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# An Application of Six Sigma DMAIC and DMADV Methodologies in a Two-wheeler Lead Acid Battery Manufacturing Industry

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**Abstract— The paper illustrates how Six Sigma DMAIC and DMADV methodologies were applied to a Two-wheeler Lead Acid Battery Manufacturing Industry for reducing the rejection rate of a specific type of battery due to acid seepage at the terminals. The root causes for the problem were identified through a data-based analysis at different stages of manufacturing. The process parameters were optimized and measures for sustainability of the results were incorporated in the process. As a result of this study, the overall rejection was reduced from the 3.32% to 1.6% by applying process DMAIC methodology and changes made in the design of the terminal by DMADV methodology that tends to 0% rejection of batteries.**

***Keywords: Battery Manufacturing Industry, DMAIC, DMADV, Lead Acid battery, Six Sigma, Two-wheeler battery.***

## I. INTRODUCTION

The document explains how the DMAIC and DMADV Six Sigma methodologies are applied in the Two-wheeler Lead-Acid battery industry to increase a yield rate of specific battery by reducing the rejections due to acid seepage at the terminals of the battery.

Six Sigma has become a popular approach in many organizations today to drive out variability and reduce the wastage in the processes using powerful statistical tools and techniques. In statistical terms, Six Sigma means 3.4 defects per million opportunities, where sigma is a term used to represent the variation in the average of a process. In business terms, it is defined as a business improvement strategy used to improve business profitability, to drive out waste, to reduce the cost of poor quality and to improve the effectiveness and efficiency of all operations to meet or even exceed customers' needs and expectations (Antony and Banuelas, 2001).

Many organizations have reported significant benefits today because of six sigma implementations. Motorola, where Six Sigma was developed in the 1980's, claims to have similar savings. The application of Six Sigma is growing and moving from the manufacturing field to encompass all business operations, such as services, transactions, administration, research and development, sales and marketing and especially to those areas that directly affect the customer.

Define – Measure – Analysis – Improve – Control (DMAIC), the framework of Six Sigma methodology has been well established as benchmarking tool for process improvement and customer satisfaction helps in solving the problems related to the Manufacturing Process.

Define – Measure – Analysis – Design – Verify (DMADV), the framework of Six Sigma methodology has been well established as a benchmarking tool for product development/design and customer satisfaction to solve the problems regarding the Design of the product or process following by the manufacturing company.

Two of seven basic tools of quality improvement, Pareto chart and Cause and Effect analysis is used to find the primary causes. As soon as the cause is identified, key improvements and process improvements are carried out. Through repeated test and verification, the problem is reduced to the manageable complexity.

The Figure 1 shows the flow diagram of Six Sigma methodology,

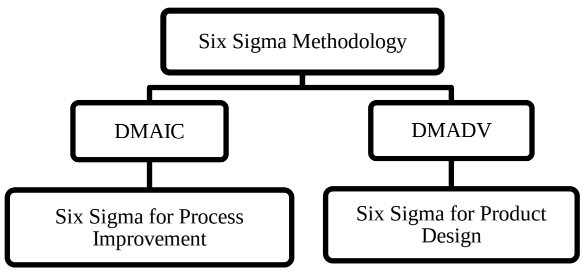


**Figure 1. Six Sigma Methodologies.**

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## II. ABOUT THE TWO-WHEELER LEAD-ACID BATTERY INDUSTRY

The industry, where the study has been carried out, manufactures a class of batteries which are categorized as VRLA (Valve Regulated Lead Acid) – AGM (Absorbent Glass Material) storage batteries made of lead alloy cells, Absorbent Glass Material, Dilute Sulfuric acid and Polypropylene Plastic casing. Battery is an assembly of Rubber cap, Top cover, Base cover and Container. Rubber cap covers the acid opening provided in the Top cover, Top cover permanently seals the base cover and base cover permanently seals the container by heat sealing technique. Battery container consists of a group of positive and negative lead oxide plates arranged based on the polarity, separated by the acid absorbed fiber glass material.

The article illustrates the case study to address the problem of rejection and rework faced by the organization during the manufacture of Two- wheeler VRLA – AGM Lead acid battery Figure 2.

