Review on casting defects and methodologies for quality improvement

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Abstract

In the current scenario of globalization, foundry industries of India play a key role as they are the major source of casting producer. According to Goldman Sachs report, in 2059, India is expected to be the third largest economy by GDP in the world. Manufacturing sectors plays a crucial role and contributes major parts in GDP and countries economic growth. Casting is most promising process to produce complex geometries with intricate details but defect free casting poses a serious threat in its development as compared to other manufacturing practices. Even the process with the controlled environment and skill workers, defects are induced during process which leads to rejection and increases cost of overall production. Therefore, the aim of this research paper is to review the existing research progress in the field of foundry industries and explore the major causes of casting defects and methodologies being adopted by practitioners in foundry industries to develop defect free casting to mitigate the adverse effect on overall cost of product.

Keywords: Defect free casting, strategies for defect free casting, casting defects

1. Introduction

Industrial sector is indispensable for economic growth of the country and contributing around 31% to overall gross domestic products (GDP). Out of which manufacturing industries contributed around 19% as per the annual report of year 2018-19. According to Goldman Sachs report, in 2059, India is expected to be the third largest economy by GDP in the world. Currently, India is the 3rd largest casting manufacturer in the world with installed capacity is around 15 million metric tons/Annum as reported in Oudhia, S. P, (2015). Casting is most promising manufacturing process to produce parts of complex geometries and intricate details and find applicability in almost in all sectors such as Automobile, agriculture, earth movers, railways, defence, machine tools etc. out of which automotive sector alone contributing 32% of consumption in total production. Almost all engineering materials are being processes through foundry practices. The major hurdle of casting process is the defects are associated with it which increases the cost of overall production. According to Chaudhari, S., & Thakkar, H. (2014), even with the controlled environment and skilled foundrymen, defects are encountered during the process which drastically affects the overall production rate. Therefore, defect free casting is the need of today's foundry practitioners. There are numerous parameters involved during casting practice which decides product yield. Therefore, thorough knowledge of various parameters becomes essential for defect free casting. These parameters include engineering materials, gating design parameters, surrounding conditions, initial pouring temperature, solidification time, pouring time, moisture level, permeability, pattern material, pattern design, ramming elements, composition of green sand etc. owing to complexity in process parameters, process becomes highly vulnerable and depends largely on skilled person. Discretion of foundrymen during the process involvement reduces the chances of defects but still producing defect free casting is a challenge. Quality of casted part can be improved through crucially selecting the process parameters and how these parameters results into defect free casting need to be addresses. Therefore, primary objective of this review study is to explore the possible defects arises during foundry practice and focusing on process and design parameters which are involved for generation of various kinds of defects. This study also aims to provide the best practices and methodology adopted by researches to mitigate the adverse effect of process parameters to make defect free casting.

2. Classification of casting process

Foundry practices are basically broadly classified into A) Expendable casting process and B) Permanent casting processes. The expendable casting processes are one in which prepared cavity or mold has to sacrificed in order to take the cast part out. Here, the constraint is on production rate owing to preparation of mold for every next cycle of casting and mold has to break to take the part out. The advantages of expendable casting are complex shapes are possible with intricate details, large casting can be produced, process can be automated, high production rate for some of expendable process such as investment casting. In case of permanent casting processes, the mold or cavity is made of metal and mold can be use again and again without breaking the mold to take out the cast part. As in permanent casting mold is made of metal, the production rate is higher than that of expendable casting processes but part geometries are limited by need to open mold.

The various factors need to be considered in casting operation includes pattern design and its fabrication, selection of mold and core material, pouring techniques, control of solidification processes, process response parameters, melting practices etc Asthana et al., (2006). The casting processes classified as

2.1 Expendable processes

2.1.1 Sand casting

The sand casting is also called as "Green sand casting" in which green sand mold is prepared by mixture of silica sand (around 92% by weight), binder (7% by weight) and water (3% of weight) as shown in Fig 1. The water is added to the silica sand to activate the binder so that the individual particles of sand get proper bondage with other sand particles as well as with moulding boxes. According to Banchhor and Ganguly, (2014) over 70% of the metal are casted by green sand process.

