Reducing Casting Defects in Foundry Industry by using Six Sigma Methodology

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Abstract - *Casting is a manufacturing process in which desired shape of a product is achieved by pouring liquid metal into a cavity having the pattern of the product called as mould and the product obtained is often called as casting. Casting companies faces various casting defects (blowhole, Shrinkage, Crack) which leads to rejection of the product as it does not meet the customer acceptance specification and it results to financial loss. Six sigma a zero defect approach used in this paper to reduce casting defects and increase the efficiency of the production to meet the customer requirements. DMAIC (Define, Measurement, Analyze, Improve, and Control) a six sigma based methodology has been applied as the problem solving approach to reduce casting defects by controlling various parameters and processes. Use of six sigma (DMAIC) technique in reducing casting defects showed great results in terms of reduction of production wastes and thereby reducing the cost. This paper, aims to illustrate the application of six sigma in small-scale foundry industry. The purpose of this paper is to demonstrate the empirical application of DMAIC methodology to reduce failure in casting product and to reduce the rejection rate of product.*

Key Words: **Casting defects, Six Sigma, DMAIC methodology, Tools and Technique, Minitab software**

1. INTRODUCTION

The six sigma define as business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction by some of its proponents. Six Sigma is a business-driven, multi-faceted approach for reducing the defects and improving the process capability. Six Sigma is a well-structured methodology that focuses on reducing variation, quantifying non-conformance and make products, process and services defect-free. The six sigma started by Motorola was the first company to launch a six sigma approach in the mid1980s. In 1988, where the Motorola specialized in electronic products, Bill Smith1986 is engineer and statistician at Motorola, introduce the six sigma concept aiming to attack the existing quality problems in the company. The Six Sigma management method philosophy focuses on better understanding of customer requirements, improving business systems throughout the organization, and enhancing the organization's financial performance. It is used to improve the organization's products, services and processes across various disciplines, including production, product development, marketing, sales, finance, and administration. It is achieved through understanding the underlying processes, and reducing or eliminating defects and waste. The Six Sigma management method integrates profound knowledge of statistics, engineering, process, and project management.

2. Problem Formulation and objective

2.1 Product and Problems

Many casting company are facing a problem of rejection for cast product during the testing due to some defects. Industry facing critical quality related problems and rejection of lots at customer end.

2.2 Research Objective

1. To find out various major defects occurring in the final product.
2. To find out various remedies of major defects occurring in final product.
3. To reduce material waste.
4. To find out sigma level of the company.

3. Methodology

DMAIC Approach

The DMAIC means Define, Measure, Analyze, Improve and control. These all work together to create the DMAIC process. This process is incredibly important in the six sigma process because it is what helps bring a diverse team together. This is what helps DMAIC is used for existing process them complete a processor model so that they can share their work and get the job done. It is used to improve an existing business process.

