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# ANALYSIS OF CASTING SYSTEM DESIGN USING A COMPUTER-AIDED SIMULATION

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## Abstract

Due to casting defects, the Akaki Basic Metals Industry (ABMI) encounters a significant rate of rejection and rework concerning flange roller products, exacerbating manufacturing lead times, increasing production costs, and diminishing customer satisfaction. According to the factory production reports, 89 flange roller cast parts were rejected due to casting defects, resulting in a financial loss. The primary factor contributing to the casting defects that lead to product rejection is the inadequacy of the gating and feeding system design, coupled with ineffective process control. Consequently, the primary objective of this paper is to analyze the casting system design for the flanged roller utilizing a computer-aided simulation methodology. To achieve this goal, the existing gating and feeding system of the flanged roller is modelled using CATIA V5, and simulation analyses are performed employing ProCAST 2019 casting simulation software. From the simulations, shrinkage porosity and hot spot defects have been identified as the principal defects present in the product. In summary, it is concluded that computer-aided casting simulation facilitates the company's ability to preemptively manage defects prior to their occurrence in the physical production environment.

***Keywords:*** *Casting defects, casting simulation, shrinkage porosity, hotspot.*

## 1. Background of the study

Casting is one of the oldest manufacturing processes involving the introduction of molten metal into a mold cavity, whereupon, upon solidification, the metal takes the shape of the mold cavity (Bhatt et al., 2014). The complete sand casting process is illustrated in Figure 1. Casting is a process that carries the risk of failure while producing the finished product (Hiremath & Dulange, 2015). As a manufacturing process, casting has some defects; no process is foolproof or perfect (Prajap et al., 2016). During the casting process, there is always a chance that a defect will occur. A casting defect, affecting the bottom line of a foundry, is an undesired irregularity in a metal casting process; some defects can be tolerated, while others can be repaired, and otherwise, the defective product must be rejected (Chelladurai et al., 2021).

Casting defects in cast parts do not occur by accident. Instead, improper design and limited process control lead to product rejection. In a casting foundry, the defect occurs in three principal processing stages of castings, i.e., design, casting, and finishing. Researchers proved that 90 percent of casting defects resulting in product rejection are obtained from poor design of gating and feeding systems, and 10 percent from poor process control (Nimbulkar & Dalu, 2016). The major cause of poor casting quality is the use of a poor gating system, which causes damage to the molten metal received during the flow through the gating system (Gulhane & Dahekar, 2014). Hence, one must improve the gating and feeding system design to minimise the casting defect in a cast part.

Some of the important considerations for the design of the casting process (Groover, 2010) are geometric simplicity, corners, section thicknesses, draft, use of cores, dimensional tolerances, surface finish, and machining allowances. A casting defect may find its root cause in pattern design, methods, molding, pouring, fettling, or any other production stage (Jain, 2009). It is possible to reduce various casting defects, hence the product rejection rate, through the proper design of the casting process, i.e., the proper design of the gating and feeding systems. Prajap et al. (2016) state that good casting process design is important for the quality and efficient production of cast parts.

Casting defects analysis is finding the root cause of defects in the rejection of casting and taking necessary steps to reduce the defects and improve the casting yield. According to (Gondkar & Inamdar, 2014) the casting defect analysis and optimization-using computer-aided casting simulation technique plays a vital role in manufacturing metal parts and determining various casting defects. Casting simulation simulates the real casting phenomenon and provides a virtual casting

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process as molten metal flows in the mould cavity in terms of time and direction.

As stated by (Choudhari et al., 2014), the casting simulation approach also provides immediate tangible benefits such as shorter lead time, higher productivity, lower rejections, and long-term intangible benefits like better image, higher confidence, and stronger partnerships for small and medium foundries. In automobile wheels, rim castings with casting yields of 60%, incomplete mould filling and molten metal turbulence during pouring due to poor gating system design are analyzed using ProCAST casting simulation software (Reddy, 2014) and shrinkage and hotspot defects are detected. Based on the simulation analysis result, an improved gating system is designed and simulated to minimize the detected casting, which results in a yield improvement of 20%.

