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Reducing casting defects and improving productivity in a small scale foundry industry using DMAIC approach

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ABSTRACT

The defects need to be diagnosed correctly for appropriate remedial measures; otherwise new defect may get introduced. The proper classification and identification of particular defect is basic need to correct and control quality of casting. Keeping rejection to a bare minimum is essential to improve the yield and increase the effective capacity of the foundry unit and also improve the productivity. This work identifies major defects slag and porosity. There are many reasons which generate these defects. So it is preferably necessary to reduce it as much as possible by appropriate analysis of the defects which includes the root cause analysis so that actual reasons behind occurring the defects can be found out to make the corrective action. In this work six sigma technique was used to identify and analyse casting defect. Final result of this work was to reduce the defect by taking corrective action. Tool should be identifying the sources of variation clearly.

Keywords*—Seven quality control tools, Productivity, Casting defects, Cold shut, Taguchi method, Regression analysis*

1. SIX SIGMA: HISTORICAL BACKGROUND

Six Sigma began in 1986 as a statistically based method to reduce variation in electronic manufacturing processes in Motorola Inc. in the USA. It is developed by Bill Smith at Motorola, later it was adopted by General Electrics and Allied Signals, where it was initiated by Jack Welch. There are two important contributions to GE's way of implementation to the evolution of Six Sigma. First, Jack Welch demonstrated the great paradigm of leadership. Second, he backed the Six Sigma program up with a strong rewards system. GE changed its incentive compensation plan for the entire company so that 60 percent of the bonus was based on financials and 40 percent on Six Sigma results. The new system successfully attracted GE employees' attention to Six Sigma. Moreover, Six Sigma training had become a prerequisite for advancement up GE's corporate ladder. Welch insisted that no one would be considered for a management job without at least Green Belt training by the end of 1998.

2. LITERATURE REVIEW

T. R. Vijayaram et al (2010) reviewed paper, some of the solutions and quality control aspects are explained in a simplified manner to eliminate the unawareness of the foundry industrial personnel who work in the casting manufacturing quality control departments. This review paper provides very valuable information to the young manufacturing and mechanical engineers who have the interest to start their career in the manufacturing concerns of medium and large scale captive foundries.

Sushil Kumar et al (2011) analyze casting defects and concluded that the quality can be improved by Six Sigma i.e. (DMAIC) approach of parameters at the lowest possible cost. It is also possible to identify the optimum levels of signal factors at which, the noise factors effect on the response parameters is less. The outcome of their case study is to optimize the process parameters of the green sand castings process, which contributes to minimizing the casting defects. The optimized parameter levels for green sand casting process are moisture content (4.0%), green strength (1990 g/cm2), pouring temperature (14100C) and mold hardness number vertical & horizontal (72 & 85) respectively.

D.N. Shivappa et al (2012), found the four prominent defects in casting rejections. They noticed that defects such as Sand drop, Blowhole, Mismatch, and Oversize in Trunion Support Bracket (TSB) castings are frequently occurring at particular locations.
Chiragkumar S. Chauhan, Sanjay C. Shah, Shrikant P. Bhatagalikar (2013) reviewed paper has been conducted in order to define role and importance of seven basic quality tools (7QC tools) within the quality management system. To stay in continuous improvement continuous staff education and training is necessary. Quality tools have an important place in data collecting, analyzing, visualizing and making a sound base for data founded decision making. The paper stresses on the use of the seven basic quality tools to improve processes and to solve problems.

Varsha M. Magar, Dr. Vilas b. Shinde (2014) studied the general idea about all 7 QC tools and its importance regarding minimizing the risk of errors in systems. It enhances workers ability to think to generate ideas, solve the problem and do proper planning. The main aim of this paper is to provide an easy introduction to 7 QC tools and to improve the quality level of manufacturing processes by applying it. QC tools are the means for Collecting data, analyzing data, identifying root causes and measuring the results. These tools are related to numerical data processing. All of these tools together can provide great process tracking and analysis that can be very helpful for quality improvements. These tools make quality improvements easier to see, implement and track.

3. PROBLEM STATEMENT

The present company is facing a casting rejection due to some defect, after observing data of the company most frequently rejected casting identified were Bearing housing, Blower hub, Outer rings, Flingers, Adaptor and Terminal box. Out of these blower, the hub was identified as most severely affected casting, hence it was considered for detailed investigation.