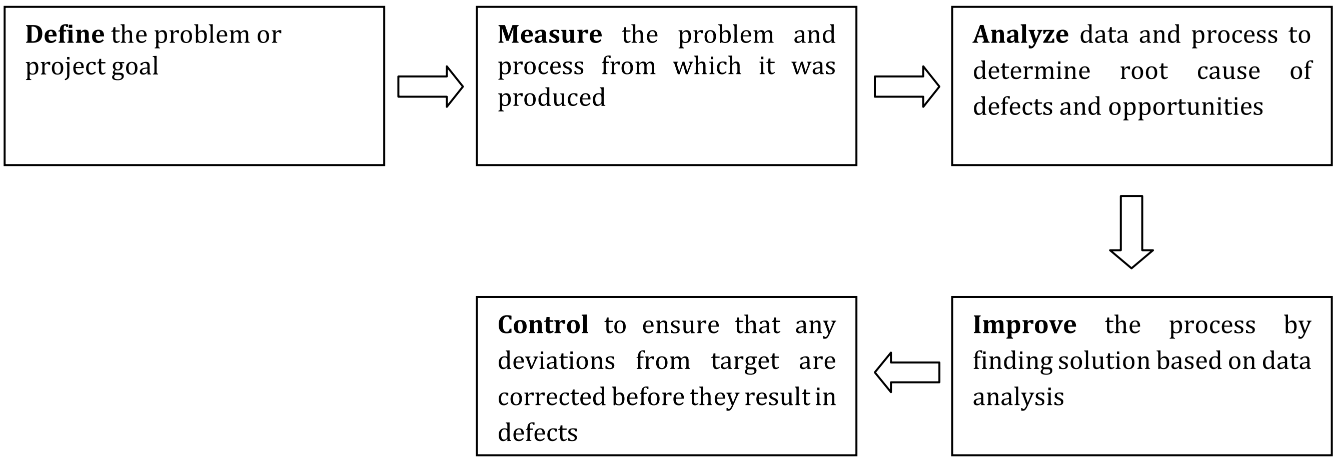

Figure-1: DMAIC Approach

4. DMAIC Implementation

4.1 Define Phase

The purpose of this phase is to define the problem, goal of the project and the process that needs to be improved to get higher sigma level. There are different six sigma tools are available for define phase.

4.1.1 Business Case

Company produces different types of casting product, which is highly produced by the method of sand casting which is held in casting department. Company is facing problem of monthly 3% of rejection in casting product which account annual loss of 7,20,000Rs. per annum to company. In which the most of the product rejected in quality checking due to the defect occur during casting process. So our aim is to reduce casting defect which in turn improve quality of product and annual loss to the company.

4.1.2 Problem statement

To reduce the rejection rate in casting product from 3% to 1%". This will done by using SIX SIGMA DMAIC Methodology.

4.1.3 CTQ (Critical to Quality)

CTQ highlights the key measurable characteristics of a product or process whose performance standards or specification limits must be met in order to satisfy the customer. They align improvement or design efforts with customer requirements. It will also help to identify the opportunities through which a product/process may fail.

After starting a project and gathering the voice of the customer (VOC), it is time to define the critical-to-quality outputs (CTQs).

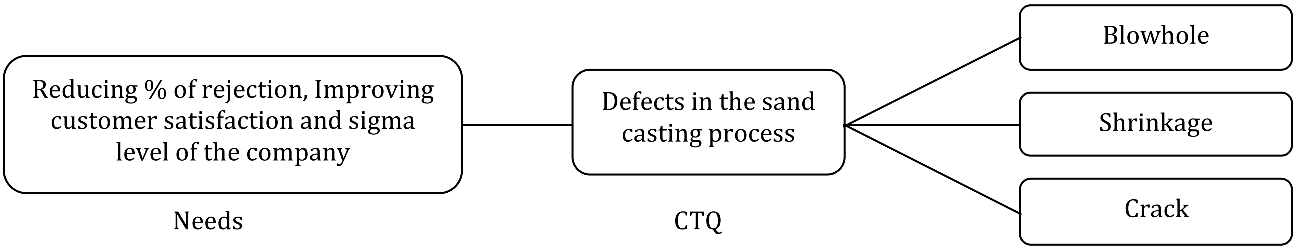

Figure -2: Critical to Quality (CTQ) Tree for rejection of casting product

4.1.4 Process Flow Diagram

A process flow diagram (PFD) or Process flow chart (PFC) is a diagram commonly used in process engineering to indicate the general flow of plant processes and equipment. The PFD displays the relationship between major equipment of a plant facility and does not show minor details.

