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Six Sigma in Manufacturing of Ingot Moulds in Foundry and Pattern Shop by Improving Sand Quality

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ABSTRACT : *The casting industries suffer from low quality production and productivity due to different aspects of process practices, where various process parameters are involved. A study performed in foundry and pattern shop of a steel industry explains various challenges that cause defects in casting. This work controls the sand quality which improves the casting and reduces the defects. Six sigma is control philosophy for reducing the defect vice versa improves the quality. This work also attempt the improvement in sand quality for Ingot mould in Foundry and pattern shop of steel industry where such innovative task has not been performed for achieving the Six Sigma by using the optimization techniques like ANOVA and Taguchi for controlling process parameters by available soft tool platform MINITAB in research society. Some other study methods also been performed for refine the results of research like Process Flow Diagram, Why Why Analysis, Cause And Effect Diagram, Pareto Pie Chart, Analyze Phase, Improve and Control Phase.*

Keywords : *Six Sigma, DMAIC approach ANOVA, Taguchi .*

I. INTRODUCTION

The term sigma is Greek word used in statistics to represent the standard deviation for a set of data which denoted by sigma **( ).** The standard deviation provides the variation of measure data. It also gives the process variation which meets the customer satisfaction. It measure how far a given process deviates from perfection.

- **Six Sigma** – it depends on three factors. Which depend on the context?

First, it's a level of quality. A statistical basis of measurement: 3.4 defects per million opportunities. So it works nearly perfectly.
Second, Six Sigma is a problem solving methodology used in any process. Find the root cause and reduce the defects also it associate costs. It also gives methodology in designing process. It reduces variation in process.
Third, Six Sigma is a management philosophy. It's based on customers who identify the defects, decrease customer satisfaction and increase cost. In today's competitive environment organization provides good service of highest value with lowest cost. Six -Sigma is a method which gives perfect and practically possible results.

- Six- sigma is basically a process based approach in which collects data which includes identify the factors critical to quality (CTQ). It also disciplined, data driven approach to process improvement and finds variation associated with each and every process so that it can be improved variation and reduced these variations.

Second concept is defect. In this point define measurable characteristics or output process which is not acceptable customer limits i.e. goes to beyond in product specification. By using various tools to decrease the variation and defects to provide service and delivery to meets customer requirements. Sigma level is calculated in ratio of defects and number of opportunities for defects.

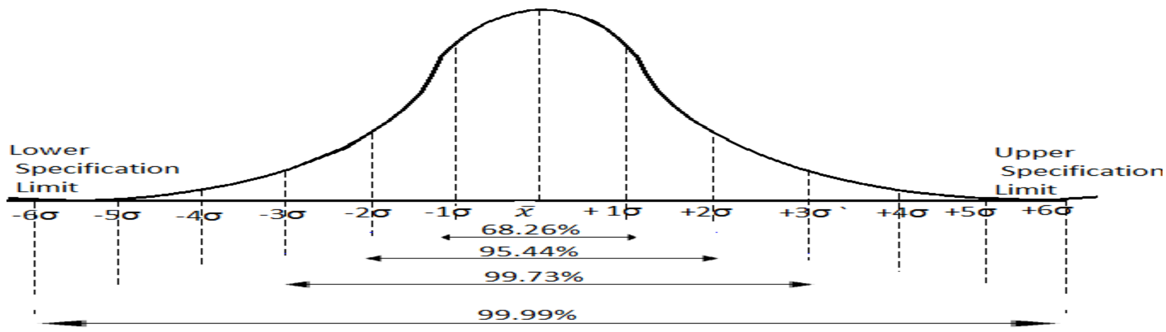

Fig 1.1 Area under the normal curve

Table 1.1 Six Sigma Limits

S. No.	Spec. Limit	Percent	DPMO
1	± 1 sigma	68.26	317300
2	± 2 sigma	95.44	45500
3	± 3 sigma	99.73	2700
4	± 4 sigma	99.9937	63
5	± 5 sigma	99.999943	0.57
6	± 6 sigma	99.999999	0.002

