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KCT BUSINESS SCHOOL

A STUDY ON PROCESS IMPROVEMENT IN A FOUNDRY TO ENHANCE PRODUCTIVITY USING SIX SIGMA TOOLS

by

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A PROJECT REPORT
submitted

In partial fulfillment of the requirements
for the award of the degree

of

MASTER OF BUSINESS ADMINISTRATION

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KCT BUSINESS SCHOOL

BONAFIDE CERTIFICATE

Certified that this project report titled "**A Study on Process Improvement in a foundry to enhance productivity using Six Sigma tools**" is the bonafide work of **Mr.Arun Vishnu. S, Reg no: 1120400012** who carried out the project under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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Sarvalakshmi Foundries (P) Limited

17-04-2013

TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Mr. S. Arun Vishnu** of KCT Business School has done a project on the topic of **A Study on Process Improvement in a Foundry to enhance productivity using Six Sigma tools** during the period between 28th January 2013 to 15th April 2013.

For Sarvalakshmi Foundries

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DECLARATION

I affirm that the project work titled **"A Study on Process Improvement in a foundry to enhance productivity using Six Sigma tools"** being submitted in partial fulfillment for the award of Master of Business Administration is the original work carried out by me. It has not found the party other project work submitted for award of any degree or diploma, either in this or any other university.

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I certify that the declaration made above by the candidate is true.

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SYNOPSIS

The focus of the study is to enhance the productivity of the foundry by improving the key process involved in producing of the castings. The productivity of the foundry is found to be greatly affected by the higher rate of rejections. In this process available Six Sigma tools are used for process improvement. In this project the different types of defects which occur in different stages of casting production process is being found and their individual contribution to the total defect is being calculated. The causes for each defect are then found and the intensity which each cause has in the total defect is also being analyzed. Then different steps to be implemented to improve each process is found and suggested for implementation. It is found that by implementing these suggestions there will be significant improvement in the method in which each process is being carried out and also there is increase in productivity of the foundry which at present stands at 50%

CHAPTER 1

INTRODUCTION

1.1 Introduction

The project is about improving the productivity in the foundry by identifying the major reasons due to which maximum defects occur during the production process. The types of defects are being identified and the total number of defective parts due to each type is being noted. The reasons contributing to each type of defect is being analyzed and the effect which each type of defect has on the productivity is being found out using Failure Mode and Effect Analysis (FMEA). As a result of this analysis the critical factors which affect productivity are identified and suitable corrective actions are suggested. These corrective actions lead to improvement in the process of casting production in the foundry. The estimated level of increase in productivity as a result of implementing the suggestions are being calculated to check whether the desired level of improvement can be achieved or not.

1.2 Industry Profile

There are about 35,000 foundries in the world with annual production of 90 million tonnes, providing employment to about 2 million people. USA tops the list in alloy production followed by China, Japan, Germany, and the CIS. In terms of number of foundries China has the highest score (9374), followed by India (6000) and then CIS (4000). The share of Iron foundries is the maximum i.e. almost 56%, followed by steel with 14% and then the non-ferrous ones with 30%. The global market potential of metal is estimated to be about US$30 billion. The growing environmental concerns and globalization of economies have led to a closure of some 8000 foundries in Europe. These countries have been contemplating to shift their business to the low labour cost centres i.e. the developing countries.

The Indian Foundry industry produces approx **7 Million MT of castings** employing estimated 500,000 persons directly & another 1.5 millions indirectly. There are approx 4500 units out of which 80% can be classified as Small Scale units & 10% each as Medium & Large Scale units. Approx 500 units are having International Quality Accreditation. The large foundries are modern & globally competitive & are working at nearly full capacity. Most foundries use cupolas using LAM Coke. There is growing awareness about environment & many foundries are switching over to induction furnaces & some units in Agra are changing over to cokeless cupolas. There are several foundry clusters .Some of the major clusters are as below. Each cluster is known for its type of products.

1. Batala
2. Belgaum
3. Rajkot
4. Agra
5. Jalandhar
6. Chennai
7. Coimbatore
8. Pune
9. Ludhiana
10. Kolhapur
11. Howrah
12. Rajkot

The growth of foundry industry is very important for inclusive growth. other engineering sectors & the overall Indian Economy. Foundry Industry is major feeder to following sectors

- Automobiles & Auto Components
- Railways
- Power Sector
- Tractor Industry
- Earth Moving Machinery
- Pumps, Compressors
- Pipes Valves
- Pipe Fittings

- Electrical/Textile/Cement/Agro Machinery
- Machine Tools & Engineering Industries
- Sanitary Castings
- Engineering products for export

Automotive Mission Plan (AMP) 2006-2016 envisages 4 Fold Growth by 2016. (i.e.) from $34 Billion industry to $ 122-160 billion industry and employing about 25 millions by 2016. AMP 2006-16 will drive demand of Castings from foundry Industry. Now the fourth largest producer of metal castings worldwide, India has increased its casting production by more than 100% since 2002. Expansion stems from India's large and rapidly growing economy, which has the potential to raise its income per capita to 35 times current levels over the next 40 years.

Coimbatore, located in the state of Tamil Nadu, is an important foundry cluster in Southern India. The foundry industry at Coimbatore came up mainly to cater to the needs of the local textile and pump-set industries. There are about 600 foundry units in Coimbatore. The geographical spread of the cluster includes Thanneer Pandal/Peelamedu, Ganapathy, SIDCO, Singanallur, Mettupalayam Road and Arasur Village. Most of the foundry units cater to the needs of the domestic market. A small percentage (about 10%) of the foundry units are also exporting castings. Nearly half the number of foundry units are manufacturing castings for the pump-set industry. The distribution of the foundry units by end-use markets is given below.

Table 1: Product distribution of Coimbatore foundries

Pumps / valves	46 %
Food processing industry	7 %
Textile machinery	6 %
Electric motors	6 %
Automotive	4 %
Others	31 %

1.3 Company Profile

Sarvalakshmi Foundries was established in 1990 as a small scale industry. At that time, annual production was 350 tons of grey cast iron castings. 30 people worked in a single shift. Melting was carried out in a cupola. Hand-moulding was the major process of manufacture. The clients were mainly manufacturers of motors and pumps.

Today Sarvalakshmi Foundries has developed into a foundry with an annual capacity of 6000 tons of grey cast iron and s g iron castings. 125 people work in 3 shifts. Melting is done in a modern medium frequency 1.5 ton capacity coreless induction furnace. Moulding is carried out in Arpha 300,Arpha 450 and BQ5 moulding machines that are well-serviced by an automated sand-plant. Sand hoppers for storing 150 tons of moulding sand are available. This ensures that sand is adequately cooled before being recycled for moulding. High speed intensive sand mixers supply sand of desired quality to the moulding machines. Adequate shot-blasting and fettling facilities are available in-house.

A well-equipped laboratory having modern process control equipments like spectrometer, universal testing machine, impact testing machine, Brinell hardness tester, microscope, sand-testing equipments, facilities for wet analysis etc are available.

The clients include manufacturers of automobiles, motors, pumps, compressors, textile machineries and other engineering industries. Sarvalakshmi Foundries have customers all over south India. Now they are aggressively planning to be world players. In order to achieve this, marketing offices have been opened in USA, Canada, France and Australia. Castings catering to a wide range of industrial segments are manufactured – valves, fittings, automobiles, pumps, motors, compressors, machineries and other engineering industries.

The following are the important machineries used in the organization.

Table 2: Equipment details of Sarvalakshmi foundries

Equipment Name	Specifications
Induction furnace	750 kW, 1.5 ton capacity, medium frequency core-less induction furnace - Inductotherm make
Ladles	250 kg capacity pouring ladles (5 nos) 500 kg capacity pouring ladles (2 nos) 1000 kg capacity ladles (2 nos) 2000 kg capacity ladle (1 no)
EOT crane	5 ton capacity (1 no)
Moulding machines	ARPHA 300 moulding flask size (mm) : 520 × 400 × 160 ht ARPHA 450 moulding box size (mm) : 850 × 600 × 200 ht BQ 5 moulding box size (mm) : 1100 × 700 × 250 ht
Sand mixers	500 kg capacity (2 no) 200 kg capacity (2 nos)
Sand plant	Including sand storage hoppers of capacity 120 tons, belt conveyors, bucket elevators, polygonal sieve, magnetic separators etc
EOT cranes	5 ton capacity (1 no) 2 ton capacity (2 nos)
Sand drier	1 ton / hr capacity (1 no)
Sand mixer	100 kg capacity (2 nos)
Core-shooter	Cores manufactured by amine process (1 no)

1.4 INTRODUCTION TO PROCESS

1.4.1 Foundry process

Foundries produce castings that are close to the final product shape, i.e., "near-net shape" components. Castings are produced by pouring molten metal into moulds, with cores used to create hollow internal sections. After the metal has cooled sufficiently, the casting is separated from the mould and undergoes cleaning and finishing techniques as appropriate. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods. Fig 1 represents the process flowchart in foundry.

