Defect Identification and Process Optimization in Metal Casting Operation

KARUN KANT DEO, ADITYA SINGH, KESHAV KUMAR, KARAN CHANDRA RAWANI, PRAHLAD KUMAR DEO, ANSHU KUMAR & SUMIT SINGH CHOUDHARY
Department of Mechanical Engineering
K.K Polytechnic, Govindpur, Dhanbad

How to Cite this Article:

SINGH, A., KUMAR, K., RAWANI, K. C., KUMAR, P., KUMAR, A. & CHOUDHARY, S. S. (2026). Defect Identification and Process Optimization in Metal Casting Operation. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(05). https://doi.org/10.55041/ijcope.v2i5.770

License:

This article is published under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

© The Author(s). Published by International Journal of Creative and Open Research in Engineering and Management.

https://doi.org/10.55041/ijcope.v2i5.770

ABSTRACT

One of the most widely used methods for forming intricate technical parts in heavy machine building, railways, automobile industry, and aviation is casting of metals. But defects, such as blowholes, inclusions, shrinkage porosity, cold shuts, porosity, and misruns, affect the mechanical properties, geometrical accuracy, quality of products, and cost of manufacturing significantly. In order to minimize the formation of defects, this paper attempts to identify common defects that occur in the process of metal casting and proposes ways to improve the process. The experiments involved sand casting procedures and varied pouring temperature, moisture content of the mold, and gating systems. Results indicate that there is an enhancement in the quality of casting due to changes made in the process parameters. The study contributes significantly towards improving the output capacity of industries, reducing waste, and increasing efficiency.

Keywords: *Metal casting, casting defects, process optimization, porosity, shrinkage, sand casting, quality control, foundry engineering.*

1. Introduction

One of the earliest and commonly applied manufacturing technologies for producing technical pieces with intricate shapes and geometrical figures is that of metal casting. Molten metal is poured into a mold and cooled to form the required shape. Metal casting is widely used in automotive, aerospace, rail, marine, agricultural, and heavy equipment sectors due to its efficiency and economic effectiveness [1], [2]. There are several types of casting, including sand casting, die casting, investment casting, centrifugal casting, among others, which are often used in the production of such items as engine blocks, turbine blades, pump housings, machine beds, railroad wheels, and others [3]. Quality control and defect prevention are essential considerations in modern foundry practices because of the increasing demand from industries for good-quality castings. Even though casting is a versatile production process, it is very sensitive to operating conditions and processing variables. Casting defects occur when there is improper handling of the pouring temperature, preparation of the mold, gate design, riser design, cooling speed, and moisture level in the mold [1], [4]. This creates adverse effects on the operational capability, mechanical properties, surface appearance, and accurate dimension of cast parts.Imperfections occurring at the surface of the casting, or within it, during the filling and solidification process of the mold are known as casting defects. Porosity, shrinkage voids, blowholes, cold shuts, misruns, hot tearing, inclusions, and cracks can be given as examples of defects [2]. Several factors, such as impurity in the molten metal, gas entrapping, pouring turbulence, solidification rate, and mold permeability, can affect the formation of these defects [5]. Defective castings in foundry industries cause high rejection rates, increased manufacturing costs, overproduction, and low productivity.The presence of porosity and shrinkage is seen as one of the most important defects in casting because it reduces the strength and fatigue resistance of parts [6]. Shrinkage defects are caused by improper feeding of the molten metal following solidification, while gas porosities are usually caused by gases dissolved within the metal, high moisture content in the molds, and ineffective ventilation systems [1]. This is because achieving proper castings with improved quality and reliability can only be achieved through a clear understanding of the root causes of the defects in casting.Recently, foundry industries have increasingly adopted process optimization approaches in an effort to achieve defect reduction and improved productivity. The systematic alteration and control of process variables aimed at achieving maximum product quality while minimizing errors and reducing costs of production is referred to as process optimization [7]. Defect detection and quality improvement in casting processes involve a number of contemporary process optimization approaches, which include DOE, Taguchi approaches, Statistical Process Control (SPC), ANN, and casting simulation [6], [7].Process parameters optimization involving pouring temperature, mold hardness, humidity, cooling and gating-riser designs improves flow properties and solidification characteristics of molten metals significantly [2]. Process optimization not only reduces turbulence but also helps in reducing gas trapping, improving efficiency of feeding, and handling of directional solidification [4]. Reduction in rate of rejection, better mechanical properties, higher degree of surface polish, cost-effective production process, and high level of productivity are some of the outcomes of optimized casting processes [4].Because of the flexibility of the technique, the low cost associated with the process, and ability to produce large and intricate parts, sand casting remains among the commonly used casting techniques [3]. This is because of the fact that the process suffers from many flaws owing to variations in the physical properties of the sand, techniques used for molding, and conditions of pouring [5]. The present research deals with finding important defect-causing factors during metal casting and the impact of process parameters on the formation of defects. Sand casting procedures are employed in tests under varied temperatures and conditions of molds. The purpose of the study is to determine optimal process parameters that can minimize defects and increase product quality. The output of the study will be useful for foundry firms because it will help reduce costs of production, improve efficiency, and enhance the reliability of cast products.