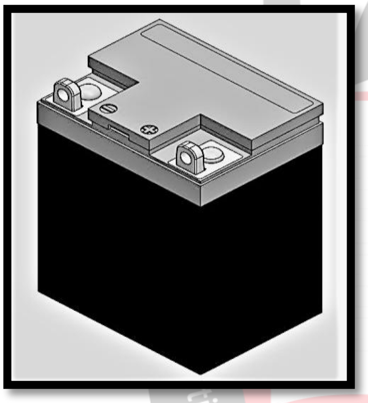

**Figure 2. Two-wheeler Lead Acid battery.**

The company had an increasing problem of rejections and rework in the acid seepage at the terminals of the two-wheeler battery, with an approximate rejection of 3.32% during the year of 2015-2016. Acid seepage at the terminal is due to deviating from the desired specification limits in the manufacturing process. This situation also increase the manpower, material and other overhead costs of manufacturing. Hence to address all the problems and to find the root causes in the company Six Sigma DMAIC and DMADV methodologies are applied.

## III. APPLIED METHODOLOGY

### *3.1. Define Phase:*

The purpose of the define phase in a Six Sigma project is to define the project with all necessary details including the objectives, scope, schedule, action plan, etc. (Gijo and Scaria, 2010, Sharma and Chetiya, 2010). This is the first activity in a Six Sigma project and if the project selection and goals setting activity are not done properly, it can lead to failure of the project (Breyfogle, 2006). Hence, after extensive discussions at the various levels of the management, detailed flowchart of the battery manufacturing process is explained. To have a better understanding of the process and have good clarity in the scope of the project, company to perform a Supplier – Input – Process – Output – Customer (SPIOC) analysis. This process provides the clarity regarding the process boundaries, the customers for the process outputs and the suppliers for the process inputs (Gijo and Scaria, 2010).

After understanding the process and the problem in detail, the problem is identified to exist in the Base cover of the battery as shown in the Figure3. To identify the root cause of the problem the manufacturing process is completely studied and analyzed by SPIOC analysis explained in *Table 1*. The need of the project is to reduce the rejection percentage due to acid seepage at the terminals.

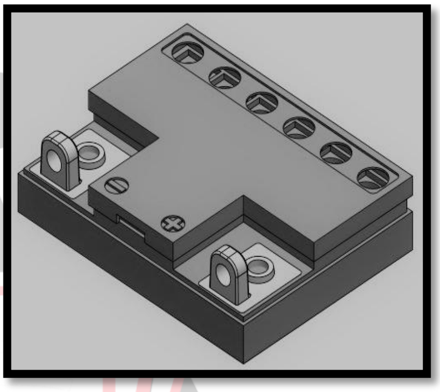

**Figure 3. Base Cover of Two-wheeler lead acid battery.**

*Table 1: SIPOC analysis* define the specific supplier where the problem occurred in the process or design with input materials and the process following for the manufacturing the part with required output for the customer as expecting.

| **Supplier** | **Input** | **Process** | **Output** | **Customer** |
|---|---|---|---|---|
| Lead Casting | Lead alloy | Gravity Die Casting | Lead bush Terminal | Two-wheeler battery Industry |
| Gumming | Gum material | Applying manually | Surface roughness on the lead terminal | |
| Plastic Injection Moulding | Polypropylene Plastic | The plastic Injection Moulding process | Battery Base cover | |

Manufacturing process flow of the battery base cover in the industry is presented in the flowchart shown in Figure 4.

Possibilities of Acid seepage at the terminal is explained from the Figure 5.1 and 5.2

