, if sufficient control is not used, the casting could have a number of defects. These defects could be caused by the following factors [7].

- An improperly designed pattern or tool or a lack of allowances
- Incorrect mould and essential ingredients,
- Improper melting, improper pouring, and improper melting practices
- Due to the materials used to make the moulding and core.
- An inadequate risering system and feed aids were used for gating.
- An improperly prepared metal
- Insufficient melting temperature and pouring rate.
- Unskilled post-melting procedures like fettling and shakeout.

The quality and integrity of the finished casting can be considerably impacted by the geometry and complexity of a part throughout the casting process [8]–[10].

*B. Defects in Castings, Contributing Factors and Remedial Actions to be Taken*

Any irregularity in the molding procedure results in casting defects, which can occasionally be tolerable, occasionally avoided with correct molding technique, or fixed utilizing techniques like welding and metallization. The main defects in each category of sand casting are listed in Fig. 2.

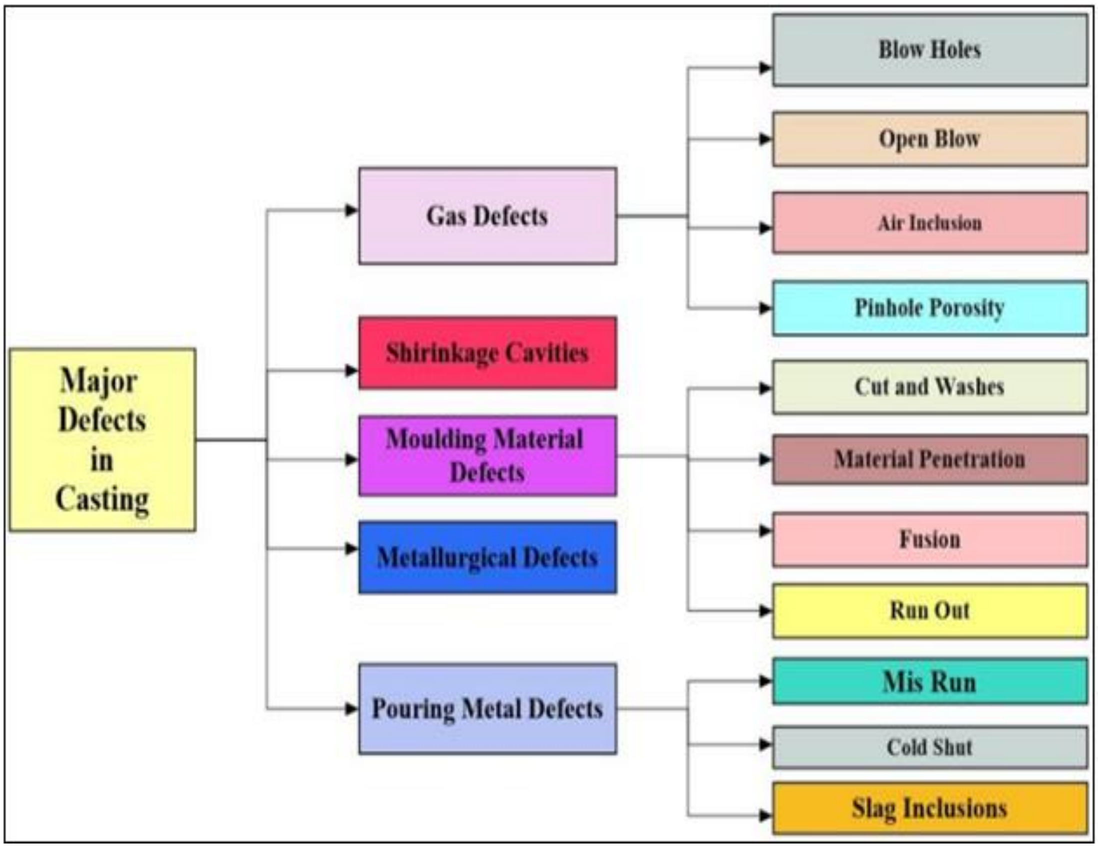

Fig 2 Basic Categories of Sand Casting Defects

The major defects that are frequently present in sand castings are summarized below, along with how they can be fixed (TABLE 1) [11–13].

