Realizing Improvements in Quality by Applying Six Sigma Methodology – A Foundry based Case Study

Benita Evangelyne J [1]
PG Scholar,
Department of Mechanical Engineering
PSG College of Technology
Coimbatore.

Dr. V. Jaiganesh [2]
Associate Professor,
Department of Mechanical Engineering
PSG College of Technology
Coimbatore.

Abstract — **In today's ever-changing customer driven market, industries are expected to improve their products and processes to satisfy customer requirements. The Six Sigma approach has set a new paradigm for business excellence. Six Sigma as a process driven improvement methodology has been adopted successfully by many industries. In this work the DMAIC (Define-Measure-Analyse-Improve-Control) approach of six sigma has been followed to reduce the rejection rate in the green sand casting process. Response Surface Methodology has been employed to develop an empirical model that correlates the casting process variables with the desired quality characteristic. The developed model is further utilised to optimise the process parameters for minimizing the casting rejection.**

Keywords— Six Sigma, DMAIC, Rejection Rate, Response Surface Methodology, Analysis of Variance (ANOVA), Optimization

I. INTRODUCTION

Nowadays, the industrial world has realized that the Six Sigma philosophy is certainly a viable solution to their shop floor problems and it has become one of the most important subjects of debate in quality management. Six Sigma is a well-structured methodology that can help a company to achieve expected goal through continuous improvement. For many companies, Sigma quality level is a measure of the process defect rate and thus can be used to measure the quality of the manufacturing process (i.e. a high Sigma level indicates that the process results in a lower defect rate, whereas a low Sigma level illustrates a higher defect rate. Reducing process variations is the core objective of Six Sigma projects, as process variations result in higher quality loss. Casting is one of the most economical routes to produce metallic components in which the liquid metal is directly poured into the mould cavity of required size and shape. The major drawback of casting processes is the hot tears, etc. Many foundries are interested to implement Six Sigma to improve the quality of their products. Indeed, the implementation of Six Sigma methodology into foundry has become globally popular. The main benefit of a Six Sigma program is the elimination of subjectivity in decision-making, by creating a system, where everyone in the organization collects, analyzes, and displays data in a consistent way. The prime focus is on minimizing the defects, developed in the cast iron differential housing cover castings manufactured by the green sand casting process. In Foundry DMAIC is implemented (Define, Measurement, Analyze, Improve, and Control) based Six Sigma approach to optimize the green sand casting process parameters to made the process more robust to quality variations.

The increasing number of applications and of products is the best proof of the success of grey cast iron foundry. Various processes are now competing, to achieve both economically and technologically advantageous production of grey cast iron castings. Green sand casting is one of the most widely used manufacturing processes for producing a variety of parts. Till date, a quite significant amount of research and development work has been done in order to optimize the green sand casting process and improve the quality of the castings.

The conventional statistical tools available today are not adequate to be effective in analyzing the casting defects and optimize the processes to minimize the impact on cost of quality. The reason for these include: the statistical techniques assume known distributions to the unknown foundry processes, the need for specially designed experiments, the need for carrying out a very large number of experiments in view of e large number of factors, the need to carry out specially designed experiments on a limited number of castings and the need to filter the potential factors. Six Sigma heavily focuses on statistical analysis as it is data driven and is a methodical approach that drives the process improvements through statistical measurements and analyses. Reducing process variations is the core objective of Six Sigma methodology, as process variations result in higher quality loss. Therefore Six Sigma approaches for reducing the rejections in casting industry have been employed.