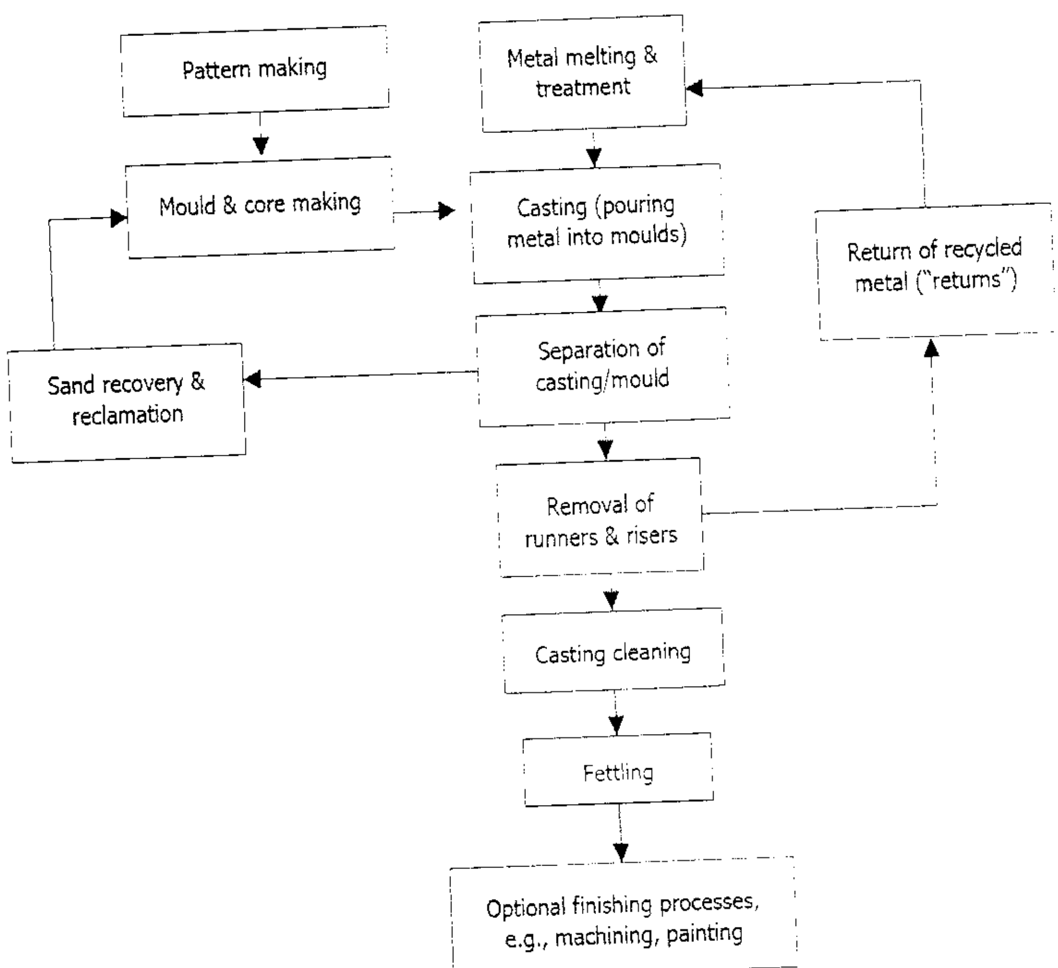

Fig 1 : Foundry process flow

Pattern making

Patterns provide the exterior (mould) or interior (core) shape of the finished casting and are produced in wood, metal or resin for use in sand mould and core making. Patterns are usually made in two halves.

Sand Preparation

Moulding sand should have good flowability (for better reproduction of pattern details), adequate green strength (to prevent its collapse during moulding), dry strength (to prevent its collapse during mould filling), sufficient refractoriness (to withstand molten metal temperature), enough permeability (to allow entrapped air and gases generated inside the mould to escape) and collapsibility (for ease of shakeout). These are achieved by a suitable composition of sand, binders, additives and moisture. Silica sand is the most widely available and economical. Modern sand plants automatically carry out mulling, mixing, aeration and testing of the sand. They also reclaim used sand through magnetic separation (to remove metal particles), crushing of lumps and finally removal of excess fines and bond (usually by washing in hot water or by mechanical impact).

Core Making

Cores are surrounded by molten metal, and have higher requirement compared to mould sand in terms of strength (to support their own weight and the buoyancy force of metal), permeability and collapsibility (especially for curved holes, otherwise they will be difficult to clean out). The most widely used binder for core sands is vegetable oil (linseed and corn oil, sometimes mixed with mineral oils), which is economical. Cores are produced by blowing, ramming or in heated processes, investing sand into a core box. The finished cores, which can be solid or hollow, are inserted into the mould to provide the internal cavities of the casting before the mould halves are joined. Sand cores are also widely used in diecasting, where permanent metal moulds are employed.

Moulding

This involves packing the moulding sand uniformly around a pattern placed in a moulding box (or flask). Most foundries are equipped with jolt-squeeze machines operated by compressed air. The combination of jolting and squeezing action gives good compaction of sand near the pattern (by jolting the sand into crevices) as well as the top where the squeeze plate comes in contact with the mould. Many modern foundries have high pressure moulding equipment, which use air impulse or gas injection to impact the sand on the pattern. These machines produce relatively less noise and dust compared to jolt and squeeze machines and have much higher productivity (several moulds per minute). A special type of high pressure moulding machine is the flaskless moulding machine pioneered by Disamatic, in which the parting plane is vertical and the mould cavity is formed between consecutive blocks of mould.

Melting

Molten metal is prepared in a variety of furnaces, the choice of which is determined by the quality, quantity and throughput required. The most common type of furnaces available are

♦ **Electric induction furnaces** are the most common type used for batch melting of ferrous, copper and super alloys. This method involves the use of an electrical current surrounding a crucible that holds the metal charge. Furnace sizes range from < 100 kg up to 15 tonnes. For production of super alloys and titanium, melting may be undertaken in a vacuum chamber to prevent oxidation.

♦ **Cupolas** are used solely by iron foundries for continuous production of molten iron. The cupola consists of a shaft in which a coke bed is established. Metal, coke and limestone are alternately charged into the furnace from the top. Molten metal trickles through the coke bed picking up essential carbon, while impurities react with the limestone to form waste slag. Both metal and slag are continuously tapped out at the bottom. Metal throughputs of 1 to 45 tonnes per hour are achieved in the UK.

♦ **Electric arc furnaces** are still used by a few ferrous foundries in the UK, mainly producing steel castings, although most have been replaced by induction furnaces. Furnaces of 3 to 100 tonnes capacity are in use in the UK. The design involves the use of a holding bath into which electrodes are inserted. The heat generated by creating a charge between the electrodes causes the metal to melt.

Casting and separation

Molten metal is poured into moulds using various types of ladles, or in high volume production, automated pouring furnaces. Metal is poured into the "runner" (a channel into the mould cavity) until the runner bush is full. The "riser" provides an additional reservoir of feed metal to counteract the shrinkage that occurs as the casting begins to cool. When the metal has cooled sufficiently for the casting to hold its shape, it is separated from the mould by mechanical or manual methods. Where sand moulds are used, the process is often referred to as shakeout or knockout, and large amounts of dust may be generated.

Removal of runners and risers

After casting, these extraneous pieces of metal are removed and often collected for re-melting. In ferrous castings and larger non-ferrous castings, they may be removed by knocking off, sawing or cutting using an arc air or oxy-propane torch. In die-castings, they are often snapped off manually.

