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HIGH PRESSURE DIE-CASTING PROCESS REJECTION REDUCTION USING LEAN SIX-SIGMA APPROACH: A CASE STUDY

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Abstract

In this era of fierce competition and robustness in manufacturing quality level, accuracy and precision are the two dire necessities for manufacturing industries. To define the process variability in terms of sigma levels, setting a target and implementing a structured approach to achieve the target is becoming a challenge. However, the common direction continues to be on reducing the number of defects and then the variability in the process to six-sigma level. The paper addresses a case of the implementation of six-sigma using the DMAIC (Define, Measure, Analyse, Improve and Control) approach to attain a level of accuracy and precision. Implementation of the DMAIC approach has resulted in a significant reduction of defects in a Tier-1 High-pressure die-casting manufacturing industry. The paper attempts to highlight the application of the simple but structured problem-solving methodology to deliver significant gains in a process quality improvement journey.

Keywords: Six-sigma, DMAIC approach, PPM (Parts per million) levels, 7QC Tools, Process capability indices - Cp & CpK, Statistical Process Control (SPC) and Measurement System Analysis (MSA)

1. INTRODUCTION

The need for a structured quality problem-solving methodology in a complex manufacturing process industry continues to attract attention. Die-casting is a complex manufacturing process. The Tier-I supplier engaged in the Die-casting manufacturing process has been supplying products to a giant Automotive manufacturer. The yield from the process has been significantly low. The quality level measured in terms of sigma levels has been low at 1.5. In order to optimise the manufacturing process yield the authors used the Define, Measure, Analyse, Improve and Control (DMAIC) approach. The initial major pain points: the parts and the type of defects in the Die-casting process were identified for the study. Higher the sigma levels are, lower is the process variability and thereby lower the rejection rates. In the six-sigma drive quality tools like 7QC and advance tools, statistical tools, SPIOC(Supplier, Process, Input, Output, Customer), SPC(Statistical Process Control), analytics and use of software like Minitab, E-draw are used effectively. It is a data driven methodology for eliminating defects, wastes and quality problems in any process. Each Six-sigma project carried out within an organization follows a defined sequence of steps and has specific value targets. The six-sigma projects areas for improvement in operations decrease process cycle-times, reduce pollution levels, bring down costs, improve customer satisfaction, and enhance profits.

2. LITERATURE REVIEW

Six-Sigma is one of the key tools used presently in varied industries in order to reduce the process variability to improve performance. It is a quantitatively driven hard tool to be applied in a structured manner. The advantages attributed with six-sigma outweighs the difficulties encountered to apply it. One of the most common difficulties attributed with six-sigma is changing the thinking of the organization. It requires restructuring the organization to provide infrastructure, training and guidance from experienced people in this field. In Wipro, during the application of six-sigma, special emphasis was made on identification of resources to be focused on. They categorized the projects according to the seriousness and focused on timely reviews of those projects. They made a special team for categorizing the projects and scheduling the timely reviews [1]. This reconfirmed that a sustainable structured approach could only lead to positive results from the six-sigma methodology. In recent times varied industries and sectors have used six-sigma to unleash their hidden potentials. Six-sigma have also been used in marketing and sales to find the road map for capturing larger market share and improve brand image. Recent times have also seen finance and accounting sector utilizing this tool to reduce error in invoice processing, improve cash flow and reduce cycle time [2]. The ability of six-sigma to be effective in any industry is because of the fact that it solely focuses on reducing variability which has always been the universal cause of error [3].Though six-sigma has been placed highly in the eyes of most of the industry experts and scholars still critique the six-sigma approach stating that six-sigma standard may not satisfy certain industries such as air-passengers and medical. In some industries it won't make any sense to apply six-sigma such as a bottling plant at a local liquor shop. Such ambiguity may result in loss of resources. Therefore, six-sigma may not always result in a positive output. One more critique that has been common to six-sigma is that it is merely a mathematical tool or technique and lacks the structure which is required for being an improvement method for example TPM(Total Productive Maintenance) [4].There has been modernization in Six- sigma approach in recent years. DMADV (Define, Measure, Analyse, Design and Verify) is another approach which is useful for emerging organizations which lacks foundation. Flexible approach towards six-sigma is the next frontier worth considering [5].Though Six- sigma is common in large companies it is still not used extensively in micro, small and medium industries. Many Tier-I suppliers in India lack the application capability of six-sigma in their industries. Most of these lack the infrastructure as well as skilled personal which is a pre requisite for the application of six-sigma. This results in disadvantage for these industries with respect to large industries which are in better position to handle and apply Six Sigma project effectively [6]. Certain scholars also believe the organizational structure and corporate strategy should also support the Six-Sigma process in order for it to be successful and show results(Fig.1) [7]. Cost savings can be realized through six sigma implementation also based on that aspect there is also a possibility of extending the application of model by using DOE (Design of experiments)0 and DFSS (Design for six sigma) tools [8]. Six Sigma techniques also provide project management methods for cross-functional process improvements resulting in a much more valuable tool than any other statistical method alone [9]. Progress should be chartered for all involved parties to see the targets and the progress along the journey. External feedback allows the company to see why defects are decreasing in real terms, not just in statistical data. Senior management needs to be involved in Six-Sigma upon implementation and remain informed as the process develops [10].

