MINIMIZATION OF SAND CAST DEFECT THROUGH INTEGRATION OF FAILURE MODE EFFECT ANALYSIS (FMEA) WITH CASTING SIMULATION

CASE STUDY: AT AKAKI BASIC METALS INDUSTRY (ABMI)

BY BEZA TADELE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN MANUFACTURING ENGINEERING

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CANDIDATE DECLARATIONS

I hereby declare that the work which is being presented in this thesis entitled **“**Minimization of Sand Cast Defect through Integration of Failure Mode Effect Analysis (FMEA) with Casting Simulation” in partial fulfilment of the requirements for the award of the degree of masters of science in Manufacturing Engineering is an authentic record of my own work carried out **January to September 2017** under the supervision of **Dr. Habtamu Beri** , Program of Mechanical Design and Manufacturing Engineering, Adama science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted to any institute for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Beza Tadele	__________________	_______________
Candidate	Signature	Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with our approval.

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Beza Tadele

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Abstract--- *This paper aims to identify and eliminate current and potential defects from foundry process in the company and presents an effective tool for solving the problem of casting process quality through the application of Failure Mode and Effects Analysis (FMEA) for improving the reliability of products, ensuring the quality which in turn enhances the bottom line of a manufacturing industry. Thus the various possible causes of failure and their effects along with the prevention are discussed in this work. Severity values, Occurrence number, Detection and Risk Priority Number (RPN) are some parameters, which need to be determined. Furthermore, some actions are proposed which require to be taken as quickly as possible to avoid potential risks which aid to improve efficiency and effectiveness of foundry practice processes and increase the customer satisfaction through reduction of casting defect. The expected quality improvement is then simulated using software (procast), which can minimize repetitive trial and error methods in searching for the best technique for eliminating defect.*

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CHAPTER ONE

1.1. INTRODUCTION

1.1.1. BACKGROUND OF THE STUDY

Discovery of casting process dates back to 3500 BC in Mesopotamia, in early stages of casting only single pieces like copper axes, and other flat objects were made. In later periods, when round objects were required to be manufactured, the mould was split into two or more parts to facilitate the withdrawal of the round objects. Metal casting is the process in which molten metal is poured into a mold and allowed to solidify into an object. The object that results from this process is also called a casting. In sand casting, sand is used to define the cavity inside a mold. In addition, sand is used to make any cores that are contained in the mold. The molten metal solidifies in the cavity between the interior of the mold and the exterior of the core.

Casting processes are widely used to produce metal parts in a very economical way, and to obtain complicated shapes with little or no machining. There are five basic steps to create sand casting. These includes design of the part itself and the specification of the material to be used for Pattern making, melting, molding, core making, and cleaning, where each step require its own kind of knowledge and experience. Two major considerations in the casting design are the quality of the final product and the yield of the casting, both of which heavily depend upon the gating system to be used [1].

A quality casting in a foundry is the one with minimum number of defects because it is very difficult to produce defect free castings due to the involvement of a number of process parameters in the casting process, hence one has to control each process parameters to achieve zero defect parts. For controlling process parameter; knowledge about an outcome and their contribution to defect occurrence of each process parameter performed during casting the product is required. Casting defect may be the result of a single cause or a combination of causes. Since the castings may have one or more defects: it is very difficult to identify which process parameter has caused the defect, unless some kind of tool that can direct towards the major causes of the casting defect among others is used. Sand casting is one of the common casting processes, due to its cost effectiveness, but it is also known for causing a number of casting defect on the product produced due to the molding material, people, environment or the cast material itself.

A number of casting defect might arise due to wrong molding material (sand) type selection or preparation, Selection and availability of molding aggregates, type of metal being poured, the type of casting being made, the mold and core making equipment owned by the foundry, and the quality requirements of the customer [1]. Type of sand can determine the refractoriness property of the sand for that specific casting that ensures if the sand grain can melt due to the molten metal temperature and a penetration or a burn on defect can occur or not and also the grain fineness number can determine the permeability property of the sand that determines whether or not the air in the mold can exit through the openings or not which ensures the occurrence of porosity defect on the cast product [2]. High amount of volatile content in the mold which acts as a binding agent for the sand either in green sand casting or the no bake sand casting, determines the occurrence of cavity defects like porosity, where a little of which can result in a mold with no or little bond with the sand particles that might collapse rather than supporting the molten metal while entering and flowing through the mold cavity [2]. In addition to the molding material the casting defects might arise due to wrong process, pouring, methoding or coating process.

Wrong melting process accounts for occurrence of defects like porosity and blow hole since hydrogen and nitrogen gas enter during the melting process. wrong pouring rate and distance between the ladle and the pouring cup can also results in mold erosion (sand inclusion), blow hole and sand burning (bun on or penetration). Wrong methoding which lacks sufficient mold passage that enables proper flow of molten metal to the mold cavity, accounts for occurrence of shrinkage porosity, cold shut and misrun and other defects. Wrong coatings either selection or preparation can also results in the occurrence of defects like scabs, blows, gas holes, inclusions and others. Moreover wrong ramming, venting, assembling, and pattern /gating system ejecting process can result in unexpected outcomes like defects aforementioned above.

Note that the defect arising due to one parameter can also result due to another, which makes the cause identification of the sand casting defect difficult. To obtain this all knowledge about casting defect, their causes, and defect remedies one has to analyze casting defects. Casting defect analysis is the process of finding root causes of occurrence of defects in the rejection of casting and taking necessary step to reduce the defects and to improve the casting yield [3].

Foundries are still using trial and error methods for solving quality problems. There are various approaches used to define, identify and determine the root cause of the defect and Failure Modes and Effects Analysis (FMEA) is among them. An identification of the more serious defect factor cause is the first approach before conducting any prevention or taking defect minimization activity in the foundry. This study focuses on determining the major root cause of casting defects; major factors or parameters that influence the casting quality; their effect on the performance and reliability of the product and finally an action for reduction of the failure or defect is proposed and the outcome is simulated using PROCAST software showing the improved quality of the product due to a measure undertaken for risk reduction.

The Failure Modes and Effects Analysis (FMEA), is a systematic method by which potential failures of a product or process design are identified, analyzed and documented, a systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with them. Once identified, the effects of these failures on performance and safety are recognized, and appropriate actions are taken to eliminate or minimize the effects of these failures. An FMEA is a crucial reliability tool that helps avoid costs incurred from product failure and liability [4].

An FMEA is an engineering analysis that can find and correct weaknesses before the product gets into the hands of the customer. If effectively used throughout the product life cycle, it will result in significant improvements to reliability, safety, quality, delivery, and cost. It addresses the elimination of premature failure due to faulty design or process, provides an organized critical analysis of potential failure modes of the system being defined and identifies the associated causes. It uses occurrence and detection probabilities in conjunction with severity criteria to develop a risk priority number (RPN) for ranking corrective action considerations [4].

Effective use of FMEAs can have a positive impact on an organization because of its preventive nature. FMEA enhances further improvisation of both the design and manufacturing processes in the future as it serves as a record of the current process in formations. It is essential that such an effective analysis has to be carried out for improving various mechanical processes so that the demand of the customers can be satisfied. The process to be simulated is identified by FMEA technique, which is shown in the action to be under taken for a good quality cast product outcome; casting simulation is important in foundries for shorten lead times, help solve problems, optimize existing jobs, train employees, improve customer relations, and attract more jobs through improved market image.

The major aim of integrating the simulation with FMEA in this thesis is just for minimization of cost and time through the process of reduction of failure occurrence. Even though FMEA is a tool for identifying root cause of failures and that enables to implement a corrective action, it needs to be cheeked for its practicality. Testing for a quality cast outcome is not only very expensive and time consuming due to the difficulty to meet the desired quality level. In fact various types of products are manufactured in the foundry (ABMI) like Trash plate & scrapper plate, Pinion & Sprocket gear, Mill roller, Armor plates, and etc…; which makes identification of faulty process parameter among others very difficult due to the non consistency nature of manual operations, a product with a repetitive defect occurrence is chosen and after the fault is fully identified, the right action is recommended, then simulation can be performed for that specific product, making sure the recommended action can resolve identified problem; then practical implementation can be performed with less error.

1.2. STATEMENT OF THE PROBLEM

The major focus of this thesis is in the foundry workshop of ABMI. The foundry suffers from poor quality and low productivity due to involvement of faulty process parameters. Casting defects can negatively impact the bottom line of the foundry. At the simplest level, they manifest as rework costs or casting scrap costs. However, in many cases, the casting defects may be discovered at the machining stage, at the assembly stage or during use of the component; which is one of the challenges that makes the fault detection difficult because all cast products aren’t inspected for quality and the foundry personnel may not have the time to conduct a detailed casting defect analyses, to determine root causes and implement corrective actions to prevent reoccurrence of these defects. In addition, the mechanical performance of the cast product can also be affected which will be noticed during the real performance of the product.

This poor quality inspection method creates a situation of quality principles ignorance that can affect the foundry in building a good background. Among the products Produced in ABMI, it is common to see defective casting products. The most frequently occurring defects that can be detected by naked eye are:

- Porosity
- Blow hole & penetration
- Sand burn

- Sand inclusion
- Inclusion
- Defective surface

Even though various reasons can be suggested for defect occurrence, from literatures and interviews and direct observation it is important to utilize a modern and systematic way of analysis for finding the major root cause for the occurrence of defect that ensure production of a sustainable quality product in the foundry. In addition to that a casting production process does not have a consistency, since there will not be always a defective product or a quality product because it depends on process parameters;. Therefore the major faulty product, process or defect shall be identified in a more scientific way, FMEA is recommended for the purpose of this study.

(A) (B) (C) (D)

Figure-1.1 Some of the casting defects in ABMI (A) Burn on defect, (B) Penetration defect

(C) Shrinkage porosity, slag, pin hole & blowhole defect, (D) Burn on defect

In the foundry under study even though there exists a visible defective product in the products surface, it is commonly assumed as that will not majorly affect the performance of the product, other process parameters like ramming, assembling, venting and pattern/ gating system ejection are also performed with less knowledge about both the outcome and effect on the product to be casted, which indicates that the foundry personals lack proper training. In addition the foundry applies a gating system that doesn't designed for a specific product, where it might cause an excess or insufficient molten metal flow for the product to be casted.

1.3. OBJECTIVE

1.3.1. GENERAL OBJECTIVE

The general objective of this study is to investigate sand casting defects at ABMI foundry and improve the process parameter that enables yield in a defect free cast product.

1.3.2. SPECIFIC OBJECTIVE

- Identify the mode of the casting process in the foundry
- Recognize potential failure modes and their causes
- Evaluate the effects of each failure mode on the product
- Identify measures for eliminating or reducing the risks associated with each failure mode
- Selecting the suitable action to be implemented for improving the cast product
- Simulating the outcome of the recommended action
- Experimental and practical study

1.4. SIGNIFICANCE OF THE STUDY

Before finding solution for any problem it is important to know the causes and among the causes the major root cause of the problem; that is leading to the occurrence of the failure. This thesis aims to investigate the major process parameters that causes defect at ABMI foundry that influences customer satisfaction and that results in low performance of the casting product.

The study enables to answer which failure is most common and serious one? What are the major causes of the failures? And among the causes which is the major one? What actions can be taken in order to minimize the occurrence of the root causes? So answering those questions will lead directly in to the right action implementation.

Therefore, among different parameters that affect the casting quality, one major parameter can be identified, by adjusting the value of the parameter or variable the value of RPN value can be reduced which practically will also improve the quality of the product. This thesis also aims to provide correct guideline to quality control department to find casting defects and will help them to analyze defects resulted from a faulty process parameter with less cost and time. This study is expected to overview the amounts of loss the company is facing in terms of money or customer complains due the reduced metallurgical properties of the products.

1.5. SCOPE OF THE STUDY

This study aims to conduct a research on identification of the basic causes of the casting defects that are routinely occurring in ABMI foundry using FMEA as a tool. After the major cause is identified using the FMEA tool, a solution is to be proposed and to make sure the outcome of the solution a simulation is to be made. Finally the simulated solution will be tested through experimental test and the improvement of the product quality with the solution is then compared with previous result.

1.6. RESEARCH METHODOLOGY AND MATERIAL

1.6.1. RESEARCH METHODOLOGY

To meet the objective of this study various tasks have been conducted these tasks are achieved through literature survey, data collection, data analysis and at last a practical test is performed, to make sure if the data collected and analyzed can meet with the intended objective of the study.

Literature Survey: The theoretical principles of the FMEA, casting and casting defect are reviewed from the literatures including books and research papers written by different authors.

Data Collection: the data regarding the type of casting method, materials, equipments and tools utilized in ABMI, the frequency & type of casting defect occurrence, current control measures and the frequently defective product, the dimensions of gating system and flux and others are identified through interviewing the foundry personnel and visual identification.

Data Analysis: The descriptive techniques have been adopted for analysis of data. In doing so tables for describing the available materials equipments and method in the foundry & percentages are used for expressing the casting defects found and minimized. The proposed solution drawing is prepared using the CATIA software utilizing the data collected, simulation is prepared with PROCAST software, and iterated to make sure if the expected result can occur or not.

Practical test: After the outcome of the recommended action is known for its positive outcome, and the simulation result is practically tested, the test is performed in the ABMI foundry changing the identified parameter by the newly designed one, a new cast product is then prepared by controlling the other input process parameters as constant as possible.

At last the FMEA RPN is recalculated making sure the risk associated with the identified input process parameter is reduced in value that might leads to identification of another process parameter which neds to be improved.

1.6.2. RESEARCH MATERIAL

The type of available equipments and materials present in ABMI foundry are as shown in the following table below.

Table-1.1 List of input materials in ABMI

Process	Material
Melting	Induction Furnace Cast iron Ferrous and non ferrous metals
Pouring	Ladle Slag remover Exothermic powder
Molding	Silica sand (new or reclamed) Furfuryl alcohol binder Sulphonic acid catalyst Isomol and iron coating covers Dolomite powder ($CaMg(co_3)_2$) Flask
Core making	New Silica sand Furfuryl alcohol binder Sulphonic acid catalyst Isomol and iron coating covers Core box
Pattern	Wood
Gating system	Wood
Flux	Metallic

As it is indicated in the above the experimental analysis out come with the designed gating system is to be made, the input methods & materials of the experimental analysis are as shown in the table below;

Table-1.2 Input materials and equipments for the experiment

s.no	Product	Dimension
1.	Sprocket gear	Do=1160 mm Dsh=300 mm Thickness=250 mm No of teeth=12 Pitch =300
	Material	Composition
2.	Cast steel	C = max 0.19 Mn = 0.40 up to 0.80 Si = 0.20 up to 0.45 P = max 0.040 S = max 0.040 Pouring temp=1560 o_C
	Method	Type and amount
3.	I. Sand II. Resin III. Catalyst	I. New Silica sand (GFN 38.07 &2304 Kg) II. Furfuryl alcohol (27.648 ml) III. Sulphonic acid (13.824 ml)
4.	Flask	1500X642 mm
5.	Pattern	Wooden
6.	Coating material	Isomol coating
7.	Chill	Cast steel

8.	Powder (additive)	Dolomite powder
9.	Ladle	Hand shank/geared ladle
10.	Furnace	Induction furnace
11.	Gating system	Wooden
12.	Venting wire	3 mm
13.	Exothermic powder	

1.7. ORGANIZATION OF THE STUDY

This thesis encompasses seven chapters presented as follows. The first chapters briefly discuss an overall view about this study. The second chapter is concerned with related literatures review of papers published by different scholars utilizing different techniques for predicting, preventing and minimizing the occurrence of different casting defects. Overview of casting defect is discussed in chapter three discussing casting defects in relation with different process parameters. Chapters four introduce the FMEA technique in detail. Chapter five explain about the foundry under the study ABMI products and production process, and major casting defects occurring under the investigation, using the FMEA technique. In chapter six the results of the FMEA technique performed in the previous chapter are discussed, and identification of an action that can helps with minimization of occurrence of the faulty process parameter or minimize the fault relating with the process parameter are discussed. In the last chapter, chapter seven conclusion and recommendation is presented.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

A variety of papers have been published by different scholars utilizing different techniques for predicting, preventing and minimizing the occurrence of different casting defects. Some are presented as follows.

Carlson, Zhiping Lin, Richard Hardin and Christoph Beckermann., 2002: presented a multi-phase model that predicts melt pressure, feeding flow, and porosity formation and growth in steel castings during solidification. By combining Darcy's law, which governs fluid flow in the mushy zone, with the equation for Stokes' flow, which governs the motion of slow-flowing pure liquid, it is possible to derive a momentum equation that is valid everywhere in the solution domain. A pressure equation is then derived by combining this momentum equation with a continuity equation that accounts for the solid, liquid and gas phases present. The partial pressures of the gas species dissolved in the melt are determined using the species concentrations, which are found by solving a species conservation equation for each gas species present. Once the total gas pressure is high enough to cause pore nucleation, the amount of porosity that forms is determined from the continuity equation. This multi-phase model has been successfully implemented in a general-purpose casting simulation code. Results are presented to illustrate the basic physical phenomena involved. The present model is valid for both microporosity and macroporosity, and is capable of predicting both shrinkage cavities and riser pipes as well. Applications were provided that demonstrated the ability of the model to predict large ranges of porosity in steel castings, and reasonable agreement was found with available experimental results [5].

Binu Bose V, K N Anilkumar., 2007: aimed at reducing rejection rate of castings in an Indian foundry to reduce the rejection rate from 15% to merely 7% using simulation model in foundries. In this paper a case study on a cylinder clamp casting of Milacron product, which is having high rejection rate in an Indian foundry is taken and the defects of casting are solved using the proposed simulation model with Magma 5 software, concluded by replacing the existing trial and error method with computer simulation foundries can reduce the rejection rate from 8.5 to 3.5 % [6].

J. Mocek, J. Samsonowicz., 2011: developed a test method to measure changes of gas pressure in sand moulds during manufacture of iron castings. The pressure and temperature measurements were taken in the sand mould layers directly adjacent to the metal – mould interface. A test stand was described along with the measurement methodology. The sensors used allowed studying the fast -changing nature of the processes which give rise to the gas-originated casting defects. The study examined the influence of binders, clays and refining additives on the nature of the gas evolution process. The effect of the base sand type - quartz or olivine - on the nature of pressure changes was compared. The test stand design ensured the stability of technological parameters in the examined mould elements, and a repeatable process of making pilot castings. The main outcome was classification of sand mixtures in terms of pressure occurring during pouring of iron castings. The obtained results confirm the usefulness of the described method for testing gas pressure occurrence in a sand mould [7].

Achamyeleh Kassie, samuel Assfaw., 2013: has conducted a statistical study to optimize process parameters at Akaki Basic Metals Industry (ABMI) in Addis Ababa Ethiopia, to minimize major steel casting defects. observe just two of the steel casting defects, gas defects and shrinkage defects which are severe in their nature. In order to minimize these defects, four process parameters were studied like Sand – binder ratio, Mold permeability, Pouring Temperature and De-oxidant amount in three levels. In order to obtain a representative experimental data it was used a factorial experiment; experiments conducted using Taguchi's DOE for identifying the optimum combination of process parameters that minimize the formation of gas cavities in steel castings made of 46MnSi4 steel. The experimental design involves using orthogonal arrays to organize the parameters affecting the casting process and the levels at which they should be varying. Instead of having to test all possible combinations, the Taguchi method tests pairs of combinations to allow collection of the necessary data to determine which factors are most affecting the casting quality with a minimum amount of experimentation, thus saving time and resources. Finally concluded by selecting the good combination of the selected parameters through trail of experiments [8].