Finishing

A range of finishing processes is usually undertaken. These include:

- Cleaning to remove residual sand, oxides and surface scale, often by shot or tumble blasting;
- Heat treatment, including annealing, tempering, normalising and quenching (in water or oil) to enhance mechanical properties;
- Removal of excess metal or surface blemishes, (e.g., flash resulting from incomplete mould closure or burrs left from riser cut-off), by grinding, sawing or arc air (oxy-propane cutting);
- Rectification of defects by welding;
- Machining;
- Non destructive testing to check for defects;
- Priming, painting or application of a rust preventative coating.

Sand recovery and reclamation

The industry recycles a large proportion of mould and core making sand internally for re-use. This involves processing to remove tramp metal and returns the sand to a condition that enables it to be used again for mould or core production.

Fettling

The removal of feeders and excess material from a casting - is the first stage of finishing a casting. The metal removal is often achieved using manual cutting or grinding. However, more emphasis is being placed on automatic fettling, whereby the casting is placed in a machine programmed to remove materials from specific areas. The method of fettling must be taken into account at the initial casting design stage, so that the process is fast and efficient.

1.4.2 Process Improvement

Process improvement is an aspect of organizational development (OD) in which a series of actions are taken by a process owner to identify, analyze and improve existing business processes within an organization to meet new goals and objectives, such as increasing profits and performance, reducing costs and accelerating schedules.

Identify, analyze and improve the Key Processes

An organization is only as good as its processes. To be able to make the necessary changes in an organization, one needs to understand the key processes of the company. Rummler and Brache suggested a model for running a Process Improvement and Management project (PI&M), containing the following steps:

1. Identify the process to be improved (based on a critical business issue): The identification of key processes can be a formal or informal exercise. The management team might select processes by applying a set of criteria derived from strategic and tactical priorities, or process selection is based on obvious performance gaps.
2. Develop the objective(s) for the project based on the requirements of the process: The focus might be on quality improvement, productivity, cost,

customer service or cycle time. The goal is however always the same; to get the key process under control.

3. Select the members of the cross-functional team: A horizontal (cross-functional) analysis is carried out by a team composed of representatives of all functions involved in the process.
4. Document the current process by creating a flowchart or "organization map.": Describe the process regarding the Organizational level, the Process level and the Job/Performer level. Develop a cross-functional process map for the process.
5. Identify "disconnects" in the process: "Disconnections" are everything that inhibit the efficiency and effectiveness of the process. The identification should be categorized into the three levels: The Organizational level, the Process level and the Job/Performer level.
6. Recommend changes (organizational, in the process or in its execution): Categorize and prioritize the main problems and possibilities, evaluate alternative solutions. Develop a cross-functional process map for the recommended process.
7. Establish process and sub-process measures: The process measures should reflect the objectives of the project.
8. Implement the improvements.

1.5 Statement of the problem

The current productivity of the industry is low due to higher rejection of casting products. The defective castings arise due to various reasons. So it becomes necessary to take corrective measures to result in process improvement in the foundry which results in increasing the productivity.

1.6 Scope of the study

To analyze the reasons leading to defective castings. The source of these problems have to be identified, their impact on overall productivity is to be analyzed and suitable remedial measures are to be identified resulting in increase in productivity of the foundry through improvement in the various processes carried out in the foundry.

CHAPTER 2
REVIEW OF LITERATURE

2.1 ***AWADHESH KUMAR* (2011) in *International Journal of Engineering Science and Technology (IJEST) under the topic"* FMEA: Methodology, Design and Implementation in a Foundry" says about** the description of FMEA methodology & its implementation in a foundry. It is used as a tool to assure products quality & as a mean to improve operational performance of the process. The work was developed in an Indian foundry, in co-operation with part of the internal staff chosen as FMEA team members & was focused on the study of core making process. This paper demonstrated the systematic use of empirical data in performing process FMEA.

The methodology operated allowed to study and analyze every single step of core making process and to achieve an exhaustive knowledge and improvement of product and process and substantial cost savings can be realized.

The improvements obtained by the implementation of the recommended actions thus reduce the individual RPN and the global risk level of the process. Thus reduces costly liability of the core making process that was not performing as promised.

FMEA aids to improve and plan preventive and schedule maintenance of the process equipments. Thus improves operational performance of the core making process. The proposed methodology traces analysis in terms of cost, a widely accepted measure of risk.

Although focussed only on core making process this paper provides light on how to carry out FMEA. The methodology to evaluate various parameters to determine the various factors needed for FMEA can be studied.

2.2 **Dr.Hathibelagal Roshan in Process Optimization As A Tool In The Analysis Of Steel Casting Defects** explains ways to minimize the castings which do not meet the customer acceptance specifications, it is not only necessary to identify the process parameters related to the specific defects, but also it is necessary to identify the levels of these parameters to produce acceptable castings. Metal casting process has several sub-processes, which in turn have a number of process variables, which could influence the occurrence of defects in castings. Conventional statistical techniques with design of experiments involves too much work for the foundries to identify the process variables and their levels responsible for the defects. The use of a process optimization tool which uses foundry production data that can be collected on the castings on a regular basis in the identification of the process variables and their levels will be presented and discussed in this paper.

Metal casting process is a complex process with several sub-processes. Six Sigma methodologies are commonly used to optimize the process and minimize casting defects. However, the conventional statistical tools available today are not adequate to be effective in analyzing the casting defects and optimize the processes to minimize the impact on cost of quality. The reason for these include: the statistical techniques assume known distributions to the unknown foundry processes; the need for specially designed experiments; the need for carrying out a very large number of experiments in view of the large number of factors; the need to carry out specially designed experiments on a limited number of castings and the need to filter the potential factors into a manageable number of factors.

This paper gives a general idea of how to approach a process improvement problem in a foundry using Six Sigma methodology. Based on this we can select the various tools available for DMAIC process. And also we can understand that by controlling the defects we can achieve the desired process improvement in a foundry.

2.3 ***V.V.Mane, Amit Sata and M. Y. Khire*** **in New Approach to Casting Defects Classification and Analysis Supported by Simulation says** lean tools can be used to identify the various reasons for the major defects which occur during the casting process. And also it is possible to identify the remedial measures which can help in eliminating these defects which result in improving the productivity of the process.

2.4 ***Bharathi Rajkumar K and Gukan Rajaram*** **(2012) in *Indian Foundry Journal* Productivity Enhancement in Foundry Industry Using Lean Tools,** talks about how to implement lean philosophy in foundry with a spotlight on increasing productivity. Here, the purpose is to develop kaizens to eliminate waste in the foundry. In this case study, the industry could not meet the customer requirements due to the increasing cycle time of the individual process and rework due to excess rejection. Processing time is more in core making, mould making and finishing section of the foundry. Time study and motion study has been conducted and the respective operation idle time and busy time have been taken. This paper describes some of the quality improvement tasks that reduce the rejection rate which also affect the productivity. Improvements have been given by charting fish-bone diagram. This paper delivers the evidence of valid advantage of applying lean principle in foundry. Implemented lean principles reduced the time in some of the processes like core making, moulding and finishing section.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Type of Research

This is a quality control project which involves the analysis of the process involved using the QC tools, finding the root cause and taking necessary steps to improve the process in the aspects like productivity, reducing wastage etc. Six Sigma is an organized & systematic method for strategic process improvement that relies on statistical & scientific methods to reduce the defect rates and achieve significant quality up- gradation. The six sigma approach for modification of process involves the following phases which are carried out in a cyclic form as show in the figure:

