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PROCESS OPTIMIZATION IN STEEL INDUSTRY USING DMAIC ANALYSIS

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Abstract: *Optimization of a manufacturing process results in higher productivity and reduced wastes. In this project, production parameters of a local steel bar manufacturing industry are to be optimized by using - Define, measure, analyse, improve, and control (DMAIC) methodology. The main aim of the research was the identification of the significant factors that affects the product quality of TMT bar, and the methodology to optimize the TMT steel bar manufacturing process to improve the product quality. Conducted a study on the selected steel industry and identified a problem concerning the quality of the product, which provides a scope for the improvement of the production process. Production data is collected and analysed to identify significant factors affecting process performance and their effect on product quality. The significant factors are identified and controlled to optimized level using factorial experimentation. Different softwares like MS Excel, Minitab etc. is used for the analysis and measurement. The sigma level of the manufacturing process is improved.*

Keywords— TMT steel bar, DMAIC, Minitab, Sigma level

1.INTRODUCTION

Manufacturing industries worldwide are undergoing a revolutionary change in operations since 1980's. Consumers became more demanding and quality concerned. Nowadays the key factor in the survival of the organization is customer satisfaction. The increased customer demand and the presence of competitors force the industry to improve the product, processes and services. Process optimization is essential to reduce production variation and achieve higher yield. Process optimization has ever remained a serious problem in manufacturing industries particularly steel manufacturing. This study is focused on steel industry which manufactures TMT bars. TMT bars or Thermo-Mechanically Treated bars are high-strength reinforcement bars having a tough outer core and a soft inner core. It has a wide variety of applications like concrete reinforcement structures, bridges and flyovers, dams, etc.

In this project a study on quality improvement through process optimization is carried out in a steel manufacturing industry. The methodology used was DMAIC analysis. DMAIC (Define, measure, analyze, improve, and control) analysis is a data-driven quality strategy used to improve processes. As part of the DMAIC analysis, a detailed study is carried out in the steel industry and identified the process parameters in the TMT manufacturing process. Various tools and techniques are used to conduct DMAIC analysis. The Critical to Quality (CTQ) factors of the TMT bar are identified. Similarly, the Key performance input variables (KPIV) are identified and their effect on the CTQs are analysed. Here an attempt has been made to conduct Design of Experiments (DOE) to select a set of optimal combination of process parameters to get a desired value of Yield.

2. LITERATURE REVIEW

Shigemori et al. [1] conducted study on a steel manufacturing process. The quality design steel with a given specification is produced efficiently using a Just-In-Time based linear regression model. Stefan Markulik [2] describes the focuses on the search for the root causes of the occurrence of foreign material rolling. The 4M method (man, machine, method, and material) was used to categorize the causes. K. I. Ahmad et al. [3] states that number of approaches in quality improvement, viz, lean, six sigma, PDCA, 5S etc, can be employed to achieve the desired level of quality taking into consideration the intricacies of the organization. This journal will provide a guideline to approach for improving quality and productivity improvement in rolling products.

Sabiya. K [4] discusses work, lean techniques are applied to the manufacturing of random rods at a leading manufacturing company of TMT reinforced bars to reduce the scrap. MUDA concept of lean technique is applied here. Gaur et al. [10] in his work suggests proper control of final quenching temperature leads optimum strength with high UTS/YS ratio. The basic requirements of rebars nowadays are low-cost deformed bars with yield strength of 500N/mm2 with adequate ductility for the seismic zones. Nearly about 55 to 60 per cent of India falls under the seismic zone.

Linderman et al. [5], defines Six Sigma as an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and scientific methods to make dramatic reductions in customer defined defect rates. Six Sigma has its origin in quality engineering, which traditionally had a strong emphasis on statistical methods. Lokkerbol [6] in his work describes The DMAIC (Define-Measure-Analyze-Improve-Control) method in Six Sigma as an approach for problem solving.

Various application of DMAIC analysis in different industries are available. Gupta, et al. [7] demonstrates, the six-sigma DMAIC phases application to enhance the process capability (long term) for bead splice. In every phase of DMAIC method, a compound of both techniques qualitative as well as quantitative was utilized. Jadhav, et al. [8], addresses the problems that are facing in a large steel company in a developing country like India regarding defects in the end product. Khawar et al. [9], Production parameters of a local steel bar manufacturing industry is optimized by using six Sigma-Define, measure, analyze, improve, and control methodology. In this they identify the significant factors along with the optimum levels that affects the process yield, and the methodology to optimize the steel bar manufacturing process.

