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# Reducing the Defects in Casting of Piston Using Six Sigma (Dmaic Approach)

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**ABSTRACT-** The fast changing economic conditions such as global competition, decreasing profit margin, and costumer demand for high quality product, product variety and reduce lead time etc. had a major impact manufacturing industries. To respond to these new paradigms in this area of manufacturing strategies is Six sigma. 6-sigma is the one of the most powerful management tool which has been increasingly adopted worldwide in the manufacturing sector in order to enhance productivity, quality and performance and make a process robust to quality variations. Six Sigma has been widely adopted in a variety of industries as a proven management innovation methodology to produce high-quality products with the lowest possible cost. This study focuses on implementing the DMAIC (Define, Measure, Analyse, Improve, and Control) based Six Sigma Approach in order to reduce the incidence of defects and increase the sigma level of the sand casting process. This research defines a step-by-step guide, using the DMAIC Methodology and its effectiveness has been evaluated with a case study which describes an overall decline of defect rejection and in the process, sigma level of the process being increased from 3.32 to 3.47.The investigation of Job Satisfaction of Employees on Six Sigma Implementation was also studied. The study generated 83 per cent response rate from 60 employees. The results show that participants in Six Sigma have experienced positive changes in most Job Satisfaction measures. Implications of this program, along with directions for future research, are provided.

**KEYWORDS:** Six Sigma, DMAIC, Pareto, Ishikawa Diagram, Cause-and-Effect Matrix.

## I. INTRODUCTION

Motorola first introduce the six sigma program in the late 1980s with the aim of increasing profitability by reducing defects. General Electric (GE) followed the approach at their manufacturing sites and later at their financial services divisions. After that, Six Sigma was thought to be applicable to all processes and transactions with GE. Six Sigma has now evolved from a quality improvement program to an overall business strategies executive system and business result oriented program, which seems more total than total quality management.

The word sigma or the symbol “σ”is used in statistical notation to represent the standard deviation in a population. The standard deviation is also used as a general measure of variation in any kind of product process. With six standard deviation between the process mean and the customers satisfaction limit, we arrive at 3.4 defects per million opportunities (DPMO); that is a 99.9997 per cent yield. Before the six sigma techniques were introduce, a three sigma level of variation was regarded as being fairly good quality performance. Three Sigma may be acceptable for a product or process having only a single or a few stages. It is not good enough for many products that are the result of hundreds of thousands of stages, such as automobile and computers.

Ultimately, the return on investment for the improvement effort and the strategic importance of the process will determine whether the process should be improved and the appropriate sigma level should be targeted.

It is a powerful improvement business strategy that enables companies to use Simple and statistical methods for achieving and sustaining operational excellence. When improving a current process, if the problem is complex or the risks are high, DMAIC should be the go to method. Its discipline discourages a team from skipping crucial steps and increases the chances of a successful project, making DMAIC a process most projects should follow.

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### 1.1. Objectives of Six Sigma

- Six Sigma aim is to eliminate the waste and inefficiency, thereby increasing customer satisfaction by delivering what the customer is expecting.
- Six Sigma is highly disciplined process that helps us focus on developing and delivering near perfect products and services.
- Six Sigma follows a structured methodology, and has defined roles for participant.
- Six Sigma is a data driven methodology, and requires accurate data collection for the processes being analyzed
- Six Sigma is about putting result on financial statement.
- Six Sigma is business driven, multi-dimensional structured approach to:

## II. LITERATURE REVIEW

Motorola bill smith initiated Six Sigma almost two and half decades ago building on the philosophy, principles and methods of Deming's total quality management. Since then, thousands of organizations have become six sigma companies by adopting specific training and project management practices. With six sigma industry based origins , it became important to assess the state the related academic contributions now that the associated field of study is maturing.