Casting is the first step in the manufacture of metallic component in which the material is liquefied by heating and poured into previous prepared mould cavity where it is allowed to solidify. Removing the solidified component from the mould cavity and cleaned to shape. In casting process there are many defects occur, these defects reduced by different researchers as [1] in a foundry industry. The industry make submersible pumps components such as Upper housing Motor Pulley, Upper housing, Mini Chaff cutter wheel in large scale and rejection comes in the form of slag inclusions in cast iron casting. These parameters were chosen for complete analysis. To minimize the rejection use DMAIC approach. the concept of six sigma [2] which is disciplined, data-driven methodology that was developed to improve manufacturing quality, company Profitability and business process. Many organizations have tried to use Six-Sigma DMAIC approach and its tools to get optimized organizational achievements. The manufacturing industry is explores the level of difficulty and level of usage of different tools of DMAIC approach. Abidakun et al. [3] paper explains Six Sigma DMAIC analysis in an aluminum mill in order to identify sources and causes of waste with provide veritable solutions. DMAIC approaches are justified [4] and minimize sand casting defects when root cause of defect is not traceable. Business strategy used to improve [5] business and efficiency to meet customer needs and expectations. The sand castings control the various parameters with DMAIC technique. The results show that the sand casting rejection due has been reduced from 6.98% to 3.10 % and the defects due to Blow holes were reduced from 2.74% to 0.11% by increasing the permeability and reducing the moisture of sand. Suraj Dhondiram Patil et.al [6] Use of design of experiments (DOE) and analysis of variance (ANOVA) techniques both are combined to determine statistically the correlation of defects with the green strength, mould hardness, and pouring rate also to find their optimum values needed to reduce the defects. Indian foundry rejection rate [7] is one of major issues, so reduce this rejection by modifying method and design the tool to gives better casting quality and increase the production cast. A.Kumaravadivel et.al [8] implement the DMAIC based Six Sigma Approach in order to minimize the occurrence of defects and increase the sigma level of sand casting process.

II. EXPERIMENTAL SETUP AND PROCEDURE

i. Define Phase

The ingot mould section produces the ingot moulds required by the plant. Each ingot mould weights 8.8 T or 9.3T and the daily production of ingot moulds are 17 nos. on average. Previous 15 days data are studied and find some ingot moulds are collapse due to decrease in hardness. For stabilize the hardness find the causes and eliminate it.

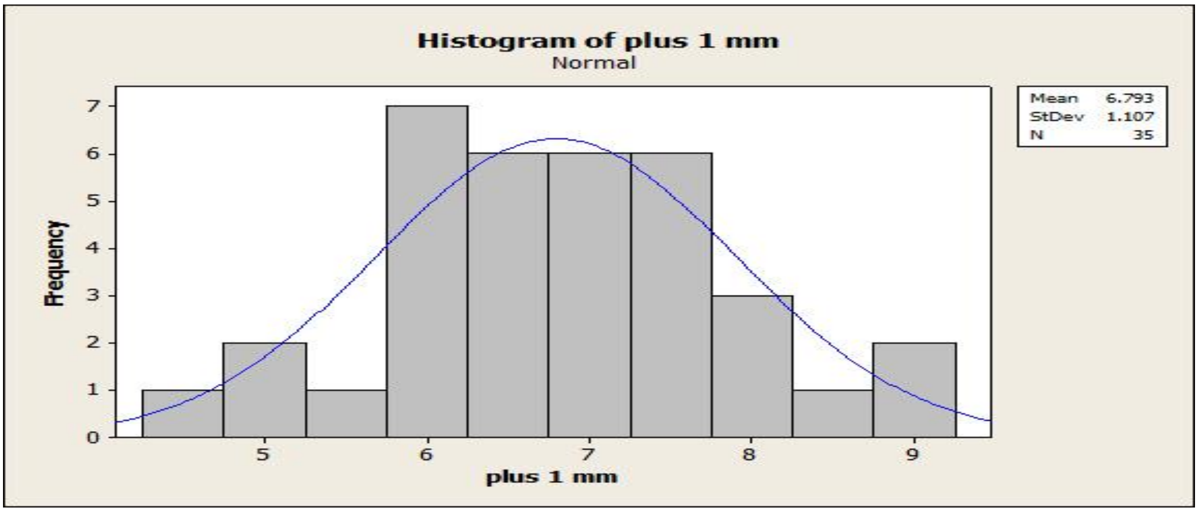

Fig 2.1 Histogram of Plus 1 mm

Figure 2.1shows histogram graph of plus 1 mm. It can be seen from the graph that the mean value of plus 1 mm sand is 6.793 and standard deviation is 1.107.