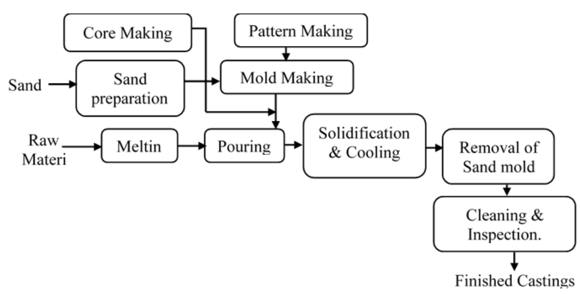


**Fig. 1 Flange roller sand casting process flow chart**

Defect-free operation (Chelladurai et al., 2021), the least number of product rejections, shorter lead time, and high productivity are the requirements for the current foundries to be competitive in the market (H.P. Rathod, N.P. Maniar, 2016). The Foundry of Akaki Basic Metals Industry, ABMI, faces challenges of casting defects, causing product rejection. Hence, the foundry is losing its market competitiveness. The company report shows that the flanged roller has a high rejection rate due to casting defects. The major casting defects resulting in product rejection of the flanged roller are shrinkage porosity, porosity, sand inclusion, misrun, mismatch, and over- and under-dimensions and reworks. To overcome these casting defects, experts in the ABMI foundry shop use the traditional trial-and-error method. Consequently, the primary objective of this paper is to analyze the casting system design for the flanged roller utilizing a computer-aided simulation methodology.

Casting simulation intends to solve the casting defects by reducing time and resources. According to (Bhatt et al., 2014; Chauhan et al., 2018, 2017; Choudhari et al., 2013b; Jain, 2009; Khan, 2018; M A Omprakas, M Muthukumar, S P Saran1, D Ranjithkumar and Kumar, 2021; Muthyam Sagar, G. S. Reddy, 2020; Pant et al., 2021; Sourabh S. Lohar1, 2021; Sunanda et al., 2020), a computer simulation as a significance of improving gating and feeding system design, replaced the conventional trial and error method of defect minimization, yield improvement, reducing lead time, reducing manufacturing cost through reducing reworks, proper molten metal utilization, and hence reduced product rejection.

## 2. Methodology

This study is a simulation study of the flanged roller to improve the existing casting system design of the flanged roller using a computer-aided simulation approach. The general methods employed to meet the study objectives are given in Fig. 2.

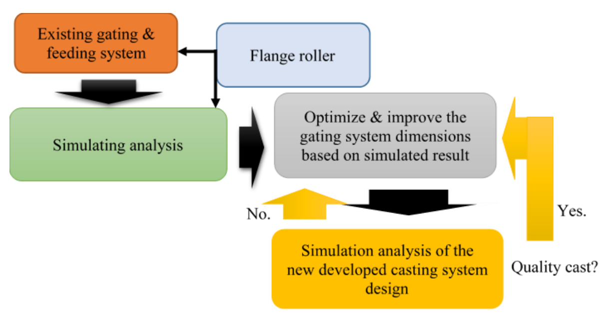


**Fig. 2 Research methods for analysis and improvement of flange roller casting system design**

The real-time data from the ABMI foundry is collected for further simulation analysis of the flanged roller. The existing casting approach of flange roller casting simulation is carried out using ProCAST 2019 casting simulation software – refer to ProCAST 2019 simulation procedure in Figure 3.

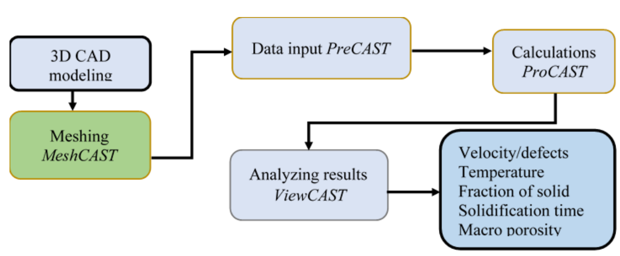


**Fig. 3 General simulation steps in ProCAST 2019**

The current gating and feeding system used for casting the flanged roller is directly measured and modelled for further simulation analysis. The existing casting process in the foundry of ABMI only has the gating system, i.e., no feeding system (riser) is used. The gating system for casting the flanged roller includes a

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pouring cup, sprue, sprue basin, runner, and in-gates (two in-gates).