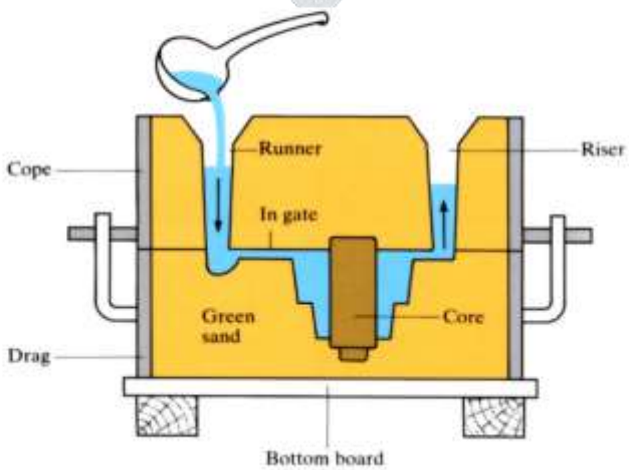

Fig 1: Green sand mold

During the process of sand casting, Wrong selection of process parameters leads to defects in final cast part. According to Guharaja et al. (2006). The Process parameters of sand casting are divided into 5 major categories as

a. Mould-machine-related parameters

b. Cast-metal-related parameters

c. Green-sand-related parameters

d. Mould-related parameters

e. Shake-out-related parameters

The improper selection of process parameter leads to casting defects such as misrun, cold shot, cold shut, penetration, blow holes etc. Therefore, the crucial selection of process parameters is need of foundry industry to produce defect free casting and minimize the adverse effect of defective casting on overall economy of the process.

2.1.2 Shell moulding

Shell moulding is expendable casting process in which the mold is prepared from thin hardened shell of sand and thermosetting resin binder such as phenol formaldehyde backed up by some other material such as sand or metal shot. Shell moulding is accomplished by following five steps

i. The metal pattern is heated upto 350 degree Celsius and coated with parting agent such as silicon. The heated metal pattern is then placed over the box which contain the loose silica sand and thermosetting binder.

ii. The box then inverted so that the loose sand along with binder fall over the heated pattern. When the sand mixed with thermo setting binder comes in contact with heated pattern, a thin shell in range of 5 to10 mm is formed by controlling the temperature and holding time.

iii. Then the box is bringing to its original position.so that uncured sand will be fallen down.

iv. The meticulously the shell is removed from the pattern. The process is repeated to form another identical shell.

v. Both shells clamped at end and keep the other end open for the purpose of pouring the liquid molten metal

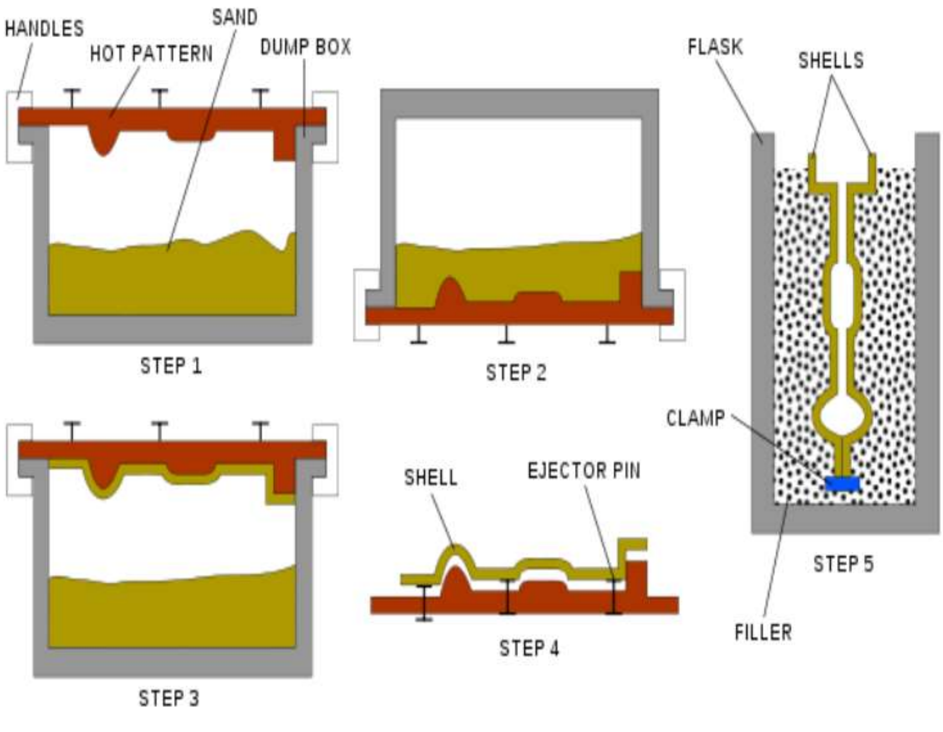

Fig 2: Steps involved in shell molding process [Iqbal et al, (2014)]