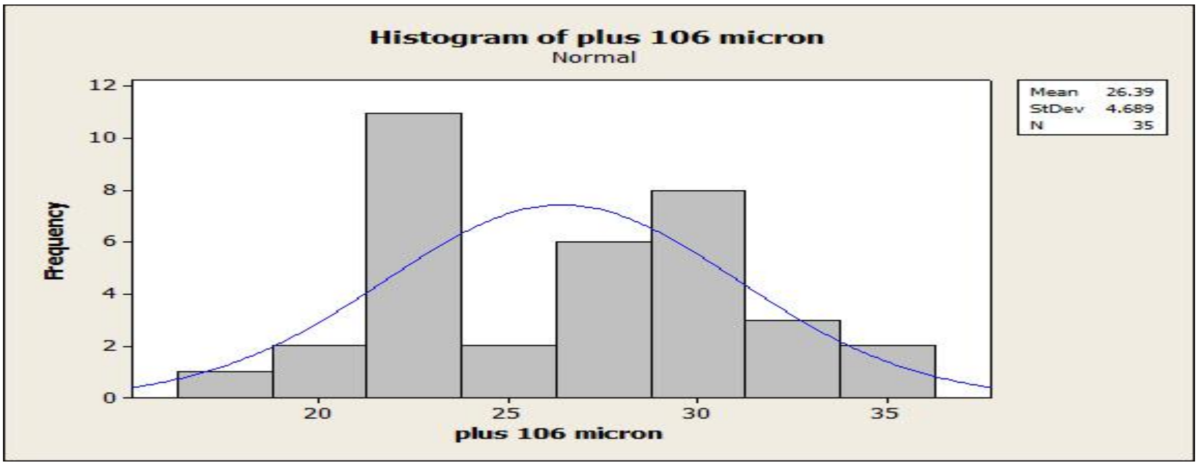

Fig 2.2 Histogram of Plus 106 micron

Figure 2.2 shows histogram of plus 106 micron. This graph shows the mean value of plus 106 mm sand is 26.39 and standard deviation is 4.689.

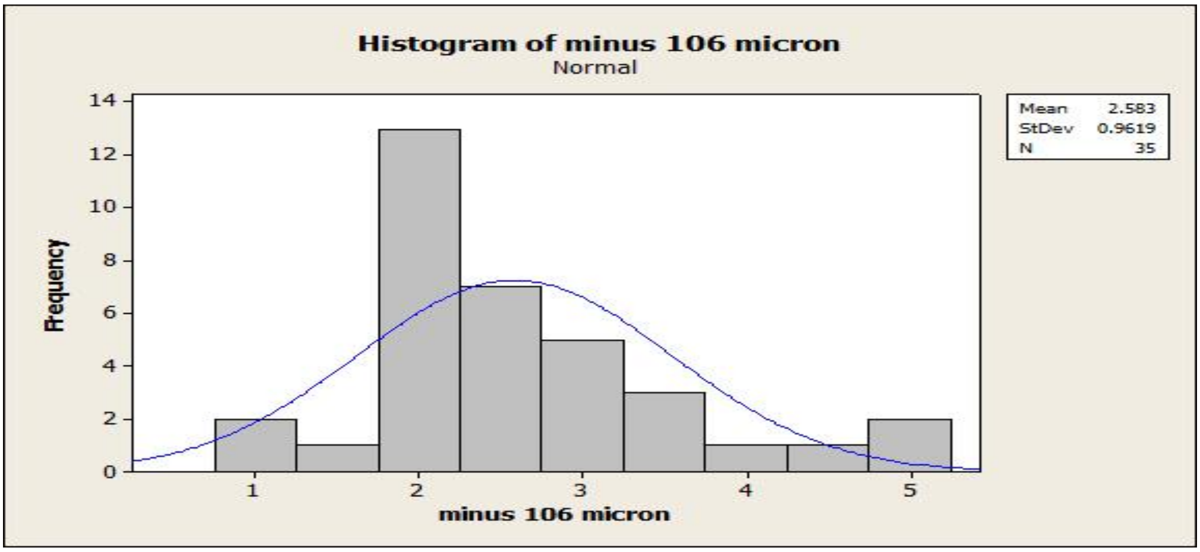

Fig 2.3 Histogram of minus 106 micron

Figure 2.3 shows histogram of minus 106 micron. This graph also indicates the mean value of minus 106 mm sand is 2.583 and standard deviation is 0.9619.