Fig. 3.1: Bearing hub shows blow holes, misrun, slag inclusion and rough surface

4. IMPLEMENTATION OF DMAIC

In the present work, an attempt was made to reduce the defects in castings in a foundry shop with the application DMAIC approach.

4.1 Define phase

The definition of the problem is the first and the most important step of any DMAIC project because a good understanding of the problem makes the job much easier. An average definition may mislead people into trying to achieve a goal which is not required or making the problem more complex. Thus, we can say that the definition of the problem forms the backbone of any DMAIC project. The present case study deals with reduction of rejection rate of casting defects in pressure die casting process at Laxmi Enterprises, Sahibabad, Ghaziabad. The company faces rejection of 15.50 % which resulted into reduced quality and productivity.

4.2 Measure phase

The objective of the measured phase is to understand and establish the baseline performance of the process in terms of process capability or sigma rating. In this phase, we decided for data collection to be done. Before going for data collection it is necessary to see that the current measurement system is capable. While collecting the data if the measurement system is not robust, the data collected may not be accurate which will result in trouble in the project.

4.2.1 Data collection: In this phase, we collect the data. Therefore it becomes very important to secure a correct measuring system before the project. So a list of problems better to say opportunities for improvements were identified, the following problems were listed down in their operations:

Table 4.1: Name of casting defects

S. No.	Type of defect
1	Blowholes
2	Slag inclusion
3	Misrun
4	Rough surface
5	Cold shut

The defects such as blow holes, Misrun, slag inclusion, rough surface have been identified by various method (Table 4.2) and data of each part was collected (for a specified time span) from the company which shows the production and rejection status of an individual part.

Table 4.2: Detection methods

S. No.	Type of defect	Detection	Appearance
1	Blowholes	Visual method	Rounded holes
2	Slag inclusion	Visual method	Pitted surface
3	Misrun	Visual method	Unfilled cavity
4	Rough surface	Touching method	Rough surface

Following is the four months data of the total pouring per month. Rejection of bearing hub is given in the following table 4.3.

Table 4.3: Data collection (before improvement)

Month	Production	Rejection	Blowhole	Slag inclusion	Misrun	Rough surface
Sep 2017	8515	521	188	172	84	77
Oct 2017	8576	545	189	186	92	78
Dec 2017	8498	536	186	178	96	76
Jan 2017	8527	552	187	184	98	83
Total	34116	2154	750	720	370	314

Total production of four month = 34116
Total rejection = 2154
Rejection % = (2154/34116)* 100 = 6.31 %

Table 4.4: Total rejection data (before improvement)

Defects	No. of defective piece	Percentage of rejection
Blowhole	750	34.81 %
Slag inclusion	720	33.42 %
Misrun	370	17.16 %
Rough surface	314	14.57 %

4.2.2 Calculation of present sigma level: We will calculate our current sigma level by Defect per Million Opportunities (DPMO) approach with the equation shown below:

$$\text{DPMO} = \frac{\text{No. of defects x 1000000}}{\text{No. of opportunities x no. of units produced}}$$

The defects per unit (DPU) are:
DPU = Total number of defects observed in the batch /Total number of units produced in the batch
In this case, rejections due to blow holes are only concerned. Any other opportunities for rejection are not accounted. Hence, the number of opportunities is one.

Hence, defects per opportunities (DPO) are: DPO= DPU/1

By the same token, defects per million opportunities (DPMO) are: DPMO = DPO×1,000,000

The sigma quality level with ± 1.5 σ shift is determined by the equation:

$$Sigma\ quality\ level = 0.8406 + \sqrt{29.37 - 2.221\ X\ \ln(DPMO)}$$

DPU= 2154/34116 = 0.06313
DPO = 0.06313/1 = 0.06313
DPMO = 0.06313 x 1000000 = 63137.53

$$Sigma\ quality\ level = 0.8406 + \sqrt{29.37 - 2.221\ X\ \ln(63137.53)} = 3.03$$

Table 4.5: Sigma level for 4 months

Current Sigma Level Calculation	
Total no. of units produced	34116
Total defects	2154
No. of opportunities	1
DPMO	63137.53
Existing sigma level	3.03

4.3 Analyse phase
The objective of this phase is to the identification of the root causes of the problem or the causes having maximum impact on the CTQs. In this phase, various tools & techniques are used for deciding the vital few causes that must be controlled to improve the performance of the process.

