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Process Improvement of Fiber Glass Industry

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Abstract: Six Sigma is a structured, statistical and logical method for process improvement. It primarily focuses on increasing the process capability by reducing process variation. This paper aims to reduce process variation of Chopped Strand Mat (CSM) in a fiber industry in the state of Goa, India. The CSM is used in automobile, aerospace, marine and many other industrial applications as housing or cover shells where strength to weight ratio is important parameter in design. The major critical to quality characteristic of CSM is GSM of fiber, where any variation in GSM of fiber leads to variation in CSM. DMAIC methodology is implemented to optimize the fiber production process and reducing process variation. Critical process parameters have been identified using brainstorming and multi-voting method. Taguchi method of experimental design has been used to identify key factors and their optimal levels. Reduction of variance coupled with an economic analysis has been carried out and reported in the paper.

Keywords: *Six Sigma, ANOVA, Taguchi, S/N Ratio, DMAIC, Process Capability, CTQ*

1. Introduction

The competitive environment and globalization makes end user more and more quality conscious and hence to survive in such a market, companies need to adopt efficient techniques that can quickly diagnose the problem cause and assist to meet customer needs and expectation. Now a days, six sigma philosophy is found to be a good solution to the shop floor problems and has become an important tool in quality management. Six Sigma is a well-structured methodology that can help a company to achieve expected goals through continuous improvement. As increased sigma level improves the quality of process and hence defects reduce.

Six sigma is based on target setting and improving process using DMAIC cycle. Methodological and disciplined DMAIC cycle implementation ensures the elimination of causes of defects and thus improving process. In DMAIC cycle problems are quantified, measured and analyzed to get root cause and hence solution can be identified and implemented.

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2. Literature Review

Customer satisfaction has become main target of organizations. Six sigma approach, which is customer oriented can be implemented to achieve this target. Six sigma approach is implemented by various organizations world-wide to fulfill customer needs and ultimately realize success. Six sigma aims 3.4 errors in one million productions [1]. Six sigma is powerful quality improvement strategy that uses statistical method to define, measure, analyze, improve and control process to achieve operational excellence [2]. DMAIC methodology not only improves quality but also the productivity and is applicable in both manufacturing and service sectors [3]. Six sigma improves process by eliminating defects by focusing on customer requirements which are critical in nature [4].

Customer requirements on critical to quality (CTQ) characteristic is main process indicator in all phases of DMAIC cycle, CTQ is a measure of process performance and adopts process capability index to measure six sigma efforts. Process capability index indicates capability of process to meet CTQ requirement [5]. Process capability is a simple number and compares required process variability and actual process variability [6]. Process capability determines capability of process to meet engineering specification and also gives information about changes during production [7].

Process capability assessment is a must for process improvement. Few problem solving tools includes process map, cause and effect matrix, failure mode effect analysis (FMEA) [8]. ANOVA methodology can be used to find significant factors that affects quality.

Taguchi method is used for parameter design and experimental planning. S/N ratio is used to measure quality characteristic deviation from required value. Input Parameters can be controlled to get desired output quality characteristics [9]. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted [10].

3. Problem on Hand

Chopped Strand Mat (CSM) is a product made out of glass fibers and is used to strengthen the components of aerospace, marine, automobile and defense applications where high strength to low weight ratio is critical. CSM to function to its fullest potential should be maintained at a specified GSM. It is observed from the quality data that there is a considerable variation in the GSM which leads to increase in the rejection rate of CSM.

The study of the CSM process signifies variation in CTQ parameter GSM. The GSM of the CSM is maintained with the even distribution of the fibers, applying resin and curing at specified temperature. The process study show that distribution of fibers is not even, which in turn is impacted by the Tex. Tex is the major factor responsible for rejection of CSM. Sigma level of the tex observed was 1.08 and hence by improving the tex process, the rejection rate can be minimized. This paper deals with identifying the process capability and causes for the variation in Tex.

4. Research Methodology

Six Sigma is a methodological and statistical approach which is proven and more applicable to the manufacturing or production organization. It is project based and coupled to the strategic goal of the organization. ‘D’ stands for Defining or identifying problem in a process, ‘M’ for Measuring or recording the data related to the process, ‘A’ for Analyzing the process based on measured data, ‘I’ for Improving the process based on the analysis and ‘C’ for Controlling the improved process.