Inference- - Figures 2.1 to 2.3 shows the graphics summary which is obtained by using Minitab software. This Minitab software is used to study the behavior of the process whether the process is normally distributed or not. In these figures the value of mean and standard deviation is also shown.

After analyze these graph, it is found that the three types of sand composition such as +1 mm, +106mm and -106mm are effective in mould quality and hardness of products. So further investigate there causes of these sand deviation to improve quality and hardness.

ii. Measure Phase

a. Cause and Effect Diagram-

It was observed that, with the same resources the production on different days are different due to varying cycle time of the ingot molding so, to find out the root cause of the problem an Ishikawa diagram was constructed as shown in the figure 2.4.

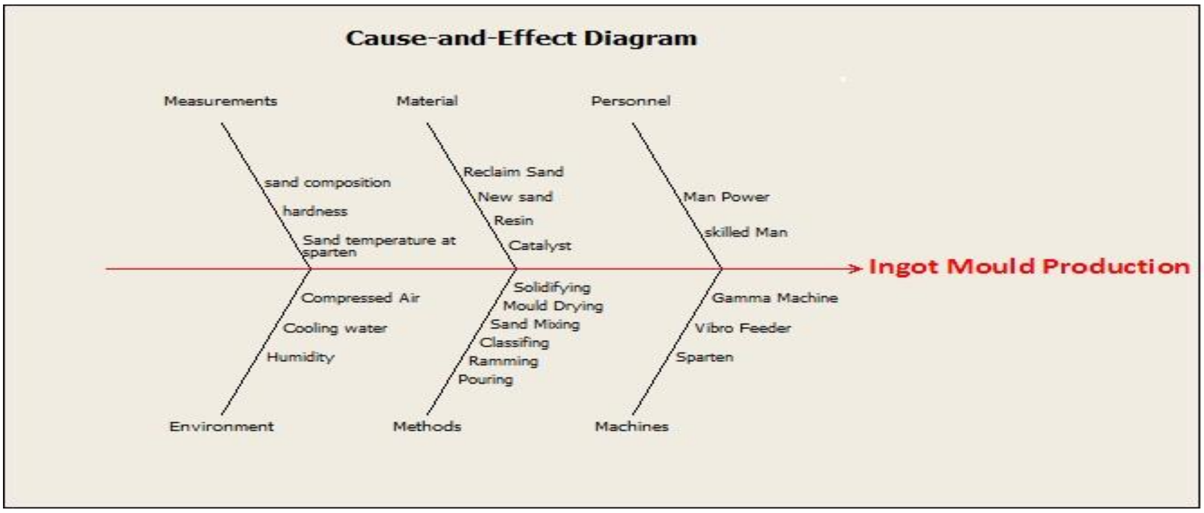

Fig 2.4 Cause-Effect diagram for Ingot Mould production

The workers and officers engaged with Ingot mould production were discussed for finding out the reasons for decreasing of hardness. The reasons were discussed based upon 5M's and environment.

Inference: - The cause and effect diagrams is used to find out the probable causes that are affecting the final output of the process, in this project after discussing with the group the causes are shown in the figure.

b. Pareto Chart-

Previous data of production of ingot mould are gathered and categorized as follows

- Type A +106 Micron
- Type B -106 Micron
- Type C +1 mm
- Type D Other

A Pareto chart was constructed to know the contributions of various complaints as shown in figure 2.5.