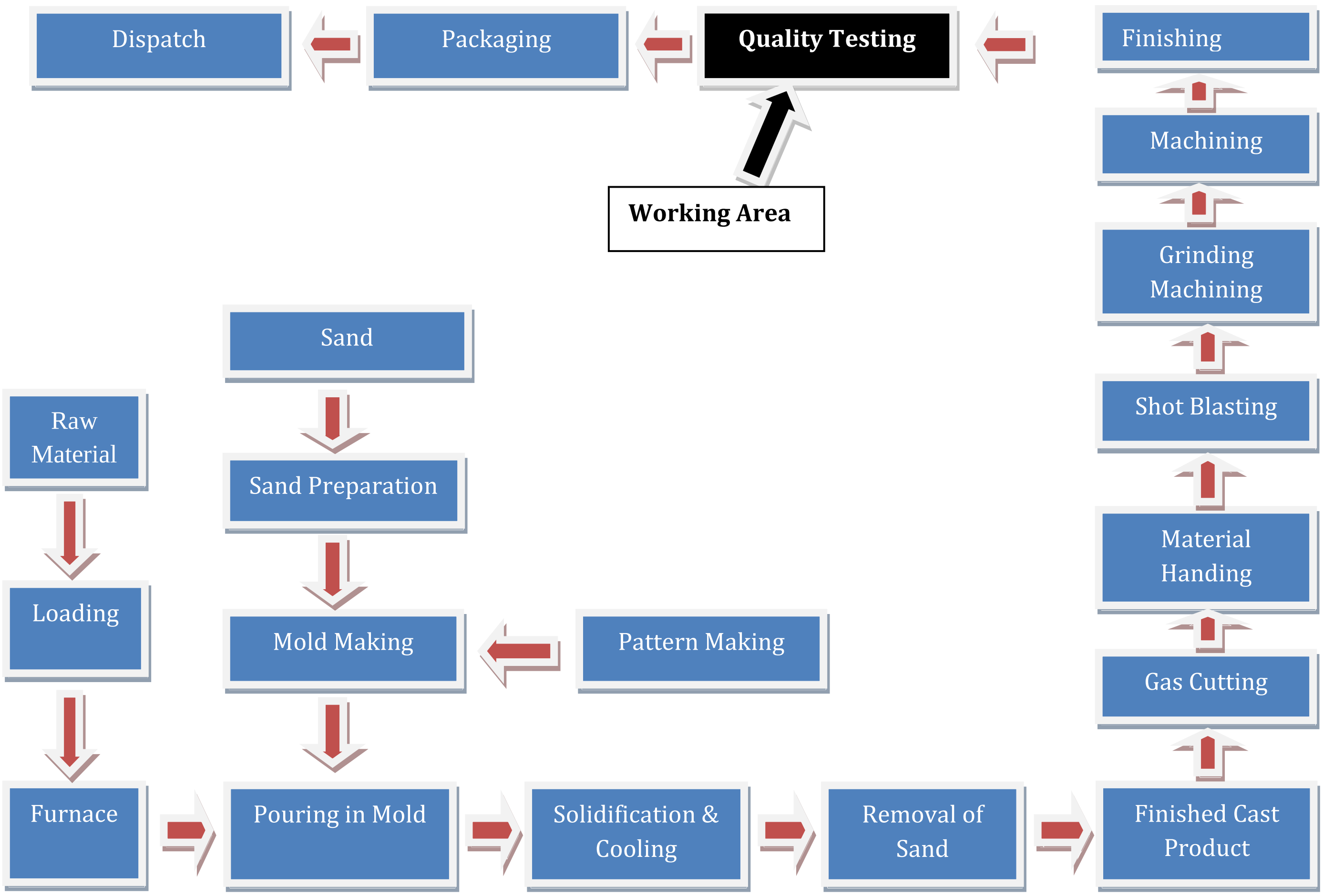

Figure -3: Process flow Diagram

4.1.5 SIPOC (Supplier-Input-Process-Output-Customer)

A SIPOC diagram is a tool used by a team to identify all relevant elements of a process improvement project before work begins. It helps define a complex project that may not be well scoped, and is typically employed at the Measure phase of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology.

