# EVALUATION THE EFFECT OF PRODUCTION CONDITIONS ON THE QUALITY OF CONCRETE BY USING CONTROL CHARTS

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## ABSTRACT

The objective of this study is to relate the quality of concrete production to the capability of the production process in such a way that the process capability could indicate the level of production quality in batching plants. The main idea in this research is that the accepting and refusing lab tests are not sufficient as quality indices and that the statically analysis including control charts and capability calculations give biter image to the performance levels of production process in batching plants . In this study, the production conditions for a batching plant are investigated and the supervision is taken as the effecting factor on the quality. Large number of testing data of compressive strength are analyzed. Results showed that it is necessary to use more detailed procedure than accepting and refusing concrete tests.

**KEYWORDS :** Production conditions , Quality Control , Process Capability , Quality of concrete , Control charts

# تقيم تأثير ضروف التصنيع على نوعية الخرسانة باستخدام مخططات السيطرة

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**الخلاصة**

يهدف هذا البحث الى الربط بين مقدرة العملية وجودة الأداء فيما يخص انتاج الخرسانة بحيث يكون بالإمكان ان تؤشر مقدرة العملية الى مستوى الجودة في مواقع انتاج الخرسانة. ان الفكرة الأساسية في هذا البحث هي ان الفحوصات المختبرية لقبول ورفض الخرسانة لا تكفي لوحدها كمؤشر للجودة وان التحليل الاحصائي بما في ذلك لوحات الضبط وحسابات المقدرة يعطي صورة أفضل بكثير عن مستويات الأداء لعملية الإنتاج في مواقع الإنتاج. لقد تم في هذا البحث دراسة ظروف الإنتاج لأحد معامل انتاج الخرسانة من حيث الاشراف كعامل مؤثر على جودة المنتج وبالمقابل تم تحليل نتائج عدد كبير من فحوصات الخرسانة لمقاومة الانضغاط كمحدد لجودة الخرسانة . وخلص البحث الى ضرورة استعمال منهج اكثر تفصيلا من فحوصات قبول ورفض الخرسانة للوصول الى جودة الأداء .

## INTRODUCTION

This study introduces an analysis for the impact of conditions of production on the quality of concrete. The study suggests that there is an impact of the quality management in the batching plant on the quality of produced concrete and this impact does not appear through the process of evaluation of results of testing concrete cubes for compressive strength either when accepting or refusing cases .DiCocco[2010] . To make this impact clear and obvious, a simple model has been constructed in order to control quality of concrete and is introduced in this study. This model is based on control charts for mean values of concrete compressive strength . Control charts are tools using to represent scattering of data around its mean . There are many types of control charts like charts of mean values and charts of ranges . Many researchs are dealing with the issue of controlling concrete quality using statistical approaches like control charts . Naiknavare worked out a model chart of quality control process for ready mixed concrete plants. Naiknavare [2007] . Jib and Harrison worked out a detailed research for using of control charts in the production of concrete Gibb and Harrison [2010] . However , these researches had been worked on theoretical examples while this study deals with real data .Many lab experiments were done on a large number of concrete cubic specimens that produced from one identity. It is well known that many factors in the environment of production play roles in changing the results of cubic concrete for compressive strength and the study takes one factor from them to be the variable and the other factors are assumed to be unchanged ( same materials and equipments…etc ) . The variable factor is the supervision which is a management issue . Building Materials & Technology Promotion Council [2013]

## EXPERIMENTAL WORK

The model of the study uses the process capability associated with control charts to investigate the quality of concrete . This is done on the basis of testing results of concrete cubes for compressive strength which is the main criteria of accepting or refusing concrete . Usually every lab takes specimens for testing with some parameters. This is done according to a time schedule taking in account the demand which is the required volume of concrete such that the collected data can be regarded sufficient. Many parameters must be taken for this process such as (water / cement) ratio, gradation of aggregate and so. In preparing this study , 202 specimens for testing were taken each of them consists of 3 cubes of concrete and the compressive strength of concrete (Fcu) was measured using a suitable machine in the labs of AL-Mustaqbal University College, British Standards [1983] , Iraqi Building Code Requirements for Reinforced Concrete [1987]. The concept of the model of this study is that there are limits for warning and for actions in the control charts obtained from concrete testing. During supervising, workers can be warned when the warning limits are reached and thus they would be ordered to make correction wherever needed. When the action limits has been exceeded the production should be stopped and the accumulated products would be tested later. If the process is automatic then these actions will be done without need to stop the machines but the concept still the same because there is a number must be entered to give the operator an index of the process control . This index is the process capability which is the main issue of this research .Seyhan [2010]

## STATISTICAL APPROACH

Many factors affects the quality of concrete and it will be complicated to consider all of them in one study. Hence , this study takes in account one factor which belongs to the managing the process of production that is the supervision.
Supervision of the production of concrete is considered from view of the following components:

1- Weigh batching Vs. Volume batching
2- Control of water
3- Frequency of supervision
4- Frequency of field and lab. Tests
5- Regularity of testing for strength and workability
6- Experience of workers

These components then were arranged for purpose of study into three quality levels as following:

**A-First level**

1- Weigh batching
2- Control of water
3- Frequent supervision
4- Frequent field and lab tests
5- Regular testing for strength and workability
6- Experienced workers

**B-Second level**

1- Weigh batching
2- Control of water
3- Intermittent supervision
4- Intermittent field and lab tests
5- Periodic testing for strength and workability
6- Experienced workers

**C-Third level**

1- Volume batching
2- Water inspection
3- Occasional supervision
4- Occasional field and lab tests
5- Occasional testing for strength and workability
6- Experienced workers

The situations of supervision were monitored among several batching cases that was done as an experiment. The numbering of tests is given in **Table(1)** and the collected data were recorded and grouped in **Table(2)**. Sarkar [2007] , The Institution of Engineers [2010]

## VARIATIONS IN RESULTS

In order to get an index for the process , data was collected for many batches . The first step was to check if the process was under control or not . To do so it should be noted that the deviations usually occur in all data in production or in service sectors. These natural deviations from the target are usually resulting from accumulating of small reasons and they never be controlled. Examples of such reasons are machine vibration, weather conditions, variation in temperature and so. Almost these deviations are small and usually accepted. These deviations are called common variations. If only these variations exist in the process then it is considered in statistical control. Montgomery [2009]

## CONTROL CHARTS

Control Charts are used to investigate the capability of process to meet specifications . It is also useful in providing important information that help in improving the process . The goal of statistical process is to eliminate variability. Although this is impossible goal , Control Charts help in decreasing variations as much as possible .

