OPTIMIZATION OF DEFECTS IN CASTING OF PISTON WITH THE USE OF "DMAIC" (DEFINE, MEASURE, ANALYZE, IMPROVE, CONTROL) METHODOLOGY

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

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Submitted by

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I, **Luvvesh Kumar Kaushik,** Roll No. **2K20/PIE/06** of MTech (Production and Industrial Engineering), hereby certify that the project Dissertation titled "**Optimization of Defects in casting of piston with the use of "DMAIC" (Define, Measure, Analyze, Improve, Control)** methodology which is submitted by me to the Department of Mechanical Engineering,Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of the Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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LUVVESH KUMAR KAUSHIK

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ABSTRACT

The goal of this research is to employ the DMAIC (Define, Measure, Analyze, Improve, and Control) Six Sigma Approach to minimize defect rates and improve the sigma level of the sand-casting process. This study specifies a step-by-step guide based on the DMAIC Methodology, and its efficacy has been assessed via a case study that shows an overall decrease in defect rejection and an increase in the process' sigma level from 3.32 to 3.47. Employee Job Satisfaction Following Six Sigma Implementation was also investigated. A total of 60 workers responded to the survey, yielding an 83 percent response rate. The findings suggest that participants in Six Sigma saw improvements in the majority of job satisfaction indicators. This program's implications are discussed, as well as future study objectives. Through an experiment, the study discusses how to reduce casting flaws in foundries. The research looks at how six sigma DMAIC (Define-Measure-Analysis-Increase-Control) methodology may be used in the automotive sector to reduce casting errors in the manufacturing of aluminum pistons, optimize process variables, and improve performance.

***Keywords*— Six Sigma, DMAIC, Pareto, Piston defects, Cause-and-Effect Matrix**

CHAPTER 1

INTRODUCTION

1.1 Six Sigma: Background

Six Sigma originated in 1986 at Motorola Inc. as a data-driven technique to minimise electronic process variability, and it has since developed into a global phenomenon. When General Electric and Allied Signals employed Jack Welch, the first of them was invented by Motorola's Bill Smith, and they were subsequently utilised by GE and Allied Signals. Understanding the development of the Six Sigma technique is beneficial to GE in two ways. To begin with, Jack Welch exemplified this kind of leadership. Second, they supported Six Sigma initiatives with such a robust incentive system. As a consequence, GE has changed the incentive benefit package for all workers such that the company pays 60% of the bonus and 40% of the bonus is contingent on Six Sigma success. The new technique was effective in capturing the attention of GE Six Sigma employees. In addition, at GE, Six Sigma training has become a prerequisite for promotion up the corporate ladder. According to Welch, no one would be considered for a management role unless they obtained at least a green belt certification by the end of 1998.

Six Sigma has seen several changes and improvements throughout the years, and this applies to both manufacturing and service sectors. Any product, process, or transaction may benefit from Six Sigma. R&D, marketing and sales, on-time delivery, administration, and other sectors with a direct impact on the customer may all be used. They may also be utilised. It comprises reviewing objective results with the use of mathematical methods and tools, as well as putting in place a project improvement strategy. It's a very data-driven approach. As a consequence of the advancements and profits it has brought, scholars and practitioners from all over the world have been paying attention to it. (Ahmad, W et al,2019).

1.2 Six Sigma: Definition

Being exceedingly disciplined, systematic, customer-centric, and profit-driven, or participating in a company-wide strategic business improvement initiative that supports in the creation and execution of really flawless ideas, goods, or services. Six Sigma, on the other hand, aims to reduce the irregularity of processes that leads to errors. Six Sigma is a competitive corporate endeavour focused at boosting profitability, market share, and customer satisfaction via the use of statistical instruments and methodologies that may lead to significant efficiency benefits. Six

Sigma is a process and product improvement strategy that incorporates both financial and methodological accounting elements. (Ahmed, N et al,2018).

Many quality assurance measures are conducted in order to become globally compatible with and obtain market and organizational excellence sectors, such as bent manufacturing, ISO certification, comprehensive quality management, quality circle, and so on. On the other hand, the outcomes of these activities are both timely and unprofitable. As a consequence, adopting and implementing a strategy that will grow successfully in such a short period of time is crucial. Six Sigma is an abbreviation that stands for "six steps to success." Is the same strategy that can deliver speedy collapse adjustments, and it's vital to look into using it to enhance efficiency, market share, and client retention. Qualitative analysis has a lot of advantages and gains.

1.3 The Six Sigma Strategy

A process must create more than 3.4 defects per million opportunities to attain Six Sigma accuracy. "An opportunity," or failing to meet the conditions, is what a prospective failure is characterised as. As a result, our primary activities must run almost flawlessly.(Ahmad, W et al,2019).

Strategy

● Know what's Important to the Customer

● Reduce Defects

● Reduce Variation

● Centre around Target

Key Concepts of Six Sigma

Six Sigma is based on a few basic ideas at its foundation.

- ✓ Attributes that are most significant to the client are considered critical to quality.
- ✓ Failure to give what the client wants is a defect.
- ✓ Process Capability: What your process is capable of producing
- ✓ Variation: The customer's perceptions and feelings

1.4 Methodology of Six Sigma

Six Sigma is a Greek letter that means "six." A sigma is a statistical measuring unit that gauges a method's capacity to reach faultless efficiency. Six sigma is the amount of sigma calculated in a process when the change around the objective is so large that only 3.4 out of one million outputs become defects, or in a process where the whole process has now increased to 1.5 standard deviations over time. The term "sigma" refers to the propagation or diffusion of the meaning of a process. Sigma This test assesses if the process is capable of providing error-free work. The consumer will be disappointed if you make a mistake. In actuality, the sigma value is a measurement of how well a company's process functions. A higher sigma level indicates a lesser probability of errors and, as a consequence, better performance. (Bhat, S.et al,2014).

Six Sigma has two key methodologies:

Both DMAIC and DMADV Methodologies are based on Deming's Plan-Do-Check-Act Cycle.

1. DMAIC
2. DMADV

DMAIC:

The abbreviation DMAIC stands for "define, measure, evaluate, improve, and record," and it stands for "define, measure, evaluate, improve, and record." To construct the DMAIC process, they all collaborate. In six sigma, this phase is critical since it assists in the construction of a dynamic team. This encourages them to develop a strategy or model to describe their task and then follow through with it. It is used to assist a company in expanding its current activities.

DMAIC consists of following steps: (Chandel et al,2016).

- Establishing process transformation goals that are reflective of client demands and corporate strategy.
- Take measurements and gather data on key parts of the present process.
- Examine the data to determine if there are any cause-and-effect relationships. Determine the interactions and make every attempt to incorporate all of the relevant components.
- Using strategies such as experiment design, develop or enhance the process based on data analysis.
- Check for any faults that need to be addressed even before any deviations from the norm. Set up pilot processes, continue production, implement control mechanisms, and keep an eye on the process at all times.

Figure 1.1: Five Steps to DMAIC approach (Ahmed, N. et al, 2018).

DMADV:

The definition, measurement, analysis, design, and verification of how DMAIC may be used to enhance an existing business process is referred to as DMADV. The new model or process configuration has been applied via DMADV.

In DMADV, the stages are as follows:

- Establishing design parameters that match client needs and the company's strategy.
- CTQs, product capacities, manufacturing process capacity, and dangers are all assessed and documented. (Critical to Quality Characteristics).
    - Evaluate design and development options, produce a high-quality design, and evaluate design capabilities to choose the best designs.
    - Specifications, design optimization, and a design verification schedule. Simulations may be required at this point.
    - Check the specifications, execute a few test runs, and then begin the manufacturing process.
    - In this study, we'll go through the DMAIC approach in detail.

1.5 DMAIC Methodology

The DMAIC approach's essential procedure is Define-Measure-Analyze-Improve-Control (DMAIC). The five steps of the DMAIC process are shown in Figure 1.1.

1.5.1 D: Define

This is the most important stage in figuring out what's wrong. It's one of the most important phases of the DMAIC process, and it deserves your whole focus and effort if possible. This method identifies and relates essential consumer expectations to business requirements. This phase aims to define and identify the strategy for exceeding the customer's expectations, taking into account all of the details such as the project title, purpose, length, team size, projected benefits, and timeline. This method emphasises the problem's size and complexity. A Project Charter's goal is to assist team members in understanding the project's scope and limits, as well as the project's performance targets, duration, finance, team members' responsibilities, and predicted project financial advantages, among other things. It also prevents project managers and team members from giving the project mixed messages. The issue should be linked to the company's business objectives and bottom line. The intended results will not be realised until the six sigma project is linked to both the organisational aim and the six sigma project (Chatrad, B et al,2016).

In this phase, the following aspects of the selected concerns were addressed:

- To work on, correct the problem statement.
- Customers' requests and expectations are the foundation of the Critical to Quality (CTQ) tree.
- Create a high-level process map to better understand the process.

Tools and techniques used in define phase:

1. Project charter.
2. SIPOC model.
3. Voice of Customer (VOC).
4. Process flow

1.5.2 M: Measure

This is essentially a data collection phase. Once the issue has been recognised, the next step is to determine whatever more steps are required to compute it. This step begins with the selection of one or more product attributes, followed by process mapping and any required testing. The findings are recorded on process control cards, and a baseline for process capacity or output is created. It's essentially a data-gathering phase in which real-world data is gathered and the current sigma amount for both the mechanism and the mechanism in question is calculated.

Depending on the kind of data, many methodologies may be used to compute the sigma level. If data is obtained improperly, the whole six sigma process will fail.
At this time, the following two major problems were addressed.

1. Data collection

Accurate and sufficient measurements and data are necessary. Data is at the center of the six sigma project.

2. Calculation of present sigma level

Depending on the data format, several methodologies may be employed to compute the degree of Sigma. The DPMO-sigma level table is used to calculate the number of discrete data defects per million opportunities (DPMO) and the sigma level.

DPMO= (Number of defects × 106)/ (Number of Opportunities × 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

Tools and techniques used in measure phase:

1. Pareto chart
2. Process flow chart
3. Statistical Quality Control (SQC) tools

1.5.3 A: Analyse

It's critical to assess both the measurement and the data to check whether they match the issue description and take into account the underlying reason. The problem's answer is then identified. Based on the analysis, the issue description must be re-established and the process began on a regular basis. The purpose of the Six Sigma project analysis process should be to figure out what's causing the significant variability in the CTQs in question. The purpose of both Six Sigma analysis processes is to find probable causes for the process problem being analysed, and then to utilise data and analysis to pick the underlying causes. Following the creation of a list of possible causes, the next step in the preparation is to check particular causes using data obtained from the process. To find out what's causing a problem, a lot of creative thinking and debate is required. The team organised and led a brainstorming session with all of the process personnel engaged, yielding a list of possible CTQ variation triggers. On the basis of all of these factors, a causation diagram has been developed.

Tools and techniques used in analysis phase:

a. Pareto Chart
b. Brainstorming
c. Root Cause Analysis
d. Five-Why Analyse Technique
e. Failure mode and effect analysis
f. Hypothesis Testing

1.5.4 I: Improve

In order to monitor the results for the specified root causes, solutions must be devised and applied throughout the project's improvement phase. Management takes a decision based on the results of the analysis. After acquiring a deeper understanding of the problem's underlying cause and collecting objective evidence, they may be able to suggest potential alternatives. Testing is necessary since there may be some interaction between input variables. Tolerances should be assessed to see whether they are really necessary. We use the best of the various solutions once we've tried them all and confirmed that the expected consequences are occurring. The improve phase focuses on coming up with solutions to reduce the underlying causes of variation, as well as testing and standardising those solutions.

Tools and techniques used in Improvement phase:

a. Pareto diagram
b. Taguchi’s Design of experiment
c. Brainstorming
d. ANOVA
e. Analysis of variance

1.5.5 C: Control

During the control phase, the current structure is institutionalised by changing numerous systems, rules, procedures, budgets, and guidelines to guarantee that the whole firm functions smoothly. The next four stages are useless if the six sigma gaols are not monitored. The major goal of this stage is to have our systems regulated once the adjustment solution has been installed, as well as to have the control condition quickly removed and the triggers set up ahead of any non-conformance. The success of the project is measured by how successfully the previous phases were executed. Instruments were created during the monitoring phase to ensure that crucial variables stayed within acceptable ranges throughout time in order to enhance the process. The following control methods were proposed based on the kind of issue and the operating system of a concern:

a. Periodic review of the various measures suggested in Improve phase.

b. Statistical Quality Control (SQC) charts. Thus, maintaining targeted sigma level.

1.6 Basic 7 Quality Control Tools

The basic 7 quality tools are

- Check Sheet
- Histogram
- Pareto Chart
- Cause and Effect Diagram
- Flow Chart
- Control Chart
- Scatter Diagram

1. Check Sheet: Simple data gathering charts are check sheets. They are easy to understand and read.

2. Histogram: A histogram is a visual depiction of the variety in a product or the outcomes of a procedure. The bell-shaped curve, which is typical of classical techniques, is often achieved. The histogram may help you figure out what's going on in the network and whether or not the data fits into the bell-shaped curves.

3. Pareto Chart: The Pareto diagram may also be used to visually assess problem clusters and give priority to them. The graphic displays the significance of challenges, flaws, and opportunities in decreasing order as a vertical bar graph.

4. Cause and Effect Diagram: The source of the issue and its ramifications The graphic demonstrates the links between distinct triggers for the analysed result. The principal types of triggers are found in the main line divisions, while numerous sub causes are found in the branches.

5. Flow Chart: Diagram of the flow of information The procedure is divided into various steps. The number of factors that contribute to the change is decreased as a result of this research.

6. Control Chart: These were used to record the outcomes, which are mentioned further below.

7. Scatter Diagram: A scatter plot is often used to demonstrate the quality and strength of a connection between two variables. It's created by plotting two variables on two axes.

1.7 Critical Success Factors of Six Sigma

The aspects listed below are critical to a successful Six Sigma deployment:

I. Commitment and involvement of top management
II. a working understanding of the six-sigma methodology, tools, and approaches
III. Projects pertaining to corporate strategy and six sigma.
IV. Customer needs and six sigma programmes are intertwined.
V. The selection, appraisal, and tracking of projects should all be done properly.
VI. a sufficient organisational infrastructure
VII. Cultural transformations are taking place.
VIII. Project management skills are required of middle-level managers.
IX. Six sigma projects are popular among suppliers.
X. Both employees and managers get training.
XI. The six-sigma project and human resources.

Six effective sigma applications are recommended for implementation, including:

- ✓ The education and training of managers and participants is continuing.
- ✓ Set clear expectations and choose project leaders wisely based on their leadership abilities.
- ✓ Projects of strategic importance are being picked one by one.