4.3.1 Pareto chart: The Pareto diagram shows the total number of defects on Y-axis and Nature of defect on X-axis. From the diagram, we can identify the critical defects by 80-20 Rule. Following is the pareto analysis made to identify the major defects those are contributing to major percentage rejection.

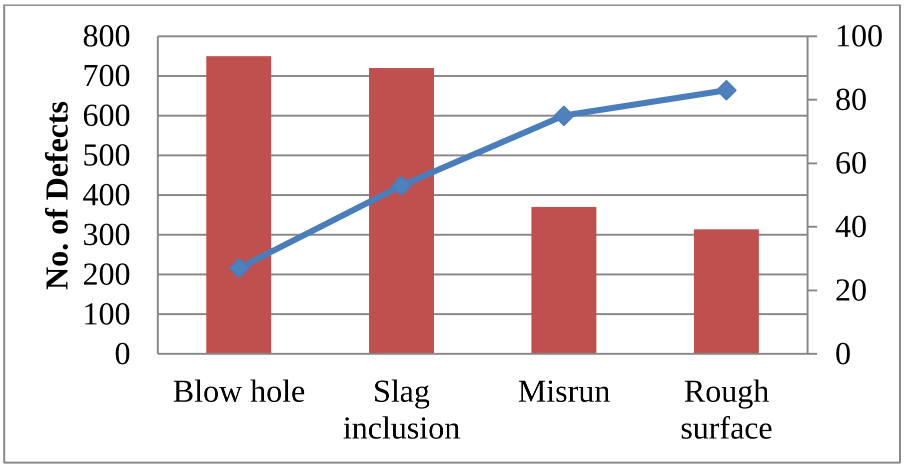

Fig. 4.1: Pareto chart of bearing hub for last four months

The blowhole is identified as one of the four major defects. It was necessary to find out the actual reasons behind the blowhole defect, to find the reasons behind the defect use of Ishikawa diagram was made which is also called as root- cause analysis.

4.3.2 Root- cause analysis for blow hole: First of all the brainstorming session was carried out to identify the probable causes of the problem. As a result of the brainstorming session, some probable causes were identified. These probable causes were then bifurcated into groups of man, machine, material and die with the help of a cause & effect diagram shown in Fig. 5.5.

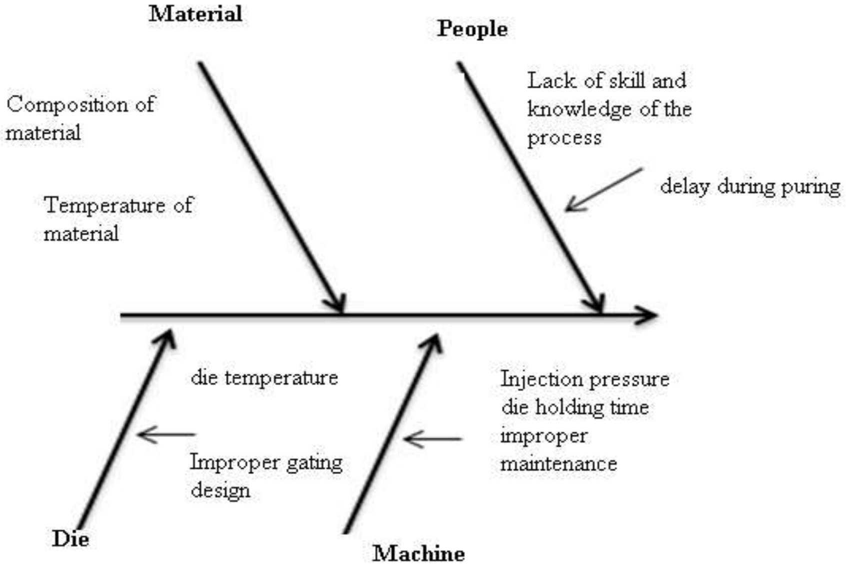

Fig. 4.2: Cause & effect diagram

The two major causes are pouring temperature, high moisture and low permeability are responsible for blow holes defects. In the sand casting process, to produce the quality products it is required that metal should be poured at the required temperature. To see the effect of a change in pouring temperature on rejection, data collection was carried out for temperature and % rejection as shown in below table 5.6. This data was then used for regression analysis to see the relation between % rejection and pouring temperature and after that design of experiment will use to find out the optimum pouring temperature.

