Industrial Engineering Journal
ISSN: 0970-2555
Volume : 55, Issue 01, No.1, January : 2026

REVIEW RESEARCH PAPER: PREDICTION AND REMOVAL OF CASTING DEFECTS AND YIELD IMPROVEMENT USING CASTING SIMULATION TECHNIQUES.

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ABSTRACT:
Casting is among the vital processes in the manufacturing industries, especially in the automotive, aerospace, and machinery industries. However, in spite of such a vast utilization, porosity, misruns, shrinkage, and cold shuts are some of the vital defects which still appear consistently in casting and have become an obstacle to gaining quality and yield. This review aims at discussing the role that can be played by simulation techniques in predicting and eliminating defects from castings, along with their great contribution to enhancing yield. The paper demonstrates the main computational approaches, such as Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA), and multiphase simulation, then discusses their applications in defect prediction, process optimization, and material flow analysis. In addition, the work discusses the integration of machine learning and AI to further enhance the accuracy of simulations and process control. The review ends with an overview of future trends and challenges in casting simulation, highlighting areas of continued research.

Keywords: Casting simulation, defect prediction, yield improvement, casting defects removal, CFD, FEA, machine learning, process optimization

1. Introduction

Casting is a very important manufacturing process wherein the liquid metal is poured inside the mold cavity and solidified. Casting manufacturing processes have certain inherent deficiencies like porosity, shrinkage, hot tears, and inclusions. Inclusion will significantly affect the final product quality and economics. Trial and error approaches for avoidance of deficiencies in casting process take a lot of time and investment.

Casting simulation methods have proved to become effective tools for dealing with these difficulties. Through the application of computer algorithms, casting simulations are capable of predicting possible defects, maximizing process parameters, as well as enhancing casting yields. This paper will give a comprehensive review on casting simulation methods, their application in defect elimination, as well as their role in enhancing casting yields.

2. Casting Defects and Their Impact

Casting defects refer to the flaws that result from the casting process. In most cases, such defects lead to parts being rejected, extra reworking, or extreme production efficiency loss. These flaws are primarily the result of irregular cast metal behavior during the casting, cooling, or molding stages. Casting flaws take several different forms. These cast defects consist of but aren’t limited to, porosity, misruns, cold shut defects, shrinkage, and finally, hot tears. These defects not only result in the cast reducing the mechanical properties but also affect the casting process.

Depending upon the nature, seriousness, and extent of the defects created in the casting, their effects can range from minor to critical in nature. The present review aims to discuss the most common defects in castings, reasons behind those defects, their effects, and remedies for such defects.

In the succeeding section, the most common casting defects will be presented together with the reasons why they occur and their effects.

2.1 Porosity

Porosity can be defined as creating holes or cavities in the casting material because of gas entrapment, shrinkage, or solidification. Porosity can also be divided into two categories:

Gas Porosity: Due to the uptake of gas during the pouring or solidifying process.

Shrinkage Porosity: The metal has shrinkage while it solidifies, producing voids in the casting.

Causes:

Insufficient degassing of melted metal.

Contaminated mold material.

Inadequate ventilation of molds

Improper gating or pouring systems.

Impact: Porosity influences the mechanical properties of the casting. This is particularly a problem when a casting is to be used for applications involving engine blocks, turbine blades, among others. Porosity can also impact the finishing properties of a casting to produce pieces that lack aesthetics, having errors in dimensions.

Detection Methods:

X-rays. X-ray radiography or computed tomography (CT)

Ultrasonic Testing.

Visual inspection for surface porosity.

2.2 Shrinkage

Contraction during cooling and solidification of the metal can cause shrinkage, which can result in internal cavities or voids of the casting. Shrinkage can arise internally as contraction cavities or on the surface as shrinkage marks.

Causes:

Poor design of the riser and feeders.

Poor control of cooling.

High temperature of pouring resulting in a non-uniform solidification.

Impact: Shrinkage results in structural weaknesses since the voids in the metal compromise the strength and durability of the metal. In critical parts, such as in automotive engines, shrinkage may even lead to catastrophic failure. It is very hazardous for thick-walled castings, such as cylinder heads or large structural parts.

Methods of Detection:

Visual check for surface shrinkage marks.

The use of X-ray or CT scanning to visualize internal shrinkage cavities.

Perform FEA for the prediction of shrinkage zones during simulation.

2.3 Misrun

"A misrun is the result of the molten material failing to fill the mould before cooling and solidifying." Misrun

"A misrun or incomplete casting is caused when the molten material does not fill

Causes:

Low pour temperature or pour rate.

Inadequate mold design leading to excessive flow resistance.

Inadequate gating system.