Design of experiments (DOE) is a systematic, efficient method that enables analysts to study the relationship between multiple input variables (factors) and key output variables. Sundarapandian et al. [11], in his research selects the optimal combination of the factors which will ensure the required yield strength and also to find out the contribution of each factor in the improvement of yield strength. The data analyzed by Taguchi Method to find out the optimum combination factors using MINITAB software.

Hmud et al. [12] study the effect of cooling media and temperature on the mechanical properties for reinforcement steel. Many tests are done to the samples at different temperature were carried out. Ghaleh [13] in this study, the effect of cooling rate was investigated on the morphology and depth of martensite layer, quenched area, and tensile properties of a reinforcement steel bar. Musonda et al [14] conducts a series of experiments at a steel plant to establish the optimum temperature of the rebar at the cooling bed. Maintaining high accuracy temperature measurements at the cooling section is essential in order to attain the overall quality of the finished product, and to realize the correct properties.

Apart from those various other tools such as control chart, fishbone analysis, process capability analysis etc. can be used in Six sigma and its DMAIC analysis. The fishbone analysis is a tool for analyzing the business process and its effectiveness. The analyst reveal that the problem area is lack of proper equipment, faulty processes, misdirected people, improper environment and poor management. Aebtarm et al. [15] suggest that the traditional C-chart has been widely applied for monitoring count data in the industrial and nonindustrial processes.

3.METHODOLOGY

DMAIC (an abbreviation for Define, Measure, Analyse, Improve, and Control) is a five-phase strategy for improving various kinds of organizational processes, whether it is a software development, manufacturing, or some other process. While it is a core tool used to conduct Six Sigma projects, it can be used alone as the framework for other improvement applications. various tools and techniques used for analysing the project to obtain the result and details. These tools include process map, control charts, process capability analysis, Pareto analysis, Sigma conversion table etc.

3.1 Define

Customer wants are identified by various interviews and discussions with the manager and staffs at different departments like sales, testing and the production department of the selected steel bar manufacturing industry. The problem identified in the production was often the mechanical properties like yield strength fall below the ISI limit which led to rejection or selling it as low-grade steel thereby causing financial loss. Hence the problem to be worked on is the improvement of the production process and thereby increasing the quality and minimize rejection. The critical-to-quality (CTQ) characteristics identified for the product are yield strength (YS) and ultimate tensile strength (UTS), mass per length. YS and UTS are measured in Newton per millimeter square (N/mm2) and Mass per length is measured in kilogram per meter (kg/m). TMT bars of different grades like Fe500, Fe550 and in different diameters like 8mm, 10mm and 12mm are produced in this industry. Out of this the TMT model selected for this study is Fe500 with 8mm diameter. The product specification of TMT bar is compared as per ISI specification to check the quality of the product. The ISI standards for Fe500 TMT bar with 8mm diameter is shown in the table below.

Table-1: Design specification for TMT bar

SPECIFICATION OF TMT BARS (IS-1786:2008)			
Mechanical properties (Min)		Bar weight (Kg/Mtr)	
Model	Fe 500	Size	8 mm
Yield Stress (N/mm^2)	500	Std	0.395
Ultimate Tensile Strength (N/mm^2)	545	Min	0.367
Elongation (%)	12	Max	0.423
Ration (UTS/YS	1.09		

The process flow chart of the industry is created in this phase which is given below.

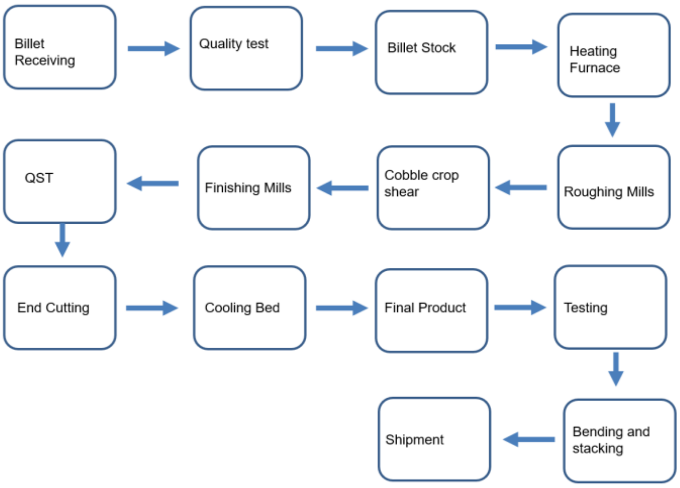

Fig-1: Process map

3.2 Measure

Data is collected from the quality department of the manufacturing firm and CTQ characteristics are measured. The CTQ characteristics include yield strength, ultimate tensile strength and mass per length for the selected product variety. The process performance is measured using the collected data by using various tools like control chart, capability analysis etc.