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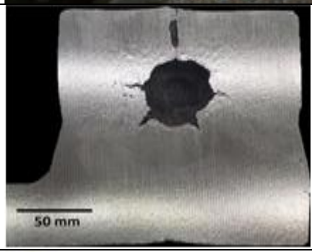
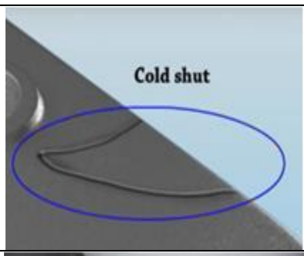
## III. DETECTING VARIOUS CASTING DEFECTS AND PROVIDING CORRECT SOLUTIONS

### *A. Parameter Optimization*

Sand casting produces castings with a variety of superior qualities. While certain imperfections are proven to be persistent and challenging to avoid, the quality of a casting always depends on good management of the massive parameters involved in the process as well as proper combination among these parameters. The quality of the product is affected by these factors. One sort of parameter is a controlled parameter, and the other is an uncontrollable parameter, often known as a noise factor. Understanding the relevant parameters is essential for controlling the process to prevent cast component rejections caused by such persistent errors. In the area of parameter optimization of sand casting defects and analyses, TABLE.2, elaborates on recent research work published by various scholars and the summative findings from their research work.

Table 1 Causes and Solutions for Sand Casting Defects

| Defect | Possible causes | Remedies | Image of Defect |
|---|---|---|---|
| Gas Defects | The lower gas passing tendency of the mould and/or<br>Improper design of the casting. | Adequate provision for evacuation of air and gas from the mold cavity.<br>Increase of permeability of mould and cores. |  |
| Shrinkage Cavities | Volumetric contraction both in liquid and solid state.<br>Poor casting design<br>Low strength at high temperature | Proper feeding of liquid metal is required<br>Proper casting design |  |
| Moulding Material Defects | Erosion of molding sand by the flowing molten metal<br>Molding sand not having enough strength.<br>Higher pouring temperatures<br>Faulty mould making procedure | Proper choice of molding sand and using appropriate molding method.<br>Choosing an appropriate type and amount of betonies |  |
| Pouring Metal Defect | The metal is unable to fill the mould cavity completely<br>Premature interruption of pouring due to workman's error | Have sufficient metal in the ladle to fill the mould<br>Proper gating system |  |
| Metallurgical Defect | Poor casting design<br>Rough handling or excessive temperature at shakeout<br>Chilling of the casting | Improvement in casting design<br>Proper metallurgical control and chilling practices |  |

### *B. Simulation/ Software Analysis*

This covers grain structure, tensions, and distortion, as well as mould filling and solidification. The process parameters (pouring temperature, rate, etc.), temperature-dependent properties of part and mould materials, and solid models of the product and tooling (parting, cores, mould designs, feeders, feed aids, and gates) are all needed. The findings of the simulation can be used to forecast casting flaws including shrinkage porosity, hard spots, blow holes, cold shuts, fractures, and distortion. The inputs, however, require a high level of expertise and might not be conveniently available to product designers. The development of the product, tooling, and process designs concurrently, assuring their compatibility with one another, is one method. Early on in the development process, casting simulation enables virtual testing. To avoid wasting money on unnecessary parts or late designs and to fulfill deadlines, do this. [20], [21].

The majority of defects will emerge during casting. The only method to achieve zero defects is to have parameters that are regulated, such as alloy composition, melting and pouring temperatures, gating systems, moulding, and solidification rates. Industries and Foundries require a technique for evaluating the process that delivers all the specifics without experimentation in order to keep up with modern trends. A person can predict defects using simulation and quickly get trustworthy results [22]–[24].

