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Evaluating the Compressive Strength and Quality Control of Locally Sourced Concrete Mix Designs in Benghazi, Libya

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Keywords:
Compressive Strength.
Quality Control.
Statistical Analysis.
Mix Design.
Local Materials.

ABSTRACT

This study investigates the quality control of concrete mix designs (C25, C30, and C35) produced using local materials in Benghazi, Libya, with a focus on compressive strength. The data collected over a seven-month period were analyzed statistically, and the results showed that the compressive strength of all mixes follows a normal distribution, ensuring the applicability of standard statistical methods for quality control. The analysis included a 95% confidence interval (CI), confirming the precision and reliability of the results in comparison to the ACI 214R-11 guidelines. Additionally, the study explored the impact of the additive Sikament R 2002 on mix performance, demonstrating that the concrete mixes consistently met or exceeded the required compressive strength values across various confidence intervals. These findings confirm that concrete mixes made from local materials in Benghazi meet international quality standards and provide a solid statistical foundation for future research in concrete quality control in Libya.

التقييم الإحصائي ومراقبة الجودة لمقاومة الضغط لتصاميم الخلطات الخرسانية المصنعة من مواد محلية في بنغازي - ليبيا

حليمة الضراط

قسم الهندسة المدنية، كلية الهندسة، جامعة بنغازي، ليبيا.

الكلمات المفتاحية:
قوة الضغط.
مراقبة الجودة.
التحليل الإحصائي.
تصميم الخلطة.
المواد المحلية.

الملخص

تبحث هذه الدراسة في مراقبة جودة تصاميم خلطات الخرسانة (C25 وC30 وC35) المُنتجة باستخدام مواد محلية في بنغازي، ليبيا، مع التركيز على مقاومة الضغط. حُللت البيانات التي جُمعت على مدى سبعة أشهر إحصائيًا، وأظهرت النتائج أن مقاومة الضغط لجميع الخلطات تتبع توزيعًا طبيعيًا، مما يضمن إمكانية تطبيق الأساليب الإحصائية القياسية لمراقبة الجودة. تضمن التحليل فترة ثقة 95% (CI)، مما يؤكد دقة وموثوقية النتائج مقارنةً بإرشادات ACI 214R-11. بالإضافة إلى ذلك، استكشفت الدراسة تأثير المادة المضافة Sikament R 2002 على أداء الخلطة، مما يدل على أن خلطات الخرسانة قد حققت أو تجاوزت باستمرار قيم مقاومة الضغط المطلوبة عبر فترات ثقة مختلفة. تؤكد هذه النتائج أن خلطات الخرسانة المصنوعة من مواد محلية في بنغازي تلبي معايير الجودة الدولية وتوفر أساسًا إحصائيًا متينًا للبحوث المستقبلية في مجال مراقبة جودة الخرسانة في ليبيا.

1. Introduction

1.1. General information

Concrete is a composite material created by mixing cement, water, coarse aggregate, fine aggregate, and admixtures in specific proportions to form a mix design intended to achieve a target compressive strength at 28 days. When evaluating concrete supplied for construction projects, compressive strength is the primary quality indicator. Naturally, variability occurs between batches due to inaccuracies in material measurements or inconsistencies in the quality of raw materials.

Controlling this variability is the core of quality control (QC) in concrete mix design. QC refers to the procedures used by concrete production facilities to ensure that the concrete consistently meets the required strength criteria.

Effective quality control in mix design is essential for achieving high-quality concrete and reducing costs through optimal material

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usage. QC ensures structural integrity, durability, workability, and economic efficiency. For optimal results, two major aspects of QC must be addressed: minimizing variability and preventing failure. Although both goals are related—low variability helps avoid failures—they are best considered independently. If the average concrete strength significantly exceeds the minimum required strength, failures are less likely.

Concrete strength is typically determined by averaging the compressive strength of multiple test specimens (cylinders or cubes) from the same batch. A single specimen is insufficient. Commonly, two (150×300 mm) or three (100×200 mm) cylinders or three (150×150×150 mm) cubes are tested to determine average compressive strength. Statistical methods, including calculation of the standard deviation, can then be used to assess reliability and consistency across batches. These metrics help monitor and improve the QC process effectively.

1.2. Study problem and significance

In Libya, quality control of concrete is hindered by several issues. Chief among them are the use of multiple, unstandardized sources of raw materials and the absence of national guidelines or codes for mix proportioning and material quality control.

This study is significant because it seeks to determine the minimum acceptable margin of error in compressive strength resulting from repeated or time-separated batches using the same mix design. These inconsistencies often lead to variations in the final concrete strength. By identifying these error margins and analyzing performance using local materials in Benghazi, the study aims to improve the reliability and consistency of concrete used in Libyan construction projects.

1.3 Objective of the study

The objective of this study is to evaluate the challenges in achieving consistent concrete quality in Libya. It focuses on two main factors:

- The impact of using multiple material sources
- The absence of standardized guidelines for mix proportioning

The study also aims to determine the minimum acceptable deviation in compressive strength across batches and repeated mix designs. To achieve this, compressive strength data from 150×150×150 mm cube specimens were collected over a seven-month period from concrete produced with local materials in Benghazi. Statistical analyses were conducted to assess data distribution and compare results to the acceptance criteria outlined in **ACI 214R-11**.