According to **M. Sokovic, D. Pavletic, E. Krulcic[2]** Six sigma is an effective way to find out where the greatest process needs are and which the softest points of the process are. Also, six sigma provide measurable indicators and adequate data for analytical analysis. Systematic application of Six Sigma DMAIC tools and Methodology within an automotive parts production results with several achievements.

**A. L. Moe and A. B.Abu [3]** are stated about Six Sigma is one of the best emerging approaches for quality assurance and management in automobile parts manufacturing. In this research, Quality Management tools such as 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 etc.

**Sunil Chaudhari, Hemant Thakkar [4]** are said this study is aimed to review the research work made by several researchers and an attempt to get technical solution for minimizing various casting defects and to improve the entire process of casting manufacturing. Modern method of casting components using various software and simulation technique is really a boon for the industrial sector. It offers number of advantages and in the form of intelligent tool to enhance the quality of cast component. This will definitely helpful in improving the quality and yield of the casting. If castings are inspected with such technological way, it keeps foundry men to alert condition for control of rejections.


### 2.1 Objective of Work

Based on the literature survey and the subsequent analysis of gaps the present work aims to investigate the effect of various parameters in a die casting process on the properties of aluminum alloy and optimize the parameters using multi-response optimization Methodology. The experiments have been conducted using aluminum alloys K-1275 The process parameters varied were the thermal characteristics (temperature of the molten metal), the injection pressure of molten metal, Coating thickness and solidification rate.

## III. SIX SIGMA –A DETAILED VIEW

### 3.1. Six Sigma description

Statistically, six sigma refers to a process in which the range between the mean of a process quality measurement and the nearest specification limit is at least six times the standard deviation of the process. The statistical objectives of six sigma are to Centre the process on the target and reduce process variation.

### 3.2. Six Sigma Implementation

Six Sigma implementation is usually a top down approach, i.e., from the strong commitment of top management. As most six sigma projects span several departments, organizational barriers could not be removed without leadership commitment to Six Sigma. Strong commitment, leadership and strategic have proven to be key factors for six sigma success. Secondly, as six sigma requires a long term mentality, it needs to positioned first as a strategic initiative and then be linked to operational goal. It is important to tie the Six Sigma loyalty, for example. Also, effective internal communication is another key issue for the success of Six Sigma implementation.

### 3.3 Training and belt structure

The deployment of Six Sigma in a company is usually starts with education. Without the necessary training, people are not able to bring about six sigma breakthrough improvements. Six Sigma establishes well defined and structural role and responsibilities for a project team and team members are given formal training according to their roles to help the team work effectively. A Six Sigma team is usually organized in a belt structure as shown in figure.

#### 3.3.1 Champion:

He is the business leader responsible for overall deployment. Champion ensures that process owner support is there during all phases. Champion learn DMAIC philosophies, deployment strategies, which include selecting high impact projects, Choosing and managing the right people to become master belt. Champion helps transferring project ownership from black belt to manager who owns the process upon completion of corrective actions.

#### 3.3.2 Black Belt:

The Quality leader acts as a team leader in DMAIC project. He is responsible for training and deployment. He is all day problem solver and assists black belt in applying the method correctly in unusual situations. In organization, normally manager acts as a black belt.

#### 3.3.3 Green Belt:

These employees in the organization execute DMAIC as a part of their overall job while working with black belt. They gain experience in the practical application of DMAIC methodology and tools. They work as team member in black belt project.

According to Six Sigma academy, black belts are able to save companies approximately US $230000 per project and can complete four to six projects per year. The ASQ has been certifying Six Sigma black belts (SSBB) internationally in recent years as shown in table 3.1.upto the middle of 2002 there were around 200 ASQ-certified black belts in the US only 11 ASQ-certified black belts outside the US.

## IV. DEFINE-MEAURE-ANALYZE-IMPROVE-CONTROL

### 4.1 The DEFINE-MEASURE-ANALYZE-IMPROVE-CONTROL (DMAIC) Methodology

The development of Six Sigma is evolutionary, not revolutionary, and integrates many useful quality management tools. Thus, it is not surprising to find overlaps between the six sigma, TQM, lean and ISO approaches. The core methodology of six sigma is driven by close understanding of customers , needs the disciplined use of facts data and statistical analysis, which consists of five phases i.e. define, measure, analyze , improve and control (DMAIC) .