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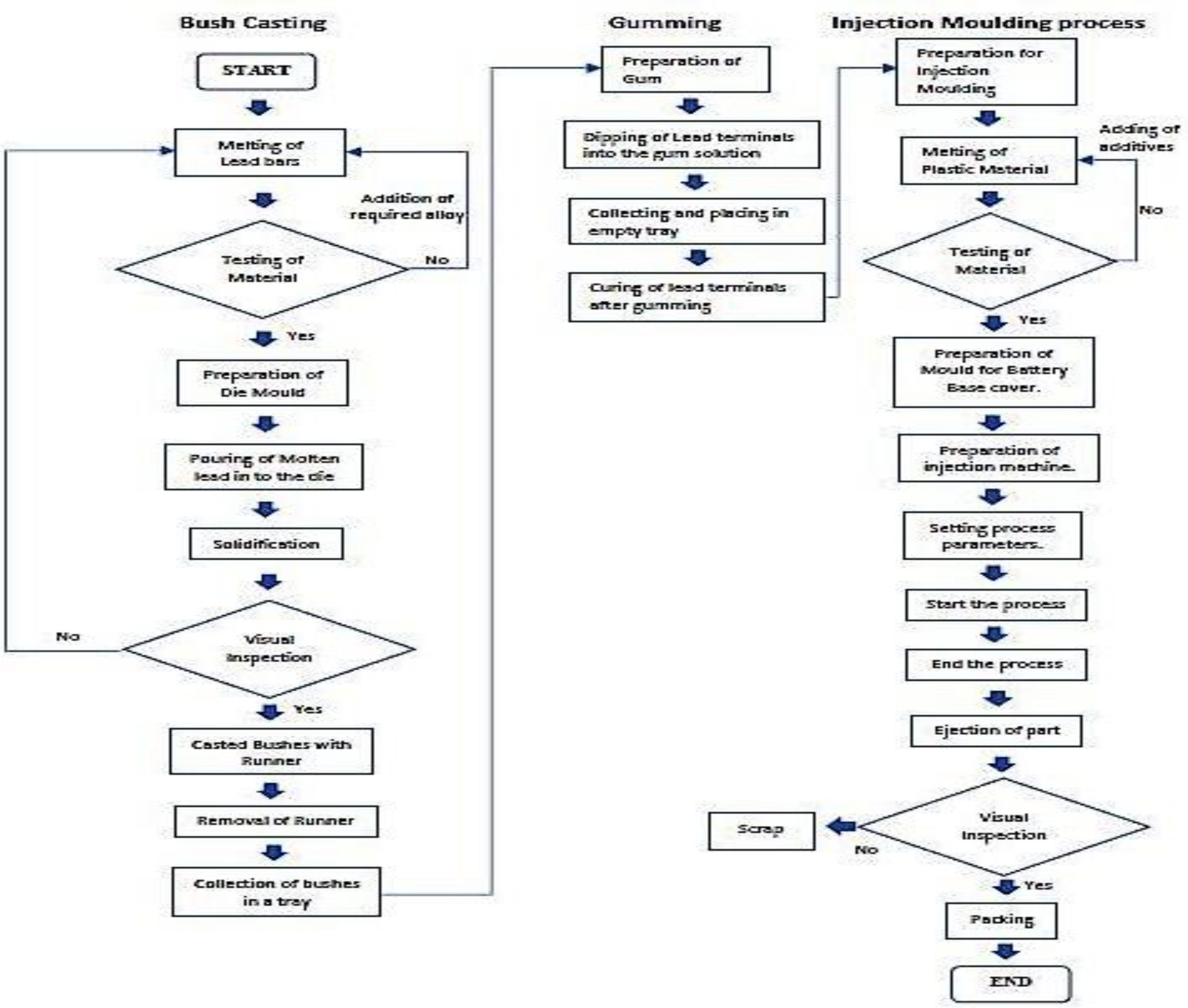


**Figure 4. Flow chart of Battery Base Cover Manufacturing.**

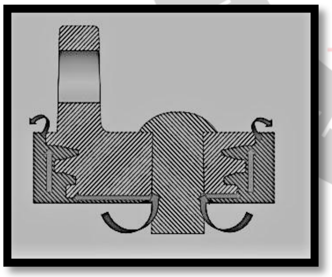

**Figure 5.1. Acid seepage form metal to plastic bonded area.**

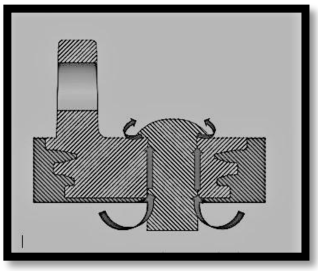

**Figure 5.2. Acid Seepage from post burned area.**

Figure 5.1 shows, acid seepage occurs at the bonded zone of plastic and lead metal. Figure 5.2 shows, acid seepage occurs at post burned area of the lead terminal.

*Post burning process*: Process done to weld the Cores of electrochemical cells in the battery to the Bush terminals in the battery base cover.

After understanding the process and the problem in detail, the objective is set to find the root cause of the problem and finding the solution for the cause.

*3.2 Measure Phase:*

In this phase, information from the existing process is gathered to evaluate the baseline status of the process. Form the process following the organization defects observed in each process are identified visually and suspected as the chance cause of the problem. The suspected chances are listed and measured by trial and error method in each process.

*List of suspected sources of variations (SSV's):*

*Table 2* explains the suspected sources of variations in the manufacturing process of battery base cover.