Effects of Misruns: Misruns cause incomplete castings which cannot be used. Misruns can lead to high rates of scraps and time delays in production. Misruns pose a challenge in complex molds with complex designs or small cavities like those in turbine blades or small mechanical parts.

Detection Methods:

Visually inspect for incomplete casting sections.

Analysis with an X-ray for incompletely framed sections.

2.4 Cold Shut
Cold shut: This is where two molten metals do not merge properly resulting in a seam of separation along the weld.
A Cold shut metal joint
Causes:
Low pouring temperature.
Insufficient mold filling speed.
Poor gating system design resulting in improper flow of molten metal.
Effects: Cold shut defects affect the structural safety of the casting, particularly in the region where a high level of stress is involved. Cold shut defects mostly exist in automotive and aeronautical castings.
Detection Methods:
These
Visual inspection for exposed seams.
Ultrasonic testing for the detection of cold shut.
2.5 Hot Tears
"Hot tears are fractures that develop as a result of cooling, as a material changes from a liquid to a solid state, when stresses are greater than strength." "Hot tears are also known as hot tears, cold tears
Causes:
High cooling rates.
Too much shrinkage when solidifying.
Poor mold design or inadequate venting.
Effect: Hot tears in a casting result in fissures that cause weakening in a casting, specifically in a thick-walled casting. Hot tears in a high-performance part occur because a high level of strength is required in a part that is subjected to heavy loads.
Detection Methods:
Visual examination for visible cracks.
X-rays or ultrasonic testing for checking any cracks inside.
2.6 Inclusions
Inclusions are generally foreign elements or materials that are embedded within a casting. An inclusion could be sand particles, slag, or oxides trapped within a liquid metal.
Causes:
Contaminated mold materials.
A type of poor-quality metal with many impurities.
Inadequate filtration or degassing.
Effect of Inclusions on a Casting: Inclusions lead to a reduction in the homogeneity of the casting. Inclusions may create points of stress within the material. Such stress points lead to the early failure of the material. Inclusions are a major drawback when it comes to the aerospace and automotive industry because of the nature of the part.
Detection Methods:
Visual examination for surface defects.
X-ray inspection or ultrasonic testing for internal inclusions.

3 Impact of Casting Defects on Industry
Casting defects can adversely affect many industries regarding the end products as well as economic expenditures. Casting defects can adversely affect many industries in the following ways:
3.1 Economic Impact
The effect of casting defects causes a higher rate of scrap materials, leading to increased material cost. The defective casting has to be re-cast or scrapped, resulting in additional labour and energy

cost. Additionally, the effect of re-casting the defective casting causes a delay in production, resulting in a higher production cost.

3.2 Safety and Reliability Concerns

In the case of sectors which deal with the manufacturing of critical parts, including the auto sector, aviation sector, and energy sector, any defects in the castings may result in critical health hazards. For example, porosity or cold shut defects in the engine parts may result in the failure of the engine, while in the aviation sector, any type of defects may result in critical health hazards due to engine or structural failures.

3.3 Quality Control and Customer Satisfaction

Casting defects affect the quality of the end product. For users of metal products required to be aesthetic in nature, such as consumer goods and metal decorations, defects such as porosity and cold shuts are not desirable. Poor quality of the end product may result in consumer dissatisfaction, leading to a loss of market share.

3.4 Reduced Yield

The occurrence of casting defects leads to a lower overall yield, which is the portion of the castings that meet quality specifications without the need to be refurbished. The overall yield is affected by the cost-effectiveness of the casting production process.

4 Strategies for Minimizing Casting Defects

There are several methods that can be used to eliminate defects in casting, including:

4.1. Process Optimization

Many defects can be reduced through control of the casting process. For instance, through control of factors such as temperature during the casting process or through the use of cooling rates and mold design, defects can be minimized. Additionally, simulation tools such as CFD or FEA can be used to ensure there is a defect-free casting.

4.2. Material Selection

The selection of the right material for the casting process plays a significant role in ensuring that there are minimal defects. Use of quality alloys that contain fewer impurities is ideal in ensuring that there are minimal porosities or inclusions. Finally, temperature control of the molten material can ensure that there are minimal defects such as shrinkage.

4.3 Mold Design

An optimized mold design would ensure smooth flow of molten metal, minimize turbulence, and prevent defects such as cold shuts, misruns, and porosity. Optimized gating and riser systems would be effective in directing the flow of metal to ensure a better distribution with less likelihood of defects during solidification.

4.4 Defect Detection Technologies

More sophisticated technologies for defect detection, like X-Ray radiographs, ultrasound testing, and 3D scanning, enable early defect detection during processing so that manufacturers can either return or repair products that may arrive with defects to customers.