4.3.2.1 Regression analysis of pouring temperature vs. % rejection: Regression analysis to see the relation between % rejection and pouring temperature and after that design of experiment will use to find out the optimum pouring temperature. Data have been collected on a single day hour basis.

Table 4.6: Data collection of pouring temperature

S. No.	Temperature °C	Total production	Total Rejection	% Rejection
1	870	40	13	32.50
2	861	42	12	28.57
3	885	37	11	29.73
4	838	43	6	13.95
5	750	53	8	15.09
6	776	56	10	17.86
7	810	43	9	20.93
8	840	52	14	26.92

Regression analysis using the above data was carried out with the help of MINITAB 17 software. The result of regression analysis is shown below.

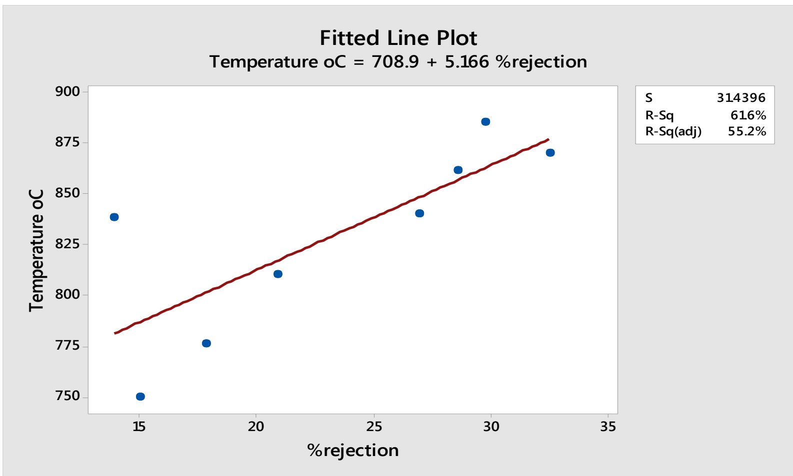

Fig. 4.3: Temperature vs. % rejection

Regression Equation:

% rejection = -75.7 + 0.1193 Temperature ºC

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	9522.8	9522.80	9.63	0.021
Error	6	5930.7	988.45		
Total	7	15453.5			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-75.7	31.9	-2.37	0.055	
Temperature ºC	0.1193	0.0384	3.10	0.021	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.77729	61.62%	55.23%	45.34%

From the above analysis it is to be noted that since p-value (0.021) is less than 0.05 which indicating that above regression model is significant but since linearity is only 61.62 %, we cannot conclude that variation in temperature is linear causes % rejection.

4.3.2.2 Regression analysis of addition of new silica sand vs. % rejection: The industry was using 5 % of new silica sand and 95 % of reuse sand. After performing the test with 100 kg of the sand sample, it was found that the percentage of moisture was high and the percentage of permeability was low. Therefore to improve the blow holes defects it was necessary to increase the percentage of new silica sand to reduce the moisture and increased the permeability. The different results have been obtained by increasing the new silica sand as below.

Table 4.7: Percentage recorded of moisture and permeability

Addition of new silica sand	Moisture	Permeability
5 %	601 %	125 cc/min
5.5 %	5.45 %	131 cc/min
6 %	4.92 %	138 cc/min

To see the effect of the addition of new silica sand on rejection, data collection was carried out for % rejection shown in table 5.8. This data was then used for regression analysis to see the relation between % rejection and the addition of new silica sand and after that design of experiment will use to find out the optimum percentage of silica sand.

Table 4.8: Data collection of the addition of new silica sand

S. No.	Addition of new silica sand	Total production	Total Rejection	% Rejection
1	5 %	240	42	17.5
2	5.5 %	229	33	14.41
3	6 %	237	28	11.81

Regression analysis using the above data was carried out with the help of MINITAB 17 software. The result of regression analysis is shown below.

