Application of Six Sigma Approach for Improving Steel Quality – A Case Study

[1]K.G.Durga Prasad,[2]M.V.Prasad, [3]B.Lakshmi Manasa

[1]Associate Professor, [2,3]Assistant Professor
[1, 2]Department of Mechanical Engg.,School of Engineering, Gayatri Vidya Parishad College for Degree & P.G.Courses (A), Visakhapatnam, Andhra Pradesh, India.
[3]Department of Mechanical Engg., University College of Engineering, JNTUK, Kakinada, Andhra Pradesh, India.

***Abstract:* The application of six - sigma methodology to enhance steel quality in a steel manufacturing industry is demonstrated in this paper through a case study. Six sigma five phase methodology i.e., DMAIC is adopted in this study. The presence of non-conformance of phosphorous content to the specification is the most significant cause for obtaining Off Grade steel, which is identified through Pareto analysis in the definition phase. In the measure phase, the process capability indices are calculated using base line statistics. Cause and Effect diagram is prepared in the analysis phase to identify the potential factors which influence the Phosphorous content in steel. Design of experiments is employed in the improvement phase to identify the ways to improve the process so as to reduce the Off Grade steel. Finally, in the control phase, the improved system is monitored by using process capability analysis.**

***Index Terms:* Six sigma, Off Grade steel, Process capability indices, Cause and Effect diagrams, Pareto Diagram.**

I. INTRODUCTION

The Indian steel industry is more than 100 years old now. India has emerged as the fifth largest producer of steel in the world. The production of steel in India is expected to reach 275 million tons by 2020 which could make it the second largest steel producer in the world. But, the steel industry needs to strive for attaining the expectations of the customer with respect to steel quality and grade requirements. Matching global standards is a major challenge which essentially accentuates product quality, cost competitiveness and customer satisfaction. In view of this, there is a need to develop economical processes for the production of steel with low contents of sulphur, phosphorous, nitrogen and other oxide inclusions. It is necessary to reduce the generation of non-conformities in manufacturing and efforts should be channelized to eliminate the activities that do not add any value to the process. To make the processes capable to satisfy the customers, a quality approach is needed. Six sigma is a quality management strategy, which can be used to reduce the off grade steel.

Six sigma is a well-structured, data driven methodology for eliminating defects, waste or quality control problems of all kinds in manufacturing, service delivery, management and other business activities. The Six sigma story began in the 1980s at Motorola and its philosophy has found extensive application in many manufacturing industries [1].Six sigma provides a scientific and statistical basis for quality assessment for all processes through measurement of quality level. Naidu (2011) adopted six sigma solutions to reduce the down time of Electric arc furnace and Billet casting machine in steel manufacturing company [2]. Zeman et al., (2013) implemented six sigma methodology in reducing rejection in a welding electrode manufacturing industry [3]. In the present global competition, it is necessary to reduce the production of non-conformities in manufacturing, which can be accomplished by implementing six sigma. The purpose of this paper is to demonstrate the application of six sigma methodology in steel melting shop to minimize the non-conformities with respect to chemical composition. The rest of the paper is organized as follows. The proposed six sigma methodology is discussed in Section 2. In the Section 3 case study is presented and finally conclusions and future scope for the work are presented in Section 4.

II. SIX SIGMA METHODOLOGY

Six sigma is a powerful tool to achieve customer satisfaction by improving the processes in any system, which may be production or service sector [4]. The name Six sigma refers to the capability of the process to deliver units within the set limits. According to the Six Sigma approach, for a stable process the distance from the process mean to the nearest tolerance limit should be at least six times the standard deviation (σ) of the process output [5]. In order to achieve six sigma quality, a process must produce not more than 3.4 defects per million opportunities if the output is normally distributed. A defect can be any type of product or service that does not conform to a standard inspection unit or satisfy the customer. In addition a defect can be an error in a product or service. The term “opportunity” is defined as a chance for nonconformance, or not meeting the required specifications. Six sigma methodology is intended for process improvement which includes different phases logically linked with one another. The methodology of Six sigma is generally described by the acronym DMAIC (Define, Measure, Analyze, Improve and Control) is used for continuous improvement of already existing products or processes [6]. The each phase of the methodology is discussed in the following paragraphs.