In summary DMAIC is a powerful tool which should be used for the significant defect / rejection reduction in manufacturing sector. The Impact of using DMAIC approach is huge and helps in reducing process variability. The approach demands a structured implementation for a sustainable result.

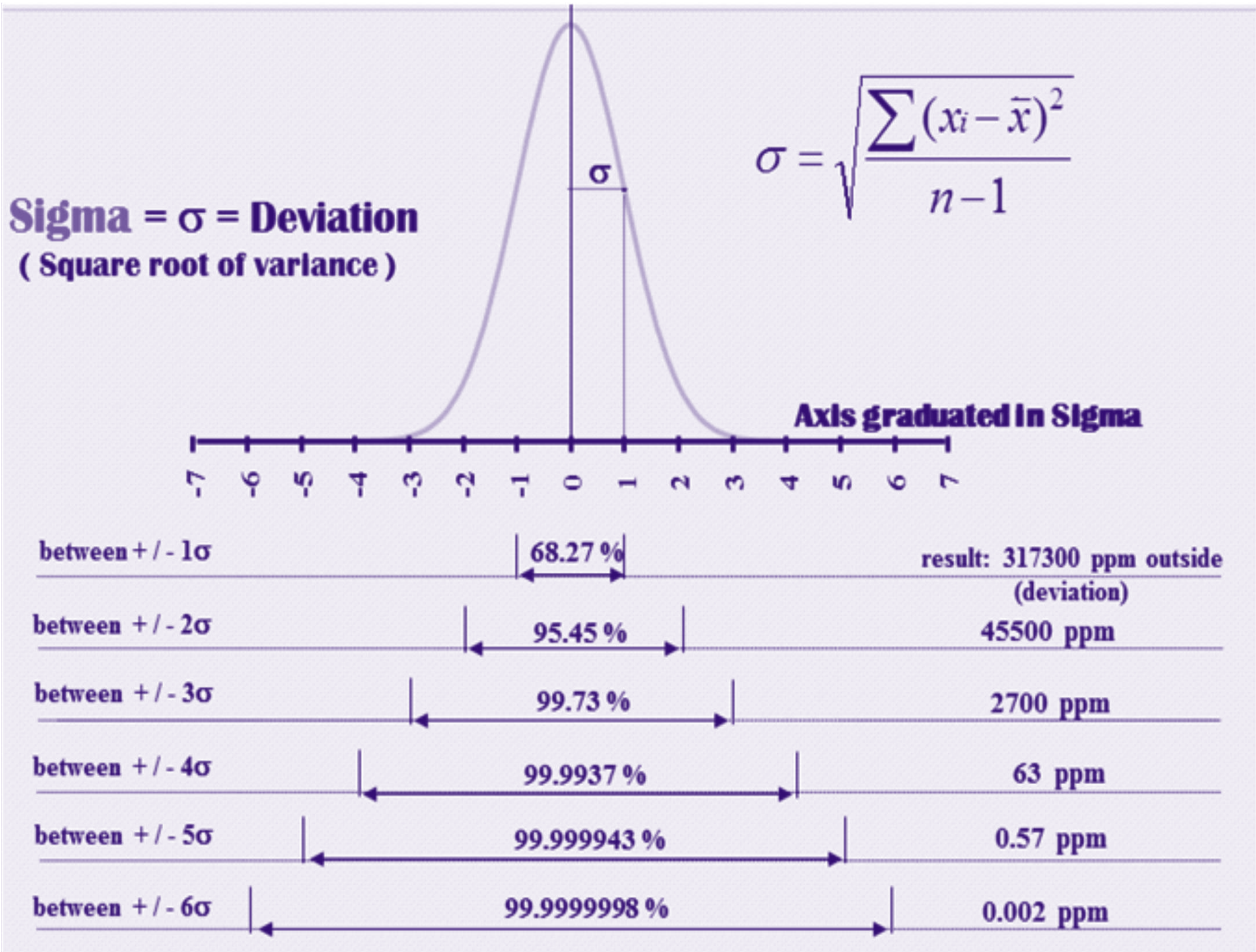


Fig.1. Sigma Levels and the corresponding ppmvalues

3. OBJECTIVES

The two objectives of the quality improvement project undertaken at the Die-casting Tier-I supplier have been;

· Understanding the High Pressure Die-casting manufacturing process and applying the DMAIC approach for a significant improvement in the process quality.

· A significant defect level reduction: from the current level of 158401ppm to 40000 ppm level. More specifically an improvement from 1.5 sigma level to a target of 2.5 sigma.

4. METHODOLOGY & ITS APPLICATION

The simple but structured approach adopted in the quality improvement study of the case, the large data analysis, the technical countermeasure evolution and its implementation thereafter has been depicted in the eight-step flowchart shown in Fig.2.