In the define phase, the specific problem is identified, and the project goals and deliverables are defined. In the measure phase, the critical to quality (CTQ) characteristics are identified and the measurement system is reviewed. The nature and properties of the data collection have to be understood thoroughly to ensure the quality of data. In analyze phase, both quantitative methods and qualitative tools are used to isolate the key information that is important to explaining defects. In the improve phase, the key factors and processes are controlled and monitored continuously to ensure that improvement is sustainable and the problem will not occur again.

### 4.2 The DMAIC process

More specifically, were implementing the DMAIC methodology in detailed steps in sequence to shift our focus from the output performance (i.e., y) to the root cause (i.e., x). Based on these steps, we transfer a practical problem into statistical problem (mapping x and y), find out a statistical solution for that [e.g., solving y = f(x)] and then transform the statistical solution into a practical solution. Each step is shown in figure 4.1 and described in the following, and the corresponding key tools will be further explained in a later section.


#### 4.2.1. Phase 1: Define (D)

This phase define the Six Sigma project, which include a problem statement, the objective of the project , the expected benefits , the team structure and project time line . At the end of this

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phase, we should have a clear operational definition of the project matrices for the final evaluation. In this phase, the main task are to identify who the customer is, select the project area, define the goal, scope and resources of the project, from a six sigma project team, define the team members responsibility and estimate the profit and cost for this project to ensure the value of project. Key tools in this phase include the project charter, business process mapping, suppliers, input, process outputs and customers (SIPOC) etc.

**4.2.2. Phase 2: Measures (M)**

By taking steps in the measure phase, we have a clear understanding of the performance of the current process and only after knowing where we are now, can we determine where we should be in the future. Three implementation steps in this phase are to select the critical- to- quality (CTQ) measures, determine deliverables, and quantify the measurability.

**4.2.3Phase 3: Analyse (A)**

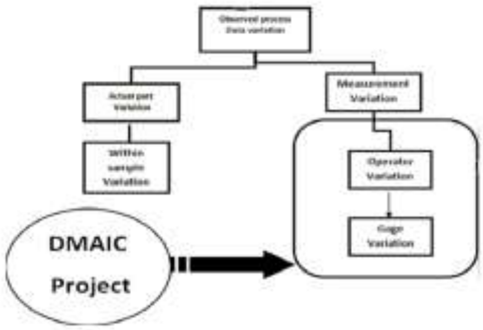
After we identify the y in process, we need to determine the x (root cause), which may impact on the performance of the y, in the analyse phase, we use various management and statistical tools to discover the x for future improvements plan, and identify the sources of variation

**4.2.4. Phase 4: Improve (I)**

As the root cause of variation is obtained, it becomes possible for us to fix these root causes. in the improve phase, the way that we can achieve a better process needs to be found, where the design of experiment (DOE) is a key technique to help us quantify the relation between the y and x, and to improve the process by finding the optimal setting of x for each y. in this phase, we follow three implementation step: screen potential sources of variation, discover variable relationship and formulate the implementation plan.

**4.2.5. Phase 5: Control (C)**

After determine the how to fix a process, we want the improvement for the process to be sustainable. The control phase is setup to ensure sustainable improvement and to deploy measurement tools to confirm that the process is in control. It is also critical to realize the financial benefits and develop a transfer plan in this phase. Three implementation steps include validating the implementation plan, controlling the inputs and monitoring the outputs and finally sustaining the change.




## V. KEY TOOLS TO SUPPORT THE DMAIC PROCESS

### 5.1. BUSINESS PROCESS MAPPING (SIPOC Diagram)

SIPOC stands for suppliers, inputs, process, outputs and customer, SIPOC diagram are graphical tool to identify all relevant element s of a business process and map the process flow before the projects begins as shown in figure 5.1. They are usually used in define phase.