Pravin Kumar, Venkatakrishnan, Vignesh Babu.S., 2013: conducted the process failure mode effect and analysis of End Milling process. A series of end milling process is done on several work pieces and the potential failure and defects in the work piece and the tool are studied. These are categorized based on FMEA, risk priority numbers are assigned to each one and by multiplying the ratings of occurrence, severity and detection. Finally the most risky failure according to the RPM numbers is found and the cause and effects along with the preventive measures are tabulated. Recommended that the analysis will be helpful as a reference guide to the end milling process failures. work serves as a failure prevention guide for those who perform the end milling operation towards an effective milling [9].

Bhupendra J. Chudasama, 2013: has redesigned of component using Pro-cast software and increasing the product life. study the solidification behavior of material and detection of hot spots in castings with the help of mentioned above casting simulation software. The simulated results also compared with the experimental works. Proved that casting simulation software can minimizing real world trial and error (and surprises) making castings right the first time by moving the trial and error process into the virtual world and determine the cost of different design and process options [10].

Aniruddha joshi, M.jugulkar., 2014: represents analysis of casting defects with Pareto and Cause and Effect diagrams to know correct cause and correct remedial factors to improve quality level and productivity of organization. Pareto principle and cause effect diagram are used to identify and evaluate different defects and causes for these defects responsible for rejection of components at different stages of manual metal casting operations. Pareto Analysis is conducted for identification of major defects those are contributing in major rejection percentage. The out actual reasons behind the defects are identified with use of Cause and Effect Diagram. Concluded that the correct identification of the casting defect at initial stage is very useful for taking remedial actions. This systematic study proves that by means of effective analysis of tools and processes, it is possible to control the casting defects [11].

Prasan kinagi, dr. R.g mench b.r. jadhav, santosh j. Jadhav., 2014: performed Design of experiment and FMEA techniques are combined to analyze casting defects. Casting Defects can be minimized with optimal level settings of process parameters. Pareto principle is used to identify and evaluate different defects and causes for these defects responsible for rejection of components at different stages of manual metal casting operations. The correct identification of the casting defect at initial stage is very useful for taking remedial actions [12].

Tejaskumar S. Parsana and Mihir T. Patel., 2014: aims to identify and eliminate current and potential problems from a manufacturing process of cylinder head through the application of Failure Mode and Effects Analysis (FMEA) for improving the reliability of sub systems in order to ensure the quality which in turn enhances the bottom line of a manufacturing industry. Thus the various possible causes of failure and their effects along with the prevention are discussed concluded FMEA analysis may easily help in improving the efficiency of the manufacturing process and quality of product thus decreasing the number of defective products and saving of rework cost and time. For each specific process the preventions suggested in the table can considerably decrease the loss to the manufacturing industry in terms of both money and time [13].

Shraban Kumar Singha, Simran Jeet Singh., 2015: has used the Artificial Neural Network (ANN) technique to minimize the casting defects by optimizing the process parameters of sand casting defect; which is one of the most promising simulation techniques at present. The Toolbox of the MATLAB software is used to run the different values of the parameters. When the program runs it gives outputs and accordingly the network shows the error between the output and the set target values and the Network corrects itself continuously until the network exceeds the minimum error goal possible. Parameters are selected on the basis of survey from different industry and a rigorous research of the previous paper on this topic The ultimate goal behind the trainings is to minimize the Mean square Error (MSE).From these validation it is concluded that minimization of the casting defect percentages is possible with the help of ANN [14].

Kidu Geberecherkos Weldeanenia and Asmamaw Tegegne Abebe.,2016: conducted a study to optimize the sand casting process parameters of trash plate castings produced from 46MnSi4 alloy steel in ferrous metal foundry applicable for roller stand of sugar industry manufactured at Akaki Basic Metal Industry. Optimum settings of the selected process parameters namely pouring time, runner size and pouring temperature were 82 seconds, 62cm2 and 1672Oc respectively. Contribution of factors were analyzed using ANOVA method and results obtained were pouring time accounted equals 66.33% of the total effect, the runner size 19.44% and pouring temperature was 6.27%. Concluded the dominant parameter affecting the quality of the plant was pouring time of liquid metal [15].

Hardik Rathod Jay K. Dhulia Nirav P. Maniar., 2016: prediction methodology of shrinkage porosity defect in sand casting process of LM25 using experimentation and ANSYS is proposed. The objectives successfully achieved are prediction of shrinkage porosity distribution in Al-Si casting and determining effectiveness of investigated function for predicting shrinkage porosity by correlating results of simulating studies to those obtained experimentally. The real-time application of the research reflects from the fact that experimentation is performed on 9 different Y junctions at foundry industry and practical data obtained from experimentation are used for simulation. Experimental results that there are more chances of shrinkage porosity occurrence near the center of geometry for Y junction. It can also be observed that large amount of shrinkage porosity was formed near the center as found in simulation. However, the location of shrinkage porosity can vary according to geometric and thermal parameter change [16].

Izudin Dugic and Ingvar L Svensson : studied the influence of chemical composition of gray cast iron on metal penetration. a series of test castings was performed at ITT Flygt's foundry. The result showed that the carbon and phosphorus content had an influence on metal penetration. The metal penetration tendency decreased when decreasing the carbon content as well as when increasing the phosphorus content. The penetration areas were analysed in a Scanning Electron Microscope (SEM) with Energy Dispersive Analysis (EDS). The analysis showed that the average chemical composition in the penetration zones was close to the initial composition of the alloy. The whole casting process was simulated with the software MAGMAsoftTM, in order to investigate the solidification characteristics as well as the porosity formation in the casting studied. The inoculation and solidification behavior will result in excess or deficiency of the metal at the end of solidification, which will lead to either metal penetration or formation of porosities [17].

CHAPTER THREE

OVERVIEW OF CASTING DEFECT

3.1 INTRODUCTION

In sand casting process different input materials are used like sand, binding chemicals, catalyst acid, chill, wooden pattern and gating system and the molten metal itself, each combine for resulting a quality cast product but most of the time the major cause for casting defect found to be the process parameter itself, most of the time due to the combination of different process parameters identification of the major cause for casting defect occurrence among others becomes very difficult. In addition the relationship of these input process parameters with the environment and human increase the probability of defective cast product occurrence.

3.1.1 HUMAN ERROR

Input process input materials are which, results in the basic outcomes like molten metal from scraps and a mold which can readily resist the high temperature from the molten metal, through a serious of preparation. The input process parameters differ according to product requirement and type of metal to be applied, for example coating materials and sand type differ from cast product to product, the sand and coating type applied for a specific aluminum cast shouldn't be applied for steel cast product. The gating system also should be designed for a specific product and it shall not be used for another product with different design, since the amount of feeding and molten metal flow of one product might not be the same with the other, gating system that can sufficiently feed one product might result either in yield reduction or insufficient molten metal flow that might solidify without completely filing the mold cavity. The input process parameter does not go wrong by itself, unless faulty operations which mostly depends on in the preparation step such as selection, proportion and preparation that determines whether it is the right type or not.

After the right type of material is selected it is important to determine the proportion, and the preparation process, in sand casting process human error is the major source of casting defects even though the right type of input materials that can meet the specification requirements is selected, manual operations specially in heavy casting operations can't be free from faults so that some kinds of errors still doesn't stop from occurring. For example due to lack of sufficient training the foundry personnel might wrongly compact the mold, use a dirty or contaminated chills or prepare a faulty venting without knowing the significance of the operation they are performing …etc.

Despite that the input material is of the right type with right material selection, the preparation step needs a good overall knowledge about the significance of the input process parameters, which takes the big part in minimizing the chance of defect occurrence. Even though the major reason for this fault is lack of training, in addition to giving training the senior personnel have the responsibility for correcting the faults of others, which makes the process tedious and full of carelessness. Human error accounts for occurrence of blowhole which most of the time blow from mold or core, therefore the gases need a sufficient venting for minimizing the chance of blow formation, a good aspiration technique can reduce the chance of such kinds of defect occurrence.

3.1.2 ENVIRONMENTAL IMPACT

In addition to the human error like selection, proportion and preparation errors, environment has its own impact on the production of quality cast product. Since most of cavity defects resulting in cast products are due to gas entrapment in the molten metal, it is preferable to evacuate the molten metal as much as possible. Since open atmosphere or air is made of approximately 80% nitrogen and 20 % oxygen, which are among major causes of porosity formation in a cast product by reacting with the molten metal, the occurrence of hydrogen related problems seems to be dependent on relative humidity and therefore more common in more temperate regions.

If the pouring location in the foundry is open to the atmosphere the probability of the atmospheric air to entrapping the molten metal is high, in addition in pouring conditions like with the higher the pouring temperature and the slowest the pouring rate, the higher the probability of reaction formation between the gas and the molten metal, mostly if oxygen dissolves in a steel it forms an oxide if it dissolves in iron it results in either oxide or carbon monoxide. [18]

The gases becomes less soluble during solidification resulting in formation of small bubbles or pin holes due to reduced gas solubility, applying the molten metal on wet coatings or some chemical binder formulations result in a reaction with the solidifying metal causing porosity at the surface. The binder and other additives vaporize while the air in the void space expands and the air in the cavity must escape through the voids.

Now among the major causes of casting defects faulty process parameters at each process steps are to be discussed:

A. Melting

Melting process is the process of preparing the sufficient amount of molten metal for casting the desired cast product. An improper melting practice might occur in one of the following steps Preparing the metal and loading Melting of metal, Refining and treating molten metal, Holding molten metal, Tapping molten metal and Transporting molten metal, each can lead to occurrence of casting defect unless a proper care is given. Soluble Gas refers to gases that dissolve in molten metal. Aluminum alloys will dissolve hydrogen. Iron alloys will dissolve hydrogen and nitrogen. Copper base alloys will dissolve hydrogen and oxygen. This means that large amounts of gas that may dissolve in the liquid metal during melting will be expelled from the metal as it solidifies.

During solidification, the dissolved gases will precipitate into tiny bubbles of gas, forming pinholes in the casting. Steel alloys will dissolve hydrogen, nitrogen and oxygen. The problem is that molten metal can hold a greater amount of gas in solution than solid metal can, due to hydrogen picked up during melting in steel casting. Pinholes can also form from nitrogen in steel casting so nitrogen contents should remain under 120 ppm or 0.0012%. Hydrogen problems in steel casting production are most problematic in alloys containing nickel especially with low temperature or high strength grades, To avoid pinholes in steel, hydrogen contents in casting should remain under 6 ppm or 0.0006%. Hydrogen is responsible for loss of ductility in tensile tests and can be reduced by low temperature baking. Some of casting defects expected in this step are porosity (pin hole), slag, and dross; in steel castings many of the reoxidation inclusions include associated porosity. Frequently when the inclusion material is removed by blasting, the associated porosity remains, pinhole formation associated with slag or dross is due to the reaction of iron oxide and carbon to form carbon monoxide, therefore a proper attention must be given in slag removal like degassing operation. [18].

B. Pouring

After the melting the molten metal is temporarily stored in large holding ladles from which metal can be tapped off as and when required. Entrapped gas from the gas design occurs at the sprue or as metal flows through the downsprue, runners and ingates. During pouring, care must be taken to ensure that the sprue remains full and gas isn't pulled down with the metal. This process step also can be one source of casting defect occurrence unless a proper care is given; a number of parameters are to be controlled like temperature, speed and moisture removal from the ladle, where each can lead to a number of casting defects.

- Temperature: if the pouring temperature is not set to proper value the result is a defective product this defect is known as thermal defects. Low pouring temperature can results in occurrence of gas defects like blowhole and pin hole. Especially in skin forming metals like steel, if the molten metal is poured too cold, the metal quickly forms a solid skin. If the gas reaches the top of the mold cavity after a skin has formed, the gas cannot permeate the solid metal skin. In another hand in regard to pouring temperature, when the molten metal contacts the mold surface, it quickly loses heat and a thin, solid skin forms against the mold. This skin prevents molten metal from penetrating into the voids between the sand grains. In skin forming alloys when the filling event is chaotic, air bubbles can be entrapped in the casting. Sometimes the air bubbles deflate, leaving the oxidized skin. When metal is poured at higher temperatures, the extra heat in the metal diffuses into the sand, delaying the skin formation. Without the rapid formation of the skin, molten metal has more time to penetrate into the sand, creating the defect like penetration or burn on, gas defects can also occur at high pouring temperatures because of an increased reaction of the molten metal at higher temperatures.
- Pouring rate/velocity: higher pouring velocities create more pressure, allowing the metal to penetrate more easily; the strength of the sand during and just after pouring, is a common cause of defects for iron and steel foundries where higher metal temperatures are required. The defects that occur due to this problem are swell, erosion and run outs, by sand with a low hot compressive strength. Erosion is excess metal on the casting surface at places where high metal velocity exists, such as at the front of a gate. Without sufficient hot strength, high metal velocity washes the mold material away, leaving an erosion scab. The loosened sand may be found as inclusions in other parts of the casting. Besides increasing the hot strength, reducing ingate metal velocities also solves this problem.
- Moisture on the ladle: this is an early preparation step while the melting process takes place, the ladle is prepared for moisture removal and heating which is an important step

prior to pouring the molten metal in to the ladle; to making sure the moisture has completely exit from the ladle. Moisture in the ladle accounts for occurrence of gas defects or porosity in cast product unless complete removal is made. An acetylene gas is ejected inside the ladle and a fire is ignited to produce a heat that prepares the ladle for holding the high temperature as the molten metal is poured, to reduce the heat transfer or keep the temperature of the molten metal as high as possible, the reverse can results in reduced molten metal temperature resulting in defects associating with low molten metal temperature, and a gas defect due to the reaction with the molten metal.

C. Molding / core making

Gas bubbles are blown into the liquid from a core or mold, if the local gas pressure in a mold or core exceeds the local metallostatic head of the molten metal, a bubble will be blown into the liquid metal. Molds and cores normally contain binders and additives which liberate gas on heating and if the gas which is evolved during casting cannot escape freely, bubbles will be trapped in the liquid metal filling the mold. The holes caused by these bubbles in the solidifying metal give rise to true blowholes, the gas generated from binder can be estimated from the loss on ignition (LOI %) as a function of temperature, at 500°C three quarters of the volatiles in the sand mixture are removed. If an entrapped gas bubble floats to the top of the mold cavity, the gas should permeate into the molding sand before the metal can solidify around it. If the permeability is not sufficient, the gas may not have enough time to leave the metal before solidification takes place. The force that pushes gas into the sand is the metal head pressure. If enough head pressure is not above the top of the casting, then the gas may not be expelled quick enough. [19]

When cores are heated, gas is evolved and must be removed through the permeability or venting of the core. When venting is inadequate for the evolved gas, blowholes will occur. The rate and quantity of gas evolved from a heated core depends upon the quantity of binders present and their condition. The pressure at the mold-metal or core metal interface rises because the air being replaced in the mold must be evacuated and removed, the air in the mold or core heats up, and the binder or other mold materials boil, decompose and heat up. The mold or core materials prevent the immediate release of the gas pressure. The resistance of the mold or core depends on the distance to the vent or free surface, the smallest cross section of the vent and lowest permeability. The resistance to gas flow through sand molds and cores is measured as permeability.

In addition to the venting the calibration of the binding agent and catalyst used for preparing a sound mold that can resist pressure from molten metal flow is important factor, but if careful attention is not given an excess volatile content might result which also accounts for formation of gas defect like blow hole and pin hole. Entrapped gas from core or mold binders occurs when these organic materials degrade as they are exposed to the heat of the molten metal. The greater the amount of resin used to manufacture the cores and molds, the greater the amount of gas to be generated. Minimum amount of which can create a very loose bond between the sand grains results in mold break up during assembly stage. And the reverse can result in formation of hard baked mold or core where the bond between the sand grains is very strong, so that the openings through which gas exit is minimized in diameter minimizing permeability.

Sand binding systems can have a significant impact on the nature of the casting skin formation. In particular, the binder containing elements such as S, O and N may adversely affect the structure of the layer. Reaction occurs between the liquid metal and the molding material, these reactions may produce products that act as glue, adhering the molding sand to the casting. This reaction usually is limited to ferrous alloys (especially steel). Therefore the proportion or calibration of the binder and catalyst for a certain amount of sand must be made as careful as possible. [19]

- Venting, ramming and coating: these are parameters which directly affect the molding and core making process, if one of that parameter performed faultily casting defect is the outcome. Each of the process has its own impact on production of quality casting product.
- Venting is the process of preparation of a hole in the mold or core surface through which a gas can exit, that can help with creating a healthy aspiration so that no gas is to disturb the molten metal through the process of mold/core heating, while the molten metal enters the mold cavity. Vents on top of the casting cavity will allow gases to escape prior to the complete filling of the cavity or possibly while the metal is in the molten state. Once the vent fills with metal, it quickly freezes off. At that point, no further removal of gas from the mold cavity can occur. But faulty venting is known for causing unhealthy aspiration which results in disturbance of the molten metal for helping the exiting gas from the mold or the core to run through the mold cavity. The gases released from the decomposing mold and core materials to flow through the molten metal until solidification occurs.

Venting also helps in situations where low permeability is a problem. After the gas enter the molten metal, diameter of the trapped bubble reduce and finally collapse resulting in a blow hole inside the solidifying metal.

- Ramming: is another important process for preparation of a compact mold that resists falling during assembly or erosion during mold filling. Since ramming specially in heavy casting is performed manually, unless the ramming pressure is controlled to appropriate value a fault is expected to occur either over or soft ramming. Soft/ non uniform compaction or ramming is responsible for occurrence of a sand inclusion during stripping of patterns, core setting or assembling of molding flasks and sand burning due to uneven distribution of inflowing metal causing local overheating the sand grains are forced to melt by the temperature of the inflowing molten metal forming a permanent bond between the solidifying metal becoming part of the casting. Improving mold compaction increases density and leaves less room for the metal to penetrate. **[20]**
- Coating: All foundry coatings are suspensions of a high temperature mineral or refractory in a liquid carrier. After being applied to a core or mold surface the liquid is removed by evaporation and a layer of refractory is left on the sand surface. The benefits of a foundry coating are only achieved if the coating is the proper one for the job and if the coating is correctly prepared, applied, and dried. The application of mould and core washes creates a high thermal integrity barrier between the metal and the mould resulting in the reduction of the thermal shock experienced by the sand system. These thermal shock leads to series of surface defects such as veining/finning, metal penetration, burn-on/in, scab, rat tail, erosion etc. The use of coatings reduces the tendency of occurrence of these defects. However, the understanding of the coating, its components, characteristics and mechanism of action is important. Improperly selected, prepared or applied coatings can result in poor casting finish and / or applied coating defects such as scabs, blows, gas holes, inclusions, etc [21].

D. Method

Methoding involves the design of system like pattern equipment and molding process, gating system through which liquid metal is distributed in to mold cavity and risering or feeding system which insures shrinkage and other solidification related defect from occurring, resulting in an optimum casting quality to be achieved. Shrinkage defects occur when feed metal is not available/ sufficient to compensate for shrinkage as the metal solidifies. Shrinkage defects can be split into two different types: open shrinkage defects and closed shrinkage defects. Open shrinkage defects are open to the atmosphere, therefore as the shrinkage cavity forms air compensates.

There are two types of open air defects: pipes and caved surfaces. Pipes form at the surface of the casting and burrow into the casting, while caved surfaces are shallow cavities that form across the surface of the casting. The density of casting alloy in the molten state is less than its density in the solid state. Therefore, when an alloy changes phase from the molten state to the solid state, it always shrinks in size. This shrinkage takes place when the casting is solidifying inside a die casting die. At the centre of thick sections of a casting, this shrinkage can end up as many small voids known as 'shrinkage porosity' [22].

