Process monitoring of RMC by application of EWMA control charts

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Abstract

Exponentially Weighted Moving Average (EWMA) control charts are one of the latest development in hybrid control charts developed for Six-Sigma Quality Control. These charts have a wide variety of applications and one of it is in process monitoring. Ready Mixed Concrete industry in India still follows very basic quality control tools of taking out mean and standard deviation. These statistical tools do not monitor the whole manufacturing process. This results in highly inconsistent quality which may not be reliable. It was realized that the standard deviation was not very high, but still the strength for the same grade of concrete was highly unpredictable. It was observed that concrete produced at the commercial RMC plants had a very high amount of design margin to secure the strength criteria against all the unanticipated constraints. This paper is an attempt to develop EWMA control chart for monitoring the process and quality of concrete, primarily in terms of its compressive strength. The results have proven to be useful in terms of detecting the small shifts from the targeted mean strength. Application of EWMA charts can bring a good amount of cement saving. These control charts can be recommended to Ready-Mixed-Concrete producers to achieve consistency in strength monitoring and also in achieving optimized cost.

Keywords: Exponential Weighted Moving Averages (EWMA), Control chart, Ready Mixed Concrete (RMC), Quality monitoring

1.INTRODUCTION

Control charts are useful and valuable tools for the visualizing the quality of any product in overall. There are many types of control charts in statistical quality control. All the charts are basically classified in two types: simple and hybrid control charts. The type of chart in use depends on the type of data i.e. either continuous or discrete, and control charts are to be selected in accordance to the available data sets. Simple control charts reflect the Shewhart control charts. Hybrid control charts were then developed by statisticians because simple control charts lacked the quality to detect small shifts in the processes. EWMA control chart has multivariate characteristics, and therefore it is highly recommendable for the RMC industry as a whole. Here EWMA charts are recommended for measuring of the quality characteristics because, in EWMA charts, the constraints of L and lambda (λ) can be put up in such a way that samples in a straight way resemble to the point of action and defect can be readily identified.

Here, obtained data by the authors is of continuous nature and therefore use of EWMA control charts is suggested. Hybrid control charts are in use from long time for forecasting but its use for quality monitoring has been very limited. Previously the use of CUSUM with V-Mask and RACUSUM have been attempted and it showed successful results[1], [2]. For CUSUM charts, designing of V-mask is mandatory because CUSUM chart itself does not have and control limits, so it shows only the trend. Also, in CUSUM with V-Mask charts, the point moving outside the V-mask may not be a faculty sample; the mean may have shifted beforehand. The actual point of action may be well within the control limits, making it a bit difficult to track and take any further counter measures.

The basic objective of the authors is that the organization should produce consistent quality of output material. This consistent output directly affects the organization in both, short and long terms. Here, fresh concrete produced at RMC plants is the output material. Fresh concrete at RMC plants is produced according to the grade specified by the client. So, a direct comparisonis made by comparing the achieved strength of the 28day cube compressive strength with the target mean strength. At present, the quality control practices in Ready-Mixed Concrete industry lack statistical monitoring. Statistical process control a sub-section of statistical quality control provides considerable statistical details.The prime advantage of statistical quality monitoring is that the data can be analyzed and minor changes can be made in anabbreviated stretchof time as the procedure is statistically known.Some short-term benefits of application of statistical monitoring is reduction in manufacturing cost by having optimized plant efficiency.

This topic is taken up for research because RMC production business has enormous growth potential in construction sector with manylarge-scale projects taking place in India. Unorganized management and absence of any statistical quality control techniques is resulting unreliable quality of concrete. So, this piece of work tries to frame a framework for the quality monitoring structure based upon the principles of EWMA control chart.

Statistical quality control is a widespread tactic used to eliminate inconsistencies from processes. It was initially introduced as a subset of Six sigma for quality performance measurement but then has evolved as a totally different tool set. Today six sigma uses some of the selected tools of statistical quality control for performance monitoring[3]. Leu & Lin [4] successfully applied statistical process control quality control charts for project performances and proved it to be better than the traditionally working Earned Value Management (EVM) method by detecting adverse changes in a timely manner.

Lowest possible cost, unique needs and wants, higher agile production models can be readily optimized with the help of statistical process control charts. Statistical process control charts have been proven to be very useful for short production runs presenting a decision-model to guide the production managers[5].

Problem identification by critically analyzing the data and enabling the project managers to control the projects effectively is one of the identified benefits of control charts. Performance measurement and analysis systems can also be readily used in multiple ways in construction projects [6].