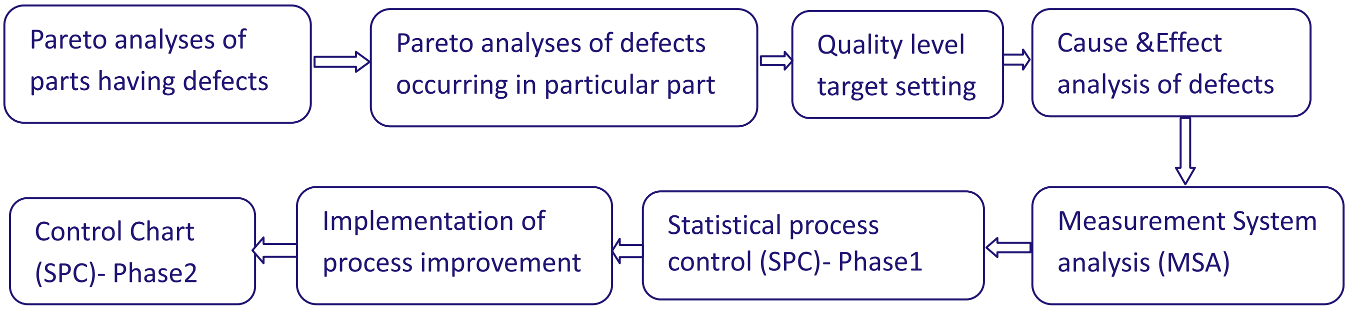


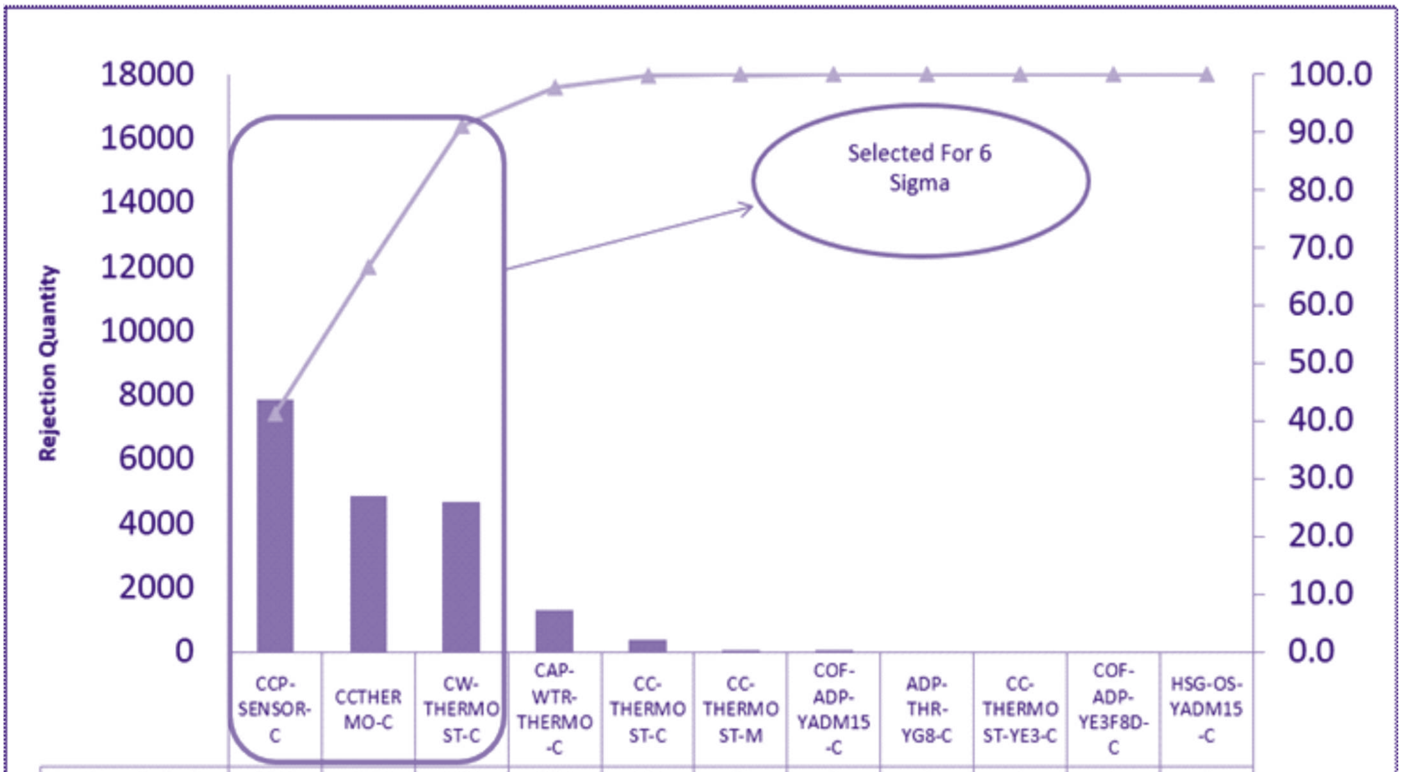
Fig.2. Flowchart of the methodology

The key methodology applied in the paper has been DMAIC of Six-sigma approach which included the comprehensive use of the 7 QC tools.

4.1 Definition Phase: Pareto Analysis of parts having defects

The initial dip-stick observation from the six months data indicated that there are 0.13 million defects from 1 million opportunities. The defect ppm level from the Fig.1 indicates a 1.5 sigma level. This, therefore, was an apt case-study for a structured study for quality improvement the target set was approximately 2.5 ppm level.

Rejection levels of eleven parts of a particular cast-product for the six-month period were studied. The Pareto chart was developed thereafter, as shown in Fig 3.The top three (vital few) contributing parts to the high rejection level were: CCP Sensor-C, CC Thermo-C and CW Thermo ST-C. The three parts contributing cumulatively to 91% rejection level have been marked in the rectangular box in Fig.3.