- Control charts

Control charts are plotted in order to know if the process meets the design specifications. Control chart of yield strength for 8mm steel bar is shown in chart 1 as an example. The desirable LSL for it is 500 N/mm² while the process mean is 505.53 N/mm². The upper and lower control limits for the process are 512.20 N/mm² and 498.85 N/mm² respectively. The process is in control.

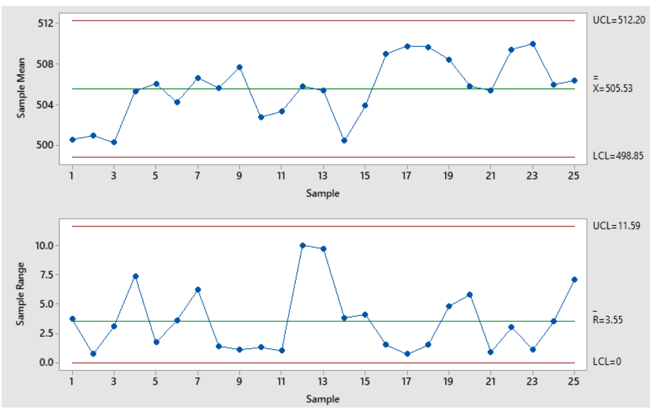

Chart-1: control chart of yield stress

Similarly, the control charts for the remaining CTQs ie ultimate tensile strength and mass per length are made and their parameters calculated. The process performance is satisfactory as mean and Lower Control Limit X-bar values of all CTQs are greater than Lower Specification Limit.

- Process capability analysis

The process capability analysis is a set of calculations used to assess whether a system is statistically able to meet a set of specifications or requirements and to evaluate their performance The steel bar manufacturing process performance is measured by carrying out process capability study. The Cpk(process capability index), Ppk(process performance index) and defects per million opportunities (DPMO) are determined for each CTQ and finally the current sigma level. The sample process capability analysis of yield strength is shown in the figure below.

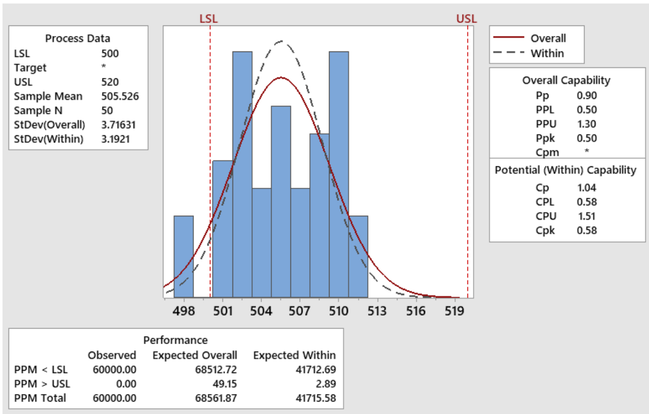

Fig-2: Process capability of yield stress

After conducting the Process capability analysis, the main factors like Cpk, Ppk, Standard deviation, DPMO etc. are observed and noted. The summarized results of measure phase are given in the table 2

Table-2: result of measure phase

CTQ Parameters	Yield Strength	Ultimate Tensile Strength	Mass per length
Process capability index (Cpk)	0.54	0.67	0.72
Process performance index (Ppk)	0.49	0.66	0.59
Standard Deviation(σ)	3.71	3.6	0.015
Per million opportunity (PMO)	1000000	1000000	1000000

Defects per million opportunity (DPMO)	68562	40000	70815
Process Yield	93.29%		
Sigma level	2.9		

The summarized results help in the sigma level calculation which is the baseline quality of the current process and needs to be improved. The sigma level of the process comes out to be 2.9 as shown in Table 2. The line DPMO for mass per length is 70815, which is greater than other CTQ's DPMO. In this project an effort is made to improve the sigma level by controlling the significant factors found in the Analysis phase of the DMAIC cycle.