Summary:

Casting defects are one of the prime concerns for manufacturers because casting defects have direct implications for the cost-effectiveness and reliability of the casted object. It is important to learn more about the casting defects and their effects before implementing any improvements in the casting process. Casting defects can be reduced through the optimal casting process and the use of casting defect detection systems, thus making the process cost-effective and more reliable.

Future developments in the simulation methods, properties of materials, and defect identification techniques will ensure even finer precision into the future for defect predictions, as well as the quality of casting products.

5 Casting Simulation Techniques

Casting is a comparatively well-known production process for the production of complex shapes and parts. Casting is a process whereby a material, usually a metal, is poured into a mold to form the desired shape. Casting is a well-known process; however, casting defects such as porosity, shrinkage, misruns, and cold shuts remain a pressing concern for many engineers. Such casting defects can pose a threat to the strength and quality of cast parts.

To overcome these issues, there exist various simulation methods for casting which provide the manufacturer with the ability to analyze the process before its actual implementation. The understanding of the filling, solidification, and cooling phases of melted material helps the engineer design informed decisions about the gate system and material flow control strategy. Casting simulation can now be performed with high accuracy due to the advancement in simulation technologies. Improved simulation accuracy will result in improved casting.

In this review, an attempt will be made to examine the available casting simulation methods, applications, advantages, disadvantages, as well as their influence on the casting process.

Overview of Casting Simulation Techniques

Simulation of casting involves the creation of a digital model of casting that enables engineers to predict the behavior of molten metal within the mold. The process of simulation may be divided into several key stages: filling, solidification, cooling, and defect analysis. These stages may be analyzed and optimized by the following main techniques of simulation:

Computational Fluid Dynamics (CFD)
Finite Element Analysis (FEA)
Multiphase Simulation
Integrated Simulation Systems
Integration of Machine Learning and AI

Each of the methods serves a different purpose and may be used in combination to give an overall analysis of the casting process.

5.1 Computational Fluid Dynamics (CFD) in Casting Simulation

One of the most widely applied simulation methods in casting processes is that of computational fluid dynamics. CFD will simulate the flow of molten metal through the mold and thereby enabling to predict how the metal will behave in a filling stage.

5.1.1 Application of CFD in Casting

Mold Filling Analysis: CFD predicts how the molten metal will fill the mold cavity. It gives information on flow velocity, turbulence, air entrainment, and metal-metal contact.

Gating System Optimization: CFD is employed for the improvement of the design of a gating system to ensure a smooth and uniform flow of molten metal into the mold. CFD can minimize the possibility of defects, such as misruns, cold shuts, and porosity, which may emanate by adjusting the sizes of the gate and runner.

Riser Design: CFD simulations also help in designing the risers and feeders that supply molten metal into the casting while it is solidifying. Properly designed risers minimize shrinkage defects and improve casting yield.

Turbulence control: CFD simulations predict turbulence to occur during the filling process, which may lead to air entrapment and other defects. Manufacturers will be able to change the pouring speed and gating design by analyzing the flow patterns in order to decrease turbulence.

5.1.2 Advantages of CFD

Flow Behavior Prediction: CFD enables the visualization of molten metal flow, which pinpoints potential problem areas such as stagnant regions, vortices, or irregular flow patterns.

Cost-effective: It reduces the need for physical prototypes and trial-and-error experiments, which are expensive and take time to complete.

Optimization of Casting Design: CFD helps in optimizing gating, riser, and mold design to reduce casting defects and improve quality.

5.1.3 Limitations of CFD

Computational Expense: High-fidelity simulations of interest are usually computationally expensive, especially for large or geometrically/physically complex castings.

Model Complexity: Most of the CFD models require material properties, boundary conditions, and other parameters in great detail, which may not be readily available in respect to every other material.

5.2 Finite Element Analysis (FEA) in Casting Simulation

Finite Element Analysis (FEA) is a numerical tool that can be utilized to study the stress and temperature variations of materials. In the area of casting simulation, the main objectives of FEA are to study the process of solidification and the thermal stresses, strain, and defects that may occur.

5.2.1 Applications of FEA in Casting

FEA helps significantly in the following:

Solidification and shrinkage analyses: FEA simulates the process of cooling and subsequent solidification of liquid metal. It can predict shrinkage porosity and ensure that solidification proceeds in an orderly manner to minimize defects.

Thermal Stress and Strain: FEA will predict the development of thermal stresses during cooling that could result in defects such as hot tears and cracks. The information obtained is invaluable for the modification of cooling rates and mold design.

Distortion and Deformation: FEA will help in predicting the distortion or warping of cast parts that may happen during solidification due to thermal gradients.

