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Process Optimization of a Local Steel bar Manufacturing Firm Using SPC and ANOVA

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Abstract:- In a steel bar manufacturing industry, identification of significant factors which affect the process efficiency is of prime importance to achieve maximum yield. In the undertaken research study, reheating furnace temperature of 1050 ^{O}C of a local steel bar manufacturing facility of Peshawar, Pakistan is found to be statistically significant with the help of analysis of variance (ANOVA) experimentation. The second analysed temperature level is 900 ^{O}C which comes out to be insignificant. At 1050 ^{O}C temperature, minimum production scrap is found and z. bench quality standard is also improved. For yield strength quality characteristic of the product the scrap level is 90% less than the production at 900 ^{O}C while the z. bench level is improved to 28%. At same temperature of 1050 ^{O}C, production scrap is reduced over 42% and z. bench is improved to 11% for ultimate tensile strength quality characteristic. 1050 ^{O}C temperature of the reheating furnace of the steel bar manufacturing process is statistically found to be optimum temperature level of production.

Keywords:- Yield, Analysis of variance (ANOVA), Steel bar manufacturing process

I. INTRODUCTION

In today's competitive world, manufacturing firms are bound to bring efficiency in their production process. The process efficiency reduces the process variation and increase the quality of the product. This process variation control ultimately optimizes the yield and minimizes the scrap. The reduction in scrap level increase the profit margins of the company and make company able to meet the customer demands on time and increase their satisfaction level.

Statistical process control (SPC) is the statistical tools used to improve the process quality and reduce the variability of the process. By the reduction of variability, the quality is improved as quality is inversely proportional to variance of the process [1]. In any manufacturing process, there present two types of causes of variance. First is the chance causes or also called natural causes of variance. The examples of chance causes include temperature and humidity fluctuation, and electricity fluctuation. These types of variations are present in every process and cannot be completely eliminated. Second cause of variance is the assignable cause or special causes of variation of the process. They include operator mistakes, measurement error, and tool wear. If only natural causes of variations are present, the process is said to be in-control. If there present special causes of variation, the process is said to be out of control. To bring process in control state, special causes of variability must be eliminated [2]. The quality of the treated water is improved with the successful usage of SPC. The use of control charts and descriptive statistics helped the researcher to analyze the water treatment plant and monitor the process parameters [3]. Statistical process control (SPC) is one of the key elements for the success of manufacturing firms. In small and medium industries, the knowledge of SPC is quite less compare to the big companies. This issue impedes the growth of small industries in long run. In the proposed research work, eSPC methodology is introduced which is an online SPC service for the small and medium industries. This package includes several quality control charts and important information analysis based on the data provided by the user companies. This method cost less compared to the physical quality control department and is found to be fruitful for discrete manufacturing organizations [4].

In a steel manufacturing industry of Japan, desired quality of the product is achieved with the help of expert system. The expert system is a decision support system that take the process parameter input values with the help of sensors, analyse the information and set the production settings accordingly to get a desired quality of the product. This is an effective but expensive technique of quality control and cannot be implemented in small production units[5]. In Indonesia, process efficiency of an asbestos manufacturing unit is optimized using DOE. Significant factors affecting the process efficiency are identified. The optimum curing temperature identified is 350 ^{O}C. With the successful application of the DOE, curing time is also reduced by one hour. Hence the production efficiency is improved as a result[6]. Optimum factors and levels for a textile industry is identified using DOE and regression analysis. The significant factors include thickness of the needle (factor A), size content of the fabric (factor B), twist per inch of thread (factor C), and number of threads per square inch (factor D). In the regression model, textile defects is set as the response and the significant factors are employed in the regression model as input variables to reduce the response. The optimum levels of factor A, B, C and D are 0.75mm, 5%, 15 and 52 * 52 respectively. At these levels of the factors, minimum textile defects are observed. The regression model made in the research can be used in any textile industry to achieve good textile quality. DOE and regression model can be applied to any other manufacturing unit to find out the significant factors and optimum level that affect the quality of the product and ultimately to the process yield[7]. To improve the yield strength of the steel bar, DOE and Taguchi method of orthogonal array is used to optimize the process parameter. Water pressure at quenching is found to be statistically significant. As the water pressure during quenching is held to an optimum level, reduced standard deviation is noticed in the production process. Optimum water pressure of quenching unit is found to be 10 bar. Other selected factors of experimentation include cooling rate, speed of the bar, and temperature of the finish rolling bar. With the help of ANOVA study, it is revealed that water pressure has the highest significant effect on the yield strength, with F-ratio of 90.82 and overall 67% contribution[8].