3.3 Analyse

The analysis phase identifies the statistically significant factors that contribute towards the rejection. Once the significant factors are identified, they can be controlled to have minimum rejection and maximum process yield. There are various factors or input parameters of the production process that affects the properties of the TMT bar produced. Some of the process parameters identified from the industry and literature review is listed below;

- Bar Temperature, Tb in°C
- Rolling Speed, S in mps
- Cooling water pressure, P in bar or Mpa
- Quenching Time, t in sec
- Raw material composition
- Water Flow Rate, Q in m3/hr.
- Quenching Water Temperature, Tw in°C

- Fishbone Analysis

A Fishbone analysis is conducted using the collected data from the industry and various other sources. The Fishbone diagram also called cause and effect diagram is shown in the figure below. The factors contributing to the quality loss are depicted in this diagram.

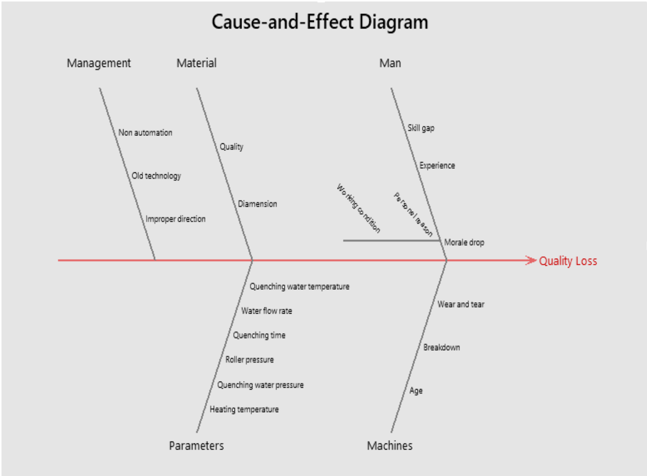

Fig-3: Fishbone analysis

- Factorial design

In TMT manufacturing process, initially one or two TMT bars are produced and tested to check whether they have desired properties and design specification. If the desired properties are not met, then the foreman will adjust the process parameters like water pressure, bar temperature etc. They will conduct some experimental runs at the beginning and once the desired specifications are obtained for the TMT bar, then the production will run on full capacity in that condition. In order to study the effect of these parameters a factorial experimentation is carried out. The selected factors and their levels are shown in the table below

Table-3: Input factors and levels

Level	Heating Temperature (°C)	Water pressure (bar)
Low	1100	5
Medium	1165	6
High	1200	7

A factorial design experimentation is conducted using MINITAB software. The details are shown in the figure below

StdOrder	RunOrder	PtType	Blocks	Temperature	Water pressure	YS	UTS	Kg/m
2	1	1	1	1100	6	503.1	549.2	0.369
8	2	1	1	1200	6	514.7	563.5	0.376
1	3	1	1	1100	5	496.8	542.7	0.355
7	4	1	1	1200	5	504.5	549.8	0.368
6	5	1	1	1165	7	515.1	560.7	0.421
3	6	1	1	1100	7	505.9	553.2	0.374
5	7	1	1	1165	6	510.8	555.7	0.392
4	8	1	1	1165	5	503.7	551.2	0.381
9	9	1	1	1200	7	516.9	566.2	0.419

Fig-4: Design experiments

- Pareto analysis

Based on the data from design experiments and considering other factors a sample pareto analysis is done and the graph is shown below

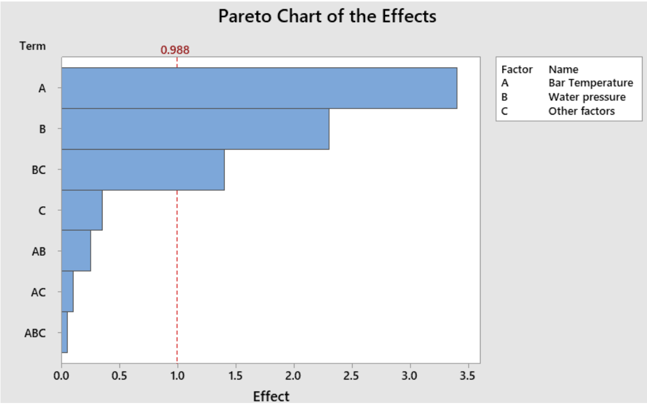

Fig-5: pareto chart

The main factors which contribute more on the desired properties are water pressure and bar temperature. The other factors are not adjusted or considered less during the production process. In the chart it shows that bar temperature and water pressure are critical factors that affect the process since they are above the critical red line. The combine effect of factors is also shown in the graph.