	CCP-SENSOR-C	CCTHERMO-C	CW-THERMO ST-C	CAP-WTR-THERMO-C	CC-THERMO ST-C	CC-THERMO ST-M	COF-ADP-YADM15-C	ADP-THR-YG8-C	CC-THERMO ST-YE3-C	COF-ADP-YE3F8D-C	HSG-OS-YADM15-C
No. of rejection	7848	4847	4659	1291	387	37	6	0	0	0	0
Cummulative %	41.1	66.6	91.0	97.7	99.8	100.0	100.0	100.0	100.0	100.0	100.0

Fig3: Pareto chart of the eleven parts of the casting

4.2 Definition Phase: Pareto Analysis of the defects in the part

After discussing with the management team and within the constraint of project time lines it was decided to focus on the rejection control of CCP-Sensor-C. The defect-wise data for CCP-Sensor-C for a six-month period was studied. A Pareto chart, as shown in Fig 3, was developed for the defects. Fig 3 indicated that the top three contributing defects were: Non-filling, Blow hole and Leakages. Together the three contributed to 74% of the defects thereby fulfilling the 80:20 rule and needed focus for control.

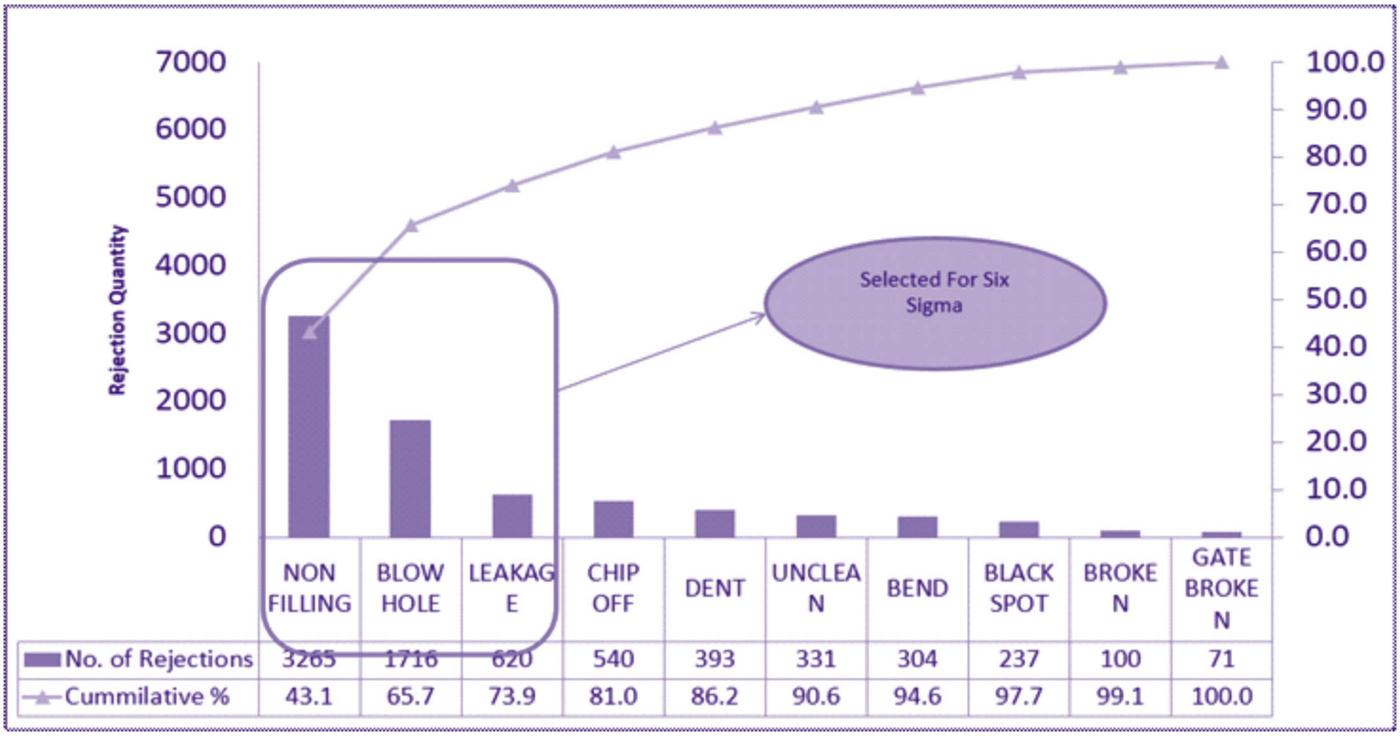


Fig4: Pareto chart of the different types of defects in CCP-Sensor-C

4.3 Measurement Phase: Quality level Target setting

As indicated in the earlier sub-section the management team set a target for the project group to reduce the current defect level by approximately 50%.On further analysis it was found that the minimum actual rejection level of each defect type, over the six-month period, cumulatively also amounted to the same level of 50%. This ensured that the achievability of the results in the given time was possible. The summary, in terms of rejection numbers and in monetary terms (INR), after the target setting process has been shown in Table 1.

Table.1 Projected rejection level and savings

Average monthly rejection	2350 parts
Target for monthly rejection	1073 parts
Selling Price per piece	INR 59.41
Monthly savings	INR 63747
Projected annual savings	INR 764964

4.4 Measurement Phase: Measurement System Analysis

In the Measurement phase, segregation of the entire process into value-added and non-value-added activities and developing a macro map using the SIPOC (Suppliers, Inputs, Process, Output, Customer) approach was carried out, as shown Fig 4.