Past research indicates that SPC, DOE and ANOVA can be used to improve the process performance of a manufacturing firm. In the undertaken research, rejection rate is minimized and process efficiency is improved by the reduction of process variation. In the subsequent section, a detailed methodology of the research study is presented.

II. METHODOLOGY

Scrap generation at a local ABC steel bar manufacturing facility, Peshawar is analyzed to know the significant factors that are contributing towards it. The product selected is 60 grade steel bar of Ø25mm. After the group discussion with the quality and production department and scrap analysis, it is revealed that reheating temperature of the furnace is the main factor that leads to scrap generation. The temperature level affects the quality of the steel bar produced. It is needed to investigate the variation of the temperature level that affects the quality of the product and ultimately contribute towards the scrap of the process.

Analysis of variance of temperature:

An analysis of variance (ANOVA) is performed to test the hypothesis that if there is a significant difference between the two temperature levels. To perform the ANOVA, hypothesis testing with 95% confidence level (α=5%) is performed and is shown below:

Null Hypothesis: H_o; $\mu_{900\,^oC} = \mu_{1050\,^oC}$

Alternate Hypothesis: H_1; $\mu_{900\,^oC} \neq \mu_{1050\,^oC}$

To perform the hypothesis testing, an experiment is designed to test the effect of reheating furnace temperature on the scrap rate. The test is performed in two phases. In the first phase, 1 ton production of 60 grade steel bar of Ø25mm is carried out and the scrap generated is noted down as shown in Table 1. The production is replicated five times and their results are summarized in the Table 1. For the reheating furnace temperature of 900 ^{O} C scrap generated is 18 kg, 12 kg, 16 kg, 14 kg, and 13 kg with their respective production of 1 ton each. And the scrap noted is 6 kg, 8 kg, 11 kg, 4 kg, and 9 kg for the temperature level of 1100 ^{O} C at each production turn of 1 ton.

Table 1: Observed Scrap

Replication	**Temperature Level**	
	Scrap at 900 ^{O} C (kg)	**Scrap at 1050 ^{O} C (kg)**
1	**18**	**6**
2	**12**	**8**
3	**16**	**11**
4	**14**	**4**
5	**13**	**9**

The gathered data is analyzed using Minitab, and analysis of variance is performed to know if there is significant difference between both the temperature levels. A p-value of 0.003 is obtained which is less than 0.05 set confidence level, as α=0.05 as shown in Table 2. As p-value is less than the α-value, null hypothesis is rejected and it is concluded that there is a significant difference in the temperature level of the reheating furnace. R-Square value of 70.04% shows that the temperature of the reheating furnace is a factor which is responsible for 70.04% scrap of the process. The remaining percentage of the scrap is due to other factors which are not taken in the current research study.

Table 2: One-way analysis of variance results

Source	P value	R-Square value
Temperature of reheating furnace	**0.003**	**70.04%**

It is further noticed that both the reheating temperature of the furnace are not same and the level of the reheating furnace temperature affects the quality of the steel bar produced and yield of the process in turn. Further it is needed to investigate that which temperature level should be used to acquire maximum yield of the steel bar manufacturing process. This investigation is carried out in the subsequent section.

To test the quality of the steel bar, two critical to quality (CTQ) parameters are yield strength (YS) and ultimate tensile strength (UTS). In this section, the effect of the reheating temperature on the YS of 60 grade steel bar of Ø25mm is analyzed. The lower specification limit (LSL) for YS of the product under investigation is 60 kilo pound per square inch (KSI).

The process capability in term of yield strength for 900 ^{O} C reheating temperature is conducted as shown in Figure 1. A sample of 900 steel bar is tested using universal testing machine (UTM) in the manufacturing facility. The mean and standard deviation of the process for YS is 68 KSI and 3.83 KSI respectively. The Z.bench quality standard value is 2.09. Cpk and Ppk is 0.68 and 0.70 respectively. The process performance is measured in terms of percent rejected parts that lie below the LSL of the product. The rejection of the process for YS is 1.84%.