Strength and Fatigue Analysis: Through the use of FEA, a structure's mechanical properties after solidification can be judged, with a good degree of accuracy, to predict the way in which the material will behave under load or stress.

5.2.2 Advantages of FEA

Accurate Stress Analysis: An accurate way of doing a stress analysis is provided by FEA. This is necessary for the prevention of hot tears and cracks.

Solidification Behavior Predictions: Predictions of the FEA simulation indicate the possible solidification patterns of the material and are used to prevent shrinkage cavities and other irregular solidification patterns in the casting process.

5.2.3 Limitations of FEA

Complexity in Modeling: The models in FEA are complex in nature and require heavy computations for obtaining precise information.

Data Property of Material: The data regarding the material properties required by FEA, specifically for new materials like alloys, may not be available at all times.

5.3 Multiphase Simulation in Casting

Multiphase models involve the simulation of behavior among the different phases that exist in the casting system, such as the metal, gas (air), and slag. The multiphase model is useful in the prediction of defects such as porosity that result from gas entrainment.

5.3.1 Applications of Multiphase Simulation

Gas Entrapment and Porosity: Multiphase modeling can determine the potential for gases like air, hydrogen gas, or nitrogen gas entrainment in the melted metal during filling. Gas pockets and simulation modeling can aid in eliminating porosity defects.

Mold Filling and Slag Formation: The multiphase model can assist in predicting the processes of slag formation and other non-metallic phases to ensure that these phases do not become entrapped within the casting.

Mold Design Optimization: Simulations are also useful for optimizing the design of the mold in such a way that the flowing of the metal into the mold is smooth without the formation of turbulence or the creation of air pockets.

5.3.2 Advantages of Multiphase Simulation

Full Defect Prediction: The multiphase simulation allows for a better prediction of defects that may arise due to gas entrapment, slag inclusion, or turbulence.

Improved Control over Process Parameters: Having knowledge of the phases and their interaction during the casting process allows control over the process parameters such that the defects can be eliminated.

5.3.3 Limitations of Multiphase Simulation

Computational Intensity: Multiphase simulations involve large computations and need considerable resources in order to simulate the interaction between the phases.

Model Accuracy

The accuracy to which multiphase flow can be simulated is highly model-dependent. This is particularly true for material models as well as boundary conditions.

5.4 Integrated Simulation Systems

The recent developments in the field of casting simulation include the incorporation of CFD, FEA, and multiphase simulation tools into a universal system. The above systems enable a more extensive analysis of the casting process; they take into consideration factors that influence the casting quality.

5.4.1. Advantages of Integrated Simulation Systems

"Comprehensive Analysis": Integrated systems offer the advantages of varied simulation models, enabling the realistic simulation of casting defects such as porosity, shrinkage, and thermal stresses.

Process Optimization

With all factors being considered together, optimization of casting parameters done by combined simulation seems to be more effective.

5.4.2 Limitations of Integrated Simulation Systems

High Computational Requirement: The integrated simulation process is computationally intensive, taking a lot of CPU time, particularly for complex components.

Complex Software Integration: The integration of simulation software may involve complex software platforms and might be difficult to manage.

5.5 Machine Learning and AI in Casting Simulation

In recent years, machine learning (ML) and Artificial Intelligence (AI) have been coupled with casting simulation methods to optimize the casting process. These AI systems are capable of learning from precedent data and improve the accuracy of defects.

5.5.1 Applications of Machine Learning & AI

Defect Prediction: AI is capable of parsing casting data to predict defects based on previous data, which helps the engineer foresee potential issues beforehand.

Process Optimization: Artificial intelligence can provide process modifications based upon simulations of casting operations, thereby improving efficiency and removing flaws.

Data-Driven Decision Making: Machine learning enables data-driven decision making by utilizing enormous production data to determine trends to optimize casting factors.

5.5.2 Advantages of AI & Machine Learning

This essay examines the

Improved Accuracy: Machine Learning models have the ability to enhance the accuracy of defect prediction and process optimization based on large amounts of data.

Real-Time Process Control: AI offers real-time process controls in casting operations to optimize the process.

5.5.3 Limitations of AI and Machine Learning_

Data Quality. This entails machine learning requiring quality data to work properly. Poor quality of data can cause predictions to fail.

Computational Complexity: Training artificial intelligence systems or performing simulations in real-time may be computationally intensive.