3.4 Improve

The improvement phase suggest improvement or implements the findings of Analysis phase into the steel bar manufacturing facility and observe the improved results.

- Response optimizer

The response optimizer is used to identify the combination of predictor values that jointly optimize one or more fitted response. That is, it can be used to find an optimum input parameter value based on the factorial design analysis. Only response variables with up-to-date models from the same type of analysis are available in the list. The result obtained from the response optimizer is given below.

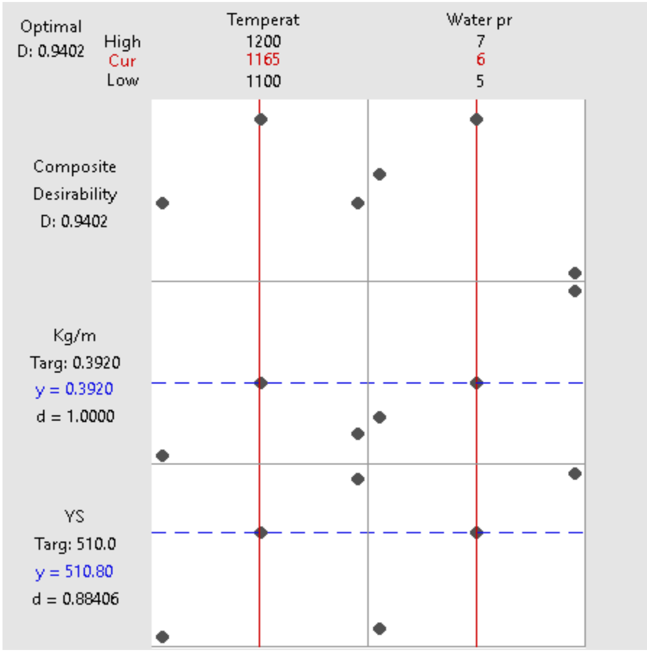

Fig-6: Response optimizer

The desired value of yield strength(510N/mm2) and mass per length(0.392Kg/Mtr) as per industrial standards are given as input values in the response optimizer and the obtained input parameter values are temperature (1165˚C) and water pressure (6 bar). The industry is suggested to run on this condition to get improved results.

- Control chart

The control chart can be tool to monitor the process over time. A sample control chart of yield stress of the process operating near the improved conditions are given below.

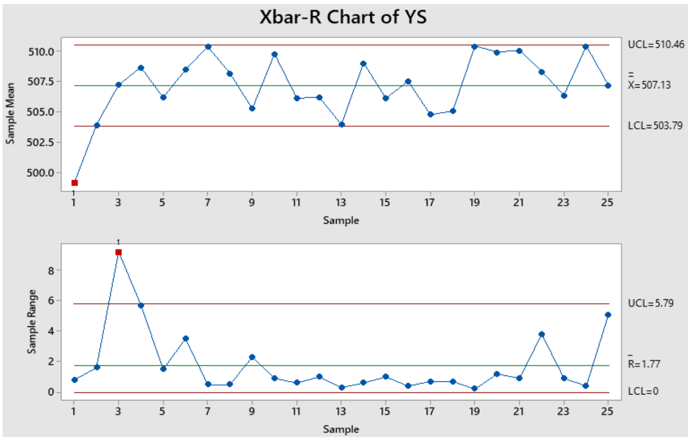

Chart-2: control chart

From the control chart we can see that the UCL and LCL are improved and shifted more toward mean. The control charts of YS and UTS have improved but the control chart of mass per length only varied little. The process mean and lower control limit are greater than the LSL of the product. Hence the process is under control. Similarly control charts for yield stress and mass per length are also plotted. The mean value became higher and near to desired level.

- Process capability analysis

The process capability analysis of sample data when working near our suggested range is conducted. The results of process capability of yield stress are shown as an example.