If the poured metal undergoes excessive turbulence while flowing through the gating system, air and gas can become entrained and flushed into the casting cavity. So a smooth surface is important while cutting the gating system, up and downs needs to be avoided. Mechanical penetration also can occur where the metal impinges on the mold wall. This dynamic pressure of the metal can force it into the sand grain openings. This often occurs near the gate entrances to the casting. High metal velocities found at the gates can produce the pressure necessary to create penetration defects.

The pattern also need to be designed applying the important allowances compensating for metal shrinkage and machining, draft allowance for preventing the mold from breaking due to sharp corner of the pattern or the gating system. sharp corners need to be avoided by a fillet or radii not only sharp corners but, non uniform wall sections also result in hotspot formation that change themselves in to defect most of the time shrinkage porosity in the thickest section. Molding process like choosing between mechanized/manual molding, green or no bake sand casting, calibration of the sand, binder and catalyst content, application of chill…etc are also to be considered in the method step, that improper methoding can result in a defective cast product.

CHAPTER FOUR

OVERVIEW OF FAILURE MODE EFFECT ANALYSIS (FMEA)

4.1 INTRODUCTION

4.1.1 DEFINITION

FMEA is a systematic analysis of potential failure modes aimed at preventing failures. It is intended to be a preventive action process carried out before implementing new or changes in products or processes.

Failure Mode and Effects Analysis (FMEA) is a method designed to:

- Identify and fully understand potential failure modes and their causes, and the effects of failure on the system or end users, for a given product or process.
- Assess the risk associated with the identified failure modes, effects and causes, and prioritize issues for corrective action.
- Identify and carry out corrective actions to address the most serious concerns.

An FMEA is an engineering analysis done by a cross-functional team of subject matter experts that thoroughly analyzes product designs or manufacturing processes early in the product development process. Finds and corrects weaknesses before the product gets into the hands of the customer [23].

FMEA is a step by step tactic to identifying all possible failure throughout the processes. “Effect Analysis” denotes to studying the consequences of those failures. The motivation for undertaking a Process FMEA is to continually develop products and process consistency thereby increasing customer satisfaction Failure mode and effect analysis is an analytical technique (a paper test) that combines technology and experience of people in identifying probable failure mode of product or process and planning for its abolition. FMEA is a “before-the event” action requiring a team effort to easily and inexpensively alleviate changes in design and production [23].

FMEA can be explained as a group of events projected to; Anything that can be done to assure the product works correctly, regardless of how the user operates it, will move the product closer to 100% customer satisfaction.

- Recognize and evaluate the potential failure of a product or process and its effects.
- Identify actions that could eliminate or reduce the chance of potential failures.
- Document the process [23].

4.2 HISTORY OF FAILURE MODE EFFECT ANALYSIS (FMEA)

The FMEA was developed and implemented for the first time in 1949 by U.S. Army and later executed in Apollo space program to temperate the risk. In 1950s the increasing attention paid to safety and the need to prevent predictable accidents in aerospace industry led to the development of the FMEA methodology. Later, it was introduced as key tool for increasing quality and efficiency in manufacturing processes. In 1977, Ford Motors introduced FMEA to address the potential problems in the Research and Development (R&D) in the early stage of production and published the Potential Failure Mode and Effects Analysis Handbook in 1984 to promote the method.

Later on the automobile manufacturers in America also introduced the FMEA into the management of suppliers, and took it as a key check issue. Find out reasons behind the failure of some subjects of mechanical engineering course and after analyzed the system through FMEA and they suggested recommend to solve the problem. Execute FMEA to develop an effective quality system and to improve the current production process for the better quality of the products.

FMEA is applied model in salmon processing and packing industry in joint with ISO 22000 and they got the valuable result from implementation. The FMEA has the potential to improve the reliability of Wind turbine systems especially for the offshore environment and made system cost effective. Modified failure mode and effects analysis (MFMEA) method to select new suppliers in term the supply chain risk’s perspective and applies the analytic hierarchy process method and found excellent result. Applied FMEA technique on two products flywheel and flywheel housing and prevent different failure mode and suggestions were successfully implemented and the industry gained considerably in terms of both money and time. Used FMEA to optimize the decision making process in new product development in automobile industry.

Before long, FMEAs became a key tool for improving safety, especially in the chemical process industries. While Engineers have always analyzed processes and products for potential failures, the FMEA method standardizes the approach and establishes a common language that can be used both, within and between companies. FMEA techniques have been around for 30 + years. More widespread use thanks in large part to U.S. automotive industry and its QS-9000 supplier requirements. QS-9000 standard requires suppliers to conduct product/design and process FMEAs in an effort to eliminate potential failures [24].

4.3 TYPES OF FAILURE MODE EFFECT ANALYSIS (FMEA)

The three most common types of FMEAs are:

4.3.1 SYSTEM FMEA

Analysis is at highest-level analysis of an entire system, made up of various subsystems. The focus is on system-related deficiencies, including

- System safety and system integration
- Interfaces between subsystems or with other systems
- Interactions between subsystems or with the surrounding environment
- Single-point failures (where a single component failure can result in complete failure of the entire system) system FMEA
- Functions and relationships that are unique to the system as a whole (i.e., do not exist at lower levels) and could cause the overall system not to work as intended
- Human interactions
- Service

4.3.2 DESIGN FMEA

Design FMEA Analysis is at the subsystem level (made up of various components) or component level. The Focus is on product design-related deficiencies, with emphasis on

- Improving the design
- Ensuring product operation is safe and reliable during the useful life of the equipment.
- Interfaces between adjacent components. Design FMEA usually assumes the product will be manufactured according to specifications.

4.3.3 PROCESS FMEA

Process FMEA Analysis is at the manufacturing/assembly process level. The Focus is on manufacturing related deficiencies, with emphasis on

- Improving the manufacturing process
- Ensuring the product is built to design requirements in a safe manner, with minimal downtime, scrap and rework.
- Manufacturing and assembly operations, shipping, incoming parts, transporting of materials, storage, conveyors, tool maintenance, and labeling. Process FMEAs most often assume the design is sound

4.4 BENEFITS OF FAILURE MODE EFFECT ANALYSIS (FMEA)

An effective FMEA identifies corrective actions required to prevent failures from reaching the customer; and to assure the highest possible yield, quality, and reliability;

- Allows us to identify areas of our process that most impact our customers
- Helps us identify how our process is most likely to fail
- Points to process failures that are most difficult to detect
- Substantially reduce costs by identifying design and process improvements early in the development process when relatively easy and inexpensive changes can be made
- Improves product/process quality and reliability
- More robust process, and reduces or eliminates the trend for after-the-fact corrective action and late changes crises
- Significantly reduce potential costly liability when product or process do not perform as promised

4.5 IMPLEMENTATION OF FAILURE MODE EFFECT ANALYSIS (FMEA)

FMEA method use at:

- Formation of the product concept, for checking whether all prospects of the customer are included in this concept.
- Define the product, in order to check whether projects, service, supplies are appropriate and controlled in the right time.

- Process of production, in order to check whether documentation primed by engineers is fully carried out.
- Assembly, for checking whether the process of the assembly is compatible with documentation.
- Organization of the service, in order to check whether the product or the service is pleasant with recognized criteria [24].

An FMEA should be the guide to the development of a complete set of actions that will reduce risk associated with the system, subsystem, and component or manufacturing/assembly process to an acceptable level.

In FMEA, failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. This FMEA conducted can be compiled and documented and this can be used in future to design an effective process cycle with an aim of avoiding the failures mentioned in the FMEA table. Later it is used for process control, before and during ongoing operation of the process. Ideally, FMEA helps select remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault). The various steps in Process Failure and Effect analysis are as follows [25]:

1. Review the process
2. Brainstorm potential failure modes
3. List potential effects of each failure mode
4. Assign a severity rating for each effect
5. Assign an occurrence rating for each FM
6. Assign detection rating for each FM and/or effects
7. Calculate the risk priority # (RPN) for each effect
8. Prioritize the FMs for action
9. Take action to eliminate or reduce the high-risk FMs
10. Calculate the Resulting RPN as the FMs are reduced or eliminated

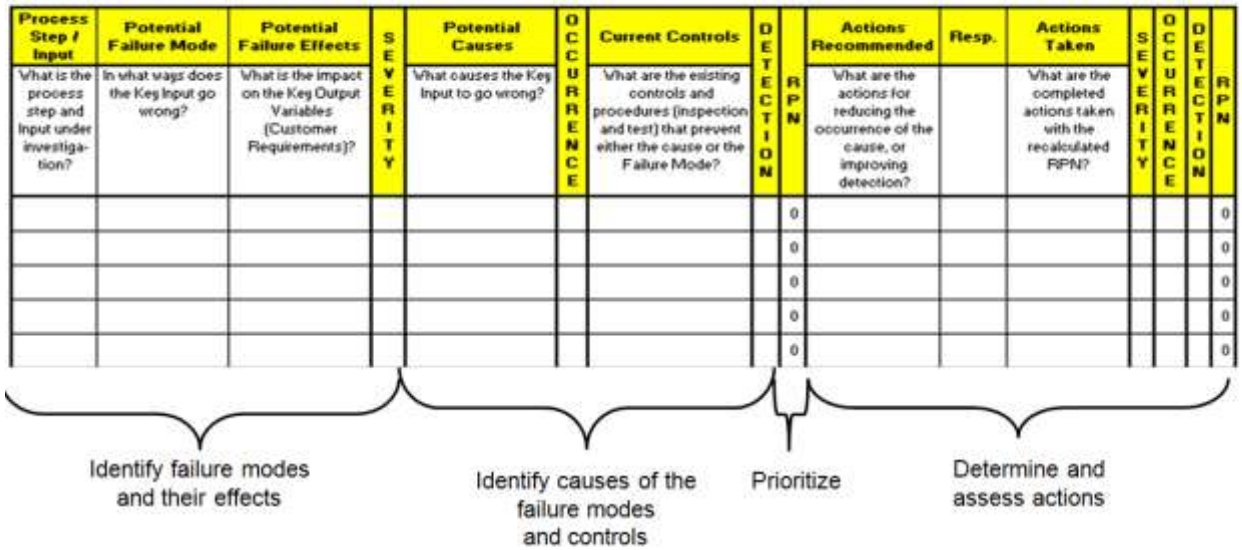


Figure-4.1 Typical FMEA Worksheet [25]

The relative risk of a failure and its effects is determined by three factors/parameters:

- Severity- the consequence of the failure should it occur
- Occurrence- the probability or frequency of the failure occurring
- Detection- the probability of the failure being detected before the impact of the effect is realized

The failure modes with the highest RPNs should be attended first, although special attention should be given when the severity rating is high regardless of the RPN. Once corrective action has been taken, a new RPN is determined by re-evaluating the severity, occurrence, and detection ratings.

The risk priority number (which will range from 1 to 1,000 for each failure mode) is used to rank the need for corrective actions to eliminate or reduce the potential failure modes. To see failure modes with the highest RPNs should be attended to first, although special attention should be given when the severity ranking is high (9 or 10) regardless of the RPN [25].

Risk Priority Number = Severity X Occurrence X Detection

4.6 ROLE OF FAILURE MODE EFFECT ANALYSIS IN FOUNDRIES

4.6.1 IDENTIFICATION OF CASTING DEFECT

Casting is a process which carries risk of failure occurrence during all the process of accomplishment of the finished product. Hence necessary action should be taken while manufacturing of cast product so that defect free parts can be obtained. Mostly casting defects are concerned with process parameters. Hence one has to control the process parameter to achieve zero defect parts. For controlling process parameter one must have knowledge about effect of process parameter on casting and their influence on defect.

A casting defect is an undesired irregularity in a metal casting process. Some defects can be tolerated while others can be repaired, otherwise they must be eliminated. It is very difficult to produce defect free castings. A defect may be the result of a single cause or a combination of causes. The castings may have one or more defects. A properly designed casting, a properly prepared mould and correctly melted metal should result in a sound casting. However, if proper control is not exercised a variety of defects may result in a casting. These defects may be because of following reasons

1. Improper pattern/tool design or lack of allowances,
2. Improper mould and core constituents,
3. Improper melting practice,
4. Improper pouring practice
5. Because of molding and core making materials.
6. Improper gating - riser system along with lack of feed aids.
7. Improper metal composition
8. Inadequate melting temp and rate of pouring.
9. Unskilled post melting treatment like shakeout, fettling etc.

During the process of casting, there is always a chance where defect will occur. Minor defect can be adjusted easily but high rejected rates could lead to significant change at high cost. Therefore it is essential to have knowledge on the type of defect and be able to identify the exact root cause, and their remedies [26]. Since identification of the exact cause of the failure/defect becomes complicated requiring some kind of engineering approaches like the FMEA that makes it easier for identification of the root cause among others.

4.6.2 CREATING THE PROCESS MAP

Identification of the key activity areas in which to concentrate quality control, inspection and manufacturing controls is the first step in implementing the FMEA tool. Casting defect might arise with faulty implementation of one or a combination of the process functions which are to be examined for identifying the root cause for a defective cast product. A typical foundry process includes the following major activities: design of the part itself and the specification of the material to be used for Pattern making, melting, pouring, solidification and cooling, sand preparation, molding, core making, sand removal, and cleaning The process functions are selected for study by considering a failure mode for each function by asking the question; what goes wrong? Does it have undesirable or significant effects? Alone or in combination? to determine the failure modes which one is seriously affecting the expected or required quality. Identify key process characteristics as potential sources of failure.

4.6.3 FAILURE DETECTION METHODS

The possible causes of the cast defect (failure modes) are to be evaluated with respect to the available data that states the casting defect causes and remedies and also through interviewing of the experts and direct observation during the process can help with the detection of the root causes and for ranking the severity, occurrence and detect numbers. The testing of the process parameters through performing an experiment will ensure the deviation of the process parameter from the standard value. This is to be done for the root cause parameter with the highest RPN; before implementing the recommended action. Imperfections at the surface of a casting can be detected by a number of non destructive tests [27].

4.6.3.1 NON DESTRUCTIVE TEST

Non-destructive testing is the use of physical methods which will test materials, components and assemblies for flaws in their structure without damaging their future usefulness done to verify the mechanical integrity or soundness of the steel casting. It can be separated in to surface examination methods which include visual, liquid pentrant, and magnetic particle and subsurface or internal examination methods like radiography and ultrasonic. In this study due to the absence of the subsurface examination technique in the industry a focus will be given to the surface examination techniques. In addition to this a chemical composition test is also important for detecting the elements inside the metal alloy.

A. Visual testing (VT)

Equipments like Surface comparator, Pocket rule, Straight Edge, Workmanship, standards are used. These techniques is used for detecting Surface flaws – cracks, porosity, slag inclusions, adhering sand, scale, etc., no matter what other techniques are required this should always be the primary method of inspection.

B. Liquid Penetrant Examination (PT)

Required equipments are Commercial kits, containing fluorescent or dye penetrants and developers Application equipment for the developer A source of ultraviolet light – if fluorescent method is used. Surface discontinuities not readily visible to the unaided eye

C. Magnetic particle examination (MP)

Special commercial equipment Magnetic powders – dry or wet form; may be fluorescent for viewing under ultraviolet light. Excellent for detecting surface and subsurface discontinuities to approximately ¼” below the surface – especially cracks [28].

D. Permeability testing (pressurizing) of castings (PT (P))

It is employed to locate leaks in a casting or to check the overall strength of a casting in resistance to bursting under hydraulic pressure. Defects are revealed by the flow of liquid or gas into or through the defects. Generally hollow test objects are tested by this method. The hollow test object is filled with gas at a pressure greater than the pressure of surrounding air. Under this condition, the test object is immersed in water. Bubbles are formed at the leaky portion of the object. The major causes of leaks in casting products are Shrinkage porosity – sometimes, Gas porosity – rarely, Oxide films caused by turbulence - most common [29].

E. Chemical composition test

An analysis of chemical composition enables to control the melting process run and to observe the prescribed range of individual elements in accordance with requirements in appropriate material data sheets. Two basic analytical methods are commonly used for chemical composition determination: Classic chemical "wet" analysis and Spectral analysis. Among the two the spectral analysis technique is the available and minimal time consumption with minimized work. Used apparatuses are called automatic spectrometers; divided in to: Optical emission types and X-ray types [30].

CHAPTER FIVE

CASE STUDY

5.1. INTRODUCTION

This chapter will explain about the foundry under the study ABMI products and production process, and identification of the major casting defects occurring under the investigation and understanding how each casting defect has occurred, by utilizing the FMEA technique. The study focuses on directing from the faulty process towards the defect, identifying what kind of faulty process parameters are performed in the foundry, in what way does the input process parameter can go wrong, what is the consequence of that fault on the product specifically what kind of casting defect can occur due to the fault, assigning severity, occurance and detectability values each with respect to the faulty process parameters, then the RPN is calculated and the faulty process parameter in association with high risk is chosen, which indicates that faulty process parameter is the major cause for occurrence of the routine casting defects in the foundry so that an action for minimizing the risk in association with that parameter will be performed.

5.2. AN OVERVIEW OF BASIC METAL AND ENGINEERING SECTOR

Akaki Basic Metals Industry was established in 1989 G.C, established for the purpose of producing and supplying spare parts and capital goods and carrying out such related activities that are deemed important for the attainment of its objectives. This Industry transferred from privatization agency to Metals and Engineering Corporation in the year 2010 G.C. ABMI is formed through amalgamation of six factories. In addition to producing and supplying spare parts and capital goods it also multiply itself by constructing such factories throughout the country and transferring to different enterprises. With the Vision of developing our country in basic metals technology and be competitive in the world market.

Akaki Basic Metals industry established to make metal melting, forging, machining, heat treatment, automotive maintenance and quality control. It was intended to respond to the need of spare parts for textile, sugar, cement industries, other construction supplies, metal industries, transport sector and to some extent to agriculture, energy and mines sector. The company can cast up to 4,500 tons of metal in two shifts annually. The ferrous foundry can melt nodular iron, grey iron, low carbon and alloyed steels. Among a large number of casting methods, ABMI utilizes the no-bake sand casting method for its advantages. There are a number of casting defects grouped under different classes.

Production Factories

1. Cast Iron Casting Factory
2. Ferrous Casting Factory
3. Non-Ferrous Casting Factory
4. Machine Parts Cast Production Factory
5. Steel Processing Factory
6. Ziquala Steel Production Factory

Table-5.1 Main Product of ABMI

s.no	Sugar Factories	Construction Sector	Cement Factories	Infrastructure	Transport Sector	EEU & EEP
1.	Head stock	Blade & Ripper tip	Cement ball	water pump	Brake Drum	Cross arm
2.	Trash plate & scrapper plate	Truck shoe	Crusher hammer	Dam gate etc..	Central Support	Different types of hooks& pins
3.	Pinion & Sprocket gear	Manhole cover with frame etc...	Mobile & fixed jaw plate		Spoket Wheel &5th Wheel	Big collar & bolts
4.	Mill roller		Armor plates		Front hub	

5.	Draw eye shaft & bushing etc…		Different types of liner plate etc		Shackle	
6.					Balance weightetc…	

The direct production areas of the company are divided in to four main divisions. They are:

1. Foundry Workshop (FWS)
2. Mechanical Workshop (MWS)
3. Hand Tools, Cutlery and Forging (HCF)
4. Heat and Surface Treatment (HST)

A. Foundry workshop (FWS): - In this workshop finished or semi finished metal parts produced by casting. The workshop has four units:
   i. Foundry design and Methods section - prepares pattern and mold design for the part design. The pattern design is converted into required pattern sets in pattern making shop, and the mould design is sent either to mechanized or manual molding area where by mold cavity is constructed.
   ii. The molding unit consists of two sub-units: mechanized molding area makes light molds automatically, while the manual molding area is dedicated for heavy molds mostly by human effort.
   iii. Ferrous metal melting unit consists of three induction furnaces for melting ferrous metals and three resistance furnaces for non-ferrous alloys.
   iv. Finishing shop comprises areas for separating molds from castings and then cleaning automatically or manually.