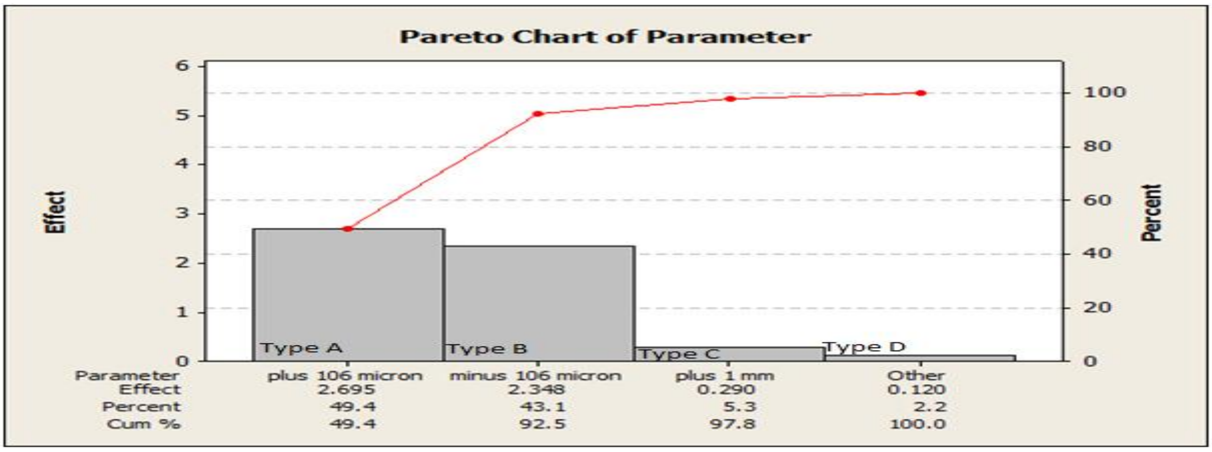

Fig 2.5 Pareto chart of parameter which effect on hardness

iii. Analysis Phase

In this phase, why why analysis is used to analyze the problem of machine performance, man power and material . Analysis is shown in table 2.1 , 2.2 and 2.3 respectively.

WHY WHY analysis

Table2.1 WHY WHY analysis for machine performances

WHY WHY analysis for machine performances		
Why?	**Answer**	**Action**
Why ingot mould production is less?	Machines are not working well	Check machines properly
Why machines are not working properly?	Machines are not maintained properly	Machines to be maintained properly
Why machines are not maintained properly?	Machines are in use continuously	No other option available
Why machines are in use continuously?	Shortage of machines	Management problem

Table2.2 WHY WHY analysis for man power

WHY WHY analysis for man power		
Why?	**Answer**	**Action**
Why ingot mould production is less?	In adequate number of manpower	Beyond Shop control
Why less number of man power?	No new recruitment	Effective utilization of manpower
Why manpower is not utilized properly?	Absenteeism	To be improved
Why Absenteeism?	Indiscipline	Personnel problems
Why indiscipline?	Improper coordination	Coordination to be improved

Table 2.3WHY WHY analysis for material

WHY WHY analysis for material		
Why?	**Answer**	**Action**
Why ingot mould production is less?	No sand in silos	Silos to be filled
Why silos are not filled?	Machines are not working properly	Machines to be maintained properly
Why machines are not working properly?	Input sand is not up to the mark	Sand is to be checked
Why sand quality is not good?	Improper composition	Proper mixing should be there
Why improper composition?	Proper sand is not used	Allahabad sand is to be purchased

Inference:-

From why why analysis it is noted that the reason for less production of ingot mould is poor performance of machines, less number of man power and poor quality of input sand. It is also evident from the above analysis, the prominent reason for less production of ingot mould is poor quality of input sand whereas other two cases it is not.

So it was decided to find out the root cause within the sand composition, which is affecting the production parameters**.**

Why Why Analysis for other measures such as method, environment etc. are not done as they are not prominent reasons.

iv. Improve Phase

This phase statistically reviews the variations in the process and determines what factors significantly contribute to the output. The main goal of this Improve phase is develop optimal solutions of the problems. The optimization process involves the large number of key process input variables to determine the greatest impact few variables of process. Taguchi is a statistics method that aims to understand variation instead of conducting many experiments and is used to provide experiment runs.

a. Taguchi-based experimental design

The Taguchi-based experimental design used in this study was an L27 orthogonal array and is shown in Table 4 the controllable factors for orthogonal array design. These control factors were classified low, medium, or high. The control factors are mainly divided in three levels as show in Table 4.