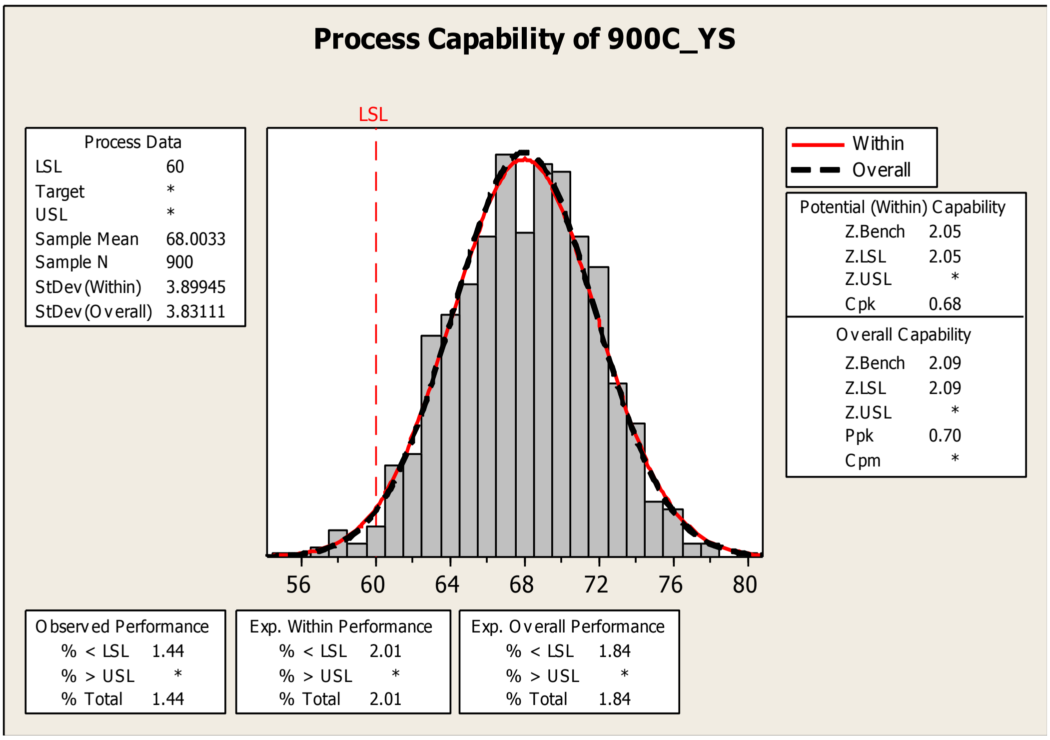

Figure 1: Process capability for yield strength at 900^{O} C

For 1050 ^{O} C reheating temperature, process capability of 60 grade steel bar of Ø25mm is analyzed in terms of YS as shown in Figure 2. The mean and standard deviation of the process at 1050 ^{O} C comes out to be 69 KSI and 3.14 KSI respectively. The Cpk and Ppk is 0.94 and 0.96 respectively. The Z.bench is 2.89. The scrap at 1050 ^{O} C reheating temperature is 0.19%. The scrap noticed at 1050 ^{O} C reheating temperature is 90% less than the scrap at 900 ^{O} C reheating temperature.

