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ELEMENT

A GUIDE TO MODERN TECHNOLOGY

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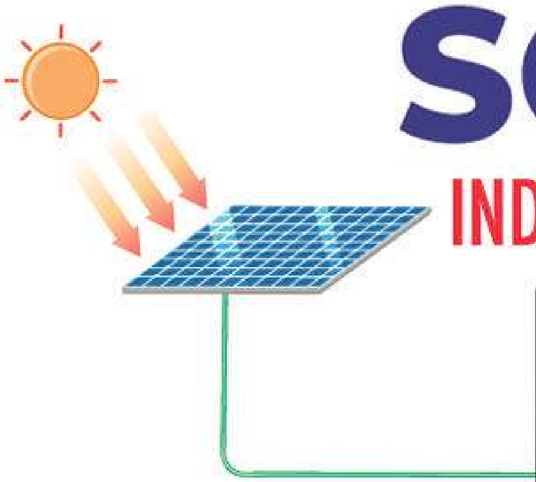

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President Message

It gives me great pleasure to present this edition of Element Magazine, a platform dedicated to sharing knowledge, innovation, and progress within the foundry and engineering industry.
The foundry sector plays a vital role in the development of modern infrastructure and manufacturing. As industries evolve with new technologies and global challenges, it becomes increasingly important for us to adapt, innovate, and collaborate. The Pakistan Foundry Association (PFA) remains committed to supporting its members by promoting technological advancement, industry networking, and international collaboration.
Through initiatives such as business development sessions, technical knowledge sharing, and international exhibitions, we aim to strengthen the capabilities of our local foundries and connect them with global opportunities.
Our collective efforts will not only enhance productivity but also improve the competitiveness of Pakistan's foundry industry in the international market.
I encourage all industry stakeholders, professionals, and young engineers to actively participate in knowledge sharing and contribute towards the sustainable growth of our sector.
I would also like to appreciate the editorial team of Element Magazine for their dedication in compiling valuable insights and industry updates for our readers.
Let us continue working together to build a stronger, more innovative, and globally connected foundry industry.

Sikandar Mustafa Khan
President
Pakistan Foundry Association

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In its early years, the company faced the typical challenges of a growing industrial enterprise—limited resources, intense market competition, and the need to establish credibility. However, through resilience and an unwavering commitment to quality, Mecas Foundry steadily built its reputation, earning the confidence of its clients and creating a strong foundation for future growth.

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With growth came the need to scale, and Mecas Foundry rose to the challenge by significantly increasing its production capacity to hundreds of tons per month. This expansion was achieved without compromising quality, supported by continuous improvements in processes, infrastructure, and workforce development.

At the core of Mecas Foundry's success is its people. A dedicated team of engineers, technicians, and skilled workers works collaboratively to deliver precision-driven, high-performance products. Their expertise and commitment to excellence continue to drive the company forward.

Looking ahead, Mecas Foundry remains focused on expanding its global footprint, adopting sustainable manufacturing practices, and investing in advanced technologies. Its journey reflects not only growth but a forward-thinking approach that keeps it aligned with the evolving demands of the industry.

The story of Mecas Foundry is one of resilience, innovation, and consistent progress. It stands as a strong example of how vision, combined with dedication to quality, can transform a modest beginning into a successful industrial enterprise.

Application of alcohol based spraying coating on green sand mould for steel casting

Z L Xu1,[3], J Wang[2], S S Yang[2], Q L He[2] and H Sh Xiong[2]
[1]Wuhan Textile University, Wuhan, 430073, China
[2]Tongling Branch, CSR Yangtze Co., Ltd., Tongling, Anhui, 244000, China

Abstract

A kind of coating suitable for green sand steel casting was developed. Thepractical application showed that the strength of the coating was high enough with no crack and no peeling under room temperature after drying the spraying coating, the performance of the coating for anti-cracking was good under high temperature, and the gas evolution of the coating was low. Using the coating, the casting surfaces finish appearedvery good.

Introduction

Sodium silicate or resin sand molding is most used for steel casting production. Due to high cost of sodium silicate sand and resin sand molding, also difficulty for shakeout, deoxidization and recycling, many foundries began to use green sand molding instead them. Green sand molding which is low cost, high efficiency, occupies an important position in the casting production [1-3]. However, directly using green sand mould to cast steels is liable to bringing about burnt-on sand, sand inclusion, sand holes or/and other casting defects, therefore, the appropriate coating matching is necessary, and the development of fireproof coating for steel casting by green sand molding is of great significance.

The characteristics of green sand casting steel coating

Pouring temperature in steel casting is high, up to 1550~1600 , it requires coating being with resistance to high temperature and burnt-on sand for steel casting mould. The strength of green sand is poor, brushing coating on the surface of green sand mould will be easy to bring up the sand, so it is not suitable for brushing, and spraying is preferred. Water-based paint will further increase the sand surface moisture, causing sand strength lower, at the same time increase the gas evolution, and drying process influence the production efficiency, so alcohol based spraying coating is more appropriate. Since the permeability of green sand mould is low, and gas evolution tendency of it is larger, the gas evolution of alcohol-based coating should be as small as possible. Spraying process requires that the refractory particle should be fine, requires that the coating should be in good adhesion strength on mould sand, be good permeability, and be more resistant to cracking and peeling.

In general, after spraying, the coating could dried by ignition, also can be natural dried. But light dry may be easy to cause coating peeling and cracking, because the volatile solvent burn fast, the coating dry too quickly, shrink sharply, and the strength of sand mould surface is basically low and get to be lower due to the solvent infiltration. Therefore, air drying after spraying coating would be advisable.

The component of spraying coating for green sand steel casting

3.1. Refractory aggregate

The component of spraying coating for green sand steel casting

3.1. Refractory aggregate

It is generally believed that zircon powder is the most suitable refractory aggregate for cast steel coatings [4]. However, the production practice shows that the single zircon powder coating may not completely resist burnt-on sand, and zircon powder coating is expensive [5]. Besides zircon powder, other high fire resistance of the aggregate such as white corundum, brown corundum, bauxite, is relatively economy, with which the burnt-on sand resistance would be better than that of the single zircon powder coatings as long as the ingredient is appropriate[6, 7].

For a long time, the ingredient of coatings only focus on composition of additives such as binder, suspending agent and accessory ingredient, ignore the collocation of refractory aggregate. Really for one kind of good quality coating, the kinds of refractory aggregate, in which the collocation about particle size are also important to be considered, in addition to the appropriate additives proportion. If the aggregate particles are too coarse, the spraying nozzle would be blocked, too fine, the coating will be not conducive to reducing crack tendency [4]. Taken together, a certain proportion of white corundum and brown corundum blended in with zircon powder as refractory aggregate was adopted in our scheme. Aggregate particles mesh distribution was between 220 ~ 325 mesh.