Table 2 A Review of the Literature on Parameter Optimization

| **Process parameters** | **Optimization Technique** | **Output parameters** | **Findings** | **References** |
|---|---|---|---|---|
| Venting quality (VQ), wet compressive strength (WCS), moisture content (MC), compact ability (Com) | Grey relational analysis based back propagation (BP) neural network | Missing data prediction | For the VQ, WCS, MC, and Com, the outcomes were 0.252, 0.2475, 0.2495, and 0.251, respectively.<br>Compared to grey system theory, the predictive value of the BP neural network was more accurate. | [14] |
| Melting Temperature (MT), Pouring Time (PT), Holding Time (HT), Moisture Content (MC) and Clay Percentage (CP) | Taguchi | Micro hardness | The first rank is assigned to CP, followed by MT in second place, PT in third place, MC in fourth place, and HT in last place.<br>According to their measuring units, the best response was discovered at CP, MT, PT, MC, and HT of 8,720, 35, 9, and 200, respectively. | [15] |
| Moisture Content%, Clay Content % and Silica Oxide($SiO_2$) % | Response Surface Methodology (RSM) and ANN analysis | Hardness and Surface Roughness | Optimum result was observed at 7.9,4.2 and 9.2 of Moisture Content%, Clay Content % and Silica Oxide($SiO_2$) %respectively.<br>ANN's precision and prediction capability makes it a more analytically helpful tool for applications in the foundry sector. | [16] |
| Degree of ramming, Mould wall thickness and Western bentonite content | Taguchi based GRA | Permeability and Hardness | The results of the grey relational analysis indicate that the degree of ramming, 7, mold wall thickness, 30mm, and western bentonite with 3% of water, 9,5%, are the levels of each parameter that need to be used.<br>The pressure plate casting mould-quality-related casting rejection and the overall casting rejection are lowered by the value of the optimized process parameters, and the cavities for gas storage result in reduced moulding sand consumption. | [17] |
| Content of silica sand, bentonite, water, and coal dust in percentage | Taguchi based GRA | Tensile strength, hardness, and microstructure | Based on the assessment of the Grey Relation Grade, the optimum green sand composition settings are silica sand at 85%, bentonite at 7%, water at 5%, and coal dust at 4%. | [18] |
| Pouring Temperature, Mold Preheating Temperature, Width/Thickness Ratio Of Cross-Section Of Sprue, Width/Thickness Ratio Of Inner Sprue Section And Length/Diameter Ratio Of Straight Sprue | Response surface method | shrinkage volume, solidification time | The shrinkage volume and integrated solidification time were reduced after the optimized parameters were solved and the pouring mechanism was improved | [19] |

Software for casting simulation was assessed by the researcher. The author chose eight midranges and high-end software programs from among the many software programs available for casting simulations. Comparisons based on different criteria, such as the casting process, problem-solving techniques, materials used in casting and molding, ability to predict defects, and design and process improvement.

Casting simulation software uses a variety of numerical solution techniques. MAGMA Soft, Solid CAST, and FLOW3D CAST software all use the FDM (Finite Difference Method). FVM (Finite Volume Method) and Vector Element Method (VEM) are both employed in the CastCAE and Nova Solid/Flow software, as well as in AutoCAST. FEM (Finite Element Method) uses the software CAPCAST, ProCAST, and FLOW3D CAST. All of these software packages predicted shrinkage flaws, porosity, cold shunt, and misrun. Foundries, academic institutions, and R&D can use these software packages. CastCAE, AutoCAST, and SOLID cast are considered to have limited features in compared to FLOW3D CAST, MAGMAsoft, ProCAST, Nova Solid/Flow, and CAPCAST[25]. The user interfaces of some of these software programs are shown in Fig. 3, and the presentation of the findings varies little from one simulation package to another[26].

