

## Strength quality control for ready mixed concrete

Mustapha Boukendakdji\*



Department of Civil Engineering, College of Engineering, University of Hail, Hail, Saudi Arabia

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### ABSTRACT

The construction sector in Saudi Arabia has grown substantially in the past three decades. It is expected that the demand on concrete will increase by 10% by 2019. The compressive strength is considered to be the most important property and it is used as an indicator to check the quality of concrete and to judge compliance with specifications. The main aim of this research is to contribute to the quality evaluation of concrete construction in the region of Hail Saudi Arabia. In this study, a statistical compressive strength, using 180 test samples after 7 and 28 days taken from different concrete constructions in the city of Hail, is analyzed using the normal distribution and control chart. For each mix, a comparison of the average value of compressive strength, standard deviations and coefficient of variation (C.V.) is made. In addition a control chart of each mix is plotted with the upper and lower limit. The results showed that, apart from two mixes, the quality ranged from good to excellent with a coefficient of variance ranging from 4.13 % to 14.74 %. The results of compressive strength are within the upper and lower limits and no single test falls below the specified strength for all mixes. For all mixes the required average strength is 3.0 standard deviations above the specified strength, resulting in over-designed and uneconomical mixes.

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## 1. Introduction

The ready-mixed concrete industry in Saudi Arabia is growing rapidly. It is expected that the demand on concrete will increase by 10% by 2019. Concrete is one of the most used materials in building and civil engineering construction works. The aim of a good quality control system is to control and minimize the variability of the concrete. Among the various properties of the hardened concrete, its compressive strength is considered to be the most important and it is used as an indicator to check the quality of concrete and to judge compliance with specifications. In the ready-mixed concrete (RMC) industry, the results of strength testing are used mainly to monitor the quality of concrete production. There are several steps and precautions that must be followed in mixing and handling fresh concrete in order to ensure a quality of concrete with the desired characteristics (Mehta and Monteiro, 2006). Concrete mix proportions have a large influence on the quality of concrete. The water-cement ratio

controls the 28- day compressive strength of concrete. The strength of concrete is also dependent on the quality of the constituent materials. Quality of concrete is also affected by other factors, such as mixing, transporting, placing, compaction, relative humidity, temperature and curing of concrete. The ready mixed concrete (RMC) companies face extra difficulties in concreting in hot weather such as slump loss. Often using an admixture or adding a small quantity of water could restore the workability. Superplasticizers can be used in the production of high strength concrete (150 MPa) owing to a very substantial reduction in the water/cement ratio (Neville, 2012).

ACI (2011) provided guidelines to evaluate data of the tests used for assessing condition of concrete. The analysis of strength test results presented in ACI (2011) assumed that test results follow normal distribution. Mathematically, normal distribution is defined by mean and standard deviation (S.D.).

This paper deals with the statistical compressive strength using 180 test samples after 7 and 28 days from different concrete constructions in the city of Hail. The main aim of this research is to contribute to the quality evaluation of concrete construction in the region of Hail Saudi Arabia. An average value of compressive strength of each mix, its standards deviation and coefficient of variation (C.V.) are

\* Corresponding Author.

Email Address: [m.boukendakdji@uoh.edu.sa](mailto:m.boukendakdji@uoh.edu.sa) (M. Boukendakdji)

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discussed. In addition, for each mix, a control chart of the individual sample compressive strength is plotted.

## 2. Variability of concrete strength

Variations in the strength of concrete in a structure and control samples of a similar age are fundamentally due to differences in curing conditions and compaction. Variations in a concrete supply are due to the variety of batching, materials, placing and handling methods.

For a specified strength ( $f'_c$ ), American Concrete Institute [ACI \(2005\)](#) requires that the required average strength should be the maximum of the following Eqs. 1 and 2:

$$f'_{cr} = f'_c + 1.34\sigma \quad (1)$$

$$f'_{cr} = f'_c + 2.33\sigma - 3.45 \quad (2)$$

A lower variability will result in a lower standard deviation ( $\sigma$ ) and a reduced target average strength ( $f'_{cr}$ ) for a specified strength ( $f'_c$ ).

Standard deviation is a measurement of variability or diversity in the compressive strength data. It shows how much variation or dispersion is there from the average strength. A low standard deviation value indicates the strength is more close to the mean and normal distribution curve has a steep slope. A high standard deviation shows that the compressive strength is spread out over larger range values from the average strength and normal

distribution curve has a flat slope as compared to low standard deviation value.