3.2. Agglomerant

Coating must have sufficient strength both at room temperature and at high temperature. Agglomerant of alcohol-based coating for room temperature involve resin, rosin, polyvinyl butyral (PVB), and for high temperature involve bentonite clay, refractory clay, phosphate, ethyl silicate and so on. Considering coating strength, crack resistance and fast drying characteristics, an appropriate constituent of organic and inorganic agglomerant blended as a multiple adhesion agent was proposed to satisfy the necessary strength for both room temperature and high temperature [8].

3.3. Suspending agent

Coating must be of good suspension stability, so as to facilitate transportation, storage and stirring to be uniform seriflux before spraying. Due to the compatibility problems to be blended into alcohol solvent, the suspending agent for alcohol-based coating is not a lot, and the suspensibility of alcoholbased coating is always less than that of water-based coating. The suspending agent for alcohol-based coating involves PVB, sodium-based bentonite, lithium-based bentonite, organic bentonite, and some commercial suspending agent such as SN suspending agent, etc. PVB and resin would form a dense protective film which does not facilitate the resin combustion gas to go out of coating and prone to blistering while burning coating, should not be added much. Sodium-based or lithium-based bentonite need water to be swelled, water will be increased in coating, which reduce the strength of sand mould surface, and is not conducive to quick drying, meanwhile, water precipitation would decrease coating stability. It is clear that neither sodium-based bentonite nor lithium-based bentonite is suitable for spraying coating. No matter what kind of coating, bentonite can't be added much, otherwise cracking will be likely to occur on coating.[4, 8, 9] As comprehensive consideration, the organic bentonite, a small amount of PVB, were added as the suspending agent.

3.4. Solvent

The solvent of coating was a kind of mixture based on anhydrous ethanol with other alcohol solvent, in which compatibility of mixture within coating would be improved, leading to quick drying.

3.5. Additives

Adding additives can improve wettability, dispersion, permeability, adhesion strength of coating, reduce or eliminate the tendency of

cracking and peeling. Additives commonly used that could enhance permeability and dispersion are JFC and OP-10[3, 4, 9].
In order to improve the agglomeration of the coating, and to reduce the tendency to burnt-on sand, an oxide sintering agent was appended.

4. Testing of coating performance

4.1. Viscosity, Baume degree and suspension property

Test of viscosity was by flow cup with a tapping hole of diameter Φ6 mm on the bottom, Baume degree test was by Baume scale, and the test of suspension property was by quiet placing in graduated flask.[4]

4.2. Coating strength at room temperature

Sand particles falling down from a viscosity cup to hit a coated glass surface until the coating was chafed, weighing the weight of the sand dropped out once the coating was abraded, the total weight of the sand was as the evaluation index of surface coating strength, seeing the reference for specific operation. [4]

4.3. Crack resistance at high temperature

A Φ60mm × 60mm cylinder specimen was made from green sand with washing silica sand 50/100 mesh (old and new sand ratio of 1:9), which contain 3.0% bentonite and 3.5% water. The sample was sprayed coating with thickness of 0.5-0.8 mm, air dried, then was put inside a furnace within which high temperature atmosphere was to 1200 °C, staying 2 minutes, the coating crack could be observed if it was likely to crack. [4, 5]

4.4. Gas evolution

Scraping coating powder and crushing down, weighing accurately for 1.0 g, the gas evolution of coating at 850 could be measured by SFL type recording gas evolution test apparatus. [4, 5]

4.5. Cracking and peeling resistance at room temperature

Evaluation of cracking situation of coating while drying after spraying on green sand moulds at room temperature was by actual observation.

4.6. Sintering and stripping property

Casting steels actually, sintering and strippingperformance of the coating was evaluated by actual observation.

5. Ingredient of coating and the main performance

Referring to the domestic and foreign literature [1-11], by some tests in laboratory and production trial in workshop, an appropriate ingredient of coating was determined, which is shown in table 1. Coating performance is shown in table 2.

Table 1.Ingredient of coating for spraying alcohol-based green sand mould (%).

Zircon powder + corundum	Organic bentonite	Organic binder	Inorganic binder	PVB	Additives	Mixture solvent
66	2.0-3.0	1.0-2.0	1.5-2.5	0.2-0.5	2.0-5.0	remainder

Table 2.Performance of coating for spraying alcohol-based green sand mould.

Viscosity (Φ 6 flow cups)/s	Baume degree/ Be	Suspension property (24 h)/%	Density/ $g\cdot cm^{-3}$	Coating strength at R.T./g	Resistance to cracking at H.T. (1200℃ ,120s)	Gas evolution /$ml\cdot g^{-1}$
14	63	>95	1.7~1.9	459	grade I	<18.5

6. Application of the coating

6.1. Production trial and effect show

Alcohol-based spraying coating for green sand was used in steel foundry, in Tongling Branch, CSR Yangtze Co., Ltd.. Surfaces of the green sand moulds for casting bolsters and frames were sprayed with coating. After drying in the air, no crack or peeling was observed on the coating film, and the casting surfaces finish were good, as shown in figures 1 and 2.

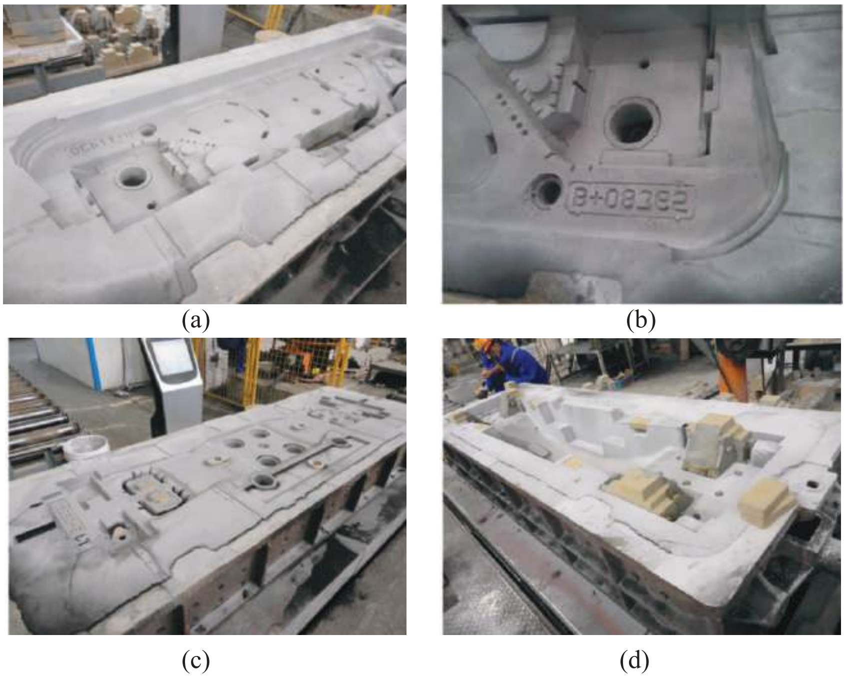
(a) (b) (c) (d)

Figure 1.Spraying coating on (a) half mould of a side frame (b)an end of mould of side frame (c) upper mould of a swing bolster and (d) lower mould of a swing bolster in production.