1.4. Previous studies

A major challenge in Libya's concrete industry is the lack of effective QC, which leads to higher production costs and inconsistent concrete quality. This issue affects both existing and ongoing construction projects, especially when local ready-mix producers are involved. When QC procedures are implemented, production costs decrease and concrete quality improves.

However, studies specifically addressing this issue in Libya are scarce. In contrast, Pacheco, De Brito et al. conducted a study in Portugal evaluating 28-day compressive strength data from three ready-mix plants. Their findings showed that, even when using similar local materials, concrete strength varied significantly depending on the production facility—highlighting the need for rigorous quality control [1].

The American Concrete Institute (ACI) identifies two key sources of strength variability:

1. **Batch-to-batch variations** due to inconsistent mixture composition and production processes.
2. **Within-batch variations** arising from measurement, sampling, curing, or testing inconsistencies.

Solanki, Munzni, and Vidyarthi emphasized that strength differences can result from varying ingredient quality, water-cement ratios, handling, and curing methods—even within the same batch [2].

Furthermore, concrete is a non-static product; its properties vary naturally. The main goal of quality control is to **monitor and reduce this variability**, typically measured by standard deviation [3].

1.5. The Importance of Quality Control

Beyond measurable outcomes, quality control provides intangible benefits. It saves time in large-scale projects, builds trust between customers and producers, and creates reliable databases that aid in future design and troubleshooting. Effective QC also reduces long-term project costs by minimizing waste and avoiding rework [3].

The dual focus of QC is:

- Preventing structural failure
- Reducing strength variability

While these goals reinforce each other, treating them separately helps identify the most effective strategies [4].

In many countries, 28-day compressive strength tests remain the standard method for acceptance or rejection. However, waiting these long wastes materials if the batch ultimately fails. According to Day and Aldred, managing large volumes of strength data is another QC challenge—it can overwhelm decision-makers and complicate analysis. That said, QC itself is a **cost-reduction measure**: it may require up-front investment, but the long-term benefit is concrete that meets required standards at the **lowest possible cost** [5].

2. Materials and Methodology

2.1. Materials

In this study local materials were used to do the mixed proportions. The materials are Ordinary Portland Cement, the coarse aggregate is aggregate with (5,10,20), the fine aggregate (sand), tap water was used and the admixture added to the concrete mix (Sikament R-2002) with weights are presented in Table (1) for 0.5m^3 volume of concrete .

Table 1: Weight proportions of concrete mix constituents for a 0.5 m³ batch.

Materials	C25 (Kg)	C30 (Kg)	C35 (Kg)
Agg.10.20	345	337.5	340
Agg.5.10	250	240	237.5
Sand	355	357.5	352.5
Admixture SIKAMENT R2002	2.5	2.7	2.8
Cement	165	180	195
Water	76.1	80.9	80.9

The using of the admixture (Sikament R 2002) the target strength reached for the samples at shorter time that requested because of this material, so to clarify the effect of the admixture added the concrete mix, the properties of the admixture Sikament R-2002 from product of data sheet of the material are [6]:

1. High water reduction.
2. Higher strength and density
3. Improved consistence retention
4. Improved durability
5. Improved water tightness
6. Improved surface finish
7. Improved cohesion properties
8. Suitable for hot weather conditions

2.2. Methodology

2.2.1. Data collected

All concrete mixes were prepared using the same materials with different amounts to get three target strengthens C25, C30 and C35. More than 200 specimens were made for the target strength C25 and C30 and more than 40 samples for C35 , all the specimens were with dimension (150×150×150)mm and tested after 7days and 28 days for 7 months (June, July, August, September, October, November, and December). The values of the compressive strength for each month calculated by breaking between 2-8 cubes for each day and the average between two cubes were calculated to get the values of the compressive strength every day per month. The numbers of the samples that are used as data to do statistical analysis are illustrated in Table (2). In additions the details for the data for each month are described in **Figures** 1,2 and 3 respectively.

Table 2: The number of samples for each mix design

Target compressive Strength	Number of Specimens (N)	
	7 days	28 days
C25	263	267
C30	213	212
C35	64	47

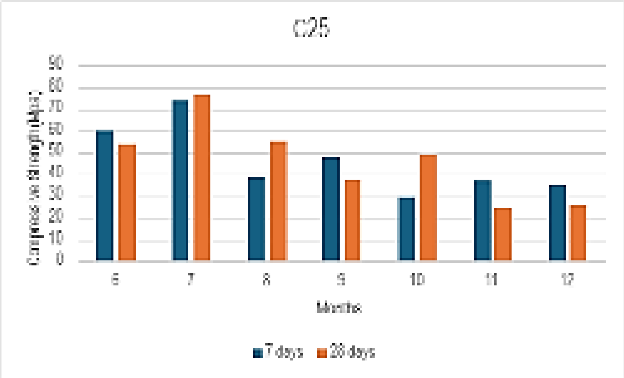


Fig.1: number of samples for mix (C25)