Table -1: SIPOC

Supplier	Input	Process	Output	Customer
Finishing Department	Manufactured Product	Loading of Product	Ok Product	Packing
Machining Department	Testing Equipment	⇓	Rejected Product	Scrap yard
		Putting Product in testing equipment		
		⇓		
		Inspection Process		
		⇓		
		Removing Product from testing equipment		
		⇓		
		If product ok then supplied to packaging and dispatch		
		⇓		
		If not the rejected		

4.2 Measure Phase

This is basically a data collection phase wherein present situation data are collected and then current sigma level is calculated for the process in question. Sigma level can be calculated by different methods, based on the type of data. For discrete data defects per million opportunity (DPMO) number is calculated and then sigma level is ascertained from the DPMO-sigma level table.

4.2.1 Data Collection Plan

Collected the product data of last 26 months, from that sorting of data was based on rejection rate of products than from remaining data again sorting data as per year and last data sorted based on cost and selling effect on the company. A data collection plan is a detailed document. It describes the exact steps as well as the sequence that needs to be followed in gathering the data for the given Six Sigma project. Table -2 illustrates the details of data collection plan for the project.

Table -2: Data Collection Plan

What to Measure	Percentage
Data Type (Attribute/Variable)	Attribute
Source from where data will be collected	Inspection lab
Data Collection Type (Sampling/Population)	Population (100%)
Data Collection Responsibility	Lab supervisor To be verified by project leader

4.2.2 Initial Sigma Level Calculation

On the basis of the data of production and rejections of last 2.2 years and number of opportunities for failure, current Sigma level was calculated using DPMO (defects per million opportunities) equation:

$$\text{DPMO} = \frac{\text{Number of defects} \times 1{,}000{,}000}{\text{Number of opportunities} \times \text{Number of units}}$$

Where,
Number of defects = number of rejections (i.e. at least one defect exists to impute the product as defective).
Number of opportunities = number of CTQs.
Number of units = number of units produced.
DPMO = Defects per million opportunities

$$\text{DPMO} = \frac{563 \times 1{,}000{,}000}{3 \times 16812}$$

DPMO = 11162.66

Based on these DPMO, we calculate Sigma level (as shown in table -3) by using table -4.

Table -3: Initial Sigma level Calculation

Units inspected	16812
Defected units	563
Opportunities per unit	3
DPMO	11162.66
Process Sigma Level	3.9

Table -4: Standard value of Sigma level and DPMO

Sigma Level	**Defects (or Errors) Per Million Opportunities (DPMO)**
1	691,462
2	308,538
3	66,807
4	6,210
5	233
6	3.4

4.2.2 Pareto Chart Analysis

A pareto chart is used to graphically summarize and display the relative importance of the differences between groups of data.