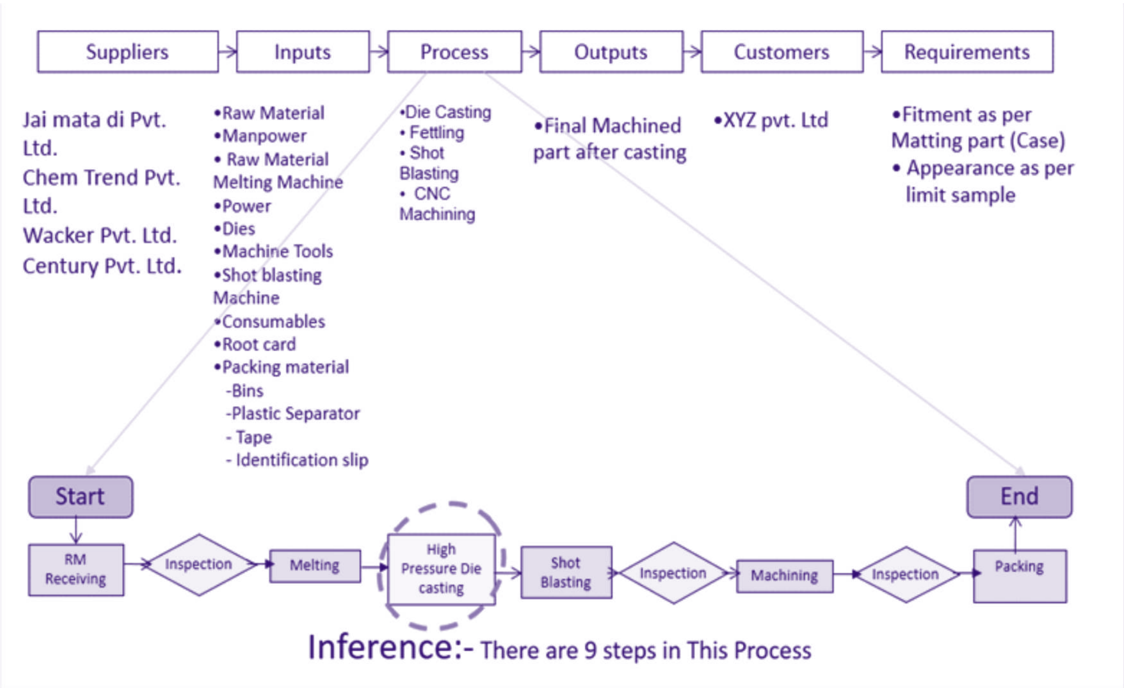


Fig. 4The SIPOC macro map of the process

4.5 Analysis Phase: Cause and Effect diagram in the defect analysis

After understanding the process of making that part and its dependent parameters the need was to develop the Cause and effect or the Fishbone diagram. All the possible causes for the three identified defects were depicted in Fig.5.