2.1.3 Expanded polystyrene process

Expanded polystyrene (EPS) foam is widely used for various applications such as packaging, vibration isolation in automobile industries, food industries etc. The one of the applications of EPS is in casting to produce the pattern from EPS and subsequently utilised the same to produce the casting as shown in fig 3.. In expanded polystyrene process, the pattern is made of EPS and the EPS pattern is vaporised as soon as it comes in contact with heated molten metal Kan and Demirboğa. (2009). Hence, the process is also called lost-foam process, lost pattern process, evaporative-foam process, and full-mold process. The following steps are involved in expanded polystyrene casting process.

i. Preparation of EPS pattern. The pattern is then coated with refractory compound
ii. Preparation of mold by imbedding the EPS pattern into the sand. Here, no need to take EPS pattern out from the sand.
iii. Pouring the heated liquid molten metal directly over the EPS pattern. EPS pattern evaporated once it comes in contact with liquid molten metal

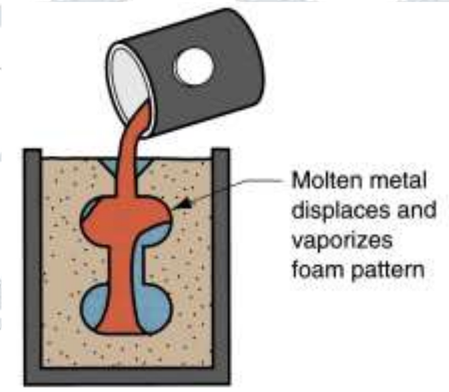

Fig 3: Expanded polystyrene casting process

2.1.4 Investment casting

Investment casting is an expendable casting process known for its capability of producing clear net shape, high-dimensional accuracy and intricate design. The complex shapes such as modern weapons, turbine blades, aircraft parts are easily manufactured by investment casting Davies and Jenkins, (2016). The investment casting has many advantages such as it gives high tolerance in cast part, lower tooling cost, intricate details are possible, highly reliable process etc. The process begins with the production of wax pattern through injection moulding. Many such wax patterns are then attached to central wax sprue to form “tree” to increase the production rate. Then the Tree is immersed in refractory slurry material so that a shell is formed all around the wax tree. Then, the wax is melted out by heating the wax tree. When the wax melted out results in cavity formation. The mold is then subsequently poured with molten metal and allow casting to solidify as shown in fig 4.