To draw X-bar Control Chart following calculations must be done : mean value for each sample $\overline{X}$ (eq. 1) , average of values of means for all samples $\overline{\overline{X}}$ (eq. 2) , average of values of ranges for all samples $\overline{R}$ (eq. 3) , Upper Action Limit UAL (eq. 4) , Lower Action Limit LAL (eq. 5) in addition to warning lines (eqs. 6 & 7). Bartlett and MacGregor [1996]

$$\overline{X} = \frac{\sum X}{n} \tag{1}$$

$$\overline{\overline{X}} = \frac{\sum \overline{X}}{m} \tag{2}$$

$$\overline{R} = \frac{\sum R}{m} \tag{3}$$

Where n is the size of sample and m is the number of samples.

Two pairs of lines should be drawn and the levels of them referring to the line of ( $\overline{\overline{X}}$ ) are calculated from :

$$\text{Upper Action Limit ( UAL )} = \overline{\overline{X}} + A2 \times (\overline{R}) \tag{4}$$

$$\text{Lower Action Limit (LAL )} = \overline{\overline{X}} - A2 \times (\overline{R}) \tag{5}$$

$$\text{Upper Warning Line ( UWL)} = \overline{\overline{X}} + \frac{2}{3} \times A2 \times (\overline{R}) \tag{6}$$

$$\text{Upper Warning Line (LWL)} = \overline{\overline{X}} - \frac{2}{3} \times A2 \times (\overline{R}) \tag{7}$$

Where A2 is a constant whose values are given for each sample size in **Table (3)** .Naiknavare [2007]. Beyond Upper Action Lines ( UAL) and Lower Action Lines (LAL) manager must take an action . Each of the two warning lines is at two thirds of the distance between the target and the action lines from either side . **Figure (1)** shows these lines .

Observations of concrete strength Fcu ( in MPa ) for various tests of concrete cubes are recorded . **Tables (4)** shows the results for group (1) . Eeach sample consists of 3 cubes .For example:

$\overline{X}$ = ( 31.5 + 33.8 + 36.3 ) / 3 = 33.9
R = 36.3 – 31.5 = 4.8
For the group as whole :

$\overline{\overline{X}}$ = (33.9 + 33.2 +……..+ 34.1 ) / 24 = 33.0
$\overline{R}$ = (4.8 + 4.7 + ……+ 2.0 ) / 24 = 3.1
UAL = 33.0 + 1.023(3.1) = 36.2
LAL = 33.0 - 1.023(3.1) = 29.8

UWL = 33.0 + (2/3)(1.023)(3.1) = 35.1
LWL = 33.0 - (2/3)(1.023)(3.1) = 30.9

**Figures (2) through (13)** shows the resulted control charts for all of the groups.
**Table (5)** gives the statistical data needed to draw the control charts for all groups . Stevenson [1996], Montgomery [2009]

Before assess the process capability, it is important to make sure that the process is under control. To do so the following conditions must be verified : Dolacek [2011]

1- No value lies outside of UAL or LAL.
2- No two consecutive values lie beyond UWL or LWL.
3- There is no case of seven consequent values lie on the same side of the target mean line.

Verification of each group of tests is shown in **Tables (6).** It can be shown according to these conditions that all processes are under control except No. 3,4 and 11.

## PROCESS CAPABILITY

The process capability can be calculated for those processes under control. First, lower specification limit must be set. The characteristic strength of concrete is defined as the value that below which 5% of population are expected to fall . If every single batch is tested, 5% of the results would fall within the lower tail of the normal distribution that starts 1.64σ below the actual mean strength. The target strength value usually is some higher value to ensure the required characteristic strength and it is given as following : Gibb and Harrison [2010] , Silvestri [2010]

$$TS = fck + k\times \sigma \qquad \textbf{(8)}$$

Where : TS = Target strength
fck = characteristic compressive strength
k = constant
LSL is given by :

$$LSL = TS - k\times \sigma \qquad (9)$$

for example , the target value for specified characteristic strength of Fcu = 30 MPa with a standard deviation of 3MPa is :

$$TS = 30 + 1.64 \times 3 = 34.92 \quad \text{say 35 MPa}$$

Hence :

$$LSL = 35 – 1.64 \times 3 = 30.08 \quad \text{say 30 MPa}$$

For each batch LSL is calculated and given in **Table (7)** . Also , the standard deviations for Fcu were calculated according to the equation(10).

$$S = \sqrt{\frac{\sum (X-\overline{X})^2}{n-1}} \qquad (10)$$

The mean value of batches and the standard deviation are shown in **Table (7)** . The process capability index is a measure relates the actual performance with the specified performance. In order to produce within specification limits, the deference between Upper Specification Limit (USL) and Lower Specification Limit (LSL) must be less than the total variation of the process . Thus the comparison between 6σ and the difference ( USL - LSL ) gives the index of the capability :

$$Cp = \frac{USL - LSL}{6\sigma} \qquad (11)$$

The process is incapable if $Cp < 1.0$ because this case means that the variation in the process is greater than the tolerance band .

Cpk is another index of capability that takes in account the centering of the process . It is calculated from equations 12 through 14.

$$Cpk = \min ( Cpl , Cpu ) \tag{12}$$

$$Cpl = \text{Lower } Cp = ( \text{mean value} - LSL ) / 6\sigma \tag{13}$$

$$Cpu = \text{Upper } Cp = ( USL - \text{mean value} ) / 6\sigma \tag{14}$$

**Table (7)** shows the process capabilities for batches where three of processes were cancelled (3 , 4 and 11 ) . The index taken here is Cpl only because it indicates the capability of process to give concrete having compressive strength exceeding the permissible limit which is LSL . **Table (8)** shows the correspondence between values of process capabilities and the levels of supervision accompanied with those processes in ordered manner. For levels of supervision see **Table(1)**.

From **Table (8)** It is obvious that levels of supervisions fairly reflects the situations of control. Values of process capability index Cpk are increasing with the improvement of supervision from a certain level to a higher level . To make process more controlled and hence to get more quality of produced concrete the level of supervision should be improved . Causay and Simon [2007]

## CONCLUSIONS

1- Control Charts of produced concrete gives much information about the state of quality
2- Process Capability index is a good measure to the level of supervision which is a factor represents the conditions of producing process of concrete that affects quality. In this study the highest value of the process capability index Cpk (2.7) corresponds to the best level of supervision A. On the other hand the lowest value of the process capability index Cpk corresponds to the worst level of supervision C.
3- Managerial decision is required to assess the level of supervision and accordingly the quality of concrete . This assessment should be done according to a trade-off between the required quality and the corresponding cost .