Summary:

The casting simulation process has greatly impacted the manufacturing process. The simulation of casting processes has enabled the prediction and prevention of casting defects prior to the occurrence of the defect in the real world. CFD analysis, FEA analysis, multiphase simulation analysis, and system integration help provide insight into the behavior of the melted metal. The fusion of AI and machine learning analysis may further enhance the defect prediction process.
As the computing capabilities and simulation methods become more advanced, the use of casting simulations in the prediction of defects, process optimization, and yield enhancement will become even more prominent in the future. It is no doubt that the cast manufacturers will benefit greatly from such developments.
The casting simulation methods employ computer models to calculate the following stages in the casting simulation:
Filling and solidification: These predictions include the flow of molten metal into the cavity, heat transfer, and solidification.
Stress analysis: These models calculate stresses due to cooling as well as stresses developed during solidification.
Electromagnetic Analysis: These simulations can predict the resulting electromagnetic forces that may affect the flow of molten metal, especially in an electromagnetic casting simulation.
Commonly used software packages for casting simulation include:
AutoCAST
ProCAST
Magmasoft
NovaFlow&Solid
ANSYS

6. Defect Prediction and Removal Using Casting Simulation

Casting is a major manufacturing technique employed across industries, from automobiles to aerospace. However, it is very often plagued by a number of defects, such as porosity, shrinkage, misruns, cold shuts, and hot tears, which seriously compromise the quality and structural integrity of the final product. Traditionally, such defects have been detected and eliminated using trial-and-error methods, along with a significant amount of time and expense in terms of physical trials and rework. In the last two decades, casting simulation techniques have emerged as strong tools for anticipating and avoiding most such defects. The simulation of the entire process of mold filling, solidification, and cooling enables casting simulation to predict defects that may arise during casting, optimize the parameters of the process, and thereby enhance the yield of products. This review analyzes the role of casting simulation techniques in defect prediction and removal, the advantages and limitations of such approaches, and their impact on the manufacturing process.
Advanced computational models used by casting simulation techniques help in emulating the casting process for the prediction of possible defects. These simulations model fluid flow, heat transfer, solidification, and thermal stresses throughout the process to give engineers valuable insight that will help mitigate defects.
6.1 Computational Fluid Dynamics (CFD) for Casting Simulation
Computational Fluid Dynamics (CFD) simulation is employed to analyze the molten metal flow inside the mold during the filling stage. Computational Fluid Dynamics simulates the molten metal process, making it possible for the engineer to accurately predict the molten metal flow through the gating system and into the molding cavity, as well as the generation of defects such as turbulence and air incorporation.
Applications in Defect Prediction:
Mold Filling: It can forecast how well the melted material will fill the mold. This helps ensure there are no misruns.
Cooling: It can forecast the regions that will freeze first or will have the lowest

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 55, Issue 01, No.1, January : 2026
Turbulence Control: CFD simulations may detect areas where turbulence is high and may develop air pockets and porosity. Turbulence may be controlled by adjusting pouring gates.
Gas Entrapment: CFD modeling of gas evolution processes enables prediction of the formation of gas bubbles, leading to porosity to help in designing processes that involve gas removal.
Advantages
Gives a clear indication of how the metal will flow inside the mold.
Enables the optimization of designs for the gating systems to minimize defects.
Helps decrease the requirements for conducting physical testing with the ability to foretell defects in the early stages of the design process.

Limitations
Computationally intensive for complex shapes.
Needs proper material properties and boundary conditions to make useful predictions.
6.2 Finite Element Analysis (FEA) in Casting Simulation
Finite Element Analysis (FEA) is employed extensively to model the thermal and mechanical processes that occur during the casting solidification cycle. It is applied in the prediction of shrinkage, hot tears, and residual stresses that occur in the casting.
Applications in Defect Prediction:
Shrinkage Prediction: FEA simulates the cooling and Solidification process, thereby enabling identification of sections vulnerable to shrinkage porosity, ensuring effective riser design.
Hot Tear Prediction: FEA analysis is useful for modeling thermal stresses and making predictions of hot tears. The thermal stresses may be reduced by adjusting the cooling rate and mold design.
Benefits:
Assists in predicting shrinkage defects, hot tears, among other solidification defects.
Correct stress-strain analysis in the process of solidification.
Ensuring optimal cooling systems for improved casting quality.
Limitations
It requires precise data with respect to material properties, which can sometimes be difficult for certain alloys.
Computationally intensive for large or complex parts.
6.3 Multiphase Flow Simulations
The Multiphase Flow Modeling simulates the behavior of various phases, including liquid metal, gas, and slag, as they interact with each other when a casting process occurs. The Multiphase Flow Modeling can also help determine how gas gets entrapped in the liquid metal or how non-metallic inclusions are formed.
Applications in Defect Prediction:
Gas Porosity: Computational simulations of multiple phases accurately model gas bubble formation and behavior in the molten material, helping to control gas content and the formation of bubbles.
Inclusion Prediction: It predicts the movement of inclusions like slag and helps in preventing inclusions from entering the casting.
Advantages
Gives a holistic understanding of the behavior of several phases in the casting process.
Enables more accurate predictions of gas defects and inclusions.
Limitations
High computational requirements.
Modelling multiphase flows can be complex and hard to validate.
6.4 Integrated Simulation Systems
The integrated simulation platforms combine CFD, FEA, and multiphase analysis to give a coupled perspective of the casting process. This enables the analysis of fluid flow, temperature stresses, solidification, and defects simultaneously. In this way, the entire casting process can be optimized.