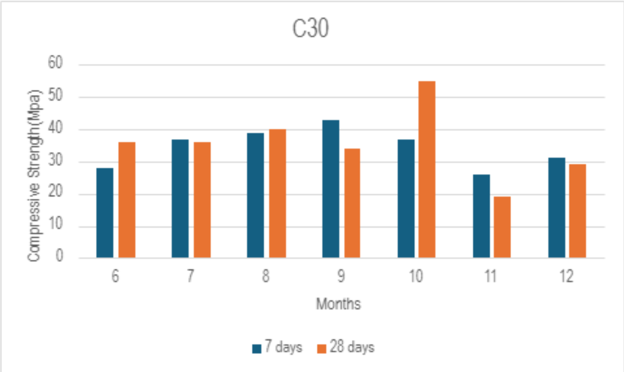


Fig.2: number of samples for mix (C30)

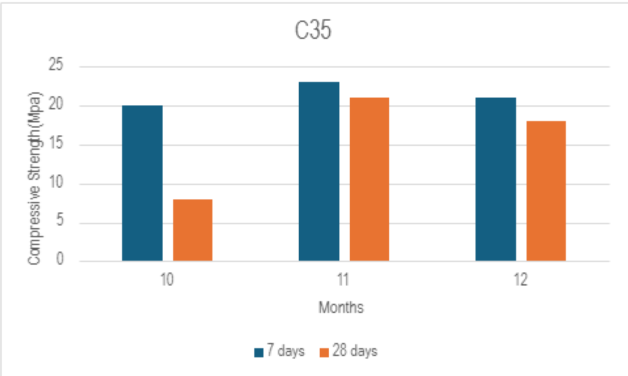


Fig.3: number of samples for mix (C35)

2.2.2 Specimen dimensions and testing mechanism

In this research, concrete cube samples with dimensions of 150×150×150 mm were used to achieve the target compressive strengths of C25, C30, and C35. The samples were tested after both 7 and 28 days over a period of 7 months. For each test day, between 2 and 8 cubes were tested, depending on when the specific mix design reached its target strength at either 7 or 28 days. The average compressive strength was calculated from the tested cubes and used as the basis for the data analysis.

2.2.3 Statistical Analysis

One primary objective of the statistical evaluation of concrete data is to discern the origins of variability. This information can be utilized to implement appropriate procedures for upholding quality control standards. For that target the following statistical calculation make clarification

2.2.3.1. Descriptive statistics:

In this paper statistical analysis was undertaken using Minitab22 to derive descriptive statistics and probability distributions for the random variable X [7]. This analysis is instrumental in formulating concrete mix design accuracy.

$$\overline{x}_j = \frac{\sum_{i=1}^{n} x_i}{j}, \quad j = 1, \ldots, n \qquad (1)$$

$$s_j^2 = \frac{\sum_{i=1}^{j}(x_i - \overline{x_j})^2}{j-1}, \quad j = 1, \ldots, n \qquad (2)$$

$$s = \sqrt{\frac{\sum_{i=1}^{j}(x_i - \overline{x_j})^2}{j-1}}, \quad j = 1, \ldots, n \qquad (3)$$

$$V = \frac{s}{\bar{x}} \cdot 100 \qquad (4)$$

Where:

$\bar{x}$: the mean value of a variable, it measures the centre of a distribution.

S^2: the variance, it represents the average squared deviation from the mean.

S: standard deviation of a variable, it measures the dispersion of the individual observations from the mean.

V: coefficient of variation.

2.2.3.2. Frequency distribution and fit verification

The goal of fitting distributions to data is to find the best match. This involves choosing the type of distribution and its descriptive statistics that best represent the observed data. While might have some initial guesses, the exact fit is often unknown. Could try fitting multiple distributions and compare their performance. One popular method for comparison is the

Chi-squared test. A lower Chi-squared value indicates a closer fit [7].

In this study, the data were examined with all the distributions and find the distribution that fit the data. The aim of the fitting to find which the best represents the actual pattern of the concrete compressive strength data.

With the aim of obtaining the more adequate representation of the actual probability distribution of the concrete compressive cubic strength, the normality test and one sample Z test selected in the statistical analysis reported the data of this research work the Normal distribution.

The Normal Distribution function f(x) ≥ 0 having the property $\int_{-\infty}^{\infty} f(x)dx = 1$ may be a probability density function. It has been observed that certain functions f(x) can successfully express the distribution of many variables. In engineering practice, it is frequently attempted to adopt one of these functions whose analytical forms are known, and values are tabulated. In practical applications, many random variables fit to the normal distribution with the following probability density function:

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{\frac{-(x-\mu_x)}{2\sigma_x^2}} \qquad -\infty < 0 < \infty \qquad (5)$$

2.2.3.3. One sample z-test

The one-sample z-test is used to test whether the mean of a population is greater than, less than, or not equal to a specific value. Because the standard normal distribution is used to calculate critical values for the test, this test is often called the one-sample z-test. The z-test assumes that the population standard deviation is known [8].