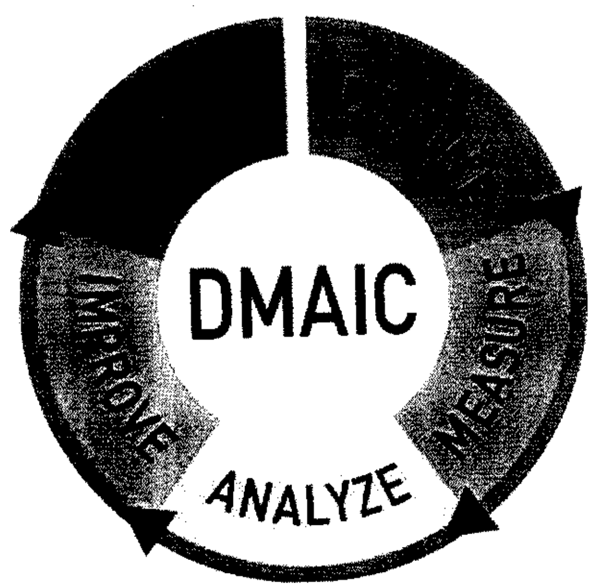

Fig 2: Standard Six Sigma process cycle

Six Sigma is a well-structured methodology that can help a company to achieve expected goal through continuous improvement. For many companies, Sigma quality level is a measure of the process defect rate and thus can be used to measure the quality of the manufacturing process. By using DMAIC procedure, the variance, waste and errors that plague an operation can be rooted out. A problem is defined and quantified, measured data is then collected to confine and clarify the problem, analytic tools are deployed to trace the problem to a root cause, a solution for the root cause is identified and implemented, and the improved operations are finally subjected to ongoing control to prevent recurrence of the problem. There are various tools which are used in each phase of the process. Few of which are listed below:

- Define Phase
    - Project Charter
    - Value Stream Mapping
    - Process Flowchart
    - SIPOC Diagram
- Measure Phase
    - Process Flowchart
    - Cause & Effect Matrix
    - Data Collection Plan/Example
- Analyze Phase
    - Pareto Chart
    - Time Series/Run Chart
    - Cause and Effect/Fishbone Diagram
    - 5 Whys
    - Hypothesis Testing (Continuous and Discrete)
- Improve Phase
    - Design of Experiments
    - House of Quality
    - Failure Modes and Effects Analysis (FMEA)
    - Simulation Software
- Control Phase
    - Process Sigma Calculation
    - Control Charts (Variable and Attribute)
    - Cost Savings Calculations
    - Control Plan

3.2 Objective of the study

Primary Objective

- To improve the productivity of the foundry by bringing in suitable improvements in various steps involved in the casting process.

Secondary Objective

- To identify the various types of defects found in the castings and their frequency of occurrence
- To identify the various causes due to which the defects occur.

3.3 Data and Sources of Data

Primary Data

These are data which are collected through manual observation to help in the course of the project:

- Defects occurring during casting production
- Split up chart containing various causes of each defect

Secondary Data

The following data are got from the organization in order to use in the course of the project

- Causes for each casting defect

3.4 Time period covered

40 days ranging between February 2013 and April 2013

3.5 Tools Used

- SIPOC
- Data Collection
- Pareto Analysis
- FMEA
- Control Plan

3.6 Limitations of the study

- The medium sized foundry leaves with option only to make measured corrective actions which require less investment
- The technical knowledge of workers involved in the process is very low making it difficult to train them according to the change required for improvement

CHAPTER 4

ANALYSIS AND INTERPRETATION

4.1 Define Phase

The Define phase is the first phase of the Six Sigma or DMAIC methodology. It is probably the simplest phase but by no means unimportant. The Define phase is where the problem statement and scope of project are defined and put down in writing. The tool used during this process is explained below.

Supplier Input Process Output Consumer (SIPOC)

SIPOC is a high-level picture of the process that depicts how the given process is servicing the customer. SIPOC can be seen as a high-level process map. It is typically used during the define phase of a process improvement project, as it helps us clearly understand the purpose and the scope of a process. It is an acronym for Suppliers - Inputs - Process - Outputs - Customers. The definition of each of these SIPOC entities is given below.

- **Suppliers** provide inputs to the process.
- **Inputs** define the material, service and/or information that are used by the process to produce the outputs.
- **Process** is a defined sequence of activities, usually adds value to inputs to produce outputs for the customers.
- **Outputs** are the products, services, and/or information that are valuable to the customers.
- **Customers** are the users of the outputs produced by the process.

The table below explains the SIPOC diagram for this particular project-

Table 3: SIPOC for foundry process

Supplier	Input	Process	Output	Consumer
Supplier of Silica sand	Raw Silica Sand	**Sand Preparation**	Mixed Sand ready for use	Moulding
Material Store	Prepared Sand Patterns and Core Moulding Boxes	**Mould Preparation**	Moulds ready for metal pouring	Pouring
Material Store	Raw material for melting Scraps	**Melting**	Molten Metal	Pouring
Furnace Mould Shop	Molten metal Prepared mould box	**Pouring**	Casting	Knock out
Metal melting department	Casting	**Knock out**	Final rough product	Finishing
Knock out	Rough casting	**Finishing**	Finished casting	External customer Stores

4.2 Measure Phase

The MEASURE phase involves more numerical studies and data analysis than the DEFINE phase. This phase focuses on measurement system validation and gathering root causes. The goal of the Measure phase of a Six Sigma DMAIC project is to get as much information as possible on the current process so as to fully understand both how it works and how well it works. The tools used during this phase is explained below.

Data Collection

Data is collected to identify the different defects which occur in the castings produced which is shown in Table 3. The defects mentioned in the table are being named below:

Table 4: Defects observed in castings

Defect Code	Particulars
D1	Crack
D2	Slag inclusion
D3	Mismatch
D4	Blow holes
D5	Shrinkage
D6	Crush
D7	Cold Shut
D8	Shift in moulding
D9	Surface finish
D10	Others

Table 5: Observed casting defects

DEFECT DETAILS AT SARVALAKSHMI FOUNDRY (BETWEEN FEB 26 TO APR 12)

Day	Total Production	Defects										Total Defects	Productivity
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10		
1	75	4	2	4	4	1	3	6	3	9	2	38	49.3
2	78	5	3	7	3	1	2	4	2	7	6	40	48.7
3	82	5	3	3	5	2	4	3	8	5	3	41	50.0
4	80	4	3	6	6	2	4	1	7	5	2	40	50.0
5	77	3	2	4	6	3	4	2	5	4	4	37	51.9
6	75	4	3	2	10	1	2	3	6	3	4	38	49.3
7	75	4	3	5	8	2	3	4	5	3	3	40	46.7
8	76	3	3	4	7	2	3	3	6	4	3	38	50.0
9	74	3	3	3	6	1	2	4	5	8	3	38	48.6
10	79	3	1	3	6	3	3	2	2	4	5	32	59.5
11	77	3	3	2	7	3	2	4	3	6	6	39	49.4
12	75	5	2	1	5	2	4	6	5	4	5	39	48.0
13	79	4	2	5	8	3	2	5	1	3	6	39	50.6
14	75	2	3	6	5	2	3	4	3	5	4	37	50.7
15	76	4	1	3	8	1	1	5	2	6	7	38	50.0
16	78	3	3	2	6	3	3	6	1	5	8	40	48.7
17	77	2	2	4	5	3	2	4	4	10	4	40	48.1
18	76	4	3	2	8	2	3	3	2	9	3	39	48.7
19	75	4	2	1	7	1	1	5	4	8	5	38	49.3
20	80	3	1	4	8	3	4	6	2	6	4	41	48.8
21	81	2	2	3	8	4	3	6	3	6	3	40	50.6
22	75	5	2	2	6	3	1	7	1	5	5	37	50.7
23	77	3	3	4	8	2	0	5	3	4	6	38	50.6
24	79	4	4	3	8	1	3	6	2	5	4	40	49.4
25	78	5	2	1	6	2	2	5	4	6	3	36	53.8
26	73	2	3	3	7	2	1	4	5	7	2	36	50.7
27	79	3	2	2	9	3	4	5	2	6	4	40	49.4
28	70	5	3	3	6	4	2	4	3	3	4	37	47.1
29	75	5	2	2	5	3	3	6	1	6	5	38	49.3
30	78	6	4	4	7	0	2	3	4	3	6	39	50.0
31	74	4	2	2	5	3	3	5	2	7	5	38	48.6
32	75	5	3	4	4	2	2	3	3	5	7	38	49.3
33	73	3	1	2	6	4	4	4	2	9	3	38	47.9
34	78	6	2	3	8	2	3	6	1	4	2	37	52.6
35	76	4	3	2	8	1	2	5	4	6	4	39	48.7
36	80	4	2	3	6	3	3	4	2	7	7	41	48.8
37	74	5	0	4	6	3	2	5	3	6	3	37	50.0
38	75	3	2	3	6	4	1	4	1	9	6	39	48.0
39	77	4	3	3	5	3	2	7	3	5	3	38	50.6
40	79	3	2	2	5	4	3	6	2	9	4	40	49.4

Calculation of Sigma level

The existing sigma level is calculated by finding out Defectives Per Million Opportunities(DMPO). It is calculated using the formula given below.