Implementation of six sigma: The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process and variation reduction, through application of Six Sigma projects. In one implementation model, all Six Sigma projects run through the independent organization, making it easy to measure the impact of the changes. However, this arrangement can create a "we versus them" mentality that can undermine the effectiveness of the Six Sigma initiatives. To avoid this, other model involves a more integrated approach. In this model, Six Sigma is incorporated into every employee's job and hence makes it more challenging to measure the impact of Six Sigma. It helps to create a culture in which a commitment to quality and excellence is pervasive. Basically Six Sigma implementation fuels three engines- Process Design/Redesign, Process Management and Process Improvement

II. OBJECTIVES

The objectives of the present work are

- To reduce rejection/rework in foundry using DMAIC -Six Sigma Methodology
- To identify the defects and to analyze it causes
- To optimize the process to reduce casting defects using RSM methodology.

III. METHODOLOGY

Fig. 1 represents the Framework to reduce the defects of castings

IV. DMAIC Phases

A. DEFINE PHASE

The present case study deals with reduction of rejection due to casting defects in a foundry industry. The company is making cast iron components and having rejection in the form of blow hole, misrun, cold shuts and sand inclusions. It is necessary to perform SIPOC analysis to have a better understanding of the process. HFB 64 LH Housing is chosen for case study because of its high rejection rate. SIPOC is created and is presented in Fig. 2, respectively.

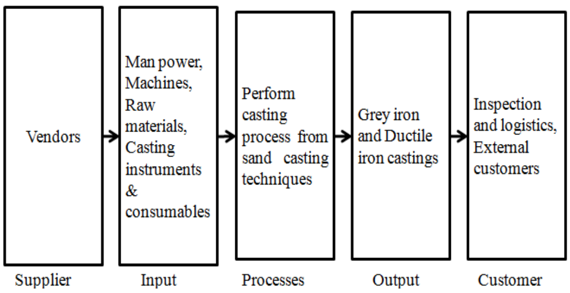

Fig. 2. SIPOC for casting process

B. MEASURE PHASE

To understand and establish the baseline performance of the process in terms of sigma rating. Defect data has been collected shown in Table I for auto component LH Housing shown in Fig. 3. Using Pareto – 80% of defective in castings (vital few) are found.

Fig. 3. Autocomponent

TABLE I. Rejection data of Auto component

Processes	Number of defects				
	Moulding	Melting	Fettling/ others	Total defectives	Total unit produced
April 17	390	6		396	4896
May 17	195	2		197	1222
June 17	-	-	-	-	-
July 17	218	81		299	3564
August 17	231	74		305	3318
September 17	340	70	1	411	3476
October 17	219	71	1	291	3294
November 17	374	110		490	6180

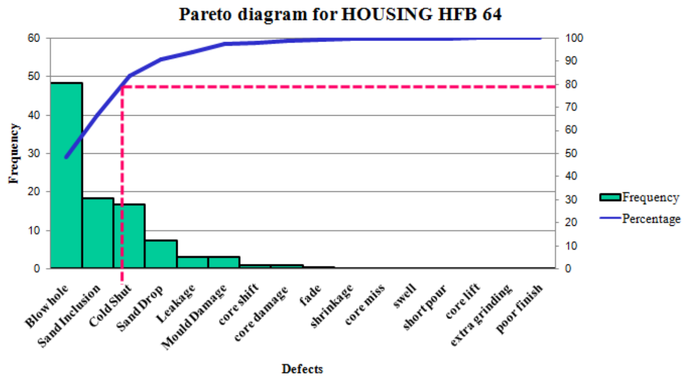

Fig. 4. Pareto chart

Fig. 4 shows the major contributor of defects that have taken place inside the industry. The six sigma level was calculated from the rejection report as shown in Fig. 5.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