The one-sample z-test makes these assumptions:

1. The data are continuous (not countable).
2. A normal probability distribution describes the data entries.
3. The sample simply and randomly comes from its population. Everyone in the population has the same chance of being included in the sample.
4. The standard deviation of a population known.

$$z = \frac{\bar{x} - \mu_0}{\sigma / \sqrt{n}} \qquad (6)$$

where:

$\bar{x}$: sample mean

μ_0: hypothesized population mean

σ: population standard deviation

n: sample size

The significance of the test statistic is determined by computing the p-value. If this p-value is less than a specified level (usually 0.05), the hypothesis is rejected. Otherwise, no conclusion can be reached.

2.2.3.4. Chi-square test:

A chi-squared test can be used to test the hypothesis that observed data follow a particular distribution [8]. The chi-squared statistic formula is:

$$x^2 = \sum \frac{(f_{obs} - f_{exp})^2}{f_{exp}} \qquad (7)$$

2.2.3.5. Confidence Interval:

A confidence interval is the mean of your estimate plus and minus the variation in that estimate. This is the range of values you expect your estimate to fall between if you redo your test, within a certain level of confidence [7].

where:

x: sample mean

z: the chosen z-value

s: sample standard deviation

n: sample size

2.2.4 Comparison with the ACI 214R-11 code:

2.2.4.1. Standards of concrete control

A crucial factor to consider in concrete design is its inherent variability. Since concrete is a dynamic material, the primary objective of quality control is to regulate and minimize these variations. This can be achieved by reducing the standard deviation. The Table (3) is a reproduction of ACI-214-11 Table 4.3 displays the standards for general constructions testing when fc`≤ 35Mpa will change from excellent to poor [9].

Table 3: Standards of concrete control for fc′≤5000 psi (35MPa) [ACI 214R-11 code Table 4.3] Overall variation

Class of operation	Standard deviation for different control standards, psi (MPa)				
	Excellent	Very good	Good	Fair	Poor
General construction testing	Below 400 (below 2.8)	400 to 500 (2.8 to 3.4)	500 to 600 (3.4 to 4.1)	600 to 700 (4.1 to 4.8)	Above 700 (Above 4.8)
Laboratory trail batches	Below 200 (below 1.4)	200 to 250 (1.4 to 1.7)	250 to 300 (1.7 to 2.1)	300 to 350 (2.1 to 2.4)	Above 350 (Above 2.4)
Within- batch variation					
Class of operation	Coefficient of variation for different control standards, %				
	Excellent	Very good	Good	Fair	Poor
Field control testing	Below 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0
Laboratory trail batches	Below 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	Above 5.0

2.2.4.2. Parameters defining acceptable strength levels by ACI 214R-11 code:

There are different criteria to ensure the result of the work of the mixes design are the required values or it's with the specific requirement. The simplest is to determine the required strength of the concrete $f_{cr}^{'}$ to equal or exceed to the specified strength $f_c^{'}$ added to product of the standard deviation *S* and the constant *Z* [9] .

$$fcr' = fc' + zs \qquad (8)$$

Where:

$f_{cr}^{'}$: The required strength of concrete (MPa)

$f_c^{'}$: The specified compressive strength of concrete (MPa)

S: Sample standard deviation, an estimate of the population standard deviation.

Z: constant multiplier for standard deviation s that depends on number of tests expected to fall below fc′.

In this research the data collected for 7 months, so the values of the compressive strength that obtained from the statistical analysis for the data compared with $f_c^{'}$ calculated by equation (8). From ACI 214R-11, If the value of $f_c^{'} \leq 35$ Mpa, the number of tests more than 30 that mean s=1 and the value of probabilities associated with values of z from Tables (4) . But if there is no historical data the minimum required average strength evaluate from the formula in the Table (5) (Table 5.2 in ACI 214R-11).

For comparing the result for the data obtained for this research with ACI 214R-11, adding the admixture (Sikament R-2002) may affect in the quality of the data result, so the mixes design that tested to use in this paper and the data are fitted the normal distribution, the values required strength of concrete fcr′ at 28 days for all the mixes obtained by measured it when the confidence intervals CI are (90, 95,95.45,98,99 and 99.73%) for each mix C25, C30 and C35, so the values of z will change with these several confidence intervals as shown in Table (6). The data tested for different values of confidence interval to make sure that the addition of the additive material (Sikament R-2002) haven't affected on the statistical analysis and the analysis has attached to ACI 214R-11. If the data met different confidence interval levels, the 95% will be accepted for all the mixes design.

Table 4: Modification factors for standard deviation [ACI 214R-11 code Table 5.1]

Number of tests	Modification factor
Fewer than 15	Refer to table 5.2
15	1.16
20	1.08
25	1.03
30 or more	1.00

Table 5: Minimum required average strength without sufficient historical data [ACI 214R-11 code Table 5.2]

Required average compressive strength	specified compressive strength
$f_{cr}^{'} = f_c^{'} + 1000$ psi ($f_{cr}^{'} = f_c^{'} + 7$ MPa)	when $f_c^{'} < 3000$ psi ($f_c^{'} < 21$Mpa)
$f_{cr}^{'} = f_c^{'} + 1200$ psi ($f_{cr}^{'} = f_c^{'} + 8$ MPa)	when $f_c^{'} \geq 3000$ psi and $f_c^{'} \leq 5000$ psi ($f_c^{'} \geq 21$ MPa and $f_c^{'} \leq 35$Mpa)
$f_{cr}^{'} = 1.10 f_c^{'} + 700$ psi ($f_{cr}^{'} = 1.10 f_c^{'} + 5$ MPa)	when $f_c^{'} > 5000$ psi ($f_c^{'} > 35$Mpa)