The strength of a given concrete is considered satisfactory if both of the following requirements are met ([ACI, 2005](#))

- The average of all sets of three consecutive tests is at least equal to the specified design strength.
- No individual strength test falls below the specified design strength by more than 3.5 MPa.

[ACI \(2011\)](#) Manual of Concrete Practice establishes standards of concrete control based on the standard deviation and coefficient of variance. In the category of overall variation there are five distinct classifications based on general construction testing and laboratory trial batches as show in [Table 1](#). Coefficient of variance is a normalized measure of dispersion of a probability. It is the ratio of the standard deviation to the mean value expressed in percentage. Concrete mix design, including the selection of appropriate constituent materials, significantly influences the performance of both fresh and hardened concrete. The water/cement ratio should be less than 0.45, and preferably around 0.40, to obtain a durable concrete ([Al-Amoudi et al., 1993](#)). The American Concrete Institute ([ACI, 2002](#)) defines the durability of concrete as that which is able to resist weathering, chemical attack, abrasion, or other processes of deterioration. High permeability in a concrete, due to high water-cement ratio, is the main cause of durability failures ([Mindess et al., 2003; Mehta and Monteiro, 2006](#)).

**Table 1:** Standards of concrete control [ACI \(2011\)](#)

Overall Variation					
Class of Operations	Standard Deviation for different Control Standards, MPa				
	Excellent	Very Good	Good	Fair	Poor
General Construction Testing	Below 2.8	2.8 to 3.4	3.4 to 4.1	4.1 to 4.8	Above 4.8
Laboratory Trial Batches	Below 1.4	1.4 to 1.7	1.7 to 2.1	2.1 to 2.4	Above 2.4
Within – Test Variation					
Class of Operations	Coefficient of Variation for different Control Standards, %				
	Excellent	Very Good	Good	Fair	Poor
Field Control Testing	Below 7.0	7.0 to 9.0	9.0 to 11.0	11.0 to 14.0	Above 14.0
Laboratory Trial Batches	Below 3.5	3.5 to 4.0	4.0 to 5.0	5.0 to 7.0	Above 7.0

Nowadays, concrete with a compressive strength of up to 100 MPa can be produced commercially with an acceptable level of variability using various types of mineral and chemical admixtures, and special superplasticizer ([FIP/CEB, 1990](#)).

## 3. Research methodology

The study of concrete quality control was carried out by statistical analysis of the compression test results of specimens at 28 days of age. In this study, a statistical analysis of the concrete specimen compressive strength was performed by determining its mean value, standard deviation, coefficient of variation. Concrete strength tests were performed on six concrete mixes produced by Ready Mixed Concrete (RMC) in the region of Hail, KSA. The mix proportions of these concretes are listed in [Table 2](#). The cement content was from 250 kg/m<sup>3</sup> to

475 kg/m<sup>3</sup>. The water / cement ratio varies between 0.36 to 0.65. Apart from mix1, mixes have a water/cement ratio less than 0.47 in order to fulfill the requirements of durability. If the water/cement ratio is more than 0.45 the extra water will create pores in concrete. As a result, it reduces the strength and durability of concrete.

Most of the projects used type I cement (Ordinary Portland cement) and type V (High Sulphate Resisting Portland Cement). Retarders are used in order to offset the effect of hot weather, when the normal setting time is shortened by the higher temperature. The second admixture used is superplasticizers. They are used either to produce flowing concrete or to produce a very high strength concrete owing to a very substantial reduction in the water/cement ratio. For each sample, three cylinders (150 mm x 300 mm) were tested at the age of 7 and 28 for compressive strength.

**Table 2:** Concrete mixes used in the region of Hail

Ingredients	Mix (1)	Mix (2)	Mix (3)	Mix (4)	Mix (5)	Mix (6)
Cement	250	350	380	425	420	475
Coarse Aggr. 20 (mm)	733	879	879	733	879	879
Coarse Aggr. 9.5 (mm)	314	377	377	314	377	377
Fine Aggr.	938	689	666	748	632	566
Water	185	184	199	199	183	189
W/C ratio	0.65	0.47	0.43	0.42	0.39	0.36
Density	2420	2479	2485	2419	2490	2486
Super-Plasticizer+Retarder	√	√	√	√	√	√

#### 4. Compressive strength results and distributions

The analysis of strength test results presented in [ACI \(2011\)](#) assumed that test results follow normal distribution.

The frequency distributions of compressive strength results are shown in [Fig. 1](#) along with the means, standard deviations, coefficients of variation, and the calculated normal probability curves. [Table 3](#) shows the basic statistical parameter (mean, standard deviation and coefficient of variation) of all mixes at 7 days and 28 days. The standard deviation varies between 1.98 and 3.72 MPa.