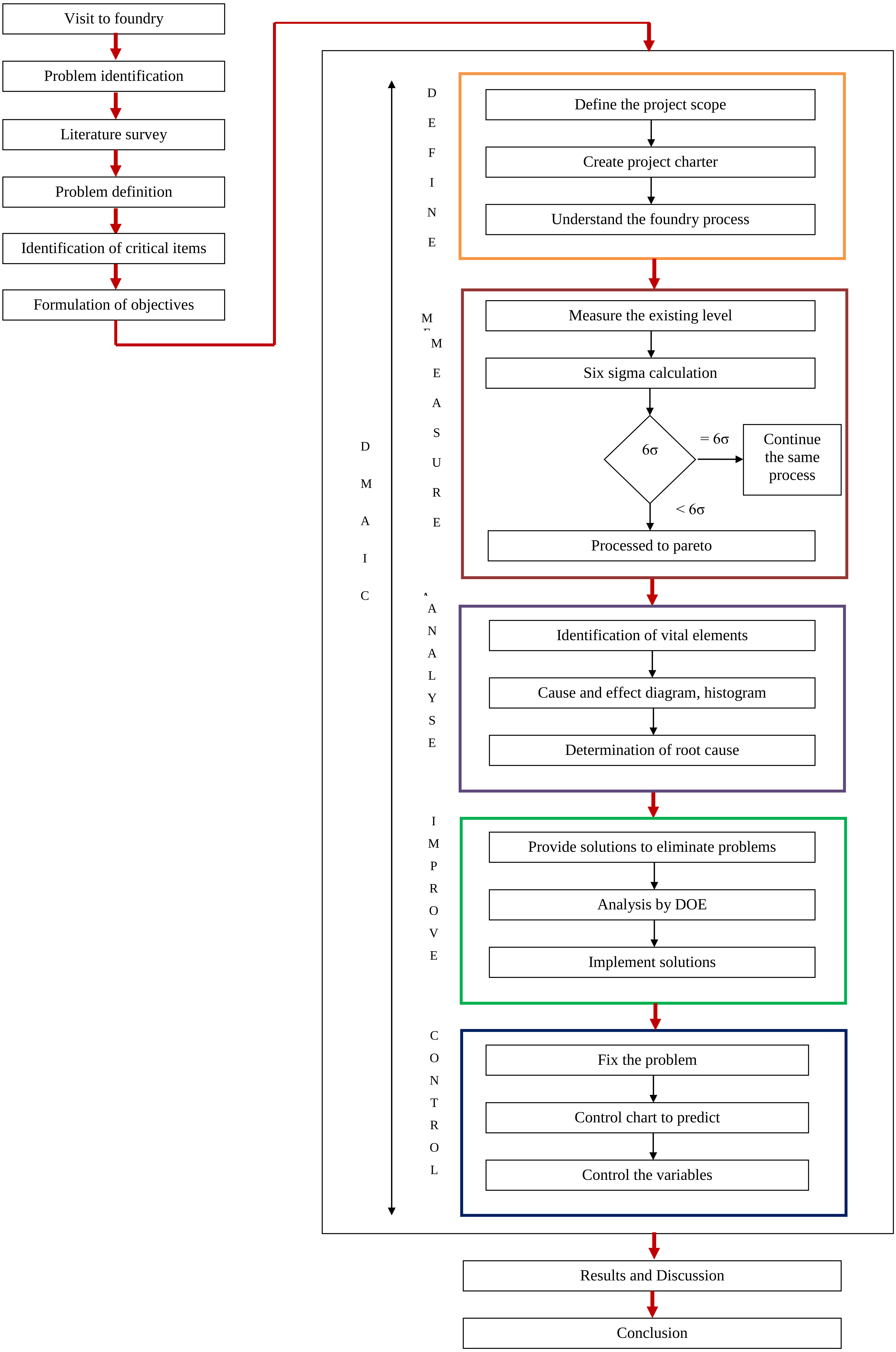

Fig. 1. Methodology

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

TABLE II. Overall rejection data

Character	Defects	Units	Opportu nities	TOP	DPU	DPO	DPMO
April 17	30212.29	366484	25	9162100	0.0824	0.00329	3297.52
May 17	32341.20	4723	23	9423629	0.0789	0.00343	3431.92
June 17	29895.47	471476	21	9900996	0.06341	0.00302	3019.43
July 17	37604.44	600248	21	12605208	0.06264	0.00298	2983.25
August 17	35697.95	477893	23	10990389	0.07471	0.00324	3247.83
September 17	37310.39	448912	21	9427152	0.08311	0.00395	3957.75
October 17	3942.85	476884	24	11445216	0.08263	0.003443	3442.74
TOTAL	2,42,391.27			72,954,690		0.023352	23380.44