Table 6: Probabilities associated with values of z [ACI 214R-11 code Table 5.4]

Percentages of tests within ±zσ	Chances of falling below $f_c^{'}$ - zσ	z
40	3 in 10 (30%)	0.52
50	2.5 in 10 (25%)	0.67
60	2 in 10 (20%)	0.84
68.27	1 in 6.3 (15.9%)	1.00
70	1.5 in 10 (15%)	1.04
80*	1 in 10 (10%)	1.28*
90	1 in 20 (5%)	1.65
95	1 in 40 (2.5%)	1.96
95.45	1 in 44 (2.3%)	2.00
98*	1 in 100 (1%)	2.33*
99	1 in 200 (0.5%)	2.58
99.73	1 in 741 (0.13%)	3.00

3. Result of the data analysis

This section presents the statistical analysis of concrete mix design quality control, focusing on the variability in compressive strength and fitting the data with Normal distribution. In addition, the findings are compared with the American Concrete Institute (ACI 214R-11) standards to assess compliance and identify deviations. By evaluating the acceptable error margins and consistency of mix proportions, this analysis provides insights into improving concrete quality in Libya's construction projects.

3.1. Statistics Descriptive

The statistics descriptive obtained from the statistical analysis by Minitab for all mixes design C25, C30 and C35 by using Minitab are display in Table (7).

Table 7: The statistic descriptive for the mixes design

Descriptive Statistics	C25		C30		C35	
	7 days	28 days	7 days	28 days	7 days	28 days
Mean	28.43	32.43	31.11	35.82	31.59	36.92
SE mean	0.1409	0.1103	0.1368	0.1804	0.2826	0.247
Standard deviation	2.285	1.803	1.996	2.628	2.260	1.696
Median	28.5	32.5	31.45	35.5	33.2	38.5
Minimum	22	28	24	30.5	26.5	34.5
Maximum	35.35	38.5	36.5	42.6	37.1	40.8
Q1	27	31.5	29.5	30.5	29.625	35.5
Q3	30	33.5	32.5	37.5	33.2	38.5

3.2. Fitting the data with Normal distribution

The calculation results shows that compressive strengths of the three mixes are fitted the normal distribution based on Chi-square values and p-values as displays in Figures 4, 5 and 6 respectively, also the result of one sample z test that showed in Tables (8,9 and 10).

Table 8: One sample z test for mix C25

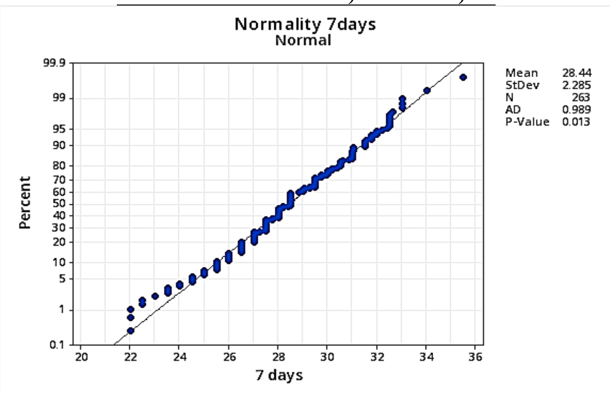
	C25	
	7 days	28 days
μ	28.43	32.43
S	2.285	1.803
95% CI forμ	(28.161, 28.713)	(32.223, 32.656)

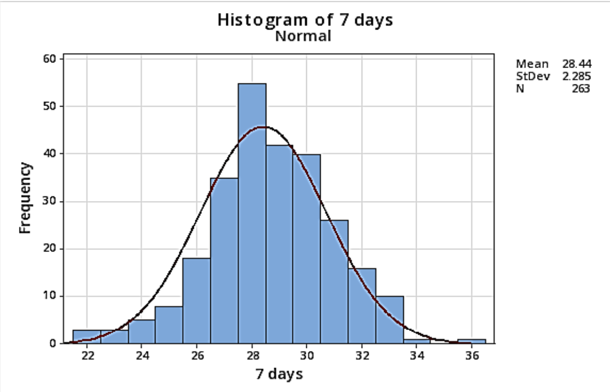
Table 9: One sample z test for mix C30

	C30	
	7 days	28 days
μ	31.11	35.82
S	1.996	2.628
95% CI forμ	(31.017, 31.213)	(35.468, 36.176)

Table 10: One sample z test for mix C35

	C35	
	7 days	28 days
μ	31.59	36.92
S	2.260	1.696
95% CI forμ	(31.524, 31.662)	(36.443, 37.413)