DPMO = DPO * 1,000,000

where DPO = D / TOP

and TOP = U * O

In the formula

D is number of defects

U is Total number of units and

O is number of opportunities for defect

For current project

D, U and O are 1740 units, 3460 units and 10 respectively.

Therefore DMPO is 50289 which means the current sigma level is 1σ

4.3 Analyze Phase

The ANALYZE phase is the beginning of the statistical analysis of the problem. The practical problem was created in the earlier phases. This phase statistically reviews the families of variation and will determine which significant contributors to the output are. Most of the analysis at this phase is not whether the AFTER process performance is different than the BEFORE process performance because none of the improvements have been implemented yet, these improvements are now becoming evident and prioritized. The tool used during the ANALYZE phase is explained below.

Correlation

Correlation refers to any of a broad class of statistical relationships involving dependence. When two sets of data are strongly linked together we say they have a High Correlation.

- Correlation is Positive when the values increase together, and
- Correlation is Negative when one value decreases as the other increases

In this project correlation is used to identify if productivity of the foundry and defects are correlated. From the calculation it is found that the correlation value between productivity and defect occurrence is **-0.705.**

It can be understood that productivity decreases with increase in productivity.

Pareto Chart

A pareto chart is used to graphically summarize and display the relative importance of the differences between groups of data. Pareto charts are most commonly used in the Analyze phases of Six Sigma's DMAIC methodology. In cases where Six Sigma teams are working on problems that have multiple, easily captured top level causes, Pareto charts are very useful in further focusing the team on the biggest opportunities. Following are the pareto charts used to find out the main reasons due to which the each type of defects occurs in the castings produced.

1. **Crack**

   Casting cracks are result of internal stresses caused by a non-uniform cooling of the casting. Hot cracks form during solidification of the alloy within the solidification interval. Cold cracks form in completely solidified casting during its consequent cooling.

Table 6: Causes for crack

S.No	Cause for defect	Frequency
1	High Moisture	80
2	High Clay	40
3	Hard mold	30
4	Hard Cores	21
	Total	171

Pareto chart corresponding to this defect is shown below.

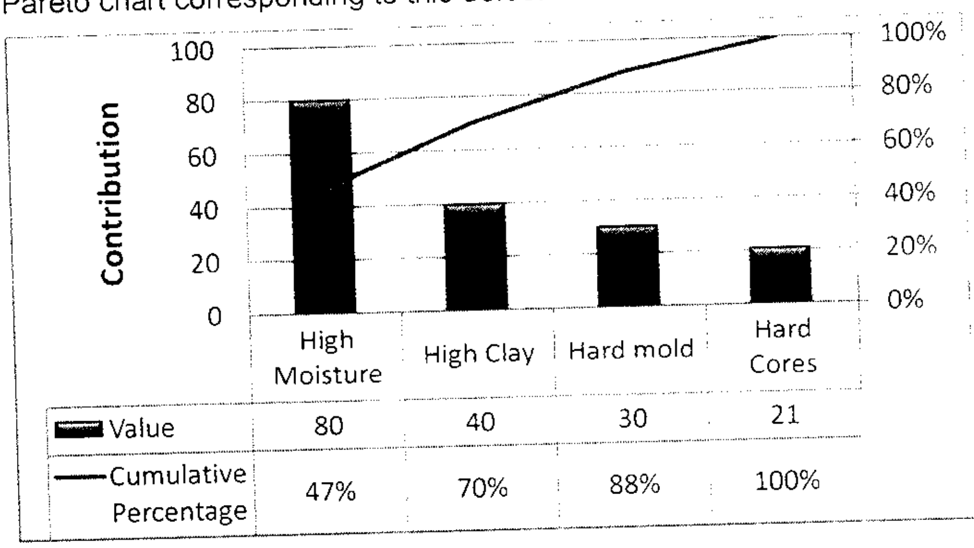

Fig 3: Pareto chart for crack

2. **Cold Shut**

A casting defect caused by imperfect fusing of molten metal coming together from opposite directions in a mold or due to folding of the surface.

Table 7: Causes for cold shut

S. No	Cause for defect	Frequency
1	Low pouring temperature	75
2	Improper or interrupted pouring	73
3	Inadequate venting	34
4	Improper gating system	30
	Total	212

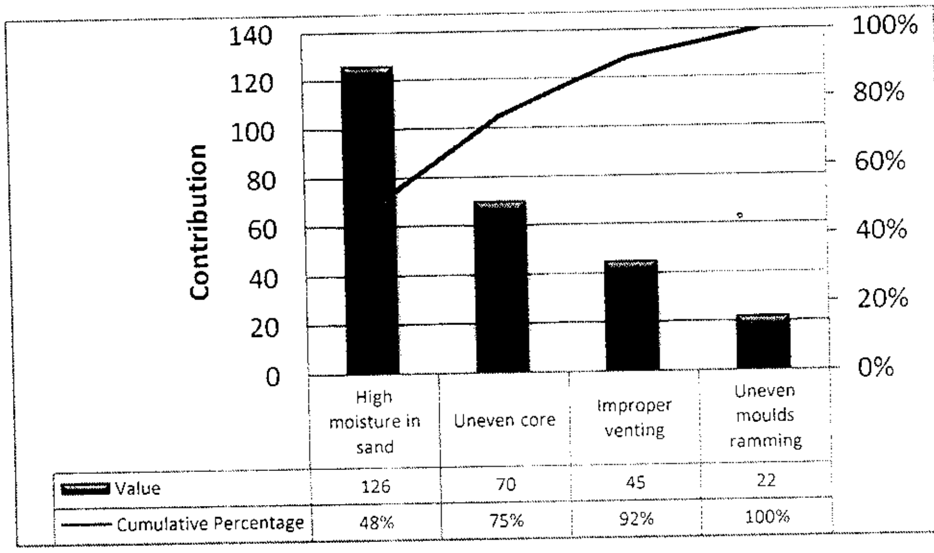

Fig 4: Pareto chart for cold shut

3. **Mismatch**

Mismatch in mold defect is because of the shifting molding flashes. It will cause the dislocation at the parting line.

Table 8: Cause for Mismatch

S.No	Cause for defect	Frequency
1	Loose pins	80
2	Misalignment of box	35
3	Improper cope and drag	17
4	Improper closing	8
	Total	140

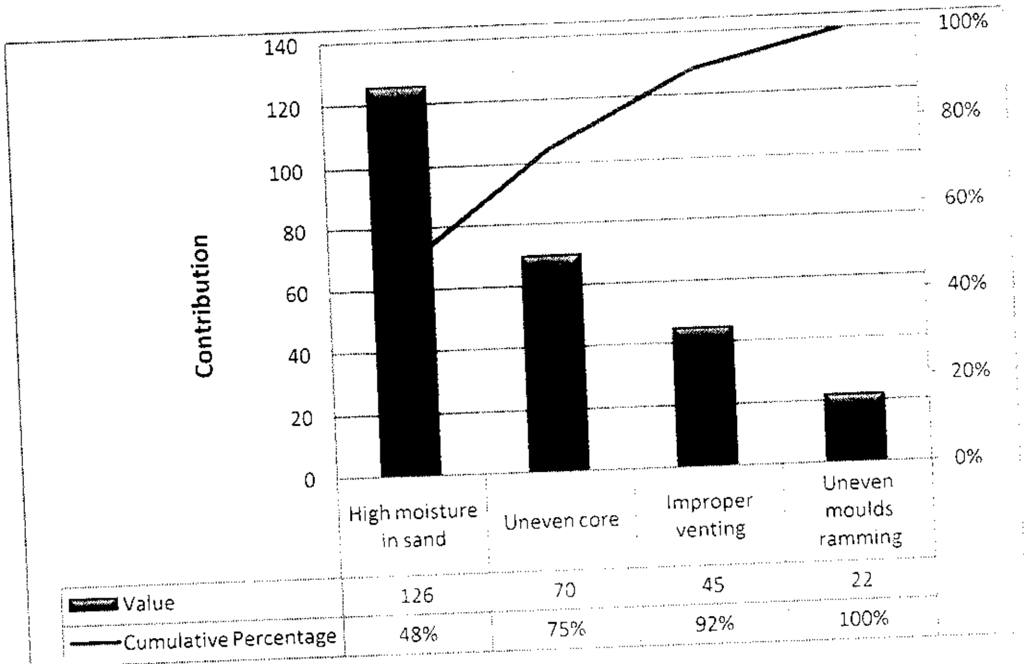

Fig 5: Pareto chart for mismatch

4. Crush

Crush occurs when a mould is closed over an ill fitting core or badly finished joint surface.

