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# QUALITY ENHANCEMENT IN PLASTIC MANUFACTURING INDUSTRY USING SIX SIGMA METHODOLOGY

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## ABSTRACT

Six Sigma is a process-oriented, da ta-driven approach focused at improving the performance of products and processes by finding and eradicating the origin of defects which are critical to customers. The purpose of this research is to study quality associated problems in an injection molded plastic product and to improve the quality of the product using Six Sigma methodology in a mid-size injection molding company. The result proved that the quality of product in plastic industry can be improved by using Six Sigma.

## KEYWORDS

DMAIC and Six Sigma.

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## INTRODUCTION

Six Sigma is a planned and disciplined process, concentrating on delivering perfect product or services to the customer on a steady basis. In statistical terms, Six Sigma defines 3.4 defects per million opportunities (DPMO). The aim of Six Sigma technique is to combine all operations all through the processes to make them yield their desired results. This study focuses at bettering the quality of a product in plastics injection molding company using Six Sigma DMAIC methodology. A mid-size plastics injection molding company got a quality grievance in one of its product from its customer. The company was needed to enhance the quality of the product for its customer satisfaction. The concept of Six Sigma quality was evolved by Motorola Corporation USA. The method was developed by William Smith to deal with the high Failure rate experienced by the system produced. Smith recommended Six Sigma as a tool to enhance is the reliability and quality of products and thus focused it at reducing defects by improving manufacturing process[1-3].

## PROCESS DETAILS

Injection molding process is one of the most cost-effective methods and is used for manufacturing a variety of parts, from the elementary component to the complex shapes that require precise dimensions. A schematic of an injection molding machine is shown in Figure No.1. In the injection molding process, plastic resins are fed through the hopper into the barrel. Plastic is melted under high temperature inside the barrel using heater bands and by mechanical shear between barrel and rotating screw. The rotating screw moves back as plastic moves forward to form a shot. As soon as there is enough supply of melt for one shot, the screw stops rotating and moves forward to pump the melt into a colder mold cavity under pressure through the gate.

In the cavity, the plastic melt cools and solidifies to take the shape of the mold cavity. The melted material is squeezed through an orifice in the die that determines the shape of the end product. The mold opens up and ejector pins move forward to eject the part from the mold. Figure No.2 shows the process mapping for circular plastic Part Manufacturing.

## SIXSIGMA DMAIC

Six Sigma uses DMAIC methodology for its application to reduce process variations.

### Define

The first step in Six Sigma Methodology is to identifying the process to be improved and customer Critical to Quality (CTQ) attributes through Voice of Customer (VOC)[4]. The purpose of this chapter is to study and analyse the flash defect using six sigma approaches. Problem identified by collecting the last two months wastage/rejection monitoring and identified in average around 6% of wastes out of total production. Customer rejection or complaints are shown in Table No.1.

Pareto charts plotted based upon the above data are shown in Figure No.3 and Figure No.4 above. Both Pareto charts of March and April of 2011 revealed that flash or the distortion of the part was the number one defect. The data of both months showed that the flash only was responsible for above 70% of the rejection. The defects due to contamination, scratches and splay were considered to be minor. Therefore it becomes obvious that focus should first be given to the flash defect.

## MEASURE PHASE[5-8]

### Gage R and R Study (Crossed)

The average flash of the part was determined as a response variable. Average flash is the best factor to measure the flash in the part or in other words the part will be considered to be flashed if it is not perfectly circular. As per customer's specification, the part with average flash between 0.8 to 1 mm was not considered as flashed or distorted part.

### Coordinate Measuring

Machine (CMM) was programmed and used as a gauge to measure the average flash of the part. Measurement System Analysis was conducted of the CMM to ensure its adequacy to measure the average flash of the part. For the study, ten random samples were selected from the manufacturing process. Three operators were chosen to participate in the study. Each part was measured two times by each operator. The output of the GR and R study is shown in Figure No.5.

### Using MINITAB 15

Multiple measurements for each part show little variation. Averages differ enough so that variations between parts are clear. The result of the study is shown in Figure No.6.

### Using MINITAB 15

The operator plot is to figure out whether measurements and variability are consistent across operators. The result of the study is shown in Figure No.7. The operator plot indicate that mean Not parallel to the x-axis the operators are measuring the parts differently on average.

**Interaction using MINITAB 15**

The result of the study is shown in Figure No.8. One operator is measuring parts consistently higher or lower than the other operators.

**Using MINITAB 15**

In a good measurement system, the largest component of variation is part-to-part variation. The result of the study is shown in Figure No.9. For the circular part data, the difference between the parts accounts for most of the variation.

The R chart and X bar chart is a control chart of ranges which graphically shows the operator consistency. The result of the study is shown in Figure No.10. These outcomes specify that Part-to-part variation is much higher compared to measurement device variation.

Table No.2 Result of gauge R and R study indicates that the CMM program was an acceptable measurement method to accurately measure the average flash of the part approximately 10% of the total measured variance is from repeatability and reproducibility of the gage.

## PROCESS CAPABILITY

Process capability is used to find out whether the average flash of the circular plastic parts coming out of current process was within the customers specification or not. Sixty pieces were pulled from the current process in a definite interval for this study. The result of the study is shown in Figure No.11.