B. Mechanical Workshop (MWS): - in this workshop parts are machined using Variety of Heavy and Light Machine tools arranged in Job shop layout fashion. Sheet metal products are also fabricated using different Sheet metal machines, welding operation and others.

C. Hand Tools, Cutlery and Forging (HCF): there are three units under HCF:
   i. Hand Tools Manufacturing unit: manufactures industrial hand tools.
   ii. Cutlery manufacturing unit: manufactures household and restaurant items.
   iii. Forging unit: performs forging operations to give initial shapes to parts.

D. Heat and Surface Treatment Shop: consists of two units: Heat treatment unit that performs hardening, tempering and carborizing operations; and Surface treatment unit that performs Chrome, Nickel, Phosphate plating and Galvanizing.

E. Design, Planning and Control (DPPC) division consists of two sections: Design and Method (D&M) and Production Planning and Control (PPC) sections. The D&M section is responsible for preparing specifications, and manufacturing methods. The PPC mainly smooth out the progress of the production processes, by Planning, and controlling the progress of production activities.

F. Maintenance section: - this section is responsible to solve mechanical and electrical failures that occur during production operations, and to carry out scheduled preventive maintenances.

5.1. IMPLEMENTATION OF FMEA

1. Process review

The first step prior to conducting the FMEA is preparing a flow chart that allow to ensure an understanding of the casting process under the study is made on each process step . Since casting process is a combination of a number of process parameters it is difficult to easily identify the major root cause of the routinely occurring defects in the foundry, therefore it is important first to identify the mode of casting both with material and practices in the foundry in order for studying the different outputs resulting from the combination of the process parameters. The type of casting process in the ABMI foundry is identified as no bake casting process which utilizes the combination of different input materials to produce the desired casting product. The input materials for each process in the casting foundry are as shown in the following table;

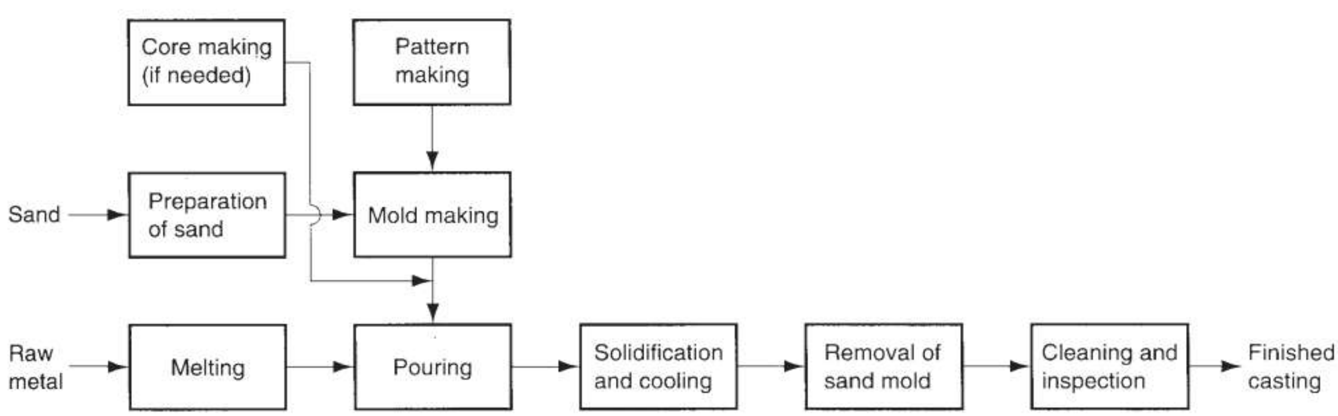


Figure-5.1 Foundry process flow chart

2. Potential failure modes

The potential failure mode of each process parameters are analyzed along with the possible cause and effect of each mode of failure. This helps to identify in what mechanism does the input parameters went wrong by listing out each input process parameters like Melting, Pouring, Molding, Core making and Gating system design. The failure or fault is analyzed in a relation with persons, material, method, equipment and environment, with respect to which will become right or wrong. This step is performed by carefully studying and evaluating the process parameters with expertise and personnel in the foundry under the study.

3. Potential effects for each failure mode

In this step an ‘if…then’ process is conducted that will direct towards the defects resulting from the faulty input process parameters. Most of the faulty process parameters results in a number of defects, which indicates that there are a number of causes for one defects (effects) occurring in the products. These step leads directly to the causes of the defects, rather than guessing the possible causes for the defect occur on the products, now the causes for the routinely occurring defects is made as clear as possible.

4. Assigning Severity, Occurrence, and Detection Rankings

The ranking for FMEA factors is based on a defined way and each of these three rankings is based on a 10-point scale, with 1 being the lowest ranking and 10 the highest. A clear and concise description for the points on each of the scales is made as shown in the generic ranking system for each factors below.

5. Severity ranking

Severity ranking is made according to the effect of the faulty process parameter or defect, that relates the casting defect with the casting product. how seriously can the defect affect the product, with respect to product confirmation to the design requirement, the probability of rejection because of the defect occurred on the product can the defect be removed using machining or not, how easy is the identification of the defect and in relation to mechanical property degradation.

Table-5.2 Ranking of severity of effect

Effect	Criteria: Severity of effect	Ranking
Major serious effect	The product does not confirm the design requirement; cause total rejection and rework, defect noticeable with a naked eye and cause major degradation of mechanical property of the product	10
Extremely high	Product does not confirm design requirement May cause rejection, defect noticeable with a naked eye and maximum scale of maintenance Affect the mechanical property of the product	9
Very high	Minimum non conformance to design requirement ,Medium scale of rejection and maintenance, defect noticeable with a naked eye Affect the mechanical property of the product	8
High	Minimum non conformance to design requirement, Minor scale of rejection and maintenance, defect noticeable with a naked eye and with aid of instruments, Affect the mechanical property of the product	7
Moderate	Minor non conformance to design requirement Minor scale of maintenance, no rejection and with minimum effect on the mechanical property, defect detected only with the aid of instruments &a naked eye.	6
Low	No rejection of the product with minor sale of maintenance, with minimum effect on the mechanical property, defect detected with the aid of instruments	5
Very low	No rejection of the product & no maintenance, with minimum effect on the mechanical property, defect detected with the aid of instruments	4
Minor	No rejection of the product & no maintenance, with no effect on the mechanical property, defect detected with the aid of instruments	3

Very minor	Conformance to design requirement, No rejection of the product & no maintenance, with no effect on the mechanical property, defect detected with the aid of instruments very rarely	2
None	No effect	1

Table-5.3 Ranking for possible failure rates (Occurrence)

Possibility of failure	Possible failure rate	Ranking
Very high	>1 in 4 1 in 5	10 9
Moderate	1 in 7 1 in 8	8 7
Low	1 in 10 1 in 12	6 5
Very low	1 in 20 1 in 34	4 3
Remote	1 in 50 <1 in 50	2 1

Table-5.4 Ranking of likelihood of detection

Detection	Criteria	Ranking
Absolutely impossible	No known controls available	10
Very remote	Very remote likelihood current controls will detect failure mode	9
Remote	Remote like hood current controls will detect failure mode	8
Very low	Very low likelihood current controls will detect failure mode	7

Low	Low likelihood current controls will detect failure mode	6
Moderate	Moderate likelihood current controls will detect failure mode	5
Moderately high	Moderately high likelihood current controls will detect failure mode	4
High	High likelihood current controls will detect failure mode	3
Very high	Very high likelihood current controls will detect failure mode	2
Almost certain	Current controls almost certain to detect failure mode	1

6. Assign an Occurrence Ranking for Each Failure Mode

How often a failure mode may occur. An estimate of how likely a failure mode is to occur and at what frequency by knowing the potential cause of failure. These is analyzed with respect to the sample casting products produced in the foundry under the study out of which are defective, and an interview made with the foundry personnel asking does this process goes wrong? how often?, and the ranking is according to the table above.

7. Assign a Detection Ranking for Each Failure Mode and/or Effect

How likely a failure or the effect of a failure can be detected. This step starts by identifying current controls that may detect a failure or effect of a failure. If there are no current controls, the likelihood of detection will be low, and the faulty process parameter would receive a high ranking.

8. Calculate the Risk Priority Number for Each Failure Mode

The risk priority number (RPN) is simply calculated by multiplying the severity ranking times the occurrence ranking times the detection ranking for each item. This number alone is meaningless because each FMEA has a deferent number of failure modes and effects. However, it can serve as a gauge to compare the revised total RPN once the recommended actions have been implemented.

$$\text{Risk Priority Number} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

9. Prioritize the Failure Modes for Action

The failure modes can now be prioritized by ranking them in order, from the highest risk priority number to the lowest. The 80/20 rule applies with the RPNs in that 80 percent of the total RPN for the FMEA comes from just 20 percent of the potential failures and effects.

The faulty product and material that face a routine defect among others is identified through the above steps while performing the FMEA, on the sprocket gear with carbon steel material manufactured for New Business, Tana Beles Sugar Factory. Therefore the rest two steps are typically to be performed for this specific material. This product is chosen because it is the one which is frequently affected by casting defects, among other products in the foundry. Typical FMEA sheet utilized for the analysis is shown below.

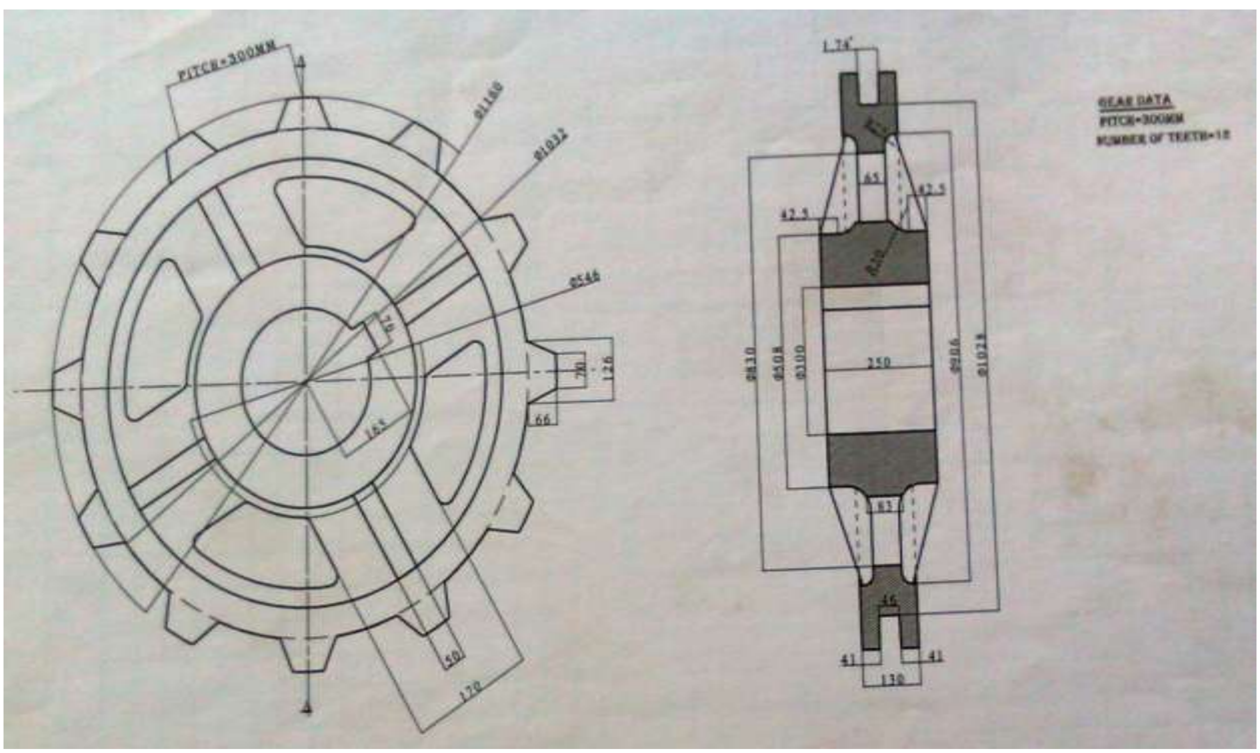


Figure-5.2 Sprocket gear drawing

CHAPTER SIX

RESULTS AND DISCUSSION

6.1 INTRODUCTION

the result of the FMEA technique performed in the previous chapter is as shown below, and an action that can helps with minimization of occurrence of the faulty process parameter or minimize the fault relating with that process parameter will be identified, which in this case is the faulty gating system, that can reduce the occurrence chance of filling related casting defect in the ABMI foundry products.

6.2 FMEA ANALYSIS RESULT

The analysis format sheet used for identifying the major cause (process parameter) for the routine occurrence of defect in the foundry is shown in the appendix, the process parameters are arranged in descending number of RPN, performing these kind of analysis prior to defect identification will give better control in minimization of defects occurrence rather than identifying defects prior to defects minimization because such kind of tools are useful in finding the major root cause among others. Therefore, for the foundry under the study, the gating system design has a major problem than others, and faulty gating system is known to cause major defects relating to filling the molten metal to the mold cavity therefore it is important to make sure if the existing gating system to be applied can supply sufficient amount of molten metal for the selected product mold cavity. Which means poor gating system design or selection accounts for most of the surface defects in the foundry product; ramming, coating and mold & core material follows proceeds with high risk number. Among the process parameters, the above two with highest risk priority number is chosen to be discussed below;

Table-6.1 List of risk priority numbers

Risk priority num. (RPN)	Parameter
1. 288	Gating system design
2. 270	Ramming, Coating material
3. 245	Mold & Core material,
4. 240	long Pouring time
5. 225	High Temperature, Ventilation, calibration

6. 210	core venting,
7. 175	Low Temperature
8. 180	pouring height & position, high Pouring rate, Assembly,
9. 168	Core Handling
10. 140	Slag

From the FMEA analysis result, it can be seen that the gating system design parameter is the major serious source the routine defects occurring in the foundry among others. The major cause of the faulty gating system selection in the foundry is, unavailability (lack) of the designed gating systems in the foundry; only a limited number of gating systems which are not designed for a specific product exists. These gating systems might or might not well fit the product design. Before going further in to the design of the gating system let's first clearly identify what kind of defects has occurred in the products produced with the currently available gating system.

The surface defects that can be identified by a naked eye on the surface of the sprocket gear are blow hole, pinhole, burn on, & shrinkage porosity. Most of them are cavity defects which might not be removed completely with machining. Therefore it is better to take proper measures than increasing the machining allowance. Most of the products in the foundry are found to have a large machining allowance and for the sprocket gear under the study a 10mm machining allowance is applied. The depth of shrinkage porosity is measured using a caliper and others are quantified in percentage. The weight of the casting is also measured since the weight of the product directly indicates the compactness or amount of porosity in the product. From the table below/ table 7, showing the percentage of surface defects in the sprocket gear products produced, it can be seen that the cavity defect has goat the largest proportion among other, the effect of which has a greater depth of effect, therefore a serious attention must be given for avoiding such an advanced level defects since it might also cause a performance degradation on the product.

6.2.1 TESTING AND INSPECTION

In conducting such study an experimental test using non destructive test on subsurface using visual, liquid penetrant or magnetic particle methods and for subsurface or internal surface examination, radiography and ultrasonic examination methods are crucial to make sure how much was the defect in the cast product and how much does the defect reduced with the current remedy undertaken.

But as a limitation it was difficult to make such kind of comparison, due to the absence of the subsurface examination technique in the industry; a focus was given to the surface examination techniques, mainly using a caliper and visual detection.

Among three similar products, the amount of defects in the surface of the sprockets are quantified in a percentage, out of the three products two of them are 100% defective that need a total rework or rejection and one is 70% defective where the defect can be minimized by machining during finishing process. Type of defects per a single product (sprocket gear) are common for three of the products with various depth and quantity, each are quantified in a percentage as shown in the table below.

Table-6.2 Defects per a single product (sprocket gear)

Sno	Product	Blow hole (%)	Pin hole (%)	Burn on (%)	Gas porosity (%)	Shrinkage porosity (depth,mm)	Weight (avg Kg)
1.		40%	30%	10%	20%	(1). 69 (2). 56 (3). 45	791
2.		40%	30%	10%	20%	(1).51 (2).50 (3).32 (4).29	

3.		10%	10%	40%	10%	(1). 45 (2). 20 (3). 10	,,

6.3 ACTION TO REDUCE THE HIGH-RISK FAILURE MODES

The major aim of performing this study is for identifying the major root cause process parameters and to minimize the chance of defect occurrence by controlling the identified process parameter. The process steps taken for preparing the experimental study are as follows:

1. Designing the gating system
2. Simulating the output of the designed and previous gating systems
3. Implementing the designed gating system

6.3.1 GATING SYSTEM DESIGN

A gating system can be defined as a passage through which a molten metal flows through to enter the mold cavity, the methods engineer, is who will choose the casting process, and then design the gating system necessary to get the molten metal into all regions of the part so as to produce a sound casting. The idea of methoding or design of the system which ensures an optimum casting quality to be achieved is very important in metal casting process. Methoding involves designing pattern equipment and molding process, gating system which insures freedom from shrinkage and other solidification oriented defects in the final casting. A gating system is required to fulfill the following attributes [31];

- It must create minimum turbulence
- It must prevent slag, dross or inclusion in ladle to reach mold cavity
- It must avoid aspiration of air and mold gas in the metal stream
- Must not cause core or mold erosion
- Must create directional solidification by creating favorable temperature gradient

- It should control the rate of filling of mold cavity
- Economical to mold and finishing after casting

In order to fulfill the above requirements it is important to give a careful attention in designing a gating system. Components of a gating system are pouring basin, sprue, runner, ingate, and riser. Each has its own significance in resulting a sound casting output. Gating system is classified in to five according to the positioning as [31];

- Top gating
- Parting line gating
- Side/step gating
- Bottom gating
- Combination of the above

i. Riser design

Casting process is a phase transformation process where the liquid metal is transformed to solid state in a pre-shaped cavity. Since the type of metal to be used is steel volumetric shrinkage is expected phenomena because of the short freezing rang the volumetric shrinkage is expected between 4 to 7%. The basic requirement of feeding system is;

- Thermally adequate: it should freeze later than the casting section
- Volumetrically adequate: to feed required amount of feed metal
- Should have adequate feeding range: should cover the entire casting to eliminate centerline shrinkage.