Application for Defect Prediction:

Comprehensive Defect Prediction: Through the integration of various simulation tools, these prediction systems can make more accurate predictions about defects like shrinkages porosities, hot tears, and misruns.

Process Optimization: Optimal design of gating systems, riser systems, and cooling systems can be achieved in integrated systems, thereby reducing defects and improving casting output.

Advantages

Offers a comprehensive environment for defect prediction in multiple steps of a casting process.

Provides a more holistic process for process optimization.

Limitations

Requires considerable computer processing capacity and is a time-consuming process.

Many challenges in applying simulation models.

7. Defect Removal and Process Optimization through Simulation

Having predicted potential defects in a product through the use of casting simulation techniques, manufacturers can now implement measures to counter these potential defects.

7.1 Process Optimization for Defect Reduction

Simulation can aid manufacturers to optimize several parameters to make defects less likely:

Gating System Design: Designing the gating system for reduced turbulence in the molten metal flow.

Riser and Feeder Design: Appropriate riser and feeder design can eliminate shrinkage defects by ensuring supply of molten material during solidification.

Cooling Rate Control: Simulation can be used in cooling rate control in preventing hot tearing by ensuring that an appropriate cooling rate is maintained.

Cooling Rate Control: Simulation can aid in cooling rate control in preventing

Mold Design

Improved mold design can allow for better heat distribution and prevent the generation of defects such as misruns and cold shuts.

7.2 Simulation for Continuous Improvement

By performing simulation iterations using varied process variables, improvements can be made to the cast designs, and defect rates can be lowered. Simulation can also be applied to real-time monitoring systems to set process variables to obtain defect-free castings.

Summary:

Porosity, shrinkage, and misruns are considered to be the major casting defects. However, advances in non-trial-and-error casting simulation techniques have significantly changed the capabilities to predict defects before their occurrence. With the use of CFD, FEA, and multiphase simulations, manufacturers can make appropriate optimizations in the design of castings, modify process parameters, and thereby ensure better quality of castings. Integration of these techniques gives a comprehensive approach to defect prediction and process optimization for increasing yields, reducing costs, and enhancing quality.

The role of casting simulation in defect prediction and removal will continue to grow as computing power further increases and simulation models become even more sophisticated, further raising the efficiency and quality of casting operations across industries.

“Casting simulation can be applied to estimate defects that may be formed during the casting process.”

Temperature gradient analysis: Regions where temperature gradients are high, likely to observe hot tears.

Solidification prediction: Regions where the solidification takes place late and are prone to shrinkage.

Gas simulation: Simulating gas evolution: Predicting the formation of gas porosity.

Flow analysis: Finding regions that have turbulent flow; inclusions may occur in these regions.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 55, Issue 01, No.1, January : 2026
Changing mold design: Variations in the thickness of the mold walls, use of chills or inserts to control cooling rates.
Optimizing the Gating System: Adjusting the gates and risers with respect to size and location for efficient filling.
Adjusting process parameter values: Changing pouring temperature, holding time, or cooling rates.
Use of vacuum degassing or filtration: Eliminating dissolved gases and inclusions in the molten metal.

8. Yield Improvement Through Casting Simulation

Casting is regarded as one of the most basic and common metal manufacturing processes. In most cases, it has some related inefficiencies like material loss and deficiency of cast quality. In recent past, simulation of casting has proved to be of great significance in the efficiency of the casting process. The aim of this review is based on the efficiency of the casting process with the help of simulation of casting. In this review, the different types of simulation of casting will be evaluated with the help of the benefits it offers. The simulation of casting will be evaluated based on the efficiency it provides in the process.
Challenges in Casting and the Need for Yield Improvement
The casting procedure is quite complex and is affected by a multitude of factors that regulate the quality of the casting produced. Some of the most significant challenges that affect low yields during the processes of casting may include:
8.1 Defects and Scrap Creation
The casting defects, including porosity, shrinkage, cold shuts, misruns, and hot tears, are considered some of the major causes of reject products and scraps. The aforementioned factors can be related to increased waste and production delays, all of which contribute negatively to the yield.
8.2 Inconsistent Material Usage
Inefficient use of raw materials is also responsible for wastage of raw materials. It might be because of the improper design of risers, improper gating design, and use of low-quality molding materials.
8.3 Energy and Resource Consumption
Casting, particularly on a massive scale, can be a energy-intensive process. If a casting design is not proper, the flow rate is inappropriate, or even cooling is not properly planned, it can result in high energy use, which can, in turn, impact the cost-effectiveness and casting yield.
8.4 Inefficient Mold and Riser Design
Inappropriate mold and riser design may bring about defects, improper filling, and inefficient use of materials. For example, oversized risers may cause overuse of materials, while inefficient mold design may generate defects or poor-quality castings that require reworking.