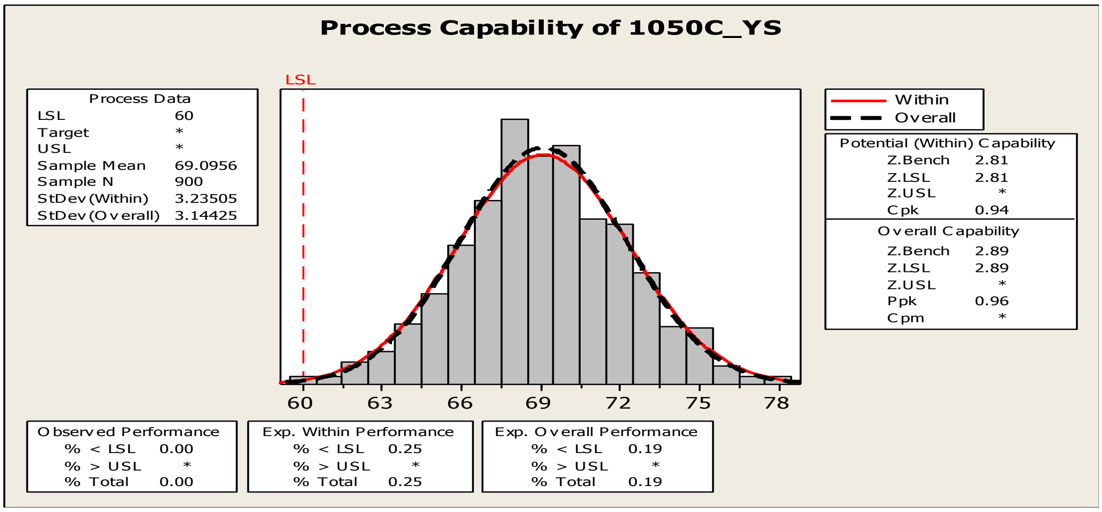

Figure 2: Process capability for yield strength at 1050^{O} C

All the process performance parameters are improved as the process is run at temperature of reheating furnace as shown in Table 3. A significant reduction of 89.67% in process scrap is noticed as the reheating furnace temperature is set on 1050^{O} C. The maximum yield of the steel bar manufacturing process is achieved at 1050^{O} C.

Table 3: Process performance in terms of YS

Sr. No	Performance parameter	Process performance at 900^{o}C	Process performance at 1050^{o}C	Percent Improvement
1	Standard deviation	3.83	3.14	18.02
2	Z. Bench	2.09	2.89	27.68
3	Cpk	0.68	0.94	27.66
4	Ppk	0.7	0.96	27.08
5	% Scrap	1.84	0.19	89.67

Second CTQ characteristic of 60 grade steel bar of Ø25mm is UTS. The LSL of the product for UTS is 90 kilo pound per square inch (KSI).

For UTS analysis of the product, the process capability at 900^{O}C reheating temperature is shown in Figure 3. The mean and standard deviation of the process for UTS is 98 KSI and 4.42 KSI respectively while the given LSL is 90 KSI. The value of the Z.bench is 1.89. The value for Cpk and Ppk is 0.63 each. The process rejects due to UTS are 2.95%.

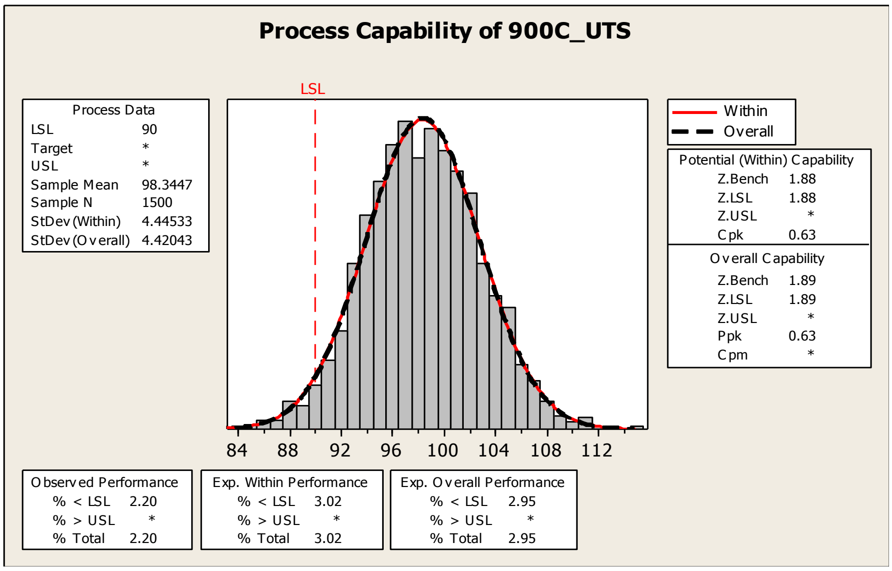

Figure 3: Process capability for ultimate tensile strength at 900^{O} C

The process capability for UTS at 1050^{O}C reheating temperature for 60 grade steel bar of Ø25mm is analyzed and shown in Figure 4. The mean and standard deviation of the process is 99 KSI and 4.31 KSI respectively. The values of Cpk and Ppk are 0.72 and 0.71 respectively. The Z.bench score is 2.12. The process reject is reduced to 1.72% at 1050^{O}C reheating temperature, which is 2.95% at 900^{O}C reheating temperature of the furnace.