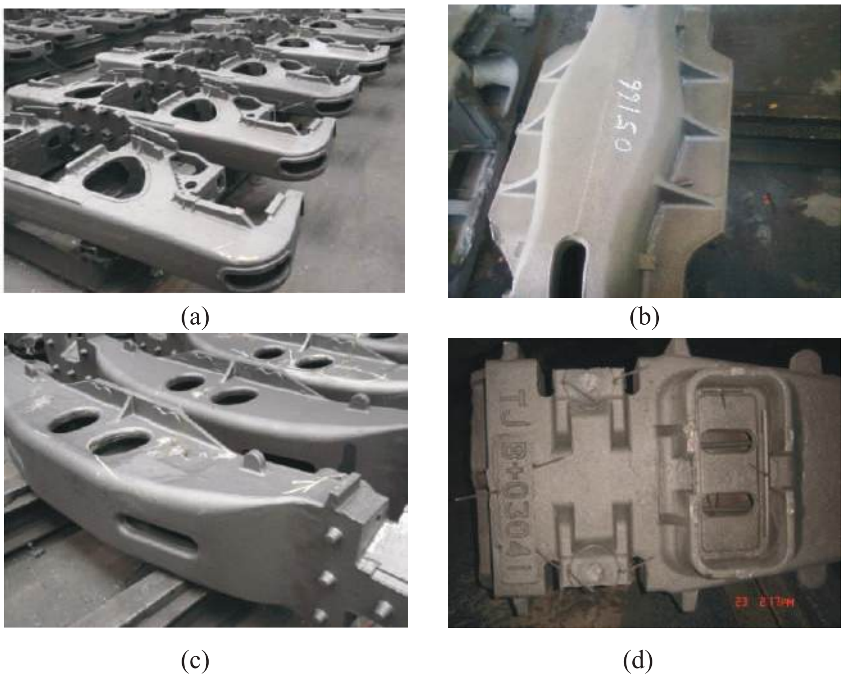
(a) (b) (c) (d)

Figure 2. Surface finish of (a) side frames (b) low beam surface of a side frame (c) swing bolsters and (d) local area of a swing bolster marked part number before shot blasting by spraying coating on green sand moulds.

6.2. Discussion

6.2.1. Influence of bentonite and agglomerant on coating.

Appropriate amount of bentonite and agglomerant, is the guarantee for good suspending and rheological properties of the coating, also the guarantee for wet strength after spraying, for dry strength at room temperature after drying, for high temperature strength while casting, of the coating. If bentonite in coating were not enough, or too much, cracking or peeling is likely to occur on the coating after spraying. This is because insufficient bentonite could lead to low wet strength, and too much of bentonite could lead to big shrinkage and cracking. If agglomerant were not enough, dry and wet strength of the coating would be low, that is liable to cause crack. Once crack occur at wet coating in the process of drying, the crack will be easy to extend, become a long crack and cause peeling on the coating after drying, as a result, the coating would have to be out of effect. Too much of organic agglomerant, maybe beneficial to the improvement of the wet and dry strength, but would cause a large gas evolution, thus pinholes might appear on casting surfaces.

6.2.2. Influence of additives on coating.

Two additives are worth noting. First, wetting agent, which promote wetting between coating and mould, should be in moderation, too much would lead to poor film-forming, even to local crack, and too little, would lead to poor permeability and poor adhesion on mould surface in some local surfaces, as a result, it would be difficulty for coating to "take root", bring about uneven shrinkage strain on the coating in the process of drying, thus would lead to peeling and cracking. Sometimes, even though no cracking and peeling at coating, the whole coating is going to fall off due to inadhesion to moulds, which immediately lose shielding effect because of cracking or being washed away at high temperature while casting pouring. The second, flake sintering additives, involve several oxides added, are to counter the oxide consumption in reaction with such as SiO2 and Al2O3 existing in sand mould surfaces. Redundant oxide would accumulate on the metal surface, form a kind of molten sintering layer that would be easy to peel off from casting due to the difference of contraction coefficient, avoiding burnt-on sand on casting, and casting surfaces would be clean. Too little oxide added would lead to poor/no resistance to burnt-on sand, and too much, would lead to deterioration of the coating strength.

6.2.3. Influence of the solvent.

A kind of mixture solvent based on anhydrous ethanol added other alcohol solvent such as isopropyl alcohol, methanol and n-butyl alcohol under the appropriate proportion, was used, which would be the guarantee of wet strength of coating. Single use of ethanol or industrial alcohol, coating is prone to crack. This may be the consequence that the single anhydrous ethanol solvent would evaporate too fast, causing the coating drying fast before it penetrate into sand mould.

6.2.4. Influence of coating spraying process.

Spraying process is important besides the quality of coating must be qualified, and the adjustment of process would be necessary to adapt depending on the change of seasons. In 20-25°c environment, the baume degree suggestion of coating 58-63 would be more appropriate. In hot summer above 30°c, the baume degree suggestion 56-60, and in cold winter below 10°c, the baume degree could be adjusted to 60-63, but not more than 65. If baume degree were too high, it is difficult for the coating to penetrate into the sand mould before air dried, and if baume degree were too low, solvent permeability is too much to deteriorate sand strength, that would be easy to cause the coating crack and peeling. Spraying pressure suggestion is 0.2-0.35 Mpa. If the pressure were too high, coating grain will rebound, make against form coating. The spraying nozzle height to the mould surfaces should be appropriate with 500-700 mm, too low for the height is similar to the consequences of too high baume degree because the solvent would be lost fast in the air.

7. Summery

7.1. The developed coating is good and feasible

The spraying coating developed for green sand casting steel, is of high wet strength, of good cracking resistance at room temperature and high temperature. No burnt-sand occurrence on steel castings and the surface finish of castings were good, after spraying on green sand moulds before casting.

7.2. Matters needing attention about preparing coating

To prepare coating for green sand casting steel as spraying coating, attention should be paid to the amount of bentonite, appropriate addition of additives and the use of mixed alcohol solvent, so as to avoid crack and peeling, to ensure the coating sintering layer formed under high temperature reaction, then the surface of casting to be easily peeled off and to avoid burnt-sand.

7.3. The correct spraying process is necessary

The correct spraying process could ensure to achieve the best effect of the coating.