Fig. 4.9: Addition of silica sand vs % rejection

Regression Equation

% rejection = 45.87 - 569.0 Addition of new silica sand

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	45.87	1.56	29.40	0.022	
Addition of new silica sand	-569.0	28.3	-20.11	0.032	1.00

Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.200042	99.75%	99.51%	96.67%

Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	16.1880	16.1880	404.53	0.032
Addition of new silica sand	1	16.1880	16.1880	404.53	0.032
Error	1	0.0400	0.0400		
Total	2	16.2281			

From the above analysis it is to be noted that since p-value (0.032) is less than 0.05 which indicating that above regression model is significant but since linearity is only 99.75 %, we conclude that variation in addition of silica sand is linearly and causes % rejection.

4.4 Improve phase

The fourth phase of the DMAIC methodology of Six Sigma is an improved phase in which the project team will decide the improvement steps based on the final validated root causes in the analyze phase. All the improvement steps should also be approved by the top management so that it creates availability of resources in the implementation of improvement steps.

Table 4.9: Improvement plan

S. No.	Causes	Suggested improvements
1	Insufficient shot volume	Keep specific extra ladle cup for a specific product
2	Lack of skill & knowledge about the process	Training of operators
3	Improper pouring temperature	Finding optimum level through Design of Experiment (DOE)
4	Silica sand %	Finding optimum level through Design of Experiment (DOE)

After discussing with the project team, top management agreed to implement all suggestions suggested to them with their full support. One by one all solutions were carried out which are discussed below.

In sand casting process it is required that the ladle cup which is used for pouring molten metal into shot cylinder should be specific to that product so that the required amount of metal can be poured. Operators were using another product’s ladle cup when the cup is damage which is having higher weight so it leads to an assumption based on pouring which results in a rejection of products. So one arrangement was carried to keep one extra ladle of so that whenever it will damage they can use the ladle instead of another product ladle.

There are two operating parameters which were validated to be the root cause of the problem so to optimize these parameters DOE was carried out. DOE was carried out with three level of each of the parameter which is shown in Table 4.10.

Table 4.10: Design of experiments

S. No.	Parameters	Level 1	Level 2
1	Pouring Temperature (°C)	750	850
2	Silica sand %	5 %	6 %

To carry out DOE for three parameters with three levels, the L4 arrangement should follow which is shown in Table 4.11.

Table 4.11: L4 Design

Run	Pouring Temperature (°C)	Silica sand %	Total Production	Total Rejection	Rejection Percentage
1	750	5 %	200	18	9
2	750	6 %	200	22	11
3	850	5 %	200	19	9.5
4	850	6 %	200	21	10.5

The experiment is carried out as per the factor settings in each test condition and 800 components are produced in 4 batches are considered. The percentage of rejection is recorded as a response to each test.

4.5 Control phase

The real challenge of the Six Sigma implementation is the sustainability of the achieved results. Due to a variety of reasons, such as people changing the job, promotion/ transfer of persons working on the process, changing focus of the individual to other process-related issues elsewhere in the organization and lack of ownership of new people in the process, quite often maintaining the results are extremely difficult. Sustainability of the results requires standardization of the improved methods and introduction of monitoring mechanisms for the key results achieved. It also requires bringing awareness among the personnel performing the activities.

5. RESULTS AND DISCUSSIONS

5.1 ANOVA analysis for blow holes defect

The experimental results analyzed with ANOVA are shown in the Table 5.1. The F value calculated through MINITAB 15 software is shown in the second last column of the ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%).

Table 5.1: ANOVA for blow hole defect

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Pouring Temperature (°C)	2	5.6296	5.6296	2.8148	3.36	0.055
Silica sand %	2	6.3519	6.3519	3.1759	3.79	0.040
Error	2	16.740	16.740	0.8370		
Total	8	28.721				
S = 0.914897 R-Sq = 67.15 % R-Sq (adj) = 57.30 %						

From the above result, it can be seen that P value of pouring temperature and silica sand is below 0.05 which means they are significantly affecting the % rejection. It is also to be noted that P value of pouring temperature is 0.055 which is also can be taken as a significant factor because it is almost 0.05.

5.2 Main effect plots for blow holes defect

We are required to select the optimal level of each of the parameters. To decide the optimal level of these parameters main effect plot was drawn which is shown in Figure 5.1.