# 3. Results and Discussion

## 3.1 Results

The simulation of the existing casting system of the flanged roller is, conducted for analyzing the effect of the gating and feeding system on filling and solidification-related variables during the casting process of the cast parts in ABMI. The first step of the simulation is meshing the cast part for ease of analysis. The meshes of 276,352 tetra elements are, generated in volume meshes using the MeshCast utility in ProCAST 2019 that requires CAD drawing of the part in standard Stereolithography (STL) format. Accordingly the predicted defects in the existing casting system are shrinkage porosity and hot spot defects.

### 3.1.1. Shrinkage Porosity Defect

Shrinkage porosity represents a defect in casting that arises from the volumetric contraction of metal as it undergoes the phase transition from liquid to solid during the solidification process. The simulation results show that shrinkage porosity within the casting is depicted as colour-coded regions in the accompanying Figure 4. The legend elucidates the percentage of shrinkage porosity, spanning from 0% to 100%, with critical areas accentuated by elevated percentages.

The pronounced shrinkage porosity is predominantly located within the central circular region and adjacent to the gating system, as demonstrated by the elevated porosity percentages (reaching 100%) in the areas denoted by purple and red. This porosity is confined to regions with reduced cooling rates, possibly attributable to inadequate material feeding from the gating system throughout the solidification phase. The simulation results reveal a cavity fill of 98%, and the solidification process appears to be fully accomplished (fraction solid = 100%), implying that the detected porosity emerges during the terminal phases of solidification.

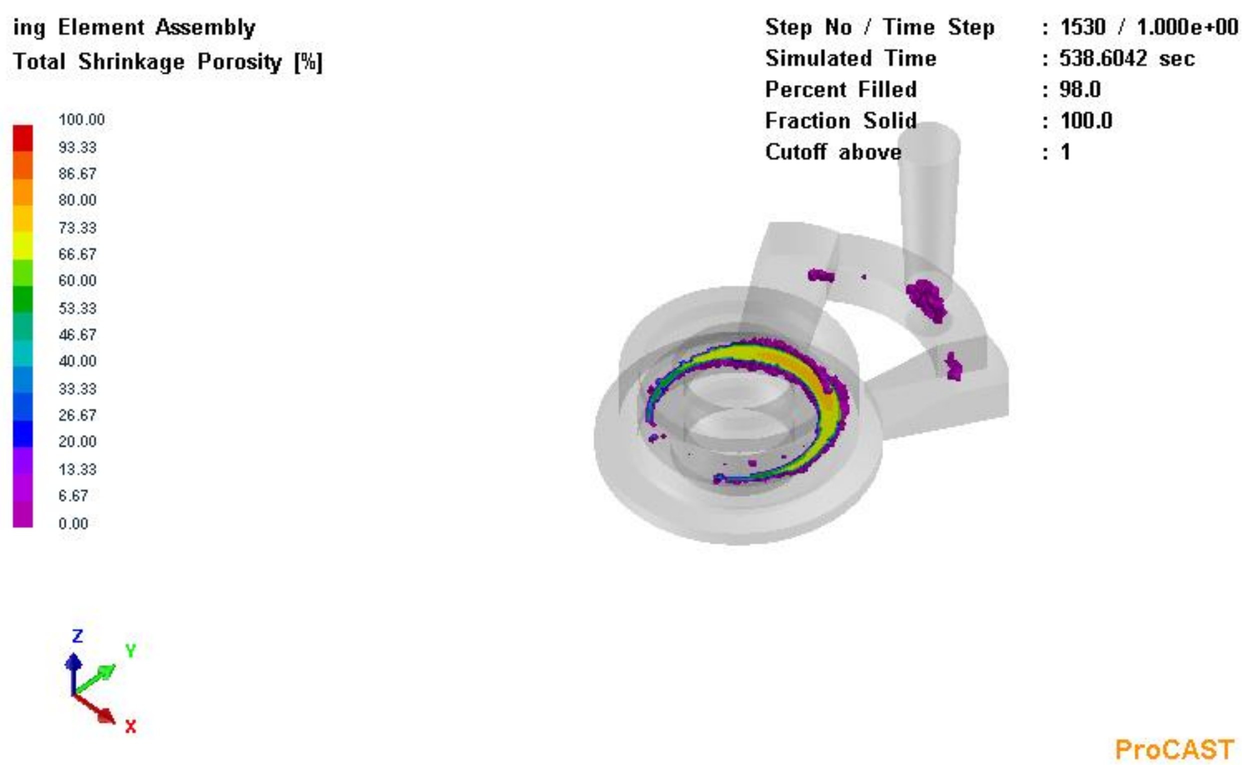


**Fig. 4 Simulation Image of Shrinkage Porosity Defects**

 