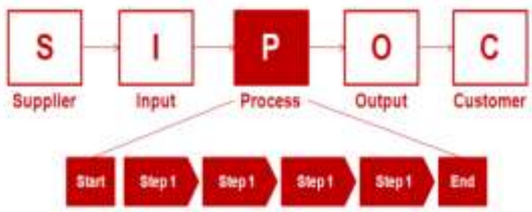



**FIGURE-5.1 SIPOC Diagram**

Supplier: whoever produces provides or furnishes the product or services for the input of process, either an internal or an external supplier.
Inputs: material, resources and data required to execute the process.
Process a collection of an activity that take one or more kinds of input and creates output that is of value to the costumer.
Outputs: the tangible products or services that result from the process.
Customer: whoever receives the output of the process, either an external customer or an internal customer?

**Steps for implementation of SIPOC**

Step1. Clear statement of CTQ and the process
Step 2. Clear statement start end point.
Step3. Identify major customer, suppliers, outputs

and inputs.
Step4. Identify the five to seven major process step using brainstorming.
Step5. Decide what step to map in detail.
Step6. Complete detailed map.

### 5.2 Quality Function Deployment (QFD)

QFD is a systemic approach to prioritize and translate customer requirements (i.e., external CTQ) into appropriate company requirements (i.e. , internal CTQ) at each stage from product development to operations to sales and marketing to distribution. This method is usually in the measure phase. It is also useful in design for six sigma (DFSS) and will be introduced in more detail in the DFSS section.

### 5.3 Failure modes and Effects Analysis (FMEA)

FMEA is a tool to reduce the risk of failure. It is also a tool to identify and prioritize CTQ at the measure phase. Various steps of failure mode and effect analysis are shown in figure 5.2
Severity: The assessment of how severe a failure mode is called severity. The severity usually scales from 1-10. Scale 1 means a minor failure mode that may not be noticed, and 10 means a very serious failure that may affect safe operations.
Occurrence: The likelihood that a specific cause will result in the failure mode, which scales from 1-10 with 10 being the highest likelihood.
Detection:The assessment of ability to identify the failure mode. A 1-10 scale is often used with 10 being the lowest delectability.
**RPN:**The risk priority number (RPN) is output of FMEA

RPN = severity * occurrence* Detection

### Step to implement FMEA

Step1: identify the products, services, or processes.
Step2: identify the potential failure that would arise in the target process.
Step3: identify the cause of the effects and their likelihood of occurrence.
Step4: identify the current controls of detecting each failure mode and the ability of the organization to detect each failure mode.
Step5: calculate the RPN by multiplying the values severity, potential causes and detection.
Step6: identify the action for reducing or eliminating the RPN for each failure mode.

**FIGURE-5.2 FMEA Process**

### 5.4Measurement System Analysis (MSA)

A statistical evaluation of the measurement system must be undertaken to ensure effective analysis of any subsequent data generated for a given process / product characteristic. MSA is usually used in the measure and control phases to validate the measurement system for y and x.
Gage R&R: Gage R&R is tool to study the variation in the measurement arising from the measurement device and the people taking the measurement.
Repeatability: Repeatability is defined as the variability that reflects the basic, inherent precision of gage itself.
Reproducibility: reproducibility is defined as the variability due to different operators using the gage (or different time, different environment)

### 5.5. Cause-Effect Diagram (Fishbone diagram)

This is a graphical brainstorming tool to explore the potential causes that result in a significant effect on output. It is usually used in the analyse phase figure5.3 shows the various potential causes that occur in a manufacturing process and have an adverse effect on the output which are delay in supply of material, machine , breakdown, measurement system error etc.