*Table 2: List of suspected sources of variations (SSV's):*

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| S. No. | Suspected Sources of Variation (SSV's) | Design SSV or Variation SSV |
|---|---|---|
| **BUSH TERMINAL CASTING** | | |
| 1 | Half fills in the bush terminals | Variable and Design |
| 2. | Gate Point projections in the casted bush terminal | Variable and Design |
| 3. | Parting line flash in the Bush terminal | Variable and Design |
| 4. | Shrinkage at the bottom thread | Variable and Design |
| 5. | Process Parameters of the Gravity Die casting process | Variable |
| 6. | The material composition of Lead alloy used | Variable |
| 7. | Design of the mould used for Gravity die casting process | Design |
| 8. | Pouring of the molten lead into the gravity die mould | Variable |
| 9. | Performance of the casting Machines used | Variable |
| **GUMMING** | | |
| 10. | Improper gumming process | Variable-Dipping |
| 11. | The material composition of the gum used | Variable |
| 12. | Curing time after gumming | Variable |
| **PLASTIC INJECTION MOLDING** | | |
| 13. | Process parameters of the injection moulding process. (Low holding time & Pressures) | Variable |
| 14. | Material using | Variable |
| 15. | Colour master batch Degradation (lack of Temp resistance) | Variable |
| 16. | Improper filling of the part (Hot runner/Cold runner) in the mould. | Design-Variable |
| 17. | Machine to machine variations | Variable |
| 18. | Cavities in the injection mould | Design |
| 19. | Variations in product design compare to other designs | Design |
| **BATTERY ASSEMBLY** | | |
| 20. | High Temp around the terminal battery formation Process due to TIG Welding or Post burning. | Variable |

Percentage of rejection rate due to Suspected sources of problems in the table are measured by performing trial and error technique. In each process of battery base cover manufacturing, the trial of 250 batteries are done on every SSV's and rate of rejection is compared and tabulated as shown in *Table 2,3 and 4*. Based on the rejection rate causes are analyzed which is done in the analysis phase of Six Sigma

*Table 3: Trails and Rejections in Bush casting process*

| S. No | Trial Name | | Code | QTY | Rej | % of Rej |
|---|---|---|---|---|---|---|
| 1 | Bush Casting Machine | Machine 1 | T1-A | 250 | 9 | 3.6 |
| | | Machine 2 | T1-B | 250 | 9 | 3.6 |
| | | Machine 3 | T1-C | 250 | 2 | 0.8 |
| 2 | With Gate Point Projection | | T2 | 250 | 5 | 2 |
| 3 | With Half fills in the bush | | T3 | 250 | 8 | 3.2 |
| 4 | Without Gate Point Projection | | T4 | 250 | 3 | 1.2 |
| 5 | Without Half fills in the bush | | T5 | 250 | 6 | 2.4 |
| 6 | Process parameters of the bush casting process | | T6 | 250 | 8 | 3.2 |

*Table 4: Trails and Rejections in Gumming process*

| S. No | Trial Name | Code | QTY | Rej | % of Rej |
|---|---|---|---|---|---|
| 1 | Full Dipping | T6 | 250 | 5 | 2 |
| 2 | Only for brush threads | T7 | 250 | 4 | 1.6 |

*Table 5: Trails and Rejections in Injection molding process*

| S.No | Trial Name | | Code | QTY | Rej | % of Rej |
|---|---|---|---|---|---|---|
| 1. | Performance of Injection molding machines | Machine 1 | T10-A | 250 | 2 | 0.8 |
| | | Machine 2 | T10-B | 250 | 5 | 2.0 |
| | | Machine 3 | T10-C | 250 | 6 | 2.4 |
| | | Machine 4 | T10-D | 250 | 2 | 0.8 |
| 2. | Cavity wise in Injection Mold | Cavity 1 | T11-A | 250 | 3 | 1.2 |
| | | Cavity 2 | T11-B | 250 | 10 | 4.0 |
| | | Cavity 3 | T11-C | 250 | 4 | 1.6 |
| | | Cavity 4 | T11-D | 250 | 7 | 2.8 |
| 3. | Regular Process Parameters | | T12 | 250 | 10 | 4.0 |

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*3.3 Analysis Phase:*

In this phase of methodology, Pareto chart and Cause and effect are adopted to find out all the root causes.