➢ *The following are the Processes for Utilizing Casting Simulation Software:*

- Use CAD to create a casting design model and save it as an STL file.
- Insert the STL file into the pro cast program.
- Describe the data that needs to be provided for the analysis.
- Describe the gating system.
- Run the program.
- Examine the results.

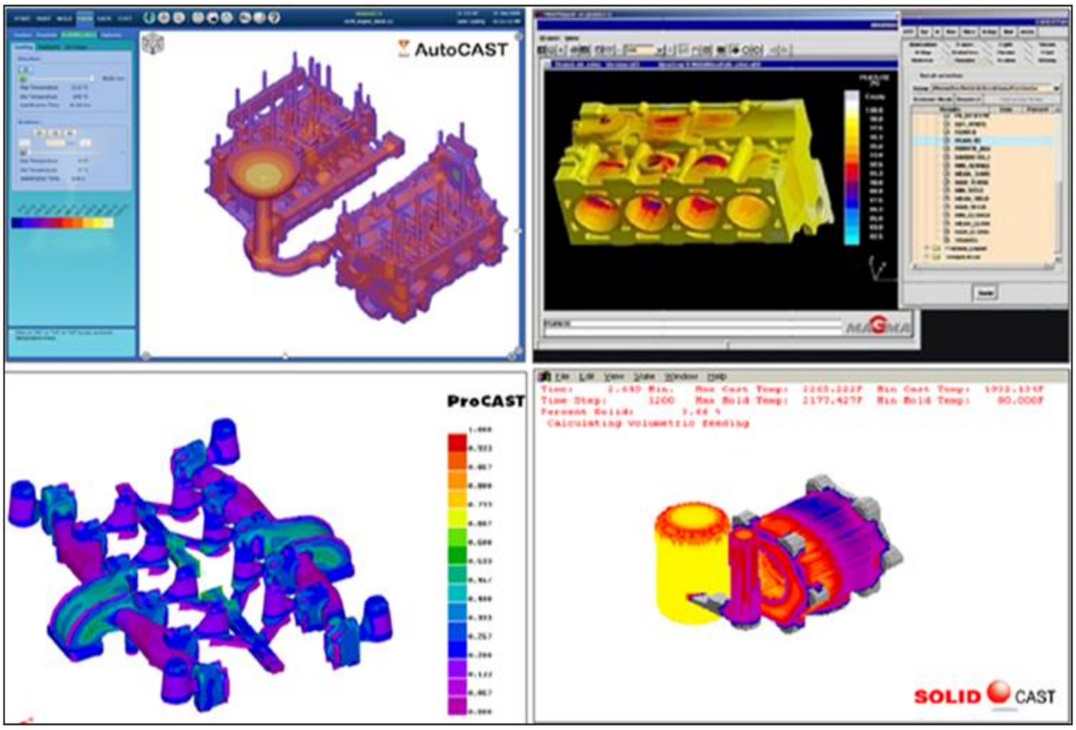



Fig 3 Popular Casting Simulation Software (Auto CAST, MAGMA, Pro CAST, and Solid CAST) user Interface

As indicated in TABLE 3., investigators selected the top defect-free items after identifying the fundamentally crucial properties using various modelling software.

## IV. OBSERVED RESEARCH GAPS AND FUTURE WORKS

➢ *Here are some of the Areas of Study that Need to be Filled in the Evaluation of Sand Casting Defects and Repair Actions:*

- Import substitution of moulding sand and clay should be given great attention in developing country.
- Remedial actions given are very specific to the working conditions of that research.
- Regarding the optimization process, less focus has been placed on identifying the empirical links between control variables and response characteristics.
- The Taguchi method and artificial neural networks are the most widely employed optimization strategies for sand casting defect optimization. The ability of these methods to take into consideration the intricate connections between the many process factors can, however, be limited. The optimization procedure could be enhanced by using more sophisticated optimization methods like genetic algorithms and particle swarm optimization.