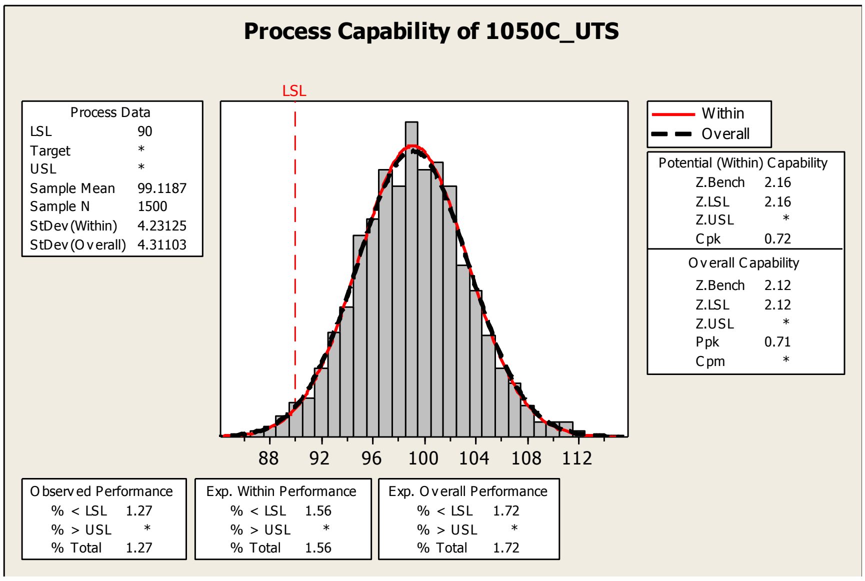

Figure 4: Process capability for ultimate tensile strength at 1050^{O} C

It is evident from the results summarized in Table 4 that reheating furnace temperature of 1050^{O} C is more suitable for the production of 60 grade steel bar of Ø25mm than 900^{O} C. At 1050^{O} C of the furnace, the scrap is significantly reduced. A 41.69% scrap is reduced as the production line is run at 1050^{O} C. The dispersion of the manufacturing process is also reduced to 2.49% as measured by the process standard deviation. At 1050^{O} C temperature, improvements in Z.bench, Cpk and Ppk are 10.85%, 12.5%, 11.3% respectively.

Table 4: Process performance in terms of UTS

Sr. No	Performance parameter	Process performance at 900^{O}C	Process performance at 1050^{O}C	Percent Improvement
1	Standard deviation	4.42	4.31	2.489
2	Z. Bench	1.89	2.12	10.85
3	Cpk	0.63	0.72	12.50
4	Ppk	0.63	0.71	11.27
5	% Scrap	2.95	1.72	41.69

III. CONCLUSIONS

Process efficiency analysis of a local steel bar manufacturing industry of Peshawar, Pakistan is performed and yield of the process is maximized. It is revealed that temperature level of the reheating furnace of the steel bar is the key factor that affects the process efficiency. Two levels of the temperature selected for the experimentation are 900 ^{O}C and 1050 ^{O}C. From the ANOVA study it is confirmed that both the temperature levels affect the production efficiency of the steel bar manufacturing industry. Yield strength and ultimate tensile strength of the 60 grade steel bar are two quality tests based on which yield analysis is performed and process efficiency is studied. The process performance parameters include Z. bench, standard deviation, Cpk, Ppk and percent scrap. The process performance for YS is improved on 1050 ^{O}C of the reheating temperature of the furnace. At 1050 ^{O}C of the reheating temperature, the results for Z. bench, standard deviation, Cpk, and Ppk are 2.89, 3.14, 0.94, and 0.96 respectively. The percent scrap at 1050 ^{O}C temperature is 0.19% which is 89.67% less than the percent scrap noticed at 900 ^{O}C temperature. The process performance for UTS is also improved when the production is carried out 1050 ^{O}C of the reheating temperature of the furnace. At 1050 ^{O}C temperature, the results for Z. bench, standard deviation, Cpk, and Ppk are 2.12, 4.31, 0.72, and 0.71 respectively. The percent scrap noticed at 1050 ^{O}C temperature is 1.72% which is 41.69% less than the percent scrap generated at 900 ^{O}C temperature. Hence it is experimentally revealed that reheating temperature of the furnace affects the performance of the steel bar manufacturing process and 1050 ^{O}C temperature is optimum temperature level on which maximum yield of the process is achieved with the minimum scrap.

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