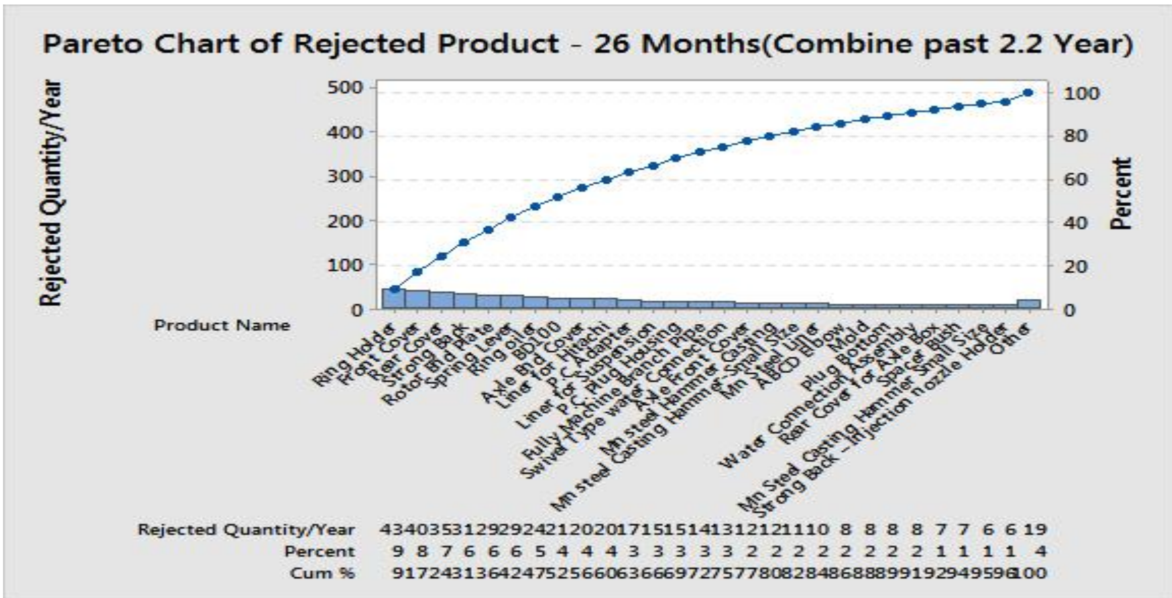

Chart-1: Pareto Chart for 26 Months Rejected Product

4.3 Analyze Phase

Analyze is the third phase of DMAIC. During this phase, the team identifies the root cause or source of problem or critical factors which will enable them to achieve a target for improvement.

4.3.1 Brainstorming

Brainstorming is carried out for finding out probable root cause of problem.

Aim of Brainstorming:

- To discover out possible core causes. Following are probable causes were identified after performing brainstorming.
- Lack of cleaning of mold box.
- Improper mold preparation.
- Improper metal pouring rate.
- Improper ramming process.
- Lack of proper maintenance of machine.
- Improper venting and gating system.
- Lack of training in mold making.
- Dirty ladle
- Poor permeability of sand.
- Poor hardness of mold.
- Poor cooling effect due to insufficient cooling time.
- Insufficient pouring temperature.
- Lack of supervision.
- Excessive moisture content in molding sand.

4.3.2 Cause & Effect Diagram

Cause & Effect diagram, also called fishbone diagram or Ishikawa diagram, is a visualization tool for categorizing the potential causes of a problem in order to identify its root causes as shown in figure below.