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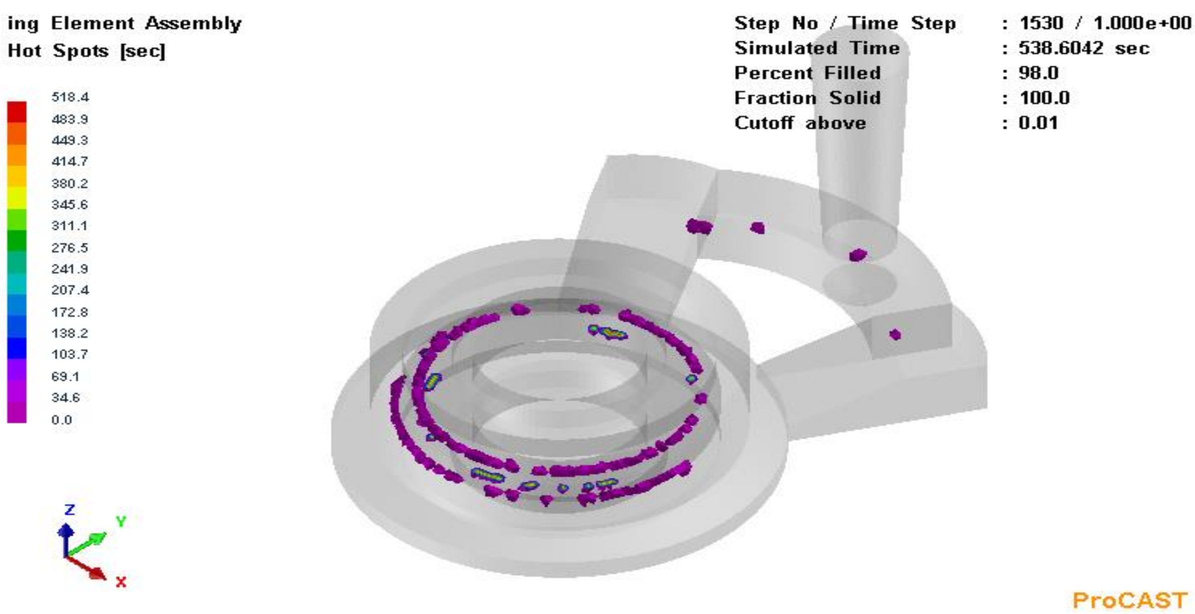


**Fig. 5 Simulation Image of Hotspot Defects**

### 3.1.2. Hot Spot Defects

The ProCAST simulation highlights areas marked by increased shrinkage porosity, demonstrating a strong linkage to the formation of thermal hot spots. Hot spots refer to specific areas within the casting that retain thermal energy for extended durations throughout the cooling and solidification phases. These regions are thermally insulated and undergo protracted solidification, resulting in inadequate feeding of liquid metal, thereby precipitating shrinkage-related defects. The data presented in Figure 5 illustrates a notable accumulation of shrinkage porosity (represented by elevated percentages, specifically in the purple and red regions) within the central circular section and the adjacent gating system regions. The simulation underscores porosity percentages that ascend to 100% in certain localized zones, thereby accentuating the critical nature of the identified hot spot. These thermal anomalies exert a direct influence on the quality of the casting by engendering voids that have the potential to undermine mechanical integrity. This academic article demonstrates that the computer-aided examination of casting imperfections is a vital tool capable of considerably reducing both time and resource investments. This result provides substantial validation for the claims articulated by Gondkar and Inamdar (2014).

## 4. Conclusion

Generally, computer-aided casting simulation enables the company to manage the defects before they happen in the real world. Therefore, the following conclusions are generated:

1. To minimize the bottlenecks and non-value-added time in casting development.
2. Reduce manufacturing cost, reduce development time and reduce trial cost.
3. The simulation tool used has the flexibility of visualizing and analyzing the processes of mould filling and solidification at a time with high resolution.

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