- To make a design and a full cast of a product with all of its accessories via rapid prototyping is limited. So that the designer could establish a relationship between theoretical data from simulations and actual experimental data gained by real-time casting, thus checking the accuracy of both sets of data by comparing them.

- A Lack of Standardization in Reporting and Classifying Defects.

It is challenging to compare the findings of various investigations since there is no standard classification system for sand-casting defects. Furthermore, it might be challenging to pinpoint the primary causes of defects and create efficient corrective measures due to the frequent lack of clarity in defect reports.

- Inadequate Understanding of the Processes that Lead to Defect Creation.

We don't fully understand the precise mechanisms by which sand casting defects develop. This makes it challenging to create preventative strategies that work for all kinds of defects.

- The Limited Application of Machine Learning and Data Analytics.

Predictive models can be created using data analytics and machine learning approaches to find patterns in faulty data. However, the sand casting industry does not frequently employ these methods.

- Insufficient Interaction between Academics and Industry Professionals.

There is frequently a disconnect between researchers who create new techniques for defect detection and prevention and practitioners who are in charge of putting these techniques into practice in the real world. The adoption of new technologies and procedures could be hampered by this distance.

Researchers can create better techniques for their prevention and detection and advance our understanding of sand-casting defects by filling in these research gaps. As a result, producers would be more productive and produce sand castings of superior quality.

The following specific research projects could be carried out to fill these gaps.

Table 3 A Review of the Literature on Sand Casting Defect Simulation

| Method /Software used | Parameters considered | Findings | References |
|---|---|---|---|
| Three different heights of pouring basin were selected with same runner design.<br>○ FEA/ Pro-Cast software | Filling and solidification time with hot spot region. | ○ The entire filling time for the inside cavity is 8.97 seconds<br>The solidification time for the cavity to cool to 600 °C is 1835 seconds.<br>The pressure plate's outer circle is where the hot spot is located. | [27] |
| FEA simulation using Z-CAST used for failure Analysis of impeller. | Hardness test on impeller at different section assisted by microstructure results. | ○ The emergence of microstructure variations that are heavily influenced by casting designs.<br>Features of solidification under-cooled graphite is more likely to occur in thin shroud areas and simulation were confirmed. | [28] |
| ○ A 3D printer was used to create an integrated mould cavity that was connected to the worm wheel, risers, and gating system.<br>○ MAGMA 5.1 Software ware used. | ○ The tensile test was performed<br>The hardness was measured<br>○ Microstructures were analyzed | Directional solidification's findings were verified.<br>Sand casting could be used to create a solid worm wheel without defects.<br>The researcher discovered a number of great advantages over conventional casting, including recovery rate, post-casting process, errors, mechanical characteristics, and cost. | [29] |
| CATIA software was used to create a 3D model.<br>Utilizing the PROCAST software, the feeding and gating system is executed. | The research predicts that the riser's position and feed volume | When compared to earlier products made at the foundry, an enhancement in the product's overall quality was seen. | [30] |

- Developing modern optimization methods that can take into consideration the complex interactions between the many process parameters.
- An investigation into the creation of a standardized defect classification system and reporting methodology.
- An investigation into the mechanism by which sand casting defects occur.
- A study to create a data analytics and machine learning-based system for sand casting defect detection and prevention.
- A study to facilitate interaction between academics and professionals working in the sand casting sector.

These are just a few examples of the research that could be done to address the research gaps in the assessment of sand casting defects and corrective actions carried out. By conducting this research, we can make sand casting a more reliable and efficient manufacturing process.

## V. CONCLUSIONS

This review examines several sand-casting defects and discusses preventive measures that can be taken to eliminate them, as well as the effectiveness of various optimization and simulation methodologies. This will aid in the analysis of the defect and the development of solutions. The casting should have as few defects as possible to improve the quality of the casting. By taking into consideration various variables at every stage of production and by applying simulation techniques before casting has been completed, rejections could be continuously controlled. It is crucial for a metal caster to recognize the defect's form and to discharge sound castings.