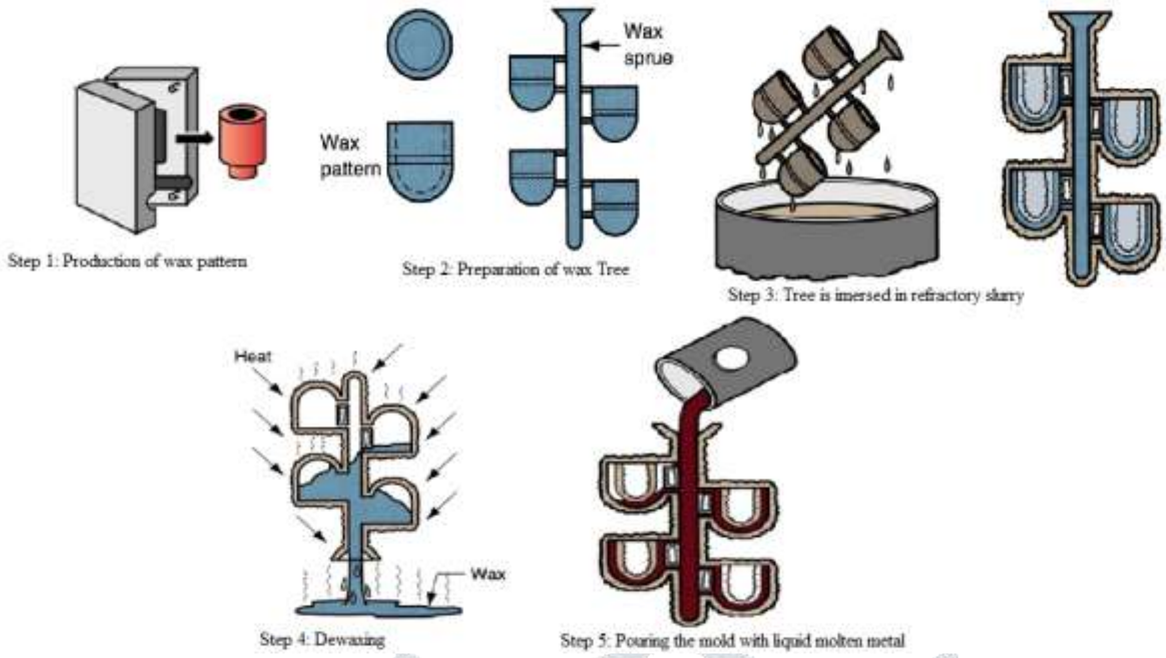

Fig 4: Steps involved in Investment casting

2.1.5 Plaster of Paris moulding

Plaster of Paris casting is expendable casting process similar to sand casting except the cavity or mold is made from plaster of Paris (i.e. gypsum - CaSO4-2H2O). Gypsum is a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$.In plaster moulding process, In mold-making, plaster and water mixture is poured over plastic or metal pattern and allowed to set. Here, Plaster mixture readily flows around pattern, capturing its fine details and good surface finish. Then The mould is extracted from the pattern, and then dried in an oven. Finally, the molten metal gets poured in the moulds.

2.2 permanent casting processes

2.2.1 Die casting

Die casting is permanent casting process in which the mold is made from metal and can be used again and again until quality in the cast part is within acceptable limit. The cavity is created in metal mold and subsequently mold is filled either by gravity, pressure or using centrifugal action produced by rotating the mold as shown in fig 5.

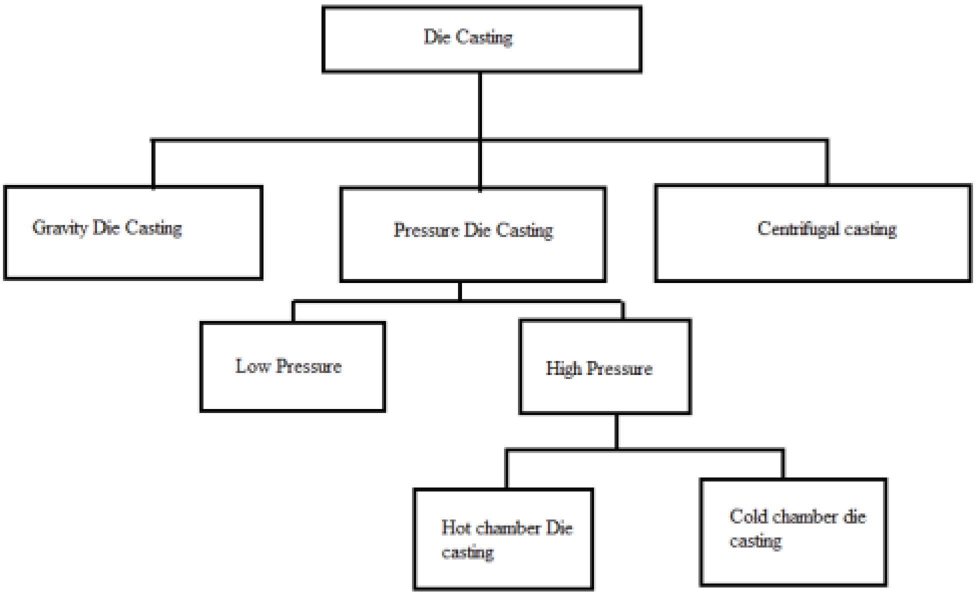

Fig 5: Classification of Die casting

2.1.1.1 Hot chamber die casting

Hot chamber die casting is generally employed for the production of magnesium alloy products Kiełbus et al. (2006). In hot chamber die casting, low melting point alloy is melted in pot surrounded by heating coils. The liquid molten metal is injected at pressure (5MPa to 35 MPa) into the cavity with the help of plunger. The pressure is maintained for some time to ensure the liquid molten metal has solidified in the metal mold. Then the part is taken out with the help of ejector pin and mold is closed again for next cycle as shown in fig 6.