Table 1: Common Casting Defects and Their Causes

Sl. N	Defect Type	Major Causes	Effects on Casti
1	Porosity	Gas entrapment, moistu	Reduced strength
2	Shrinkage cav	Improper solidification	Internal voids
3	Blowholes	Excessive moisture	Surface cavities
4	Cold shut	Low pouring temperatu	Weak joints
5	Misrun	Poor fluidity	Incomplete castir
6	Sand inclusior	Mold erosion	Poor surface fini
7	Hot tears	Uneven cooling	Cracks in casting

2. Material & Method

Purpose of the experiment: detection of critical drawbacks in casting process of metals and optimization of essential process parameters that would have influence on the casting process.Sand casting was selected due to the variety of its applications, relatively low cost of manufacturing, and its capability to produce complex parts. During the experiment, critical casting defects such as porosity, shrinkage, blowholes, cold shuts, and misruns were considered in relation to pouring temperature, humidity of the molds and gating parameters.Aluminum alloy is selected as casting material due to the following properties – superior castability, low density, corrosion resistance and extensive applications in industry and automobile sector. Due to the properties of aluminum alloys and their composition, these alloys are well suited to be tested and optimized [1]. Silica sand, bentonite clay, water, and additives in specific quantities have been mixed to make molds in green sand method. The clay added in green sand mold provided bonding strength, while the sand acted as the refractory material [2]. Proper management was required of the moisture content in order to ensure correct mold permeability and collapsibility.The test equipment comprised of crucible furnace to melt aluminum alloy, molding boxes, pattern making, pouring and feeding systems, thermocouples to monitor temperatures and finishing tools. The ingots and aluminum scrap were heated in the crucible furnace to pouring temperatures varying from 680°C to 760°C. In order to ensure accurate process control during the entire process of pouring, a digital thermocouple was used to measure the temperature of the molten metal.The wooden patterns used to construct the mold cavity were standard sized. A gating system was designed with a view to minimizing turbulence when pouring the liquid metal and controlling its flow rate into the mold cavity. Risers were added to compensate for the shrinkage that occurs during the solidification process. Several experiments were conducted through variations of different process parameters such as pouring temperature and moisture content of the mold under constant conditions.Under atmospheric conditions, the molten metal was poured manually into sand molds that were created. The castings were removed from the molds using the shakeout method after cooling. The grinding and finishing operations were performed to eliminate any unwanted metal parts like the risers and runners. The obtained castings were then put through visual examination and defect evaluation.Visual inspection, dimensional inspection, and microscopic inspection techniques were applied in detection of defects. As internal defects such as porosity and shrinkage holes were detected by means of sectioning techniques, surface defects such as blowholes, cold shuts, and sand defects were detected visually. In order to evaluate casting quality and casting consistency, the rejection ratio was determined for each experiment.Process optimization was done by detecting how defects occurred under different operational conditions. The low rejection ratio, good surface finish, and high casting quality were some of the factors that were considered while selecting the optimum process parameters. Statistical observations were made on the relationship between process parameters and defect formation. It was observed that the optimum casting conditions resulted in less defect formation and higher foundry productivity.