**Flash using MINITAB 15**

The $C_{pk}$ value of 0.02 revealed that the current process is not centered towards the mean and was not capable of producing the part well within the customer specification.

## ANALYSEROOT CAUSE ANALYSIS

The investigation of manufacturing process problem required the understanding of different process criterias that affects quality of the part. To better understand the injection molding process, a team was formed to investigate and solve the flash defect in the part. The outcome was summarized in a cause-and-effect -level I diagram in Figure No.12.

**For flash defects using MINITAP 15.**

The outcome was summarized in a level II cause-and-effect diagram in Figure No.13.

**For Flash defects using MINITAP 15**

For the man category, the problem could be due to operator's lack of experience and practice. From the material side, imbalanced material flow could cause the flash.

## IMPROVE

Some of the common tools used in this phase include Regression analysis and Design of Experiments, (DOE).The molded part with flash shown in Figure No.14.

## INJECTION MOLDING PROCESS

Based on the discussion and input from the project team, it was decided that a $2^4$ factorial design would be appropriate for the experiment. The four factors, pack pressure, pack time, injection speed, and screw RPM, are weighed to influence the formation of flash. Their appropriate settings were identified. Figure No.15, Shows that molded circular plastic Part without Flash.

## APPLICATION OF DESIGNOF EXPERIMENTS

Design of experiment is an important tool in the Injection molding industry for improving the performance of a manufacturing process.

## DATACOLLECTION

Sixteen randomized experimental runs were generated. The experiment was carried on by running each and every setting for ten cycles to stabilize the machine and then four circular parts were made consecutively. The high and low levels for each factor are shown in Table No.3. Each and every molded part is assessed for flash at the five different locations as indicated in Figure No. 16. The measurements are in millimetre and the average of the recorded values for each and every part is weighed as the flash. From the experiment, there is one run with the entire factors at lower levels that produce defective circular part Figure No.16.

Figure No.17 represents the run order of the experiment, with high and low settings of each factor for each run, and the average flash measurements on circular parts. Figure No.17 shows that design of experimental run and average flash.

## DATA ANALYSIS AND RECOMMENDATION

By examining the plot, we can come to a conclusion that the important effects from the analysis are the main effects of A (pressure of the pack), C (speed of injection), and D (RPM of the screw) and the interactions between A C and CD. Figure No.18 shows the normality plot of the effects. The main effects A, C, and are plotted in Figure No.19, and the interaction effects AC and CD are plotted in Figure No.20. The AC interaction shows that low pack pressure (A) and low injection speed (C) would produce low average flash. From CD interaction, we notice that screw RPM (D) has little effect on flash generation at low level of injection speed (C). Table No.4 shows the estimated regression coefficients based on the significant effects and interactions.

For the reduced model using only the significant effects A, C, D, AC, and CD, the projected regression equation with $R^2$= 96.4% is given by,

Y = - 3.39 + 0.0211 Pack pressure A + 3.26 Injection speed C - 0.0141 Screw RPM D - 0.0104AC+0.0227CD -------------- (1)

Table No.4 illustrates the ANOVA output following the removal of the non-significant terms. A lack of fit test indicates that the estimated reverting model is sufficient. The independence and constant variance assumptions of residuals were checked, and outcomes were pleasing. The normality plot of the residuals in Figure No.21 verifies the normality assumption and assists our outcome and analysis.

Based on our analysis, the production run should set the pack pressure at low level (151 psi), pack time at high level (5.02 sec), injection speed at low level (0.5 in. /sec), and screw RPM at either low (101 rpm) or high level (201 rpm).

## CONFIRMATION RUNS WITH THE RECOMMENDED SETTINGS

We conducted the confirmation runs for the recommended settings. Ten circular parts were produced consecutively for each setting, and the flash was measured. The results were tabulated as shown in Table No.6.

Figure No.22 and Figure No.23, show the circular plastic parts produced by settings 1 and 2, respectively. The confirmation run showed that excessive flash could be reduced to zero under properly controlled conditions. It is our belief that the combination of statistical tool and injection process knowledge can provide engineers a solid problem-solving foundation.

## CONTROL

The final phase of the DMAIC methodology focuses on how to maintain the implemented improvements. These development might enclose building the new standards and procedures, training the workforce, and instituting controls to make sure that developments do not die over time.

- Master cycle sheet will be maintained so that parameter settings will be in place.
- In-process inspection will be performed to measure the average flash of the part to make sure part is not flashed.
- Control chart will be plotted of the average flash data to monitor the improved process.