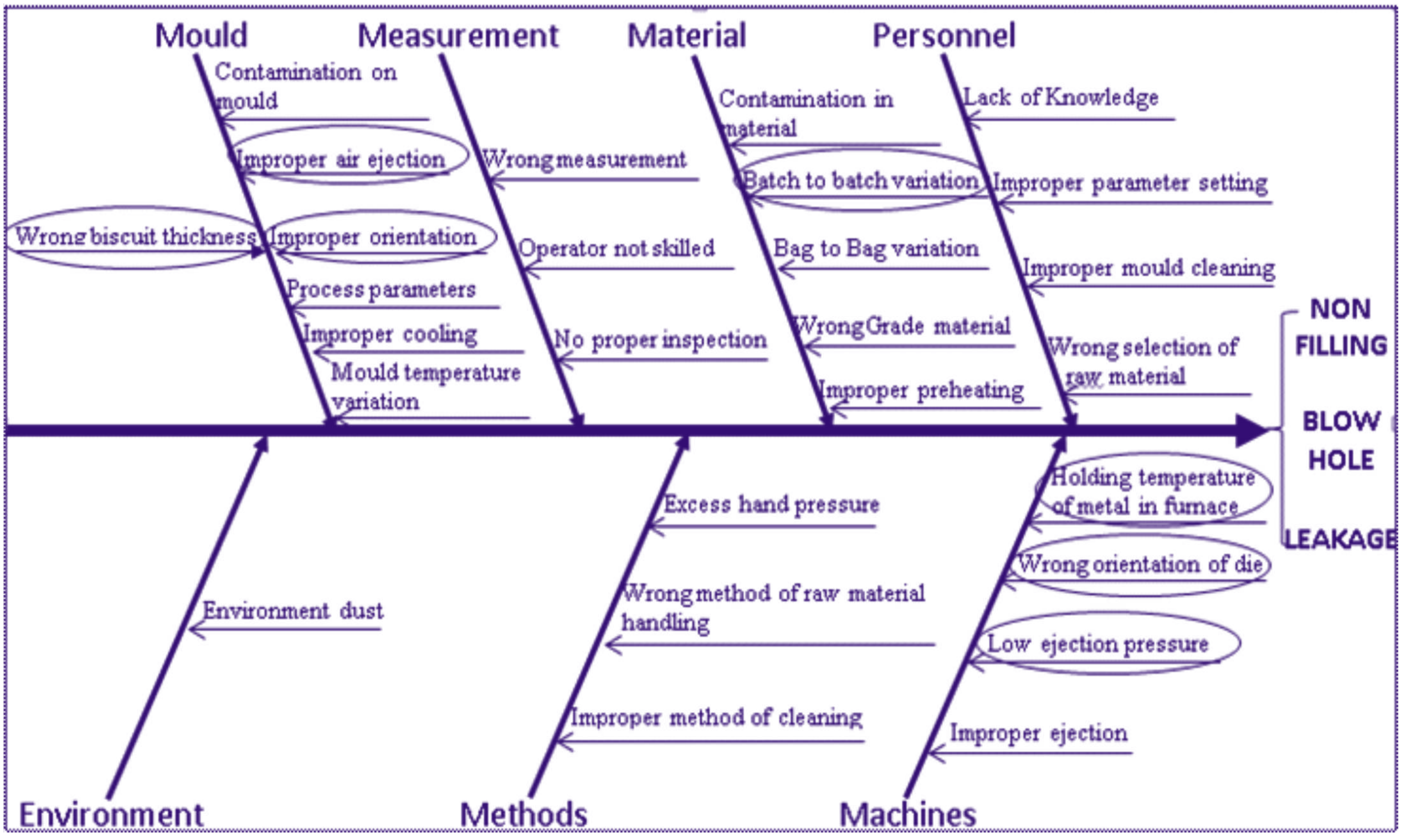


Fig.5. Combined Cause and effect diagram of Leakage, Blow-hole and Non-filling.

The combined Fishbone diagram with all the possible causes for the three defects was evolved which has been shown in Fig. 5. Thereafter, the root causes for the three defects were identified. This was based on a deep/intense technical discussion amongst the experts from four key functions, Production, Maintenance, Quality and Process-engineering. This was followed by carrying out a set of defined experiments with controlled conditions to assess the impact levels of the different variables mentioned in the Fishbone diagram. Finally, the funnelled five common root causes were identified leading to the occurrence of the three defects which are encircled in the Fig.5. These five root causes were:

- *Batch-to-batch variation,*
- *Inappropriate air ejection,*
- *Varying biscuit thickness,*
- *Improper orientation of the die, and*
- *Holding temperature in melting- furnace*.

The next step was to identify the countermeasure for these identified root causes. The first one taken up was *Batch-to-Batch variation* and for that MSA (measurement system analysis) was the right choice to perform. This included gauge R&R (Reproducibility and Reproducibility) study which determined the accuracy and precision of operators working on that part.

In the MSA process the team took 50 sample parts and deliberately divided it into parts which were;

- completely acceptable parts,
- completely rejected parts that are approved by operator and rejected by supervisor, and
- parts that are rejected by operator and approved by supervisor.

The study was carried out on three operators. The data was collected and put into Minitab(software) and run for R&R study. The study showed how many times an operator agreed with the standard and was within the appraisers mean with its peers. The outputs from the software are depicted in Figs. 6 and 7.The inference drawn from Fig.6: Operator B data agreed with the least percentage among the three within-appraisers and with the standard measurement. The inference drawn from Fig. 7: According to data the standard overall percentage accuracy would have to be 96%, but the operator B was below this standard. Finally, the results in the case confirmed that 1 out of 3 operators needed training on inspection to reduce the *Batch-to-Batch* variation.

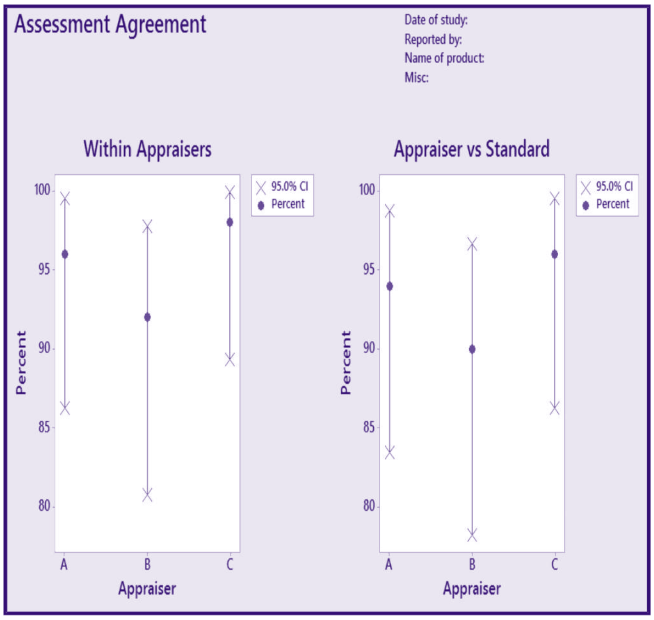


Fig. 6: Gauge R&R analysis: Assessment agreement summary.