Define phase:

The goals of the improvement activity are clearly defined in this phase. At the top level the goals will be the strategic objectives of the organization, such as a higher return on investment (ROI) or market share. At the operations level, a goal might be to increase the throughput of production department. At the project level goals might be to reduce the defect level and increase throughput. The parameters which greatly influence the goals of the enterprise in respect to quality are called critical to quality (CTQ) parameters. In the process of defining the goals CTQ parameters have to be identified. Pareto analysis may assist the six sigma team to establish CTQ parameters.

Measure phase:

In this phase past data pertaining to CTQ s is collected. The baseline statistics such as sample mean (μ), standard deviation (σ) and process capability indices Cp and the Cp_k for each CTQ are calculated. The mean is the simple average of the observations in a data set. The Sample mean is determined by adding all observations in a sample and dividing the number of observations in that sample. Standard deviation measures the variability of the observations around the mean. It is equal to the positive square root of variance. The variance also measures the fluctuations of the observation around the mean. The larger is the value, the greater is the fluctuation. The process capability index is an easily understood aggregate measure of the goodness of process performance.

Analyze phase:

Critical analysis is carried out in this phase with the help of Cause and Effect diagram. The Cause and Effect diagram is used to identify and systematically list the different root causes that can be attributed to a problem. Thus, these diagrams help to determine which of several causes has the greatest effect. The main application of these diagrams is the dispersion analysis. In dispersion analysis, each major cause is thoroughly analyzed by investigating the sub causes and their impact on quality characteristics. The Cause and Effect diagram helps to analyze the reasons for any variability or dispersion.

Improvement phase:

In this phase, the new ways have to be created to improve the existing system. The various project management and other planning tools help to improve the system. Design of experiments (DOE) is one of the approaches to improve the process. DOE is a test or series of tests in which purposeful changes are made to the input variables of a process so that it can be observed the corresponding changes in the output response. The next step is to optimize the changes of input variables to attain the best possible response. To locate the optimum combination of input variables, a factorial experiment is required.

Control phase:

The control phase aims to institutionalize the improvement results from six sigma through documentation and standardization of the new procedures. It includes the setting up of monitoring and process control systems [7]. In this phase control charts are prepared in respect of CTQs to sustain the quality improvement. These charts are used to monitor the performance of the system.

III. CASE STUDY

A case study has been under taken in an integrated steel plant located in southern India. The plant was commissioned in August 1992 with a capacity to produce 3 million tonne per annum of liquid steel. The present study is mainly carried in Steel Melting Shop (SMS) of the steel plant with a view to reduce the off-grade steel. The study also focused on investigating the combination of different levels of the most important factors that affect the performance of steel making with respect to quality and to provide the set of optimum operating levels for the process variables that minimize the process variation. The one of the chronic problems during steel making in the SMS is the production of off-grade steel which is about 2.3%.The table1 shows the data pertaining to steel grades for the past six months.

Table 1: Data on diverted heats

Month	No. of heats diverted	% of heats diverted	Grade-wise and element-wise breakup of diverted heats										
			Grade-wise						Element-wise				
			2831	WTP	MSOFF	MCOFF	HCOFF	Other	C	P	S	Si	Mn
01	26	1.3	5	12	2	5	2	-	6	18	-	1	1
02	26	1.5	7	12	1	1	5	-	5	20	1	-	-
03	42	2.0	7	22	-	3	5	4	12	24	1	4	-
04	49	2.6	17	11	7	3	9	2	14	29	4	1	1
05	84	3.1	15	14	7	9	19	20	19	45	20	-	-
06	54	2.9	12	18	2	6	15	1	15	25	14	-	-

In order to identify the most significant causes, Pareto diagram shown in figure 1 is constructed for the data mentioned in the table1.

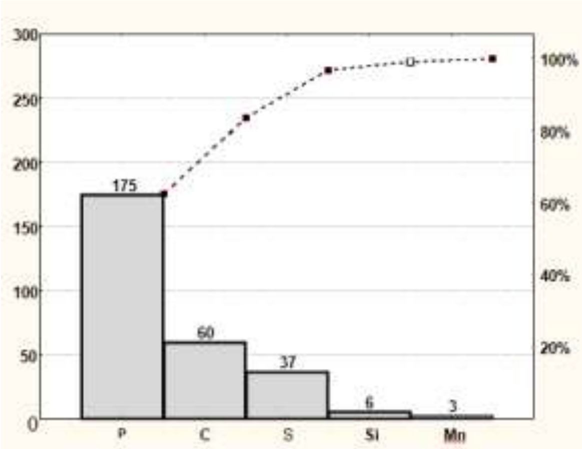

Fig.1: Pareto diagram

From the Pareto analysis it is observed that 60 % of the problem is due to phosphorus, about 20 % is due to carbon and about 17 % is due to sulfur. It is necessary to deal with phosphorous from vital few, which is a major contributor for non-conformities. Now the variation of phosphorous content of steel is to be measured. Twenty samples for the low carbon steel (1008 grade), medium carbon steel (MC) and high carbon steel (HC) are considered for the present study. The process capability indices (Cp, C_{pk}) for 1008, MC and HC are computed for all the grades and are shown in table 2.