$$DPO = \frac{242391.27}{72,954,690} = 0.003322$$

$$DPMO = DPO \times 10^6 = 0.03322 \times 10^6 = 3322$$

Six sigma level = 4.22

1	690,000
2	308,000
3	66,800
4	6,120
5	320
6	3.4

Fig. 5. Six sigma calculations

C. ANALYZE PHASE

With the help of the Pareto chart, factors that influenced the rejection most are identified. It is the key component of any defect reducing program. This is the stage at which new goals are set and route maps created for closing the gap between current and target performance level. The conventional quality technique like brainstorming, root cause analysis, Cause and effect diagram as shown in Fig. 6 etc. may be used for carrying out the analysis. The vital elements are analyzed from Pareto chart drawn in measure phase
and found to be

- Sand Inclusion, Sand drop
- Blow hole
- Cold shut

From the cause and effect diagram the root cause found to be sand properties.

FMEA sheet is taken for risk prioritization and developed for sand inclusions / sand drop and shown in Table III.

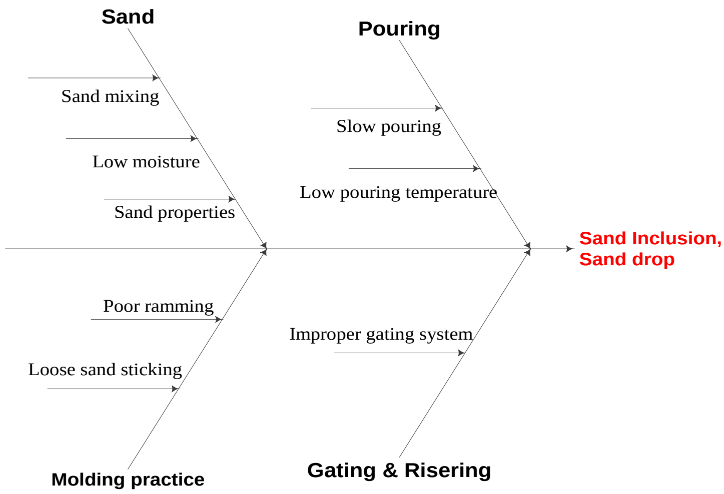

Fig. 6. Cause and Effect diagram

TABLE III. FMEA for sand inclusion, sand drop

S.NO	POTENTIAL FAILURE	POTENTIAL CAUSES	S	O	D	RPN
1	Sand inclusion, Sand fusion and blow holes	Water addition is more Low moisture Sand fines/ coarses more	6 4 6	2 2 2	2 2 2	24 16 24
2	Sand inclusion	Machine setting is not done	2	3	2	12
3	Sand inclusions, sand drop	Not cleaning of mould using air guns	4	2	2	16

From FMEA & cause and effect diagram, it may be concluded that the most significant factors that affect casting defects are

1. green compression strength
2. compatibility
3. pouring temperature
4. mould hardness and
5. moisture content.

Conducted lab test on sand properties to make control charts to check whether the factors are under control or not. The control charts are shown in fig.7 and 8 and observed that moisture and compatibility are under control. The experiments are carried out using,