**Table No.1: Customer rejected due to Defects**

| S.No | Description | March | April |
|---|---|---|---|
| 1 | Total quantity shippes | 190000 | 210000 |
| 2 | Rejected due to flash | 25000 | 23000 |
| 3 | Contamination (Rejected) | 3400 | 3800 |
| 4 | Rejected due to scaratches | 3200 | 2800 |
| 5 | Rejected due to splay | 2400 | 2100 |
| 6 | Rejected due to glate blush | 1900 | 1200 |

**Table No.2: Result of Gauge R and R study**

| S.No | Scource | Varcomp | % Contribution (Varcomp) |
|---|---|---|---|
| 1 | Total Gauge R and R | 0.00528 | 12.80 |
| 2 | Repeatability | 0.00218 | 5.30 |
| 3 | Reproducibility | 0.00309 | 7.50 |
| 4 | Operators | 0.00051 | 1.26 |
| 5 | Circular parts | 0.00257 | 6.24 |
| 6 | Part- to- Part | 0.03598 | 87.2 |
| 7 | Total Variations | 0.04126 | 100 |

**Table No.3: Input Variable**

| S.No | Factors | Low Level | High level |
|---|---|---|---|
| 1 | Pack pressure (A) | 151 | 451 |
| 2 | Pack time (B) | 1.01 See | 5.02See |
| 3 | Injection speed (C) | 0.5in/See | 2in/See |
| 4 | Screw RPM (D) | 101rpm | 201rpm |

**Table No.4: Regression coefficients for average flash**

| S.No | Term | Coefficient | SE Coefficient |
|---|---|---|---|
| 1 | Constant | -3.393000 | 1.396000 |
| 2 | Pack pressure(A) | 0.021106 | 0.002475 |
| 3 | Injection speed (C) | 3.259500 | 0.957900 |
| 4 | Screw RPM (D) | -0.014056 | 0.007425 |
| 5 | AC | -0.010418 | 0.001698 |
| 6 | CD | 0.022747 | 0.005093 |

S = 0.764019   R-Sq = 96.8%   R-Sq(adj) = 95.3

**Table No.5: Analysis of variance (ANOVA Table)**

| S.No | Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|---|
| 1 | Regression | 5 | 179.381 | 35.876 | 61.46 | 0.000 |
| 2 | Residual Error | 10 | 5.837 | 0.584 | - | - |
| 3 | Lack of Fit | 2 | 1.635 | 0.818 | 1.56 | 0.268 |
| 4 | Pure Error | 8 | 4.202 | 0.525 | - | - |
| 5 | Total | 15 | 185.218 | - | - | - |

**Table No.6: Flash produced for confirmation run**

| S.No | Pack pressure | Pack time | Injection speed | Screw RPM | Flash (mm) |
|---|---|---|---|---|---|
| 1 | Low | High | Low | Low | 0.21 |
| 2 | Low | High | Low | High | 0.01 |