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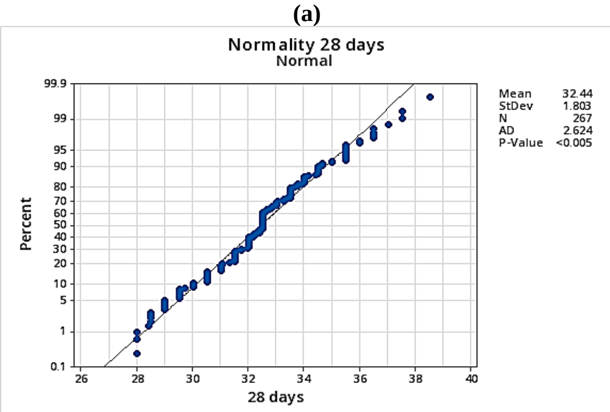
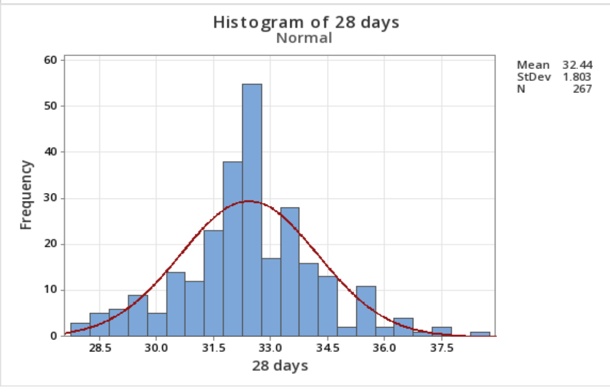
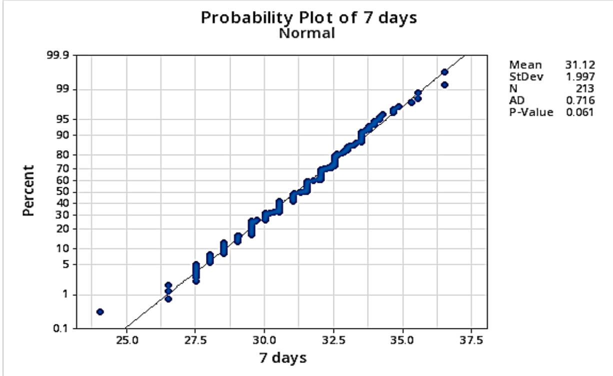
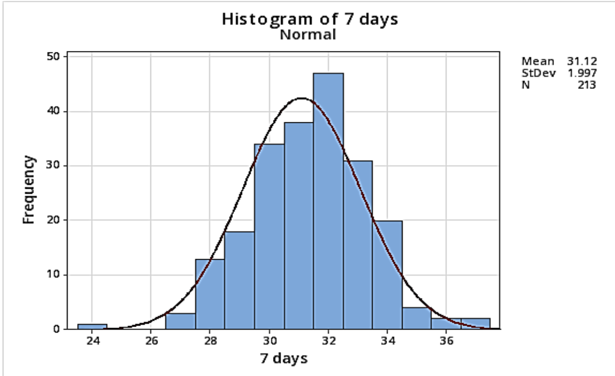




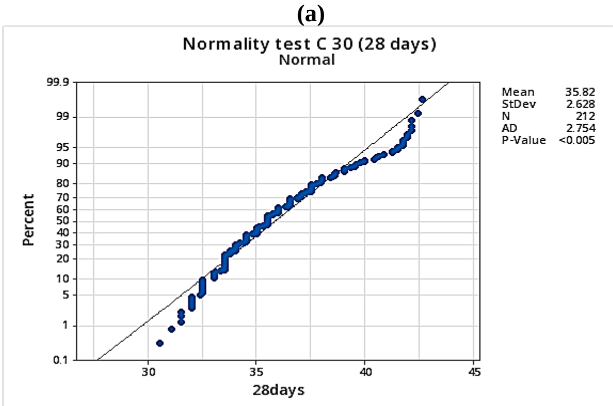
(b)

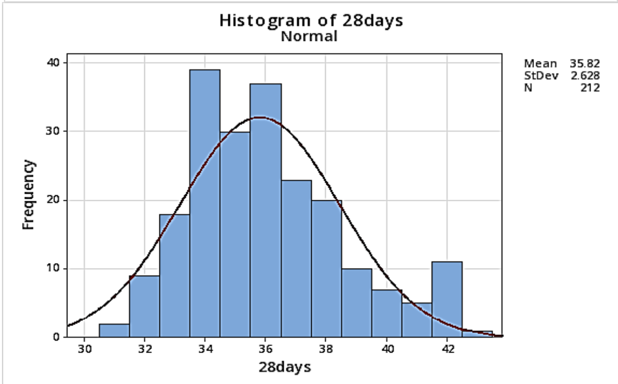
Fig. 4: Normality test and histogram for C25: (a) 7 days, (b) 28 days





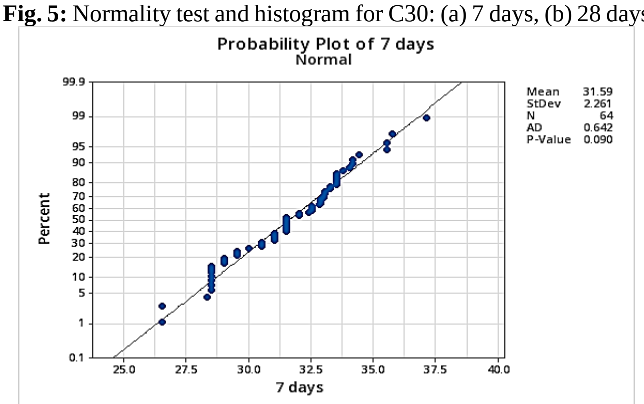
(a)