1. Moisture test – moisture teller
2. Compatibility test – Sand rammer

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

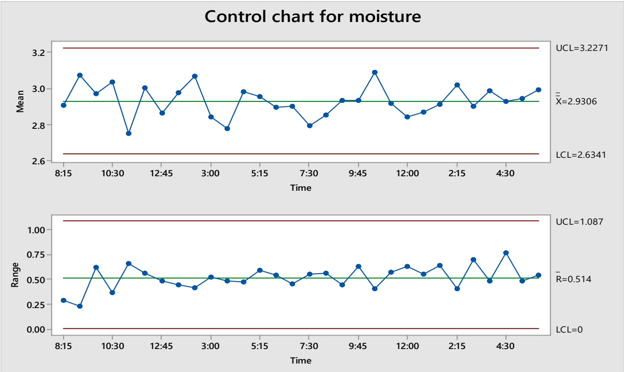

Fig. 7. Control chart for moisture

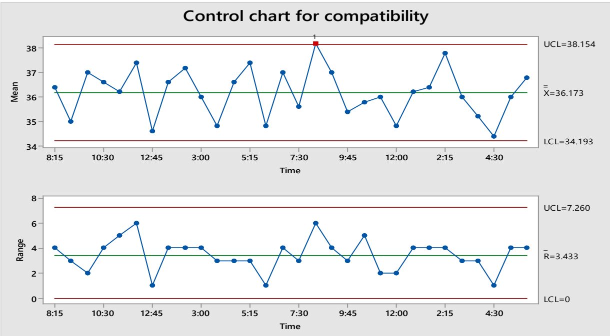

Fig. 8. Control chart for compatibility

D. IMPROVE PHASE

The objective of improve phase is to empirically explore the solutions to eliminate these causes. Response surface methodology has been used for the design and modelling of the experiment. Response surface methodology is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. In analyze phase we find that the sand properties are under control. Though the properties are under control we need to optimize the process within the range of control. To optimize the response the factors and their limits are to be fixed as shown in Table IV.

The response surface y can be expressed by

$$y = f(\xi_1,\xi_2,\ldots,\xi_k)+\varepsilon; \quad (1)$$

ε includes effects such as measurement error of the response.

a second-order polynomial equation is used in RSM as given by

$$\eta = \beta_0 + \sum \beta_j x_j + \sum \beta_{jj} x_{j2} + \sum\sum \beta_{ij} x_i x_j \quad (2)$$

$k\ {}_j=2_i < k\ {}_j=1\ k\ {}_j=1;$

where, parameters β_{ij} = 0, 1,.... k, are called the regression coefficients [9].

The final mathematical models for percentage defects, which can be used for prediction within same design space, are given as follows:

In terms of actual factors

% of defects= +5800.72559 + 184.62405*A -2496.09863*B - 64.09819*C -2.03400*A*C + 27.60217*B*C (3)

Table IV. Process Control Limits and their levels

EXPERIMENTAL ANALYSIS

Design-Expert v9 software is used for analysis of the measured responses and determining the mathematical models with best fits. The adequacy of the model is tested using the sequential F-test, and the analysis-of-variance (ANOVA) technique as shown in Table VI using the same software to obtain the best-fit model. L9 array is selected and the % of defects is given as response to get the optimization values. Table V shows the entered response value for further results.

Process parameters	Designation	Range	Factor Levels		
			1	2	3
Clay (%)	A	10-15	10	13	15
Moisture (%)	B	3-3.6	3	3.3	3.6
Mold Hardness (No's)	C	88-93	88	91	93

The fit summary for percentage defect suggests the 2Fl relationship. The ANOVA table of the 2Fl model with other adequacy measures like, R2, adjusted R2 and predicted R2 are given in Table VII.

The Model F-value of 25.81 implies the model is significant. There is only a 1.14% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant.

In this case AC, BC is significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

If there are many insignificant model terms model reduction may improve your model.