Table 2: Values of Cp, C_{pk} for all grades of steel

Sample Grades	***USL***	***LSL***	**σ**	***Cp***	C_{pk}
1008	0.040	0	0.0063	1.058	0.64
MC	0.045	0	0.0064	1.172	0.48
HC	0.030	0	0.0578	0.087	0.30

From the table 2, it is observed that phosphorous in all the steel grades is not at a variation of 6σ level. Therefore it is necessary to analyze and identify the potential factors which influence the phosphorous in steel. The root causes are identified by constructing the cause and effect diagram shown in figure 2. The most significant causes are the opening temperature (first temperature measured after a blow is finished), tapping time (time taken to pour liquid steel into the ladle from converter), holding time (idle time between blow finish and tap start), percentages of MgO and FeO in slag and heat weight in tonnes.

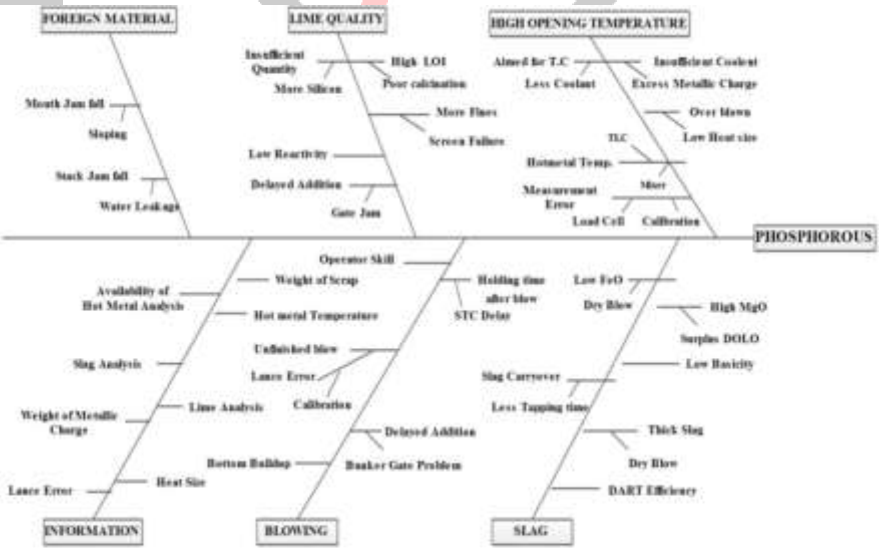

Fig. 2: Cause and Effect diagram

In order to know the effect of these factors, 2^2 factorial design is considered. The four combinations are chosen for 2^2 factorial design are (i) opening temperature and tapping time (ii) opening temperature and holding time (iii) slag FeO and slag MgO (iv) slag FeO and heat weight. Two levels were chosen for each factor shown in table 3.

Table 3: Levels of the factors

Sl.No	Factors	Level-I	Level-II
1	Opening temperature (OT) in °C and Tapping time (TT) in min.	1680°C, 4 min	1730°C, 4 min
2	Opening temperature (OT) in °C and Holding time (HT) in min.	1680°C, 4 min	1730 °C, 12 min
3	Slag MgO(%) & Slag FeO(%)	8 % & 14 %	12 % & 24 %
4	Slag FeO(%) & Heat Weight in tonnes	14 % & 125 T	24 % & 150 T

The factor effect estimates for all the factors are calculated and are shown in table 4.

Table 4: Estimates of factor effects

Factor	Effects	Factor	Effects	Factor	Effects	Factor	Effects
OT	14.4375	OT	24.93	Slag MgO (%)	10.3750	Slag FeO (%)	−12.7500
TT	−12.5625	HT	7.18	Slag FeO (%)	−20.3750	Heat weight (t)	9.0000
OT and TT	−1.8125	OT and HT	7.81	MgO and FeO	−1.3750	FeO and Heat weight	3.1250

Analysis of variance (ANOVA) helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. The F-test is carried with a view to identify the significant effect of the factor on enhancing steel quality. The ANOVA results are shown in table 5.