1.8 Six Sigma and Indian SMES

Indian corporations utilise advanced strategies to boost productivity, such as Six Sigma and other continuous quality improvement programmes, in today's market of globalisation and competition. Because Indian SMEs are expected to compete on a global scale, they must be aware with international quality standards and consumer expectations. Indian enterprises must use Six Sigma and other continuous process improvement strategies to satisfy these worldwide requirements (Sambhe, 2012). Although Six Sigma's effectiveness in major industries may be proved in a number of ways, few SMEs have incorporated it in their operations, demonstrating a lack of knowledge of Six Sigma's impact on SMEs. According to a study of Six Sigma's penetration and advantages in Indian industries, 69 percent of Six Sigma is employed in the manufacturing business. With a 15% share of the market, IT is placed second. Six Sigma comprised manufacturing and service, among other things, with a percent contribution. "Cost

reduction" is the most essential benefit for large-scale industries, while "profitability increase" is the most important benefit for SMEs.(Lande, M et al,2016).
The successful use of the Six Sigma approach in a small-scale foundry firm to minimise refusals and revamp the leaf spring production process is one example of an attempt to demonstrate the impact of Six Sigma in Indian SMEs. The Six-Sigma initiative improved all essential input variables, resulting in a decrease in overall rejection from 48.33 percent to 0.79 percent. The installation of Six Sigma resulted in an annual savings gain of USD 8,000. (Gijo et al., 2014).
Indian SMEs adopted a potential Six Sigma approach to lower production costs for recycled track shoes. The sigma level was increased from 1.51 to 4.15 after key input parameters were optimised, resulting in a decrease in poor quality expenses (COPQ) from Rs. 22,72,480 to Rs. 20,187 per year. Six Sigma boosted the annual savings of Rs 2,252,293 and the return on investment (ROI) by a large amount (Gholap and Desai, 2012).
Many writers in Indian SMEs use some of the best practises. Six Sigma was successfully used to increase efficiency and productivity in the aluminium plating process, reducing defect rates from 17.22% to 4.822%. (Shanmugaraja and colleagues, 2011). Lowering the sleeve rejection rate using Six Sigma resulted in higher output and profitability. At an Indian foundry, the six Sigma approach was utilised to decrease the piston rejection rate in one of the categories (Singh and Khanduja, 2012). Better client commitments, as well as greater efficiency and quality, are all signs of successful operations in Indian SMEs. (Desai, 2012).

1.9 Casting Process

Casting procedures include patterns, moulding or assembling, sand production, core manufacture, melting, pouring, and shakeout. For intricate components, the whole casting process is crucial. The optimal foundry method, which encompasses all procedures, may be established after extensive investigation.
In the industrial sector, process casting is arguably the most extensively used method. Template for mould packing, core of mould assembly, mount designs, gating system, and sand for mould preparation are all used in casting. Remove the prepared moulds and pour molten metal into them. Remove the cooled casting when the metal has hardened. Such procedures are occasionally used because of their convenience of usage, cost-effectiveness, and ability to manufacture small castings. Casting is a process, and there's a risk the ultimate product may fail at some point along the way. The dynamic interactions between numerous components or processes, such as metal composition, design procedures, moulding, melting, pouring, shake-out, fettling, grinding, and so on, make up process casting.

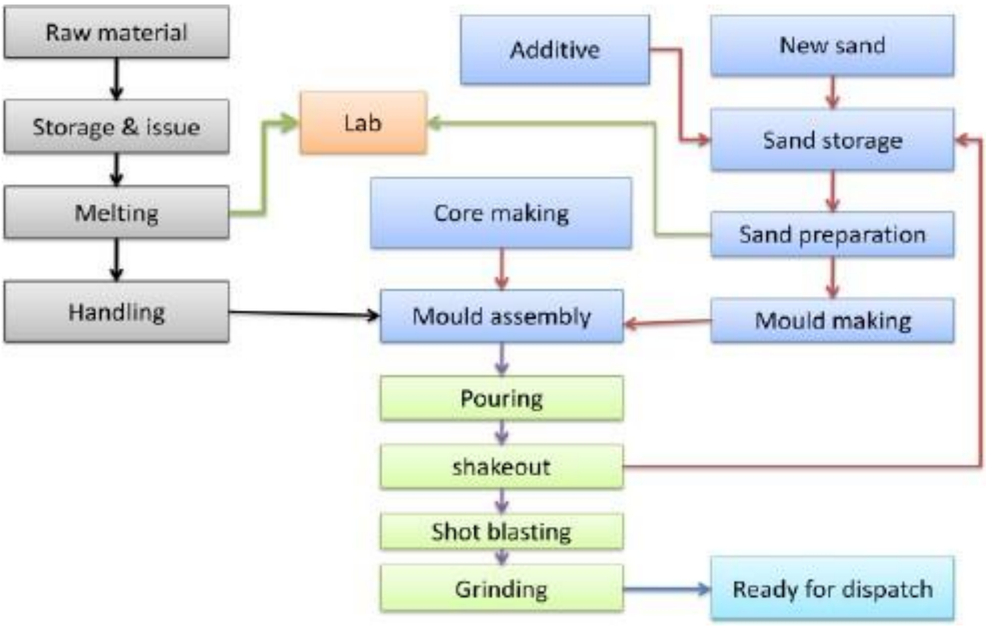


Fig.1.2 Various casting process from raw material to finish product (Albliwi, S. et al,2015)

1.10. Description of Casting Process

Metal is poured into a mould that is shaped like the component to be created, and then the hardened metal is removed from the mould. (Kalpak jain1989, De Garmoet et. al.1999)

Like other manufacturing processes, casting requires a high level of quality. Defect-free components are the goal, along with product standards that demand dimensional accuracy and surface quality criteria. Consider the following significant variables and their impact on quality characteristics (Malek, J., & Desai, D,2015).

- The rate at which molten metal flows into the mould cavity.
- Heat transmission and cooling speed of the metal in the mould during solidification.
- Material used to make the mould
- The transition of a molten metal to a solid state..

There are many different forms of casting technologies, but there are two main types of casting that are relevant, and the literature on statistically based strategies for dealing with faulty products is focused on those two: Sand casting and die casting are two types of casting.

1.11. Sand casting

In the traditional method of casting metal, sand has been used for thousands of years as the mould material. Using a gating mechanism to allow molten metal to flow into the cavity and cool until solidification, sand casting embeds a pattern in sand. To avoid having to dispose of the sand moulds, we utilise single-use ones. The sand casting process flow chart is shown in Figure 1.3.

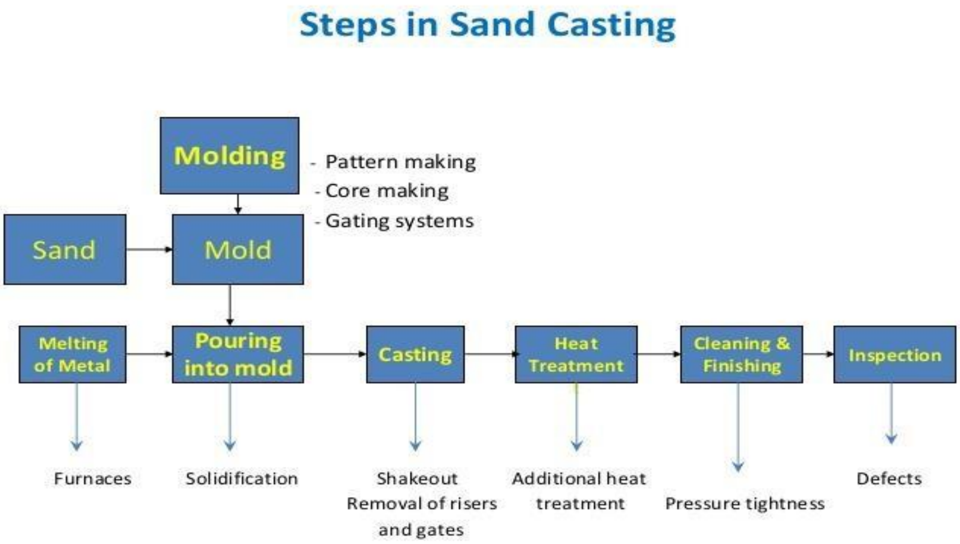


Figure -1.3: Flow chart of sand casting (Antony, J et al,2015).

1.11.1. Die casting

A multi-use metal mould and pattern with heat-resistant characteristics is utilized instead of sand. The internal flow of liquid metal in die casting is kept under pressure and at a reasonably fast speed. Metal dies are costly, and most of them are made up of two sections that are opened to retrieve the cast result once it has solidified.

The die casting process is done in two ways:

1. Hot chamber die casting process
2. Cold chamber die casting process

➢ **Cold Chamber Die Casting Process**

Higher-melting-point alloys, such as aluminium and magnesium, are cast in a cold chamber die casting technique. Because the cold chamber is outside of the furnace, as opposed to the hot chamber, a method of transporting molten metal from the holding furnace to the cold chamber is required. The cold chamber is located between the front platen of the die casting machine and the die. When casting aluminium alloys, the molten metal is often transported via a ladle mechanism, which may be operated manually or mechanically. A small machine's casting cycle time may be 10 seconds, whereas a big machine's cycle time can be 2 minutes. The molten metal is ladled into the cold chamber for each shot in the cold chamber process, as illustrated in Figure. The melt is exposed to the plunger walls or plunger for a shorter period of time. This is especially beneficial for metals that alloy readily with iron at higher temperatures, such as aluminium, copper, and their alloys. Die casting moulds are costly since they are composed of hardened steel, and the manufacturing process takes a long time. Iron and steel, which are stronger and harder metals, cannot be die cast.

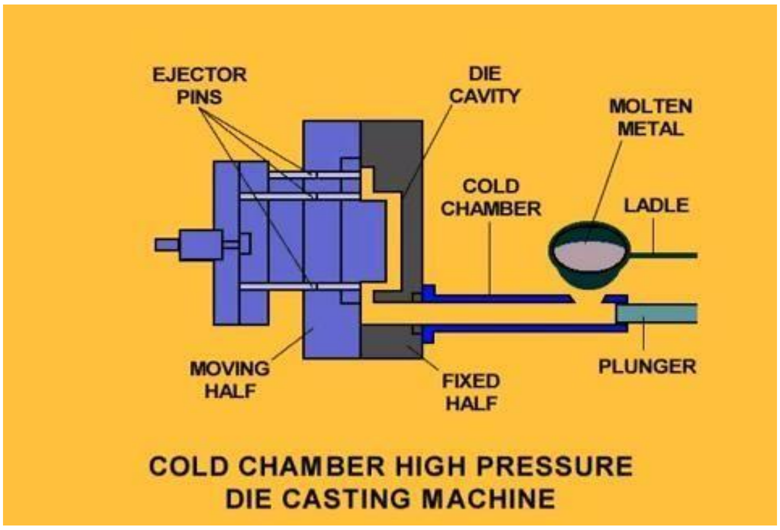


Figure-1.4 Cold Chamber Die Casting Machine (Albuquerque Marques, et al,2017)

1.12. Casting Defects

However advantageous casting may be, there is one big drawback to this process: the faults that may be present in the finished product. A partial list of casting flaws may be summed up as follows: the product pulled out of the mould may have any of the following probable flaws: (AmericanFoundry Society, 2007).

- **Cracks and crushes**

  Craters or crushes may occur during removal of the casting from the mould, as can poor pattern design and clamping.

- **Cuts**

  Cuts are rough patches caused by mould or core surface erosion. Excessive pouring temperature or soft or non-uniform moulds.

- **Drops**

Drops occur when moulding sand falls over the casting during solidification or when the mould is broken carelessly.

- **Erosion scabs**

Scabs are faulty pieces of cast metal caused by eroding sand from incorrect moulding during the cooling process. High moisture content, high pouring temperature, and interrupted pouring are all common causes.

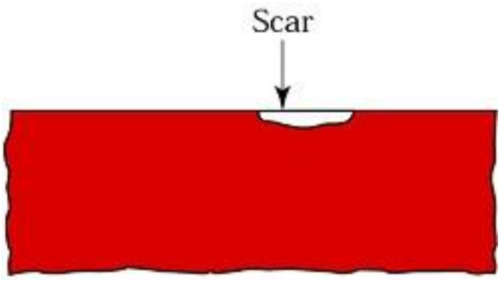


Figure -1.5 Scabs (Desai et al,2008).

- **Expansion scabs**

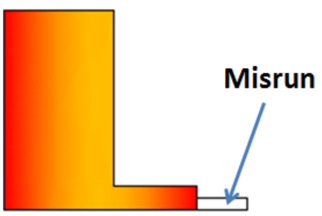
Unwanted roughness Metal layers are applied to the casting. The cause might be due to sand composition or molten metal being poured too slowly.

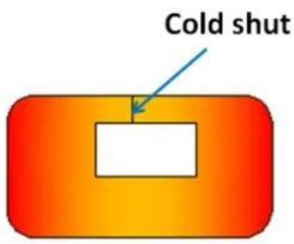
- **Gas defects:**

The product pulled out of the mould has porosities and gas holes in the cast metal. This might be caused by dissolved gas or a foreign material in the molten metal. Other factors might include a lack of permeability in the moulding material or improperly mixed sand, resulting in excessive gas concentrations in certain locations.

- **Misruns and cold shuts**

Misruns happen when the liquid metal does not fill the mould cavity completely. Cold shuts are undesirable casting discontinuities caused by faulty metal fusion. Insufficient molten metal temperature during pouring or an incorrect metal composition are





common causes.

Figure -1.6 Misruns and cold shut. (Gandhi, S,2019)

- **Rough surface**

Casting goods that do not have the requisite surface smoothness Problems with sand grains may be the cause of a rough surface.

- **Shrinkage defects**

Shrinkage may occur for a number of reasons, but it most often occurs when there is a lack of molten metal to correctly feed the cavity when shrinkage occurs due to solidification.

- **Swell**

A swell is the consequence of metal pressure enlarging the mould chamber, resulting in localized and overall casting expansion.

- **Shift**

A shift causes a mismatch in a casting portion, commonly near the parting line. Normally, this flaw is discovered.

1.13. Defect analysis

When a faulty casting is made, it is vital to examine the faults and discover the source of their formation in order to take suitable corrective action. The onset of any fault is often influenced by a vast number of interrelated events, making it difficult to pinpoint the specific reason.

1.14 Objective Of Study

In today's highly competitive market, every company must increase its efficiency and effectiveness to remain competitive. This may be accomplished more rapidly if they centred their efforts on correcting specific flaws that would cause the components to be rejected in the first place. In the end, this is the most feasible approach, and the organisation will be able to achieve competitive business efficiency as a result.

The goals for the DMAIC solution are as follows: -

- ✓ To figure out what's creating the casting flaws in the first place.
- ✓ To increase the quality of the product by decreasing casting faults.
- ✓ To enhance the whole casting process
- ✓ to raise the standard of living

- ✓ To boost a manufacturing company's productivity.

By carrying out this project, it is possible to achieve a number of secondary goals in addition to the primary goal.

- ➢ Adopt Six Sigma's DMAIC technique, as well as its benefits to the organization, to reduce product rejection and rework.
- ➢ To increase manufacturing rates while meeting customer satisfaction goals.
- ➢ Recognizing the importance of enhancing the organization's quality.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

Motorola Bill Smith started Six Sigma approximately 25 years ago, expanding on Deming's whole quality management concept, principles, and procedures. Since then, numerous of firms have adopted particular training and project management procedures to become six sigma corporations. It became necessary to evaluate the academic contributions to six sigma as the linked area of study matured because of its industry-based roots.