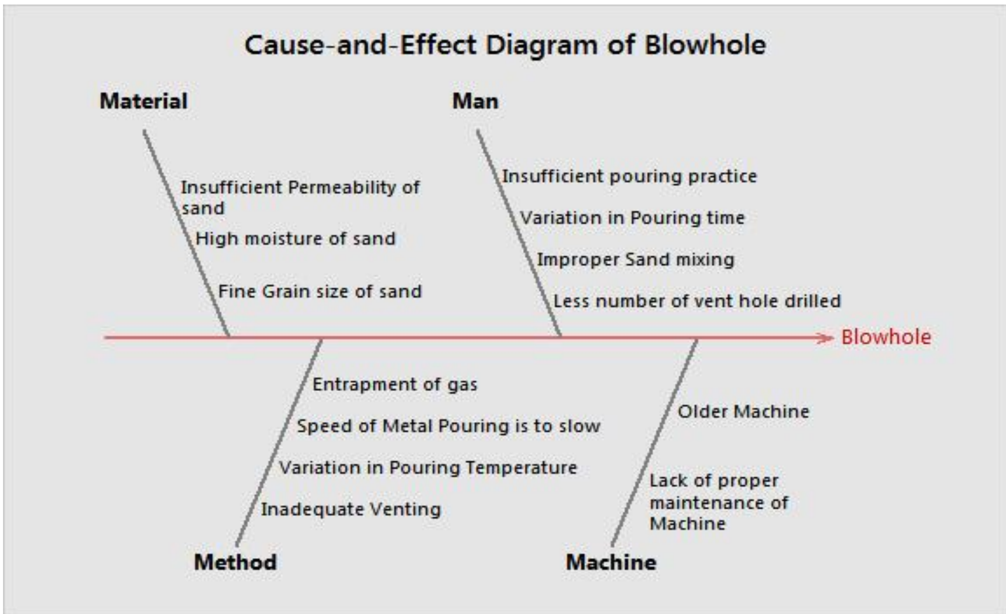

Figure -4: Cause and Effect diagram of blowhole

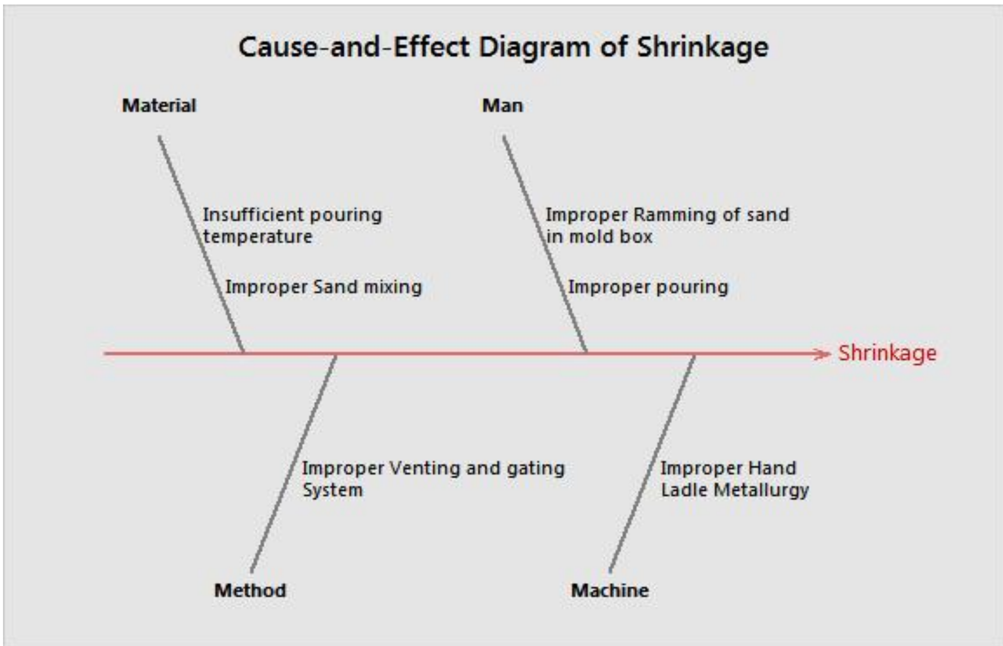

Figure -5: Cause and Effect diagram of Shrinkage

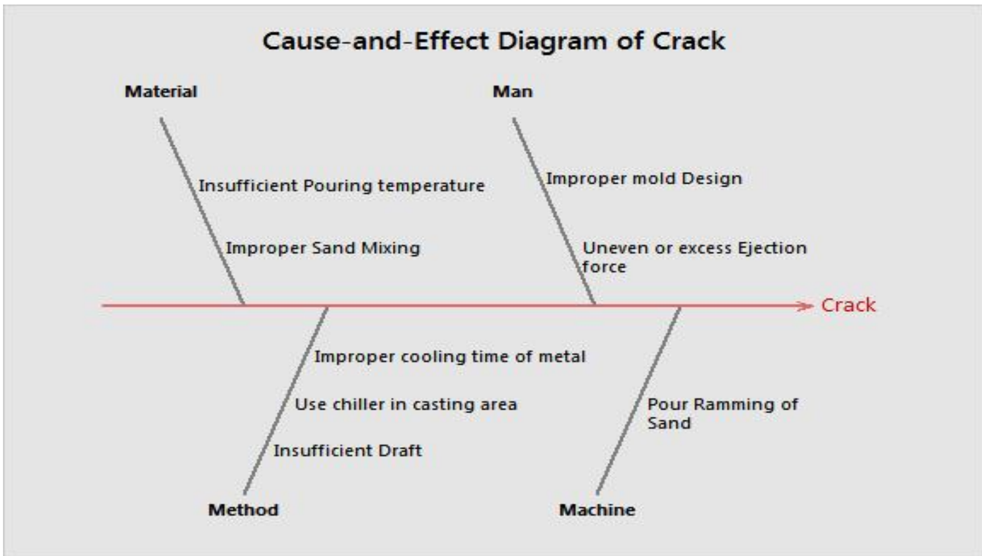

Figure -6: Cause and Effect diagram of Crack

4.3.3 Cause Validation

The causes find out by brainstorming are validated by GEMBA and Measure method.

Table -5: Cause & Validation

Sr.No	Causes from C & E Diagram	Analysis Method	Validation Remarks
1	Lack of cleaning of mold box	GEMBA	Not Valid
2	Improper mold preparation	GEMBA	Valid
3	Improper metal pouring rate	GEMBA	Not Valid
4	Improper ramming process	GEMBA	Valid

5	Lack of proper maintenance of machine	GEMBA	Not Valid
6	Improper venting and gating system	GEMBA	Valid
7	Lack of training in mold making	GEMBA	Not Valid
8	Dirty ladle	GEMBA	Not Valid
9	Poor permeability of sand	Measurement	Valid
10	Poor hardness of mold	Measurement	Valid
11	Poor cooling effect due to insufficient cooling time	Measurement	Not Valid
12	Insufficient pouring temperature	Measurement	Valid
13	Lack of supervision	GEMBA	Not Valid
14	Excessive moisture content in molding sand	Measurement	Valid

4.3.4 Why-Why Analysis

It is a method of questioning that leads to the identification of the root cause(s) of a problem. A why-why is conducted to identify solutions to a problem that address its root cause(s). Rather than taking actions that are merely band aids, a why-why helps to identify how to really prevent the issue from happening again. Table -6 indicates why-why analysis of the final causes.

Table -6: Why-Why Analysis

Sr.No	Root Causes	Why-1	Why-2	Why-3	Why-4	Why-5
1	Improper Mold Preparation	Unskilled Labour	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program
2	Improper Ramming Process	Unskilled Labour	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program
3	Improper Venting and Gating System	Unskilled Labour	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program
4	Poor Permeability of sand	Poor Maintenance	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program