Table 5: ANOVA results for all the factors and its combinations

ANOVA Table for OT and TT					
Source of Variation	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**F**	**P-value**
OT	1667.531	1	1667.531	274.04	0.000000
TT	1262.531	1	1262.531	207.488	0.000000
OT and TT	26.281	1	26.281	4.31	0.046968
Error	170.375	28	6.085	-------	--------
ANOVA Table for OT and HT					
OT	4975.031	1	4975.031	648.2880	0.00
HT	413.281	1	413.281	53.8540	0.00
OT and HT	488.281	1	488.281	63.6271	0.00
Error	214.875	28	7.674	----	----
ANOVA Table for Slag MgO (%) and Slag FeO (%)					
Slag MgO (%)	861.125	1	861.125	52.3594	0.00
Slag FeO (%)	3321.125	1	3321.125	201.9359	0.00
Slag MgO (%) and Slag FeO (%)	15.125	1	15.125	0.9197	0.34
Error	460.500	28	16.446	-----	-----
ANOVA Table for Slag FeO (%) and Heat Weight					
Slag FeO(%)	1300.500	1	1300.500	52.90810	0.000000
Heat weight	648.000	1	648.000	26.36251	0.000019
Slag FeO (%) and Heat Weight	78.125	1	78.125	3.17835	0.085467
Error	688.250	28	24.580	-----	-----

It is observed from the table 5, that the factor combination OT and HT possesses higher F value (i.e., 63.6271) compared to other factor combinations. This indicates that the OT and HT combination will have more significant impact on phosphorous content in steel. The interaction plot and contour plot for opening temperature and holding time are shown in figure 3(a) and figure 3(b) respectively.

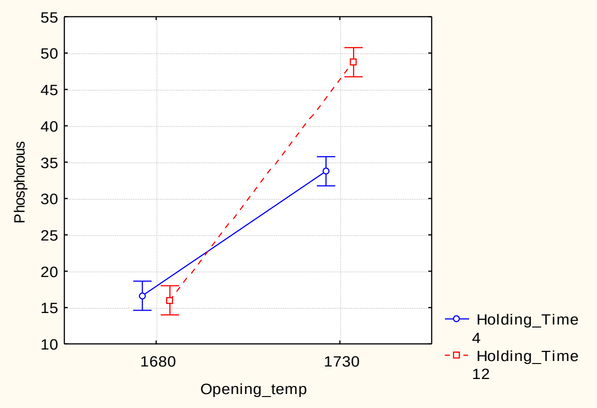

Fig. 3(a): Interaction plot

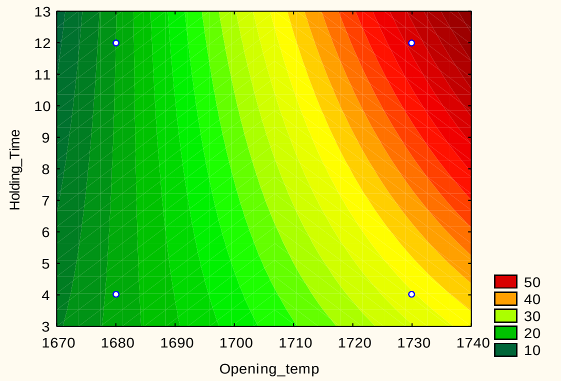

Fig. 3(b): Contour plot

The contour plot shows the various combinations of OT and HT so as to achieve the desired level of phosphorous 0.03%. The table 6 shows the appropriate operating levels of OT and HT to meet desired level of phosphorous.

Table 6: Proposed operating levels for Opening temp and holding time

Opening Temperature (°C)	**Max. Holding time** (min.)
1690	12
1700	11
1710	7
1720	4

IV. CONCLUSIONS

In this paper DMAIC procedure of six sigma is employed to produce high quality steel in steel manufacturing company. The vital cause for off grade steel is phosphorous which is identified through Praeto analysis. The cause and effect diagram is prepared to understand the various factors which influence on the presence of phosphorous content in steel. In this work two factors each at two levels are considered by adopting 2^2 factorial design. The opening temperature, holding time has significant interaction effect on phosphorous response. The operating levels for opening temperature and holding time are proposed to maintain the desired levels of phosphorous in steel. The work can be extended to study the effects of other elements such as carbon and sulphur and other process variables on reducing non-conformities in steel making.

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