According to Ahmadet al (2019) Lean Production, ISO Certification, Total Quality Management, Quality Circle, and many more product innovations are used to achieve worldwide compatibility and company and organizational excellence. In spite of this, the outcomes of their efforts were both timely and unprofitable. Developing and implementing an approach that might result in considerable change in a short amount of time is the goal here. An approach like Six Sigma may provide big results in a short time period, but it must also be thoroughly investigated to determine its use in terms of efficiency, market share or benefit for quantum advancements in consumer pleasure.

Ahmed et al. (2018) Companies benefit greatly from Six Sigma's problem-solving capabilities, which make it a wonderful tool to have at their disposal. This study examines the use of the Six Sigma methodology in the Egyptian home appliance industry. Both flaws are identified and described in detail using Six Sigma DMAIC approaches, and the essay provides a trustworthy plan for minimising their severity (definition, measurement, analysis, improvements, and control). An experimental design (DOE) and regression analysis helped determine the optimal temperature for both the molten aluminium metal and the rise in defects. Moreover Aluminum molten metal temperature has a substantial effect on the quantity of defects in aluminium components, according to research and statistical analysis using Six Sigma (DMAIC) approach (DOE and regression analysis). A reduction in aluminium molten metal flaws of 10.49 percent and an increase in the Six Sigma ratio (from 2.8 to 3.06 percent) were achieved after optimising conditions. Six Sigma has also been credited for helping organisations save costs and improve quality by lowering the number of errors that they make.

Anuj Kumar et al (2017) The purpose of my investigation is to: 1. Determine the root causes of brake drum casting issues. 2. Identify a nearby Haryana foundry. By reducing faults in the casting of the brake drum, you may increase efficiency. With and without DMAIC, examine brake drum issues.

Jaykar Tailor and Kinjal Suthar (2017) A quality control system based on the six sigma methodology. Defect reduction in numerous domains was studied using the DMAIC Methodology. In recent years, Six Sigma methods and strategies have been utilised in a wide range of sectors to enhance the efficiency, cost, and diversity of final goods. In order to boost profits by eliminating errors, Six Sigma originated as an organic market development.6. Companies may use Six Sigma to design, measure, analyse, improve, and manage (DMAIC) processes via the use of basic but effective mathematic tools. Throughout the paper, they examine several research publications to see how the DMAIC method is used.

Patil Sachin S and Naik Girish (2017). There is a lot of interest in R's process management strategies for casting fault reduction. Conventional and non-conventional funerals were common throughout India. Because of the high degree of process parameters, the low level of automation, and the lack of properly educated employees, the foundation industries have poor quality and productivity. Sand inclusions, poor surface quality, disinvestment, porosity, cold shut, and flash are among the main casting flaws that migrate. Techniques like melting, pouring, shaking, fettling, or machining must be improved since casting involves a dynamic relationship between numerous composition-related criteria and operations.

Darshana Kishorbhai Dave (2017) DMAIC was employed (Defining, Measuring, analysing, improving, controlling). The DMAIC settings were tweaked to eliminate both casting faults (blow holes, metal spreads, surface splits, and irregular layer thickness) and defects (blow holes, metal spreads, surface splits, and irregular layer thickness) (Blow holes, metal spreads, surface splits, irregular layer thickness). Defect-related rejection has decreased from 31.703 percent to 12.82 percent, according to the findings.

Borikar et al. (2017) I worked on a project called Casting Part Optimization by Reducing Cold Shut Flaw. Cold shut was shown to be the major cause of 80% of refusals. The authors used a number of strategies to minimise Cold Shut. This weakness may also be seen in moulds that are not adequately ventilated due to gas back pressure. Temperature, phosphorus, and silicon levels were all controlled using various control tools. The lowest defect temperature is 1362–1382°C, which reduces the Cold Shut to 0.06 percent for minimal defects between 9% and 5% and the Silicon range between 2.4 and 2.6 percent.

Vivek V. Yadav and Shailesh J. Shaha (2016) For the sake of reducing casting rejects, a new research has been presented at the foundry. Single-cylinder head issues are major problems. Blowing holes are a major contributor to the overall rejection rate in this investigation. The root cause analysis is necessary to establish the true cause of the blow holes. What is the purpose of quality management tools like the Pareto diagram and the Cause and Effect diagram (Ishikawa) and why are they used? Therefore, remedial and preventive measures are recommended and performed. " Wet green sand on the central gas vent during moulding is put to the process control check board as a control point and as a process enforcement. Blow hole rejection and overall rejection have dropped significantly after these adjustments were implemented. The blow hole rejection ranges from 7.74 percent to 1.81 percent. There is an 8.60 percent rise in production and a decrease in gross sales loss of almost half as much.

Suraj Dhondiram Patil et al (2016) A study was done to discover how to make green sand casting. The Six Sigma approach is being used to apply it to the component transmission situation. Defects in the transmission case may be eliminated entirely using the Taguchi approach and the DMAIC technique. "Define-Measure-Analysis-Improve-Control" is the acronym for DMAIC. It is essential to have a project contract, phase map, and cause-and-effect diagram on hand at all times throughout a project. Faults and mould hardness, green power and pouring rate will be analysed using design of experiments (DOE) and analysis of variance (ANOVA) to identify optimum values for reducing/eliminating defects in the cast iron casting process. Taguchi analysis was used to analyse or forecast the findings of the study. Based on the findings, new process parameters were implemented and the outcomes were much better than the baseline. For this essay, the primary goal is to distinguish between present and suggested methods, which will be discussed extensively in the next part.

Harvir Singh and Aman Kumar (2016) Cast faults, including pinholes, shafts, sand holes and slags as well as mould modifications, dividing lines defects, rider and rider flaws and other cast defects, were examined. PN 10: Foundry shop management of casting faults across many valves, which might reduce casting efficiency. By altering variables including pouring temperature, green pressure, mould hardness, and penetrability, they investigated Taguchi strategies for minimising casting faults. At this casting company, the tests were carried out using standard-suited and foundry men's experience of casting valves PN 10 with varied sizes and significant parameter variations. Agra-based AV VALVE Pvt Ltd first told us about casting issues. Determine the most serious issues, such as a failure to close properly or excessive shrinking. They utilise a fish bone diagram to figure out what's wrong with the casting. " There are four possible causes of these casting faults, thus we've gotten to that conclusion. Pouring Temperature (oC) Sand Particle Size (AFS) The phrase "Mould Hardness Number" refers to the mold's hardness rating of 4. Permeability Quantity Tests conducted on a variety of castings reveal that the average casting percentage is 6.25 percent. MINITAB 17 is used to get the optimal solution using Taguchi's rule. A total of 4,416 materials were rejected throughout the casting process, which includes these excellent solutions. As a consequence, casting errors may rise by 1.25 percent.

Singh and Kumar (2016) Valve control difficulties such as cold shut, shrinkage, and scab were investigated. In research, the Taguchi approach is utilised to reduce faults caused by flow temperature, permeability, mould toughness, and sand particles. For testing reasons, the L9 orthogonal range is employed. The S/N Rate response, contribution to other process variables, and interactions between S/N ratio both levels and other process parameters are all investigated in order to get optimum process parameters. After a variety of experiments and procedures, the optimal validation temperature was determined to be 13400°C, with a permeability of 150(No), a sand particle size of 42 AFS, and a mould hardness number of 91.132.

Nimbulkar and Dalu (2016) In order to better comprehend the final solidifying region, the casting and removal of these defections were worked on as part of the gating device design. They used the Auto-CAST X1 simulation tool to duplicate a prior gating system for efficiency and malfunction testing, following which they made changes to the present gating system. Because the molten metal flux was not uniform and gases were fast escaping into the atmosphere, they realised that the vertical raising technique was no longer acceptable for thick casting components; as a consequence, they devised a horizontal raising system for such components. The number of food-related malformations has dropped by roughly 30%.

Rohit Chandel and Santosh Kumar (2016) It focuses on analysing and removing process alterations that effect rejection and workflow at various stages of production using a definite measure-analysis-improve-control (DMA ICC) technique. When utilised as a problem-solving approach, DMAIC reduces the rejection rate from 8.79 percent to 5.30 percent and the rework rate from 12.8 percent to 8.2 percent. Also found was a significant increase in sigma from 2.85 to 3.13.

2.2 The quality of the Product by Decreasing Casting Faults

Recognizing your new role at the foundry. A day-old foundry firm is now producing a variety of commodities, including ferrous and non-ferrous metals. This case study focuses on the steel foundry. Casting procedures include casting, moulding, core forming, melting, pouring, and shaking. The foundry industry studies shrinkage, bubble hole, porosity, pinhole, powder

inclusion, cold shut, mis running, surface fractures, flash, and other casting faults. Explain how errors occur and what efforts will be taken to avoid them in the future.

A flow process chart—materials that depict non-value-added activity across time and remove all activity by raw materials—is referred to as method mapping.

Harvir Singh and Aman Kumar (2016) It has been found Taguchi's Casting Defects Minimization Method. In his theoretical investigation, the author used Taguchi's approach and Minitab 17 to get the optimal solution. After a study indicated that 80 percent of rejections were due to cold closures, scab, and shrinkage, data from a foundry was gathered for three months. The main cause of the deficiencies was investigated using the fish bone diagram "Pouring Temperature (°C), Sand Particle Size (AFS), Mould Hardness Number, and Permeability Number." The Taguchi L9 orthogonal array approach is used in the tests. The optimal answer, which is 1340°C pouring temperature, 150 permeability number, 42 AFS sand particle size, and 91.132 Mould Hardness Number, is determined using MINITAB 17. Using the best method, the number of rejections was reduced from 6.25 percent to 4.416 percent.

Chatrad B et al (2016) Metal melting, alloying, pouring, pouring and filling, ladle impurities, and other faults have all been explored. Finally, the ideal casting flaw-free parameters, as well as the economic implications of major production processes relevant to those case studies and possible objectives, were produced. The proportion of rejections is lower around 14200c-14800c. The proportion of rejections rises at temperatures as low as 14000°C and as high as 14800°C. As the pouring time increases, the likelihood of rejection increases. The number of defective components has grown as a consequence of the increased handling time. Porosity and inclusions increased as a result of impurities in the ladle and mould induced by insufficient cleaning.

C.B. Patel and Dr. H.R. Thakkar (2015) analysed the findings of a number of researchers in order to eliminate defects and boost productivity. They arrive to the conclusion that defect analysis decision-making relies heavily on quality instruments.

Chintan C. Rao and Darshak A. Desai (2015) The major topic of this research study is a broad examination of the publishing and case industries, as well as the methodology used by the business. It also goes through the different techniques and processes utilised by businesses, as well as the advantages of using the DMAIC approach. The efforts of the industry are detailed in this report, which also includes a specific publication and case study.

Javedhusen Malek, Darshak Desai (2015) Dedicated to paving the way for Indian SMEs to adopt Six Sigma in their respective industries. The essay looks at Six Sigma's reliance on a small Indian operation to reduce reject/rework rates while employing the pressure die casting process to produce materials. The preceding article discusses the integration of all DMAIC phases in process, as well as the influence of Six Sigma on quality assurance.

Shantanu Joshi and B.R. Jadhav (2015) There has been a documented improvement in the reduction of casting flaws and the increase in production in the vehicle component. The author used a combination of experimental and technical design to investigate the issues associated with sand in shell mould casting. Through the use of a cause-and-effect diagram, it was possible to determine the fundamental cause of troubles and parameters. Once again, the most crucial circumstances for experimentation have been identified. On the basis of Taguchi, nine observations and responses are carried out. The ANOVA test is used to determine the percentages of casting rejection that have a statistically significant impact on the casting process parameters. The failure rate has dropped from 3.2 percent to 1.5 percent in the last year.

2.3 Improvising and acquiring the solution in casting

For consistency and output, the foundry industry employs tools such as seven-sigma-simulated tools, DOE, the Taguchi approach, methodology research, total quality management and total quality control, casting processes, six-sigma-DMAIC methods, and other equipment and procedures. When the moment comes. Allow us to truly grasp the scope of the advantages that this technology may provide to the foundry industry at large

Jitendra A Panchiwala et al (2015) Various experts studied and attempted to get technical solutions to decrease a range of casting flaws and enhance the overall casting process

Sushil Kumar, P.S. Satsangi and D.R. Prajapati (2011) suggest Six Sigma is a structured and methodical approach to strategic process improvement that uses statistical and scientific approaches to minimize defect rates and enhance overall quality. A case study is conducted for a foundry that uses Six Sigma technique to reduce failure rates. To accomplish the practical run for differential housing castings, the optimal parameters are used. The proposed strategies improved quality and stability by optimizing control parameters. This research intends to use Six Sigma technique to develop an innovative way to enhance the quality (defect reduction) of a foundry on the chosen projects.

According to **M. Sokovic, D. Pavletic, E. Krulcic (2006)** Six sigma is a useful tool for determining where the most pressing process demands are and where the process's weakest spots are. Six sigma also provides quantifiable indications and sufficient data for analytical examination. The systematic use of Six Sigma DMAIC tools and methodology in the manufacture of automobile components yields a number of benefits.

A. L. Moe and A. B. Abu (2015) Six Sigma is one of the greatest developing methodologies for quality assurance and management in the automotive parts manufacturing industry, according to the experts. COPQ analysis, Data Analysis, Pareto charts, Cause and Effect diagrams, Process Capability Study, Failure Mode Effects Analysis (FMEA), Design of Experiments (DOE), Visual and Control Charts, and other Quality Management techniques were used in this study.

Sunil Chaudhari, Hemant Thakkar (2014) The purpose of this study, according to the researchers, is to analyse the research work of many researchers in order to develop technical solutions for lowering various casting faults and enhancing the whole casting manufacturing process. Modern ways of casting components that use various software and simulation approaches have considerably benefitted the industrial sector. It offers several advantages and serves as an intelligent instrument for increasing the quality of cast components. This will be effective in improving the casting's quality and output. When castings are checked in such a technologically sophisticated way, foundry staff are constantly on the lookout for rejections.

According to A**. Kumaravadivel U. Natarajan (2011)** This study provides a step-by-step guide based on the DMAIC Methodology, and its effectiveness has been assessed via a case study that shows an overall decrease in defect rejection and an increase in the process' sigma level from 3.32 to 3.47. Employee Job Satisfaction Following Six Sigma Implementation was also investigated. A total of 60 workers responded to the survey, yielding an 83 percent response rate. The findings suggest that participants in Six Sigma saw improvements in the majority of job satisfaction metrics.

Achamyeleh A. Kassie Samuel B. Assfaw (2013) It is indicated that this project is meant to observe just two of the severe steel casting faults, namely, gas defects and shrinkage defects. In order to reduce these flaws, four process factors were investigated in three levels: sand–binder ratio, mould permeability, pouring temperature, and deoxidant quantity. A factorial experiment was employed in order to collect representative experimental results. By optimizing the process parameter, the relative effect of each element on the casting defect/porosity/ was established, and recommendations were made using the Statistical Analysis approach.