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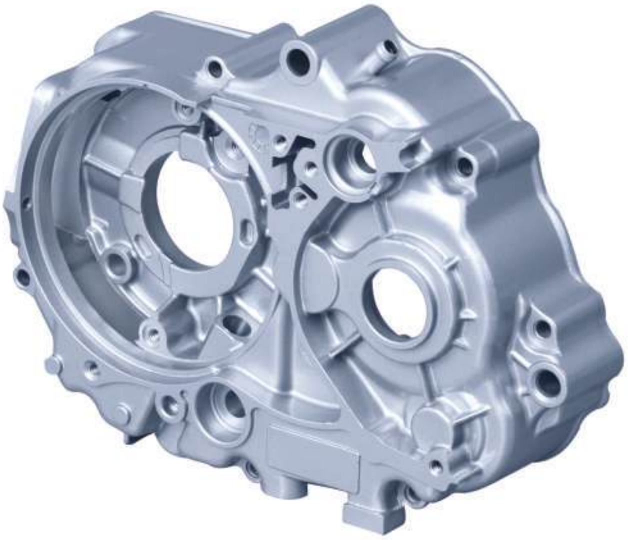

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Theory of combined imbalance for quality improvement in green sand

Harshwardhan Pandit, Anand Deshpande
a Visvesvaraya Technological University, Department of Mechanical Engineering, KLS Gogte Institute of Technology, Udyambag Industrial Area, Udyambag, Belagavi, Karnataka 590006, India

Abstract

Foundry is the discipline of experiments. Foundry operation consists of many interconnected, dynamic processes that are complex in nature which demand skills, techniques and caution to ensure and maintain a consistent quality of castings. Such a methodologically complex processes with numerous variables of process parameters also impose quality limitations on final castings. On account of the same, defect reduction becomes the important objective in green sand casting foundries. Foundries need process expertise to improve efficiency by reducing sand casting defects. The identification of process variables is known as process knowledge. This involves the approach to data collection, the conceptualization method, and the study to assess the various process variables associated with a defect-free casting generation. The paper presents a new perspective in the form of the Theory of Combined Imbalance of process parameters, a new dimension for understanding the defect generation mechanism in green sand molded castings.

Introduction

In the foundry, every casting produced constitutes a research experiment. For every casting the values of geometric, material and process parameters are different. As foundry parameters are not systematically recorded, their link to the originating conditions is lost. Thus a considerable amount of knowledge generated every day is lost as the foundries do not use it for casting quality improvement. Process parameters play a vital role in casting defects, especially in green sand molded casting compared with the human body, the ailment in the body is generated due to the imbalance of tridosha, i.e. the Vata, the Pitta and the Cough, so do the casting defect is generated due to an imbalance in the process parameters forming the sand mold and entering inside the mold. Although metal casting is one of the oldest processes known, industries suffer from poor casting quality due to the large number of parameters involved in the process. The consistency and the quality of the product can be improved by lowering the defect rate by identifying the correlation of process parameters with casting defects. A systematic method is advocated in this paper to correlate mold and melting process parameters with the defect's generation and reduce it thereby. Many preventive steps are taken from casting, design of method systems, quality of raw material, various processes, including molding, melting, pouring, etc., yet castings suffer rejection due to defect generation. Pre-process steps such as simulation in casting design, filling analysis, design of gating and risering systems are performed. Post-process steps are analysis of rejection, cause assignment and taking remedial actions. Inprocess steps include optimization and maintenance of process parameters to a definite level.

2. Literature review

A detailed literature survey was performed to identify and understand the array of the work carried out so far. Some of the significant research work involves the following. Yang and Whang [1] developed a computerized diagnostic system for casting defects based on user-entered data and sketch, limited to identifying the defect and suggesting the remedial measures based on a series of questions to the user. Plant and Hu [2] developed a prototype of a decision support system to diagnose casting production defects which allows the causes of the defect to be determined through the use of IF-THEN rules. Fujikawa et al. [3] developed an expert system to cause defects using a conditional probability for defect cause identification and suggested the remedies. Ransing et al. [4] developed an Intelligent Computer-Aided Defect Analysis (ICADA) system, based on artificial intelligence technique, to identify design, process, or material parameters responsible for the occurrence of defective casting in a manufacturing campaign. Perner [5] developed image analysis techniques using the similarity between two images that can be used to identify the defect on image interpretations and case-based reasoning. Karunakar [6] developed a technique using artificial intelligence to predict some of the casting defects based on the inputs such as green compression strength, green shear strength, permeability, moisture content as mold properties, and % of C, Mn, Si, S, P, Cr as the chemical composition of charge metal.

The data was trained against specific parameters, and a network was built. Chougule and Ravi [7] developed a system capable of identifying similar casting projects based on a case-based reasoning methodology working on similarity index to select process planning for a new casting on case-based reasoning. Dwivedi and Sharan [8] developed a knowledge-based engineering module to diagnose a defect in a cylinder block casting. It classified the casting defect depending upon its size, shape, and occurrence. They also developed expert advisers for the detection and interpretation of defects by non-destructive testing. It mainly uses IF-THEN rules. The system was modeled in FORTRAN and C languages. Bakir et al. [9] advocated using decision tree and regression analysis in defect cause modelling. They selected a highly rejected component and analyzed it on regression analysis and the decision tree method. They also deducted that decision tree analysis can be considered the base for planning the statistical design of experiments to optimize casting parameter values. Vijayaram et al. [10] discussed the general quality control aspects in a detailed manner. Besides, statistical quality control (SQC) is also highlighted to understand its recent application and techniques adopted in the developing metallurgical engineering foundries. Quality control, Statistical quality control (SQC), Quality circle, Quality assurance, Control charts were the prime. Karunakar and Datta [11,13–15] used backpropagation neural networks to prevent casting defects.

They also investigated controlling green sand mold properties using artificial neural networks and genetic algorithms. Perzyk [12] discussed the use of statistical and visualization data mining tools for foundry production. This paper advocates the importance of the utilization of historical data and its processing for the production of sound casting. Sika and Ignaszak [16] discussed the main assumptions, algorithms, and functions of the KMES Quality system. It also discussed the data mining process in creating a new knowledge foundation and structure of the exploration data system. Analysis of the data from different departments –synchronizing different parameter values in real-time is essential. Chokkalingam and Nazirudeen [17] demonstrated a systematic procedure to identify and analyze a significant casting defect, mold crush, automated transfer case casting, identified through defect diagnostic study approach using a cause-effect diagram and Pareto chart as principal diagnosis tools. Roshan and Ransing [18] advocated the need for optimizing process parameters in a foundry without much experimentation.

They only stressed the utilization of previously recorded data of casting, which includes factual information regarding process parameters, chemical composition, etc., for arriving at an optimized parameters level. Some limitations of the design of experiments, i.e., DOE, motivated to develop the system. Mane et al. [19] advocated the need to correctly identify and characterize the casting defect and suggested a new classification of casting defect. In this work, they presented a three-step approach to casting defects identification, Analysis, and rectification. Gorny et al. [20] proposed developing an attribute table as a new tool that supports the identifications of defects constructed on input data.