Comparison of EWMA and CUSUM control charts for online strength monitoring of RMC was carried out by [7]. It was observed that CUSUM control charts with V-mask was more sensitive and effective for RMC industry. On the other hand EWMA control charts were effective for highway industry. Sarkar & Dutta [8] made an attempt to develop economic design model for the CUSUM control charts particularly for Indian concrete industry. [9] Applied QFD as a six-sigma tool for performance monitoring of RMC. They observed application of the QFD tool can prove to be very effective for commercial batching plants. Furthermore, [10] had made an attempt to explore and develop a multivariate EWMA model which can monitor the quality and overall performance of RMC.

2.METHODOLOGY

2.1Mathematical Formulation

Here some practical cases are taken for consideration where the 28day cube compressive strength of M20 grade of concrete is taken and the EWMA control chart is then generated for the quality monitoring purpose.
The statistic formula of Exponentially Weighted Moving Averages is calculated based on the following equation[11]:

$$z_i = \lambda x_i + (1-\lambda)\, z_{i-1} \ldots \qquad (1)$$

where, $0 < \lambda \leq 1$ is a constant and the starting value (required with the first sample at $i = 1$) is the process target;

z_i is the smoothened value that is obtained by applying the statistical smoothening of Lambda (λ),

x_i is the sample number.

the Upper Control Limit (UCL) and Lower Control Limits (LCL) are calculated with the following formula:

$$UCL=\mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]} \qquad (2)$$

$$CL = \mu_0$$

$$LCL = \mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]} \qquad (3)$$

Here, L is a constant and Lambda (λ) is the constant as defined for equation (1).
After the chart has been an in-depth analysis is being done. As the chart is easier to read as compared to other multivariate charts, points of failure are easy to notice and discover. Root-cause-analysis of these points can then be carried out in a detailed fashion and necessary action can then be taken.

2.2Data Collection

The data has been collected from the batching plants in and around Ahmedabad. The batching plants under consideration are well known and are working from at least 5 years. These batching plants have a capacity of handling

3 sites in parallel which is considered relatively good according to the regional characteristics. The data in the form of 28day cube compressive strength has been obtained by in person visit and then the data is analyzed with the help of EWMA control charts. Each sample is the mean of three individual cubes.

2.3Data Analysis:

An EWMA control chart is generated from the collected data. The upper and lower control limits are then established in accordance with the mean and standard deviation. All the data points are then plotted. The data is then analyzed in accordance to the trend analysis. The points of defect are then identified as the points moving outside the control limits. A detailed trend analysis is then given so that potential root-causes can be identified.

3.DATA COLLECTION:

For case 1 and 2 the following Table-1 shows the collected data shows the

TABLE-1: 28 DAY CUBE COMPRESSIVE STRENGTH

SR. NO	OBSERVED COMPRESSIVE STRENGTH AT PLANT-1(N/MM^2)	OBSERVED COMPRESSIVE STRENGTH AT PLANT-2 (N/MM^2)
1	23.11	22.88
2	24.33	23.55
3	22.75	23.37
4	20.86	22.22
5	23.84	21.44
6	23.17	25.82
7	20.37	21.80
8	22.28	22.73
9	21.68	22.31
10	22.66	23.37
11	22.00	22.84
12	22.48	23.31
13	22.22	23.13
14	22.33	23.28
15	20.75	22.15
16	21.31	21.11
17	21.60	22.48
18	23.37	22.04

19	23.75	21.33
20	24.77	21.77
21	23.46	22.40
22	22.46	23.35
23	25.80	23.86
24	22.67	22.67
25	22.78	22.78
26	22.87	22.87
27	22.62	22.62
28	22.98	22.98
29	23.63	23.63
30	22.65	22.65

4.DATA ANALYSIS

Table-2 EWMA chart control limits for Case-1

Sr. No.	Observed compressive strength	Smoothened Values	Upper Control Limit	Lower Control Limit
1	23.11	23.15	23.121	22.395
2	24.33	23.23	23.223	22.293
3	22.75	23.26	23.277	22.238
4	20.86	23.05	23.310	22.206
5	23.84	22.73	23.329	22.186
6	23.17	23.35	23.342	22.174
7	20.37	23.04	23.349	22.166
8	22.28	22.98	23.354	22.161
9	21.68	22.84	23.357	22.158
10	22.66	22.95	23.359	22.156
11	22.00	22.93	23.361	22.155
12	22.48	23.00	23.361	22.154
13	22.22	23.03	23.362	22.154
14	22.33	23.08	23.362	22.153
15	20.75	22.89	23.362	22.153