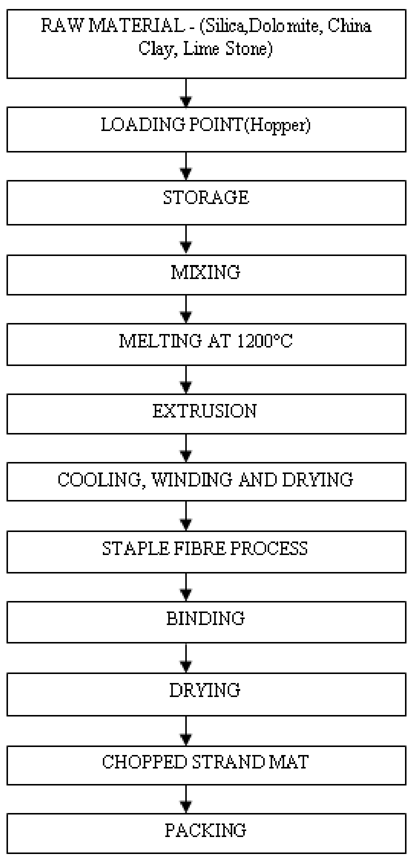

Fig. 1: Process Map

Initially the data pertaining to the CSM are collected from the quality department and analysis is carried out to determine the existing process capability. To improve upon the existing process, various CTQs which affect the quality of CSM are identified. As the major quality characteristic of the CSM depends upon the GSM of the mat, more research is put in analyzing the factors which results in the variation in GSM. Tex being the major contributor for GSM, now it becomes inevitable to investigate the parameters that cause variation in the Tex. Multivoting technique is adopted to narrow down the parameters that cause considerable variation in the Tex. Based on the parameters identified experimental trails are conducted using Taguchi's L9 orthogonal array. The results of the design of experiment are analyzed using ANOVA and S/N ratio in order to obtain the most significant factors and appropriate optimal levels.

The process map for the CSM is shown in the Fig. 1. The raw materials are mixed in a hopper, melted in a furnace to convert them into molten glass and then extruded out of the bushes as fibers. Then the fibers are winded and chopped. The chopped strands are distributed evenly on a layer of resin and cured. This final product is called Chopped Strand Mat.

The critical to quality characteristics of CSM is caught on, based on the input provided by the quality personnel. GSM is important critical to quality characteristic of CSM. The ideal GSM to be maintained for the acceptance of the product is 450±32. From the exhaustive analysis with the quality data it has been found out that the potential process capability index C_p = 0.93 and adjusted process capability index C_{pk} = 0.88 as indicated in the Fig. 2. The sigma level present before the implementation of this study has been calculated to be 2.79.

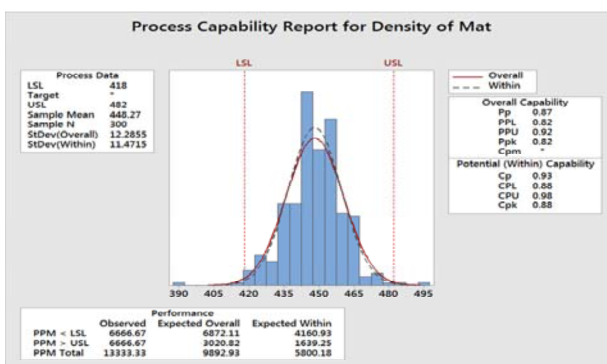

Fig. 2: Process Capability Chart for GSM

With the aid of brainstorming various causes for the variation of GSM in CSM are identified. To name a few, distribution, wet patches and holes, surface wet, poor winding, black brown strands, brown spots, cotton patches and thick strands. Data is collected for these several defects for a period of nine months and analyzed. The total numbers of rolls produced in this period are 203576 and the defectives found are 6810. Hence the percentage defective being operated is 3.345%. From the Pareto analysis shown in Fig. 3, it was detected that the distribution contributes to 60% of total defects. Distribution is the defect due to uneven distribution of the chopped fibers in a mat.