Table 2:- Materials Used in the Experimental Investigation

Sl. No.	Material	Function/Application
1	Aluminum Alloy	Used as the casting material
2	Silica Sand	Used for mold preparation
3	Bentonite Clay	Acts as bonding material in mold sand
4	Water	Controls mold moisture content
5	Wooden Pattern	Forms the mold cavity shape
6	Coal Dust Additive	Improves mold surface finish

Table 3: Experimental Equipment Used

Sl. No.	Equipment	Function
1	Crucible Furnace	Melting of aluminum alloy
2	Thermocouple	Temperature measurement
3	Molding Box	Preparation of sand molds
4	Hand Rammer	Compaction of molding sand
5	Grinding Machine	Finishing and cleaning operation
6	Inspection Tools	Detection of casting defects

Table 4: Process Parameters Used During Experimentation

Sl. No.	Process Parameter	Specification/Range
1	Pouring Temperature	680°C – 760°C
2	Moisture Content	3% – 7%
3	Mold Type	Green Sand Mold
4	Cooling Condition	Natural Cooling
5	Gating System	Pressurized Type
6	Solidification Method	Controlled Solidification

Table 5: Defect Inspection Methods

Sl. No.	Inspection Method	Purpose
1	Visual Inspection	Identification of surface defects
2	Dimensional Inspection	Checking dimensional accuracy
3	Sectioning Analysis	Detection of internal defects
4	Microscopic Examination	Detailed defect characterization
5	Surface Finish Analysis	Evaluation of casting surface quality

3. Experimental Details

Experimental research on defect formation and process optimization in metal casting processes has been carried out in the foundry laboratory based on the sand casting method. Due to its outstanding castability, lightness, non-corrosive properties, and wide use in industry for the production of car parts, aluminum alloy was selected as the material for casting [1]. The first objective of the research was to identify defects in casting with varying parameters, including porosity, blowholes, shrinkage voids, cold shuts, and misruns.The following materials such as silica sand, bentonite clay, water, and additions of coal dust were employed to make green sand molds. The correct combination of molding sand provided sufficient strength, permeability, and collapsibility of the molds. Wooden patterns of normal dimensions have been applied for preparing the mold cavity. In order to ensure uniform compaction of the sand around the casting, the mold cavities were formed in the molding box through manual ramming.The aluminum alloy was melted in a crucible furnace. The process temperature of the molten metal was monitored using a digital thermocouple. To study the effect of changes in temperature on the formation of defects, different pouring temperatures of 680°C, 720°C, and 760°C were adopted. Similarly, the mold moisture was varied from 3%, 5%, to 7% to study the effect on mold activity and gases.A pressurized gating system was designed to control the entry of the molten metal into the mold cavity and reduce turbulence in the pouring process. Risers were incorporated into the design due to contraction during solidification. Inspection was done carefully before casting in order to ensure proper dimensions of cavities, venting and gating design.In atmospheric conditions, the aluminum alloy was poured by hand into molds that had been prepared for the process. After casting, the castings were allowed to cool naturally within the molds until they were fully solidified. Shakeouts were done to remove the castings from their molds. Grinding and finishing methods were used to remove any excess material on gates, risers, and runners.Casting inspection and defects evaluation were carried out carefully on the casted components. Defects such as porosity and shrinkage cavities in the castings were identified using sectioning and microscopy while blowholes, cold shuts, and sand inclusions were observed visually. Additionally, dimensional measurement was done in order to evaluate casting accuracy and consistency in quality.Number of rejected castings generated at different process settings determined the percentage of rejected castings. Based on the experimental result, too much moisture level and wrong pouring temperatures significantly increased the occurrence of defects. The most ideal setting that results to the least rejection rate is having a pouring temperature of 720°C and moisture content of 3% to 5%.A lot of valuable information about the relation between casting defects and process variables were gained through this experiment. This is useful since the optimal settings achieved during the study can be implemented in the foundries industry in order to increase production efficiency and improve product quality.