### Step to be taken

Step1: Define clearly the effect or analysed symptom (y) for which the possible cause (x) must be identified.
Step2: Place the effect symptom (y) being explained on the right of a sheet of a paper.
Step3: Use brainstorming or a rational step by step approach to identify the possible causes.
Step4: Each of the major areas of possible causes should be connected with the central spine by a line.
Step5: Add possible causes for each main area.
Step6: Check for completeness.

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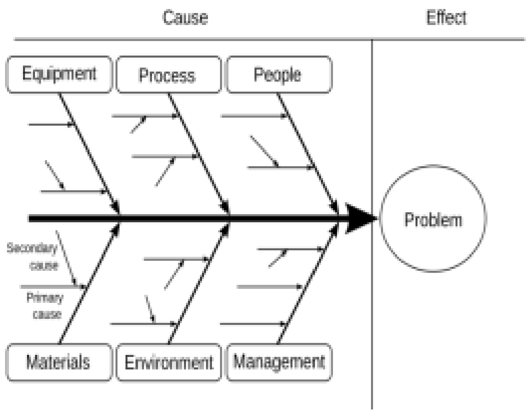


**Figure: 5.3 Cause and effect diagram**

### 5.6. Design of Experiment (DOE)

DOE is major tool in the improve phase. It is used for screening the few potential causes characterizing the relationship between the output and causes, and optimizing the setting of the vital parameters. The various steps taken in the design of experiment are shown in figure 5.4

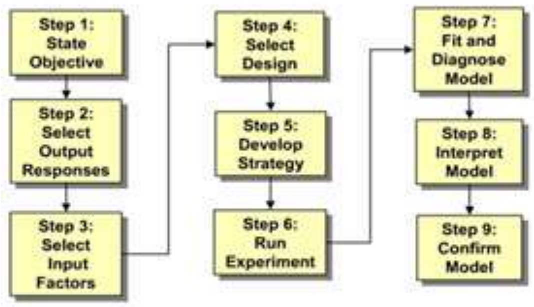


**FIGURE- 5.4 Flow chart of DOE**

## VI. PROBLEM FORMULATION

In all processes the smallest variation in quality of raw material, production conditions, operator behavior and other factors can result in a cumulative variation (defects) in the quality of the finished product. DMAIC approach aims to eliminate these variations and to establish practices resulting in a consistently high quality product. Therefore, a crucial part of DMAIC work is to define and measure variation with the intent of discovering its causes and to develop efficient operational means to control and reduce the variation. The expected outcomes of DMAIC efforts are faster and more robust product development, more efficient and capable manufacturing processes, and more confident overall business performance.

Present work was done at SHRIRAM PISTONS: PATHREDI, VIBHANI (RAJ.) on application of DMAIC methodology and Selection of tools and techniques for problem solving, because of its high rejection rate. The main component of SHRIRAM PISTONS: PATHREDI, VIBHANI (RAJ.)is pistons and ring.

### 6.1. Objective of the Problem

The main objective of this work is that eliminating the casting defects in production of piston in foundry shop using the six sigma tools and DMAIC methodology. Here we check the main causes of defects and reducing them by appropriate tool, and improve the quality of pistons.

1. To identify the root factors causing casting defects
2. To improve the quality by reducing the casting defects

The present work deals with elimination of casting defects in a foundry industry. DMAIC approach is justified when root cause of defect is not traceable. In the present work, an attempt has made to reduce the defects in castings in a foundry shop with the application DMAIC approach.

#### 6.1.1 Define phase

The first phase of DMAIC is to define and identify key issues and problems through both the voice of customer and the voice of business, as well as the analysis of casting processes. From the literature and views of experienced foundry personnel, casting defects is the most dissatisfaction area in this industry. The casting defects for the said foundry for year 2009 is found to be 4.72052%, which is accounted for Sigma value of 3.18. After intense brain storming, several influencing and controllable process parameters are identified and measured. The effective range of the parameters identified is studied for its effects on the Sigma performance of the process. Performance measures of the existing process are determined by collecting data from the foundry floor.