Rejection percentages in each trail are represented in the Pareto chart shown in *Figure 6.*

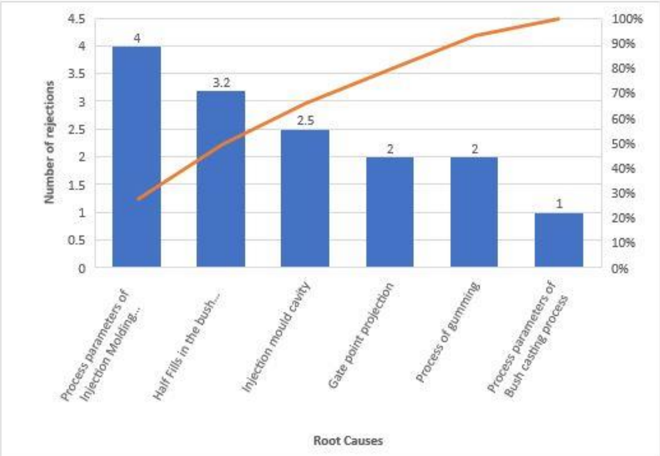


**Figure 6. Pareto chart of rejections.**

Cause and Effect Diagrams in each process explains the causes and their effects, analyzed in each process of battery base cover manufacturing are shown in *Figure 7.1, 7.2, and 7.3*

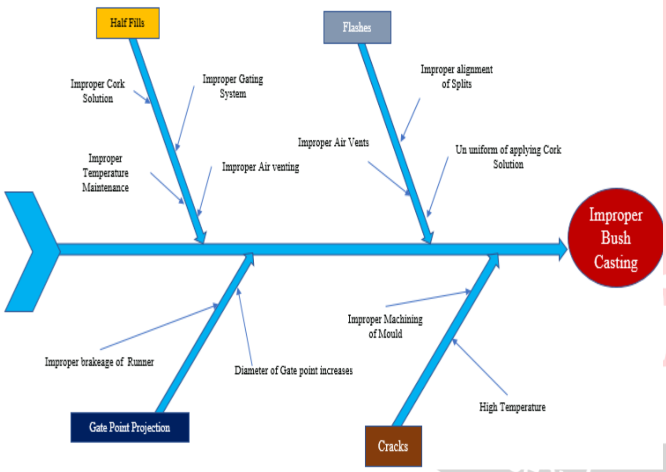


**Figure 7.1. Cause and Effect diagram of Bush casting process.**

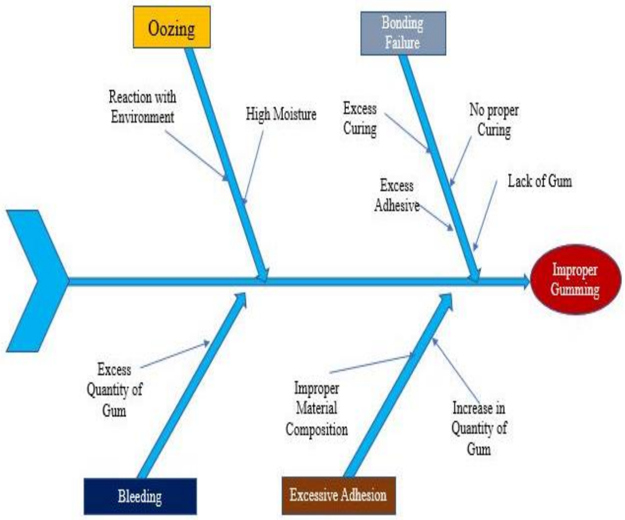


**Figure 7.2. Cause and Effect diagram of Gumming process.**

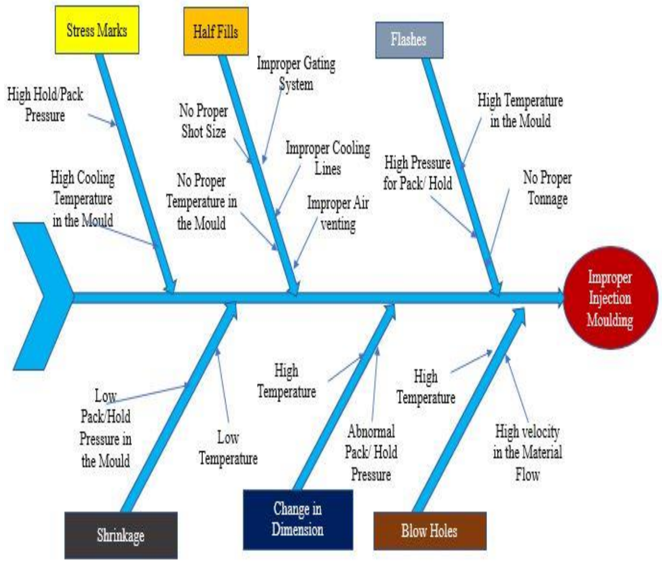


**Figure 7.3. Cause and Effect diagram of Injection molding process.**

*3.4 Improve Phase:*

In this phase, solutions for the selected root causes are identified and implemented to observe the results. As per the decisions in the analysis phase, a DOE was planned and conducted during the phase to identify the optimum settings for the process parameters selected for experimentation in Casting, Gumming, Plastic Injection molding process. During the brainstorming, session team felt that defects in the bush terminal casting, gumming process and Injection molding process must be avoided and chances of failures must be decreased. Hence, these interactions are considered for further study. The first experiment started from the bush terminal casting process followed to plastic injection molding changes.