Dr. B. Ravi (2011) In summary, the industry's current late DFM technique (which involves looking back, or hindsight) must be converted to early DFM (looking ahead, or foresight). As a consequence, any quality issues may be identified early in the product lifecycle and prevented by making necessary design changes. Casting DFM, when combined with process control, may achieve zero defects at the lowest feasible cost. We welcome OEMs and foundries to test and improve our system alongside us. This endeavour is causing a number of issues, prompting the recruitment of a new generation of academics to help the "mother of all industries.

R. B. Heddure, M. T. Telsang (2014) For identifying and analysing casting defects, the authors of this article employ the six sigma approach and the Shainin tool. The Shainin tool operates on the idea of elimination. By performing remedial action, the final outcome of this activity must be a reduction in slag and porosity fault. The tool should clearly indicate the causes of variance. Shainin is a tool that aids in the elimination process. It is possible to obtain a degree of certainty of 95%. This tool is beneficial for quality improvement and defect elimination. This work minimises the two defects slag and porosity, resulting in a larger proportion of total foundry rejection. To boost production and raise the unit's effective capacity, the Shainin tool must minimise rejection to a bare minimum. As a consequence of the experiments, it is possible to lower the rate of rejection and increase output.

Virender verma, Amit Sharma, Deepak juneja (2014) The focus was placed on reducing defects (Blow holes, Misrun, Slag inclusion, Rough surface) in sand castings by using the DMAIC approach to regulate the parameters. By lowering moisture and enhancing sand permeability, the rejection rate owing to blow holes flaws was decreased from 2.74 percent to 0.11 percent. By employing slag -30 materials, the rejection rate owing to slag flaws was decreased from 2.52 percent to 0.89 percent. By employing chaplets, the rejection rate owing to Misrun faults was decreased from 0.96 percent to 0.68 percent. The addition of coal dust decreased rejections owing to rough surface flaws from 0.73 percent to 0.42 percent.

Tushar N. Desai and Dr. R. L. Shrivastava (**2008)** This article uses a case study to illustrate how to increase quality and productivity in a manufacturing company. The paper examines a Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) application in an industry, which provides a framework for identifying, quantifying, and eliminating sources of variation in an operational process, optimizing operation variables, and improving and maintaining process yield with well-executed control plans. Six Sigma enhances the important operational process's process performance (process yield), resulting in improved resource efficiency, fewer variances, and consistent quality of the process output.

Several research have been carried out in order to determine the optimal sand phase characteristics that may be used to produce improved castings. Casting faults were reduced by 6 percent when the sand requirements were specified correctly. DoE is a technology that can be applied across the board in the processing industry, according to the company. Several small enterprises in India may be able to benefit from these tactics in order to raise output, define a critical process parameter, and increase the unit's overall efficiency.

Our review of all scientific articles also revealed that six sigma is a break-up approach that employs six sigma, but that it has been demonstrated that unless we work hard and have excellent top management participation, we will only see a minimum of a 50 percent increase in quality and productivity. It might also be claimed that such organizations often use the DMAIC technique in order to improve their overall efficiency. Small foundries are encouraged to implement Six Sigma efforts inside their organizations in order to enhance customer loyalty, efficiency, and financial benefits while also boosting their competitiveness in the global foundry market, which is the purpose of this study.

CHAPTER 3

METHODOLOGY

3.1. Methodology of Six Sigma

Analysis of data using statistical methods, such as Six Sigma, is used to identify the main causes of quality issues and apply controls. Six sigma is often used to boost productivity in the industrial industry. In addition to product creation and supply chain management, the concept may be used in other areas of business.

In the statistical context of six sigma, this means that a process must have a standard deviation of at least six times greater than the process's mean. Six sigma's statistical goals are to decrease process variance and centre the process on the target.

When it comes to quality initiatives, six sigma stands out because of its top-down approach, which requires detailed analysis, fact-based decision making, and a control plan. There is a long-term commitment required for six sigma. Without the full support of senior management, this won't work. Six sigma transforms an organisation by instilling a culture of fact-based decision-making across the organisation. According to Karen riding, a master consultant at the six sigma school, the programme transforms "DNA" of a firm by altering the way leaders think and by strengthening the management pipeline by building management and communication skills in employees .(Mishra, N., & Rane, S. B,2018).

3.2. Six Sigma Implementation

Senior-down application of six sigma is common; in other words, a strong commitment by top management is required. A lack of leadership support for Six Sigma would make it impossible to eliminate organizational impediments. Six sigma's success has been largely attributed to a combination of strong dedication, strong leadership, and sound strategic planning. Six sigma must first be connected to the company's strategic goals and subsequently to the company's day-to-day operations, since it demands a long-term mindset. For example, tying the Six Sigma loyalty is essential. Internal communication is also critical to the successful deployment of Six Sigma.

3.2.1. Training and belt structure

The first step in implementing Six Sigma in a business is generally education. Six sigma breakthrough gains cannot be made unless the proper training is provided. Six Sigma provides a framework for a project team's duties and responsibilities to be clearly defined and structured, and each member of the team receives specialized training in accordance with their obligations.

The belt structure of a Six Sigma team may be seen in the image.

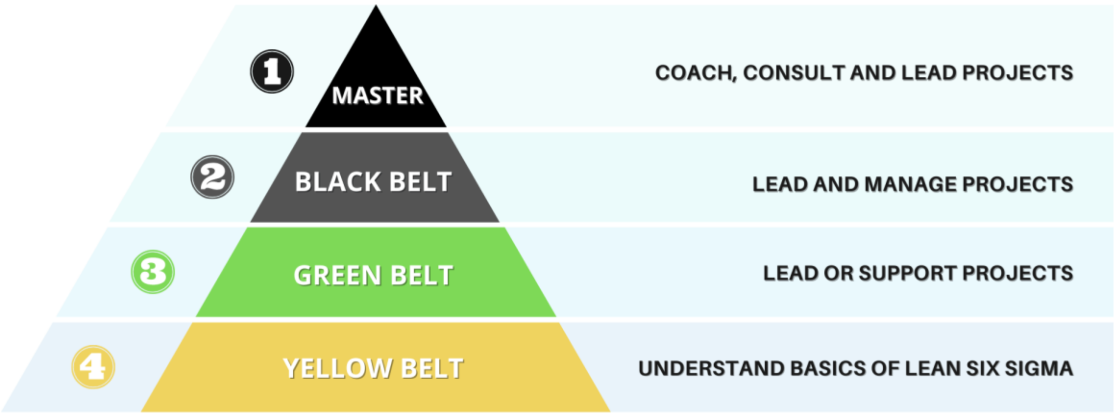


Figure- 3.1: Training and belt structure (Hakimi et al,2018)

➢ **Champion:**

He is the business leader in charge of the whole deployment. During all stages, the champion ensures that the process owner is supported. To achieve a master belt, champions must grasp DMAIC ideas and deployment methodologies, which include choosing high-impact projects and selecting and managing the proper personnel. After corrective measures are completed, the process is transferred from the black belt to the manager, who owns the process.

➢ **Black Belt:**

In a DMAIC project, the Quality leader serves as a team leader. It is in charge of both training and deployment. He is a problem solver all day and supports the black belt in effectively implementing the system in uncommon scenarios. Normally, a manager serves as a black belt in a company.

➢ **Green Belt:**

While working with black belt, these individuals in the business do DMAIC as part of their entire job. They acquire experience with the DMAIC technique and tools in a real setting. In the black belt project, they work as part of a team.

According to the Six Sigma Academy, black belts may save organisations up to $230,000 each project and accomplish four to six projects per year. As indicated in table 3.1, the ASQ has been certifying Six Sigma black belts (SSBB) abroad in recent years. There were around 200 ASQ-certified black belts in the United States by the middle of 2002, but only 11 ASQ-certified black belts outside the United States.

Table 3.1 Number of Six Sigma black belts certified by the American society for quality (ASQ) internationally. (Gupta, V., Jain et al,2018)

Indonesia	1	United kingdom	1
India	5	Hong Kong	1
Japan	1	Mainland china	0
Australia	1	Taiwan	0
Brazil	1	Singapore	0

3.3. DMAIC Methodology

Six Sigma is an evolutionary, not revolutionary, quality management methodology that incorporates a variety of valuable quality management methods. As a result, it's not unexpected that the six sigma, TQM, lean, and ISO methodologies overlap. Six sigma's basic approach is driven by a deep knowledge of consumers, and it necessitates the disciplined use of factual data and statistical analysis, which is divided into five phases: define, measure, analyse, improve, and control (DMAIC).(Tailor, J., & Suthar, K.,2017).

The define phase identifies the issue and establishes the project's objectives and deliverables. The essential to quality (CTQ) features are selected and the measurement system is examined in the measure phase. To guarantee data quality, the nature and qualities of the data gathering must be properly understood. In the analyze phase, both quantitative and qualitative techniques are employed to separate the critical information needed to explain problems. The main components and processes are continually managed and monitored throughout the enhance phase to ensure that the improvement is durable and that the issue does not return.

3.3.1. The DMAIC process

We're using the DMAIC technique in particular phases to move our emphasis away from the output performance (i.e., y) and toward the fundamental cause (i.e., x). We convert a practical issue into a statistical problem (mapping x and y), find a statistical solution for it [e.g., solving y = f(x)], and then convert the statistical answer into a practical one using these procedures. Figure 4.1 depicts each stage, which is discussed in the next part, with the relevant critical tools mentioned in a subsequent section. (Trimarjoko et al,2019).

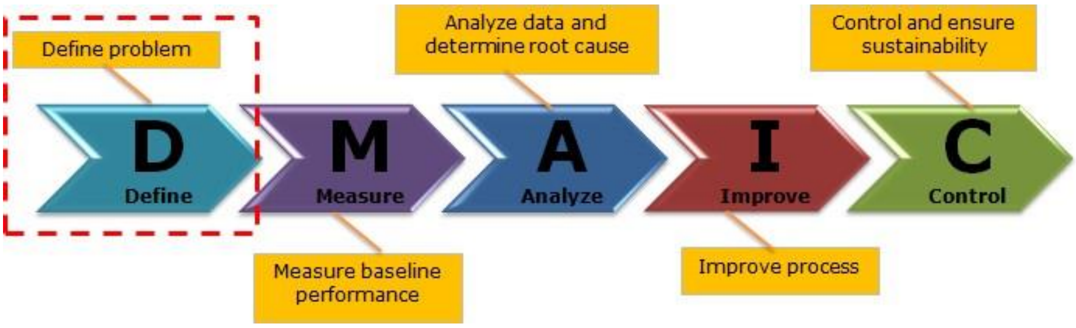


Figure- 3.2: Phases of Six Sigma.(Kumar, D. et al,2015)

- **Phase 1: Define (D)**

Here, the project's goals, scope, team structure, and timetable are all laid out for you, so you can get started on your Six Sigma journey. It is expected that we will have a detailed operational definition of the project matrix at the end of this phase. Determine who the customer is, choose the project area, identify the project purpose, scope, and resources, and outline the duties of the team members to ensure the project's value. Estimate profit and cost for this project. SIPOC (suppliers, input, process outputs, and consumers) are all significant instruments in this phase, as is the project charter.

- **Phase 2: Measures (M)**

We can only know where we're going if we know where we are now, and we can only prepare for the future if we know where we are now. This information is obtained by taking actions during the measurement phase. This phase includes the selection of quality-critical (CTQ) measures, the formation of deliverables, and the quantification of measurability.

- **Phase 3: Analyse (A)**

After identifying the y in process, we utilize a variety of management and statistical methodologies to unearth the x that will be used to develop future improvement plans and to identify the reasons of variation that will be used to develop those plans.

Establish the baseline

Determine the present process's process capacity to get a sense of where we're at. Heuristics like as histograms and process capability indices (PCI) are important tools to employ in collecting and analysing current process data. We also must compute the defects per million opportunities (DPMO) and the z-score (Z).

Determine improvement plan

To make the project's purpose obvious, we quantify the improvement goals. Hypothesis testing may help us evaluate if the improvement goals vary substantially from current performance (i.e. the baseline). Benchmarking, hypothesis testing, and analysis of variance (ANOVA) are a few of the most important methods.

Identify variation sources

We create a list of all the probable variables (x) that might have an impact on the performance of y. A regression analysis may be carried out, if necessary, in order to determine the potential value of x. Among the most important tools are brainstorming, cause and effect diagrams, regression analysis, and so forth.

- **Phase 4: Improve (I)**

As we learn more about the root causes of variance, we will be able to address them. The design of experiment (DOE) is a vital strategy to help us quantify the relationship between the y and x, and to enhance the process by determining the ideal setting of x for each y in the improve phase. Three implementation steps are followed in this phase: Identify probable sources of variation, establish a variable connection, and create a strategy for execution.

Screen Potential Sources of Variation

In the next phase, we separate the few essential x from the numerous inconsequential x that exist. DOE is a critical tool in the screening of risk factors. It is possible to conduct both full factorial and fractional factorial experiments. If historical data is required, it should be handled with caution, and a comparable model or simulation may also be employed if necessary.

Discover Variable Relationships

We create the transfer function [y = f (x)], which connects the crucial x to the y. We next establish and check the ideal settings for the crucial x based on this. DOE is also an important technique for characterization and optimization. In this stage, many DOE approaches such as response surface methods (RSM), resilient design, and the Taguchi method may be used. In addition, modelling and surveys may be utilized to discover the association.

- **Phase 5: Control (C)**

When we find out how to fix it, we want the process improvement we create to be long-lasting. A control phase, which includes the deployment of measurement devices, is performed to ensure long-term success. Consider the financial benefits and develop a transfer plan now. Verifying the implementation strategy, guaranteeing input and output control, and monitoring and maintaining the change are the first three steps.

Validate the Implementation Plan

Measurement systems will be validated on the x in order to evaluate how effectively they regulate x. If necessary, improvements will be made to the measurement system prior to moving ahead. DPMO and new sigma values will also be reported at this stage.

Control Inputs and Monitor Outputs

In this stage, we establish a monitoring strategy for the y and x and identify how each essential x may be regulated (e.g., variable control chart, error proofing, etc.). Statistical process control (SPC), attribute control charts, variable control charts, Pokka-Yoke, and other techniques are important.

Sustain the Change

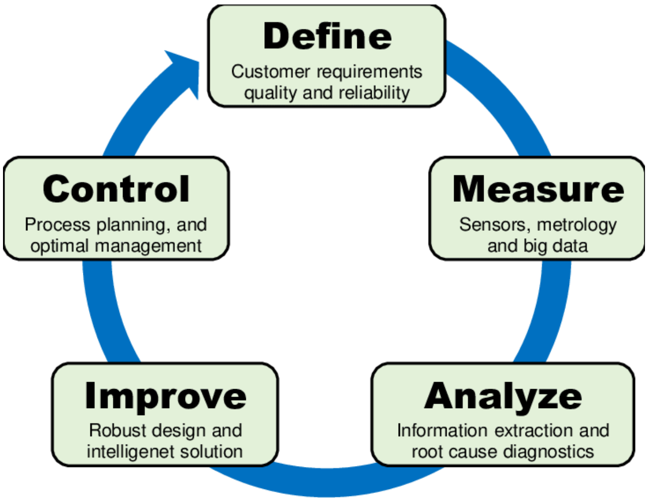


Figure-3.3: DMAIC Approach (Kumar, S,2020)

This step's goal is to make sure that changes stick once the improvement method is applied. Each x requires the development and implementation of process control. We'll also look at the financial benefits that may be realized and whether or not this project can be applied to other areas, lines, sites, or processes. Out of control planning, error proofing, audit strategies, and other tools are important in this last level.