Table 9: Causes for Crush

S.No	Cause for defect	Frequency
1	Improper sand mixing	62
2	Uneven clamping	33
3	Improper closing of clamping	10
4	Improper closing of mould	7
	Total	112

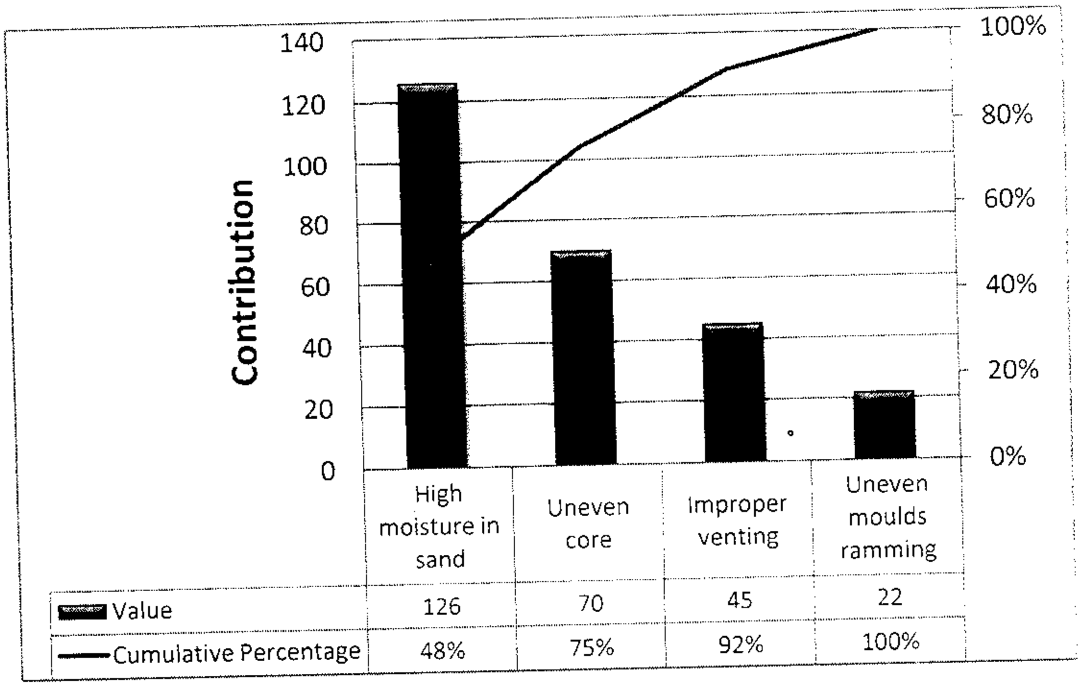

Fig 6: Pareto chart for crush

5. Slag Inclusion

These are relatively small particles which remain suspended in the alloy at the time of pouring, or which may be precipitated due to changes in solubility on cooling.

Table 10: Causes for slag inclusion

S.No	Cause for defect	Frequency
1	Sand preparation	47
2	Gating problem	30
3	Wrong mixture	20
4	Low moisture	10
	Total	107

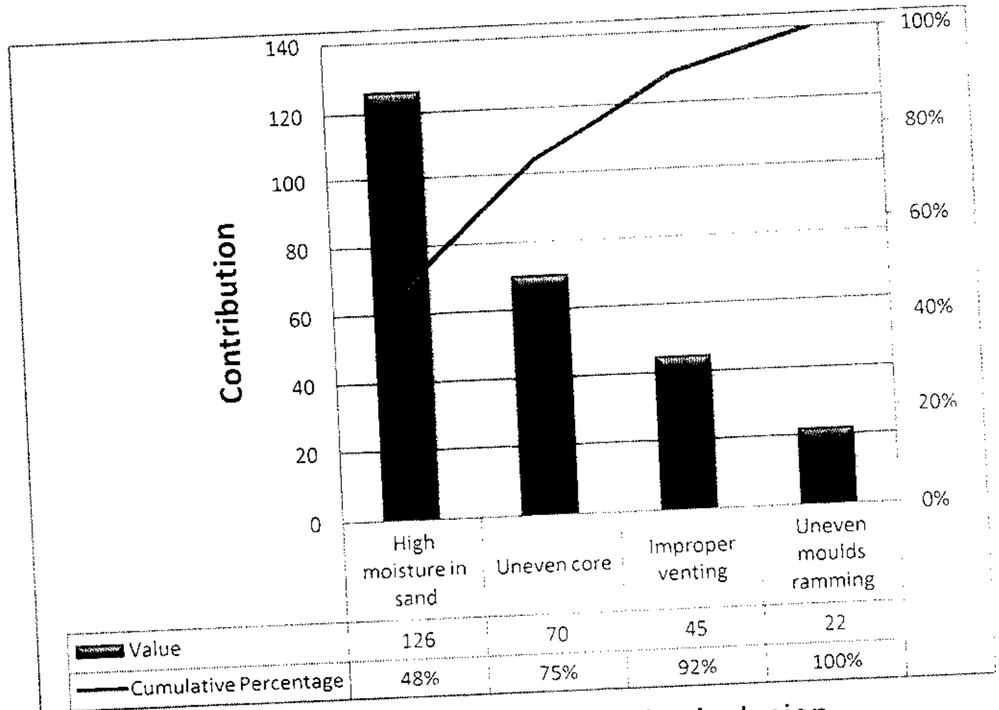

Fig 7: Pareto chart for slag inclusion

6. Shift in moulding

The following are the causes due to which mould shift occurs.

Table 11: Causes for shift in moulding

S.No	Causes for defect	Frequency
1	Movement of core	72
2	Improper support	41
3	Improper pattern	20
4	Movement of box without pins	8
	Total	141

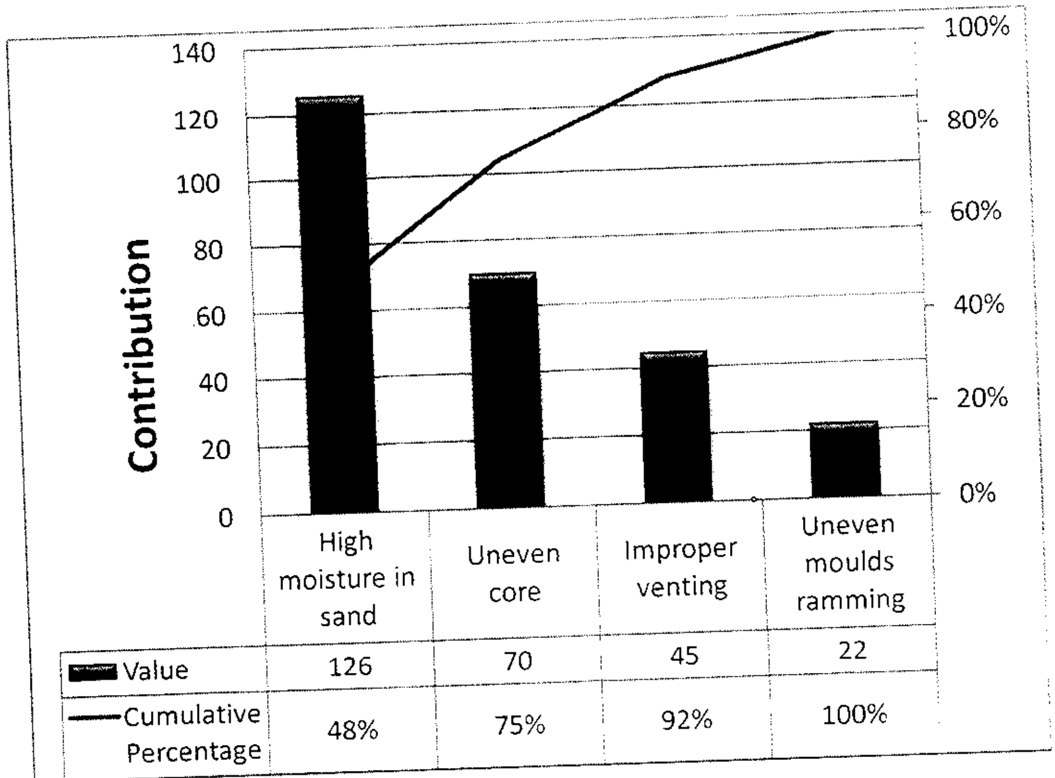

Fig 8: Pareto chart for shift in moulding

7. **Blow Holes**

Blowhole is a kind of cavities defect, which is also divided into pinhole and subsurface blowhole. Pinhole is very tiny hole. Subsurface blowhole only can be seen after machining.