In the bush casting process the defects like half fill in the threads of the bush terminal, parting line flash, shrinkages in the bottom thread is reduced. In gumming process the quality of the gum solution is improved to increase the roughness on the surface of the lead bush terminal and in Injection molding process, changes made in process parameters like injection velocity, injection pressure, holding velocity, holding time.

Finally, optimum results were implemented after preparing an implementation plan with responsibility target date. The results were observed after successful implementation of the solutions. The data on acid seepage is recorded during the implementation and after implementation of the changes. The overall rejection percentage was reduced from 3.32% to 1.6%, which was very significant for the process.

*P Chart:*

*Figure 9*, shows the P - chart results of the 15 trials done with 250 number of batteries after changing the process the process parameters in each process of the battery cover manufacturing.

*Table 6: P chart.*

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| Trial | Rej | Qty | P | MEAN | LCL | UCL |
|---|---|---|---|---|---|---|
| 1 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 2 | 3 | 250 | 0.012 | 0.0077 | 0 | 2.895 |
| 3 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 4 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 5 | 1 | 250 | 0.004 | 0.0077 | 0 | 2.887 |
| 6 | 1 | 250 | 0.004 | 0.0077 | 0 | 2.887 |
| 7 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 8 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 9 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 10 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 11 | 2 | 250 | 0.008 | 0.0077 | 0 | 2.891 |
| 12 | 1 | 250 | 0.004 | 0.0077 | 0 | 2.887 |
| 13 | 0 | 250 | 0 | 0.0077 | 0 | 2.883 |
| 14 | 4 | 250 | 0.016 | 0.0077 | 0 | 2.899 |
| 15 | 3 | 250 | 0.012 | 0.0077 | 0 | 2.895 |
| Total | 29 | 3750 | | | | |

| | Value |
|---|---|
| Average (p bar) | 0.007733 |
| Standard deviation | 0.96115 |
| Z | 3 |
| Upper Control Limit | 2.51 |
| Lower Control Limit | 0 |

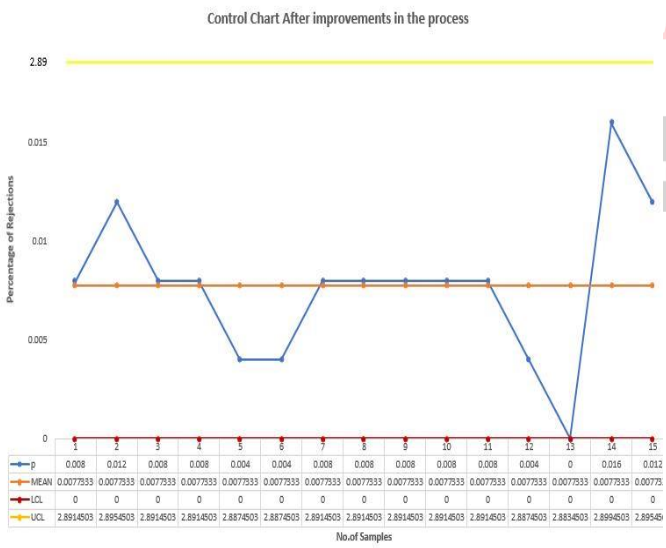



**Figure 9. P Chart.**

The *Figure8*, shows the rejections due to the acid seepage in a sample of 250 batteries trailed for 10 times with regular process parameters and changes in process parameters.