TABLE V. Experimental design matrix and experimental results

Std order	Run order	Clay (%)	Moisture (%)	Mold hardness	Response (% of defects)
2	1	10	3	88	14.28
9	2	13	3.3	91	28.57
4	3	15	3.6	93	28.57
7	4	10	3.3	93	14.28
3	5	13	3.3	88	14.28
5	6	15	3.6	91	14.28
6	7	13	3.3	93	28.57
1	8	10	3.3	91	28.57
8	9	15	3	88	42.87

TABLE VI. ANOVA for the percentage defect model

Source	Sum of squares	df	Mean square	F-Value	P-Value	Remarks
Model	846.15	5	169.23	25.81	0.0114	Significant
A	5.64	1	5.64	0.86	0.4221	
B	0.34	1	0.34	0.053	0.8334	
C	44.35	1	44.35	6.76	0.0803	
AC	392.32	1	392.32	59.84	0.0045	
BC	385.9	1	385.90	58.86	0.0046	
Residual	19.67	3	6.56			
Cor Total	865.62	8				

TABLE VII. Adequacy measures

R-Squared	0.9773	Std. Dev	2.56
Adj R-Squared	0.9394	Mean	20.60
Pred R-Squared	0.5880	C.V. %	12.43
Adeq Precision	15.018	PRESS	356.72

EFFECT OF PROCESS PARAMETERS ON RESPONSE

Fig. 9 illustrates the relationship between the predicted and actual values of percentage casting defects. This figure also indicates that the developed model is adequate and predicted results are in good agreement with measured data.

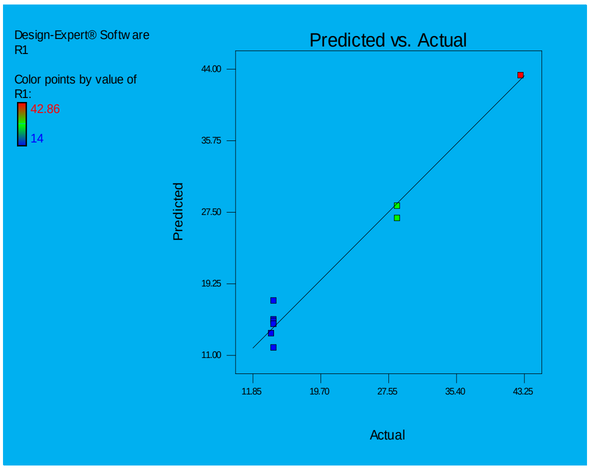

Fig. 9. Plot of Predicted vs. Actual response of percentage casting defects

EFFECT OF PROCESS PARAMETERS ON THE PERCENTAGE OF DEFECTS

The effects of parameters are shown only for significant model terms. It is clear from the Fig. 10 that medium clay percentage and mold hardness provided a better quality of castings. With increase in clay percentage, the defects are also noted to be increasing and also it is clear from the Fig. 11 that medium moisture percentage and mold hardness provided a better quality of castings. With increase in moisture percentage, the defects are also noted to be increasing.

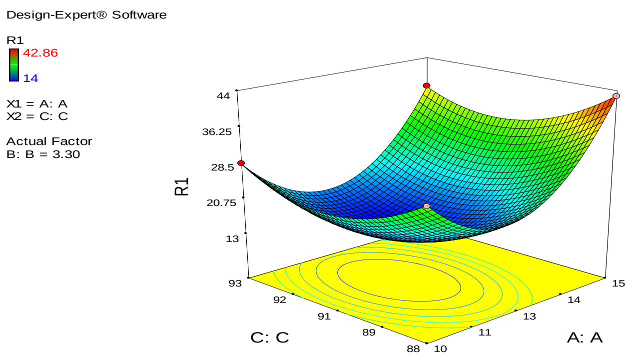

Fig. 10. Response surface plot showing the effect of parameter A and C on percentage of casting defects

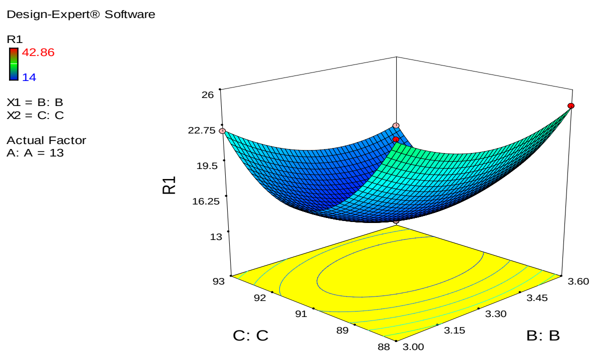

Fig. 11. Response surface plot showing the effect of parameters B and C on percentage of casting defects