Table-3: EWMA chart control limits for Case-2

Sr. No.	Observed compressive strength	Smoothened Values	Upper Control Limit	Lower Control Limit
1	22.88	23.15	23.121	22.395
2	23.55	23.23	23.223	22.293
3	23.37	23.26	23.277	22.238
4	22.22	23.05	23.310	22.206
5	21.44	22.73	23.329	22.186
6	25.82	23.35	23.342	22.174
7	21.80	23.04	23.349	22.166
8	22.73	22.98	23.354	22.161
9	22.31	22.84	23.357	22.158
10	23.37	22.95	23.359	22.156
11	22.84	22.93	23.361	22.155
12	23.31	23.00	23.361	22.154
13	23.13	23.03	23.362	22.154
14	23.28	23.08	23.362	22.153
15	22.15	22.89	23.362	22.153

16	21.31	22.54	23.363	22.153
17	21.60	22.53	23.363	22.153
18	23.37	22.43	23.363	22.153
19	23.75	22.21	23.363	22.153
20	24.77	22.12	23.363	22.153
21	23.46	22.18	23.363	22.153
22	22.46	22.41	23.363	22.153
23	25.80	22.70	23.363	22.153
24	22.67	22.69	23.363	22.153
25	22.78	22.71	23.363	22.153
26	22.87	22.74	23.363	22.153
27	22.62	22.72	23.363	22.153
28	22.98	22.77	23.363	22.153
29	23.63	22.94	23.363	22.153
30	22.65	22.88	23.363	22.153
	22.72	Average		
	1.16	Standard Deviation		
	20.37	Minima		
	25.80	Maxima		
	5.43	Range		

16	21.11	22.54	23.363	22.153
17	22.48	22.53	23.363	22.153
18	22.04	22.43	23.363	22.153
19	21.33	22.21	23.363	22.153
20	21.77	22.12	23.363	22.153
21	22.40	22.18	23.363	22.153
22	23.35	22.41	23.363	22.153
23	23.86	22.70	23.363	22.153
24	22.67	22.69	23.363	22.153
25	22.78	22.71	23.363	22.153
26	22.87	22.74	23.363	22.153
27	22.62	22.72	23.363	22.153
28	22.98	22.77	23.363	22.153
29	23.63	22.94	23.363	22.153
30	22.65	22.88	23.363	22.153
	22.76	Average		
	0.91	Standard Deviation		
	21.11	Minima		
	25.82	Maxima		
	4.71	Range		

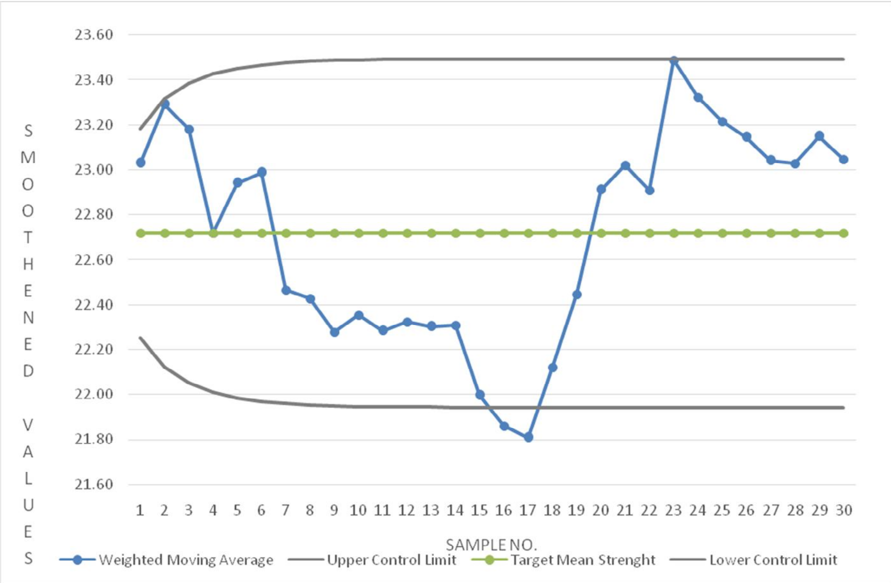

Figure 1: Exponentially Weighted Moving Average Chart for 28day cube compressive strength for M20 grade of concrete (Case 1)