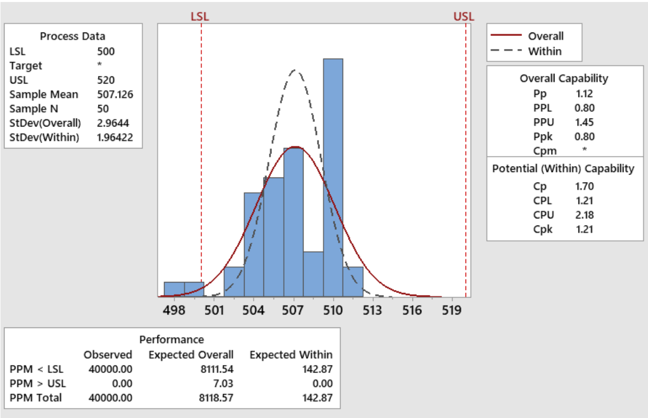

Fig-7: Process capability analysis

After conducting the Process capability analysis, the main factors like Cpk, Ppk, Standard deviation, DPMO etc. are observed and noted. Similarly, the process capability of ultimate tensile strength and mass per length are calculated. The summarized results of improvement phase are given in the table below.

Table-4: Improvement phase summary

CTQ Parameters	Yield Strength	Ultimate Tensile Strength	Mass per length
Process capability index (Cpk)	1.21	1.36	0.88
Process performance index (Ppk)	0.8	0.95	0.7
Standard Deviation(σ)	2.96	3.4	0.013
Per million opportunity (PMO)	1000000	1000000	1000000
Defects per million opportunity (DPMO)	40000	40000	34619
Process Yield	96.1%		
Sigma Level	3.2		

3.5 Control

The results are communicated to the team and the production department is directed to run the production process under the suggested factors settings. In the control phase the production control team monitors the process to make sure it operates correctly.

A one-sample Z-Test is performed on the improved data to check whether if the mean of the process is greater than the given product LSL. The test is performed with a 95% confidence level and the results are summarized in table 5 given below.

Table-5: One-sample Z-test results

CTQ parameter	Standard deviation	Alternate hypothesis	P-value	Results (alternate hypothesis testing)
Yield strength	2.96	μ>500	0	Accept
Ultimate tensile strength	3.4	μ>545	0	Accept
Mass per length	0.013	μ>0.367	0	Accept

The one-sample z test for μ>LSL is performed. The p-value less than α(0.05) indicate the rejection of Null Hypothesis, Ho=μ≤LSL and hence the Null Hypothesis is rejected and Alternate Hypothesis, Ha=μ>LSL is accepted. Hence it is concluded that the mean value of the CTQ's are greater than LSL as desired.

4. RESULTS AND DISCUSSION

Table-6: Measuring vs. improvement phase results

CTQ Parameters	Measurement phase			Improvement phase		
	YS	UTS	Mass per length	YS	UTS	Mass per length
Process capability index (Cpk)	0.54	0.67	0.72	1.21	1.36	0.88
Process performance index (Ppk)	0.49	0.66	0.59	0.8	0.95	0.7
Standard Deviation(σ)	3.71	3.6	0.015	2.96	3.4	0.013
Defects per million opportunity (DPMO)	68562	40000	70815	40000	40000	34619
Process Yield	93.29%			96.1%		
Sigma Level	2.9			3.2		

After conducting DMAIC analysis the summarized results of measurement phase and improve phase is compared and tabulated. The table containing comparison of the summarized results are shown above.

All the CTQ characteristics, Cpk and Ppk are improved, and DPMO and standard deviation are minimized as the steel bar manufacturing is conducted on the suggested levels of identified process control parameters. From the table it can be observed that the various measuring indices of the TMT manufacturing process have improved slightly. This shows the effect of changes in control parameters. The performance indices like Cpk and Ppk are improved, and DPMO and standard deviation are reduced. The process yield was improved approximately from 93.29% to 96.1%. The sigma level of the process is also improved slightly from 2.9 to 3.2.

5. CONCLUSION

The DMAIC analysis conducted on a steel manufacturing industry. Detailed process study is conducted on the selected TMT bar manufacturing process and process map is created. The critical to quality (CTQs) factors are defined and key input parameters are identified that significantly affect the product quality. The data from the production and quality department is collected and analysed using various tools in the MINITAB software. The process performance is measured in terms of Cpk, Ppk, Process yield, DPMO and Sigma Level. The process yield calculated is 93.29% and sigma level was 2.9 for the process. To improve the process performance, a process analysis is carried out and a factorial design experiment is performed. The factors selected include heating temperature and water pressure which are the main adjustable parameter that can be employed. The production data was collected when the line was operated at different input factors and the effect was noted. The statistically significant factors along with the optimum level settings are found after the factorial experimentation. The optimum process parameters are identified using response optimizer and suggestion is given to the industry. Improved data was collected from the industry and improved results are presented. The process yield is improved to 96.1% of the total production and the sigma level is improved to 3.2. In future research more sample size, more factors and levels can be considered.

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