3.4. BUSINESS PROCESS MAPPING (SIPOC Diagram)

In order to map out the flow of a project before it begins, a tool called SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) is used to visually identify all of the essential factors involved in the business process. A lot of the time, they're used throughout the define phase of the project.

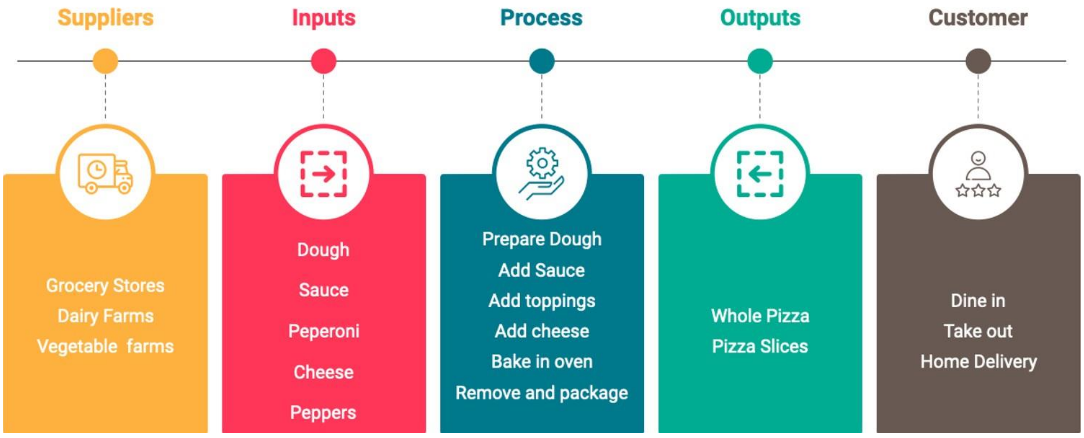


Figure-3.4: SIPOC Diagram (Kuntal, A,2015)

Supplier: Suppliers that generate and provide inputs to the process, whether internally or externally provided, are called input providers.

Inputs: To carry out the procedure, you'll need the following materials, resources, and data.

A process is a set of activities that take one or more types of input and provide useful output for the customer.

Outputs: the tangible products or services that result from the process.?

Steps for implementation of SIPOC

- ✓ Step1. CTQ and the method are well stated.
- ✓ Step 2. Clear statement start end point.
- ✓ Step3. Determine the most important customers, suppliers, outputs, and inputs.
- ✓ Step4. Using brainstorming, identify the five to seven key process steps.
- ✓ Step 5: Decide whatever step you want to sketch out in detail.
- ✓ Step6. Complete detailed map.

3.5 Research Gap

Increasing the number of faults in the final product at each step will result in the slightest changes in raw material quality, production circumstances, operator behaviour, and other factors at the conclusion of the process. The DMAIC method's primary purpose is to eliminate these inconsistencies and create procedures that consistently provide high-quality outputs. The categorization and assessment of variations in order to determine their causes, as well as the development of appropriate operational strategies to manage and minimise variation, are all part of the DMAIC process. In the wake of its efforts, DMAIC forecasts much more efficient and stronger product growth, as well as effective and competent production and a more efficient organisation in general. Because of their high rejection rate, the current research concentrated on the application of DMAIC techniques, as well as the selection of ways and strategies to address issues that were encountered. In the company's actual castings, the most often rejected castings had the following defects: shift defect, swell defect, porosity defect, and mismatch defect (according to the data). In the mix hub, a casting with severe damage was detected, and it was taken into consideration for a more thorough investigation.

On the other hand, the effective range of the parameter and its influence on the process's Sigma performance are explored. It is necessary to collect data from the foundry floor in order to establish performance metrics for the present process.

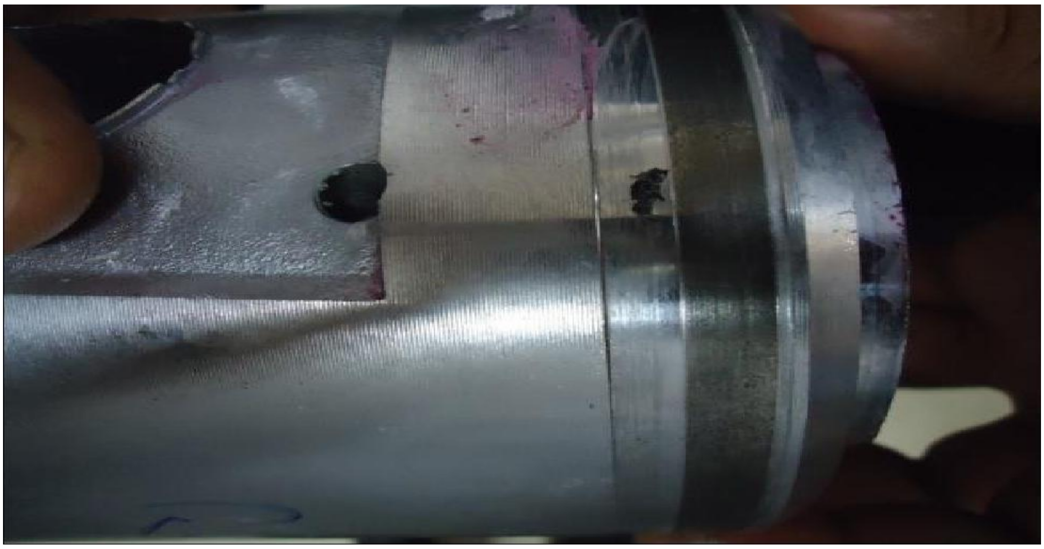


Figure- 3.5 Shift Defect in Piston.

Figure- 3.6 Swell Defect in Piston

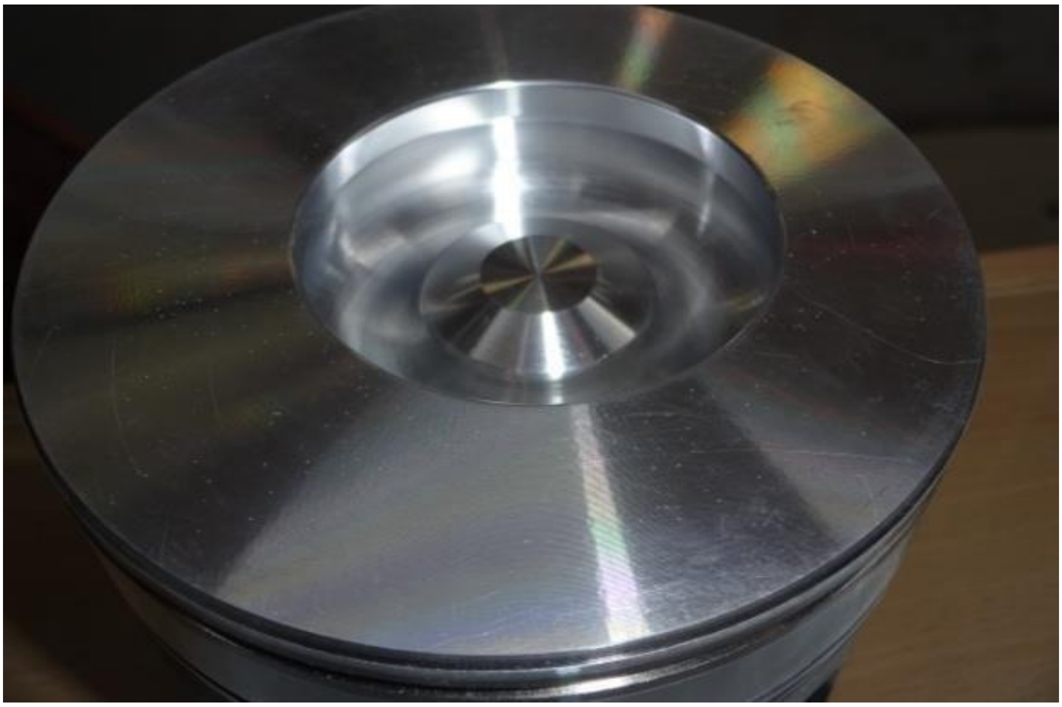


Figure-3.7 Porosity Defect in Piston

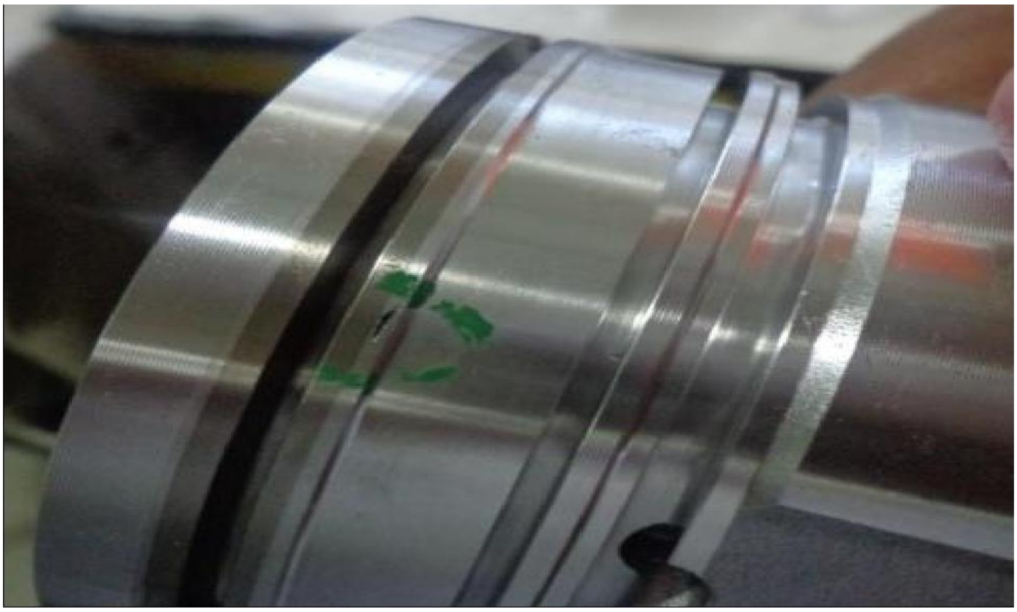


Figure- 3.8 Mismatch Defect in Piston

3.6 Present Work

Casting errors have a negative impact on the bottom line of the foundry, especially when it comes to high-volume casting. A casting flaw degrades the surface quality and mechanical qualities of the casting by reducing the quality of the casting surface. Profitability, efficiency, and component production are all negatively impacted as a result of the company's operations and activities. Excellent analysis would also help to minimise these risks to the greatest extent feasible. The foundry is now working on casting rejection because to major flaws in the casting. It is necessary to do quality analysis in order to determine the true reasons of blow holes by investigating the underlying cause. When doing an analysis, tools such as Pareto analysis, cause-and-effect diagrams, and Why analyses (Ishikawa) may be used. Corrective and preventative actions are also recommended and put into action.

3.7 Quality Function Deployment (QFD)

At each step of product development, operations, sales, marketing, and distribution, QFD is a systematic strategy to priorities and transform consumer needs (i.e., external CTQ) into suitable corporate requirements (i.e., internal CTQ). In most cases, this approach is in the measurement phase. It's also helpful in the design for six sigma (DFSS) process, which will be covered in further depth in the DFSS section. (Westgard,et al,2017).

3.8 Failure modes and Effects Analysis (FMEA)

FMEA is a technique for lowering the risk of failure. It also serves as a tool for identifying and prioritising CTQ throughout the measurement phase. Figure 3.5 depicts the many processes of failure mode and effect analysis.

Severity: The severity of a failure mode is a gauge of its seriousness. The severity is typically graded on a scale of 1 to 10. On a scale of one to 10, one indicates a minor failure mode that may go undetected, while ten represents a major failure that may risk safety.

Occurrence: On a scale from 1 to 10, the chance that a certain reason will result in the failure mode.

Detection*:* The capacity to identify the cause of failure is evaluated. On a scale of one to 10, ten being the least delightful, is a common scale to use.

RPN: The risk priority number (RPN) is output of FMEARPN = severity * occurrence* Detection.

Step to implement FMEA

- Step1: find out what the goods and services.
- Step2: assess the probability of a failure in the target process.
- Step3: determine the origin of the effects and the probability of their occurrence.
- Step4: Identify the current controls for recognising each failure mode, as well as the ability of the group.
- Step5: multiply the severity, probable causes, and detection results to get the RPN.
- Step6: For each kind of failure, specify the steps that should be taken to reduce or eliminate RPN.

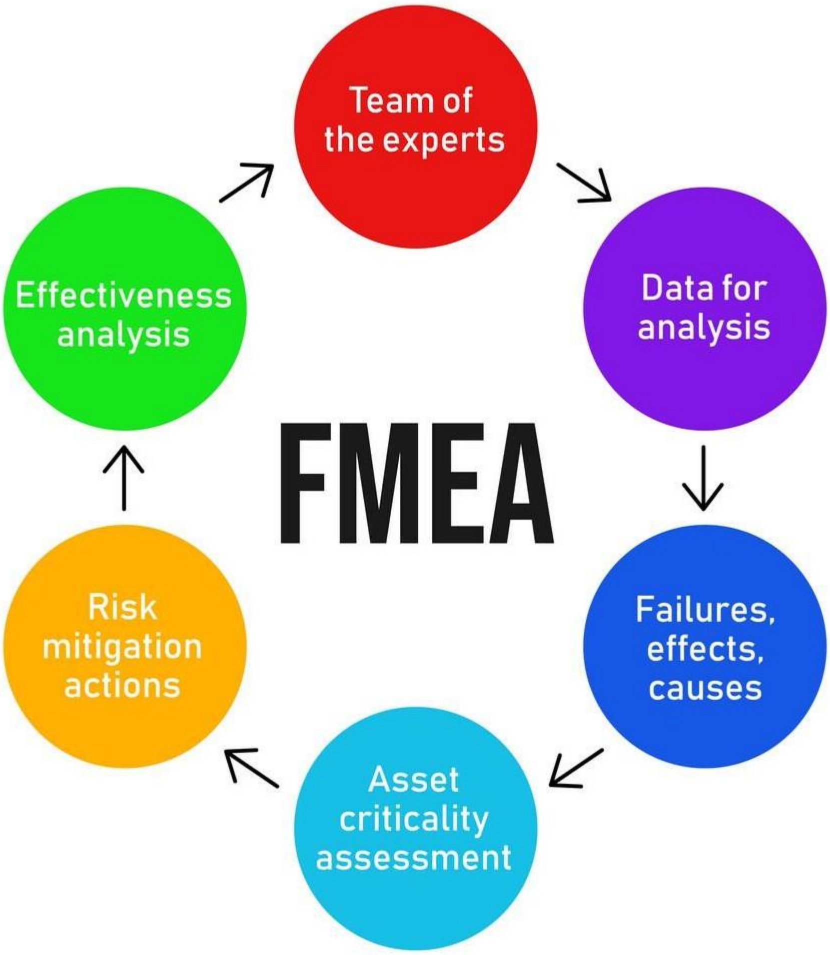


Figure 3.9: FMEA process (Patel, M,2020)

3.9 Measurement System Analysis (MSA)

To enable successful analysis of any future data obtained for a specific process / product feature, a statistical assessment of the measuring equipment must be performed. MSA is often used to verify the measurement system for y and x during the measure and control stages.