**Shift Defect**

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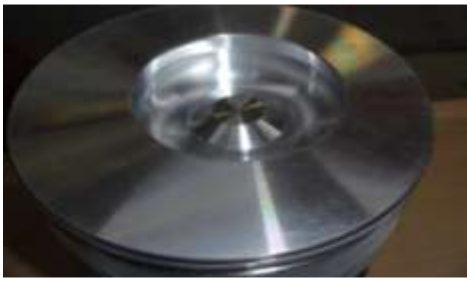


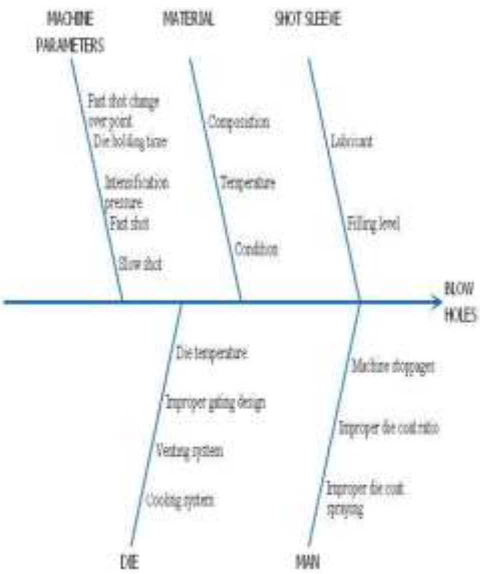
**Porosity Defect**

### 6.1.2 Measure phase

Brain storming sessions are conducted by the team working under chartering and the data are collected for analyzing causes of defects. After intense brain storming, several influencing and controllable process parameters are identified and measured. Out of which, the most significant contributors considered in the current stage, various defects are measured quantitatively and qualitatively due to uncontrollable parameters present in the casting process. The most significant defects considered in the current research and it is analyzed in the Pareto diagram as given in Figure 6.2. Only three major defects, which created major changes (inclusion, gas porosity, shrinkage defects), are taken into account. Sigma is calculated before implementing DMAIC model.

### 6.1.3 Analyse Phase

With the help of the cause and effect matrix, factors that influenced the rejection most are identified. Root causes from probable causes are analyzedin order to reduce or eliminate casting defects. FMEA is a key tool for analyse effect of failure mode




### 6.1.4 Improve phase

In that phase we improve the defect occurs in piston casting process with the help of Design of Experiment (DOE) technique. Here we are using the Taguchi analysis process for optimize the various selected parameter.

#### 6.1.4.1Selection of Factor

The determination of which factors to investigate depends on the responses of interest. The factors that are believed to affect the responses were identified using cause and effect analysis, and brainstorming

#### 6.1.4.2 Orthogonal Array

OA plays a critical part in achieving the high efficiency of the Taguchi method. OA is derived from factorial design of experiment by a series of very sophisticated mathematical algorithms including combinatorics, finite fields, geometry and error-correcting codes. The algorithms ensure that the OA to be constructed in a statistically independent manner that each level has an equal number of occurrences within each column; and for each level within one column, each level within any other column will Occur an equal number of times as well.

#### 6.1.4.3 Measuring and Test Equipment Used

Rockwell hardness and surface roughness tests were conducted on all the samples, produced after each of the 9 trials. Also, density was measured using a weighing machine, and micrometer. The details of important test equipment used in experimental study are given below:

**Surface Roughness Tester**

Surface roughness was measured using the Mitutoyo Surf test model SJ-301 available, the equipment uses the stylus method of measurement, has profile resolution of 12 nm and measure roughness up to 100µm. A tracing length of 4.8 mm was used for analysis

#### 6.1.4.4 Signal to Noise Ratio for Response Characteristics

The parameters that influence the output can be categorized in two categories, controllable factors and uncontrollable factors. The control factors that may contribute to reduced variation can be quickly identified by looking at the amount of variation present in response. The uncontrollable factors are the sources of variation often associated with operational environment.