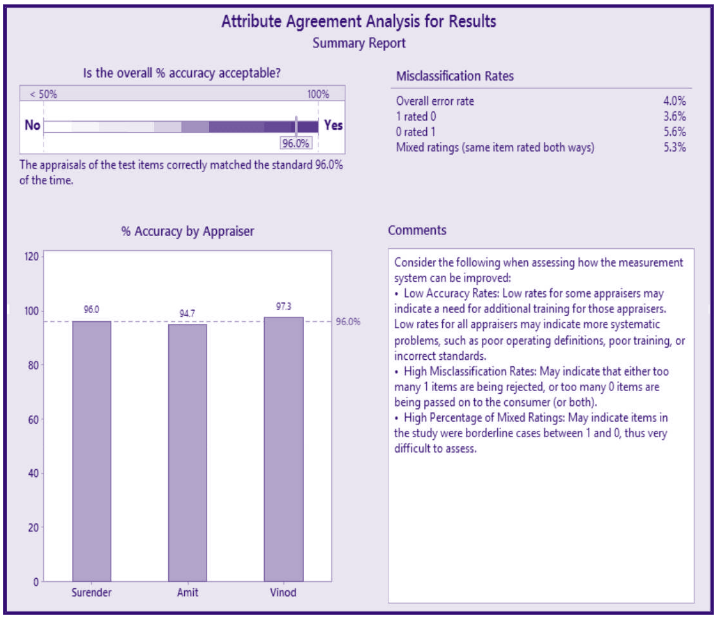


Fig. 7 : Gauge R&R analysis: Attribute agreement result summary

Subsequent to the R&R analysis and recommendations, the need for SPC(statistical process control), which is a part of Analysis phase, was felt. As the data was of the attribute category the need was to develop a p-chart to check whether the process is under control or not and finally evaluate the current process capability levels. The p-chart trend, with the current data, was found to be within the 3-sigma process control limits and hence the process was concluded to be statistically stable.

The current (pre-improvement stage) data was utilised to assess the process capability indices (Cp and CpK) using the Minitab software for the different parameters. Figs 8 and 9 indicate the process capability related outputs of two parameters; Accumulator and Intensification Pressures, from the Minitab software. The pre-improvement process capability related data for the different parameters have been tabulated in Table 2.

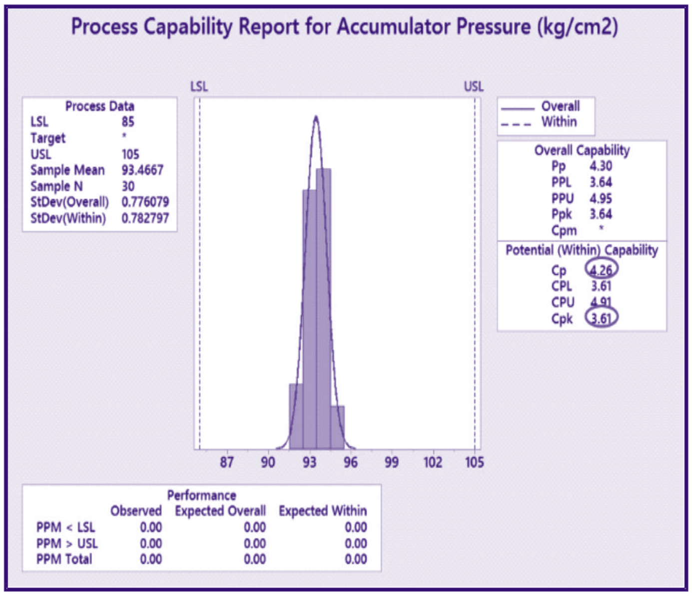


Fig. 8: Cp & Cpk of Accumulator Pressure

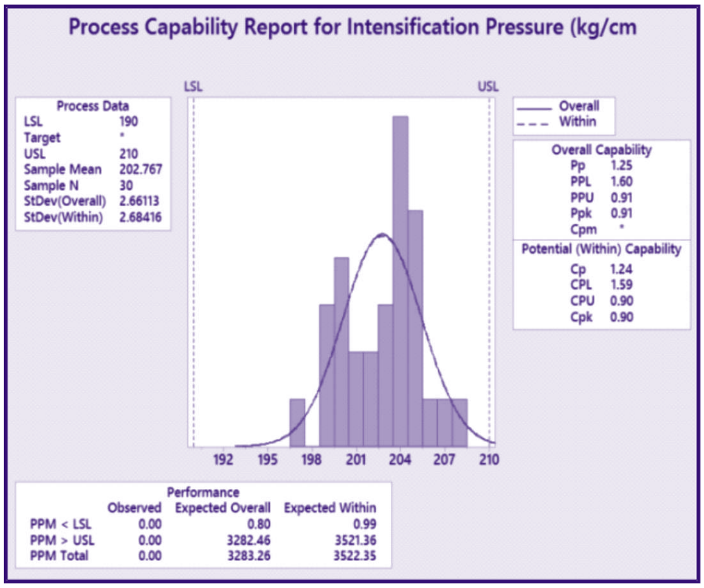


Fig. 9: Cp & Cpk of Intensification Pressure

The root causes that came out were: *batch-to-batch variation, biscuit thickness, holding furnace temperature, ejection pressure* and *improper orientation of die*. With better controls of the first four parameters under different die orientations a series of experiments were conducted. The defect levels with every trial were measured. During these numerous controlled experimental trials it was found that best results came when the position of die was in vertical position. This led to the conclusion that the rejections would drastically reduce by repositioning the Die, coupled with controlled conditions in the other four parameters.

4.7 Control Phase: Standardisation and statistical control check of the process

In order to arrive at the best and consistent results the standardisation of the process control factors was carried out. The specific details have not been shared in the paper in view of keeping the technical process confidentiality. The next step in the control phase was the application of the Process capability measure (Cp and CpK indices) after the process improvement implementation. The P-Chart from the SPC approach was utilised to confirm if the process was under statistical control, which it was. All process parameters were under statistical control. The post- improvement Cp and Cpk values of the parameters were observed to have improved significantly keeping in view the short duration of the improvement case study. Table 2 indicates the process capability values of the parameters 'before' and 'after' improvement processes. The values provided the confidence of the improved process. However, there was a lot of scope for further improvement, especially in the area of CpK.