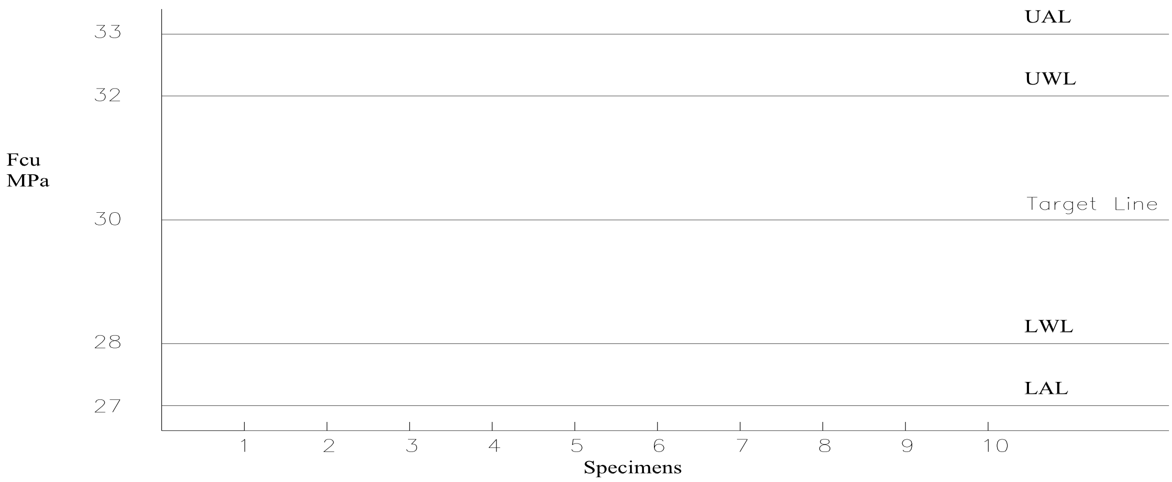
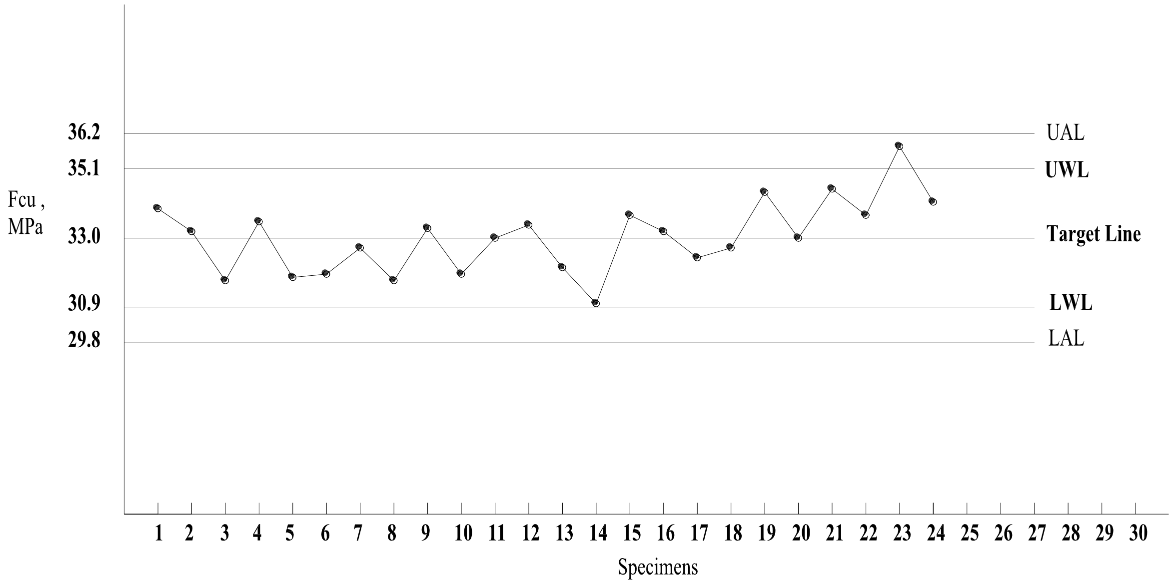
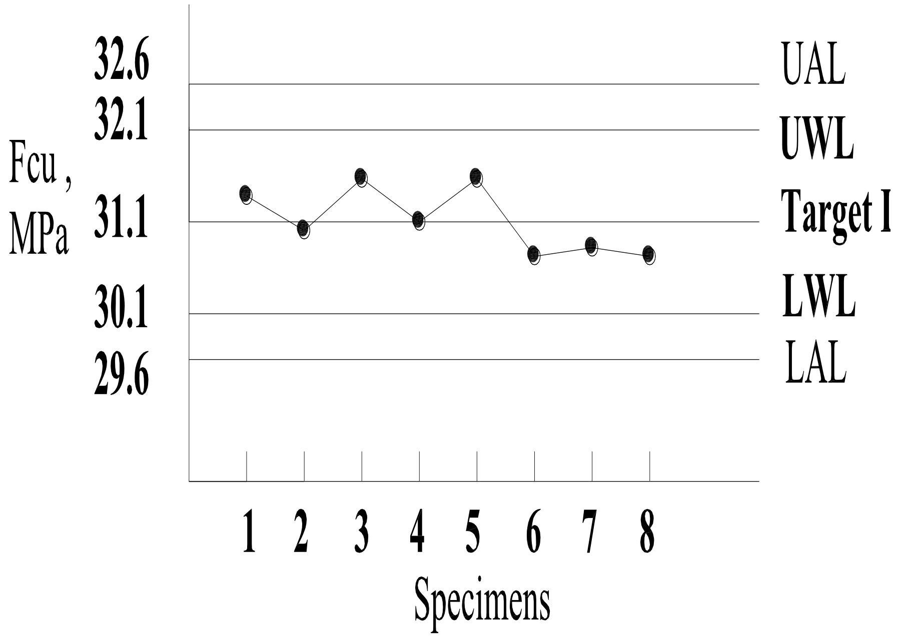