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

OPTIMIZATION

Numerical optimization

By numerical optimization, the target or the goal of the experiment can be set. Here the aim is to minimize the defective components in housing castings. From Fig. 12, it was noted that there were 4 possible solutions for minimizing the defect percentage close to zero.

Solutions	Clay %	Moisture %	Mold hardness No	Defects %	Desirability
1	13	3.3	91	11.30	0.998
2	10.1	3.02	88.88	12.82	0.992
3	10	3	88.26	13.39	0.981
4	10	3	88	14.08	0.978

Fig. 12. Optimal conditions obtained by numerical optimization

Confirmation experiments

The main purpose of these confirmation experiments is to validate the setting obtained from Design expert software which is likely to achieve the defect free castings.

TABLE VIII. Optimum setting of parameters

Parameter	Notation	Optimum setting
clay	%	13
moisture	%	3.30
Mold hardness	No	91

A set of 3 confirmation experiments were conducted with the optimal settings producing 30 samples of housing castings.On inspecting the samples for defects, all the 30 castings were found to be defect free.

Hence, the parametric settings may be taken as optimal for producing large quantities of housing castings with minimal or no defects. In general, the use of higher clay content and mold hardness with moderate moisture percentage led to better castings as shown in Table VIII.

E. CONTROL PHASE

In this phase, verification was made whether the current process must be in control after the successful implementation of improvement solutions.

The main purpose of six sigma is not only making process improved but also having the optimum results sustained in long run. Hence, the standardization of the process is required. For that, proper documentation of the process and appropriate training of the people associated with the process should be conducted so that they can able to manage the process effectively. After implementing the optimization setting or revised approach, the product would meet Six-Sigma level and yield good results.

In Control Phase verification was made whether the expected improvements actually occur. The major defects namely SD and SI were analyzed and corrective and preventive action were taken and timely monitor is done for the process in order to ensure sustainability of the achieved results. In addition, the current sigma value is calculated which is found to be approximately 4.39. The rejection percentage declined to 8.73% from 9.18%, and the expected results and improvements were achieved and recommended for further approach.

V. RESULTS AND DISCUSSIONS

In The following are the conclusions drawn out of this study.

1) In this work, parametric optimization for controlling casting defects in LH housing was attempted by Box-Behnken design of experiments (DOE).

2) The major parameters that were responsible for producing casting defects in housing components were identified as proportions of clay, moisture and Mold hardness respectively.

3) Each parameter was analyzed with three different levels. Further the contribution of the parameters was analyzed using ANOVA technique to find their effects. Interaction effects between the factors were also studied. F-Test of the ANOVA revealed the significant parameters in the casting process. These parameters were noted to be more critical in producing quality cast components.

4) The optimized parametric setting was determined by Design expert software: Clay – 13% Moisture – 3.3% Mold Hardness – 91 as a range of values for the input conditions that can be easily practiced by workmen in industries.

5) It can be concluded that the sigma value before improvement is 4.22, while it becomes 4.39 after improvement and rejection % decreases to 8.73 from 9.18.