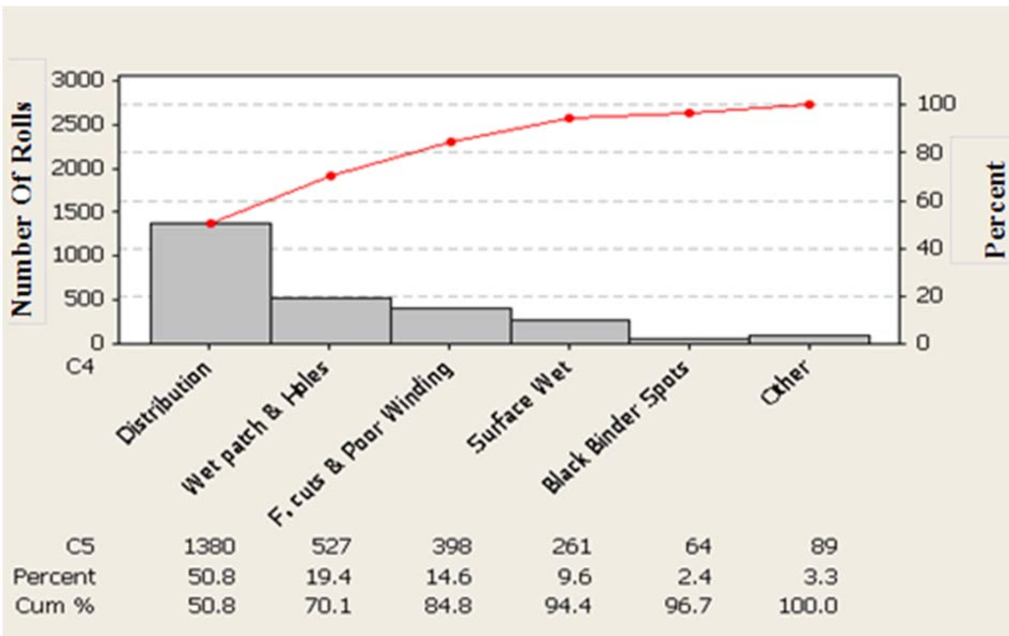

Fig. 3: Pareto Chart for Various Causes of GSM Variation

The possible causes for the distribution are found to be tex variation, chopper, diverter and blower. Brainstorming and Multi voting is conducted to find out the major cause of distribution variation. It was identified that Tex is the major contributor for the distribution variation where Tex is the unit of measure for the linear mass density of the fiber and defined as mass in grams/thousand meters.

Tex being the critical parameter for distribution variation, data are collected for Tex to determine the process capability and it was found to be $C_p = 0.36$ and $C_{pk} = 0.35$.

The Tex being the most vital reason for causing the distribution, it becomes necessary to investigate the key parameters that influence the Tex, which are Furnace Temperature, Winding Speed and Skill level of the operators. These parameters form the basis of further analysis.

The levels for each of the parameters i.e. Furnace Temperature, Winding Speed and Skill level of the operators that cause variation in Tex are shown in Table1. The experiments are conducted to study the effect of the various parameters on the Tex variation. These experiments are designed using Taguchi's L9 orthogonal array. For this study, three levels are considered for each parameter and the L9 orthogonal array is used as shown in Table2. For the design of experiment, two replicates are taken for each trial.

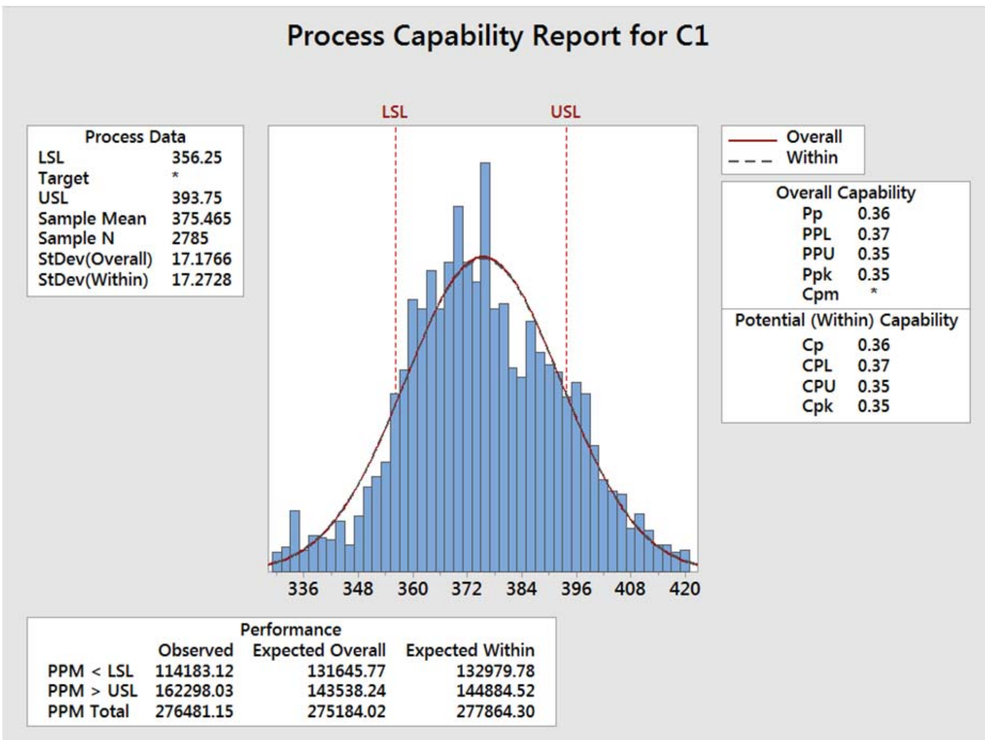

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Fig. 4: Process Capability Chart for Tex Variation

Table 1: Levels of Control Factors

Levels	Operator Skill Level (A)	Furnace Temp(ºC) (B)	Winder Speed(rpm) (C)
Low	1	1245	1050
Medium	2	1247	1100
High	3	1249	1150

Table 2: L9 Orthogonal Array

TRIAL	FACTORS			OUTPUT	
	A	B	C	R1	R2
1	1	1	1	340.78	353.92
2	1	2	2	491.12	463.7
3	1	3	3	448.72	460.66
4	2	1	2	317.2	315.74
5	2	2	3	453.02	429.64
6	2	3	1	481.98	502.04
7	3	1	3	320.06	314.18
8	3	2	1	497.88	472.28
9	3	3	2	476.8	450.46

The results obtained are tested using ANOVA to find out the most significant factor which causes the variation in Tex. Minitab software is being used to carry out the ANOVA and the results are shown in Table 3.