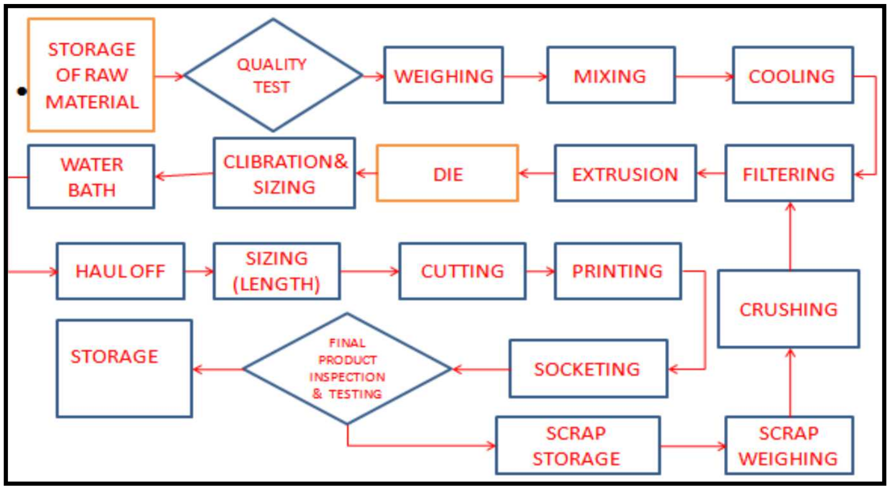


**Figure No.2: Process mapping for circular plastic**

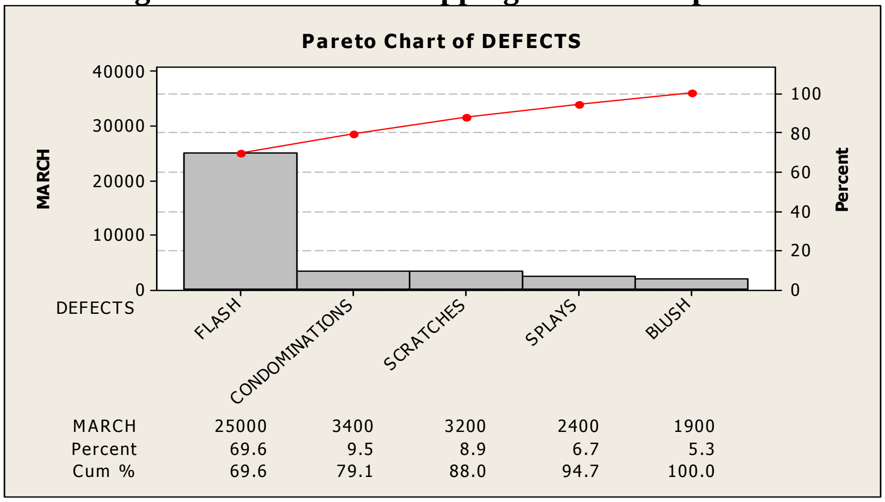


**Figure No.3: Customer rejected during month of March**

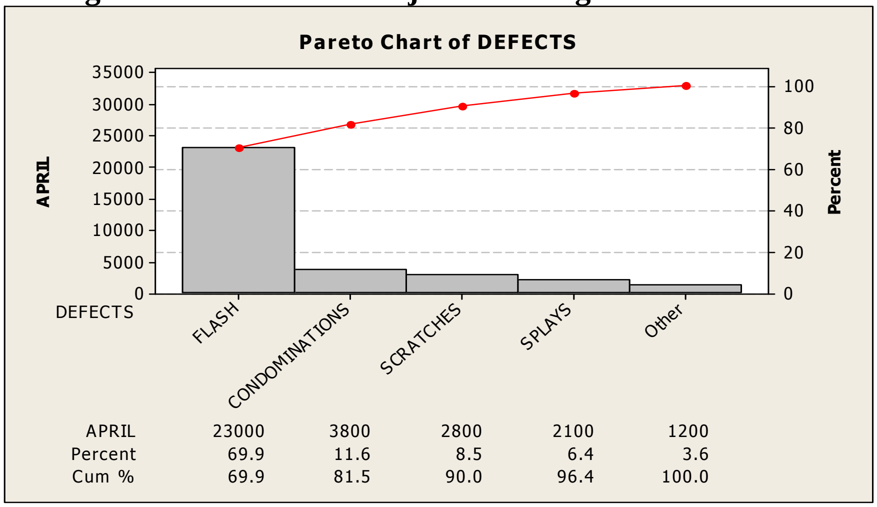


**Figure No.4: Customer rejected during month of April**

| | StdOrder | RunOrder | Circular part | Operators | Average flash |
|---|---|---|---|---|---|
| 1 | 19 | 1 | 7 | 1 | 0.85 |
| 2 | 25 | 2 | 9 | 1 | 1.00 |
| 3 | 7 | 3 | 3 | 1 | 0.86 |
| 4 | 22 | 4 | 8 | 1 | 0.85 |
| 5 | 16 | 5 | 6 | 1 | 1.00 |
| 6 | 10 | 6 | 4 | 1 | 0.86 |
| 7 | 1 | 7 | 1 | 1 | 0.60 |
| 8 | 28 | 8 | 10 | 1 | 0.80 |
| 9 | 13 | 9 | 5 | 1 | 0.66 |
| 10 | 4 | 10 | 2 | 1 | 1.00 |
| 11 | 17 | 11 | 6 | 2 | 1.00 |
| 12 | 26 | 12 | 9 | 2 | 1.00 |
| 13 | 20 | 13 | 7 | 2 | 0.95 |
| 14 | 8 | 14 | 3 | 2 | 0.80 |
| 15 | 29 | 15 | 10 | 2 | 0.55 |
| 16 | 11 | 16 | 4 | 2 | 0.80 |
| 17 | 2 | 17 | 1 | 2 | 0.60 |
| 18 | 23 | 18 | 8 | 2 | 0.75 |
| 19 | 14 | 19 | 5 | 2 | 0.40 |
| 20 | 5 | 20 | 2 | 2 | 1.06 |
| 21 | 27 | 21 | 9 | 3 | 1.05 |
| 22 | 24 | 22 | 8 | 3 | 0.70 |
| 23 | 18 | 23 | 6 | 3 | 1.00 |
| 24 | 9 | 24 | 3 | 3 | 0.80 |
| 25 | 30 | 25 | 10 | 3 | 0.85 |
| 26 | 15 | 26 | 5 | 3 | 0.45 |
| 27 | 6 | 27 | 2 | 3 | 1.05 |
| 28 | 12 | 28 | 4 | 3 | 0.80 |
| 29 | 3 | 29 | 1 | 3 | 0.50 |
| 30 | 21 | 30 | 7 | 3 | 0.95 |
| 31 | 49 | 31 | 7 | 1 | 0.95 |
| 32 | 34 | 32 | 2 | 1 | 1.00 |
| 33 | 55 | 33 | 9 | 1 | 1.00 |
| 34 | 40 | 34 | 4 | 1 | 0.95 |
| 35 | 46 | 35 | 6 | 1 | 1.00 |
| 36 | 31 | 36 | 1 | 1 | 0.50 |
| 37 | 58 | 37 | 10 | 1 | 0.70 |
| 38 | 52 | 38 | 8 | 1 | 0.80 |
| 39 | 37 | 39 | 3 | 1 | 0.80 |
| 40 | 43 | 40 | 5 | 1 | 0.46 |
| 41 | 47 | 41 | 6 | 2 | 1.05 |
| 42 | 50 | 42 | 7 | 2 | 0.90 |
| 43 | 35 | 43 | 2 | 2 | 0.95 |
| 44 | 32 | 44 | 1 | 2 | 0.55 |
| 45 | 41 | 45 | 4 | 2 | 0.75 |
| 46 | 44 | 46 | 5 | 2 | 0.40 |
| 47 | 53 | 47 | 8 | 2 | 0.70 |
| 48 | 56 | 48 | 9 | 2 | 1.05 |
| 49 | 38 | 49 | 3 | 2 | 0.75 |
| 50 | 59 | 50 | 10 | 2 | 0.50 |
| 51 | 51 | 51 | 7 | 3 | 0.95 |
| 52 | 57 | 52 | 9 | 3 | 1.05 |
| 53 | 42 | 53 | 4 | 3 | 0.80 |
| 54 | 54 | 54 | 8 | 3 | 0.75 |
| 55 | 33 | 55 | 1 | 3 | 0.55 |
| 56 | 36 | 56 | 2 | 3 | 1.00 |
| 57 | 48 | 57 | 6 | 3 | 1.05 |
| 58 | 39 | 58 | 3 | 3 | 0.80 |
| 59 | 45 | 59 | 5 | 3 | 0.50 |
| 60 | 60 | 60 | 10 | 3 | 0.80 |