Process Parameter	**Unit**	**Level and Value**		
		1	**2**	**3**
1 mm sand	mm	6.24	7.68	9.12
+106 micron sand	micron	22.083	28.066	34.050
-106 micron sand	micron	2.88	4.04	5.20

b. **Analysis of Variance (ANOVA)**

Analysis of variance (ANOVA) is used to test significant differences involving two or more means by comparing variances in groups. ANOVA calculate the amount of variation in a process and determine if it is significant comes due to random noise which is input that consistently comes randomly and expected variation in output. Also partitioned the total variation which comes into different sources and compare the variance due to inconsistency between groups or treatments of variance due to inconsistency between groups.

Source: The source of the variation.
DF: Degrees of freedom associated with each SS (sums of squares, a measure of the variation between the samples). It measures how much "independent" information is available to calculate each SS.
SS: Amount of variability in the data due to different sources**.**
MS: The sum of squares divided by their respective degrees of freedom.
F: Determines if the defects of operator, part or operator × part significantly impact the measurement.

v. Control Phase

The last phase is control phase and the purpose of this phase is to sustain the benefits of the new process and to ensure that previous problems do not resurface. For complete success of Six Sigma, proper documentation of the process is recommended. The critical process parameters are continuously monitored and documented to update the information.

The following actions were planned and taken.

- Maintain proper input sand composition and proper cooling.
- Control dust extraction. Skilled persons required to open and closed the valve.
- Also resin and catalyst composition is mixed with sand is properly.

Sand conveying time, stripping, dry oven, pouring is equal interval of time.

III. RESULT AND DISCUSSION

On the basis of experimental work, performance measure i.e. hardness is calculated. All the works are summarize in the form of table. Table 5.1 shows experimental results and S/N ratios for hardness.

Table 3.1 Experimental results and S/N ratios for hardness based on L27 (3^3) array

Run no.	**1 mm sand**	**+106micron Sand**	**-106 micron Sand**	**Hardness**	**S/N Ratios**
1	6.24	22.083	2.88	32	30.1030
2	6.24	22.083	4.04	30	29.5424
3	6.24	22.083	5.20	26	28.2995
4	6.24	28.066	2.88	34	30.6296
5	6.24	28.066	4.04	26	28.2995
6	6.24	28.066	5.20	24	27.6042
7	6.24	34.050	2.88	32	30.1030
8	6.24	34.050	4.04	26	28.2995
9	6.24	34.050	5.20	26	28.2995
10	7.68	22.083	2.88	30	29.5424
11	7.68	22.083	4.04	26	28.2995
12	7.68	22.083	5.20	24	27.6042
13	7.68	28.066	2.88	30	29.5424

14	7.68	28.066	4.04	26	28.2995
15	7.68	28.066	5.20	24	27.6042
16	7.68	34.050	2.88	28	28.9432
17	7.68	34.050	4.04	32	30.1030
18	7.68	34.050	5.20	28	28.9432
19	9.12	22.083	2.88	34	30.6296
20	9.12	22.083	4.04	30	29.5424
21	9.12	22.083	5.20	24	27.6042
22	9.12	28.066	2.88	32	30.1030
23	9.12	28.066	4.04	30	29.5424
24	9.12	28.066	5.20	24	27.6042
25	9.12	34.050	2.88	30	29.5424
26	9.12	34.050	4.04	30	29.5424
27	9.12	34.050	5.20	30	29.5424

Fig. 3.1 shows the main effect plot for hardness based on the values of S/N ratio. Main effect plot shows the individual effect of process parameters on the hardness.

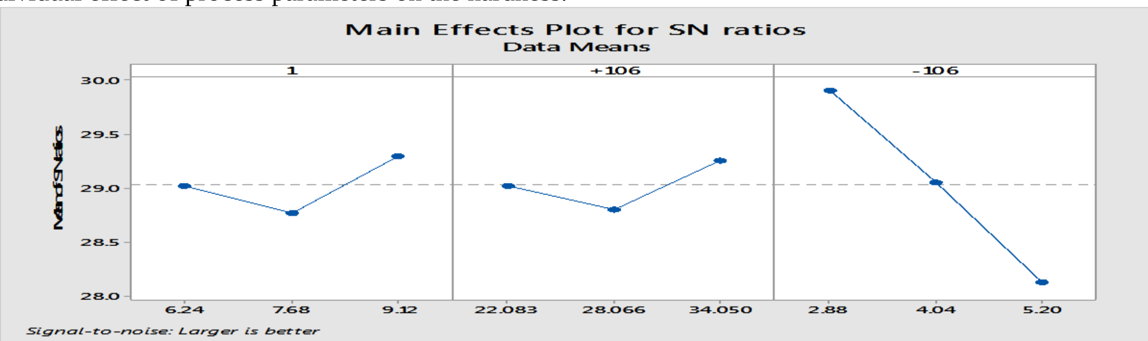

Fig 3.1 Main effect plot for hardness based on S/N ratios

Points comes out from main effect plot is listed below;