The first step in designing a riser is to determine the optimum feeder size, and for that a modulus method or Chvorinov's formula is applied, where he has shown that solidification time of a casting is proportional to the square of the ratio of volume to surface area of the casting [31].The type of riser to be applied is top riser type, in identification of the section with largest modulus (section that solidify last in the product) where a greater probability of shrinkage porosity might occur is the first step, because application of the riser is for controlling the shrinkage porosity that might occur on the section with largest modulus. Therefore from the drawing of the sprocket gear above the section with the largest modulus can easily be identified as the hub where transformation of the molten metal consume longer period of time.

a. Calculation of the modulus of the hub; Modulus is the volume divided by surface area or the heat to be removed by the rate of removal, since the hub is a hollow cylinder the modulus of a hollow cylinder will be;

$$\text{Chvorinov's equation: } T_{st}=C_m(\frac{V}{A_s})^n$$

Where: $(\frac{V}{A_s})$ is the modulus (the heat to be removed by the rate of removal), V volume of casting and A_s surface area

T_{st}, is solidification time,

C_m is mold constant

n is constant

$$M_c = \frac{V}{A_s} = \frac{t \times h}{2(t+h)}$$

Where: M_c is modulus of casting, t thickness & h height of the hub

$$= \frac{104 \times 250}{2(104+250)} = 36.72$$

b. Modulus of the riser, the modulus of the riser must be greater than the section so that it will solidify last after sufficient feeding of the thickest section. Modulus of riser can be defined as;

$$M_r = 1.2M_c = 1.2 \times 36.72 = 44.06$$

Where: M_r is modulus of casting

c. Riser size

<u>Diameter of the riser (D_r)</u>

$D_r = 6M_r = 6 \times 44.06$=264.4~265 mm

<u>Height of the riser (H_r)</u>

$H_r = 1.5D_r = 1.5 \times 265 = 397.5$~$400\ mm$

d. Feeding distance

Assuming a 50% coverage by risers

Mean diameter $= \frac{D_o+D_i}{2} = \frac{508+250}{2} = 379$ mm

Total coverage by risers= $\pi \times mean\ diameter \times 0.5$

=3.14 ×379× 0.5 = 595.03 mm

Number of the risers = $\frac{595.03 \text{ mm}}{265.0 \text{ mm}}$=2.24 ~ 2 risers

e. Gross weight of casting (G_w) to be poured

Net weight of casting (W_N) =707.851 Kg

$V_r = \pi r^2 h$= 3.14 × $(0.1325)^2$ ×0.4= 0.022 m^3; where: V_r is volume of the riser

$W_r = \rho \times V = 7860 \,{}^{Kg}/_{m^3} \times 0.022 m^3$ =173.31 Kg; where: W_r is weight of the riser

Maximum$yield$ of steel selected as 0.65

G_w =$\frac{W_N}{\text{max.Yield}}$ = $\frac{707.851}{0.65}$=1089.0015 Kg

f. Feeder neck dimension

$D_N = L_N + 0.2D$, let $L_N = 55\, mm\ where\ D_N$ & L_N are diameter and length of neck

=55+(0.2× 265) =108mm

g. Volume of feed metal (V_{feed})

$V_{feed} = 0.14 \times V_r = 0.14 \times 0.022\, m^3$= 0.00308 m^3

$$V_c = \frac{W_c}{\rho} = \frac{707.851}{7860} = 0.0900\, m^3$$

$V_{shrinkage} = V_c \times \frac{V_{sh}}{100}$ =0.0900× $\frac{0.072}{100}$ = 0.0000648 m^3,

whereV_{sh} $(volumetric\ shirinkage) of\ steel = 7.2\%$

V_{feed}>$V_{shrinkage}$, the riser is enough

h. Pouring time

T= S $\sqrt[3]{T}$ × W_g,

where S (correction factor) is between (1.5-1.6), by taking the average, $\frac{1.5+1.6}{2}$ =1.55

and mean thickness of $\frac{250}{2} = 125mm$

T=1.55 $\sqrt[3]{125}$×1089.0015=79.73 sec

Pouring rate (R_p)= $\frac{W_g}{T} = \frac{1089.0015}{79.73}$=13.66${}^{Kg}/_{s}$

ii. Design of sprue

Effective pouring height =h-${}^{a^2}/_{2C}$, let h=400

$=400-{125^2}/{(2 \times 250)}$=368.75 mm

Chock area (A_c) $=\frac{W_g}{\rho tc(2gh)^2} = \frac{1089.0015}{7.860\times0.2\times79.73(2\times9810\times368.75)^{0.5}}$, c,(nozzle coefficient)=0.2

Chock area (A_c) =0.00327m^2

$A_c=\frac{\pi D^2}{4}$ where, $D_c=\sqrt{\frac{4A_c}{\pi}}=\sqrt{\frac{4\times0.00327}{\pi}} = 0.06451m = 64.51mm$

$D_{up} = 1.15 \times D_c$=1.15× 64.51=74.186mm

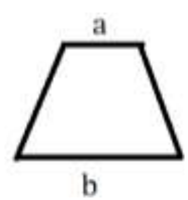
iii. Gating ratio and runner and ingate area

The gating ratio chosen for steel is 1:2:1.5

Area of ingate=0.00327m^2 ×1.5=0.004905m^2=49.05cm^2

The depth of the ingate is found from using formula;

Gate thickness=${1}/{2}$local casting thickness =${1}/{2}$(132mm)=65 mm



The values of a & b are selected as; 80mm & 90mm respectively with length of 160 mm.

Area of runner =0.00327m^2 ×2=0.00654m^2=65.4cm^2

Where dimensions of a & b selected similarly as 80mm & 90mm respectively

6.3.2 SIMULATION ANALYSIS

After the proper gating system is designed it must be checked whether or not it can give an outcome that can meet with the desired objective; casting simulation is known for its waste and time reduction by minimizing the number of trial and errors in the foundry. In order to make sure that the existing gating system design applied for casting the sprocket gear product has a design error or not a comparison is made in burn on and shrinkage porosity defects using the simulation result. A drawing of the sprocket gear is prepared with the actual and designed gating systems by CATIA software; which is then simulated for the casting outcome using PROCAST software; the simulation results for the two casting defects are then compared on the actual and the designed gating systems. The geometries of actual and designed gating system elements are as shown in the table below.

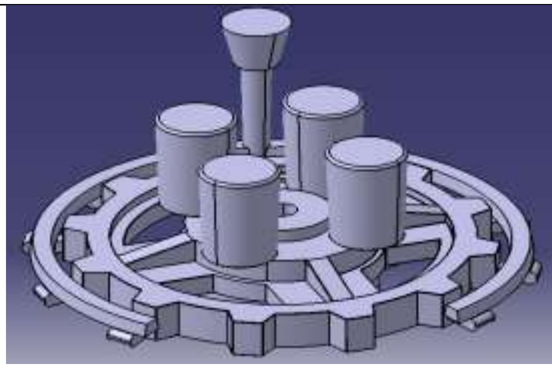
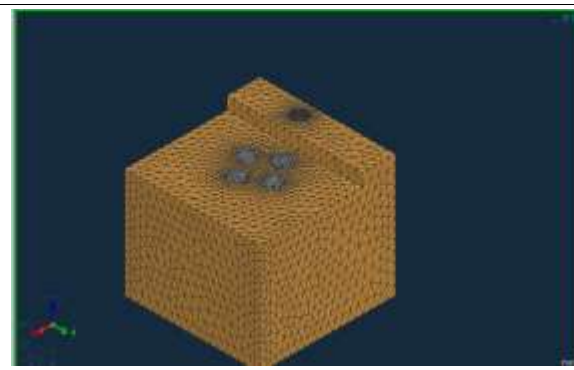
Table-6.3 Geometries of actual and designed gating system elements

Gating system	Actual		Designed	
	Number	Geometry (mm)	Number	Geometry(mm)
Riser	4 Top	D=220 H=330 Dn=107 Hn=10	2 Top	D=265 H=400 Dn=110 Hn=50
Sprue	1 Tapered cylinder	Dt=85 Db=70 H=40	1 Tapered cylinder	Dt=85 Db=70 H=40
Runner	1 (270^0) Trapezoidal	W=65,50 Depth=50	1 (270^0) Trapezoidal	W=90,80 Depth=65
Ingate	10 Trapezoidal	W=80,50 Depth=50,40	10 Trapezoidal	W=90,80 Depth=65
Pouring cup	1 Conical	Dt=190 Db=240 H=170	1 Conical	Dt=190 Db=240 H=170

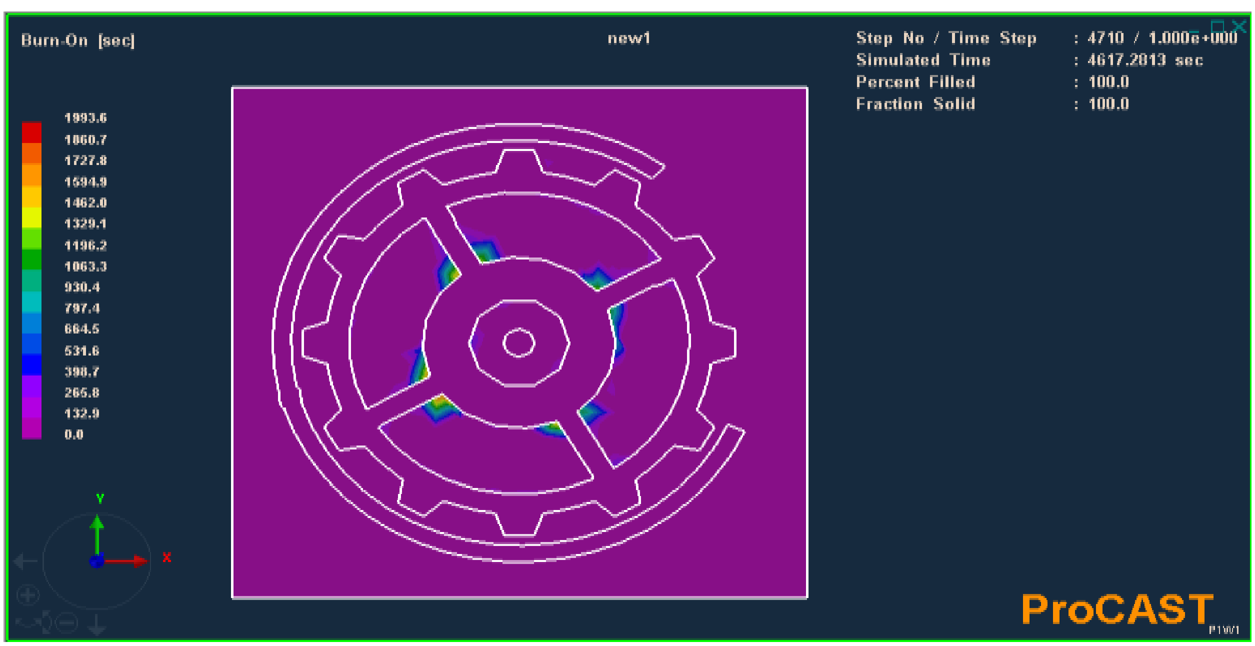
Even though focus of the current study is filling related defect, specifically shrinkage porosity that directly relates with the gating system design, the burn-on defect also have showen some improvement, in association with the redesigned gating system design, the result of both defects with respect to the actual and the designed gating system are presented below.

Figure-6.1 Simulation Results

I. With Actual Gating System

<table>
<tr><th>CATIA drawing</th><th>Pre cast</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Note: this CATIA drawing is as per the actual dimension and placement in the foundry
And the pre-cast is prepared with the actual casting method in the foundry, with open riser and with actual sprue and pouring cup dimension.</td></tr>
<tr><td colspan="2">Burn on: since burn on defect directly relates with time where molten metal causes localized overheating of the sand mold or cores in a specific location, the longer the overheating, the higher the probability of burn on/penetration occurrence. The product’s burn on defect is indicated in seconds the molten metal spending in specific locations, time intervals are displayed with different colors from minimum to maximum.</td></tr>
</table>

A. Top surface

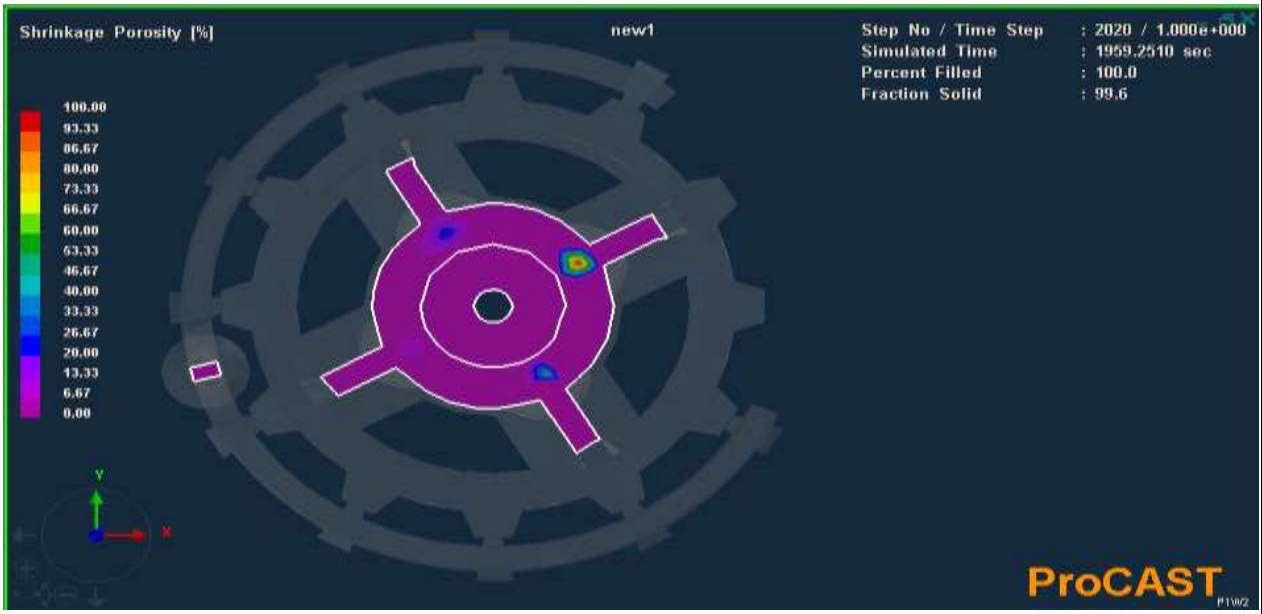


B. Bottom surface

Note: the molten metal overheating effect at specific location is between 1462.0 to 398.7 sec with maximum value of 1993.6 sec.

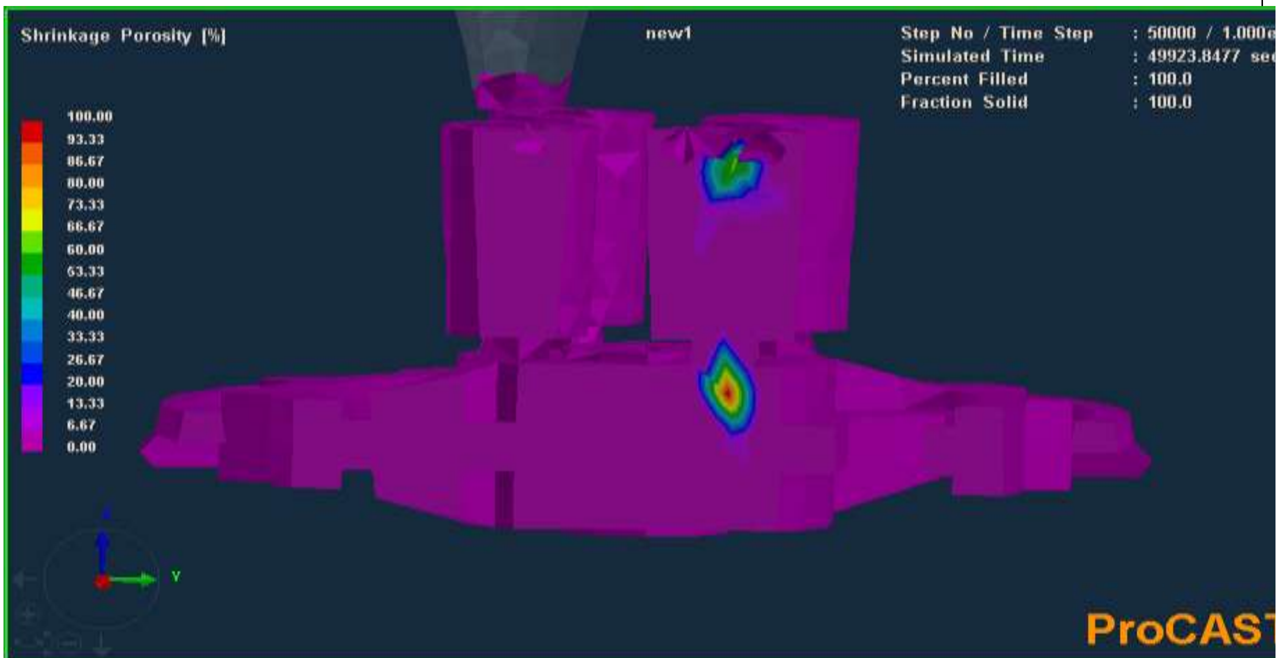
Shrinkage porosity: this defect is displayed in a percentage where 100% mean there is a hollow cavity, which is indicated in red color. While 0% means the product is totally solid in that location, indicated in purple color, where shrinkage porosity with depth of between 100% and 0% are indicated with different colors.

A. Top surface



B. Section view at the center of the riser

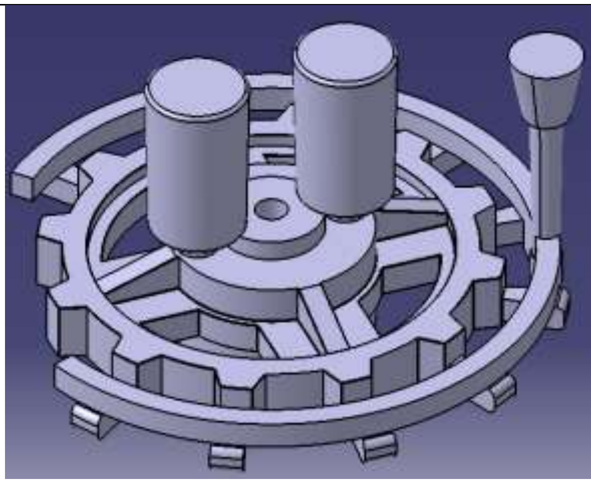
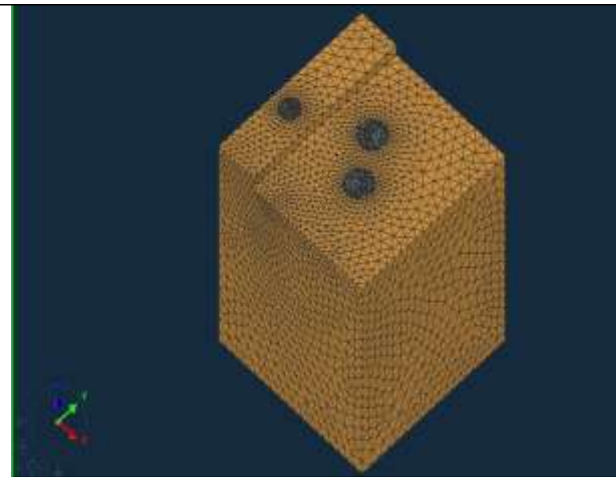
C. Section view at the center of the riser



D. Section view at the center of the riser

Note: shirinkage porosity has occurred at three locations of the top hub surface, which is below and at the verry center of the three risers, except one.