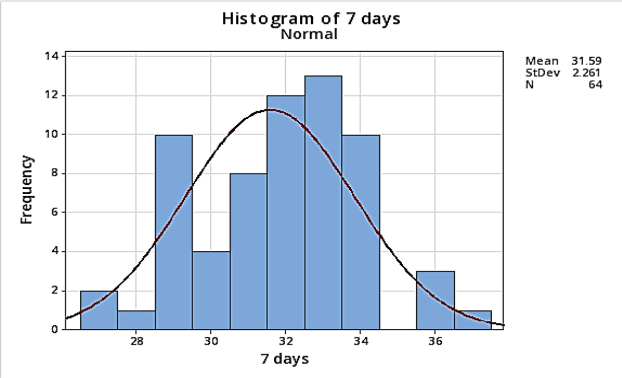




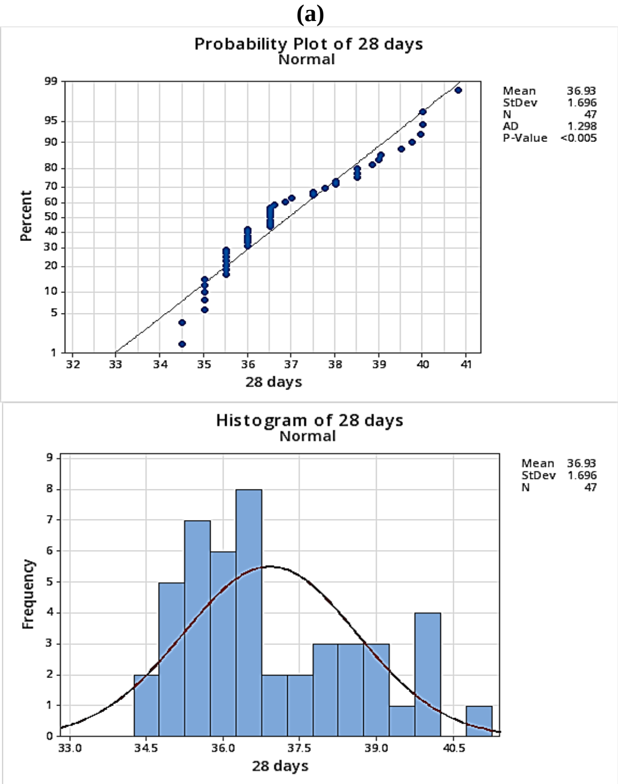
(b)

Fig. 5: Normality test and histogram for C30: (a) 7 days, (b) 28 days





(a)



(b)

Fig. 6: Normality test and histogram for C35: (a) 7 days, (b) 28 days

3.3. Compared the result for the data with the parameters of ACI 214R-11code

Due to the addition of Sikament R-2002, the confidence interval values for each mix design (C25, C30, and C35) were calculated using Minitab 22 to ensure that the supplementary materials do not influence the results. These values are presented in Table (11). Furthermore, to assess whether the data conforms to the ACI 214R-11 criteria, the required strength (fcr') for C25, C30, and C35 at 28 days was determined using the equation provided in Equation (8). The results were then compared under two conditions:

1. The standard deviation for each mix was computed based on experimental data using Minitab, with results summarized in Table (7).
2. Theoretical Standard Deviation: The required strength (fcr') was recalculated using a fixed standard deviation of s = 1, as prescribed by the ACI standards Table (4).

The comparative analysis of these conditions is presented in Table (12), providing a clear assessment of the impact of the additive and the conformity of the data with ACI specifications.

Table 11: Confidence interval for mixes design by Minitab22

	Confidence Interval (CI for μ)					
fc′	90 %	95 %	95.45%	98 %	99 %	99.73%
C25	(32.258, 32.621)	(32.223, 32.656)	(32.219, 32.660)	(32.183,3 2,696)	(32.155, 32.724)	(32.108,3 2.770)
C30	(35.525, 36.119)	(35.468, 36.176)	(35.461, 36.183)	(35.402, 36.242)	(35.357, 36.287)	(35.280, 36.363)
C35	(36.521, 37.335)	(36.443, 37.413)	(36.433, 37.422)	(36.352, 37.503)	(36.290, 37.565)	(36.185, 37.670)

Table 12: Confidence interval for mixes design using ACI 214R-11 equation

	Confidence Interval (CI)						
fc′	CI	90 %	95 %	95.45%	98 %	99 %	99.73%
C25	f_{cr}' code	26,65	26,96	27	27,33	27,58	28
	fcr′ data	27,975	28,534	28,606	29,201	29,653	30,410
C30	f_{cr}' code	31,65	31,96	32	27,33	32,58	33
	f_{cr}' data	34,336	35,151	35,256	36,123	36,780	37,884
C35	f_{cr}' code	36,65	36,96	37	37,33	37,58	38
	f_{cr}' data	37,798	38,324	38,392	38,952	39,376	40,088