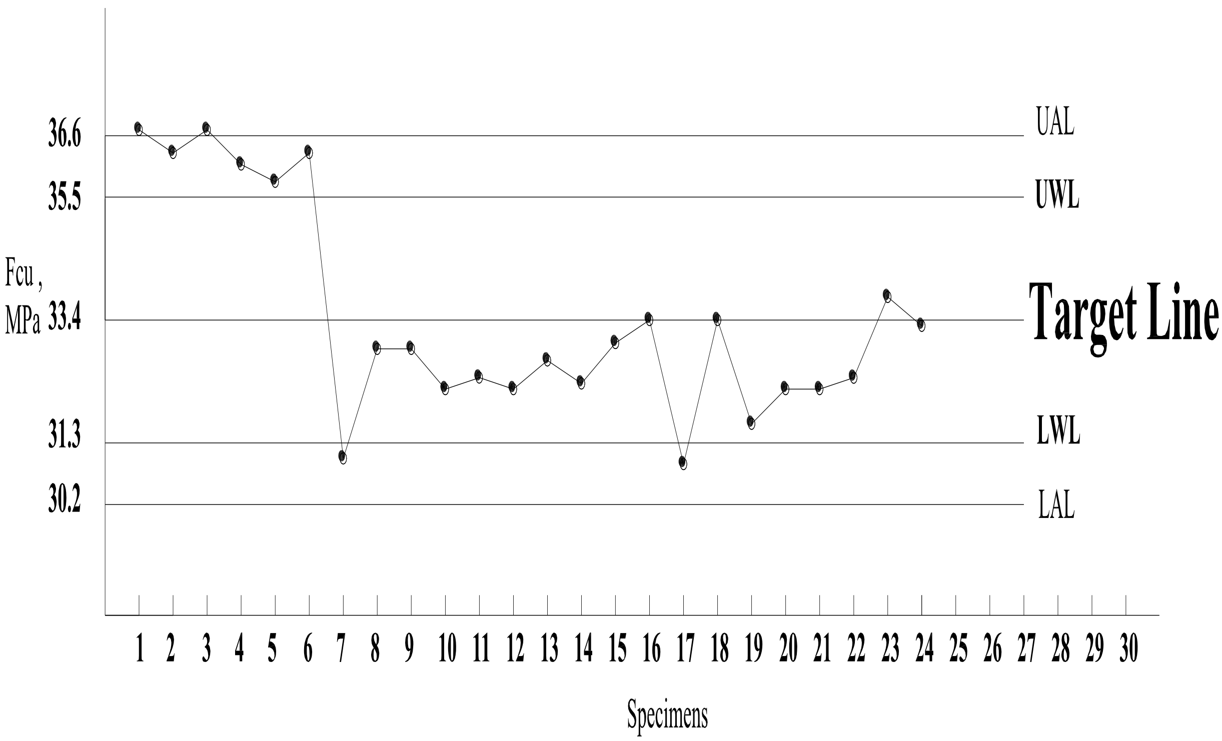

**Figure (1)** : Action Lines and Warning Lines



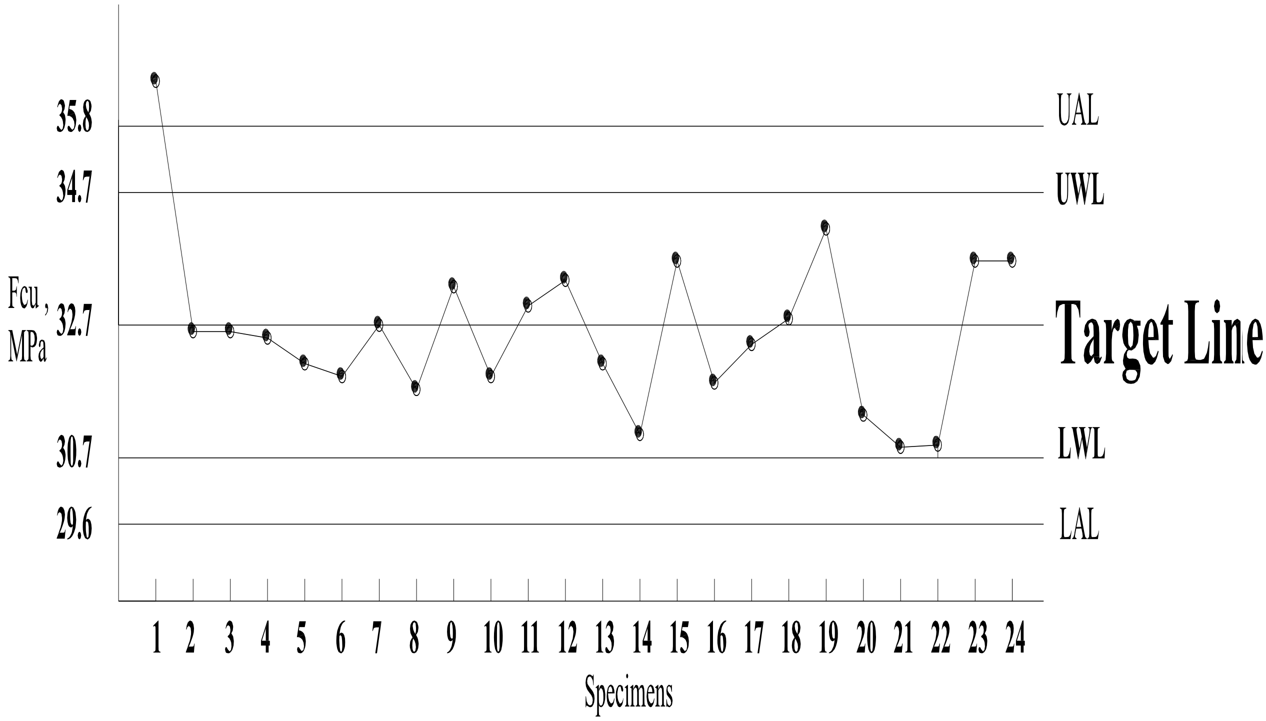

**Figure(2)** Control chart for group (1)



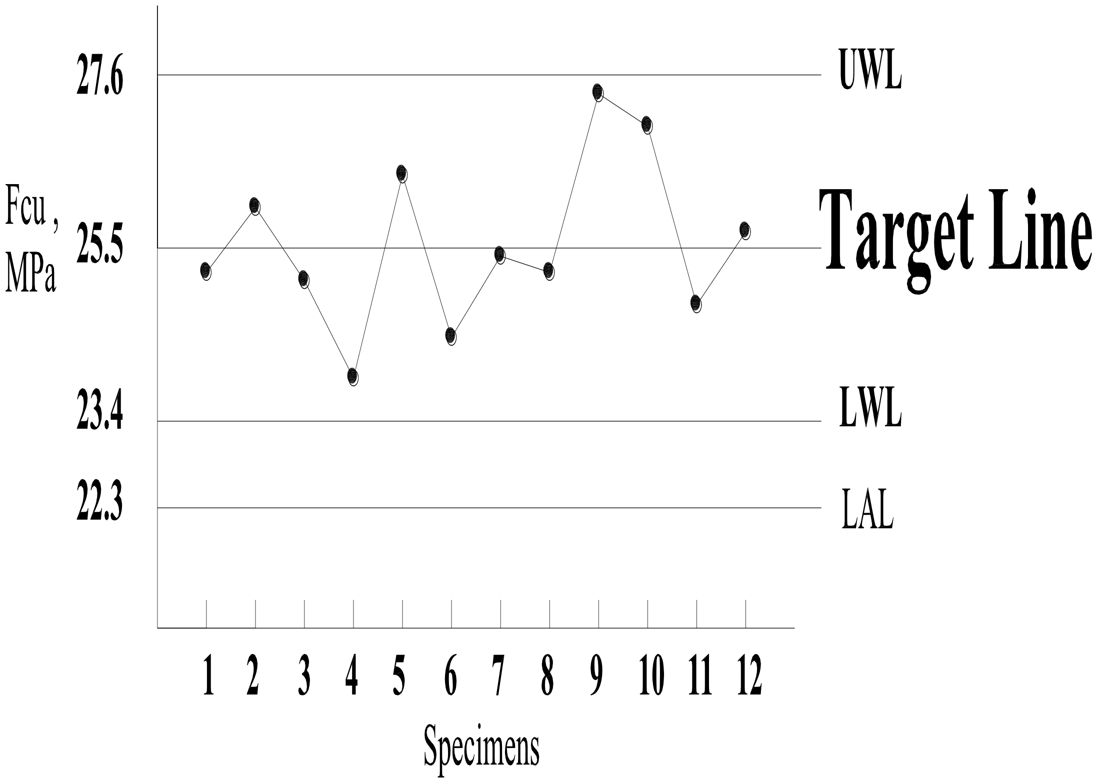

**Figure(3)** Control chart for group (2)



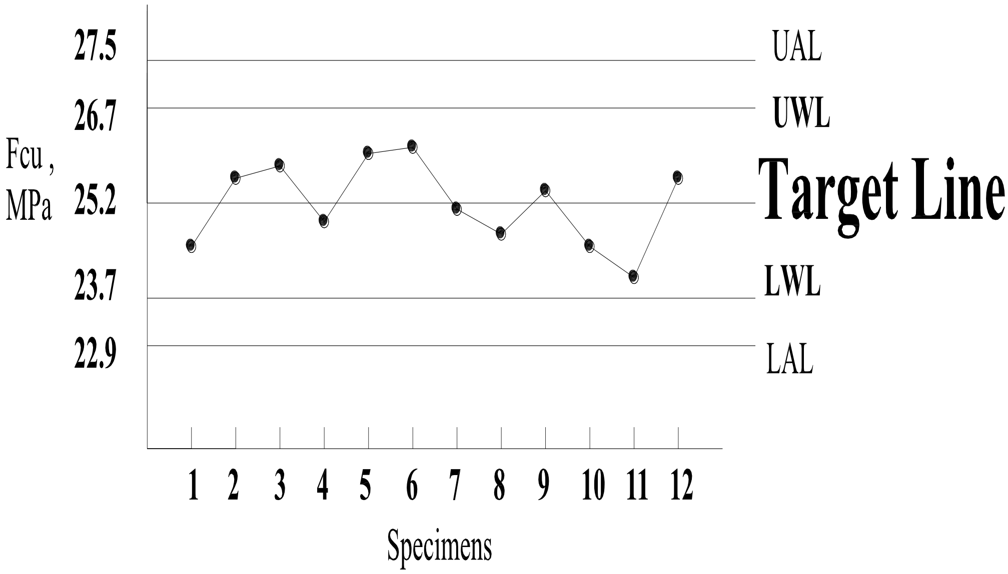

**Figure(4)** Control chart for group (3)



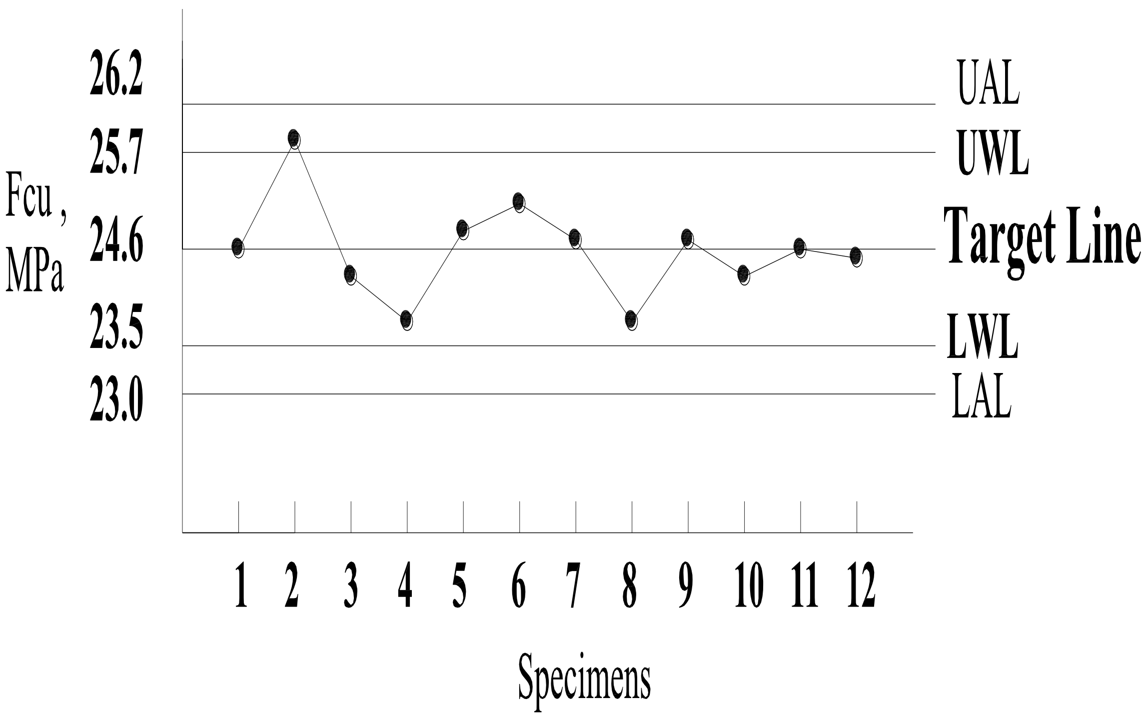