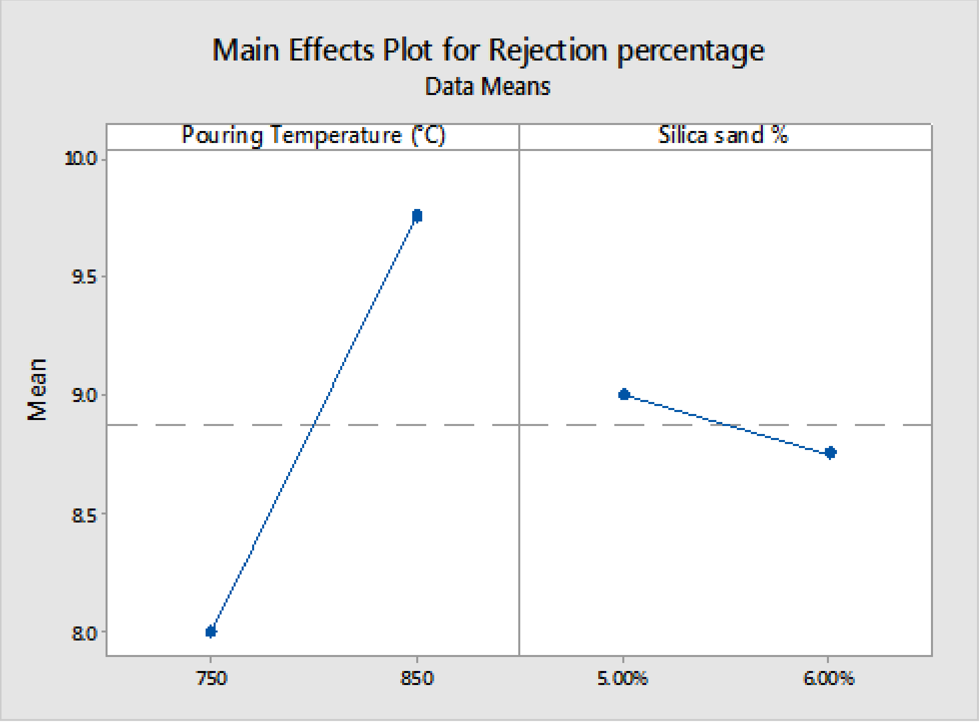

Fig. 5.1: Main effect plot for % rejection

5.3 Determination of optimum solution

From the above chart we conclude that the following parameters are the best from the rejection point of view:

Table 5.2: Optimum levels

Parameter designation	Process parameters	Optimal levels
A	Pouring Temperature (°C)	750
B	Silica sand %	6

5.4 Confirmation test

After deciding optimal levels for all three factors, it was discussed with top management for getting permission for confirmation run. After getting permission, this optimal level experiment was run which is shown below.

5.4.1 Improvement in blow holes defects: The confirmation run was successful with all two parameters optimal level then these parameters were set to that level and after that data collection was done to identify the improvement in a rejection which is shown in Table 5.3.

Table 5.3: Data collection of rejection after improvement for blow holes

Parameter set	Pouring Temperature = 750 °C	Silica sand = 6 %	% Rejection
No. of Batches	**Total Production**	**Total Rejection**	
1	480	25	5.2
2	500	19	3.8
3	440	21	4.77
4	485	16	3.29
5	527	24	4.55
Total	2432	105	

Total production = 2432
Total rejection = 105
Rejection % of slag inclusion defects = (97/2532)* 100 = 3.83 %

5.4.2 Improvement in slag defects: The root factors for slag defects were rough ladle lining and skimming metal. Therefore to reduce the slag inclusion defect some new material has been added which was not used by the company before applying the technique.

1. Slag defects have minimized by the addition of Slax-30 material up to 2%
2. By using a clean ladle

After the implementation of these improvements, the data of the company was collected again.

Table 5.4: Data collection of rejection after improvement for slag inclusion

Parameter set	Pouring Temperature = 750 °C	Silica sand = 6 %	% Rejection
No. of Batches	**Total Production**	**Total Rejection**	
1	533	18	3.38
2	477	22	4.61
3	527	17	3.23
4	483	18	3.73
5	512	22	4.30
Total	2532	97	

Total production = 2532
Total rejection = 97
Rejection % of slag inclusion defects = (97/2532)* 100 = 3.83 %

5.4.3 Improvement in misrun defects: The root factors for Misrun defects were core shift and low pouring temp. Therefore to remove this casting defect temperature has been improved and core shift has been controlled. So following action has been taken to improve this defect.