Gage R&R: Gage R&R is a tool for analyzing measurement variance caused by the measuring instrument and the personnel who take the measurement.

The variability that represents the underlying, inherent accuracy of the gauge itself is characterized as repeatability.

Reproducibility: The variability caused by various operators utilizing the gauge is characterized as reproducibility (or different time, different environment).

Steps to implement MSA

- ✓ Step1: Gather the information. In most cases, there are two or three operators who measure 10 units at a time. Each unit is then measured 2-3 times by each operator.
- ✓ Step2: calculate R&R by doing the calculation.
- ✓ Step3: evaluate the result.

3.10 Cause-Effect Diagram (Fishbone diagram)

There are many possible explanations for big output effects, and this is a graphical brainstorming tool for exploring them. A variety of probable reasons that might occur in a manufacturing process and have a negative impact on the output are shown in Figure 3.10. These include material supply bottlenecks, machine failures, measurement system mistakes, and so on.

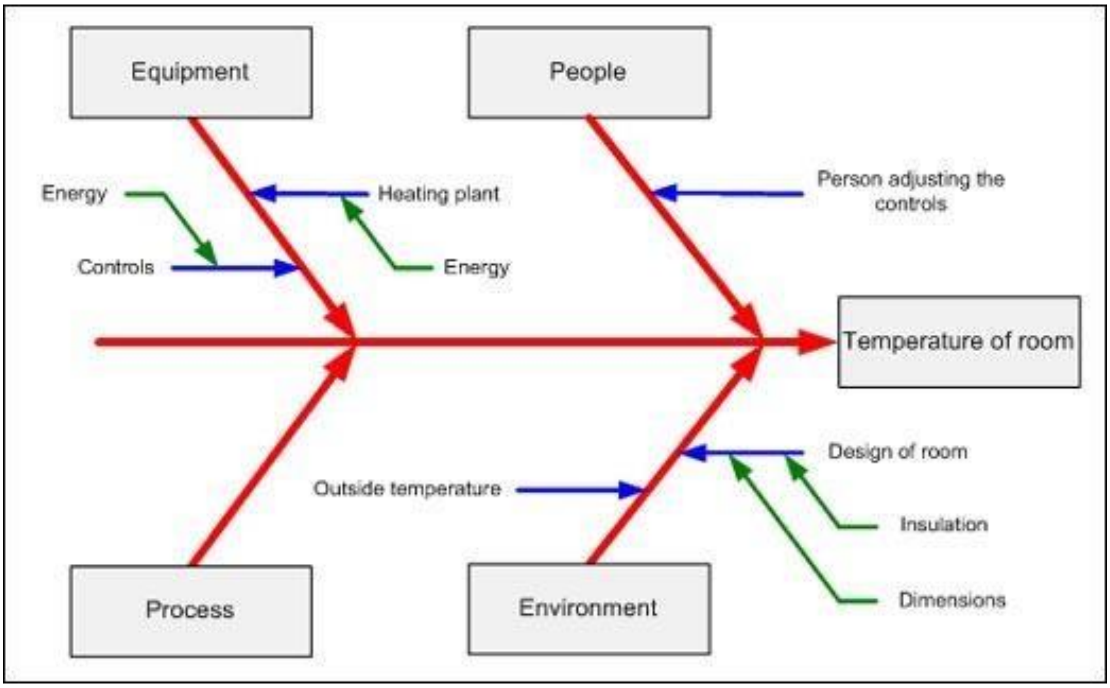


Figure: 3.10: Cause and effect diagram (Makwana, A. D,2021)

Step to be taken

- ➢ Step1: Determine the precise nature of the consequence (y) or symptom (x) for which a plausible explanation (x) must be found.
- ➢ Step2: On the right-hand side of a sheet of writing paper, write the effect symptom (y) that is being discussed.
- ➢ Step3: To determine the various reasons, employ brainstorming or a methodical step-

by-step approach.

- Step4: A line should link each of the primary regions of likely causes to the core spine.
- Step5: Make a list of likely reasons for each major area.
- Step6: Make sure everything is in order.

3.11 Design of Experiment (DOE)

DOE is a critical tool during the improvement phase. When screening the few probable reasons, it is used to characterize the link between the output and the causes, and it is used to optimize the setting of the essential parameters, among other things. Figure 3.11 depicts the many stages that were followed throughout the design of the experiment.

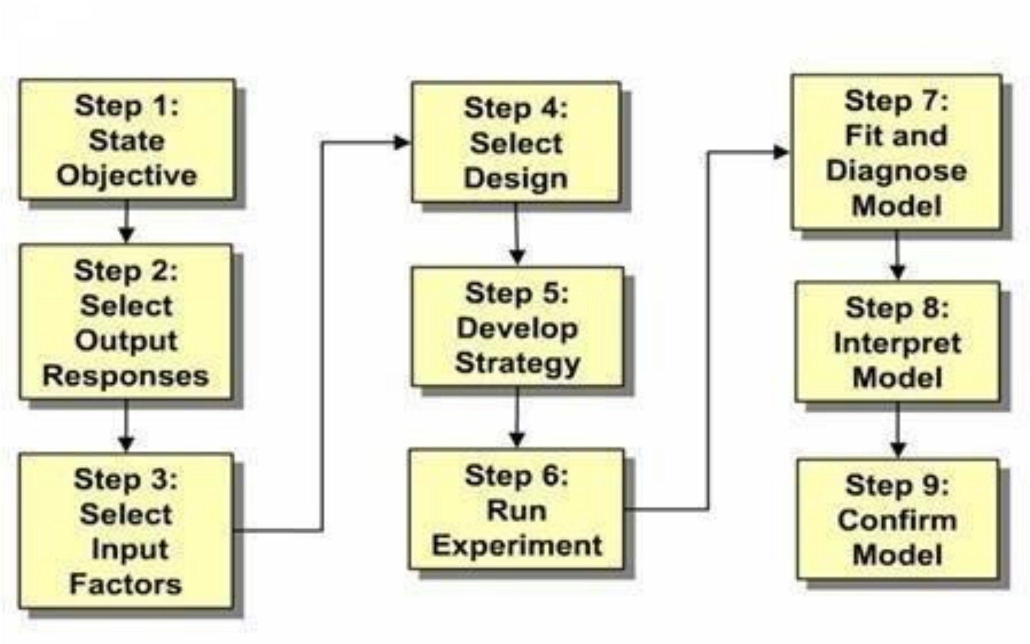


Figure 3.11: Flow Chart of Doe (Panchiwala, J.2015)

3.12 Study Area for data collection of Experimental Work

This experimental work Performed in ***Shriram Pistons & Rings Ltd, HIMALAYA HOUSE, 3rd Floor, 23, KG Marg, New Delhi, Delhi***. External **Piston** design product is used to manufacturing by foundary in Industry Area.

Figure 3.12: Industry Area of Renuka Industries

We gathered data from four months of Industrial Production, as well as fluctuations in fault rates. The primary goal of this research is to decrease shrinkage in the External Piston of ductile cast iron manufactured at the New Delhi casting factory. Data from the industry was gathered over a six-month period using the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology, and the flaws were detected using the Six Sigma DMAIC technique. To detect and address faults, a range of quality control instruments are employed at various phases of the DMAIC process. Apart from that, the Taguchi approach must be used to generate the L9 orthogonal array from the Minitab programme. Finally, in order to decrease the number of flaws, the most optimum solution is developed and recommended to the industry.

CHAPTER 4

DATA ANALYSIS AND INTERPRETATION

4.1. Data Analysis

A rational, systematic approach should be used in the problem-solving process. These put a strong focus on finding and addressing the root or major source of the issue. In addition, less organised approaches of dealing with problems risk trying to erase their symptoms. A variety of high-quality tools have been used to solve organisational issues. The basic quality tools involve,

- Check sheet
- Pareto chart
- Ishikawa diagram
- Cause and effect matrix
- Histogram

4.2 Implementation Of DMAIC

The DMAIC approach was used successfully in this research to eliminate cast faults in a foundry unit.

4.2.1 Define Phase

Identifying the issue is the most important step in almost every DMAIC project, since having a clear understanding makes the process simpler. As a consequence of a common view, people may attempt to achieve an unachievable goal or overcomplicate the matter. As a consequence, they may believe that every DMAIC project starts with the identification of a problem. In this case study, the decrease of both the casting fault rejection rate and the pressure die casting process is investigated. The corporation is preparing for a 15.5 percent layoff, which would reduce production and efficiency.(Dave, D. K.,2017).

4.2.2 Measure Phase

The measurement phase's purpose is to determine and establish the process's baseline output in terms of process capacity or sigma. As part of this process, they agreed to collect data. Before any data is gathered, it's vital to make sure that the present measuring equipment is adequate to the job. If the measurement equipment isn't completely stable when collecting data, the results won't be reliable, producing issues with the project. The instrument's resilience for information and conversation is assessed using repeatability and reproducibility (R&R) tests. In our situation, the articles were reviewed by two inspectors. The items were just thoroughly scrutinised, with no tools being used in the process. They utilised MINITAB 17 to undertake machine analyses for discrete data since our data is discrete.

- **Data Collection**

On the spot, they collect data. As a consequence, obtaining an appropriate measuring system prior to the commencement of the project is critical. Following the identification of concerns and growth opportunities, a list of issues was compiled-

Table-4.1 Rejection rate of piston

Month	Production pieces	Rejection pieces	Gas porosity	Inclusion	Shrinkage
Dec.2021	18465	1894	631	778	485
Jan .2022	23218	2629	620	1106	903
Feb .2022	18400	1700	600	630	470
Total	60083	6223	1851	2514	1858

Percentage Rejection in three month (%) = 6223/60083 = 0.1035 X 100 = 10.35%

Table-4.2 Percentage reduction in various defects

Defects	No. of defective piece	Percentage of rejection
Gas porosity	1851	1851/60083 = .03X100 = 3.08%
Inclusion	2514	2514/60083 = .04X100 =4.18%
Shrinkage	1858	1858/60083 = .03X100 =3.09%

4.3. Measure phase

The team operating under chartering conducts analysis sessions, and data is gathered for investigating defect reasons. Several influencing and controllable process characteristics are found and assessed after extensive brainstorming. Various faults are assessed quantitatively and subjectively owing to uncontrolled characteristics inherent in the casting process, which are the most important contributors evaluated in the current stage. The most severe flaws evaluated in this study are shown in Figure 4.1 as a Pareto diagram. Only three primary faults that caused significant alterations (inclusion, gas porosity, and shrinkage defects) are included. Before applying the DMAIC paradigm, the value of Sigma is computed, and it is 3.47.

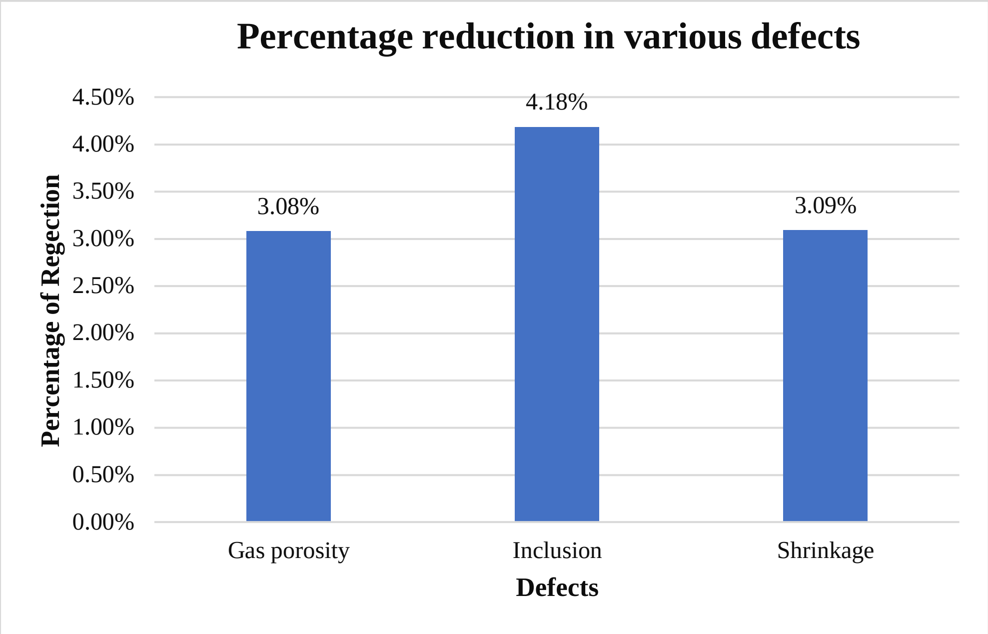


Figure-4.1. Defects Level

4.4. Analyse Phase

It is possible to identify the elements that most significantly affected rejection with the use of a cause and effect matrix. The root causes of casting faults are identified and investigated to decrease or eliminate casting flaws. The failure mode and effects analysis (FMEA) is a critical technique for analysing the impact of failure mode.

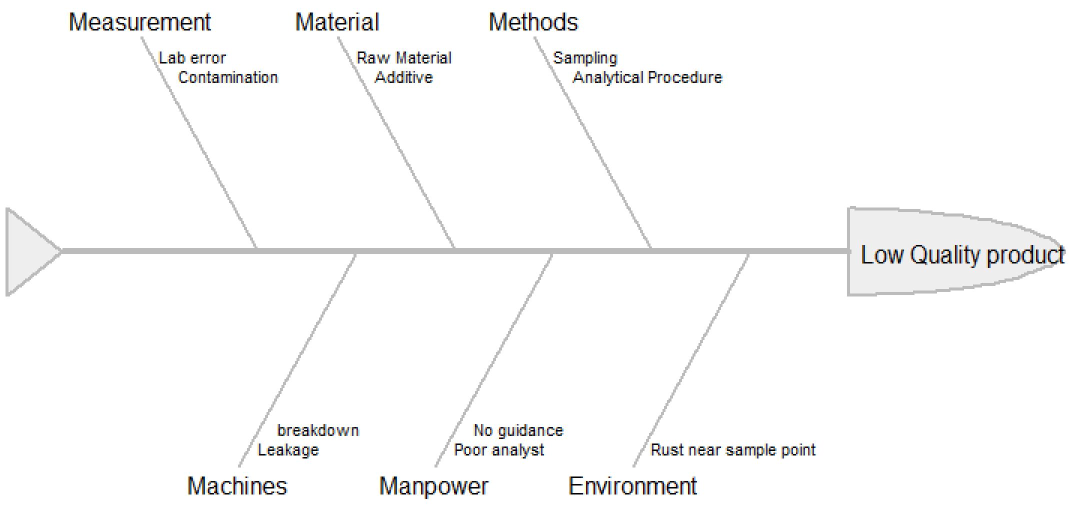


Figure- 4.2. Causes and Effect Process

Improve phase

During this step, we use the Design of Experiment (DOE) approach to improve the fault that arises during the piston casting process. To optimize the numerous specified parameters, we are employing the Taguchi analysis technique.