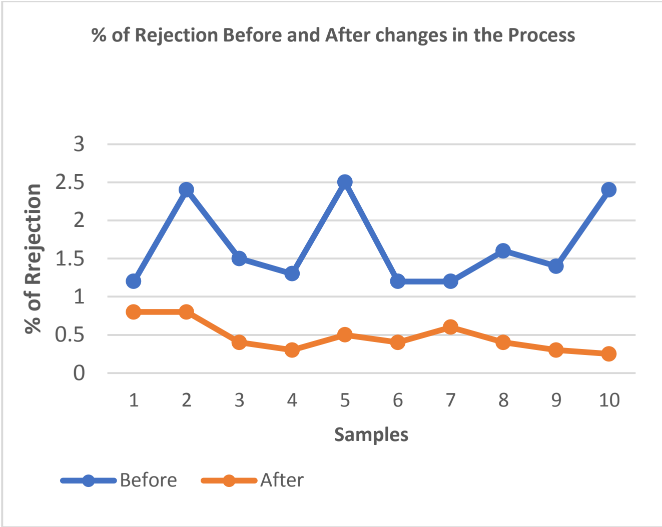



**Figure 8. Percentage of Rejection Before and After changes in the Process.**

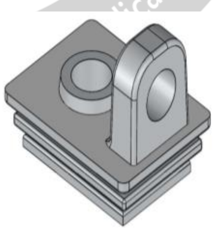
*3.5 Design Phase:*

In this phase of the project, a new design of lead design terminal is proposed to the industry for better plastic bonding with the lead terminal.

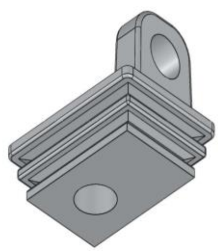
In this phase of methodology, sharp corners and edges of the terminal threads as shown in *Figure 10* is modified to rounded edges as shown in *Figure 11*. The proposed design, a prototype is done with the support of the team. Mold for the proposed design is done with the help of an external vendor of the company with same material properties of the metal used and the external dimensions of the mold.

In the proposed design, the volume of plastic filled in between the threads is 506.52mm$^2$, whereas in the old design it is 473.84mm$^3$. Area of plastic bonded at the bottom thread is in the proposed design is 140.08mm$^2$ whereas in the old design it is 118.62mm$^2$.

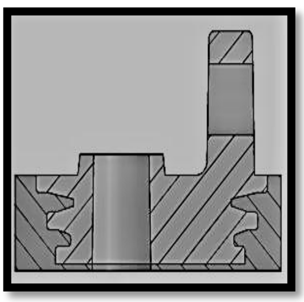
*Existing Design:*



**(a).**



**(b).**



**(c).**

**Figure 10. Old Bush terminal of Two-wheeler battery.**

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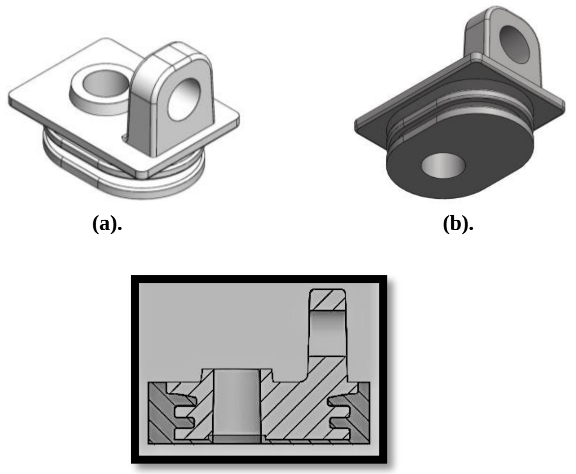
*Proposed Design:*




**(c).**

***Figure 11. Proposed Bush terminal of Two-wheeler battery.***

*3.6 Verify Phase:*

To verify the design changes in the terminal, a trial of 1500 batteries are put to test the design of the terminal, the rejection rate is reduced from 1.6% to the 0% The design is further put into a test to measure the performance of the battery with the proposed design.

The trial results are evidence for the significant improvements in reducing the acid seepage at the terminal. The reducing process proposed by the analysis result of DMADV has improved the quality of the battery base cover and reduced the rework cost.

*3.7 Control Phase:*

In this phase of the project, the solutions are implemented for the identified root causes.

Figure 12, shows the results of trials performed after improvements in the company.

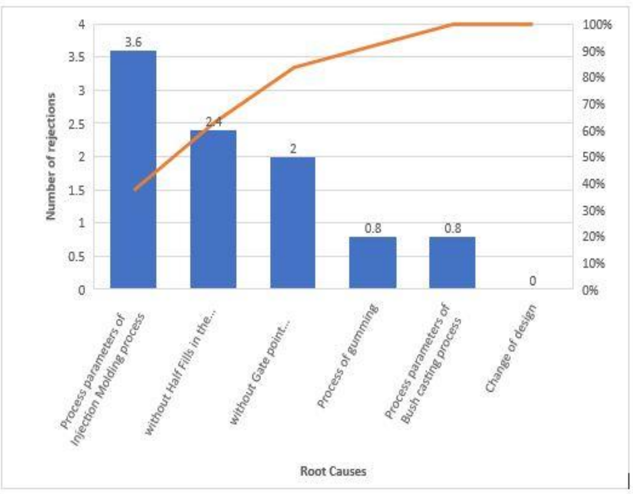



**Figure 12. Pareto chart after changes in the process and design of the battery terminal.**

## IV. RESULTS AND DISCUSSIONS

As seen in the experimental section, DMAIC and DMADV methodologies have proved to be the effective tools for improving the quality of the battery. It has been recognized that DMAIC and DMADV uses an organized approach to address the problem.