- Effect of 1 mm sand indicated that hardness initially decreases at certain level (i.e. from 6.24 to 7.68) and after that hardness level increases (from 7.68 to 9.12) as increase the quantity of 1 mm sand. So 1 mm sand has least significant factor on hardness.
- Effect of +106 micron sand behavior is same as 1 mm sand observed that hardness initially decreases at certain level and after that level of hardness increases as increase the quantity of +106 micron sand and it has least significant factor on hardness.
- -106 micron sand shows the major significant factor on hardness. It observed that when -106 microns sand increases hardness decreases. So the quantity of -106 micron sand is minimum as possible.

Fig. 3.2 shows interaction plot for hardness between sand qualities (1mm, +106 micron, -106 micron) and hardness.

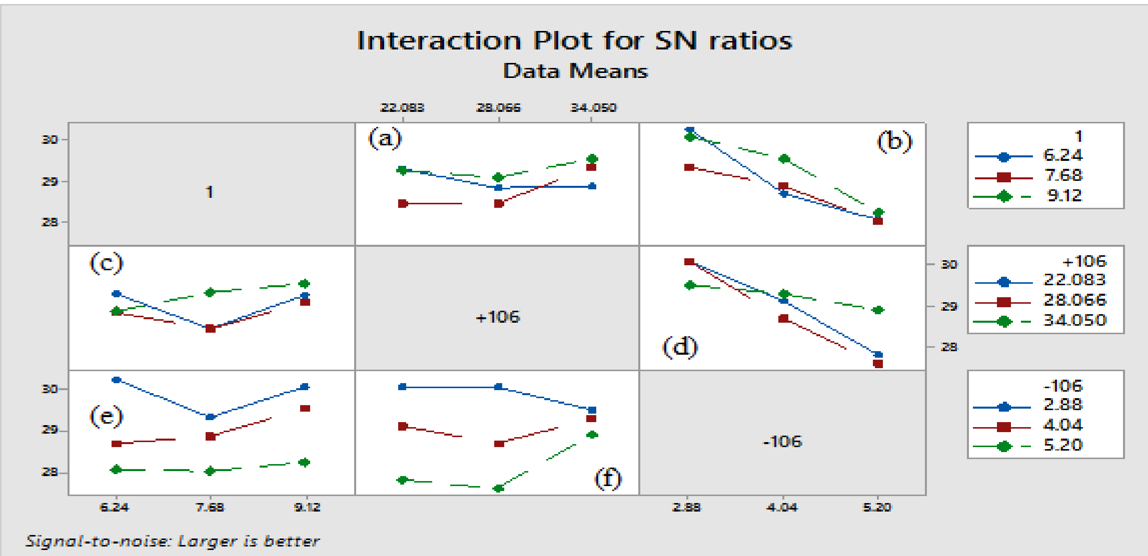

Fig 5.2 Interaction plot for hardness

Table 3.2 SN ratio parameters

S. NO.	Graph Representation		Input Parameter
1	For 1mm	(a)	+106 and hardness
2		(b)	-106 and hardness
3	For +106 μ	(c)	1 and hardness
4		(d)	-106 and hardness
5	For -106 μ	(e)	1 and hardness
6		(f)	+106 and hardness

Residual plot of hardness is shown in fig. 3.3. This layout is useful to determine whether the model meets the assumptions of the analysis.