Table 12: Causes for blow holes

S.No	Causes for defect	Frequency
1	Insufficient new sand	123
2	Hardness of sand	76
3	Insufficient venting	51
4	Contaminated sand	21
5	Over rammed moulds	23
	Total	294

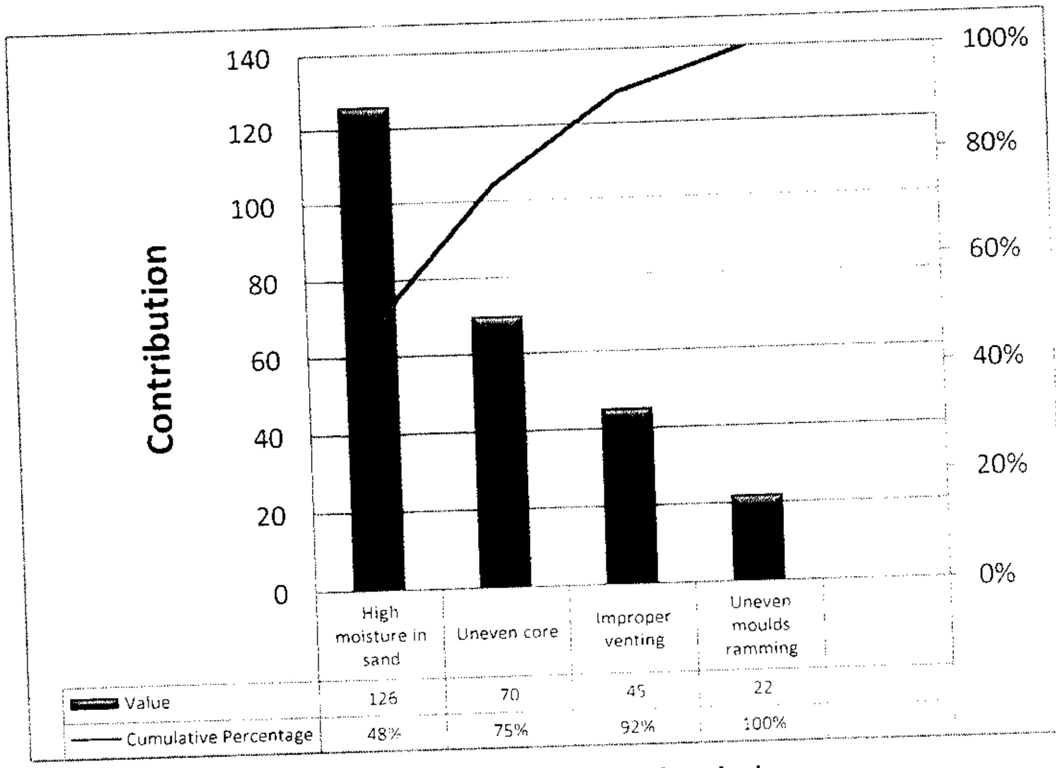

Fig 9: Pareto chart for blow holes

8. Shrinkage

Shrinkage defects include dispersed shrinkage, micro-shrinkage and porosity. Shrinkage cavities are also called as shrinkage holes, which is a type of serious shrinkage defect.

Table 13: Causes for shrinkage

S.No	Cause for defect	Frequency
1	High pouring temperature	72
2	Unsuitable composition of material	17
3	Low mould hardness	10
4	Inadequate ramming	9
	Total	108

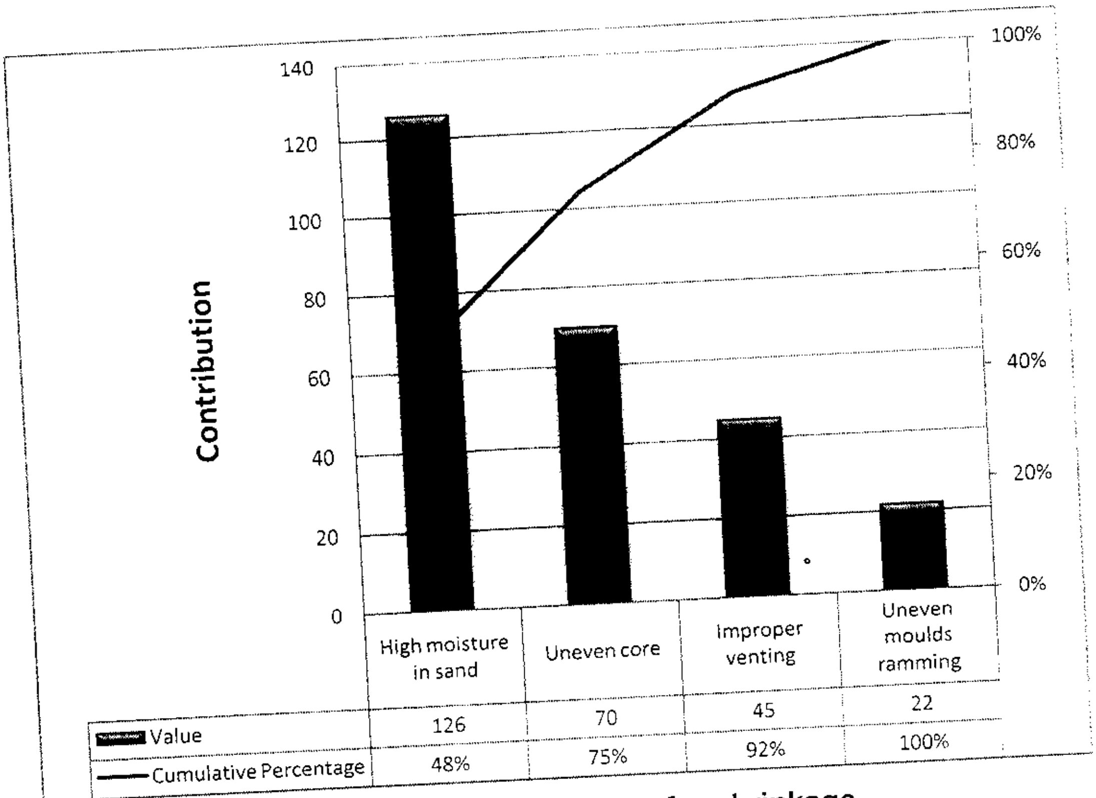

Fig 10: Pareto chart for shrinkage

9. **Surface finish**

The following are the causes for surface defects in casting products

Table 14: Causes for surface finish

S.No	Causes for defect	Frequency
1	High moisture in sand	126
2	Uneven core	70
3	Improper venting	45
4	Uneven moulds ramming	22
	Total	263