*Key Performance Indication:*

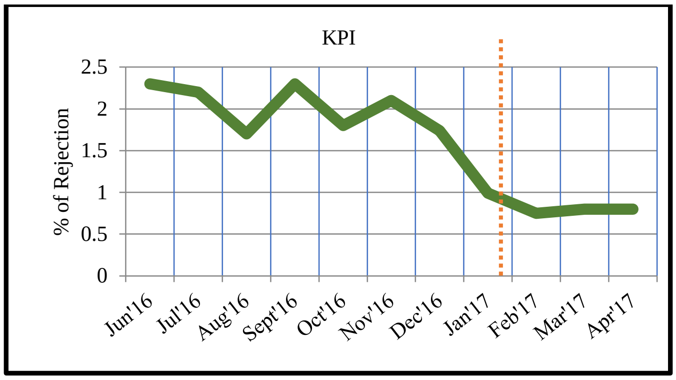



**Figure 13. Key Performance Indication.**

*Figure 13* shows the results of the battery rejections after changes made in the process parameters of each manufacturing process of battery base cover. In the month of January 2017, the changes in the process parameters shown a very good result with fewer rejections compared to the previous rejections.

Methodology DMAIC helped in making a change regarding the process followed in the organization. The process changed due to acid seepage at the terminal are

- It has been suggested that Half fills in the bush threads must be not allowed for further process.
- Gate point projections in the bushes must be stopped and avoided allowing for the further process is suggested,
- It has been suggested that parting line flash in the bush terminal must be avoided and the terminals with this kind of defect are not allowed for further process,
- Dual time gumming with an equal interval of curing is suggested,
- Sorting of bushes after gumming is suggested,
- For better quality in gumming process, bonding property of the gum prepared manually must be inspected and verified.

Methodology DMADV helped in make changes regarding the design of the lead terminal. Changes which are suitable and possible with fewer constraints are proposed as shown in the figure.

Design changes that are proposed to decrease the rejection rate of the acid seepage at the terminal are,

- Sharp Corners of the threads are rounded.
- Area of the bush at the bottom thread is increased to improve the bonding strength with the plastic.

## V. CONCLUSION

Six Sigma methodology and powerful tool for improving the quality of the process and the design of the product. Six Sigma is used for improving the existing process and the existing design or in the process of new product design

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development. Six Sigma is a problem-solving tool used for solving the various problem in the organization. Six Sigma helps in reduction of defects in the process and the product. Six Sigma methodologies are followed by the two-wheeler battery industry for improving the quality of the battery and the quality of the process following. Reduction of customer complaints is reduced by the following the methodologies.

Based on the results of the DMAIC and DMADV methodologies the conclusions drawn from the investigation are as follows:

Manufacturing process flow of the battery is completely studied and analyzed for identifying the scope of the problem.

Defects at the terminals are studied and rectified to the largest extent possible.

Causes for the acid seepage at the terminals of the batteries have been analyzed and redesign of the terminals are explained.

Performance of each manufacturing process followed for part of the battery causing defects are physically verified in trial and error method and results shown in table 3 ,4 and 5. are compared to find out the causes.

Defects in each manufacturing process of the base cover are listed and analyzed.

Modelling of proposed designs of bush terminal and mould for casting is carried out and the acceptable designs are arrived at using Solidworks 2016 software.

Changes are made in the design of the bush terminal by removing the sharp corners at the threads and increasing the bottom area of the bush by providing an undercut. Proposed design performance is verified by performing trials on a particular battery type that was defective earlier. The quality of the battery is improved by making changes in the process by applying DMAIC methodology and the rejection rate of the batteries due to acid seepage around the lead bush terminal are reduced from 3.32% to 1.6%.

The quality of the battery is improved by making changes in the design of the bush terminal by applying DMADV methodology and the rejection rate of the batteries due to the acid seepage around the lead bush terminal is reduced from the 2.0% to 0%.

DMAIC methodology helped to optimize the process in the battery base cover which results in the acid seepage rejection rate.

DMADV methodology helped to optimize the design of the bush at thread area, resulting in better performs and less rejection rate compared to the earlier design.

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