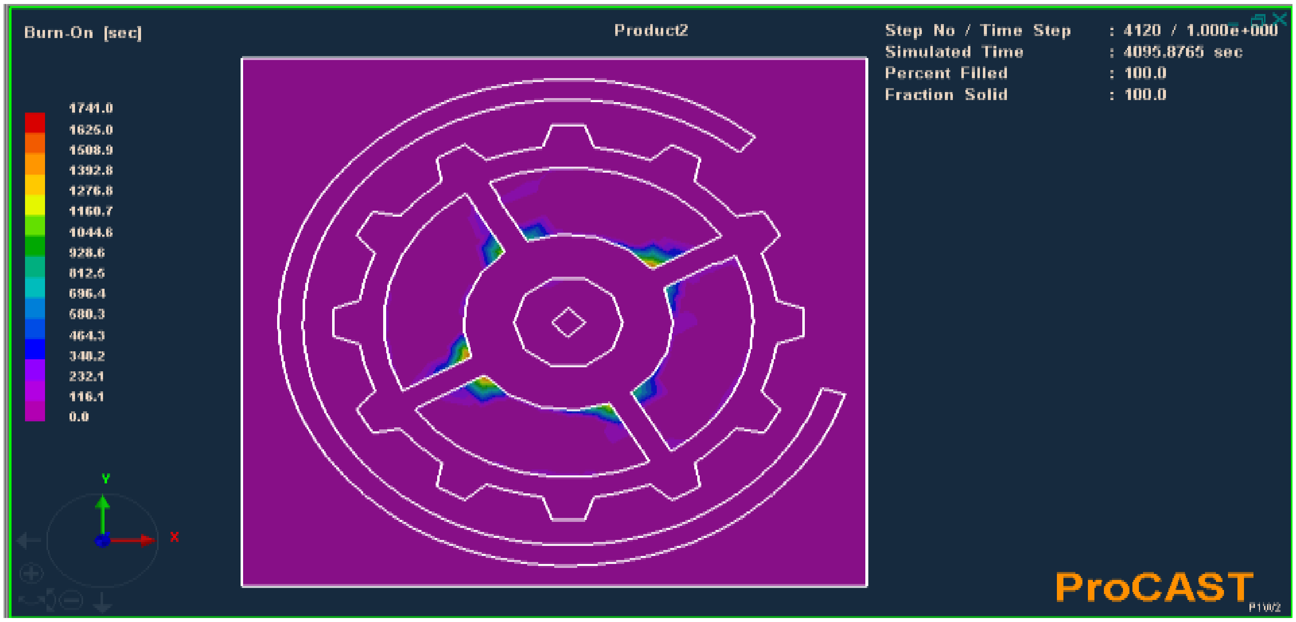
II. With Designed Gating System

Ca1tia drawing	Pre cast
	

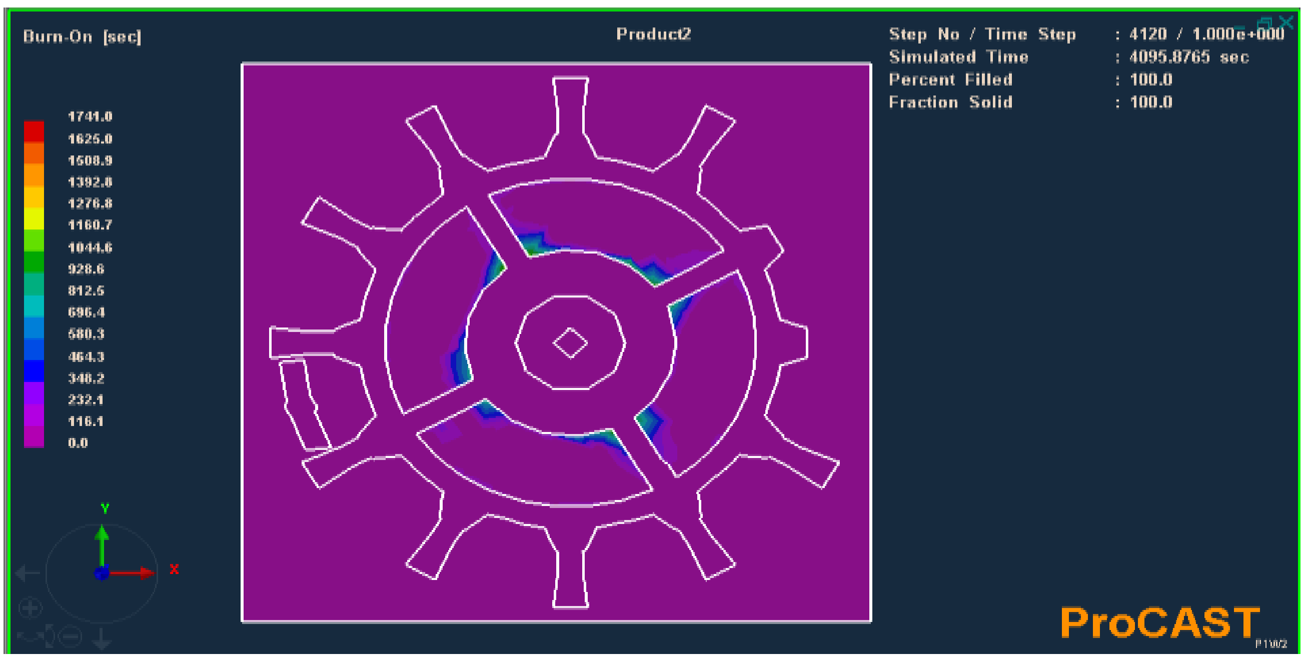
Note: this catia drawing differs from the above in both dimension and number of risers, the precast is prepared with the actual casting method in the foundry, with open riser and with actual sprue and pouring cup dimension.

Burn on: since burn on defect directly relates with time where molten metal causes localized overheating of the sand mold or cores in a specific location, the longer the overheating, the higher the probability of burn on/penetration occurrence. The product's burn on defect is indicated in seconds the molten metal spending in specific locations, time intervals are displayed with different colors from minimum to maximum.

A. Upper surface



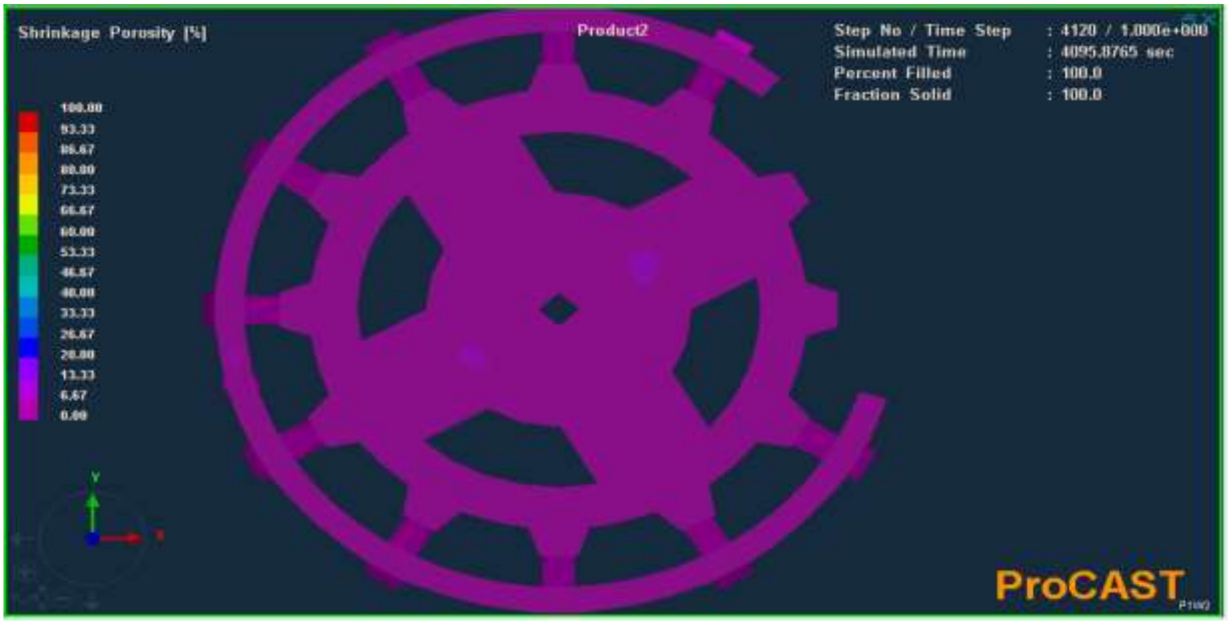
B. Bottom surface



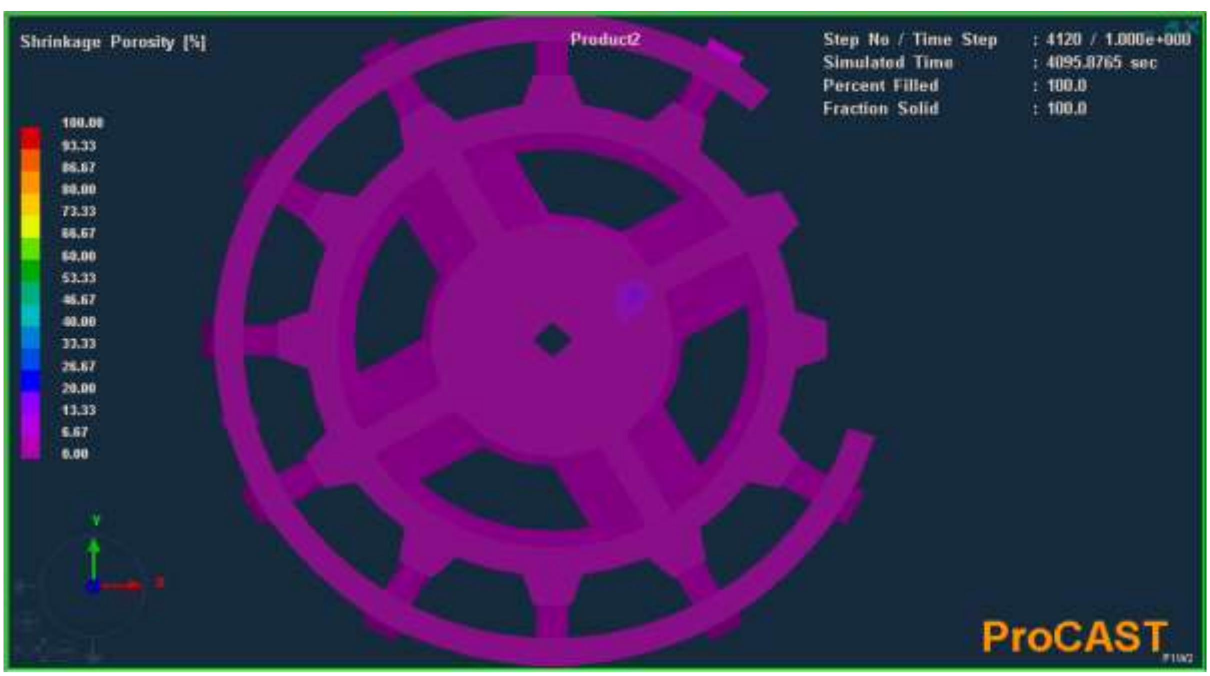
Note : the molten metal overheating effect at specific location is between 1392.0 to 348.2 sec with maximum value of 1741.0 sec., burn on defect is found in reduced value, due to the reduced number of risers, which resulted in a reduced heat concentration.

Shrinkage porosity: this defect is displayed in a percentage where 100% mean there is a hollow cavity, which is indicated in red color. While 0% means the product is totally solid in that location, indicated in purple color, where shrinkage porosity with depth of between 100% and 0% are indicated with different colors.

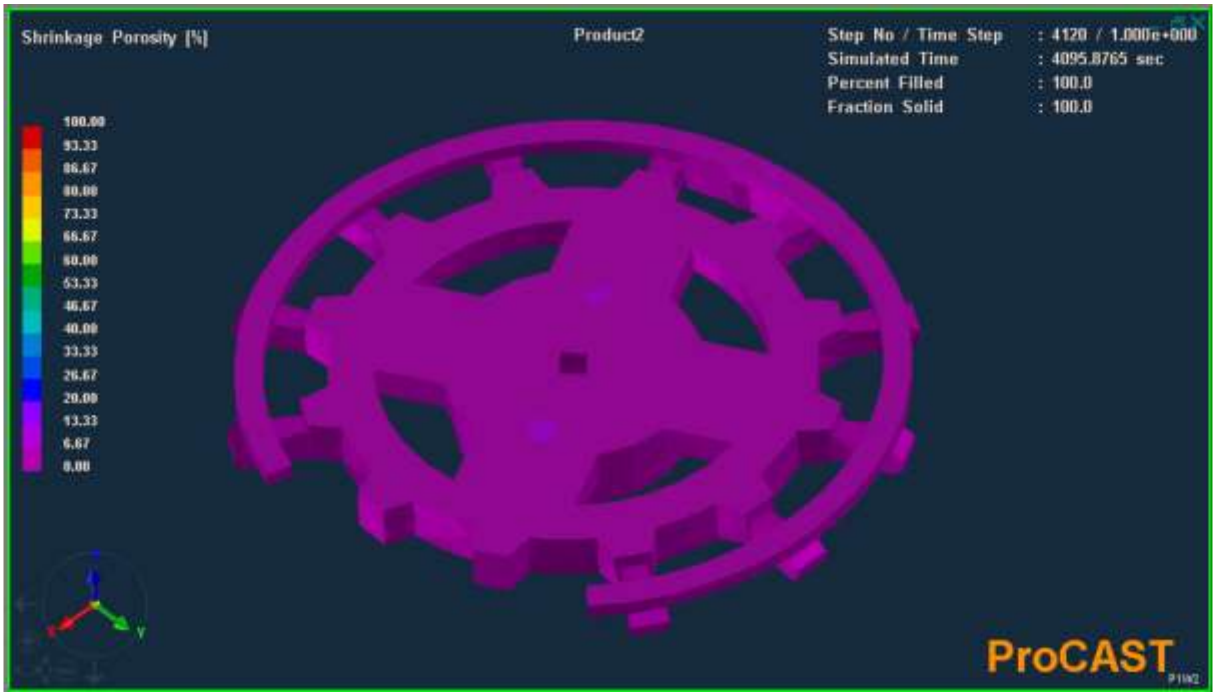
A. Upper surface



B. Bottom surface



C. Isometric view



6.3.2.1 SIMULATION RESULT DISCUSSION

As it can be seen from the simulation result both defects has shown some degree of reduction in the sprocket gear with designed gating system than with the actual one. Since steel has short freezing rage there is a high probability of shrinkage cavity formation in the thickest section of the cast product. Therefore a proper attention must be given to the methods design to ensure that sufficient amount of molten metal is entering the mold cavity which includes riser, ingate, sprue, runner design; since gating system is the passage through which a molten metal flows to enter the mold cavity; if insufficient dimension is applied for the gating system it will directly affect the flow of molten metal, and insufficient amount of molten metal might enter to the mold cavity resulting in porous product where the cavities formed in solidification doesn't feed with right amount of molten metal.

Since the process is sand casting and due to the nature of the material (steel) the total avoidance of the shrinkage porosity defect is not possible; but the size can be minimized by applying a sufficient hot metal reservoir on the thickest section of the product which is the hub of the sprocket gear. The reason behind the reduction of casting defects in the sprocket gear with the designed gating system is as discussed below;

i. Designed gating system and shrinkage cavity defect minimization

Riser Effect

An improper design of riser leads to improper feed of the cavities such that it might solidify before it feeds sufficient amount of molten metal to the cavities formed during solidification process [31]. As it can be seen from the gating system design above the new riser design can hold an increased amount of molten metal than the actual one; therefore the feed of the cavities that form during the solidification of the molten metal can be insured. The simulation result of the actual and the designed riser also shows a big variation in the shrinkage porosity depth and diameter; which indicates that an improper riser design is made or chosen for the product.

Since the type of the riser applied for the product is an open type of riser a proper care should be given for minimizing the heat transfer between the molten metal on the top of the riser and atmosphere; even though an exothermic powder is applied on the top of the riser it can’t make sure that the shrinkage porosity will not occur. In addition to that an improper increase in the number of risers on the product also can’t assure the minimization of the shrinkage porosity or proper feeding of the product rather than reducing the yield of the casting.

The simulation result can be taken as a proof for that four risers are applied on the top of the casting but it doesn’t stop the shrinkage porosity from occurring on the other hand an improvement on the outcome of the product is shown with reduced number of risers which indicates that if the volume of the reservoir can sufficiently hold a molten metal it can be assured that a proper feeding will result that can feed enough amount of molten metal before it’s solidification; therefore there will be a minimization in the shrinkage porosity on the product.

The problem of the actual riser is not only on the design but also on the positioning; i.e due to improper riser neck or core print design the center of the riser is shifted from the center of the hub by the core print in to the corner. Which leads half circle of the riser base which is not in contact with the casting to solidify fast that includes the center of the riser where a molten metal responsible for the feeding action is present.

These faults will then results in a shift in feed direction of the molten metal from the very center of the riser in to non uniform path flow of the molten metal from the center of the riser, since the solidified metal in the riser base will restrict the molten metal from following directly to the cavities. Due to these reason the product cavities will not be feed properly; for these reason the riser neck is increased in height which allows the positioning of center of the riser to be on the center of the hub therefore the disturbance of molten metal flow from the reservoir to the cavities can be avoided.

Ingate And Runner

In addition to the riser, a slight dimensional change on the existing ingate and runner has been made both in depth and width. An ingate and runner are passages through which a molten metal enters the mold cavity therefore if an improper passage is prepared then an improper flow of the molten metal will occur. In addition to providing a passage for the molten metal the runner has an advantage of slag trapping on its top narrow surface therefore if the height of the runner is not sufficient enough the slag will restrict the molten metal from entering the mold cavity; which then increases the rate of heat transfer between the mold surface and the molten metal; that will results in reduction in the rate and amount of molten metal flow and facilitates the occurrence of gas defects since the reduction in the rate of mold cavity filling can create a sufficient time for entrapment of gasses on the molten metal that will dissolve on time, which are the major causes for the occurrence of gas defects on the surface of the casting.

Increasing in the amount of molten metal entering the mold cavity can also ensures that there exists a sufficient amount of molten metal in the mold cavity so that will compensates for the reduction in the number of cavities occurring during the solidification process; that makes the casting product solid or dense enough. For that reason the size of the ingate has increased, even though increasing the size of the ingate has a disadvantage during the removal or grinding process; it is considered as one option for the minimization of the cavities on the product.

Pouring Cup And Sprue

The dimension of the pouring cup and sprue is kept as it is; because according to the simulation result a change in the dimension doesn't considered to be important since the outcome of the product has shown an improvement in the outcome without changing the sprue or pouring cup that will proofs that the design is sufficient for the casting product. The only change made is on the position of the sprue; as it can be seen from the catia drawing the position of the sprue is shifted from the center on the actual one but on the designed one the position is on the center of the product or between the centers of ten runners. The only effect noticed is that when the position is shifted from the center the molten metal on the shortest path will enter the mold cavity fastest than the longest path, which causes unequal solidification of the molten metal that is one of the causes of cavity occurrence on the casting product.

ii. Designed gating system and burn-on defect minimization

The major reason for the occurrence of the burn on defect is, a thin sand crust permanently adhering to the casting surface when the metal at the mold metal interface stays hot enough for sufficient period of time, is when the molten metal has caused a sintering effect on the sand due to high temperature especially on the thickest location of the casting or hot spots which is an isolated pool of liquid metal in the solidifying metal. Location that have highest probability for occurrence of burn on defect are identified as sharp corners, under riser, next to thick sections of the casing and on the surface of thin cores, where the mold tends to heat above solidification temperature of the metal and the mold stays at high temperature for relatively long period of time [32].

Even though a direct relationship between burn on defect and gating system doesn't exist the simulation result of the burn on defect has shown a big reduction on the burn on defect, in positions that are next to the thickest section of the sprocket which is the hub and below the risers. Which shows that; increasing in the number of risers where increases in the amount of heat that facilitates the occurrence of sintering; which is increasing the temperature of at the hot spots that are below the surface where the riser is placed. Therefore reducing the number of the riser leads to the reduction on the percentage of the burn on defect, is now minimized due to the reduced number of risers where the high temperature of molten meal is now reduced on the hot spots.

In order to make sure that the simulation result meets with the actual casting product it is important to compare with the actual casting product. For the actual one with four riser system the three sprocket gear products has been shown in the previous section for ensuring the reality of the defects, but only the shrinkage porosity and the burn on defect is shown and the output is nearly similar. hundred percent similarity between the actual casting and the simulation result cannot be found because the simulation is considering most of the input parameters as constant therefore a perfect surface finish will occur. But that is not true in the actual production of the casting product in the foundry where a lot of input parameters are shifted from the desired value. In order to make the comparison between the casting products of the actual and the designed one it is important to make an experimental analysis in order to make sure whether the expected outcome will occur or not.