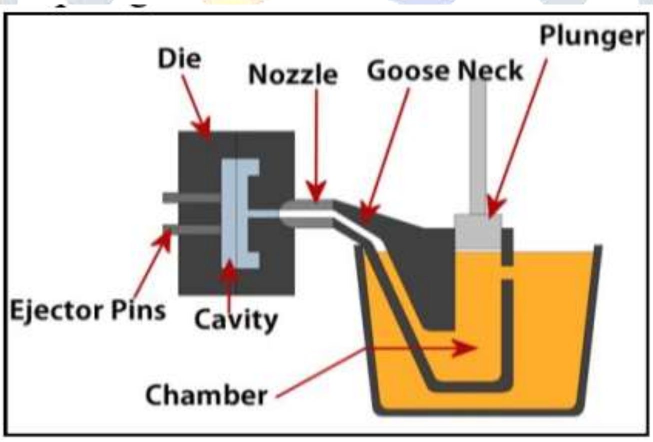

Fig 6: Hot chamber die casting(Pandya et al,2017)

2.1.1.2 Cold chamber die casting

In cold chamber die casting, material is heated and melted at different location and bring back using the laddle to the die casting machine. The molten metal is then poured into the cold chamber and then it is injected into the mold under the application of pressure in the range of (20MPa to 350MPa) as shown in fig 7. The high melting point alloys such as aluminium, brass, and magnesium alloys can be easily process as the plunger is not always in contact with liquid molten metal as in case of hot chamber die casting.

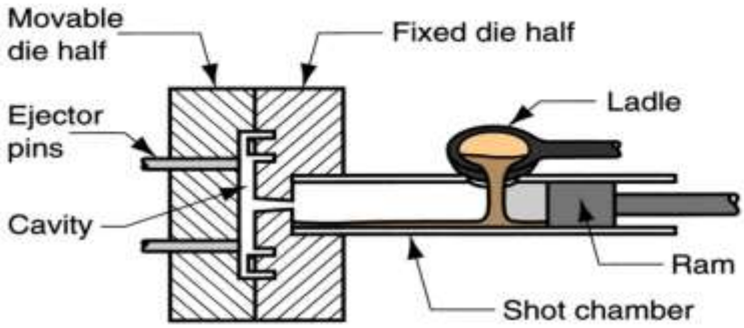

Fig 7: Cold chamber Die casting

2.2.2 Variation of permanent mold process

- Slush Casting

Slush moulding is an excellent method of producing open, hollow objects, including rain boots, shoes, toys, dolls and automotive products. The basic process of slush moulding involves exposing a hollow mold to heat, filling a hollow mold with vinyl plastisol or vinyl powder compound as shown in fig 8. Inverting the mold to pour out the excess liquid plastisol or unfused powder compound and then heating the mold again to fuse the vinyl compound which remains in the mold.

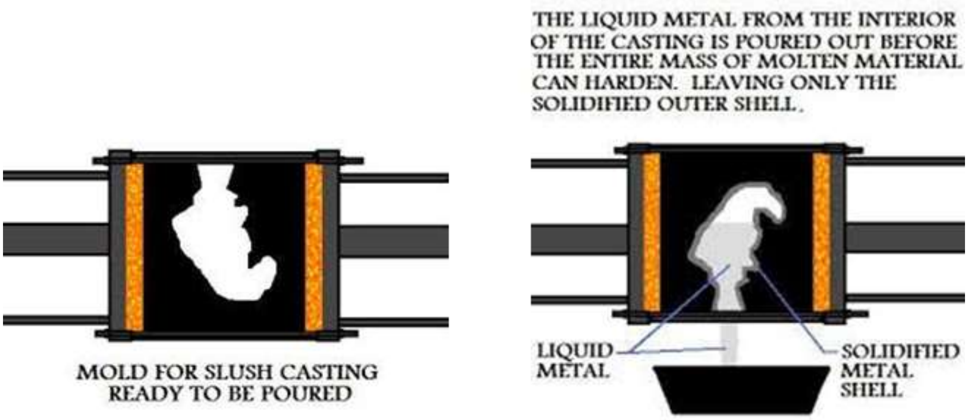

Fig 8: Slush casting

- **Low pressure casting**

In low pressure die casting, Mold is connected to a crucible that contains the molten Metal. The pressure difference induces upward flow, which subsequently filled the mold