**Figure(5)** Control chart for group (4)



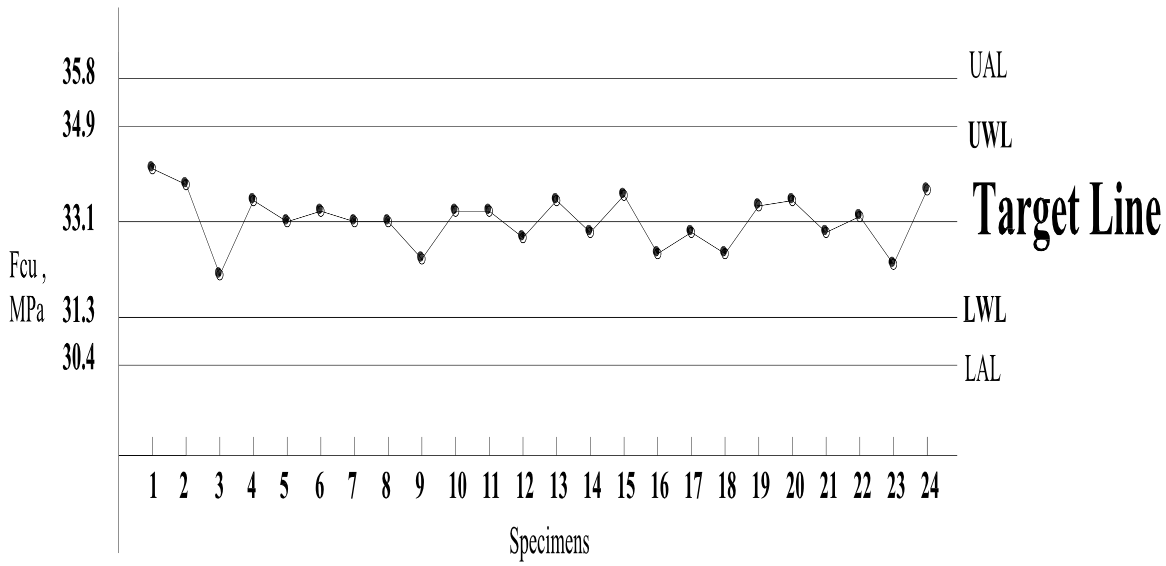

**Figure(6)** Control chart for group (5)



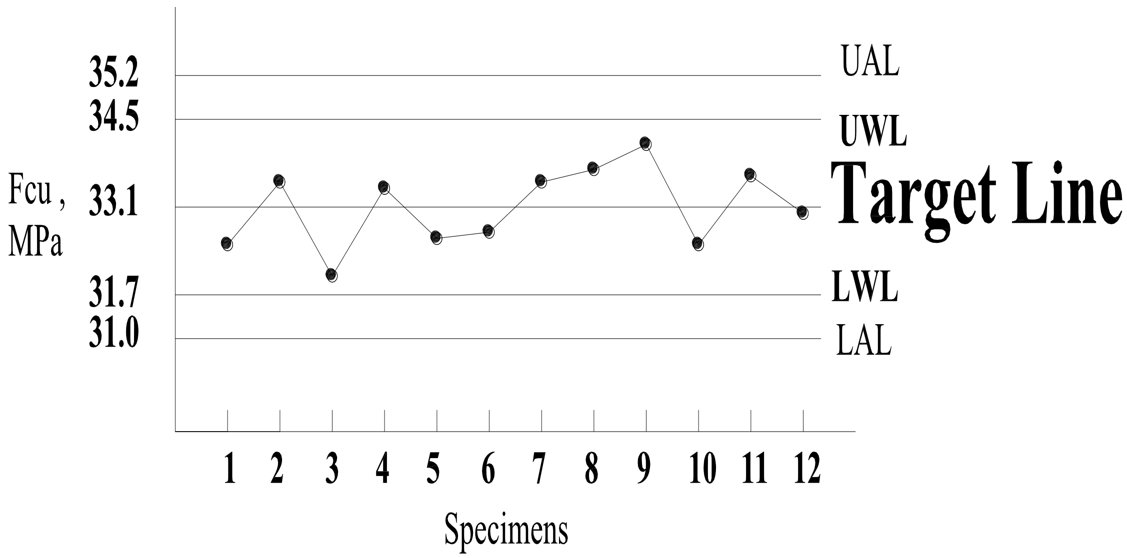

**Figure(7)** Control chart for group (6)



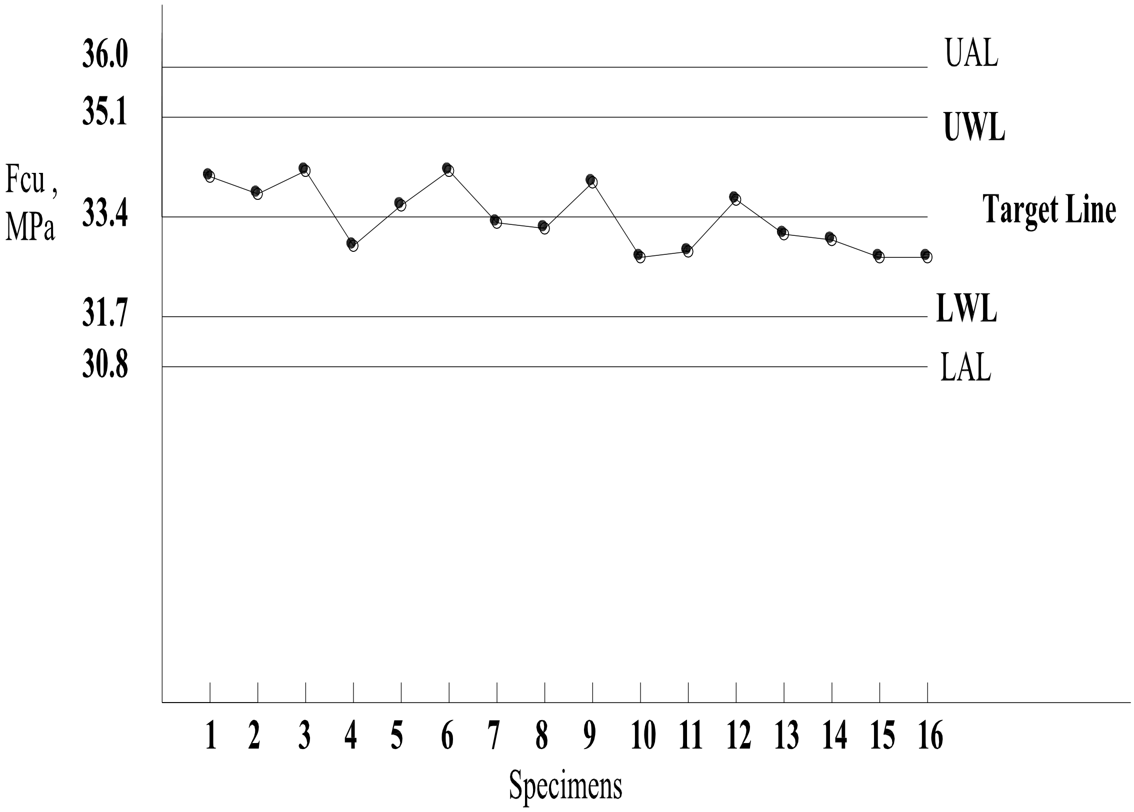

**Figure(8)** Control chart for group (7)



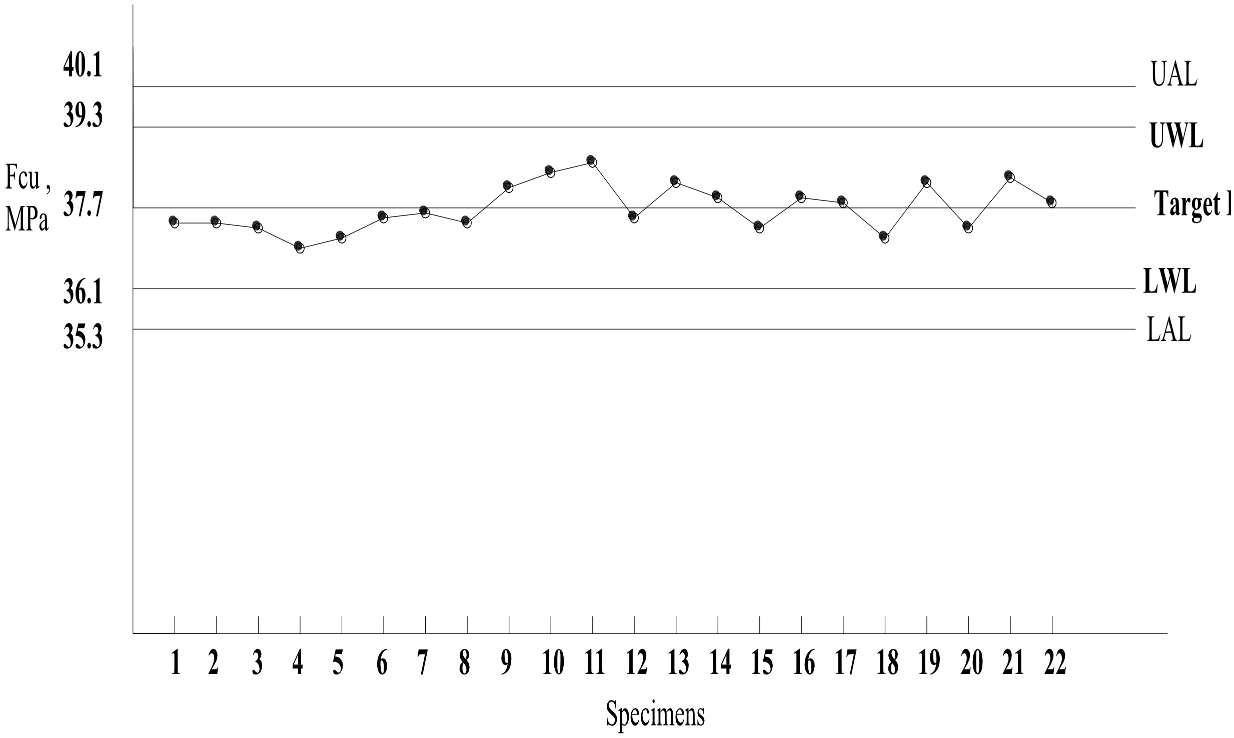

**Figure(9)** Control chart for group (8)



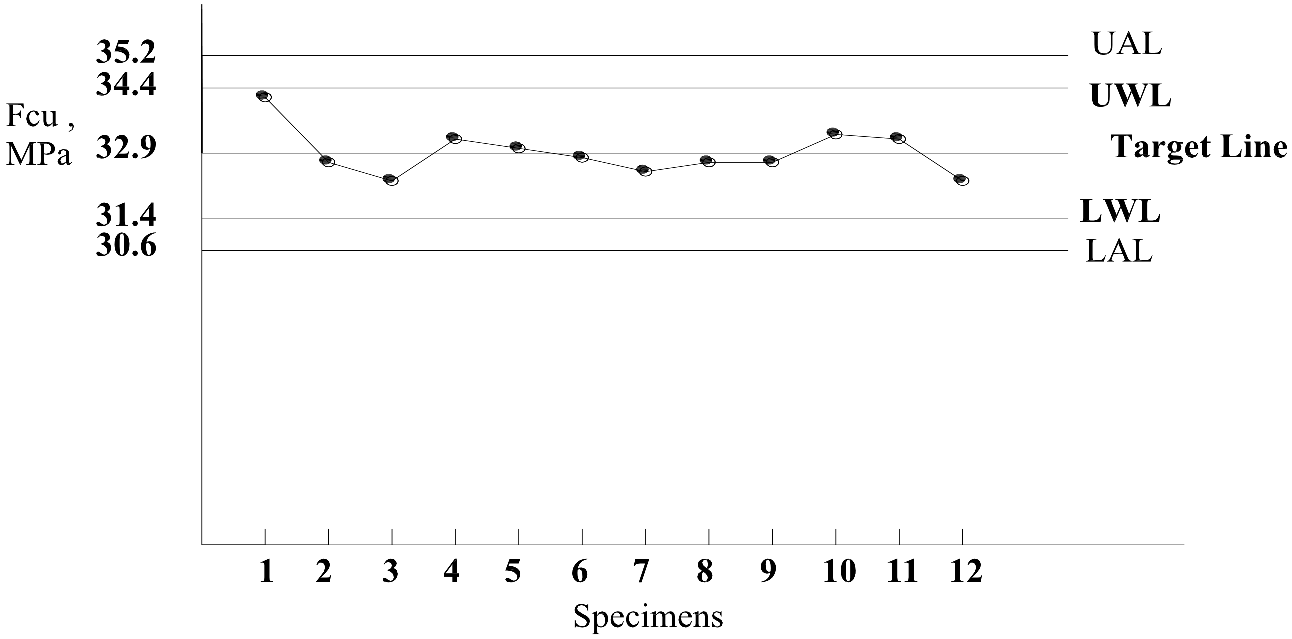

**Figure(10)** Control chart for group (9)




**Figure(11)** Control chart for group (10)




**Figure(12)** Control chart for group (11)




**Figure(13)** Control chart for group (12)

**Table(1)** Numbering of tests

| Level | Number of test |
|---|---|
| A | 2,6,7,8 |
| B | 5,9,10,12 |
| C | 1,3,4,11 |

**Table(2)** Collected data for supervision

| Level | Batching ( weigh or volume ) | Water quality control | Frequency of supervision | Frequency of field and lab tests | Regularity of strength and workability tests | Experience of workers |
|---|---|---|---|---|---|---|
| A | weigh | control | Frequent | Frequent | Regular | experienced |
| B | weigh | control | Intermittent | Intermittent | Periodic | experienced |
| C | volume | inspection | Occasional | Occasional | Occasional | ordinary |