6.3.3 EXPERIMENTAL ANALYSIS

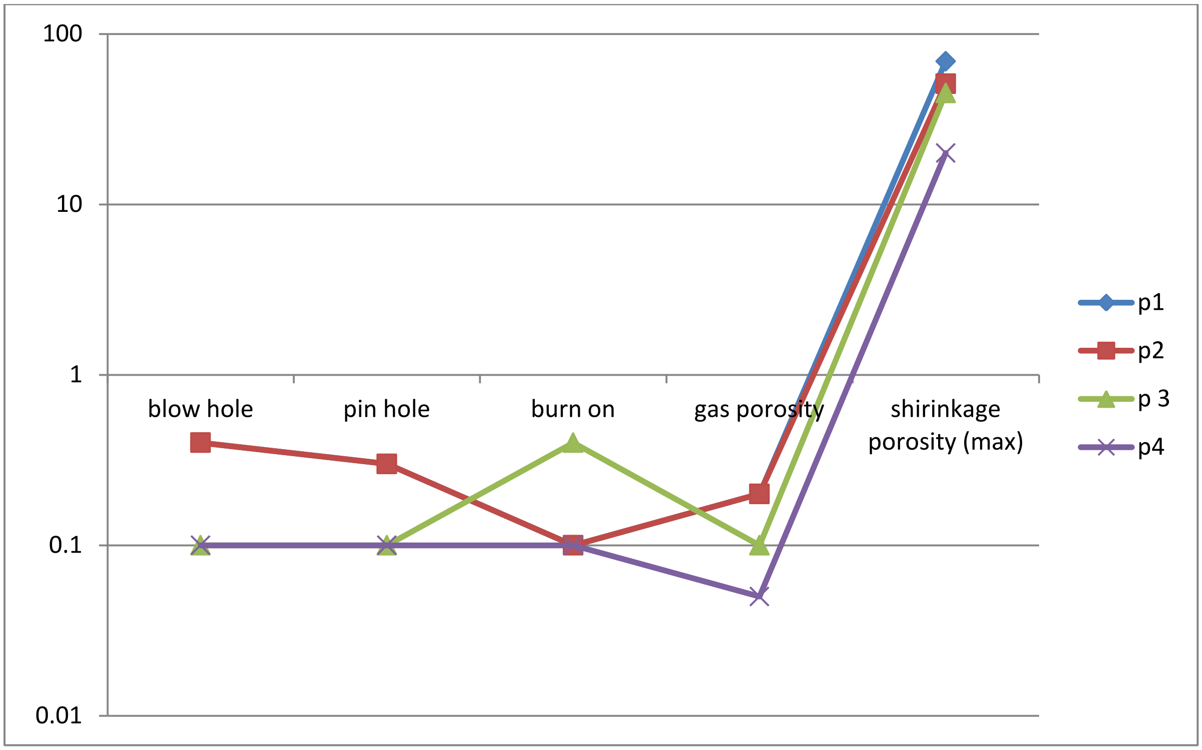
A proper attention has been given to make sure if the methods and material utilized have been applied properly, for assuming a constant value. But no matter how much attention is given for sand casting process it is impossible to produce defect free cast product; because of the high probability of faulty process parameters occurrence in sand casting process. Identification of faulty process parameters in this study was made using the FMEA technique, but implementation of fault correction was very difficult in the current foundry, because most of the defects do require purchasing process like sand and new gating system preparation, which makes these project very costly and time intensive.

Even though the correction of most of the process parameters were not easy; experiment on the casting is made by utilizing the available methods and by manually correcting some unwanted errors in the methods; such as the gating system dimensions. While other input parameters were applied with proper care. The casting output and the percentage of defects in the new sprocket gear cast product is discussed below.

Table-6.4 Percentage of defects in the new sprocket gear

Product 4	Blow hole (%)	Pin hole (%)	Burn on (%)	Gas porosity (%)	Shrinkage porosity (depth,mm)	Weight (Kg)
	10%	10%	10%	5%	(1). 20 (2). 7	806

Graph 6.1 comparisons between four different sprocket gear products



Since the basic idea of this thesis is minimization of filling related defects specifically the shrinkage porosity by applying the new gating system design; it's clear from the result that the depth of shrinkage porosity has reduced in this sprocket gear; when compared to the existing sprocket gears produced before. The weight of the product can be considered as a proof that the new product is much more denser or compact than the others; therefore defect minimization is nearly fulfilled; but why does the simulation result doesn't much with the actual product? To answer this question it is important to list out the unexpected errors occurred during the casting process.

6.3.3.1 FAULTY PROCESS AND EXPECTED SIMULATION RESULT

I. **Absence of designed gating systems in the foundry:** the desired dimension is prepared by manually scratching the internal surface of the gating system cavity, and by extending the height of the riser by attaching one riser above another. These can be one cause of defect because the face prepared by the scratching can't be fully uniform that results in unequal feeding & turbulent flow of the molten metal which can increase the probability of blow holes and pin holes defect occurrence.

II. **Break-up of mould sections during removal of pattern and gating system;** this is because of an extended curing time of the mold and an insufficient dolomite powder, the gating system and the pattern has stacked to the wall of the mold cavity. The stacking of the pattern and the gating system specially the runner and the ingate, with the mold has caused the removal action and maintenance of the damaged mold surface with a new sand to be very difficult and take several time.

The maintenance of the mold surface doesn't include the broken riser face because the new sand and the original mold face doesn't have similar strength to resist the erosion of the molten metal therefore the riser face was left broken as it is, that affected specially one of the riser during filling activity.

During pouring the molten metal to the mold cavity the hot metal leaks through the broken face resulting in formation of an opening on the base of the riser by eroding the weak surface around it. The molten metal which is now mixed with the sand, during eroding the week riser base surface, floats above the molten metal, initiating a directional solidification, the solidification direct towards the base of the riser, resulting in a thin solid surface on the broken side of the riser base, solidifying the molten metal present within the riser.

Therefore feeding action of one side of the riser has a very limited period of time because of the solidification that directs further towards the center of the riser, resulting in reduced feeding action that through time might stop completely. Such that the cavities formed inside will not be sufficiently supplied by a molten metal; these fault has caused a cavity of 20mm depth on the top surface of the product.

(A) (B) (C)

Figure-6.2 (A) showing a broken mold where one of the riser neck face has fail down, (B) un-piped riser, 2 molten metal that leak and mixed with the eroded sand, (C) Portion of the riser that solidifies fast, and molten metal that leaks through broken base

As it can be seen from the photo above, it is clearly shown that one of the riser has piped while the other shows a very small opening shifted from the center; it can be verified as that the riser size is sufficient but due to faulty operation an early solidification has restrict the riser from feeding the molten metal properly. But if proper care has been given, like giving sufficient curing time to the mold and performing gating system and pattern removal with care, this kind of defect might not be occurred, two of the risers might have similar feeding and the shrinkage porosity might be reduced.

III. **Inappropriate neck height:** the center of the riser has been shifted from the center because of the contact between the core print and the riser base, since the riser applied for the experiment doesn't have neck. Riser neck was prepared manually during filling the flux with sand, resulting in neck height of 10mm, which is very small compared to the core print height which is 50mm that can push the riser base away from the center. That has resulted in cast product feeding to shift from the center to the corner, in addition to that short riser necks are known for causing fast solidification, but as it can be seen from the photo below even though the riser is feeding in a direction away from the center it covers most of the feeding activity compared to the other/unpiped one. But some small depth shrinkage cavities are present on the surface of the sprocket below the riser.

(A) (B) (C)

Figure-6.3 (A) Riser base with no neck, (B) piped riser, that have feed the entire casting (C) Cavities below the riser base

Since the feeding action of this riser doesn't takes place on the center there will be high probability of turbulence occurrence, during molten metal flow from top to the bottom solidification time of this riser has long period of time than the other one since there is no mold breakage. And also feeding action is directional from depth cavities towards the above and since the other riser hasn't covered the expected feeding length, this riser has done most of the feeding activity; so that the molten metal in the riser has solidify without completely feeding shrinkage cavities with 6mm formed in the above surface, around the center of the riser.

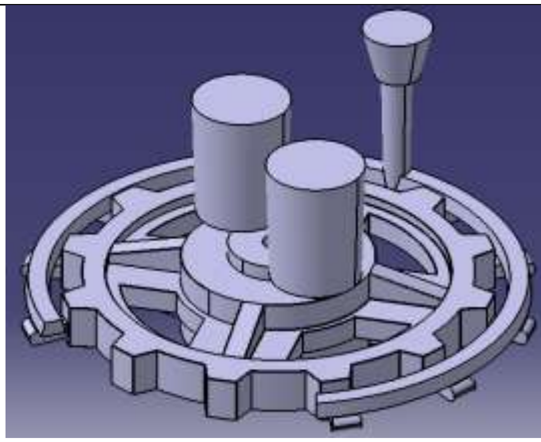
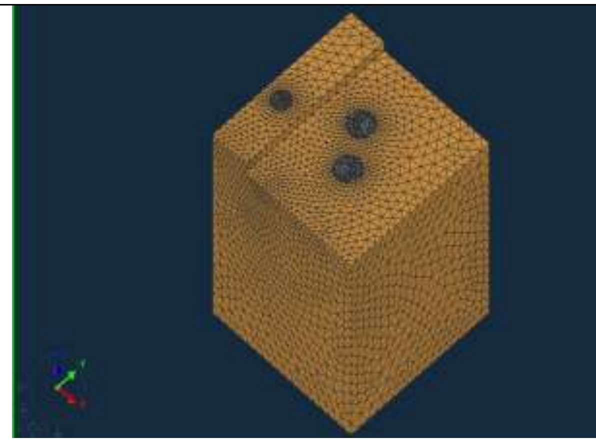
Summarizing the above reasons will give a brief explanation of why the simulation result doesn't match with the outcome of the casting during the experimental test, that have a direct relationship with the feeding activity. But since the correction of those faulty processes parameters consume much time and cost, as an option for the faulty process parameters that resulted in unexpected output specially due to faulty riser positioning is to change the position and to place it on the space between the ribs, because the existing riser in the foundry has no neck and most of the faults arising with the feeding process are due to disturbed solidification.

6.3.3.2 RISER REPOSITIONING

Taking preparation of a specific gating system design as the first option for solving feeding related defects, the second option is to deal with the existing gating system in the foundry is repositioning. The basic reason behind this repositioning is due to the absence of the designed gating system in the foundry; that resulted in a very short riser neck and shifted the riser from center, which causes in a disturbed solidification process. In the previous positioning the riser center were placed on the corner of the hub or at the end face of the ribs in contact with the hub, which is a hot spot since areas that are in contact with thick surface doesn't solidify fast the shrinkage porosity will be formed in this places, parting the rib and the hub surface. To ensure the soundness of the ribs it is better to place the risers away from the hot spots, since the ribs have thinnest cross section it can solidify fast ensuring a sound surface. Shrinkage porosities will now be formed only on the surface of the hub without affecting the ribs.

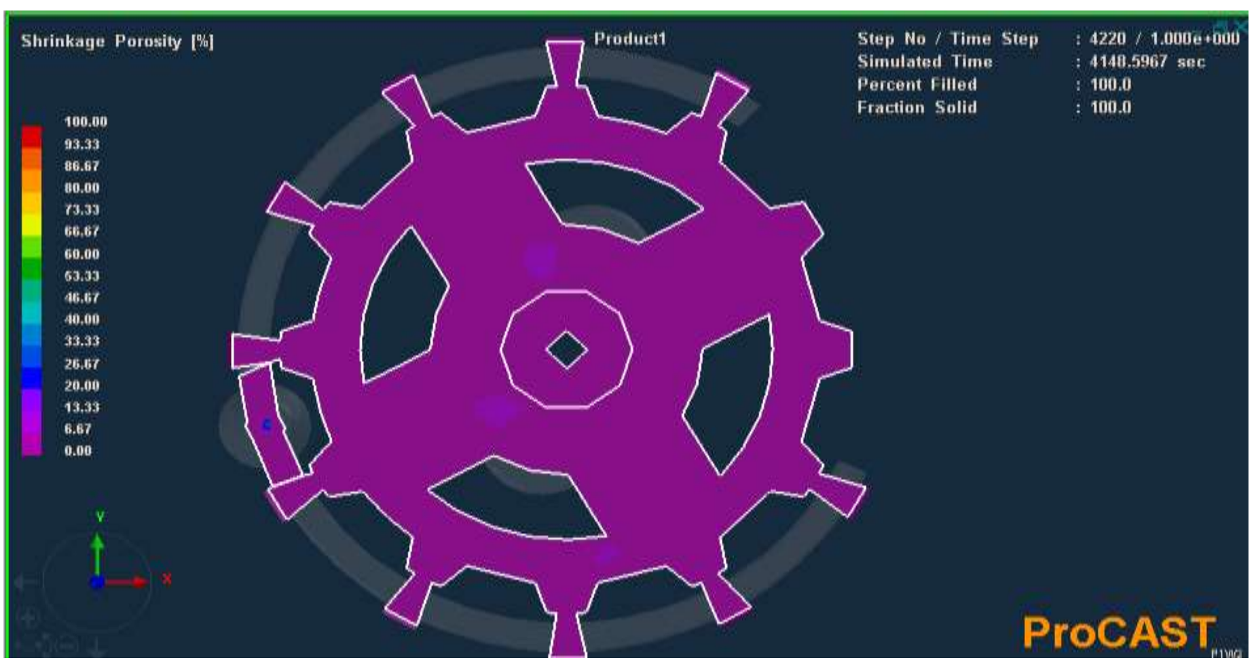
These new placement of the riser drawing is prepared with the CATIA software and simulated with PROCAST software to ensure improvement on the output. Note that the simulation result using the new placement of the riser on between the ribs is quite similar with that placed on the ribs side, the riser design has not been changed, which explains that the mismatch between the simulation and the actual experimental test has occurred due to the faulty placement and the riser can sufficiently feed the product, the figure below explains the result.

Figure-6.4 simulation result with repositioned risers

Catia drawing	Pre cast
	

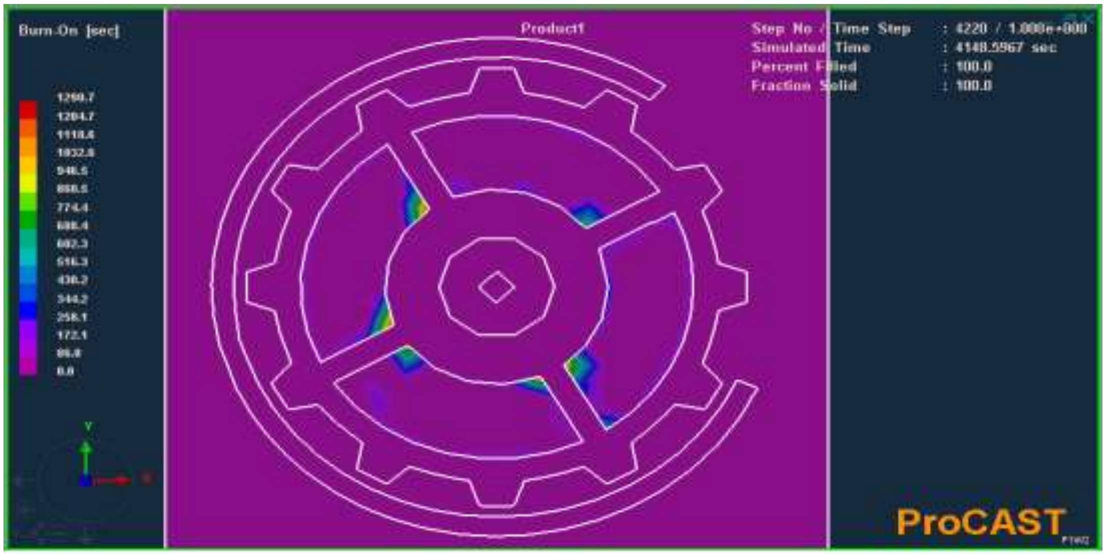
Note: there is no dimensional difference in this CATIA drawing with the designed one; only positioning of the risers is changed, which means during practical test the risers was placed on the hub parallel to the ribs, now it is changed to space between the ribs.

Shrinkage porosity



Note: there is no big difference in shrinkage porosity simulation result between this product and simulated with risers placed in between the ribs.

Burn on



Note: the molten metal overheating effect at specific location is between 1118.0 to 250.2 sec with maximum value of 1290.0 sec, burn on defect is reduced in value, not only due to the reduced number of risers but also due to the position of the riser between the hot spots, rather than o the hot spots; which resulted in a reduced heat concentration.

6.4 RAMMING AND FOUNDRY COATING

These are the faulty process parameters next to gating system design that contribute for the defects occurrence on the sprocket gear products in the foundry. These parameters accounts for occurrence of gas defect, pin hole, inclusion, burn on and penetration defect for products in the foundry. As it can be seen from the simulation result the value of the burn on has reduced due to the designed gating system, by minimizing the spots where high temperature concentrate by assuming appropriate ramming and coating. But in the actual product these burn on value has even reduce from that value the reason behind is proper coating and ramming process. The reasons for occurrence of the high burn on defect in the previous sprocket gears products is because there doesn't exist a proper ramming or coating method in the foundry, since these are applied manually with hand if the personnel has no adequate knowledge about the process, the defects can't stop from occurrence.

I. Foundry Coating

Foundry coatings can be thought of as paints especially developed for the metal casting industry. The difference between conventional paints and a foundry coating is that the foundry coating is designed to withstand the high temperatures of molten metal and to act as a barrier between molten metal and a core or mold surface. All foundry coatings are suspensions of a high temperature mineral or refractory in a liquid carrier. After being applied to a core or mold surface the liquid is removed by evaporation and a layer of refractory is left on the sand surface. This layer or barrier can prevent or minimize the penetration of molten metal into the sand, can reduce or prevent "burn-on" and erosion of the sand and generally improves the quality of a casting surface [33].

Components of a Foundry Coating

- Refractory Mineral: determines the resistance of the coating to molten metal, the effect of the coating on casting properties and to a great extent, the application properties of the coating, is typically 90 -95%
- Carrier / Reducer: carry or transfer the refractory particles to the core and mold surface. Upon evaporation of the carrier, a layer of refractory solids remains behind, which will act as a barrier between the sand and molten metal.
- Binder: bond the refractory particles together and to the sand.
- Suspending Agent: keep the refractory particles in suspension and to prevent hard settling during storage, shipment, and use of the coating at its working viscosity.
- Special Additives - Defoamers, Wetting Agents, Biocides, etc.: modify and improve application characteristics, shelf life, and contribute to overall casting performance [33].

Commonly Used Carriers

- Water
- Isopropyl Alcohol
- Methanol
- Naphtha

Benefits of using refractory coating

- Reduce or eliminate metal penetration
- Reduce or prevent “burn-on”
- Prevent erosion of sand by molten metal
- Smooth surface finish
- Improve overall casting quality
- Reduced scrap
- Lower cleaning costs

From the result from the experimental test most of the advantages of the foundry coating are reflected by the reduced burn on, smooth surface finish, and improved overall casting quality, the surface finish of the sprocket gear has improved due to application of the right quality and type of coating. Even though the molding material has bad property the coating material can accommodate for the faulty property of the mold, therefore if the coating material, process & preparation is made properly the defect due to the bad molding material can reduce to a greater extent, but Improperly selected, prepared or applied coatings can result in poor casting finish as it can be seen from the previous sprocket gear products and coating defects such as scabs, blows, gas holes, inclusions, etc can be resulted. For the sprocket gears previously produced two of them has been coated with an iron coating (water soluble) which is to be applied for non ferrous metals only, that has caused a bad surface finish, while on the experimental test the surface finish becomes much improved because of the coating which is isomol (alcohol based) or organic solvent based. Even though the outcome of the experimental test is found to be good the typical selection for characterization of the coating is not made, the coating is applied with the help of the expertise [34].