Selection of Factor

The replies that piqued our attention were utilized to choose which factors to investigate further. The techniques of cause and effect analysis and brainstorming were employed to determine the components that were believed to have an impact on the responses. Table 4.3 contains a list of the variables that were assessed, as well as their levels.

Table-4.3 Selection of parameter

Factor	**Level 1**	**Level 2**	**Level 3**
Pouring temperature of molten metal (A)	750	770	790
Injection Pressure of molten metal in Kg/cm^2 (B)	170	180	190
Type of coating (C)	Oil coating	Oil + graphite coating	Dycot coating
Type of cooling (D)	Air Cooling	Water Cooling	Oil Cooling

CHAPTER-5

RESULT NOTATION

Orthogonal Array

The Taguchi method's great efficiency is due in part to the presence of OA. A sequence of very advanced mathematical procedures, involving combinatorics, finite fields, geometry, and error-correcting codes, are used to obtain OA from factorial design of experiments. The algorithms guarantee that the OA is built in a statistically independent fashion, with each level having an equal number of occurrences within each column, and for any level inside one column, each level within any other column will also occur an equal number of times. The columns are then said to being orthogonal to one another. In the Taguchi technique, OAs are accessible with a range of parameters and intensities. Because each column is orthogonal to the others, if the findings for one level of a certain component vary significantly from those for another, it's because altering that factor from one level to the next has a significant influence on the quality feature being tested.

The selection of orthogonal array is influenced by a number of factors:

- The number of relevant elements and interactions
- The number of levels for each of the variables of interest.

Taguchi's orthogonal arrays are experimental designs that only employ a subset of the entire number of factorial possibilities available to the designer in the first place. Instead of including all possible elements into a single run, arrays are meant to incorporate the greatest number of factors possible in a limited number of runs. The columns of the arrays are both balanced and orthogonal. This means that all factor combinations occur in each pair of columns in the same number of instances as each other. Orthogonal designs allow for the estimate of the effect of each element on the response without taking into account the influence of the other factors. Once the degrees of freedom are known, the next step, which is to choose the orthogonal array (OA), becomes straightforward. The number of treatment conditions must be equal to or more than the number of degrees of freedom, and the number of rows in the orthogonal array must be equal to or greater than the number of treatment conditions. After an appropriate orthogonal array has been selected, the factors may be assigned to the various columns in the array. This experiment made use of a L9orthogonal array of five columns and nine rows, as seen in the figure. Therefore, using the L9orthogonal array, only nine tests are required to cover the entire range of casting parameter possibilities. With the L9 orthogonal array, Table 4.4 depicts the experimental setup for determining the casting parameters and their values.

Table 4.4: L9 orthogonal array

Trial no.	**Pouring temp**	**Injection pressure (kg/cm^{2})**	**Coating type**	**Cooling medium**
1	750	170	Oil coating	Air
2	750	180	Oil+ Graphite	Water
3	750	190	Dycot	Oil
4	770	170	Oil + Graphite	Oil
5	770	180	Dycot	Air
6	770	190	Oil coating	Water
7	790	170	Dycot	Water
8	790	180	Oil coating	Oil
9	790	190	Oil + Graphite	Air

Measuring and Test Equipment Used

Rockwell hardness and surface roughness testing were done on all of the samples generated after each of the nine trials. The density of the substance was also measured using a weighing machine and a micrometre. The sections that follow provide details on some of the most important test equipment utilised in experimental research:

Surface Roughness Tester

In order to assess surface roughness, the Mitutoyo Surf test model SJ-301, which is now available, was used. This equipment employs the stylus technique of measurement, has a profile resolution of 12 nm, and can detect roughness up to 100 microns. Analyses were carried out using a trace length of 4.8 mm.

Figure-4.3. Surface Roughness tester

Density Testing

We may calculate the density of a casting by comparing its weight in air to its weight in water, and then determining how dense the casting is in each situation, using the Archimedes principle.

Rockwell Hardness Tester

The diameter of the depression on the sample surface determines the hardness of the sample. The indents in the pyramid-shaped steel ball indenter were measured for 20 seconds on a B scale while the indenter was subjected to a small force of 10 kg.

Figure-4.4. Rockwell Hardness Testing Machine

Signal to Noise Ratio for Response Characteristics

The two types of parameters that have an influence on the result are those that can be controlled and those that cannot be controlled. By assessing the amount of variation in the response, it is possible to quickly identify control factors that may result in a reduction in variance. The uncontrolled factors are the most prevalent causes of variation that are associated with the operational environment in most cases. Table 4.5 is a summary of the response characteristics for this investigation.

Table 4.5: S/N Ratio Response characteristic

Response Name	Response Type	Unit
Density	Higher is better	gm/cm^3
Hardness	Lower is better	HRB
Surface Roughness	Lower is better	Microns

Uncontrolled factors (also known as design variables) have an impact on the output, while controllable factors (also known as design variables) have no impact (also known as noise variables). It is the designer's responsibility to maintain control over design variables, the values of which can be easily changed and updated.

Analysis of Surface Roughness (Ra)

Table 6.6 depicts the results obtained while assessing the surface roughness of a surface.

Table 4.6 Analysis of Surface Roughness

Trial no.	**Pouring temp**	**Injection pressure**	**Coating type**	**Cooling Type**	**Surface roughness**		**Mean (Ra)**	**S/N ratio**
1	750	170	Oil	Air	2.22	2.16	2.19	-6.80970
2	750	180	Oil + graphite	Water	1.6	1.59	1.595	-4.05526
3	750	190	Dycot	Oil	1.32	1.29	1.305	-2.31278

4	770	170	Oil + graphite	Oil	2.26	2.24	2.250	-7.04374
5	770	180	Dycot	Air	1.63	1.61	1.620	-4.19047
6	770	190	Oil	Water	.90	.87	.885	1.05989
7	790	170	Dycot	Water	2.15	2.12	2.135	-6.58817
8	790	180	Oil	Oil	1.75	1.72	1.735	-4.78631
9	790	190	Oil + graphite	Air	1.52	1.55	1.535	-3.72258

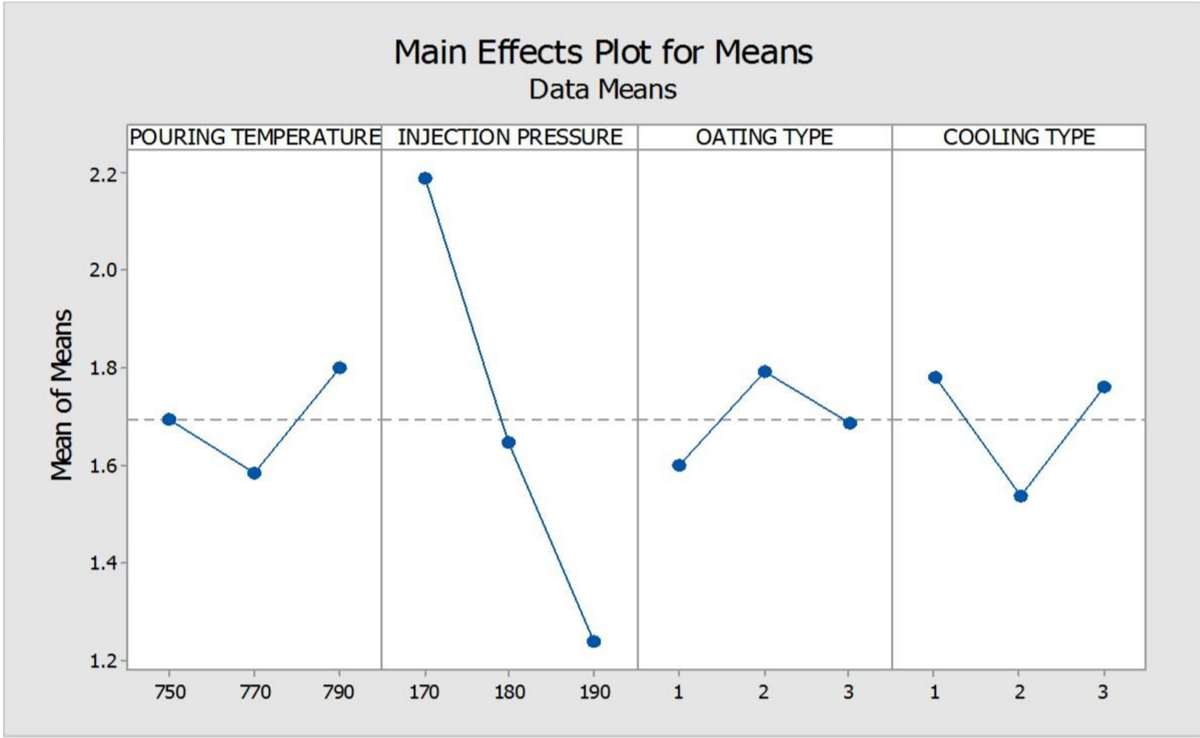


Figure-4.5: Plot of mean of means and Surface Roughness.

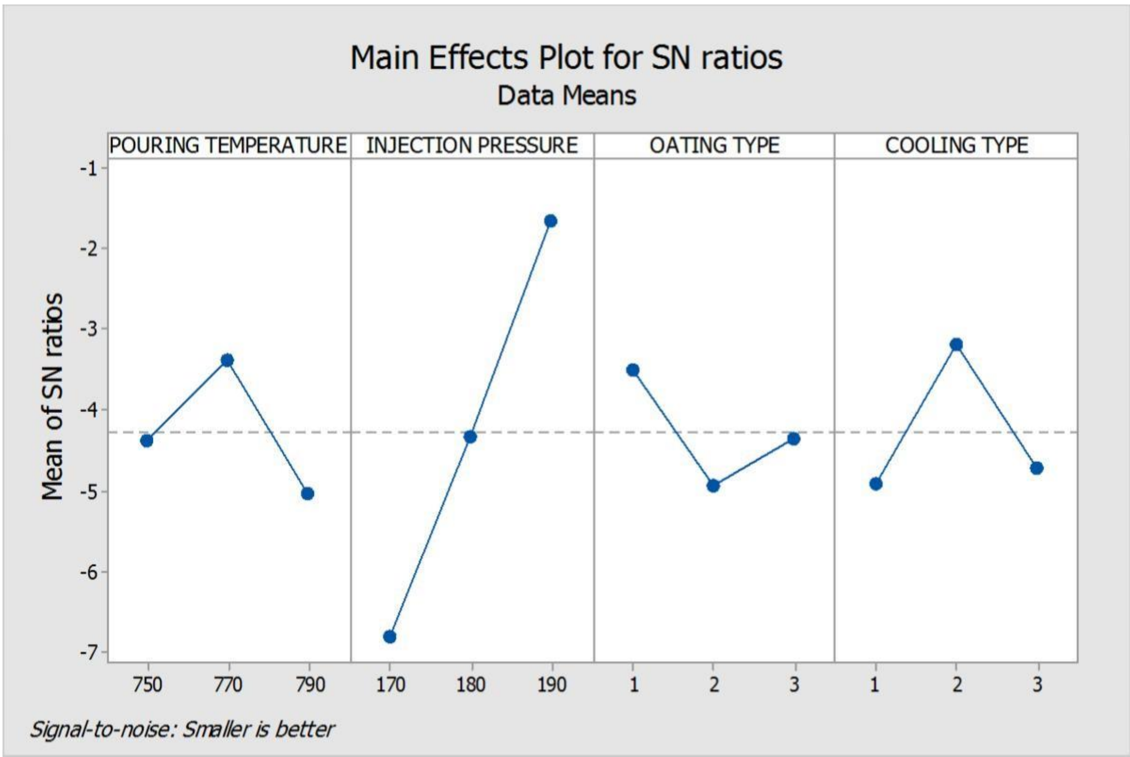


Figure- 4.6: Plot of mean of S/N ratio and Surface Roughness.

Results for S/ N ratio- Surface Roughness

The S/N ratio is a measurement of the degree of variance in a process that combines numerous repetitions into a single number. The S/N ratios were computed to determine the primary contributing components and interactions that produce surface roughness variation. The smaller the surface roughness, is the better.

Table 4.7 Reponses of S/N Ratio with Surface Roughness

Level	Temperature	Pressure	Coating	Cooling
1	- 4.393	-6.814	-3.512	-4.098
2	-3.391	-4.344	-4.941	-3.195
3	-5.032	-1.658	-4.364	-4.714
Delta	1.641	5.155	1.428	1.713
Rank	**3**	**1**	**4**	**2**

Optimization for Surface Roughness

As a result of these parameters, the lowest roughness was observed in the S/N ratio when the injection pressure was maintained at 190 kg/cm2, the pouring temperature was maintained at 770oC, and cooling water was used during casting since these factors decreased variance Coating is completely irrelevant.

- ✓ **Analysis of Density**

The response factor for the casting was determined to be the density of the casting (quality characteristic). As a result of the fact that casting density has a direct relationship with casting errors, it was chosen as one of the quality criteria. Internal defects like as porosity, blow holes, and other imperfections are less prevalent with denser castings, which means they are less expensive to produce.