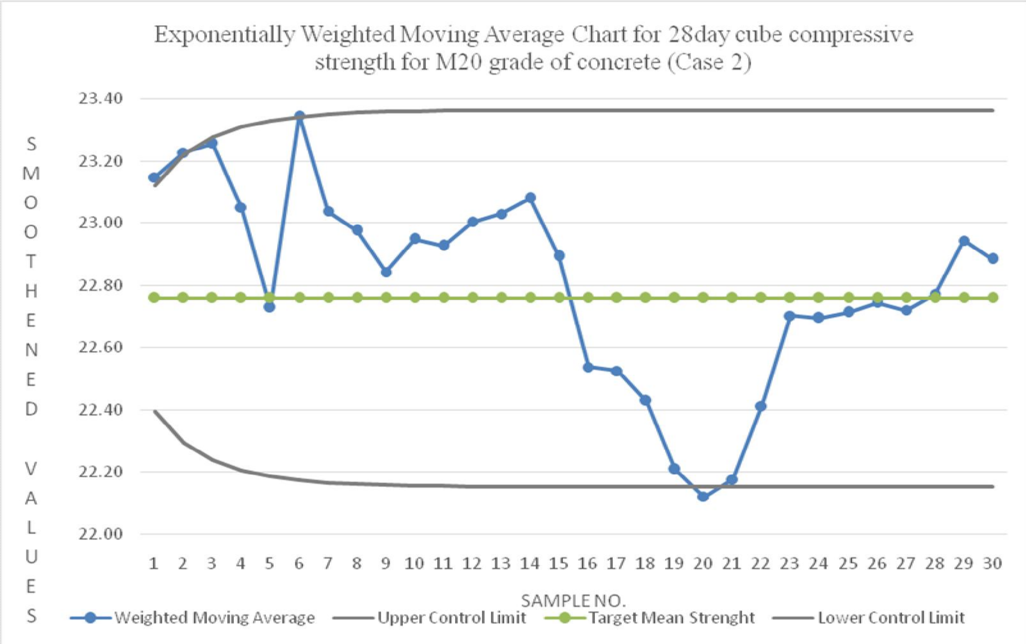

Figure 2: Exponentially Weighted Moving Average Chart for 28day cube compressive strength for M20 grade of concrete (Case 2)

4.1Inference (Case 1):

From figure 1, it can be stated that initially the trend is highly fluctuating or unstable with the sample strength continuously shifting up and down. After sample number 7, it can be observed that the trend is linear with continuous 9 samples below the mean; which is also not a good sign. Though these samples do not move below the lower control limit but random scattering is not observed. With nine samples having approximately equal values indicates about a large shift in the process. With sample sixteen moving out of the lower control limit, with only one previous warning sample i.e. sample 15, it may be termed as special cause variation which is very dangerous for the concrete industry. Because in concrete industry anything less than the designed compressive strength is not acceptable.

4.2Inference (Case 2)

Here also the initially the trend is highly fluctuating till sample 7 with sample 1 and 2 moving out of the control limits. Then again, we observe continuous eight values of the same order indicating a non-random scattering. From sample 15 till sample 19, it should be enough alarming signal of a downward trend to rectify and not let the sample 20 move below the lower control limits. It should be noted that at sample 20, a strict root-cause investigation is to be conducted. Again, from sample 23 to 28, all the samples have nearly the same values, which is rarely possible.

5.Conclusion

As it can be observed that in both the cases the mean is 22.72 and 22.76 respectively and standard deviation is 1.16 and 0.91 which may be considered as very less, but the range of the strength samples is 5.43 and 4.71 respectively depicting a high probability of variation from the mean. This means that the quality if the concrete may not be reliable. It has been observed that many RMC batching plants have a very high design buffer and design the concrete for one grade higher strength to ensure security of the minimum strength. At present, none of the RMC batching plants use this technique and incur a significant amount of material and production cost. With the application of EWMAcontrol chart tool a consistent quality of concrete can be produced.In general, it can be stated that the samples moving outside the control limits use higher amount of cement in their respective design mix. On the other hand, wherever the samples move out of the control limits, it means those samples have considerably less strength then allowed. Faulty mix-designs could be readily rectified and the production process can be put under a continuous check for consistency. Thereby by application of this tool commercial RMC batching plants can produce superior quality concrete at optimum cost.

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