The system asks questions to the user serially, thus helping him to identify the defect. The attributes table is then compared with the current description of a casting defect in hand. Based on the rules, the defect is identified. The diagnosis of the defect is then. Ignaszak and Sika [21] illustrated an Analysis of SPC (Statistical Process Control) procedures usability in foundry engineering. It advocated paying attention to the complexity and necessity of correct preparation of data acquisition procedures. Integration of SPC systems with IT solutions in aiding and assisting during the manufacturing process is essential. Thakare and Tidake [22] reviewed various methods adopted by foundries to reduce defects, and a new approach is proposed for controlling and reducing the defects. This paper described successful applications of KDAM (Knowledge Discovery and Analysis in Manufacturing) to the creation of rules for optimizing gas porosity in sand casting molds. Chen et al. [23] conducted experiments based on integrating artificial neural networks and the Taguchi method on constructing the real estate appraisal. Sheth et al. [24] studied five prominent defects in casting rejections.

They performed a systematic analysis to understand the reasons for defect occurrence. Suitable remedial measures were identified and implemented lean six sigma up to some extent and generate feedback system between two industry. Panchiwala et al. [25] review quality and productivity improvement methods in Small Scale foundry industry. Tools & techniques used in the foundry industry based on quality and productivity aspects like 7 QC – tools, DOE, Taguchi method, etc. Banchhor and Ganguly [26] studied models to establish relations between the input value and corresponding output value on a data set collected from a DISAMATIC foundry. Models for molding sand characteristics were developed using multiple linear regression analysis and ANN, and a comparison is made between regression models and ANN models. Chatrad et al.

[27] studied the effect of pouring temperature on rejection percentage using DOE by changing the selected variables, and different results were derived. Pandit and Dabade [28] investigated historical data in the foundry for casting parameter optimization. Pandit et al. [29] developed a new prototype of an interactive system for casting defect identification and Analysis using a structured procedure.

Domain	Specification
Use of simulation in method design	Casting simulation is widely used as a powerful tool to visualize mold filling, solidification, and cooling and to predict the location of internal defects such as shrinkage porosity, sand inclusions, and cold shuts. The majority of the research is addressed to casting defect identification, employing expert systems, similarity charts, other tools, etc.
Casting defect identification Casting parameter optimization	The majority of the research is addressed to casting defect identification employing expert systems.control charts etc., for productivity improvement, has also been widely addressed. The experiments are conducted by changing levels of process parameters. Levels for which the defects and rejections are observed minimum are then set as standard parameters, and the production process is continued.
Casting rejection analysis	The casting rejection analysis using various statistical process control tools is also the researchers' key area. It involves investigating the rejection attributed to various casting defects analyzing their root causes, and then obtaining the solution in terms of the remedial measures.

3. Findings from literature review

The literature review helps to understand the critical areas in which work has been done so far. Following Table 1 shows the summary of findings from the literature review. Simulation in method design, casting defect identification, casting process parameters optimization, and casting rejection analysis are addressed widely. Design of castings, conducting various tests on the sand, controlling the melting process also has been addressed.

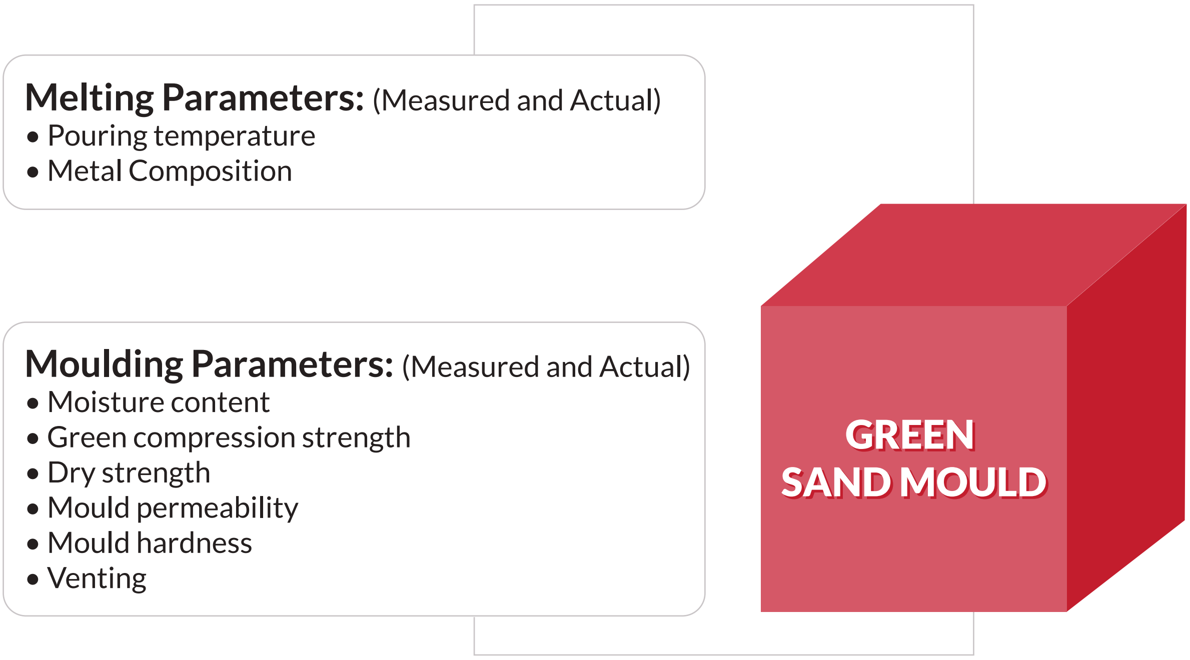
4. Types of defects noticed during casting process

The following types of defects are generally noticed during the casting process. It is observed that apart from metal composition, casting design, method design parameters, the defects enlisted in Table 2, also attribute their occurrence to molding sand and molten metal temperature-related process parameters.

$$GCS(Y_1) = b_0 \pm b_1x_1 \pm b_2x_2 \pm b_3x_3 \pm b_4x_4 \pm b_5x_5 \pm b_6x_6 \pm b_7x_7$$

5. Mold mechanism of defect generation

Sand molding is an ancient technique of manufacturing. In the foundry industry, the sand cast system is the most common casting form. Greensand is used in almost all sand cast molds for ferrous castings. Greensand is made up of good quality silica sand along with 10% bentonite clay for binding. It also contains 2 to 5% water with 5% sea coal. What additives and sand grades are used depends on the type of metal being cast. Greensand accounts for approximately 90% of the molding materials used in the process.



Greensand molds are used to produce complex shape castings of various sizes depending upon the requirements. However, there are still defects, flaws, or imperfections that remain and are very difficult to eliminate from castings. Fig. 1 shows a typical mold. Every mold has two factors, viz. variable factor and constant factor. Whereas constant factors include the design of casting, pattern, mold box dimensions, several cavities for particular casting, gating and risering i.e.methoding systems, etc., the variable factors include factors that change over the period e.g., pouring temperature, moisture content, green compression strength, etc. The casting defect thus generated in the mold is the function of this individual mold characteristic. For many practical purposes, it is assumed to be constant.