9. The Role of Casting Simulation in Yield Improvement

Simulations of casting have become an important innovation in ensuring yield enhancement by solving the above-mentioned challenges. The key simulation methods employed in optimizing casting methodologies include the following:
9.1 Computational Fluid Dynamics in Casting Simulation
The use of the term -Computational fluid dynamics of use in simulating metal flow in the mold. The technology also helps in understanding metal flow during filling and predicting turbulence and air pockets that may cause defects in the final products. The use of computational fluid dynamics also helps in designing gates that affect yields.
Applications in Yield Improvement:
Mold Filling and Flow: CFD analysis will help in locating areas of the mold where turbulence and irregular filling of material may occur. This would result in various mold-filling-related issues. The process of gating molds could be further perfected for minimal material waste.

Turbulence and Gas Entrapment: CFD simulation enables the gas entrapped during the filling stage to be determined, which enables the manufacturers to take necessary steps to reduce porosity and produce quality castings. The turbulent flow is controlled by manipulating the flow rate and the gate design, allowing the defects caused by gas porosity to be minimized.

Optimization for Pouring Rates: CFD simulations enable the optimization of pouring rates to achieve optimal filling while reducing wastage resulting from over-flow or improper metal flow.

Advantages:

Accurate predictions of metal flow behavior within the mold.

This will provide optimizations of gating and pouring systems, which eventually will result in better material utilization and fewer defects.

Material waste is reduced by being able to identify potential flow-related issues before actual production.

Limitations include

High computational resources are required in the case of a complex geometry.

Results are only as good as the input data, which in this case includes material properties and boundary conditions.

9.2 Finite Element Analysis (FEA) for Solidification and Thermal Stress

To simulate the solidification and cooling of molten metal within the mold, Finite Element Analysis is used. FEA would model the thermal behavior of the casting, predicting thermal gradients, stresses, and strains that could lead to defects such as shrinkage porosity, hot tears, and cracks.

Applications to Improve Yield:

Shrinkage and Porosity Prediction: FEA helps predict areas where shrinkage porosity may form, and it allows the engineers to design efficient risers, feeders, and cooling strategies to eliminate shrinkage defects. By optimizing these things, one can reduce material wastage due to shrinkage, leading to better yield.

Thermal Stress Analysis: Through FEA, the thermal stresses are predicted that are created during cooling. These may lead to hot tears or cracking in the castings. Manufacturers may optimize cooling rates and mold design to reduce thermal stresses and avert material loss due to defective castings.

Riser and Feeder Design: FEA helps in optimizing the design of the riser and feeder to effectively provide molten metal to the casting during solidification. This minimizes material wastage and ensures the casting has enough metal to improve yield.

Advantages

Accurate prediction of shrinkage, hot tears, and thermal stresses during solidification.

Riser and Feeder Positioning Optimization: Reduction in wastage of material and improved casting quality.

Enhanced methods for solidification, giving improved control over material consumption.

Limitations

Need accurate data for material properties to work correctly.

Involving complex models may consume massive computational time.

9.3 Multiphase Simulation for Gas and Inclusions

In a multiphase simulation, the process models the behaviors of the various phases that occur during casting, such as metal, gas, and slag. It is useful in estimating the trapping of gases and other problems that might occur during casting.

Applications in Yield Improvement:

The method described

Gas Porosity Control: Multiphase analysis can also predict gas pocketing or bubbles that can occur when gas is present in the molten metal during filling and result in porosity defects in the parts. Based on gas metal dynamics, porosity can be minimized by optimizing process conditions.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 55, Issue 01, No.1, January : 2026
Inclusion Prediction and Removal: Slag and non-metallic inclusions may cause serious defects to a casting if entrapped. Multiphase models also assist in predicting the inclusion motion so that designers can optimize mold design and degassing processes to eliminate defects due to inclusions.
Optimized Material Flow: The simulation results enable understanding how molten metal fills in the mold, thus aiding designers in designing optimized molds because error-free metal flow also results in less waste due to improper flow from pouring metal to complete mold filling.
Advantages:
Provides a closer understanding of the behavior of gases and inclusions in liquid metals.
Enables adjustments to processes to lower defects related to gases and the wasting of materials.
Improves material quality by preventing the inclusion of slag or foreign particles.
Limitations:
Requires detailed material data for accurate modeling.
Very computationally intensive, in particular for large-scale simulations.
9.4 Integrated Simulation Systems
Integrated simulation systems use different techniques combined, including CFD, FEA, and multiphase flow simulations, on one comprehensive platform. That will also enable the manufacturer to analyze every single aspect of a casting process within one integrated workflow and further enhance overall process efficiency.
Applications in Yield Improvement:
Holistic Process Optimization: By combining several simulation technologies together, manufacturers can also concurrently work on optimizing their gating systems, risers, cooling processes, and mold flow. By doing so, they can make sure that all factors related to casting processes are optimized.
Less Waste of Materials: Better defect prediction and prevention in integrated castings regarding shrinkage defects, gas porosity defects, and cold shut defects contribute to improved yields of sound castings.
Cost and Time Efficiency: Through the use of integrated simulation systems, manufacturers can overcome the high costs associated with physical experimentation and the time required for redesigning, thus improving cost-effectiveness and yield.
Benefits:
Offers a complete solution for optimizing the entire casting process.
Enables quick iterations and progress through the assessment of multiple factors at the same time.
It avoids wastage of materials by detecting and addressing potential problems early.
-Requirements
It consumes a lot of computational power.
High complexity in the integration of different simulation methodologies.

10. Impact of Yield Improvement through Casting Simulation
Using casting simulation techniques, manufacturers can enhance yield and minimize material waste. These are the advantages:
Enhanced Material Utilization: The optimization of gating systems, risers, and cooling systems is achieved to ensure optimal use of molten metal.
Defect Reduction: Identifying and preventing defects such as porosity, shrinkage, and hot tears goes a long way in ensuring quality castings.
Cost Savings: A reduced amount of scrap and rework leads to less material cost and labor cost, thereby making the casting process more cost-effective.
Enhanced Productivity: The optimization of the entire casting process enables the achievement of short cycle times and minimal down time, which ultimately results in increased productivity.
Summary:

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 55, Issue 01, No.1, January : 2026

Casting simulation methods: Casting simulation methods have become essential in the improvement of yield since such methods empower engineers with the capability to foresee and correct shortcomings, optimize processes, and improve casting quality. Methods such as CFD simulations, FEA simulations, multiphase, or integrated systems provide useful knowledge regarding metal flow, thermal forces, gas entrapped areas, and solidification. These methods enable the manufacturing firm to minimize wastage and maximize the production yield of quality castings. As computer capabilities improve, casting simulation is poised to become a critical element in the optimization of casting processes, leading to further enhancements in the cost-effectiveness and yield.

Through the prediction and prevention of defects, casting simulation can ensure a much-improved casting yield. The following can be done:

Decreasing scrap rates: This is where attempts are made to reduce scrap rates to a low figure by minimizing the production of defective castings that

Optimizing material usage: Excess material needed for material feeding and risers is minimized.

Reducing cycle times: Increasing the speed of the casting process through optimized cooling rates and reduced downtime.

Enhancing the quality of the end product: Ensuring consistent quality of the casting.

11. Case Studies

A number of case studies have shown the benefit of casting simulation in improving the casting quality as well as the casting yield. For instance:

Automotive sector: The simulation was applied for optimizing the casting of engine blocks and cylinder heads with the intention of improving porosity and properties.

Aerospace sector: Simulation has been employed to design optimal complex turbine blades with high integrity.

Medical Devices:

Simulation has been employed to manufacture implants of high quality and exact size and having minimal defects.

Simulation and Its Applications

Simulation is used in medicine, where simulation

12. Future Trends

Continued strides in computing power and advances in simulation software should continue to improve the power of casting simulation. In the future, the trends will be:

Integration of multi-physics simulations: thermal-fluid flow-stress analyses will be combined in order to gain a deeper insight into the casting process.

Advanced materials model development: More realistic material properties and behaviors are developed in the simulations.

Real-time process monitoring and control: The use of simulation data in real time to modify the parameters of the process for optimization of the casting quality.

Artificial Intelligence and Machine Learning: Employing techniques from AI and ML to automate the processes of simulation and identification of optimum design parameters.

13. Conclusion

Casting simulation techniques have cropped up as very important tools, allowing for predictions and the prevention of casting defects, hence enhancing casting yield and product quality. Through the use of computational techniques in casting, casting engineers will be able to optimize their processes, save money, and increase the profitability of their products in the global market. The importance of casting simulation is bound to increase even more as technology advances into the future.

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