Table 6: Experimental Conditions Used During Investigation

Sl. No.	Parameter	Values/Conditions Used
1	Casting Process	Sand Casting
2	Casting Material	Aluminum Alloy
3	Mold Type	Green Sand Mold
4	Pouring Temperatures	680°C, 720°C, 760°C
5	Moisture Content	3%, 5%, 7%
6	Gating System	Pressurized Type
7	Cooling Method	Natural Cooling
8	Inspection Method	Visual and Microscopic
9	Defects Investigated	Porosity, Blowholes, Shrinkage, Misrun
10	Mold Preparation Method	Hand Ramming Technique

Table 7: Experimental Observations

Trial N	Pouring Temperature (°	Moisture Content (°	Major Defect Observ	Casting Qual
1	680	3	Misrun	Poor
2	680	5	Cold Shut	Moderate
3	720	3	Minor Porosity	Good
4	720	5	Sound Casting	Excellent
5	760	7	Blowholes	Poor

4. Result & Discussion

Experiment findings have shown that the quality of the casting and occurrence of defects is largely dependent on pouring temperature and moisture levels in the molds. Misrun and cold shuts were observed at low pouring temperatures as a result of poor fluidity of the liquid metal. As a result of increased gas solubility and turbulent mixing during mold filling at very high pouring temperatures, gas porosities and blowholes occurred. The optimal casting quality was achieved when the pouring temperature was at 720°C and the moisture levels between 3% and 5%. The use of pressurized gating and controlled cooling methods greatly improved casting

© 2026 The Author(s). Published by IJCOPE Journal. Website: https://ijcope.org/

quality by minimizing shrinkage and turbulence defects. It can be concluded from the findings of the study that foundry production efficiency can be raised while minimizing rejection of castings.

Table 8: Effect of Pouring Temperature on Casting Defects

Pouring Temperature (°C)	Major Defect Observed	Casting Quality
680	Misrun, Cold Shut	Poor
720	Minor Porosity	Excellent
760	Blowholes, Gas Porosity	Poor

Table 9: Effect of Moisture Content on Casting Quality

Moisture Content (%)	Defect Observed	Quality Level
3	Minor Surface Defects	Good
5	Sound Casting	Excellent
7	Blowholes and Porosity	Poor

Table 10: Rejection Rate Analysis

Trial No.	Pouring Temperatu (°C)	Moisture Content (%)	Rejection Rate (%)
1	680	3	12
2	680	5	10
3	720	3	4
4	720	5	2
5	760	7	15

Table 11: Optimized Process Parameters

Process Parameter	Optimized Value
Pouring Temperature	720°C
Moisture Content	3% – 5%
Gating System	Pressurized Type
Cooling Method	Controlled Natural Cooling

5. Conclusion

The study under consideration has successfully analyzed major defects that occur during metal casting operations and the impact of process parameters on casting quality. As per the experimental results, defect formation depends on pouring temperature, humidity of the mold, and the gating system used in the process. Poor regulation of metal flow and solidification resulted in defects such as porosity, blowholes, misrun, and cold shut.It is found that sound castings with lower rejection percentage and high surface quality were obtained at the pouring temperature of 720°C and humidity from 3 to 5 percent. Furthermore, turbulence and shrinkage defects could be minimized with the use of pressurized gating systems and controlled solidification conditions. Process improvements not only led to less material waste and decreased cost but also greatly improved casting quality and efficiency. The experiment shows that casting rejections can be greatly reduced and casting industry productivity enhanced through proper defect identification and optimization of processes. For the production of quality casts, industrial casting processes could apply the ideal parameters as shown in the experiment conducted.

6. References

[1] J. Campbell, *Complete Casting Handbook*, 2nd ed. Oxford, U.K.: Elsevier, 2015.

[2] D. M. Stefanescu, *Science and Engineering of Casting Solidification*, 3rd ed. Springer, 2015.

[3] P. N. Rao, *Manufacturing Technology: Foundry, Forming and Welding*, 5th ed. New Delhi, India: McGraw Hill, 2018.

[4] S. Kalpakjian and S. Schmid, *Manufacturing Engineering and Technology*, 7th ed. Pearson Education, 2014.

[5] M. C. Flemings, “Solidification processing,” *Metallurgical Transactions*, vol. 5, no. 10, pp. 2121–2134, 1974.

[6] R. Wlodawer, *Directional Solidification of Steel Castings*, Oxford, U.K.: Pergamon Press, 1966.

[7] G. Taguchi, *Introduction to Quality Engineering*, Tokyo, Japan: Asian Productivity Organization, 1990.