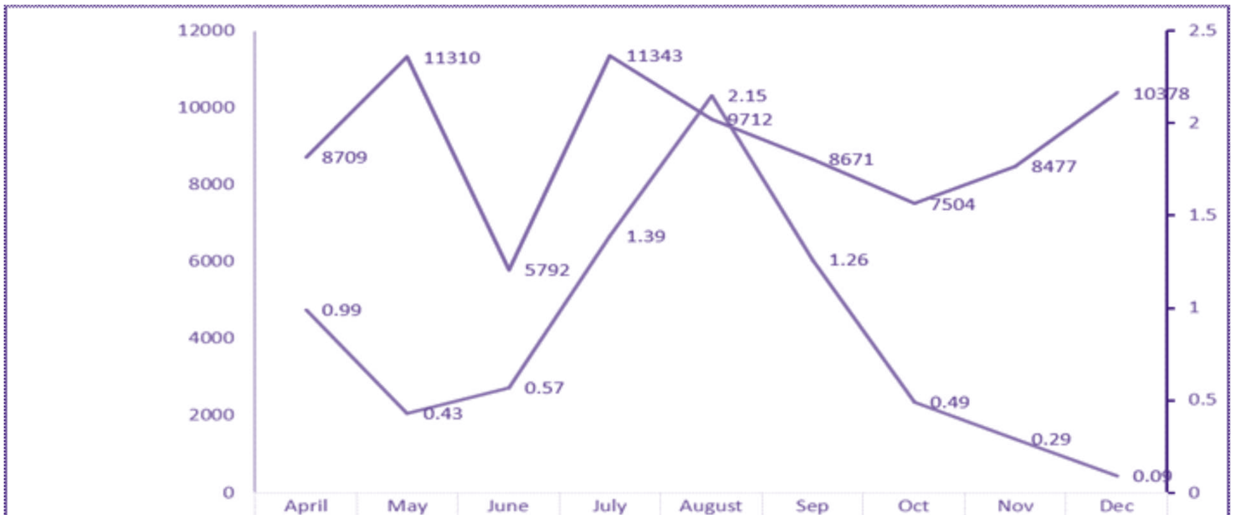
Table 2. Pre and Post improvement process capability measures of the parameters

Stage / Parameters	Pre-improvement stage		Post-improvement stage	
	Cp	Cpk	Cp	Cpk
Intensification pressure	1.13	0.41	1.24	0.9
Accumulator pressure	2.39	2.1	4.26	3.61
Biscuit thickness	0.82	0.76	1.13	1.64
Holding metal temperature	1.27	0.54	1.64	1.49
Velocity1 of molten metal	2.21	1.84	3.84	3.25
Velocity2 of molten metal	1.43	0.03	1.2	0.88

5. RESULTS AND DISCUSSION

All process improvements with optimised control parameters were implemented by the month of Aug to monitor the results. The operator was trained to prevent any measurement errors. Over a period of subsequent six months, the Leakage defect came down from 2.15% to 0.09 % of total defects, the Blow-hole defects come down from 10.58% to 1.3% and the Non-filing defects reduced from 6.34% to 0.15%. In cumulative terms, in the part-CCP Sensor-C, the rejection level reduced to a level of 2.76%. In other terms, the rejection rate came down to approx. 27000 ppm against a target rejection level of 40000 ppm. The improvement was significant and satisfying to the top management. The Leakage related defect trend over nine months has been depicted in Fig 10. Thegraph clearly indicates a significant and consistent reduction of the defects from Aug onwards. Similar results also have been reported for the other two defects: Blow-holes and Non-filing. In summary

- The drastic rejection level reduction of approximately 75% was a delight to the top management which resulted in a significant financial annual saving to the industry.
- DMAIC is a powerful tool to be used in any sector which can bring drastic reduction in defect levels. It is a structured approach and can be applied by anyone with a little training in Six-sigma approach.
- Knowledge of SPC and MSA is must for statistical analysis to improve sigma levels.



	April	May	June	July	August	Sep	Oct	Nov	Dec
Production quantity	8709	11310	5792	11343	9712	8671	7504	8477	10378
Rej %	0.99	0.43	0.57	1.39	2.15	1.26	0.49	0.29	0.09

Production quantity Rej %

Fig 10: Improvement in Leakage

6. CONCLUSIONS

The powerful and structured Six-sigma approach seeks to improve the quality of the output of a process by identifying and removing the causes of defects and minimizing variability in manufacturing processes. It uses a set of quality management methods, mainly empirical, statistical methods, and creates a special infrastructure of people within/outside the organization who are experts in these methods. The DMAIC approach in the case study has facilitated in identifying and quantifying the means of quality issues, the root causes and counter measures. The approach has highlighted - what can be measured will be analysed and implemented and measurement skill by the operator, often play a critical role. The structured approach in the quality improvement journey of the Tier-I supplier under study reduced the defects level by approximately by 83%, from 158000 ppm to 27000 ppm. The High pressure die-casting manufacturing process has witnessed an improvement from the current sigma level of 1.5 to 2.5 sigma. The process has potential for further improvement to take it to a 4-sigma level.

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