CASTING DEFECT	DESCRIPTION	CAUSES	REMEDIES
Blowholes	Present on the surface of the casting as rounded or oval cavities due to entrapment of gases in solidifying metal. Found in cope part.	. Excessive sand moisture content . Sand grains are too fine. . . Too hard rammed sand. . . Insufficient venting . Low Permeability of the moulding sand.	Moisture content in control and at desired level . Use of high permeability sand . Use of appropriate grain size sand . Sufficient ramming Adequate venting
Scab	Scab is inclusion defect also referred as slag inclusion (inside the casting) and sand inclusion (irregularly formed on surface of casting).	. Less compatibility of the molds. . Higher pouring rate with impact due to ladle distance .High pouring time	. Increasing the compatibility of mold. . Usage of the proper gating and the pouring practice. . Minimise high pouring rates . Proper method design to help pouring time optimum . Mixing of sand evenly . Maintain compressive strength . Maintain moisture content
Shrinkage holes, Porosity	Cavity formation due to volumetric contraction of solidifying metal. Open cavities are exposed on surface of casting while closed cavities are hidden beneath the surface of casting. Concaved rough surfaces.	. Uneven dry sand with low vcompressive strength	. Proper method design . Use the optimal pouring temperature to ensure sufficient fluidity. . Fluidity is insufficient in molten metal.
Misrun	Incomplete filling of mould cavity, two stream of molten metal don't meet. Thus it is a kind of incomplete casting.	. Low fluidity of the molten metal being poured . Low pouring temperature of the molten metal decreasing the fluidity . Too thin section/s with improper method design . Delay in pouring . Low ladle capacity	. Use of finer sand . Reduce moisture content. . Reduce the pouring temperature
Rough surface	Defect with not uniform, uneven and rough casting surface. With larger sized sand grains, the metal fuses in to the sand and solidifies.	Sand mixture is not adequate. Water content is too high. Very high pouring temperature. low strength of sand large grain size high permeability soft ramming of sand	. use of high strength of sand . use of fine grain size . optimum permeability . good ramming of sand
Cold shut	Surface defect with line appearance due to incomplete fusion of the two streams of molten metal.	Low pouring temperature. Incomplete fusion Metal solidifies before mould is filled. Poor permeability of sand.	. Increase pouring . . . .temperature. . Improve venting. . Increase permeability of sand

6. Theory of combined imbalance

The theory of combined imbalance considers that every mold has two unique sets of process parameters, viz. process parameters forming the mold (molding parameters) and process parameters entering the mold (molten metal parameters) as enlisted in table

3. Thus, every mold under consideration has a unique set of process parameters values than the other. The interaction within the mold and subsequent casting formation after the molten metal entry are unique to every mold. The reason behind this is the difference in process parameters in each mold. The general levels of process parameters values are indicated in the following table

4. The dynamic process parameters exhibit a change in their values due to their dependence on time and temperature, i.e., their values are the functions of the elapsing time or the effect of dropping the temperature of molten metal entering the individual mold.

- Behaviour trends of process parameters: It appears that significantly less study is undertaken to assess the possibility of the structured behavioural trends of process parameter values as a function of time and temperature.

- Study of correlation between trend behaviour of process parameters and defect generation: It appears that very few studies have investigated the possibility of a well-defined correlation between the behavioural trends of selected process parameter values and their relationship with the generation of casting defects.

Furthermore, the process parameters establish a dynamic correlation amongst them and establish a dynamic balance. Thus, the Combined Imbalance theory states that the molds having a balanced dynamic correlation of process parameters will generate a defect-free casting, and defective casting will be generated in a particular mold only when the process parameters exhibit a combined dynamic imbalance.

Parameter	Details of parameter
Mold forming parameters	All those parameters are associated with constituents that form the mold's mass, i.e., mold material and mold geometry. This includes – . AFS No, Green Compression Strength, Loss on Ignition/ Volatile data at the mill and in return sand, Active Clay, Compactibility, Permeability, %Moisture, Return Sand Temperature and Moisture, Prepared Sand Temperature, Sieve Analysis, Green Shear Strength, Wet Tensile Strength, Shatter Index, Friability, Sand to metal ratio/casting weight, Shot blasting times/consumption, Sand carryover at knockout, Liquid Metal weight per box, mold hardness.
Mold entering parameters	. All those parameters associated with constituents that enter the mold, i.e., molten metal . Pouring Time, Pouring Temperature, Pouring Sequence, Number of Cavities, Cavity location, Furnace, Ladle treatment, Inoculation

General ranges of some selected process parameters.

Process parameter	Range
Moisture content (%)	2.8–3.4
Green compression strength (g/cm2)	1,500–1,800
Pouring temperature (C)	1,380–1,450
Mould hardness (no.)	80–100
Permeability (no.)	100–160

7. Time-temperature dependentness of process parameters

Controlling process parameters has a significant impact on the rejection rate in a foundry. The parameters of the casting process play a pivotal role in determining component rejection. The manufacturer of casting components has control over several parameters, including the pouring temperature, carbon equivalent, moisture content, inoculation, green compression strength, permeability, and mould hardness of the sand.

However, certain process parameters such as the temperature outside, the rammingpressure, pouring height, cooling time for poured metal etc. may be uncontrollable due to environmental and other factors. The time–temperature dependentness of the process parameters is the changes in their values that occur as a function of the elapsing time and temperature. It is observed that individual mold exhibits a unique environment created by the process parameter values unique to the mold. For example, the 1st mold's pouring temperature is much higher than the pouring temperature in the 10th mold.

Table 5 enlists the time–temperature dependentness of various process parameters entering /constituting green sand mold. The defect generated inside a particular mold should be considered due to the imbalance of the dynamic correlation of process parameters in a particular mold. The correlation of process parameters, if imbalanced, gives rise to the generation of the defect in a particular mold. For this understanding, it is required to establish the variability of the process parameters in a series of molds. Thus, every mold is an individual entity with a unique set of process parameters and mold characteristics as shown in the above Fig. 2.