- **Vacuum permanent mold casting**

Vacuum moulding is a variation of low-pressure casting in which a vacuum is used to Draw the molten metal into mold cavity. In vacuum die casting process, dies are enclosed in an airtight bell housing. The housing or receiver has two openings: the sprue, at the bottom, through which molten metal enters the die and the vacuum outlet at the top. The sprue opening is submerged below the surface of the molten metal and the vacuum is drawn. This pressure differential causes the molten metal to flow up the sprue and into the die cavity, where it solidifies

2.2.4 Centrifugal casting

Centrifugal casting is a process in which mold is rotated about its central axis as the metal is poured into it. Due to centrifugal force, a continuous pressure will be acting on the metal and metal is get filled into the mold. According to shape of mold, the centrifugal casting method can be classified as a)True centrifugal casting b)Semi centrifugal casting c) centrifuging

3. Materials for casting

Selection of materials for casting is an important consideration as material flows by either through gravity or pressurised ways into the mold. According to Asthana et at, (2006) viscosity of the liquid metal plays an important factor that ensures accessibility of liquid into intricate details and hence low viscosity ensure the liquid metal flows easily into intricate details of mold. Table 1 shows different materials with their required pouring temperature for casting practices

Table 1: Metal and alloy with their pouring temperature [Asthana et al. (2006)]

Alloy	*Pouring Temperature, °K*
Solder	505
Sn alloys	589
Zn alloys	616–727
Al alloys	895–1005
Cu alloys	1172–1450
Cast irons	1616–1755
Ni-base Superalloys	1700–1810
High-alloy steels	1755–1866
Low-alloy steels	1840–1980
Ti alloys	1977–2089
Zr alloys	2116–2172

4. Classification of defects in casting

According to Siddalingswami et al. various controlling factors such as pouring temperature, gating design, moisture contents, sand properties, mold rotation, etc and non-controlling factors such as rate at which liquid molten metal is poured, environmental conditions etc lead to the generation of various kinds of defects in casting as shown in fig 9. These defects are classified into three categories.

4.1 Filling related defect

- **Blow holes/sand blow**

Balloon-shaped gas cavity caused by release of mold gases is entrapped during pouring of molten metal into the mold.

- **Sand inclusion**

It is entrapment of oxide or solid sand particles get entrapped and mixed in molten metal leads to formation of sand inclusion

- **Cold shut**

Metal splatters during pouring and solid globules form and become entrapped in casting

- **Porosity**

Release and entrapment of air gases release when molten metal gets in contact with green sand mold. This air gases are entrapped when molten metal is poured into the mold.

- **Misrun**

A casting that has solidified before completely filling mold cavity

- **Pin holes**

Formation of many small gas cavities at or slightly below surface of casting

4.2 Shape related defects

- Distortion/ warpage
- Mold shift

A step-in cast product at parting line caused by sidewise relative displacement of cope and drag **4.3Thermal related defects**

- Thermal cracks/ tear
- Shrinkage cavity

5. Methodologies adopted for defect free casting

The various research articles published in literature to provide insight into casting defects and provided methodologist to improve quality of the casting. According to Chokkalingam & Nazirudeen, (2009) investigated the mould crush defects occurred during casting of automobile transfer case casting poured in cast iron grade FG 220.Pareto analysis has been done to identify major defect and found indentation in the surface is the major concern in casting known as mould crush. The mould crush cause due to mismatch in core during pasting. The solution proposed to mould crush are make single core, liminating aligning and pasting works.

Jadhav and Jadhav, (2013) investigated the cold shut defect in automobile block of grey CI grade FG150. They analysed that cold shut defect in casting is reduced by controlling the pouring temperature and alloy composition. Seven methodology namely check sheet, Pareto analysis, cause effect diagram, flow chart, scatter diagram, histogram and control chart has been investigated to analyse the cold shut defect occurred during casting. It is observed that cold shut defect is reduced by 50%.

Wadekar et al., (2015) investigated the porosity and shrinkage occurred during gravity die casting through computer aided simulation. The flow ranging from0.7 to1kgs/s is used to find optimum parameters. It is found that bubbles are entrapped during the process and can be eliminated by providing vents in mould.

Joshi & Jugulkar, (2014) investigated the casting defects such as mold shift, mould crush, porosity, shrinkage cold shut. The author analysed these defects through quality control tools such as Pareto and cause and effect diagram and found that high pouring temperatures ensures the elimination of porosity, shrinkage and cold shut whereas air blasting ramming eliminated mould crush and mold shift. Also sand mulling eliminates the problem of buckling, surface finish and porosity.