Practical issues like a lack of standardization, a limited application of machine learning and data analytics, a lack of interaction between academics and professionals in the industry, an inadequate understanding of how production processes lead to the creation of defects, and a lack of sophisticated optimization methods for sand casting defects are not thoroughly investigated, and future works are identified.

### *A. Acronyms*

- **ANN:** An artificial neural network;
- **CAD:** computer-aided design;
- **FEA:** Finite element Analysis;
- **GRA:** Grey relational analysis;
- **RSM:** Response surface methodology;
- **STL:** It is a type of file that is frequently used for computer-aided design (CAD) and 3D printing. Stereolithography, a common 3D printing technology, is represented by the acronym STL.

## REFERENCES


[1]. M. A. A. Khan, A. K. Sheikh, B. S. Al-Shaer, M. A. A. Khan, A. K. Sheikh, and B. S. Al-Shaer, *Evolution of metal casting technologies—a historical perspective*. Springer, 2017.

[2]. D. Weiss, "Advances in the sand casting of aluminium alloys," in *Fundamentals of Aluminium Metallurgy*, Elsevier, 2018, pp. 159–171.

[3]. S. Sulaiman and A. M. S. Hamouda, "Modeling of the thermal history of the sand casting process," *J. Mater. Process. Technol.*, vol. 113, no. 1–3, pp. 245–250, 2001.

[4]. H. Fredriksson and U. Akerlind, *Materials processing during casting*, vol. 210. Wiley Online Library, 2006.

[5]. S. B. Jaju, R. P. Mohanty, and R. R. Lakhe, "Towards managing quality cost: A case study," *Total Qual. Manag.*, vol. 20, no. 10, pp. 1075–1094, 2009.

[6]. Chadha, U., Selvaraj, S.K., Pant, H., Arora, A., Shukla, D., *et al.*, "Phase change materials in metal casting processes: a critical review and future possibilities," *Adv. Mater. Sci. Eng.*, vol. 2022, 2022.

[7]. C. Chelladurai, N. S. Mohan, D. Hariharashayee, S. Manikandan, and P. Sivaperumal, "Analyzing the casting defects in small scale casting industry," *Mater. Today Proc.*, vol. 37, pp. 386–394, 2021.

[8]. S. Chastain, *Metal casting: a sand casting manual for the small foundry*, vol. 1. Stephen Chastain, 2004.

[9]. M. Srinivasan, *Science and technology of casting processes*. BoD–Books on Demand, 2012.

[10]. A. K. Chakrabarti, *Casting technology and cast alloys*. PHI Learning Pvt. Ltd., 2022.

[11]. C. Chelladurai, N. S. Mohan, D. Hariharashayee, S. Manikandan, and P. Sivaperumal, "Materials Today : Proceedings Analyzing the casting defects in small scale casting industry," *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.05.382.

[12]. I. C. Studies, "Casting Defects Analysis in Foundry and Their Remedial Measures with Casting Defects Analysis in Foundry and Their Remedial Measures with Industrial Case Studies," no. October, 2016, doi: 10.9790/1684-12614354.

[13]. V. Khalajzadeh and C. Beckermann, "Simulation of Shrinkage Porosity Formation During Alloy Solidification," *Metall. Mater. Trans. A*, vol. 51, no. 5, pp. 2239–2254, 2020, doi: 10.1007/s11661-020-05699-z.

[14]. Q. Xu, K. Xu, L. Li, and X. Yao, "Optimization of sand casting performance parameters and missing data prediction," *R. Soc. open Sci.*, vol. 6, no. 8, p. 181860, 2019.

[15]. C. M. Sharma, R. Sharma, and A. Sharma, "PROCESS PARAMETER OPTIMIZATION OF SAND CASTING PRODUCT USING DOE METHOD 325 TAGUCHI METHOD", International Journal of Modernization in Engineering Technology, Volume 04, 2022.