**Figure No.5: Output run of the GR&R study**

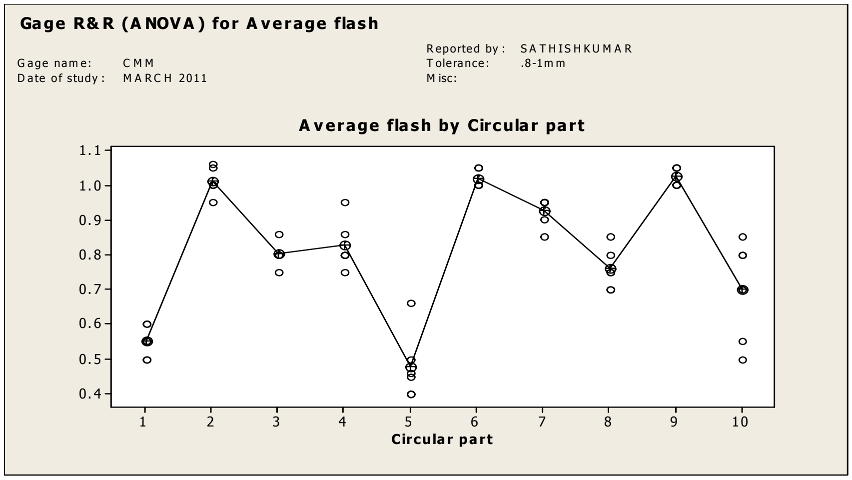


**Figure No.6*:* Result of average flash by circular part**

a. *Measurements by parts*

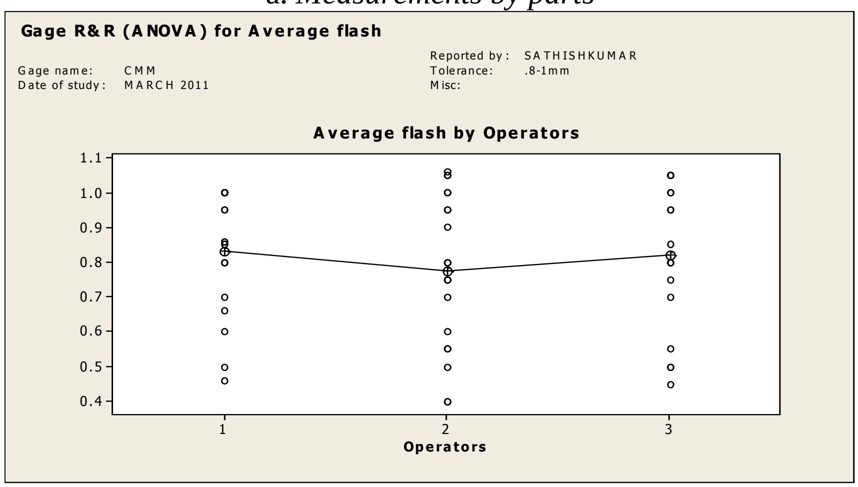


**Figure No.7*:* Result of average flash by operators**

b. *Measurements by operators*

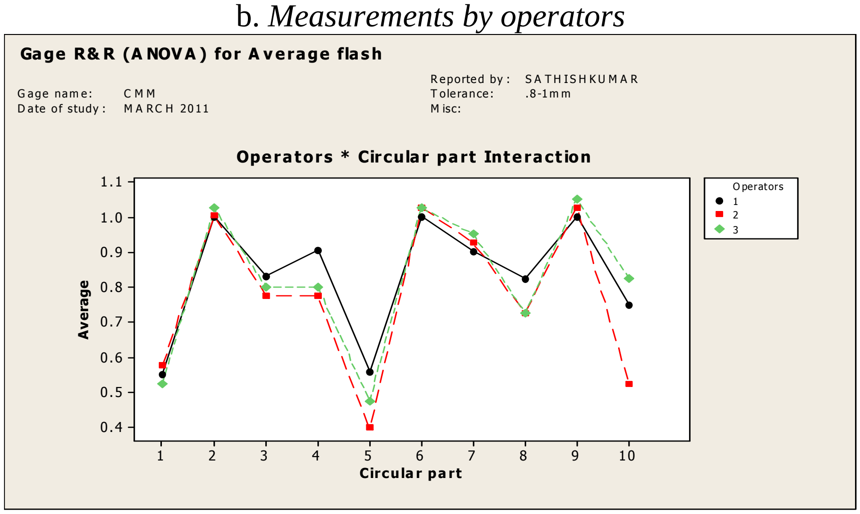


**Figure No.8*:* Result of operators by circular part**

c. *Operator with part interaction*

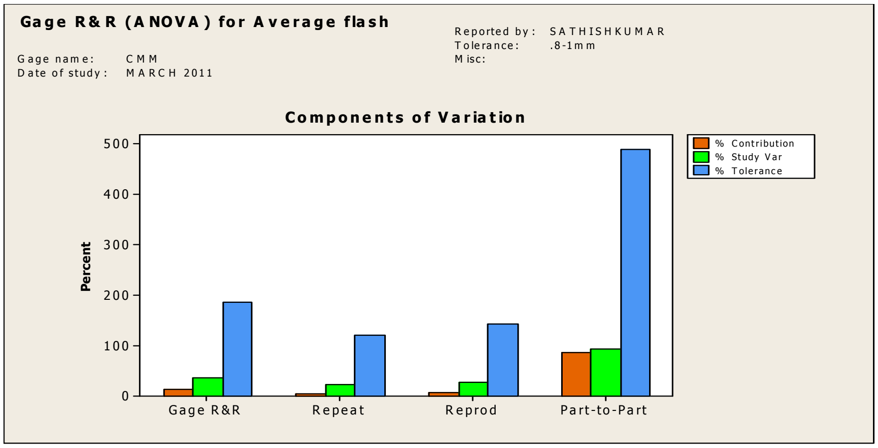


**Figure No.9: Result of components of variations**

d. *Components of variations*

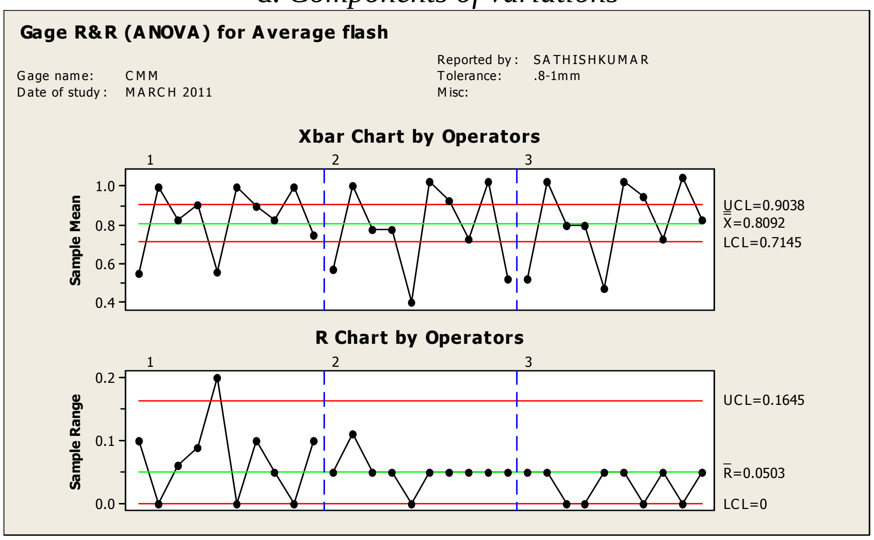


**Figure No.10: Result of X bar and R chart by operators using MINITAB 15.**

e. *R chart and X bar chart*

