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Quality Control in Construction using Six Sigma Technique

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Abstract—*Six Sigma is one of the promising tools that can be efficiently utilized for monitoring the quality requisites of any process. Though immensely popular with the manufacturing industries, an attempt has been made in this study to implement this simple yet efficient approach to the construction industry as well. Considering strength as the prime amongst the numerous deliverables in construction, the six sigma strategy is applied to the above mentioned characteristic. The deviations or defects arising in concreting process due to various controllable and non controllable factors are identifies and remedies are suggested. In this study, the concept of DMAIC- Define Measure Analyse Improve and Control is deployed to eliminate the defects and achieve results close to zero defects.*

1. INTRODUCTION

Quality is one of the most critical factors for the success of any construction project, being the basis of reliability and customer support all over. Managing quality can be extremely difficult owing to the vast number of attributes and variables associated with it. Every parameter needs to be kept optimum in order to ensure the best possible quality. In other words, control has to be effected upon all those factors that contribute to the overall fitness of the process and its output. The process under consideration in this study in Concreting, with its Compressive Strength as the most Critical To Quality(CTQ) factor.

The approach adopted in this study to conserve quality in construction concreting is Total Quality

Management (TQM) which aims at inculcating quality from the very beginning and at each and every stage of the process. Here, quality is made everyone’s responsibility and each person must contribute to the improvement of quality of the product or service offered. Six Sigma, one of the tools of TQM, is employed in this case, to analyse, improve and control the quality of concreting process.

2. THE SIX SIGMA TOOL

The Six Sigma technique, a subset of TQM, is a problem solving methodology that relays on statistical methods to reduce variations. It can also be considered as a process improvement methodology. This concept aims at reducing the defects down to 3.4 per million, or in other terms, it aims at achieving 99.993% success. It is derived from the Standard Normal Distribution, illustrated by a bell shaped curve known as the Standard Normal Curve. Limits of three times the standard deviation (3 σ) is said to cover 99.993% of the total area. Our desire is to confine the output values within this 3 σ limit and narrow down this limit so as to render the process and its outputs more consistent and qualified.

3. METHODOLOGY

The structural framework for implementing quality control in concreting with the help of Six Sigma principle is derived from DMAIC- Define Measure Analyse Improve Control system. This schematic cycle of steps enables one to monitor and regulate the process as well as to identify and eliminate shortcomings and flaws in the activity. It also aids in reducing the number of faults to less than 4 per million opportunities

3.1. Define

The first step in conducting a six sigma based quality assurance programme is to identify and understand the process in hand. In this case, the process or the activity under screening is Concreting. The parameters that affect the quality of concrete is carefully studied and analysed. Amongst all the parameters, the Compressive Strength, Homogeneity and Workability are listed to be the most influencing factors contributing to quality of the finished product, i.e. cured concrete. Out of the three, Compressive Strength is chosen as the Critical to Quality (CTQ) factor that tends to influence the success percentage of the process.

Concrete samples in the form of cubes were collected from a Ready Mix Concrete (RMC) Plant in Chennai. 140 samples for each of the three stages of tests at 3, 7 and 28 days of curing would be tested for compressive strength. Queries reveal that 3 different batches of aggregates with varying characteristics were used for preparing these mixes. The strength values will be analysed for variances and defects and the sigma levels would be identified. If the sigma levels are found to be lower, then it would be necessary to conduct a study on the reasons for poor quality in the process. If the sigma levels are found to be considerably higher, care needs to be taken to narrow the limits of variance to achieve greater quality standards. Control practices are imposed to sustain the improvements attained.

3.2. Measure

Once the plans for exercising six sigma control are devised, the Critical To Quality parameter is measured, i.e, the Compressive Strength is measured. This is done by means of a Compression Testing Machine in which vertical loads are applied gradually until the cracks appear, indicating failure. The values are tabulated against the scale of N/mm^2. The testing of the cubes are done at 3, 7 and 28 days for each mix(2 samples each). Since 3 batches of aggregates were used, the strength values are tabulated separately for each batch of aggregate and their means, Standard deviations and percentage variations are calculated.