The standard deviations of the ready mixed concretes were between 1.98 and 3.57. The coefficient of variation varies between 6.29% and 14.74%. Then the concretes are classified as poor, fair, good, very good and excellent according to the standards of control according to the values recommended by [ACI \(2011\)](#) ([Table 3](#)). Only one concrete mix is classified as poor concrete because the coefficient of variation is more than 14 and three concretes falls within the “excellent” ([Table 3](#)). The assessment of the concrete quality of these projects revealed that the quality ranged from poor to excellent according to [ACI \(2011\)](#) criteria with a Coefficient of variance ranging from 4.13 % to 14.74 % ([Table 3](#)). The average strength at 7 days was

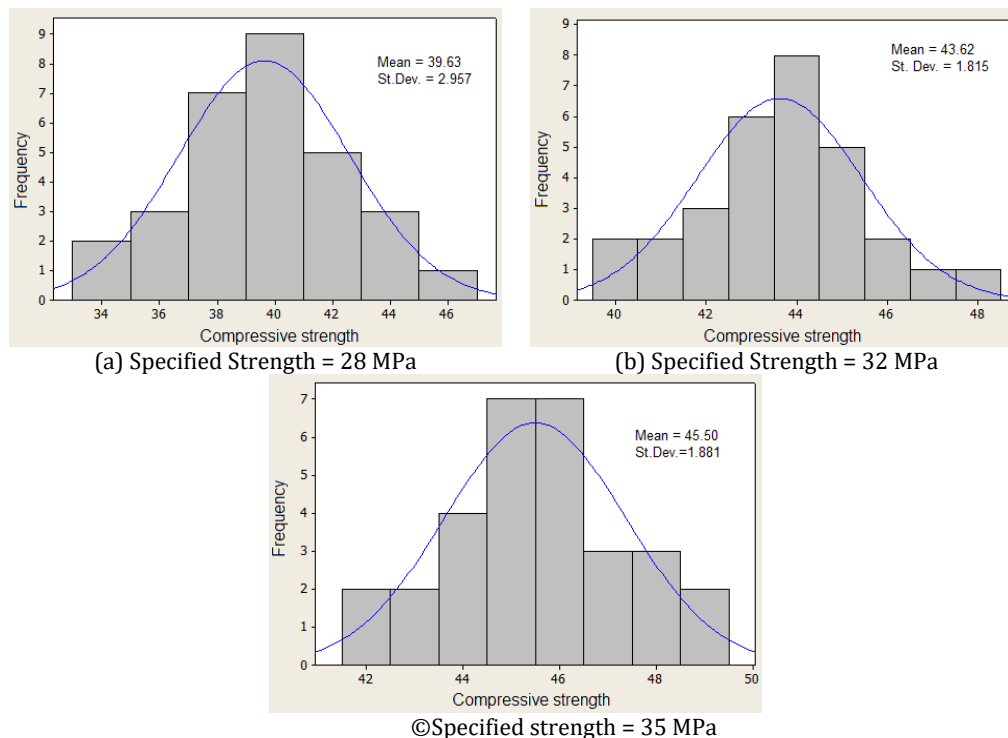
about from 68.8 % to 79.0 % of that of 28 days ([Table 4](#) and [Fig. 2](#)).

The difference between the average strength and the specified strength is from 8,8 to 11.6 MPa. It means that all types of concrete used are not economic. However these mixes used a water/cement ratio ([Table 2](#)) less than 0.5 in order to fulfill the requirements of the durability of concrete. In addition, concrete mixes are generally over-designed, for fear of producing results that do not satisfy minimum specified strength criteria.

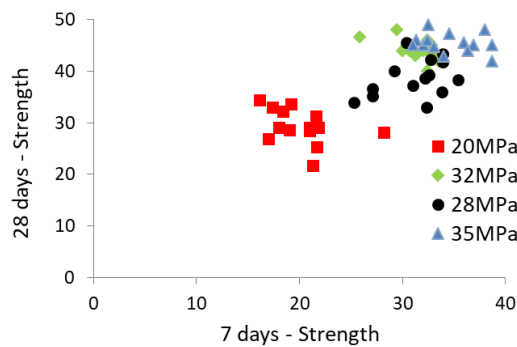
#### 5. Control charts

Control charts have been used in manufacturing industry and construction applications to verify that a process is in control. There are many types of control charts, the simplest of which plots individual results in chronological order ([Mamlouk and Zaniewski, 2011](#)).