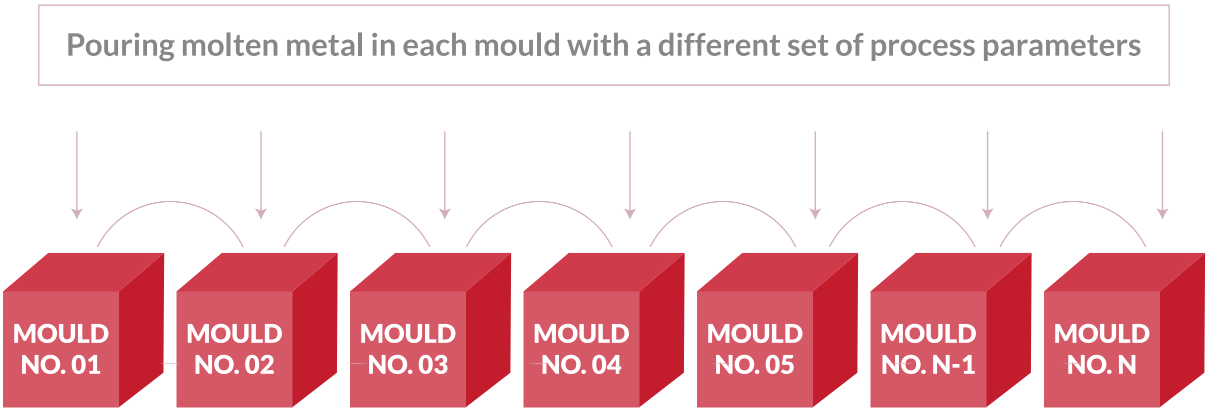
For the sake of simplicity, the values of parameters entering the mold, defining mold atmosphere are usually assumed to be constant, which is not. This variability of the various process parameters of different mold is the root cause of the generation of casting defects. Hence it is required to find out the predictability of individual mold characteristics to track the impact of varied mold environments on defect generation. As a function of time and temperature, the value of these parameters changes. For example, as per Fig. 2, the pouring temperature (PT) for mold no. 01 will be much lesser than tapping temperature (TT). Thus, **TT > PT1 > PT2 > PT3 > PT4 > . . .. .PTn- 1 > PTn**.

This pouring temperature is a function of heat lost to the atmosphere, ladle initial temperature, mold size, casting weight, number of molds, mold filling time, handling time, etc. Similarly, it needs to do so for other parameters to investigate the trends with factor affecting their values. The factors related to casting and mold design such as wall thickness ratio, hole aspect ratio, shape complexity, minimum mold cavity gap, metal/mold material ratio, feeder modulus, feeder efficiency, max/min temperature ratio, max/min gradient ratio, metallostatic head, choke area, gating ratio, gate velocity, max/ min metal rise velocity, cavity fill time etc. are considered constant as the design related issues are already addressed in the design stage.

Table 6 enlists various process parameters that can be assumed constant. Based on the study of numerous researches performed in the foundry and a review of the literature demonstrate that for any experiment involving foundry process parameters, especially the Taguchi method, it is required to consider the noise factor.

Thus, for the green sand casting process the noise factors generally are – the grain size of sand, composition of sand, pouring time, pouring temperature, humidity, metal composition etc. The majority of rejections are caused by pouring and moulding parameters. Thus, pouring temperature, inoculation, carbon equivalent, moisture content, green compression strength, permeability, and mould hardness are considered critical process parameters.

PROCESS PARAMETER (IN EACH MOLD)	**TYPE OF DEPENDENCY**	**NATURE**	**EFFECT**
Pouring Temperature	Time-dependent	Drops continuously	It affects molten metal viscosity and pouring time, blowholes, gas porosity, cracks/ tears, shrinkage cavity, cold shut, misrun, hot tear.
Pouring Time	Temperature-dependent	Increases continuously	Drop in temperature of molten metal changes pouring time, sand inclusion,
% Moisture	Time and temperaturedependent	Drops continuously	Affects many other mold parameters, causes blowholes, pinholes, hot tear,
Metal viscosity	Temperature-dependent	Increases continuously	More the viscosity, more will be the pouring time, causes cold shut, gas porosity, misrun,
Green Compression Strength	Time-dependent	Drops continuously	Affected by moisture content and temperature
Active Clay	Temperature-dependent	Drops continuously	Affected by loss of moisture content, causes hot tear
Compactibility	Time-dependent	Drops continuously	Affected by loss of moisture content, causes hot tear, surface finish,
Permeability	Time-dependent	Increases continuously	Affected by loss of moisture content, it causes blowholes, metal penetration, pinholes,
Green Shear Strength	Time-dependent	Drops continuously	Affected by temperature and moisture content, it causes metal penetration, sand holes,
Wet Tensile Strength	Time-dependent	Drops continuously	Causes defect such as scab, rattail, buckle
Mold Hardness	Time and temperaturedependent	Drops continuously	Causes defects such as drop, hot tear,



Parameter	Details of parameter
Design related Parameters	All those parameters are associated with the design of casting, pattern and mould which includes –The factors related to the design of casting such as wall thickness ratio, hole aspect ratio, shape complexity, minimum mold cavity gap, metal/mold material ratio, feeder modulus, feeder efficiency, max/min temperature ratio, max/min gradient ratio, metallostatic head, choke area, gating ratio, gate velocity, max/min metal rise velocity, cavity fill time are constant as designed..
Chemical Composition Parameters	All those parameters associated with composition of molten metalThe factors related to the chemical composition such as **%C, %Si, %S, %P, %Mn, %Cr, %Mo, %Cu, %Mg, %Ti, %Mo, %Al, %Ni, %Sn, %V, %B, %Ca, Mn/S** Ratio, **%Ca/%Al** Ratio, Carbon Equivalent, Weight percent free carbon, Weight percent total carbon, Weight percent combined carbon, etc. are assumed constant since these are complex parameters and are maintained for a particular batch. The values of these parameters are uniform overall molds.

8. Mathematical modelling and establishing statistical correlations for predictions

Mathematical models can be built suitably by employing data mining tools and techniques such as regression analysis, trend analysis, back-propagation neural networks, correlation coefficients, etc., considering the geometric, process and material characteristics of particular castings. The design parameters of pattern and mold are also considered. To establish the relationship between variables the regression analysis can be suitably used. It involves the response variable i.e. y as a dependent variable and variable i.e. the predictor variable as the independent variable.

The regression analysis aims to construct a model to correlate y to x, which can predict values for the response variable. The regression can be carried out using suitable software. The use of multiple regression methodology for the prediction of various sand process parameters is demonstrated by studies. Mishra et. al. [30] trained and tested the collected sample data for multiple regression analysis using MINITAB 15 software for modelling of the green sand mold system with input of the five mould properties as grain fineness number (x1), % of clay (x2), % of moisture (x3), the mulling time (x4), hardness of the sample (x5) and green compressive strength as output (Y1). The regression equation for GCS [30] is represented in equation 1 as follows:

GCS Y1 ð Þ¼1:02
0:0327x1 þ 0:0659x2 þ 0:0186x3
0:0151x4 þ 0:0033x5 ð1Þ

Now, the above-predicted values are for molding sand prepared just before mold preparation. Depending upon the size of mould box, number and nature of cavities, the molding time, the temperature and the humidity at the shop floor, the number of molds prepared for pouring, time elapsed from molding of individual mold to pouring of individual mold needs to be addressed. Thus, modified regression equation for GCS is represented in equation 2 as follows –

Where b1, b2, b3, b4, b5, b6, b7 are the respective slopes and x6, x7 are variable considered for mulling to actual pouring time (can be referred as standing time) and temperature parameters for molding sand. For correlating the mold environment with defect generation, this needs to be further extended for individual mold giving an idea for the dynamic set of parameters in individual molds. Considering appropriate conditions and impact factors, suitable regression equations can be developed for predicting the desired process parameters at individual mold level to correlate and analyze the effect of mold environment on the generation of a defect. Gukendran et. al. [31] demonstrated the use of neural network models and fuzzy logic for predicting the mould and chemical properties for green sand casting by predicting major casting defects like porosity, hot-tearing, blow-holes, pin-holes, cold shut, as well as shrinkage by using backpropagation and perception from the neural network. using the parameters like sand compatibility, sand permeability, moisture content, sand grain strength, melting temperature, clay content and chemical properties of the charge with inputs as presence or absence of defects as output. It was observed that fuzzy logic models appeared to have superior learning precision with generalization capability and could predict the input parameters of green sand mold more accurately than the backpropagation neural network model.