4. Results and Discussion

In this research, concrete cube samples with dimensions of 150×150×150 mm were used to achieve the target compressive strengths of C25, C30, and C35. The samples were tested at 7 and 28 days over a period of seven months. On each test day, between 2 and 8 cubes were tested, depending on when the mix design reached its target strength. The average compressive strength for each batch was calculated and used in the analysis. To evaluate the data in accordance with ACI 214R-11 guidelines, the potential influence of the admixture Sikament R-2002 on the quality of results was considered. All mix designs were confirmed to follow a normal distribution, and the required 28-day compressive strength (fcr′) for each mix (C25, C30, and C35) was determined across various confidence intervals (90%,95%,95.45%, 98%, 99%, and 99.73%). This statistical approach ensured that the use of the admixture did not adversely affect the reliability of the results. If the data satisfied multiple confidence levels, the 95% confidence interval was adopted as the standard for all mix designs. The results of the statistical analysis provide insights into concrete quality control practices in Libya, particularly using locally sourced materials in Benghazi. Furthermore, the compressive strength outcomes were compared with ACI standards to assess compliance and identify opportunities for improvement. After completing the study and completing all calculations, the discussion of the results ca be reviewed as follows:

1.The analysis of the sample data collected for seven months for all mixes C25, C30 and C35 were found to follow Normal distribution. So, when data follows a normal distribution, the statistical methods can be applied accurately and reliably.

2.Following the compressive strength for the data to normal distribution means the critical for quality control and ensuring concrete meets required specifications.

3.A normal distribution allows for defining acceptable error margins in concrete mix design and it makes it easier to set upper and lower control limits for strength variation, minimizing the risk of weak or over-strength concrete.

4.The values of the standard deviation for each mix C25, C30 and C35 at 28 days are 1.803, 2.628 and 1.696 respectively and all the values less than 2.8. Which mean the standard of concrete control is Excellent as mentioned in Table (3) according to ACI 214R-11.

5.The data for the mixes follows a normal distribution and it confirmed ACI 214R-11 criteria-based quality control measures.

6.The statistical analysis was conducted with a 95% confidence interval (CI), ensuring that the true mean of the measured compressive strength for all mixes falls within the calculated range 95%. This interval provides a measure of the precision and reliability of the observed results in comparison to ACI standards.

7.Because of the addition for the Sikament R 2002 to the mixes, the data was tested with different values of confidence intervals (95,95,95.45,98,99 and 99.73%) as showed in tables10 and 11, and the values of minimum required strength of concrete (fcr') compared to the limit of ACI 214R-11 as the following:

- For the mixes C25, C30 and C35 the values of fcr′ not less than reference values for the American code for all confidence interval that tested, so that mean the mixes are made from local materials with this proportion is matched the requirements of ACI 214R-11.

8.The 95% confidence interval is chosen as reference for this research result because 95% CI provides a good balance between reliability and usability of results.

9.Since confidence intervals rely on normal distribution, so the result of the research gains a strong statistical foundation. A 95%

confidence interval was more meaningful when data is normally distributed, ensuring accurate reliability assessment of concrete quality.

10. The research confirms that concrete mix strength from local materials from Benghazi city follows a normal distribution with 95% confidence interval, so future studies can build on this finding. Also, that will help construction companies or factories in Libya and quality control labs apply more scientific methods in monitoring concrete performance.

5. Conclusion

The analysis of concrete mix designs (C25, C30, and C35) using local materials in Benghazi has yielded promising results. Data collected over a seven-month period followed a normal distribution, supporting the application of statistical methods and confirming the reliability of the findings. The compressive strength of all mixes fell within acceptable limits as defined by the ACI 214R-11 guidelines, with standard deviations below 2.8—demonstrating excellent quality control.

The 95% confidence interval was used to assess the reliability of the data, offering a balanced approach between precision and statistical confidence. The addition of *Sikament R 2002* to the mixes showed promising results, with compressive strength values consistently meeting or exceeding ACI requirements across all tested confidence intervals. This confirms that the concrete mixes, made with local materials, meet international standards for quality and performance. This study establishes a strong statistical foundation for future research on concrete mix designs in Libya and offers valuable insights into improving quality control practices in local construction projects.

6. Recommendations for Further Study:

1. Longer-Term Data Collection:

Extend the data collection period beyond seven months to evaluate long-term consistency and to examine how environmental and seasonal variations may influence compressive strength.

2. Broader Mix Design Testing:

Investigate a wider range of concrete mix designs, including those using different material sources or varying admixture types and dosages, to understand their effects on strength and variability.Field Testing and Real-World Application:

In addition to laboratory testing, conducting field studies on construction sites where these mixes are used can provide practical insights into the performance of the concrete under real construction conditions. This would help assess the robustness of the findings in actual construction environments.

3. Field Validation under Site Conditions

Complement laboratory testing with in-situ studies to observe the actual performance of concrete on construction sites. This will ensure that laboratory results translate effectively to real-world applications.

4. Comparison with Other International Standards

Expand comparative analysis to include other regional or global standards (e.g. EN 206, BS 8500), to evaluate whether Libyan concrete mixes are competitive and compliant with broader international benchmarks.

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