[Fig. 3](#) shows a control chart of the compressive strength of ready mixed concretes tested at 7 and 28 days. It can be seen that the results are within the upper and lower limits and no single test falls below the specified strength for all mixes. In addition, for all mixes the required average strength is 3.0 standard deviations above the specified strength, resulting in over-designed and uneconomical mixes.



**Fig. 1:** The frequency distributions of concrete tested at 28 days



**Fig. 2:** Relationship between 7-days-and 28-days compressive strength

## 6. Conclusion

A statistical analysis is presented dealing with compressive strength of six ready mixed concretes. Major findings are as follows:

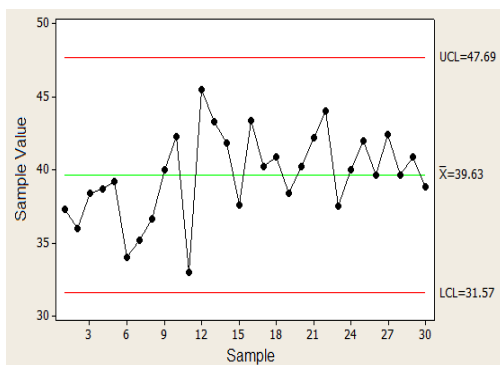
- The standard deviations of the ready mixed concretes were between 1.98 and 3.72. The assessment of the concrete quality of these projects revealed that the quality ranged from poor to excellent according to ACI criteria with a Coefficient of variance ranging from 4.13% to 14.74%.
- The average strength at 7 days was about from 68.8 % to 79.0 % of that of 28 days.
- All mixes have a water/cement ratio less than 0.5 in order to fulfill the requirements of the durability of concrete. Therefore, these mixes were over-designed.
- The results of compressive strength are within the upper and lower limits and no single test falls below the specified strength for all mixes.
- For all mixes the required average strength is 3.0 standard deviations above the specified strength, resulting in over-designed and uneconomical mixes.

**Table 3:** Average strength, standard deviation and coefficient of variation of concrete tested at 7 and 28 days

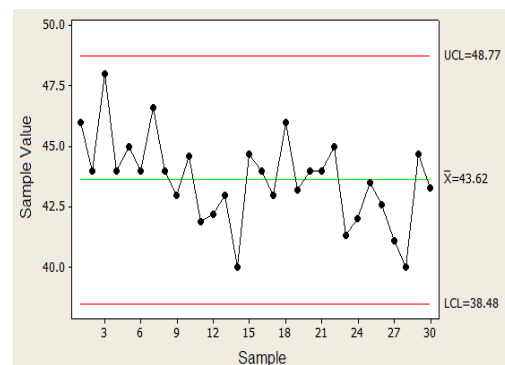
Age (days)	Specified strength at 28 days	Average strength (MPa)	Stand. Dev. (MPa)	Coef. of var. (%)	
7 days	20	19.8	2.926	14.74	Poor
	28	31.3	2.97	9.47	Good
	32	31.42	1.98	6.29	Excellent
	35	34.4	2.67	7.77	Very Good
28 days	20	28.8	3.57	12.39	Fair
	28	39.63	2.967	7.49	Very Good
	32	43.62	1.815	4.16	Excellent
	35	45.50	1.881	4.13	Excellent

**Table 4:** Ratio between concrete strength at 7 days and 28 days

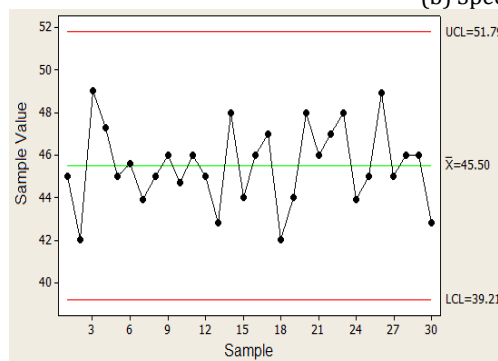
Specified strength at 28 days	Average strength MPa at 7 days	Average strength MPa at 28 days	$\frac{\text{strength at 7 days}}{\text{strength at 28 days}} \times 100$
20	19.8	28.8	68.8%
28	31.3	39.63	79.0%
32	31.42	43.62	72.0%
35	34.4	45.50	75.6%



(a) Specified Strength = 28 MPa



(b) Specified Strength = 32 MPa



©Specified strength = 35 MPa

**Fig. 3:** Control Chart for all concretes tested at 28 days

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