5	Poor Hardness of mold	Poor Maintenance	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program
6	Insufficient Pouring temperature	Poor Maintenance	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program
7	Excessive Moisture content in molding sand	Poor Maintenance	Lack of Awareness	Lack of Knowledge	Lack of Guidelines	No Training Program

4.4 Improve Phase

This phase statistically reviews the variations in the process and determines what factors significantly contribute to the output. The main goal of this Improve phase is develop optimal solutions of the problems. Improve the process to remove cause of defects. Improve the process by finding solution of problem based on data analysis in previous phase.

4.4.1 Brainstorming for Solution Identification & Responsibility

Brainstorming for solution identification is done in order to know what will the possible solution for root cause as shown in table -8.

Table -7: Brainstorming for Solution Identification & Responsibility

Sr.No	Root Causes	Possible Solution	Responsibility
1	Improper Mold Preparation	➢ Improve mold preparation process	Supervisor
2	Improper Ramming Process	➢ Sufficient ramming should be done	Labor/Supervisor
3	Improper Venting and Gating System	➢ Modified Venting and Gating System to reduce turbulence	Supervisor
4	Poor Permeability of sand	➢ High permeability sand should be used	Lab Incharge
5	Poor Hardness of mold	➢ Improve Hardness of mold	Lab Incharge
6	Insufficient Pouring temperature	➢ Adjust Proper pouring temperature ➢ Low pouring temperature	Supervisor
7	Excessive Moisture content in molding sand	➢ Control Moisture content. ➢ Use rust free chills & clean inserts.	Lab Incharge

4.4.2 Solution Selection Matrix

The Solution Selection Matrix provides a method of assessing the positive impact of each proposed solution on reaching the goal as well as the relative effort, time to implement and cost. Improvement teams rate each solution resulting in individual scores and then indicate whether they choose to implement the solution or not.