3.3. Analysis

The tabulated values are critically examined for defects. For this study, a deficient sample is considered as one which has deviated for more than 1 N/mm^2 from their respective means. The number of defects for each batch and each test category (days) is sorted out individually on the basis of the above mentioned tolerance. The number of defects are then converted to a scale known as DPMO- Defects Per Million Opportunities, a scale in which the defects are identified against one million opportunities of testing.

$$\textbf{DPMO} = \frac{\text{(Number of Defects X 1,000,000)}}{\text{((Number of Defect Opportunities /Unit) Number of Units)}}$$

For this study, the number of defect opportunities per unit is 1 since only one test is carried out to assess the compressive strength of the samples. The number of units for Batch I, II and III are 52, 44 and 44 respectively. The number of defects are found to be higher at three days and gradually decrease at day seven and again trend a higher at twenty eight days.

The DPMOs are then converted into sigma levels by using the standard set of values given in Table 1. DPMOs having values between two particular sigma levels are interpolated to arrive at the appropriate sigma levels.

Table 1: Sigma Levels and their DPMOs

Sigmal Level	**1**	**2**	**3**	**4**	**5**	**6**
DPMO	690,000	308,000	66,800	6,210	320	3.4

The sigma levels of each category are enlisted in Table 2. The sigma levels are found to vary through a range of 1.5 to 3, with the least occurring in Batch III at 3 days and the highest at 7 days for Batch II. It is seen that the levels are the least at 3 days for all the batches and the highest at 7 days

Table 2: Sigma Levels

Batch/Day	Batch I	Batch II	Batch III
3 day	0.54158	0.75443	0.87392
7 day	0.86949	0.71086	0.50438
28 days	1.0426	0.73443	0.73846

Table 3: Standard Deviations

Batch/Day	Batch I	Batch II	Batch III
3 day	1.9	1.74	1.5
7 day	2.72	2.99	2.81
28 day	1.95	2.24	2.52

When it comes to the Standard Deviation of the group of values, highest values are observed with Batch I at 28 days, meaning maximum divergence from the mean. Similarly, the lowest values are found associated with Batch III at 7 days. The standard deviations of the batches at 3, 7 and 28 days are displayed in Table 3.

3.4. Improve

The aim of this study is to narrow down the limits of the control limits (UCL and LCL), thereby reducing the variability of the test values and consequently rendering the process more consistent and qualified. Some of the means of improving the Concreting process and its output characteristics are suggested below:

- Formulate standards for each activity and enforce conformance to it.
- Periodically assess the site conditions and perform according to the requirements.
- Use of aggregates or any other raw material of the same or similar characteristics.
- Highlight the importance of quality control to the workers and motivate them to participate in it.
- Conduct initial tests on materials and equipments and record their performances before designing for any concrete mix to maintain the desired levels of parameters.

3.5. Control

It becomes necessary to control the attained improvement to facilitate further upliftment of the performance of any activity. Once an improvement strategy has been implemented and better results are obtained, control mechanisms must be put in place to prevent the improvements from falling back to the baseline. For this purpose, Control Charts could be used as a reference to confine the outputs to the required limits. Samples whose strength values fall outside the control limits are to be considered defective and go to the reject lot. Control charts for all the batches at 28 days are as depicted in Fig. 1, 2 and 3.