[16]. G. Mahesh, D. Valavan, N. Baskar, S. T. Jayasuthakar, and S. Saravanan, "Optimization of Aluminum Sand Casting process parameters on RSM and ANN methods," vol. 11, no. 1, pp. 340–348, 2021, doi: 10.36909/jer.12949.

[17]. M. Nandagopal, K. Sivakumar, S. Velmurugan, R. B. Durairaj, and G. Mageshwaran, "( Al 2 H 2 Na 2 O 13 Si 4 ) BLENDED GREEN SAND CASTING PROCESS PARAMETERS TO IMPROVE THE MOULD QUALITY," pp. 1–15.

[18]. N. F. B. W. Anuar, P. S. Xiang, Z. Marjom, A. M. Azize, and S. A. Hassan, "Analysis of optimized green sand on mechanical properties of LM6 aluminum alloy based grey analysis method," in *AIP Conference Proceedings*, 2022, vol. 2496, no. 1.

[19]. H. Chen, Q. Gao, Z. Wang, Y. Fan, W. Li, and H. Wang, "Optimization of Casting System Structure Based on Genetic Algorithm for A356 Casting Quality Prediction," *Int. J. Met.*, pp. 1–22, 2022.

[20]. S. Tripathy and G. Sutradhar, “Simulation Based Fluidity and Solidification Analysis of Aluminium-Copper Sand Cast Alloy,” *Key Eng. Mater.*, vol. 941, pp. 37–46, 2023.
[21]. A. Ktari and M. El Mansori, “On the improvement of castings quality in hybrid low-pressure sand-casting (LPSC) process in a fully integrated CAE environment,” *Int. J. Adv. Manuf. Technol.*, pp. 1–18, 2023.
[22]. N. Li *et al.*, “Numerical research of gas-related defects for gray cast iron during sand casting,” *Mater. Lett.*, vol. 340, p. 134177, 2023.
[23]. X. Li, X. Guo, H. Tang, R. Wu, and J. Liu, “An improved cuckoo search algorithm for the hybrid flow-shop scheduling problem in sand casting enterprises considering batch processing,” *Comput. Ind. Eng.*, vol. 176, p. 108921, 2023.
[24]. L. Harshwardhan, R. C. Kaushik, T. Bheda, M. Somasundaram, and U. NarendraKumar, “Simulation of Sand-Casting Process Using Altair Inspire Cast,” in *Recent Advances in Materials Technologies: Select Proceedings of ICEMT 2021*, Springer, 2022, pp. 447–456.
[25]. S. Arabia, “A COMPARATIVE STUDY OF SIMULATION SOFTWARE,” vol. 17, pp. 197–209, 2018.
[26]. Ravi, B. "Casting simulation–best practices." transactions of 58th IFC, Ahmedabad (2010): 19-29.
[27]. S. Shrivastava and N. Verma, “Numerical Simulation and Optimization of Parameter of Sand Casting”, International Journal of Research Publication and Reviews, Vol 3, no 9, pp 1214-1218, 2022.
[28]. Pratesa, Yudha, Badrul Munir, and Suryadi Najamuddin. "Application of casting simulation in failure analysis of impeller." Journal of Failure Analysis and Prevention 19 (2019): 431-437.
[29]. Jin, Chul Kyu. "Gating system design and casting simulation application for the grooved worm wheel by using zinc alloy sand casting process." Advances in Mechanical Engineering 15, no. 6 (2023): 16878132231183927.
[30]. B. Tadele Bekele, J. Bhaskaran, S. Dufera Tolcha, and M. Gelaw, “Simulation and experimental analysis of re-design the faulty position of the riser to minimize shrinkage porosity defect in sand cast sprocket gear,” *Mater. Today Proc.*, vol. 59, pp. 598–604, 2022, doi: https://doi.org/10.1016/j.matpr.2021.12.090.