9. Results

Research studies have reported the analysis of data using multiple regression analysis along with response surface methodology for modelling of green sand molding system successfully predicting the output. Such modelling techniques can be exclusively used by foundries to determine and establish a set of sand molding input process parameters to obtain a desired level of output. Even the backpropagation neural network can satisfactorily predict mold properties in most of the cases indicating the presence and absence of defect by 0 and 1 respectively.

10. Discussion

Considering appropriate conditions and impact factors, suitable regression equations can be developed for predicting the desired process parameters at individual mold level to correlate and analyze the effect of mold environment on the generation of the defect. Equations of heat transfer, dimensions and design of parts, melting parameters etc. form a valuable base for developing equations.

The output process parameters forming the individual mold health are pouring temperature, moisture content, green compression strength, permeability, and mould hardness. The balance and imbalance criteria can be established depending upon the analysis and interpretation of the data mined from each run of individual casting basis. The identification, analysis and prediction of balance and imbalance of process parameters in molds will improve the quality of the casting.

11. Conclusion

The majority of the studies have focused on areas such as the use of simulation in casting design, development of expert systems for casting defect identification, use of advanced statistical tools and intelligence techniques for optimization of process parameters and rejection analysis.

A defect, still, can be the result of a single factor or a combination of multiple factors. As values of process parameters change from individual mold to mold, mathematical models can help to establish a correlation between the process parameters and the generation of defects. The trend in changes of process parameter values too can be estimated. Defects are the product of the interaction of many process parameters, several of which are difficult to identify.

Hence it calls upon studying the behavioural trends of various process parameters and their impact on casting defect generation.

The theory of combined imbalance forms the basis of further investigation and understanding of the mold metal interactions and correlations of process parameters for the generation of defect-free casting. CRediT authorship contribution statement Harshwardhan Chandrakant Pandit: Conceptualization, Visualization.

Anand Sharad Deshpande: Methodology, Investigation, Supervision. Declaration of Competing Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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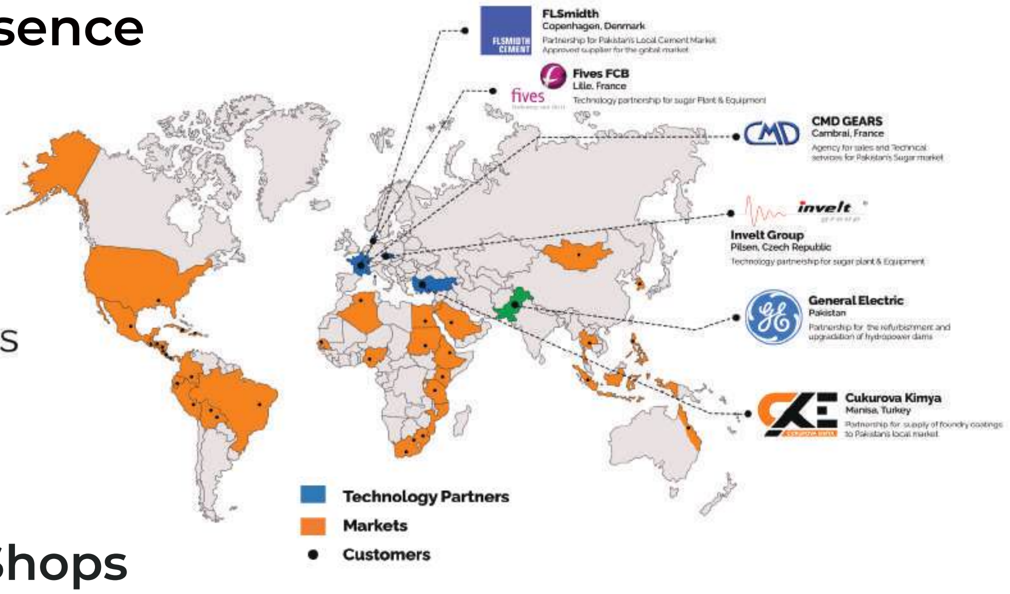

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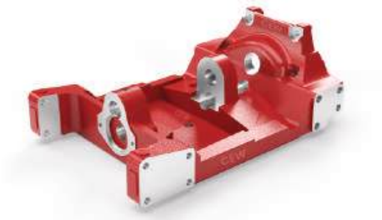
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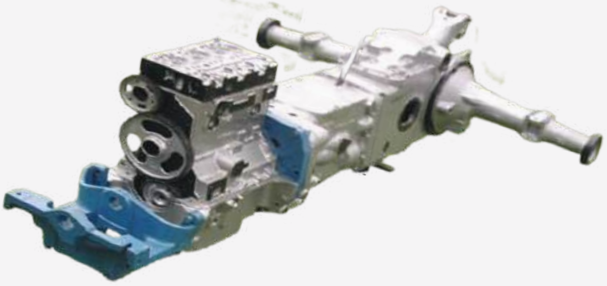

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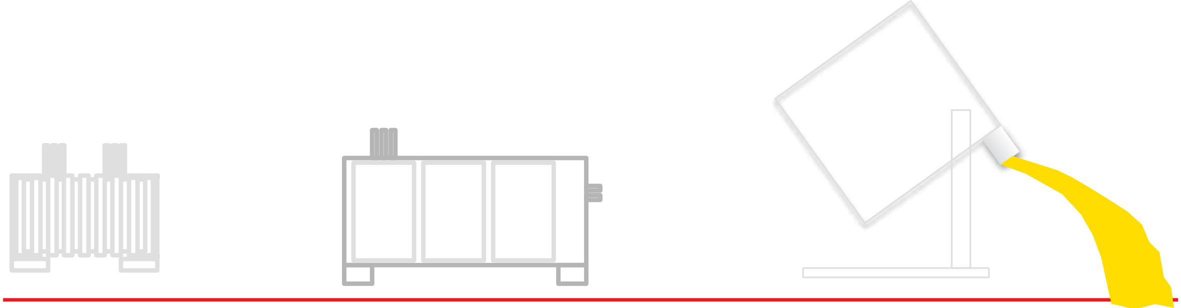

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Parallel Type

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