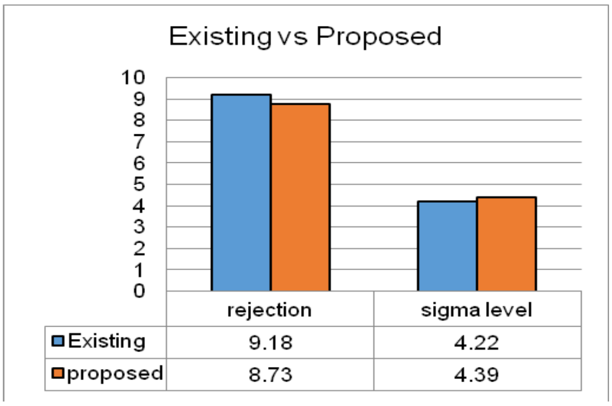

Fig. 13. Comparison of existing and proposed process

VI. CONCLUSION

The industries have become globally competitive in seller's market due to high demand. Hence production quantity is increased where the industries faces high rejection rate. This work presents the step-by-step application of the Six Sigma DMAIC methodology for reducing the rejection rate of casting in an Indian foundry unit. The research findings show that the rejection rate of casting has been reduced from 9.18% to 8.73% for HFB 64 LH Housing item. It substantiated the fact that the efficiency and performance level of the sand-casting process can be improved by adopting the Six-Sigma approach. From this study, it is evident that applied tools detect a greater number of possible failure causes and thus the failures in the production process can be prevented.

REFERENCES

[1] Sachin S,Dileeplal J., "Six Sigma Methodology for Improving Manufacturing Process in a Foundry Industry", International Journal of Advanced Engineering Research and Science,Vol-4, Issue-5, ISSN: 2349-6495(P) | 2456-1908(O),May- 2017.

[2] Vaibhav Ingle, MadhukarSorte, "Defects, Root Causes in Casting Process and Their Remedies: Review", Int. Journal of Engineering Research and Application ISSN : 2248-9622, Vol. 7, Issue 3, (Part -3) March 2017, pp.47-54.

[3] Anujkumar, Naveen kumar, Dinesh kumar, "Defects reduction in brake drum in foundry shop using DMAIC technology", International Journal of Scientific Research Engineering & Technology (IJSRET), ISSN 2278 – 0882 Volume 6, Issue 7, July 2017.

[4] Bhushan Shankar Kamble, "Analysis of Different Sand Casting Defects in a Medium Scale Foundry Industry - A Review", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 2, ISSN(Online): 2319-8753, ISSN (Print): 2347-6710, February 2016.

[5] B. K. Sharma, Manan Shukla, Ganesh Dubey, "Implementation of Lean Manufacturing in Foundry Industry - An Overview", Indian Foundry Journal, Vol. 61, Issue No. 6, June 2015

[6] Avinash Juriani, "Casting Defects Analysis in Foundry and Their Remedial Measures with Industrial Case Studies", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 6 Ver. I (Nov. - Dec. 2015), PP 43-54.

[7] Tejaskumar S.Parsana and Mihir T. Patel, "A Case Study: A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry", Bonfring International Journal of Industrial Engineering and Management Science, Vol. 4, Issue No. 3, August 2014.

[8] Prasan Kinagi, Dr. R.G. Mench, "A Development of quality in casting by minimizing defects", International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME) Vol. 1, Issue 1, pp: (31-36), Month: April 2014 - September 2014.

[9] A.Kumaravadivel and U. Natarajan, "Application of Six-Sigma DMAIC methodology to sand-casting process with response surface methodology", International Journal of Advanced Manufacturing Technology (2013) 69:1403–1420.

[10] Dr D.N. Shivappa, Mr Rohit, Mr.Abhijit Bhattacharya, "Analysis of Casting Defects and Identification of Remedial Measures – A Diagnostic Study", International Journal of Engineering Inventions ISSN: 2278-7461, Volume 1, Issue 6, PP: 01-05, October2012.

[11] S. Subramanian, "Green Sand Practices for Defect-Free castings", The Institute of Indian Foundrymen National Centre For Technical Services

[12] S.R. Devadasan, V. Mohan Sivakumar, R. Murugesh, P.R. Shalij, Lean and Agile manufacturing: Theoretical, Practical and Research Futurities, Prentice Hall India Learning Private Limited, 2012.