Table -4.8 Analysis of Density of material

Trial no.	**Pouring temp**	**Injection pressure**	**Coating type**	**Cooling type**	**Density**		**Mean density**	**S/N ratio**
1	750	170	Oil	Air	2.30	2.30	2.30	7.23456
2	750	180	Oil + graphite	Water	2.544	2.542	2.5430	8.10693
3	750	190	Dycot	Oil	2.656	2.569	2.6125	8.33751
4	770	170	Oil + graphite	Oil	2.146	2.143	2.1445	6.62651
5	770	180	Dycot	Air	2.307	2.307	2.307	7.26095
6	770	190	Oil	Water	2.403	2.402	2.4025	7.61327
7	790	170	Dycot	Water	2.222	2.224	2.2230	6.93879
8	790	180	Oil	Oil	2.586	2.590	2.5880	8.25928
9	790	190	Oil + graphite	Air	2.658	2.656	2.6570	8.48783

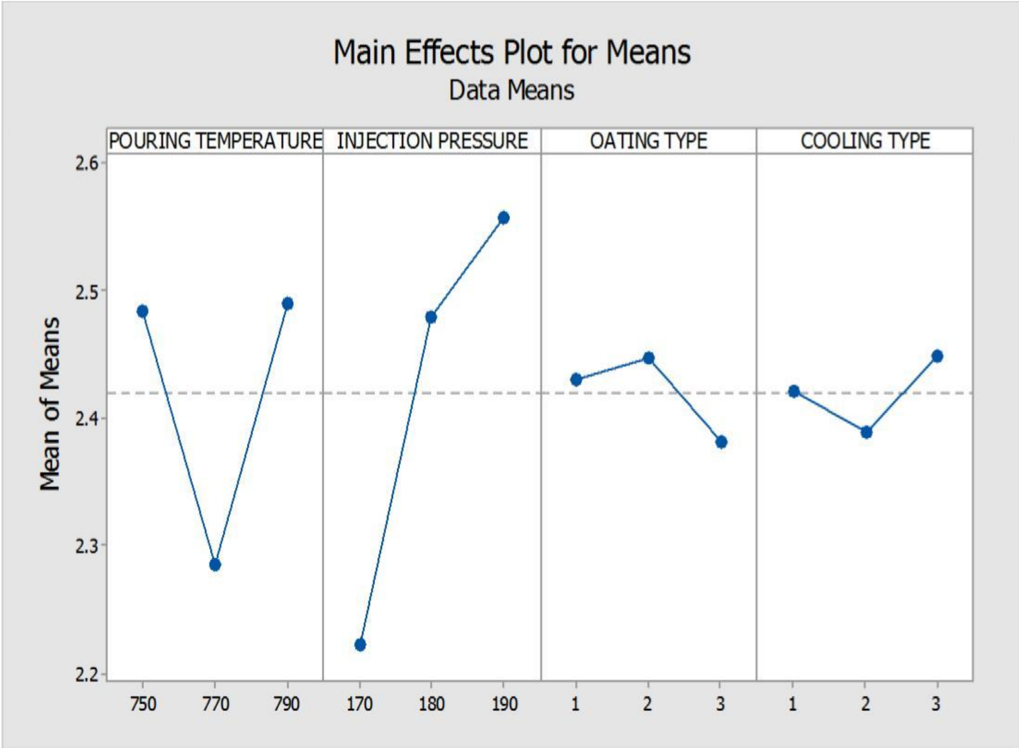


Figure- 4.7 Graph of mean of means and Density of Material.

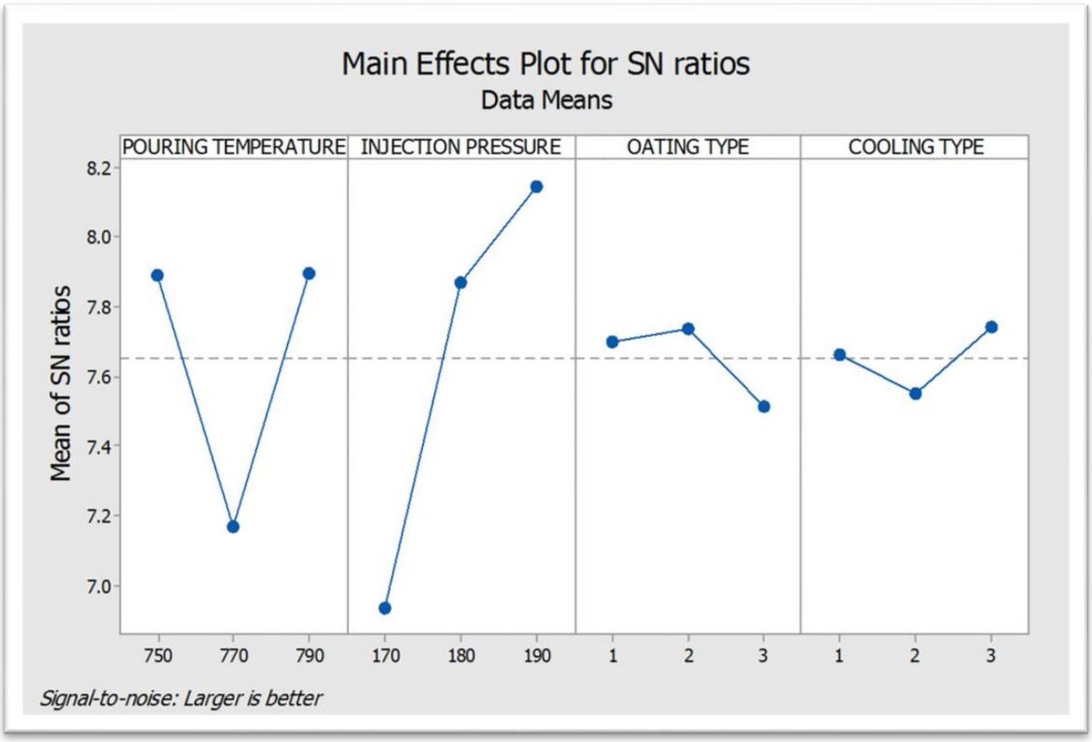


Figure-4.8 Graph of mean of S/N ratio and Density of Material.

- ✓ **Result for S/ N ratio – Density**

The S/N ratios were determined in order to determine the primary contributing components and interactions that cause density change. The higher the density, the better.

Table-4.9 Reponses of S/N Ratio with Density

Level	**Temperature**	**Injection**	**Coating**	**Cooling**
1	2.485	2.223	2.430	2.421
2	2.285	2.479	2.448	2.390
3	2.489	2.557	2.381	2.448
Delta	0.205	0.335	0.067	0.059
Rank	**2**	**1**	**3**	**4**

- ✓ **Optimization for Density**

As determined by the S/N ratio, the highest density was obtained when both the injection pressure and the pouring temperature were maintained at 190 kg/cm2 and a temperature of 790oC, respectively. The settings for cooling and coating are completely irrelevant.

Analysis of Hardness

To assess the hardness of the material, a Rockwell Hardness Tester was employed to conduct the test. The hardness of the samples is determined by the diameter of the indentation on the sample surface. The indents in the pyramid-shaped steel ball indenter were measured on a B scale for 20 seconds while a slight force of 10 kg was applied to the indenter. Hardness data are shown in Table 4.10 for each of the nine experiments performed.

Table-4.10 Analysis of Hardness

Trial no.	**Pouring temp**	**Injection pressure**	**Coating type**	**Cooling Type**	**Hardness**		**Mean hardness**	**S/N ratio**
1	750	170	Oil	Air	70	71.66	70.83	-37.0049
2	750	180	Oil + graphite	Water	66.62	67.33	66.97	-36.5184
3	750	190	Dycot	Oil	67.33	68.66	67.99	-36.6500

4	770	170	Oil + graphite	Oil	67	67	68	-36.6511
5	770	180	Dycot	Air	75.33	71.33	73.33	-37.3089
6	770	190	Oil	Water	72.66	71.66	72.16	-37.1661
7	790	170	Dycot	Water	70.3	71.0	70.66	-36.9842
8	790	180	Oil	Oil	69.33	71	70.16	-36.9230
9	790	190	Oil + graphite	Air	70.66	71.66	71.16	-37.0449

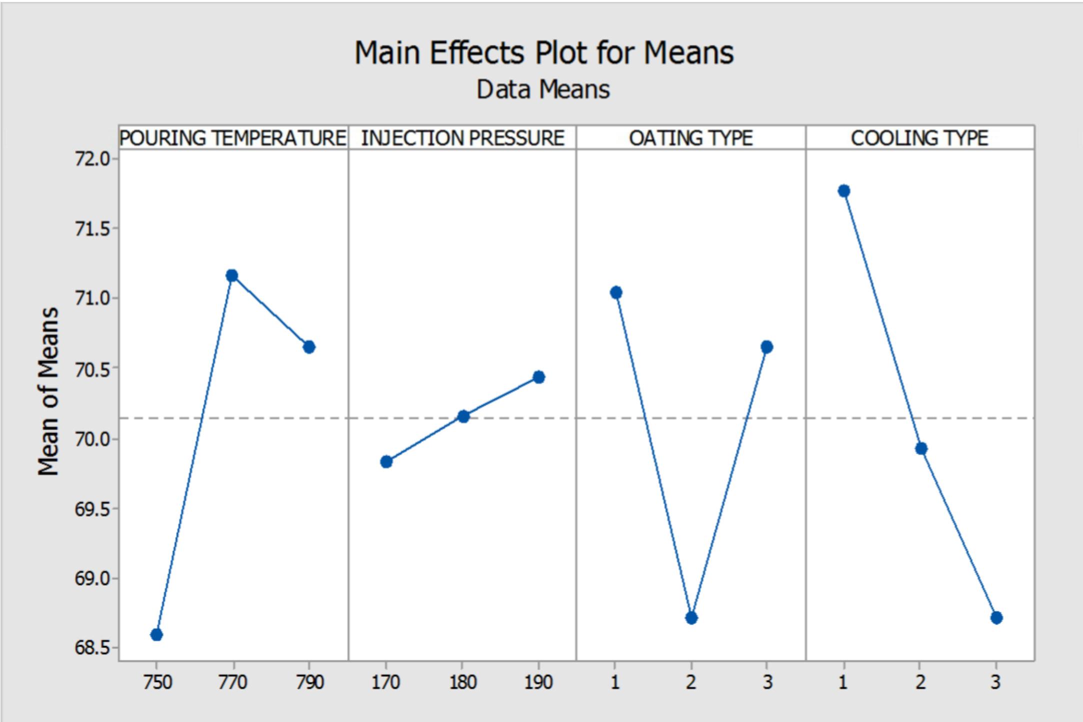


Figure-4.9 Plot of means of mean and Hardness.

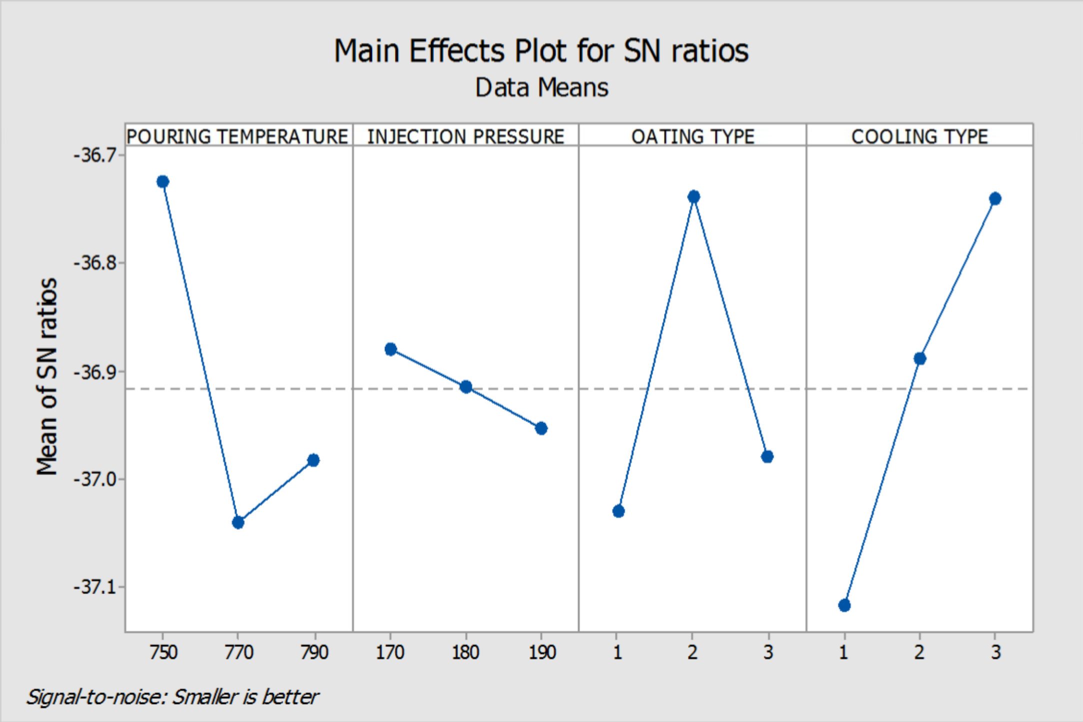


Figure-4.10: Plot of means of S/N ratio and Hardness.

Result for S/N ratio – Hardness

The S/N ratio is a measurement of the degree of variance in a process that combines numerous repetitions into a single number. Hardness S/N ratios were computed to discover the primary contributing components and interactions that cause hardness variance. The lesser the hardness, more better.

Table 4.11 Reponses of S/N Ratio with Hardness

Level	Temp	Injection	Coating	Cooling
1	-36.72	-36.88	-37.03	-37.12
2	-37.04	-36.92	-36.74	-36.89
3	-36.98	-36.95	-36.98	-36.74
Delta	0.32	0.07	0.29	0.38
Rank	**2**	**4**	**3**	**1**

Optimization for Hardness

It was discovered that the lowest hardness was achieved when the injection pressure was kept to a bare minimum and the pouring temperature was kept at 750oC, and that cooling oil and oil–graphite coating were used during casting to minimize the variation in the casting's hardness, respectively.

Control

The Control stage is the last and most important step, with the only objective of preserving the optimal response acquired throughout the trials. The documentation of the process is recommended for full Six Sigma success. After the answer is found, the process remains under control, and the out-of-control condition is diminished. Before non-conformities are formed, the corresponding reasons are identified, and action is done to address the situation. The intended outcomes and improvements have been accomplished, and a new method is advised. The organization should next record the process and teach employees with the support of the Six Sigma improvement group.

CHAPTER-6

CONCLUSION & FUTURE SCOPE OF THE WORK

6.1Conclusion

Their study project is to investigate the possibilities of Six Sigma in Indian small and medium-sized businesses (SMEs). Six Sigma implementation in SMEs is a new quality-improvement methodology that has achieved universal recognition among academics and practitioners. Small and medium-sized enterprises (SMEs) were long assumed to exist primarily in large businesses, and the goal of this study is to examine whether the Six Sigma roadmap can be applied in SMEs. This case study will serve as motivation for SMEs in India to engage in activities that will help them build their company.

A case study from the Pressure Die Casting industry is given as part of this thesis, demonstrating how Six Sigma may be utilised to create considerable increases in both process and business efficiency. The pressured die casting technology has recently made substantial advances that the industry was utterly unaware of. The DMAIC approach was selected to be used throughout the testing process in order to limit the amount of rejection of a casting product known as the bear hub as much as feasible.

- A case study of the DMAIC approach in the Indian Foundry industry is discussed in this work.
- Die Casting quality is controlled by one of the primary Die Casting features, and the proper application of DOE may result in a significant improvement.
- In addition to melting temperature, injection pressure, coating, and cooling type, other factors, such as plunger speed, cooling phase, and so on, may be used to determine the final product.
- As of right now, we're working with the aluminium alloy KS-1275, but we can also make use of the aluminium alloys LM-6, LM-29, and A-351 if necessary.
- Surface Roughness, Hardness, and Density Optimization is a strategy that enhances the quality of components and minimises the number of defects.

6.2 Future Scope of The Work

6.2.1 It is necessary to conduct a comprehensive analysis of the features of aluminium alloys by modifying process parameters, and it is possible to make significant improvements tothe properties of aluminium alloys via research and development.

6.2.2 It is necessary to conduct a comprehensive analysis of the features of aluminium alloys by modifying process parameters, and it is possible to make significant improvements tothe properties of aluminium alloys via research and development.

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