**6.1.4.5 Analysis of Density**

The response factor (quality characteristic) chosen is density of the casting. Density of the casting is chosen as a quality characteristic since it has direct relationship with casting defects. Generally denser the casting lesser the internal defects such as porosity, blow holes etc.

**6.1.4.6Analysis of Hardness**

Hardness was measured on a Rockwell Hardness Tester. The hardness measurement is dependent on the diameter of indentation on the samples. The indents formed in the pyramid shaped steel ball indenter were measured on B scale with a minor load of 10 kgfor 20 Seconds.

**6.1.5 Control**

The Control stage is the last and final stage and its sole purpose is to preserve the optimized response obtained from the experiments. For complete success of Six Sigma, proper documentation of the process is recommended. The process stays in control after the solution has been arrived and the out of control state is reduced. The associated special causes are determined and action is taken to correct the problem before non-conformities are produced. The expected results and improvements are achieved and recommended for further approach. Then the company is advised to document the process and provide training to the workers with the help of Six Sigma improvement group.

## VII. RESULTS & DISCUSSION

The effect of various input parameters i.e. thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (oil coating, oil+ graphite coating, Dycot coating), and cooling medium (air cooling, water cooling and oil cooling) were evaluated using DOE and Taguchi design analysis. The purpose of the DOE was to identify the important parameters in prediction of surface roughness, density and hardness.

1.DOE analysis showed that injection pressure was the only factor that significantly affects the surface roughness. All other factors, namely, pouring temperature, coating and cooling were found to be insignificant. The injection pressure directly affects the quality of the surface produced and reduces porosity and other gas defects. It is concluded that lowest roughness was observed when injection pressure was kept at 190 kg/cm$^2$, pouring temperature at 770ºC and for cooling water was used during casting because these decreases variation.

2.DOE shows that injection pressure and pouring temperature are the factors that significantly affect density. The other two factors, namely, coating and cooling were found to be insignificant. It is concluded that highest density was observed when injection pressure was kept at 190 kg/cm$^2$and pouring temperature at 790ºC. For S/N ratio of density, except coating and cooling medium, the other two factors pouring temperature and injection pressure were found to be significant..

3. DOE shows that cooling pouring temperature andcoating are the factor that significantly affects the hardness, whereas injection pressure was found to be insignificant. For S/N ratio of hardness, except injection pressure, all other factors are significant.

According to F-test cooling was observed to be the most significant factor affecting the hardness, followed by pouring temperature and coating. It is concluded that lowest hardness was observed when roughness was observed when injection pressure was kept at pouring temperature at 750ºC and for cooling oil and oil–graphite coating was used during casting because these decrease variation.

4. DMAIC approach is widely used for improve the piston Quality and reduction of defects.

5. After utilization the six sigma concept in organization and implement the DMAIC approach the defects level is reduces from 2.35%.

6. Before implementing this approach the defects level is 10.35% but now it is 8% defects is occur in piston manufacturing by material KS-1275.

## VIII. CONCLUSION & FUTURE SCOPE OF THE WORK

1. This report presents an application of DMAIC methodology within a Foundry industry based in India.

2. One of the important Die Casting parameter that influences the quality of piston and proper application of DOE can result in breakthrough improvement.

3. Excepting melting temperature, injection pressure, coating and type of cooling other parameter may be used like as plunger speed, cooling phase etc.

4. Present work is done on material KS-1275; we can also use the LM-6, LM-29, A-351 aluminium alloy material.

5. This Optimization process of Surface Roughness, Hardness, and Density give better quality for component, and also reduced the defects.

6. As the aluminum alloy has wide number of applications in automobile, aerospace, and many other manufacturing industries, but still not much

work is available on its properties with different input process parameters.

7. A rigorous study should be done to analyze the properties of aluminum alloys by varying process parameters and much work can be done in enhancing the properties of aluminum alloys.

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