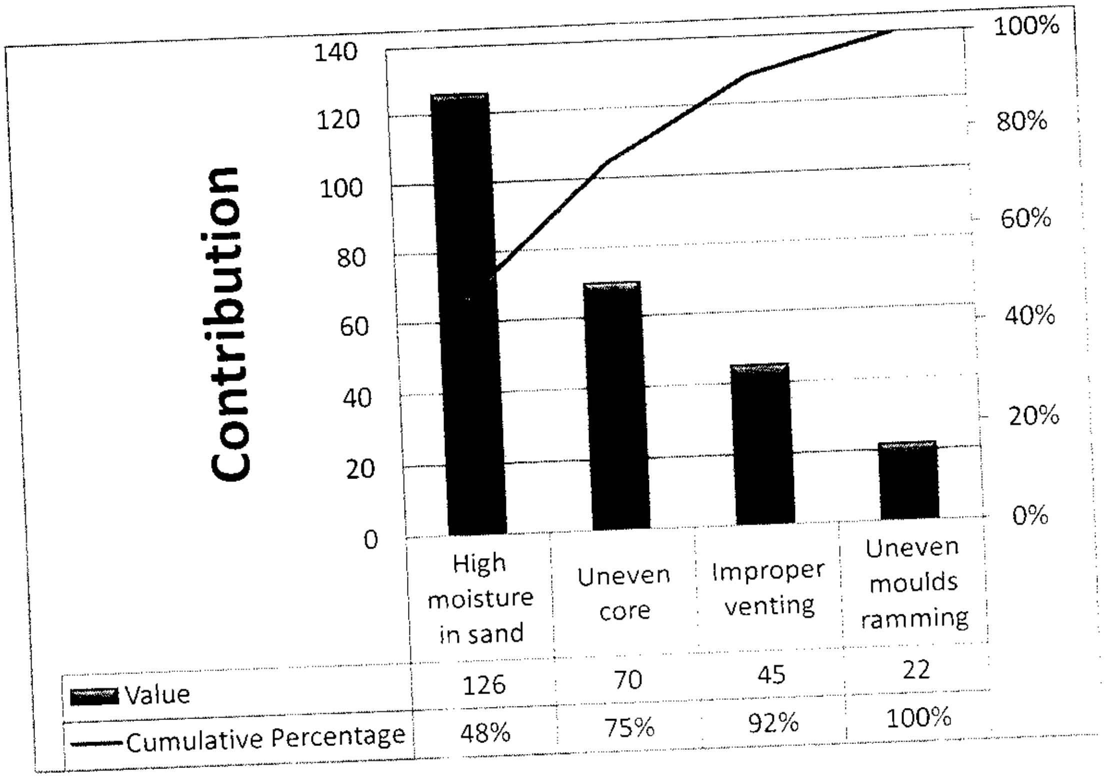

Fig 11: Pareto chart for surface finish

4.4 Improve Phase

The objective of Improve Phase is to identify improvement breakthroughs, identify high gain alternatives, select preferred approach, design the future state, determine the new Sigma level, perform cost/benefit analysis, design dashboards/ scorecards, and create a preliminary implementation plan. Failure Mode and Effect Analysis (FMEA) is the tool used in Improve phase for this project.

Failure Mode and Effect Analysis (FMEA)

The acronym FMEA stands for "Failure Modes and Effects Analysis". It represents a technique aimed at averting future issues in project processes and eliminating risks that may hamper a solution. Implemented within the Six Sigma methodology, FMEA, or Failure Modes and Effects Analysis, further identifies and evaluates defects which could potentially result in reducing quality of a product. Defects within the methodology are defined as anything that reduces the speed or quality at which a product or service is delivered to happy customers. While Six Sigma techniques are implemented to discover and reduce the variables in processes which cause non-random fluctuations, FMEA is used to discover and prioritize aspects of the process that demand improvement and also to statistically analyze the success of a pre emptive solution.

To implement FMEA the following steps are to be followed.

- Probably failure modes for each stage
- Effects of this failure mode
- Severity of effect on scale of 1-10
- Identification of failure mode cause
- Identification of ease of detecting problems and rate it on scale of 1-10
- Statistical analysis of data collected for occurrence of event and rate it on scale of 1-10
- Caluclation of RPN
- Identifying corrective action
- Allocation of necessary actions to responsible individuals
- Re-evaluation of the process

Table 15: FMEA for reducing foundry defects

Potential failure mode	Potential failure effects	SEV	Potential causes	OCC	Current process controls	DET	RPN	Actions recommended
High Moisture	Crack	9	Increased moisture content in moulding sand	8	Pre heating of sand	4	288	Pre heating of sand to control moisture content
High Clay	Crack	9	More clay content in the sand	7	Inspection of sand	3	189	Maintain the clay content in sand between 3 to 4% by modifying sand composition
Hard mold	Crack	9	The mold is hard than required level	7	Inspection before usage	3	189	Use relatively drier sand for mold preparation
Improper sand mixing	Crush	8	More amount of reused sand	8	Visual instruction indicating proper composition	5	320	More new sand than reused sand
Uneven clamping	Crush	8	Improper clamping	7	Visual inspection	4	224	Introduce two way clamping
Sand preparation	Slag inclusion	7	Improper composition of sand mixture	8	Manual inspection while provideing vent holes	5	280	Introduce two way clamping
Gating problem	Slag inclusion	7	Faulty gating design	7	Manual inspection of gating design	7	343	Reconsider the current gating design

High moisture in sand	Surface finish	7	Increased moisture content in moulding sand	7	Pre heating of sand	5	**245**	Pre heating of sand to control moisture content
Uneven core	Surface finish	7	Outer surface of core has dents	7	Visual inspection of core after preparation	6	**294**	Smoother patterns used for core preparation
Insufficient new sand	Blow holes	9	Improper composition of sand mixture	8	Manual inspection while provideing vent holes	5	**360**	More new sand than reused sand
Hardness of sand	Blow holes	9	Improper composition of sand mixture	8	Manual inspection while provideing vent holes	5	**360**	More new sand than reused sand
Insufficient venting	Blow holes	9	Vent holes provided not enough to allow heat to escape	7	Providing vents according to instruction from supervisor	4	**252**	Provide more vent holes at critical points
Movement of core	Shift in moulding	8	Improper mould preparation	7	Checking the sand before packing	3	**168**	More pressure to be exerted
Loose pins	Mismatch	8	Gap present between the pins after closing	8	Checking for movement	3	**192**	Change pins from time to time
Low pouring temperature	Cold Shut	8	More time between molten metal taken from furnace and pouring	8	Using guided ways for easier movement	3	**192**	Regulate distance between furnace and mould box
Improper or interrupted pouring	Cold Shut	8	Pouring metal in a hurry	7	Pouring metal till it overflows	3	**168**	More care to be taken while pouring molten metal
High pouring temperature	Shrinkage	8	Too high temperature of molten metal	8	Waiting for few seconds before pouring	4	**256**	Regulate distance between furnace and mould box
Unsuitable composition of material	Shrinkage	8	More scrap metal used	7	Metal weighed before putting into furnace for melting	3	**168**	More new metal to be used

CHAPTER 5

FINDING, SUGGESTIONS AND CONCLUSION

5.1 Findings

- The sand composition is not as per the required composition leading to many defects during mould preparation, venting, crack in casting, slag inclusion, hard moulds, inadequate venting, etc
- In the sand composition the percentage of reused sand is high thus leading to inappropriate sand mixture
- Pre heating of sand is of short duration thus not removing the moisture content fully
- Clay content of the sand is above the desired level
- Metal composition has more level of scrap material than the optimum level thus leading to less strengthen castings.
- Time taken between taken molten metal from furnace and pouring it into mould varies with distance of the mould box from furnace thus leading to blow holes, shrinkage and partially filled castings
- Overflow of molten metal is carried out to ensure casting is filled throughout the cavity
- Clamping pins are not tight enough to hold the mould during the movement
- The core is not soft enough on the surface sometimes having loose sand particles on it while kept inside the mould
- Mould is not being closed properly thus leading to movement of core kept inside the mould
- More time taken to transport core as only one core is taken at a time

5.2 Suggestions

- Increase the content of fresh sand from 50% to 65% thus allowing more permeability thus allowing heat to escape easier when hot molten metal is being poured.
- The clay content of the sand to be maintained at 3 to 4% which is the optimum level
- This clay content provides required adhesiveness to the sand to keep it strong throughout the process
- The moisture content has to be reduced by pre heating the sand before sand preparation.
- The composition of molten metal must have more fresh or new alloy than the alloy obtained from scrap
- Handling of castings must be taken care during Knock out and Fettling process to avoid damage of castings
- Material handling equipments for carrying more than one core at a time thus reducing the time consumption for mould preparation
- Fixing the optimal distance for pouring molten metal into the mould. This will ensure properly filled moulds and high quality castings.

5.3 Conclusion

By implementing these suggestions it is possible to match the standards as required to produce castings which are less defective. These steps lead to increase in the productivity which is actually achieved through improvement of each individual process involved in the foundry process.

5.4 Scope for future study

There are few more reasons which are also responsible for defective castings. Only a few have been taken for the study and being analyzed. After successful implementation of these processes the other problems can be analyzed and suitable solutions can be found thus resulting in further enhancement of the productivity.

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