1. Misrun defects have been minimized by the addition of flux (limestone) from 0.2% to 0.3%.
2. To avoid core shift chaplets have used to reduce Misrun defects

After the implementation of these improvements, the data of the company was collected again.

Table 5.5: Data collection of rejection after improvement for misrun defect

Parameter set	Pouring Temperature = 750 °C	Silica sand = 6 %	% Rejection
No. of Batches	**Total Production**	**Total Rejection**	
1	546	21	3.85
2	485	19	3.92
3	533	22	4.13
4	487	23	4.72
5	530	17	3.21
Total	2581	102	

Total production = 2581
Total rejection = 102
Rejection % of slag inclusion defects = (102/2581)* 100 = 3.95 %

5.4.4 Improvement in rough surface defects: The root factors for rough surface defects were a poor coating of pattern, loose ramming so to remove this defects it was very necessary to correct the coating of patterns and loose ramming. Therefore some improvements have been done to reduce the rough surface defects.

1. Soft ramming has been improved by the addition of coal dust from 0.9% to 1.1%.
2. Varnish coating on the pattern has been used.
3. Coating of mold inner surface by zirconium paste.

After the implementation of these improvements, the data of the company was collected again.

Table 5.6: Data collection of rejection after improvement for rough surface defect

Parameter set	**Pouring Temperature = 750 °C**	**Silica sand = 6 %**	**% Rejection**
No. of Batches	**Total Production**	**Total Rejection**	
1	536	19	3.54
2	510	22	4.31
3	496	20	4.03
4	530	17	3.21
5	487	21	4.31
Total	2559	99	

Total production = 2599
Total rejection = 99
Rejection % of slag inclusion defects = (99/2599)* 100 = 3.8 %

5.5 Calculation of sigma level after study

We will calculate our current sigma level by Defect per Million Opportunities (DPMO) approach with the equation shown below:

$$\text{DPMO} = \frac{\text{No. of defects x 1000000}}{\text{No. of opportunities x no. of units produced}}$$

The defects per unit (DPU) are:
DPU = Total number of defects observed in the batch /Total number of units produced in the batch

Total no. of defects = 105 + 97 + 102 + 99 = 403
Total units produced = 2432 + 2532 + 2581 + 2559 = 10104
DPU = 403/10104 = 0.03988

In this case, rejections due to defects are only concerned. Any other opportunities for rejection are not accounted. Hence, the number of opportunities is 2.
Hence, defects per opportunities (DPO) are:

DPO= DPU/2 = 0.019943

By the same token, defects per million opportunities (DPMO) are:

DPMO = DPO×1,000,000 = 0.019943 x 1,000,000 = 19942.6

The sigma quality level with ± 1.5 σ shift is determined by the equation:

$$Sigma\ quality\ level = 0.8406 + \sqrt{29.37 - 2.221\ X\ \ln(DPMO)}$$

$$Sigma\ quality\ level = 0.8406 + \sqrt{29.37 - 2.221\ X\ \ln(19942.6)} = 3.55$$

5.6 Cost analysis

There is reduction in the rejection rate and finally cost (in terms of profit). The cost analysis is given in Table 6.4.

Table 5.7: Cost analysis of bearing hub

S. No.	**Product**	**Cost @Rs 28 Kg/wt**	**Previous rejection cost**	**After implementation Rejection cost**
1	Bearing hub	10.4 Kg/ Rs. 291.2	2154 x 291.2= Rs. 6,27,245	403 x 291.2 = Rs. 1,17,354

5.7 Productivity improvement

Productivity analysis has been carried out as shown below:

Table 5.8: Productivity improvement before and after

	Rejection	**Percent saving**	**Total Production**	**Defective item**	**Good item**	**Productivity**
Before	6.31 %	3.69 %	34116	2154	31962	93.6 %
After	3.98 %		10104	403	9700	96 %

6. CONCLUSION

This thesis presents a case study from the pressure die casting section demonstrating how the implementation of Six Sigma can bring breakthrough improvement in the performance of the process as well as in business. The industry was not aware of such improvements in the pressure die casting process which can be carried out. The application of the DMAIC methodology has been utilized in reducing the rejection of the die casted product named bearing hub.