The parameters that characterize foundry coatings in order to understand the behavior of coatings containing refractory materials, is need to be considered before applying it to the mold are listed below;

- Specific Gravity
- Viscosity
- Baume´ Parameter
- Solid content

- Colloidal Stability
- Coating Thickness
- Coating Penetration Depth
- Coating Permeability
- Wettability and Surface Tension

Refractory Considerations

- Types of Metal Poured
- Pouring Temperatures (min. and max.)
- Cross Sectional Areas of Casting
- Resistance of Refractory to Metal Penetration
- "Peel" Characteristics
- Thermal Conductivity of Refractory
- Thermal Expansion and Contraction
- Application Characteristics
- Cost
- Toxicity of Refractory
- Uniformity of Refractory from Shipment to Shipment
- Permeability

Carrier Considerations

- Compatibility of carrier with sand binder and / or refractory
- Method of drying and available equipment
- Required drying speed
- Flammability and "burning" characteristic
- Toxicity
- Odor
- Method of application (dip, spray, brush, swab, or flow-coat)
- Cost of carrier
- Cost of labor
- Available floor space & utilization of floor space [34]

II. Ramming

Ramming in the foundry under the study is performed specially for heavy castings is by using any wooden plank usually a long riser and a number of people gather to hit the sand specially in alongside of the flux for making the mold surface stick firm to the pattern gating system and flux. If the persons performing the ramming are not aware of the advantage and disadvantage and proper ramming technique, wrong ramming will occur which will then results in mostly a porous product, because if the mold is rammed hard the air will not have a space to exit the mold rather it will directly exit towards the molten metal causing a cavity which then becomes porosity.

Ramming also accounts for occurrence of penetration and burn on defects because of soft ramming where the molten metal can easily get through each opening of the mold causing sintering, and the sand and metal will then create a permanent bond with each other [35]. In addition soft molds cause mold erosion during filling the mold cavity resulting in a product with sand inclusion on the surface. Even though proper mold coating can accommodate for the wrong ramming, if the mold hardness is not in the proper value or if there doesn't exist sufficient venting for the gas in the mold there is a high probability of porosity occurrence. The only option for this fault is to perform the ramming operation with trained personnel who can understand the whole technique behind ramming process. And laboratory test like permeability test should be performed after the mold is dried.

Figure-6.5 Ramming practice in the foundry

6.5 THE RECALCULATED RPN

Now the last step in FMEA analysis is recalculating the RPN after proper measure has been made (taking action), the new RPN value will now be reduce for corrected parameters while the others might take the top ranking due to lack of measures. Note that most of the faulty process parameters where modification has not been made has goat the top five while the others where controls has been made to minimize the faulty process parameters has goat below five ranking; which can proof that Ramming, Coating material, Mold coating, Gating system design, Core coating, mold Ventilation, calibration & Slag process are controlled to some extent to minimize the risk (defect) that can occur due to those faulty process parameters. Note also that 100% control over all of the process parameters is impossible in sand casting.

The reason behind the RPN of gating system design can't become zero or being the last in the RPN ranking is because of the reasons why the simulation result doesn't match with the actual experimental test as discussed in the above section, in addition Since the process is sand casting where a complete defect elimination is impossible but minimization, the desired outcome is only possible with minimization of the faults associated with the input process parameters that are leading to defect occurrence.

The process parameters where control has not been made are parameters which require long periods of time for analysis, in addition those parameters needs some costs relating to some raw materials, and instruments for proper testing of the cause and effect of the faulty process parameter, which makes the minimization of the risk associating with those process parameters difficult in the current experimental test. But since the major objective of the project is minimization of defect associated with faulty process parameter in the sprocket gear (cast steel material) the output has meet with objective and RPN is for the process parameters in the foundry and the improvement of the RPN value is only valid for the sprocket gear (cast steel) product only and a better improvement needs to be made for minimizing the defects occurring on the rest of the products.

Table-6.5 Recalculated RPN

Risk priority num. (RPN)	Parameter
1. 245	Mold material, Core material
2. 240	long Pouring time
3. 210	core venting
4. 180	pouring height & position, high Pouring rate, Assembly
5. 175	Low melt Temperature
6. 168	Ramming, Coating material, core handling
7. 144	Gating system design , Core coating
8. 120	High Temperature ,mold Ventilation, calibration
9. 96	Slag

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

In order to obtain the good quality cast products within the available resources, the selection of optimal parametric combination plays important role, but this might not be easy when it comes to reality in foundries. The basic reason for sand casting defects occurrence is presence of a number of process parameters, a combination of which will result in cast product. Hundred percent control over all of the process parameters is impossible, but unless a proper care is given to each parameters during, the selection, preparation and application process, the chance of defect occurrence will be very high, because only reduction is possible in casting defect, there is no elimination.

The basic objective of this study was to minimize casting defects present in the foundry under the study, by identifying the causes of routine defects and among them the major problem that is causing the foundry to suffer from a routine defect occurrence. This study is directing from the problem to the solution, the problem is not the casting defect but the faulty process parameter, and casting defect was considered as an effect, and the solution was to minimize the chance of fault occurrence by taking important measures. Solving one fault can minimize the occurrence chance of number of defect, since casting defect might be the result of one or a combination of causes. The simulation was also an important tool for predicting the output quality of the cast product, reducing the trial and errors making sure whether or not the combinations of the process parameters have an optimum value or not.

Therefore this thesis has proved that problem identification is the primarily an important step in dealing with metal casting manufacturing related problems specially with casting defect. And focusing in each process parameters prior to casting the product can direct towards the major problem rather than studying the causes of each casting defects that is routinely occurring in the foundry, because one might list out a number of reasons which might makes it difficult to identify which process was affecting the most among others.

7.2 RECOMMENDATION

During conducting this study different problem in the ABMI foundry was noticed the following are among the problems.

Old machineries and equipments: most of the machineries in ABMI foundry are old, where most of the sensors stop functioning or give wrong reading value other than the maintenance downtime cost. The mixer also suffers from routine a breakdown that is causing a hazardous working condition due to resin leaking through the machine and other problems.

Training: a continuous training for the personnel is quite important, even for making a solution within resources shortage situations.

Tools , equipments and materials: other than old materials and equipments there is lack of tools especially for mold preparation, some materials like chromate sand and other types of sands with good refractoriness properties doesn't present, testing and inspecting machineries and equipments are not giving function,. Foundry accessories are Important in building a good working mood for the workers and increase the chance of manufacturing cast product with minimum defect occurrence.

Methoding: preparation of specific gating system for specific product during the design stage is important, because of the problems mentioned during the study, specially for minimizing feeling related defects.

Handling: equipments handling like the flux, some cast products, scraps and other input sources for melt preparation, and gating systems lack inspection and proper handling which through a time might stop proper functioning.

Other than Selection, preparation and application process, availability of accessories plays an important role in increasing the chance of defect minimization. Taking the above recommendations as an input the foundry shall take proper measures for becoming the number one quality casting foundry. In addition to that by properly implementing the FMEA technique and casting simulation each of the faults can be avoided one by one, because the history of FMEA can clearly indicate which problem is minimized and which problem currently needs attention.

REFERENCE

1. RAI technology university “Engineering minds” metal casting book. (www.raitechuniversity.in)
2. prof. Dr. Altan turkeli 2008 “foundry technology Sand, sand additives, sand properties, and sand reclamation” MSE-432 Foundry Technology.
3. Rajesh rajkolhe, j. G. Khan, march 2014 "defects, causes and their remedies in casting process: a review” international journal of research in advent technology, vol.2, no.3
4. Robin E. Mcdermott Raymond J. Mikulak Michael R. Beauregard “The basics of FMEA”
5. Carlson, K.D., lin, Hardin, and Beckermann, 2002, “modeling of porosity formation and feeding flow in steel casting,” in proceedings of the 56^{th} SFSA technical and operating conference, paper no. 4.4, steel founders' society of america, chicago, il,.
6. Binu bose, Anilkumar , December 2013 “reducing rejection rate of castings using simulation model”international journal of innovative research in science, engineering and technology an iso 3297: 2007 certified organization, volume 2, special issue 1issn (online) : 2319 – 8753 issn (print) : 2347 - 671
7. J. Mocek, J. Samsonowicz, “changes of gas pressure in sand mould during cast iron pouring” archives of foundry engineering published quarterly as the organ of the foundry commission of the polish academy of sciences issn (1897-3310) volume 11 issue 4/2011 87 – 92
8. Achamyeleh Kassie, samuel Assfaw, may 2013 “minimization of casting defects” IOSR journal of engineering ,
9. Pravin Kumar, Venkatakrishnan.R, Vignesh Babu.S, september - october (2013) “process failure mode and effect analysis on end milling process- a critical study” international journal of mechanical engineering and technology (ijmet) volume 4, issue 5, pp. 191-199
10. Bhupendra J. Chudasama, 2013 “Solidification Analysis and Optimization Using Pro-Cast” Master of engineering Department of mechanical engineering S. P. B. Patel Engineering College, Linch (Mehsana) Gujarat (India)
11. Aniruddha Joshi, M.Jugulkar, april-2014 “investigation and analysis of metal casting defects and defect reduction by using quality control tools” international journal of mechanical and production engineering, issn: 2320-2092, volume- 2, issue- 4.
12. Prasan Kinagi, Dr. R.G Mench B.R. Jadhav, Santosh J. Jadhav, april 2014 “A development of quality in casting by minimizing defects” international journal of recent research in civil and mechanical engineering.

13. Tejaskumar S. Parsana And Mihir T. Patel, august 2014 “A case study: a process FMEA tool to enhance quality and efficiency of manufacturing industry” Bonfring international journal of industrial engineering and management science, vol. 4, no. 3.
14. Shraban Kumar Singha, Simran Jeet Singh, may-2015 “analysis and optimization of sand casting defects with the help of artificial neural network” IJRET: international journal of research in engineering and technology eISSN: 2319-1163, pISSN: 2321-7308 volume: 04 issue: 05
15. Kidu Geberecherkos Weldeanenia, Asmamaw Tegegne Abebe, november 2016 “optimization of sand casting process parameters for 46mnsi4 alloy steel trash plate castings applicable for roller stand” international journal of engineering trends and technology (ijett) – volume-41 number-8.
16. Hardik Rathod Jay K. Dhulia Nirav P. Maniar, december 2016 “prediction of shrinkage porosity defect in sand casting process of lm25” international conference on advanced material technologies, (icamt)-2016 dadi institute of engineering and technology (diet), visakhapatnam, andhra pradesh, india.
17. Izudin Dugic And Ingvar Svensson “the effect of chemical composition on the metal expansion penetration in grey cast iron” division of component technology jönköping university, box 1026, s-551 11 Jönköping, Sweden
18. American foundry society, 2005, Schaumburg, IL USA silver anniversary paper, division 4 porosity in castings R. Monroe steel founders’ society of America, Crystal Lake, Illinois Paper 05-245(04).pdf, page 1 of 28 afs transactions.
19. C.F. Walton and T.J. Opar, Ed., 1981 “Iron Casting Handbook”, Iron Castings Society, “Molding Methods and Materials” 1962, American Foundrymen's Society,
20. Avinash Juriani “Casting defects analysis in foundry and their remedial measures with industrial case studies” M.Tech scholar, department of mechanical engineering, Indian school of mines, Dhanbad, Jharkhand, India
21. Rabia Aftab, M. Iqbal Qureshi, M. Mujahid, Salman Khalid “Effect of different coatings on the surface finish and hardness of manganese steel castings school of chemical and materials engineering”, national university of sciences and technology, Islamabad, steel castings and engineering works, Gujranwala.
22. International Journal of Innovative Research in Science, March 2017, Engineering and Technology, (An ISO 3297: 2007 Certified Organization) Website: www.ijirset.com Vol. 6, Issue 3.

23. Carl S. Carlson, published by John Wiley & Sons, 2012 'Effective FMEA' www.effectivefmeas.com
24. Tejaskumar S. Parsana And Mihir T. Patel, August 2014 "A case study: a process FMEA tool to enhance quality and efficiency of manufacturing industry" Bonfring international journal of industrial engineering and management science, vol. 4, no. 3.
25. Rajesh Rajkolhe, J. G. Khan, march 2014 "defects, causes and their remedies in casting process: a review" International journal of research in advent technology, vol.2, no.3, e-issn: 2321-9637 375.
26. "Molds and Cores Systems in Foundry" http://www.springer.com/ 978-3-319-14582-2
27. Testing and inspection of casting defects by the ASM committee on nondestructive inspection of castings
28. Steel founders' society of america 780 mcardle dr. Unit g, crystal lake, il 60014, USA www.sfsa.org
29. Prof. Ing. Tomáš Elbel, Csc. Doc. Ing. Jiří Hampl, Ph.D, "Diagnostics and casting quality control (lecture notes)"
30. Prof. Dr. D. B. Karunakar, "Metal Casting", Mechanical and Industrial Engineering Department Indian Institute of Technology, Manufacturing Processes – I, Roorkee Module – 2 Lecture – 9
31. Brooks Graduate Research Assistant And Christoph Beckermann Professor, "Prediction of burn-on and mold penetration in steel casting using simulation Brandon", department of mechanical and industrial engineering, the university of iowa, iowa city, iowa 52242, USA
32. U. C. Nwaogu, N. S. Tiedje, August 2011 " foundry coating technology: a review" Materials sciences and application, 2011, 2, 1143-1160 doi:10.4236/msa.2011.28155 published online (http://www.scirp.org/journal/msa)
33. Kgs. Lyngby, Denmark, 2011, Technical university of denmark, department of mechanical engineering, institute of production and process technology,. Email: *ugon@mek.dtu.dk received; revised may 16th, 2011; accepted may 31st, 2011.
34. Mr. Siddalingswami. S. Hiremath Pg Scholar, sep.-2015 "advanced techniques in casting defects and rejection analysis: a study in an industry", international journal of innovations in engineering research and technology [IJIERT] mechanical engg.dept, agpit, solapur/solapur university, Maharashtra India Dr. S. R. Dulange Professor, issn: 2394-3696 volume 2, issue 9,

APPENDIX

POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
(PROCESS FMEA)
Process Responsibility: Manufacturing/ABMI Foundry

Process: casting Product: sprocket gear, (carbon steel)___ Date: April 04/2017 Team:	Prepared by: Beza Tadele FMEA Number:1 Page: P a g e

Process step/ input	Potential failure mode	Potential effect of failure	SEVE SEVER.N	Potential cause(s) of failure	OCCCU.N	Current Controls	D ET.N	RPN	Recommended action	RTCD	Action Results: Actions Taken	New Sev	New Occ	New Det	New RPN
MOLDING Ramming	Uneven molding compaction Soft molds Hard molds	Burn on and penetration Inclusion Gas defect	9	Improper ramming Improperly trained personnel	5 5	Visual inspection Giving Training & working together with expertise	6	270	Ensure uniform & permeable mold compaction		Improved sand compaction	7	4	6	168
Mold coating	Improper coat selection preparation, or applications	Burn on,penetration,bad surface finish, Gas holes, inclusions	9	Inefficiently trained personnel	5	Giving training to employee	6	270	Proper selection, preparation & application, laboratory test		Proper coating	7	4	6	168

Mold material	Bad molding material properties	Gas defects Sintering	7	High gas pressure in the mould arising from molding material having high moisture and/or volatile content Low permeability. Gases may be absorbed from the atmosphere, or may be injected as part of process Low refractoriness of the sand	7	Laboratory test of the molding material Visual inspection By expertise Drying the mold using a LPG gas (torch) And Visual inspection Using a De-Gasser in the molten metal	5	245	Reduce gas pressure in the mould by appropriate adjustment to molding material properties Ensuring adequate venting of moulds and cores.		___				
Calibration	Uneven sand mixing (calibration)	Burn on & penetration	9	Improper mixing ratio (calibration)	5	Adjusting the calibration of the risen, sand and catalyst	5	225	Proper mixing ratio of sand, and binder.		Proper volatile & moisture content (calibration)	6	4	5	120

Assembly	Break-up of mould sections during stripping of patterns, core setting or assembling of molding flasks Mould breakage during assembly	Sand inclusion ,, Pin hole	6	Improper assembly Improperly trained personnel Wrong timing in stripping	5 5	Visual inspection Giving training to employee	6	180	Check moulds for pressure marks and, if necessary, insert pressure pads Carefully blow out mould cavities Frequent cleaning of mould boxes.		——				
Ventilation	Poor ventilation	Burn on & penetration porosity	9	Inefficiently trained personnel	5	Giving training to employee	5	225	Sufficient ventilation		An adequate venting of moulds	6	4	5	120
Coating material	Improper coat selection preparation, or applications	Burn-on, penetration,bad surface finish, Gas holes, inclusions	9	Improper coating process Or material	5		6	270	Proper selection, preparation & application,		Proper coating	6	4	6	144

POURING Temperature	Temperature of liquid metal too high	Burn on & penetration Gas defects	9	Uneven distribution of inflowing metal with resultant over-heating	5	Measuring the temperature of the molten metal using a pyrometer and noticing the change in color of the molten metal	5	225	Even out incoming metal flow Reduce pouring rate		Proper temperature	6	4	5	120
	Metal pouring temperature too low.	,,	7	Wrong T^o reading of furnace, improper training of personnel	5			175	proper metal pouring temp		—				
Slag	Slag on the metal surface.	,,	7	Improper slag removal	5	Using a slag remover	4	140	Remove slag from metal surface.		Slag removed	6	4	4	96

Pouring rate	Pouring rate too high, with heavy impact against mould wall surface resulting in erosion Pouring time too long	Sand inclusion Gas defect	6 8	Improperly trained Personnel	5	Giving training to employee	6	180 240	Avoid high pouring rates and impact of metal stream against mould walls Shorten pouring times, improve distribution of gates Proper pouring time.		—				
pouring height & position	Ladle too far above pouring basin Tilting of metal stream directly to cores.	Sand inclusion erosion	6	Improperly trained Personnel	5	Giving training to employee	6	180	Optimum pouring height. Automate core-setting. Check and, if necessary, modify core prints before start of production		—				

Gating system design	Poor design Too many sharp internal corners Sudden changes in thickness of the sections	Shrinkage porosity Hot tears Gas defects	8 8	Interruption to pouring during filling of the mold Hot spot formation bubbles entrapped by turbulence	6 6	Visual inspection	6	288	Improve mold filling by modificatio n to running and gating system Riser to be Properly located Use separate riser to feed heavy section Feeding of sharp corners to avoid hot spots		Improved gating system design	6 6	4 4	6 6	144
CORE MAKI NG Venting	Inadequate core venting	Gas defect & sintering	7	Improperly trained Personnel	5	Manual venting and visual inspection	6	210	Improve core venting, provide venting channels, ensure core prints are free of dressing		—				

Handling	Excessive moisture absorption by the cores	Gas defect	7	Improper handling of core	4	Visual inspection	6	168	Dry out cores and store dry, reducing absorption of water and reducing gas pressure Apply dressing to cores,		——				
Core material	Low gas permeability of the core sand Excessive release of gas from core	,, ,,	7 7	Wrong sand material Too coarse sand	7 7	Utilization of the core material and coating material according to the type of metal and product size Visual inspection	5	245	Use slow-reacting binder. Reduce quantity of binder. Use coarser sand Reduce amounts of gas by proper selection of sand type.		——				
Coating material	Improper coat selection preparation, or applications	Burn on,penetration,bad surface finish, Gas holes, inclusions	9	Improper coating process Or material	5		6	270	Proper selection, preparation & application,		Proper coating	6	4	6	144