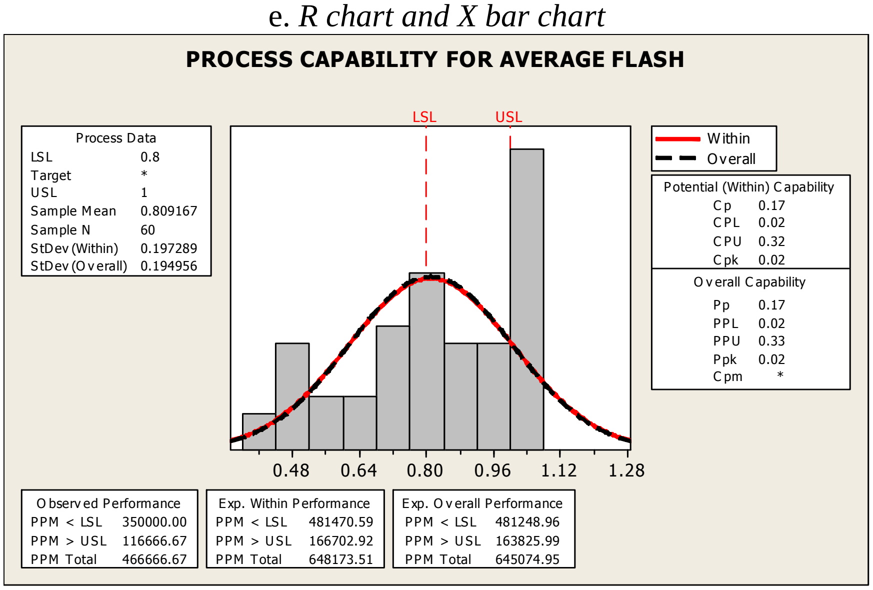


**Figure No.11: Process Capability Study of Average**

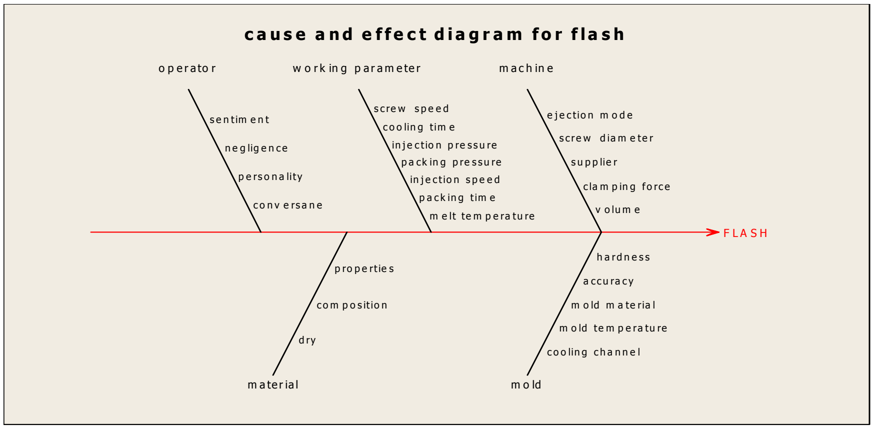


**Figure No.12: Level-I Cause-and-Effect Diagram**

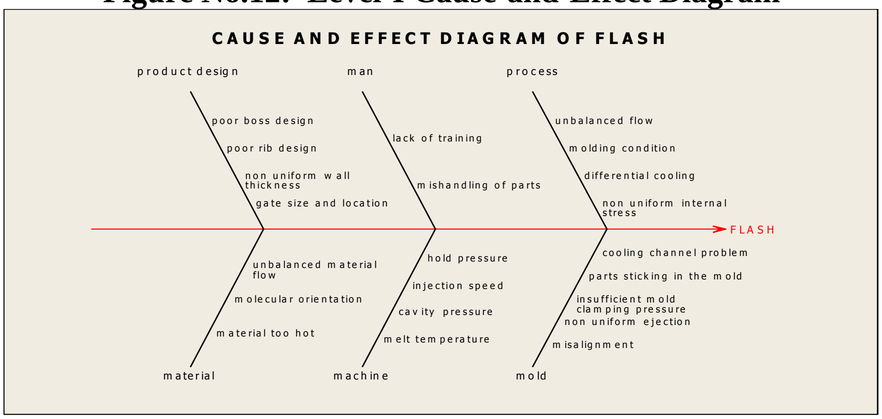


**Figure No.13: Level-II Cause-and-Effect Diagram**

**Figure No.14: The Molded circular Part with Heavy flash**

**Figure No.15: Circular plastic part without flash**

**Figure No.16: Flash measurement**

| ↓ | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| | StdOrder | RunOrder | CenterPt | Blocks | packpressure A | packtime B | injectionspeed C | screwRPM D | Average flash |
| 1 | 11 | 1 | 1 | 1 | -1 | 1 | -1 | 1 | 0.000 |
| 2 | 13 | 2 | 1 | 1 | -1 | -1 | 1 | 1 | 5.626 |