**Table (3)** Values of A2

| **n** | **A2** | **n** | **A2** |
|---|---|---|---|
| **1** | **----** | **7** | **0.419** |
| **2** | **1.880** | **8** | **0.373** |
| **3** | **1.023** | **9** | **0.337** |
| **4** | **0.729** | **10** | **0.308** |
| **5** | **0.577** | **11** | **0.285** |
| **6** | **0.483** | **12** | **0.266** |

**Table (4)** result for group (1)

| Number | 1 | 2 | 3 | $\overline{X}$ | R |
|---|---|---|---|---|---|
| 1 | 31.5 | 33.8 | 36.3 | 33.9 | 4.8 |
| 2 | 35.1 | 30.4 | 34.2 | 33.2 | 4.7 |
| 3 | 30.3 | 30.1 | 34.8 | 31.7 | 4.7 |
| 4 | 34.9 | 31.9 | 33.7 | 33.5 | 3.0 |
| 5 | 32.9 | 30.9 | 31.6 | 31.8 | 2.0 |
| 6 | 29.9 | 32.6 | 33.1 | 31.9 | 3.2 |
| 7 | 31.6 | 32.9 | 33.6 | 32.7 | 2.0 |
| 8 | 30.2 | 35.1 | 29.8 | 31.7 | 5.3 |
| 9 | 33.1 | 34.4 | 32.4 | 33.3 | 2.0 |
| 10 | 33.4 | 30.6 | 31.8 | 31.9 | 2.8 |
| 11 | 33.6 | 30.2 | 35.1 | 33.0 | 4.9 |
| 12 | 32.8 | 33.1 | 34.4 | 33.4 | 1.6 |
| 13 | 32.4 | 33.4 | 30.6 | 32.1 | 2.8 |
| 14 | 31.8 | 29.9 | 31.2 | 31.0 | 1.9 |
| 15 | 35.1 | 33.8 | 32.1 | 33.7 | 3.0 |
| 16 | 34.4 | 32.2 | 32.9 | 33.2 | 2.2 |
| 17 | 29.6 | 34.8 | 32.9 | 32.4 | 5.2 |
| 18 | 30.9 | 33.7 | 33.4 | 32.7 | 2.8 |
| 19 | 35.9 | 34.2 | 33.2 | 34.4 | 2.7 |
| 20 | 36.8 | 32.4 | 29.9 | 33.0 | 6.9 |
| 21 | 33.4 | 34.9 | 35.3 | 34.5 | 1.9 |
| 22 | 33.3 | 34.1 | 33.8 | 33.7 | 0.8 |
| 23 | 36.8 | 35.7 | 34.9 | 35.8 | 1.9 |
| 24 | 32.8 | 34.6 | 34.8 | 34.1 | 2.0 |

**Table(5)** Statistical data needed to draw control charts

| Test Number | Number of samples | $\overline{\overline{X}}$ | Standard Deviation σ | $\overline{R}$ | UAL | LAL | UWL | LWL |
|---|---|---|---|---|---|---|---|---|
| 1 | 24 | 33.0 | 1.11 | 3.1 | 36.2 | 29.8 | 35.1 | 30.9 |
| 2 | 8 | 31.1 | 0.38 | 1.5 | 32.6 | 29.6 | 32.1 | 30.1 |
| 3 | 24 | 33.4 | 1.83 | 3.1 | 36.6 | 30.2 | 35.5 | 31.3 |
| 4 | 24 | 32.7 | 1.20 | 3.0 | 35.8 | 29.6 | 34.7 | 30.7 |
| 5 | 12 | 25.5 | 1.02 | 3.1 | 28.7 | 22.3 | 27.6 | 23.4 |
| 6 | 12 | 25.2 | 0.67 | 2.2 | 27.5 | 22.9 | 26.7 | 23.7 |
| 7 | 12 | 24.6 | 0.54 | 1.6 | 26.2 | 23.0 | 25.7 | 23.5 |
| 8 | 24 | 33.1 | 0.50 | 2.6 | 35.8 | 30.4 | 34.9 | 31.3 |
| 9 | 12 | 33.1 | 0.63 | 2.1 | 35.2 | 31.0 | 34.5 | 31.7 |
| 10 | 16 | 33.4 | 0.57 | 2.5 | 36.0 | 30.8 | 35.1 | 31.7 |
| 11 | 22 | 37.7 | 0.47 | 2.3 | 40.1 | 35.3 | 39.3 | 36.1 |
| 12 | 12 | 32.9 | 0.50 | 2.2 | 35.2 | 30.6 | 34.4 | 31.4 |

**Table (6)** result of verifications for all groups

| Test Number | Condition(1) | Condition(2) | Condition(3) | Case |
|---|---|---|---|---|
| **1** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **2** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **3** | **Not Verified** | **Not Verified** | **Not Verified** | **Not Under Control** |
| **4** | **Not Verified** | **Verified** | **Verified** | **Not Under Control** |
| **5** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **6** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **7** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **8** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **9** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **10** | **Verified** | **Verified** | **Verified** | **Under Control** |
| **11** | **Verified** | **Verified** | **Not Verified** | **Not Under Control** |
| **12** | **Verified** | **Verified** | **Verified** | **Under Control** |

**Table(7)** : Properties and Capabilities of Process

| Test Number | LSL (MPa) | $\overline{\overline{X}}$ (MPa) | σ | Cpk |
|---|---|---|---|---|
| **1** | **30** | **33.0** | **1.11** | **0.9** |
| **2** | **28** | **31.1** | **0.38** | **2.7** |
| **5** | **22** | **25.5** | **1.02** | **1.1** |
| **6** | **22** | **25.2** | **0.67** | **1.6** |
| **7** | **22** | **24.6** | **0.54** | **1.6** |
| **8** | **30** | **33.1** | **0.50** | **2.1** |
| **9** | **30** | **33.1** | **0.63** | **1.6** |
| **10** | **30** | **33.4** | **0.57** | **2.0** |
| **12** | **30** | **32.9** | **0.5** | **1.9** |

**Table(8)** : Capabilities of Process and Corresponding Levels of Supervision

| Test Number | Level | Cpk |
|---|---|---|
| **1** | **C** | **0.9** |
| **5** | **B** | **1.1** |
| **6** | **A** | **1.6** |
| **7** | **A** | **1.6** |
| **9** | **B** | **1.6** |
| **12** | **B** | **1.9** |
| **10** | **B** | **2.0** |
| **8** | **A** | **2.1** |
| **2** | **A** | **2.7** |

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