From the experiment following conclusions were drawn:

a. Optimum parameters are: Pouring temperature = 750 °C, Silica sand = 6 %.
b. In this case study, the performance of the pressure dies casting process was improved from 3.03 σ to 3.55 σ by reducing the rejection rate from 6.31 % to 3.98 % with an increase of profit of ~2 Lakh.
c. A p value of pouring temperature and silica sand is below 0.05 which means they are significantly affecting the % rejection. It is also to be noted that P value of pouring temperature is 0.055 which is also can be taken as a significant factor because it is almost 0.05.
d. The rejection due to Blow holes defects was reduced from 34.81 % to 4.31 % by reducing the moisture and increasing the permeability of sand.

e. The rejection due to slag defects was reduced from 33.42 % to 3.83 %
f. The rejection due to Misrun defects was reduced from 17.16 % to 3.95 % by using chaplets.
g. The rejections due to rough surface defects were reduced from 14.57 % to 3.8 % by addition of coal dust.
h. Productivity increases from 93.6 % to 96 %.

7. REFERENCES

[1] B.R. Jadhav, Santosh J Jadhav, "Investigation And Analysis Of Cold Shut Casting Defect And Defect Reduction By Using 7 Quality Control Tools", International Journal of Advanced Engineering Research and Studies, ISSN: 2249–8974, September 2013.
[2] Pranay S. Parmar, Vivek A. Deshpande, "Implementation of Statistical Process Control Techniques in Industry: A Review", Journal of Emerging Technologies and Innovative Research, ISSN: 2349-5162, Vol 1, Issue 6, November 2014.
[3] Varsha M. Magar1, Dr. Vilas B. Shinde, "Application of 7 Quality Control (7 QC) Tools for Continuous Improvement of Manufacturing Processes", International Journal of Engineering Research and General Science, ISSN 2091-2730, Volume 2, Issue 4, June-July, 2014.
[4] Uday A. Dabade, Rahul C. Bhedasgaonkar,"Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique", Elsevier Forty-Sixth CIRP Conference on Manufacturing Systems,2013.
[5] Aniruddha Joshi, L.M.Jugulkar, "Investigation And Analysis Of Metal Casting Defects And Defect Reduction By Using Quality Control Tools", International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 2, Issue- 4, April-2014.
[6] Chirag B. Patel, Dr.Hemant R. Thakkar, "Reducing Casting Defects And Improving Productivity In A Small Scale Foundry: A Review", International Journal of Advanced Research in Engineering, Science & Management, Volume 3, Issue- 4, April-2014.
[7] R. B. Heddure, M. T. Telsang, "Casting Defect Reduction Using Shainin Tool In Ci Foundry – A Case Study", International Journal of Mechanical And Production Engineering, Volume- 2, Issue- 6, PP: 70-73.
[8] Vivek V. Yadav, Shailesh J. Shaha, "Quality Analysis Of Automotive Casting For Productivity Improvement By Minimizing Rejection", International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 4, Issue-6, PP: 1-8.
[9] Jitendra A Panchiwala1, Darshak A Desai, Paresh Shah, "Review on Quality and Productivity Improvement in Small Scale Foundry Industry", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 12, PP: 11859-11867.
[10] Patel Rumana, Darshak A. Desai, "Review Paper: Quality Improvement through Six Sigma DMAIC Methodology", International Journal of Engineering Sciences & Research Technology, Vol. 3, Issue 12, PP: 169-175.
[11] Chintan C. Rao, Darshak A. Desai, "A Review of Six Sigma Implementation in Small Scale Foundry", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 12, PP: 11894-11897.
[12] Anuj Kumar, Naveen Kumar, Dinesh Kumar, "Defects Reduction In Brake Drum In Foundry Shop Using DMAIC Technology", International Journal of Scientific Research Engineering & Technology, Volume 6, Issue 7, PP: 114-119.
[13] Jaykar Tailor, Kinjal Suthar, "Review on Defects Reduction in Multiple Sector by Using Six Sigma DMAIC Methodology", International Conference on Ideas, Impact and Innovation in Mechanical Engineering, Volume 5, Issue 6, PP: 111-116.
[14] Suraj Dhondiram Patil, M M Ganganallimath, Roopa B Math, Yamanappa Karigar, "Application of Six Sigma Method to Reduce Defects in Green Sand Casting Process: A Case Study", International Journal on Recent Technologies in Mechanical and Electrical Engineering, Volume 2, Issue 6, PP: 37-42.