| 3 | 4 | 3 | 1 | 1 | 1 | 1 | -1 | -1 | 0.000 |
| 4 | 9 | 4 | 1 | 1 | -1 | -1 | -1 | 1 | 5.376 |
| 5 | 2 | 5 | 1 | 1 | 1 | -1 | -1 | -1 | 6.001 |
| 6 | 3 | 6 | 1 | 1 | -1 | 1 | -1 | -1 | 5.501 |
| 7 | 1 | 7 | 1 | 1 | -1 | -1 | -1 | -1 | 6.151 |
| 8 | 5 | 8 | 1 | 1 | -1 | -1 | 1 | -1 | 7.876 |
| 9 | 15 | 9 | 1 | 1 | -1 | 1 | 1 | 1 | 0.426 |
| 10 | 7 | 10 | 1 | 1 | -1 | 1 | 1 | -1 | 4.626 |
| 11 | 8 | 11 | 1 | 1 | 1 | 1 | 1 | -1 | 0.501 |
| 12 | 6 | 12 | 1 | 1 | 1 | -1 | 1 | -1 | 4.376 |
| 13 | 12 | 13 | 1 | 1 | 1 | 1 | -1 | 1 | 10.501 |
| 14 | 16 | 14 | 1 | 1 | 1 | 1 | 1 | 1 | 9.001 |
| 15 | 14 | 15 | 1 | 1 | 1 | -1 | 1 | 1 | 9.001 |
| 16 | 10 | 16 | 1 | 1 | 1 | -1 | -1 | 1 | 9.601 |