Table 3: Analysis of Variance for Tex

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	313.0	313.0	156.5	1.00	0.335
B	2	44545.0	44545.0	22272.5	282.88	0.004
C	2	1671.2	1671.2	835.6	10.61	0.086
Error	2	157.5	157.5	78.7		
Total	8	46686.6				

From the ANOVA it is very much evident that the factor ‘B’ i.e. the furnace temperature is the most significant factor.

The significant factor causing Tex variation has been identified from the ANOVA. Now referring back to the problem statement which states that there is considerable variation in the GSM, the process should be improved to minimize this variation. Hence the process should be run with optimal factor levels which are identified in Fig 5 of S/N ratio [11] as A2B1C2.

$$S/N \text{ Ratio} = 10\log_{10}\left[\frac{Y_a}{\sigma_{n-1}}\right]^2 \quad (1)$$

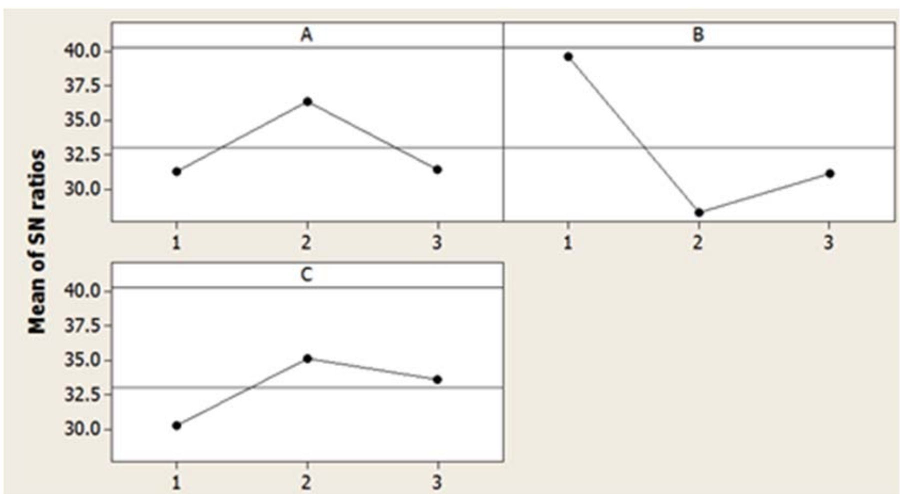

Fig. 5: S/N Ratio Chart

5. Results and Discussion

The S/N ratio analysis shown in Fig. 5 gives the optimal set of factor levels which can be applied to the process, through which the variation in GSM can be minimized. From the Fig. 5 the optimal factor levels are found out to be A2 medium level operator skill, B1 1245°C temperature and C2 1100 rpm.

The sigma level of the existing process is 2.79. On an average 757 rolls are getting rejected from a production volume of 22620 rolls. The cost of each roll is Rs.5075/- and hence the total cost incurred by the company due to rejection is Rs.3841775 per month. The major contributor for the rejection rate is the Tex variation. The tex variation accounts to 60% of the defective rolls, hence the company incurs a loss of Rs.2305065 per month only due to tex variation.

Hence by implementing the predicted optimum levels of factors, it is possible to eliminate the rejection of rolls due to tex variation thereby saving an amount of Rs.27660780 annually. After identifying the critical factors and their optimal level, the values were validated using Minitab 16 software, which are given below:

S/N Ratio	St Dev	Ln (StDev)
45.1020	4.03522	0.573901

However, for the actual implementation these validated values and factors identified with optimal level were informed to the industry. After due implementation the industry may report the confirmation run details.

6. Conclusions

This paper intended to reduce the defects in the CSM caused due to the variation in the GSM. The factors leading to the defects were identified and experiments designed using Taguchi's method were conducted. Upon the data collected ANOVA was performed and the significant factor was detected. The S/N ratio analysis was carried to find out optimal factor levels, which were found to be medium skill level of operator, 1245°C of furnace temperature and 1100 rpm of winding speed. These factor levels minimize the GSM variation thereby leading to the process improvement of CSM by reducing the standard deviation of the process.

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