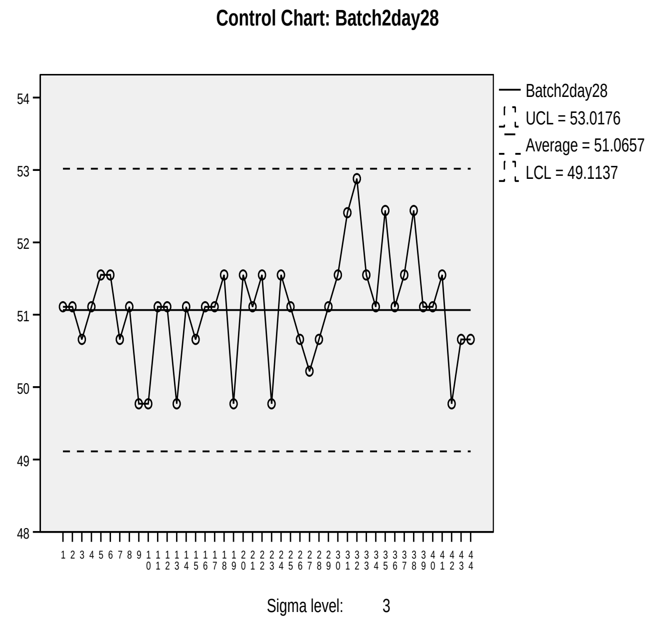

Fig. 1 Control Chart for Batch 2 (28 days)

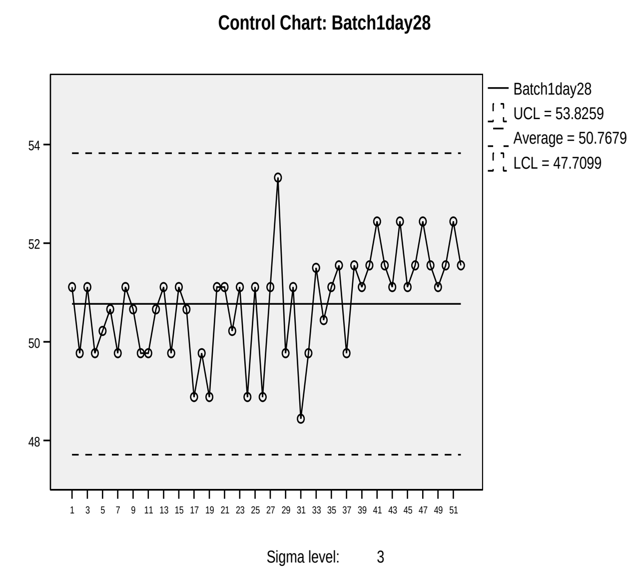

Fig. 2: Control Chart for Batch 1 (28 days)

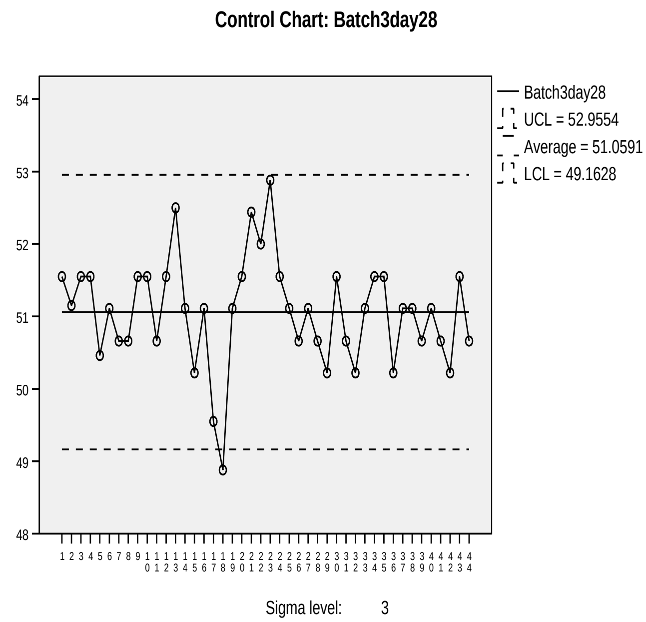

Fig. 3: Control Chart for Batch 3 (28 days)

4. CONCLUSION

Quality is the most desirable deliverable in any project and its prompt preservation and deployment paves way for the success of the projects. Thus, it becomes essential to regulate the parameters that influence quality and position the deliverables at the best. Six Sigma technique proves helpful in ensuring the fitness of the products, where construction and concreting are no exceptions. This method works the best not when the mechanism ends in one go but when the sequence of steps are reputed in a cycle until near zero defect is achieved.

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