**Fig.17. Design of experimental run and Average flash**

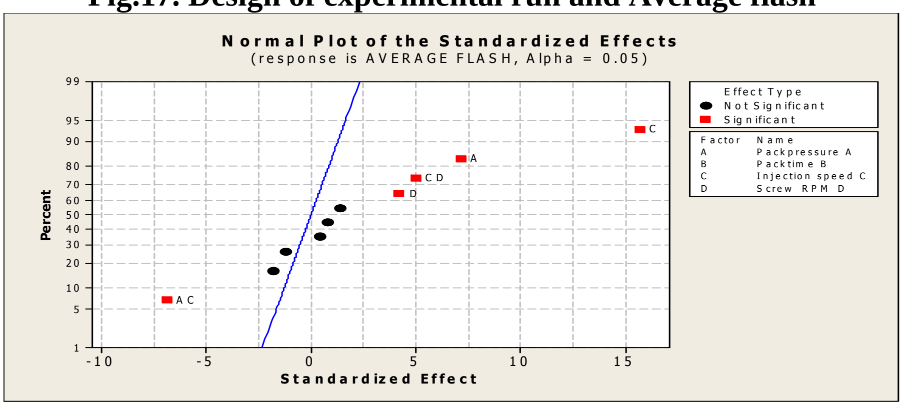


**Figure No.18: Normal probability plot of the effects**

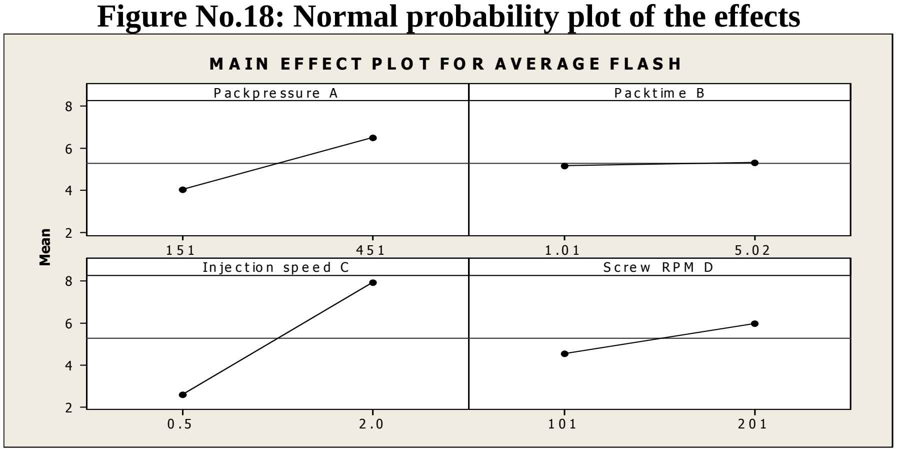


**Figure No.19: Main effects plot for average flash**

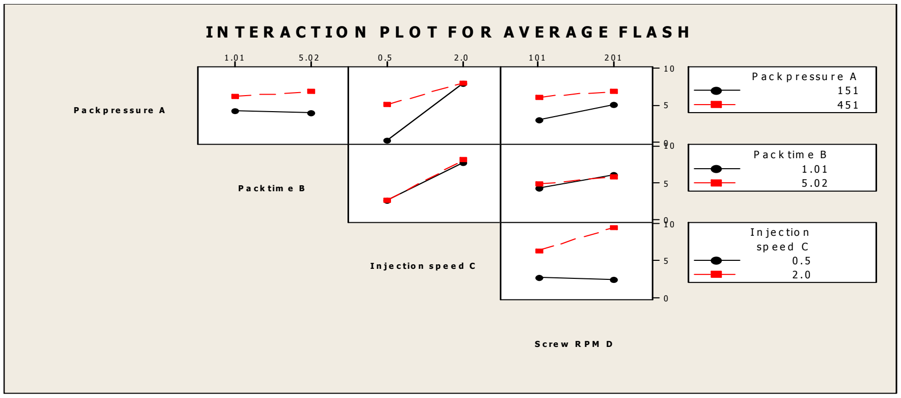


**Figure No.20: Interaction plot**

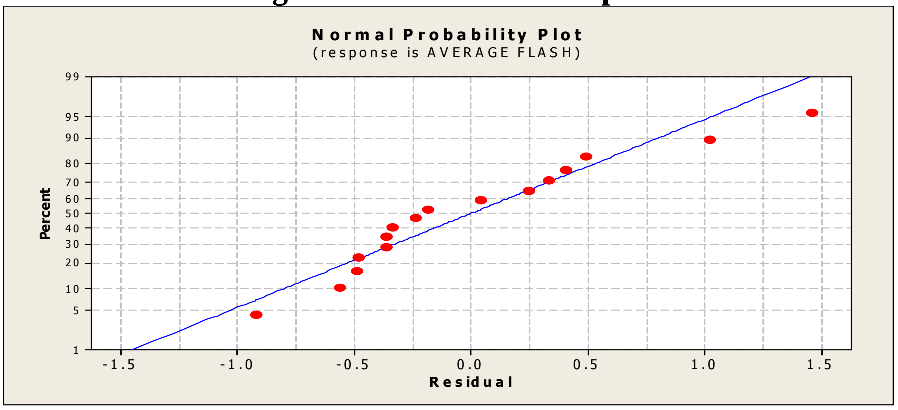


**Figure No.21: Normal probability plot for residuals**

**Figure No.22: Setting 1**

**Figure No.23: Setting 2**

## CONCLUSIONS

Due to increased customer expectations and global competition the Indian industries are desperately trying to improve productivity at lower cost and still maintain finest product quality. Under these circumstances, improvement of quality by reducing the failure cost will improve the process environment and energy saving along with the growth of firm. A perfectly executed project using DMAIC methodology can provide further improvement throughout the organization. In this study, the DMAIC methodology implemented step by step, and different factors were tested for their effects on the amount of rejections/wastage. Based on this analysis, recommendations have to be provided to reduce the overall amount Rejections.

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## CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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