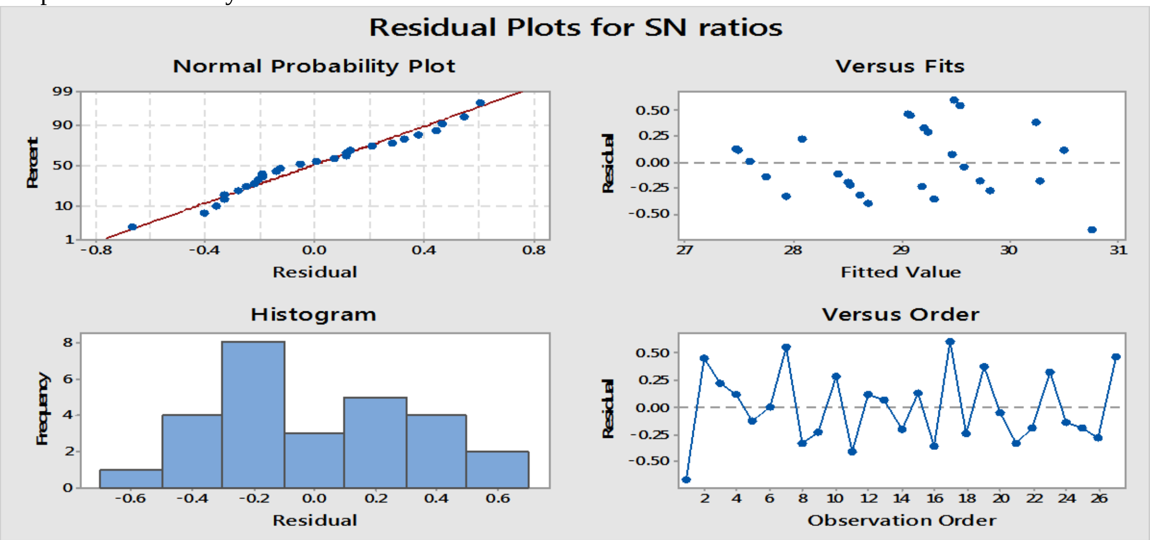

Fig 3.3 Residual plots for hardness

The residual plots in the graph and the interpretation of each residual plot indicate below:

- Normal probability plot indicates the data are normally distributed and the variables are influencing the response. Outliers don't exist in the data.
- Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliners exist in the data.
- Histogram proves the data are not skewed and no outliners exist.
- Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order.

Table 3.3 is response table for s/n ratio, for calculation Larger is better methodology is adapted to calculating these value. Values inside the table are the average s/n ratio for parameter in that particular level. According to that values factor delta is calculated and higher to lower values of delta represent the rank of the parameter. Higher rank shows that parameter is having more effect on the hardness. In this case -106 micron sand is having rank 1^{st}.

Table 3.3 Response table for signal to noise ratio larger is better (hardness)

Level	**1 mm sand**	**+106 micron sand**	**-106 micron sand**
1	29.02	29.02	29.90
2	28.76	28.80	29.05
3	29.29	29.26	28.12
Delta	0.53	0.45	1.78
Rank	**2**	**3**	**1**

5.1 ANOVA analysis

Table 3.4 is ANOVA table for hardness, which showing the factor degree of freedom, sum of square, mean square, f- value and percentage contribution.

For calculating degree of freedom;

Degree of freedom = level- 1

Other factors are calculated using mathematical expression describe in previous chapter. Here main factor which having importance in % contribution. Percentage contribution means parameters contribution on hardness. In this case -106 micron has been highest contribution on hardness.

Table 3.4: Analysis of variance for hardness

Source	DOF	Sum of squares	Mean square	F value	% contribution
1mm	2	1.2655	0.6327	1.80	7.67
+106micron	2	0.9299	0.4650	1.32	5.64
-106 micron	2	14.2898	7.1449	20.34	86.68

IV. CONCLUSION

In this study, DMAIC based Six Sigma approach implemented to optimize the processes parameters and performance level of the casting process can be improved by using ANOVA and Taguchi method of experimental design is used to analyze the optimum levels of individual process parameters which is affecting the casting process. Apart from other administrative reasons, it can be concluded that the sand composition plays a major role in productivity of the system. The following observations are made:

1. Dust content i.e. particles below 106 micron affect the sand flow in pneumatic conveying system; higher dust content will reduce the volume of sand conveying.
2. High dust content also increases the volume of resin and catalyst.
3. High dust content of the moulding sand affects the permeability of the mould thus the quality of the casting.
4. Dust in the system tends to clog the filters more frequently.

Dust seats on the fins of the cooling coil, hence reducing the efficiency of the cooling system, this eventually results in to mould collapse due to hot sand. The binders loose effectiveness in hot environment.

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