Khade and Sawant, (2014) investigated the problem of lower yielding in casting of brake disc. The author modelled various gating system design in CAD and simulate the process to obtained yielding in each gating design using Autocast-X flow plus. It is concluded that modified gating design results in more cast yielding.

Dabade & Bhedasgaonkar., (2013) employed design of experiments (DOE) and simulation to analyse the casting defects and obtained optimum parametric setting to avoid failure in casting. Numerous iterations have been performed in simulation to reduce the possibilities of shrinkage. It has been reported that with new feeding system shrinkage are reduced by 15% and casting is yielded by 5%.

Singh & Kumar, (2016) employed Taguchi method to optimize the process parameters to reduce the casting defects such as scab, shrinkage and cold shut. The optimum solution is then applied to casting and found that casting defects are improved by 1.25%.

Jacob & Arun Kumar, (2016) employed taguchi Methodology and selected four variables namely moisture contents, green strength, particles size and mould hardness. By employing the optimized variables, the rejection rate is reduced by 3.40%.

Gupta et al, (2013) investigated the casting defects such as Blow holes, Misrun, Slag inclusion, Rough surface by employing DMAIC (Define, Measure, analysis, improve, control) approach. It is observed that blow holes are reduced from 2.5% to 0.86% by minimising moisture and improving permeability, slag is reduced from 2.68% to 0.78% and misrun is reduced from .2 % to 0.68% by using chaplets. It has been investigated that the various methodologies are being adopted by researchers and foundry practitioners to eliminate the defect in casting such as Pareto analysis, cause and effect, simulations, design of experiments etc. The selection of appropriate method is based on type of casting ,no of casting to be produces and cost associated with the process, and quality aspects required.

Table 2: Methodologies adopted for defect free casting

Author	**Methodology**	**Casting defect**	**Remedies**
Chokkalingam & Nazirudeen, 2009	Pareto Analysis	Mould Crush	1. Skill workers should do alignment and pasting of two halves. 2.Prefer making single core, liminating aligning and pasting works
Jadhav and Jadhav,2013	check sheet, pareto analysis, cause effect diagram, flow chart, scatter diagram, histogram and control chart	Cold shut	Cold shut defect in casting is reduced by controlling the pouring temperature and alloy composition
Wadekar et al., 2015	computer aided simulation	Porosity and Shrinkage	Venting pins are provided in mold to eliminate porosity
Joshi & Jugulkar, 2014	Pareto Analysis, Cause and effect diagram	mold shift, mould crush, porosity, shrinkage cold shut	1. High pouring temperatures ensures the elimination of porosity, shrinkage and cold shut. 2. air blasting ramming eliminated mould crush and mold shift 3. Sand mulling eliminates the problem of buckling, surface finish and porosity.
Khade and	Simulation using	Cast yielding	modified gating design results in more cast

Sawant., 2014	Autocast-X flow plus		yielding
Dabade & Bhedasgaonkar., 2013	Design of Experiments and simulation	Shrinkage and cast yielding	With new feeding system shrinkage are reduced by 15% and casting is yielded by 5%.
Singh & Kumar,2016	Taguchi Method	Scab, Shrinkage and cold shut	Casting defects are improved by 1.25%.
Jacob & Arunkumar, 2016	Taguchi Method	Casting defects	Rejection rate is reduced by 3.40%.
Gupta et al,2013	DMAIC (Define, Measure, analysis, improve, control)	Blow holes, Misrun, Slag inclusion, Rough surface	1.blow holes are reduced from 2.5% to 0.86% by minimising moisture and improving permeability, 2.slag is reduced from 2.68% to 0.78% and 3. Misrun is reduced from 1.2 % to 0.68% by using chaplets.

Conclusion

Defect free casting is indispensable in the manufacturing sector as casting is one of the most promising manufacturing processes to produce complex part with intricate details. Defect free casting is the main challenged currently faced by industry owing to difficulty to control the process parameters and therefore industries have to implement and adopt various practices and methodologies to improve the casting process. It is concluded from available literature that simulation practices are best amongst other strategic tools as it saves time as well as capital investment before the start of actual production and is beneficial tool to identify challenges that may occurs during casting process to minimise defects. The other approaches are also beneficial such as Pareto analysis, design of experiments, DMAIC (Define, Measure, analysis, improve, control), Simulation, cause and effect diagram to analyse the current scenario of casting defects and with crucially analysis those defects the quality of the process can be improved.

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