Table -8: Solution Selection Matrix

Sr.No	Solution	Impact	Effort	Risk	Cost	Score	Solution Selection Remarks
1	➢ Improve mold preparation process	10	9	9	10	38	A
2	➢ Sufficient ramming should be done	10	10	8	10	38	A
3	➢ Modified Venting and Gating System to reduce turbulence	10	9	9	10	38	A
4	➢ High permeability sand should be used	10	8	10	10	38	A
5	➢ Improve Hardness of mold	10	8	10	10	38	A
6	➢ Adjust Proper pouring temperature ➢ Low pouring temperature	10	10	8	10	38	A
7	➢ Control Moisture content. ➢ Use rust free chills & clean inserts.	10	8	10	10	38	A

On the basis of solution selection matrix as shown in table -8, all the seven solutions are highly required. So we have to implement all the above solution as per the requirement of industry.

4.4.3 Result Comparison

$$DPMO = \frac{25 \times 1{,}000{,}000}{3 \times 1890}$$

DPMO = 4409.17

Based on these DPMO, we calculate new Sigma level (as shown in table -9) by using table of standard value of sigma level and DPMO.

Table -9: New Sigma level

Units inspected	1890
Defected units	25
Opportunities per unit	3
DPMO	4409.17
Process Sigma level	4.3

Table -10: Result Comparison

	Before	**After**
Units inspected	16812	1890
Defected units	563	25
Opportunities per unit	3	3
DPMO	11162.66	4409.17
Process Sigma level	3.9	4.3

4.5 Control Phase

The aim of control phase is to sustain the improvements achieved in the improvement phase and gain a sustainable improvement in system.

4.5.1 GEMBA Board

GEMBA or GENBA: A Japanese word meaning "the actual place" or "the real place". Gemba Board is a very effective Visual Management Tool to Monitor and communicate current status of the Work Place. A Gemba Board System is an excellent way of opening up communication channel between Management and work Place so that one knows status in day to day running work. This form of Communication helps an organization to become more transparent. A workplace that is easily understands by all. Anyone could walk into a work unit and at a 'glance' understand the status of that work unit, what is current status, and whet improvements are needed.

4.5.2 Standard Operating Procedure (SOP)

Standard operating procedures are written, step-by-step instructions that describe how to perform a routine activity. Employees should complete them in the exact same way every time so that the business can remain consistent. The standard operating procedures should be the basis for training any new employees. They should also be updated every year to ensure they stay relevant to the current needs of the organization. SOPs are **step by step procedures** on how to do something that is critical to quality, critical to safe operations, or critical to security.

5. CONCLUSIONS

Six sigma is one of the best quality improvement technique till now. There are two methods in six sigma one is DMAIC and another is DMADV. We have used DMAIC methodology for our industrial engineering project. We implemented this method in small scale foundry industry which produces casting products. In first step of the method we defined our domain and problem. In second step of this method, first we took previous 26 months (2.2 years) data from the department to found out current sigma level which is 3.9 by using standard formula. We use analysis and improve step of this method to find out various causes (Shrinkage, Blowhole, Crack) and their appropriate reason or solution. By implementing this method we improved sigma level from 3.9 to 4.3. The overall result of present work is clearly shows that by applying DMAIC methodology the rejection has reduced from 3% to 1.3% monthly(36% to 15.6% yearly) and saving of cost 4,08,000Rs. approx. yearly. By using Six sigma method it's help in improve in process, quality and productivity.

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