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# Prediction of Target Mean Strength of Concrete Mixes

**Masala Mwiko*, Michael Nshumfwa Mulenga**

Department of Civil and Environmental Engineering, School of Engineering, The University of Zambia, Lusaka, Zambia

**Email address:**
masalamwiko@gmail.com (Masala Mwiko), mnmulenga@unza.zm (Michael Nshumfwa Mulenga)
*Corresponding author

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**Abstract:** In practice cured concrete strength may exhibit strength variation from batch to batch and within batch despite the mixes being of the same proportions and with quality control. On the other hand, structural concrete elements are designed to meet specific characteristic strength. In order to ensure compliance to the specified characteristic strength, concrete mix designers target strengths higher than the specified characteristic strengths, commonly known as Target Mean Strength. This study aimed at establishing the margins between characteristic strength and Target Mean Strength for various local concrete mixes. In order to achieve this overall objective, a semi structured questionnaire was used to identify the popular concrete mix design models in the country. The identified model was then validated through experimental mix designs, concrete mixes, cube casting, curing and strength testing. The mixes were designed for normal concrete classes; C20, C25 and C30. The sample size for each of these classes was guided by the British-DOE method of mix design that demands for standard deviation to be calculated from at least 20 results and the Indian Standard IS 456:2000 that demands a sample size of at least 30 for each concrete class. This study utilized 101 concrete mixes; 31 samples for C20 and 35 for each of the C25 and C30 classes. Three concrete cube specimens were cast for each mix, cured for 28 days and tested for compressive strength at the Civil Engineering Laboratory of the University of Zambia. From the compressive strength results, the probability density function for each class was generated using Microsoft Office excel. The determined standard deviations (s) from the distributions were 8.19, 8.00 and 8.27 MPa for concrete classes of C20, C25 and C30, respectively, which implied margins of 13.43, 13.12 and 13.56 MPa, respectively for 95% reliability (k=1.64). Therefore, the established margins (k x s) can be used for predicting Target Mean Strength of concrete mixes at 95% reliability for the Zambian concrete mixes provided the BS-DOE model is applied and constituent materials are similar to those used in the study.

**Keywords:** Characteristic Strength, Target Mean Strength, Standard Deviation, Margin, British-DOE

## 1. Introduction

Concrete is a composite material whose main constituents are cement, sand, aggregates and water. Sometimes chemical additives are added to the mixture for improving particular desired properties of concrete [1]. Concrete is known for high compressive strength and is one of the most commonly used construction materials worldwide owing to its properties, economy and readily availability constituents [2]. However, concrete specimens cured for prescribed 28 days may exhibit variation in strength from batch to batch and within the batch [3]. In order to take care of these exhibited variations, modern concrete mix designs are targeted at strength higher than the specified minimum characteristic strength [4]. This targeted strength is commonly known as Target Mean Strength (TMS).

### *1.1. Background*

Concrete mix design is the process of correctly selecting and proportioning of concrete ingredients to achieve the desired strength, durability and workability in an economical manner [5]. It is a complex and challenging task owing to the varying properties of the constituent materials, site exposure condition and particular work for which the mix design is demanded for [6]. According to British Standards Institution [7], the proportions of prescribed concrete mixes should achieve the intended performance in fresh and hardened state with adequate margin. Therefore, the knowledge of various properties of mixing constituents, experience of concreting and site change conditions is required for successful mix design [6].

It is generally accepted from the various codes of practice that the variation in concrete strength follows a normal distribution pattern [1, 3, 8]. In order to account for strength variations, concrete mix designers target TMS, so that not more than 5% test results fall below the desired strength referred to as characteristic strength [9]. Therefore, pre-determining mixes for designer specified characteristic strength from concrete mixes is one thing, but knowledge of further prediction of Target Mean Strength of concrete mixes is another important aspect desired for optimal reliable mix designs [6].

In order to establish the appropriate TMS of a concrete class from the parent distribution, consecutive concrete strength result data of at least thirty is required for the distribution according to Bureau of Indian Standards [8]. However, it can be time consuming and not economically viable to produce such large number of destructive tests results each time a new mix is required. To simplify concrete mix design, various countries in the world have developed their own models in order to suit the local materials [10].

This study focused on establishing the standard deviation for predicting TMS of concrete mixes through laboratory experimental trial tests. The mix materials were locally obtained in Zambia and proportioned using the BS-DOE method of concrete mix design.

### *1.2. Problem Statement*

Despite the variations that are commonly exhibited in cured concrete strength of the same mix proportion, it is expected for designed concrete to achieve the intended performance in fresh and hardened state with adequate margin [7]. According to Bureau of Indian Standards [8], the adequate margin can be established from the distribution produced from a sample size of at least 30 consecutive strength results for each class of concrete. However, this undertaking of producing large sample size of trial cubes and strength testing can be costly and time consuming, i.e. waiting for the prescribed 28 days curing period [11].

### *1.3. Significance of the Study*

The margin established in this study for predicting TMS of concrete mixes assumed 95% reliability in achieving specified characteristic strength. This is in accordance with BSI [7], which specifies the compressive strength of concrete being denoted by concrete strength classes which relate to the characteristic strength (5%) cylinder or cube strength test. Therefore, the research results can assist in achieving the desired hardened concrete strength for mix designers when using the Zambian local concrete materials. In addition, the study provides baseline concrete strength data for future standardization of concrete mix designs in Zambian.

### *1.4. Aim*

The aim of the study was to establish appropriate margins for predicting Target Mean Strength of selected concrete mixes based on Zambian local materials.

### *1.5. Objectives*

The objectives were to:

1) Review existing concrete mix design approaches for Target Mean Strength models in various regions of the world.
2) Establish a concrete mix design model that utilizes local design parameters for Target Mean Strength of normal concrete grades.
3) Validate the established concrete mix design model with local materials through experimental cube casting, curing and testing for compressive strength at the age of 28 days.

### *1.6. Research Questions*

1. What concrete design approaches exist worldwide?
2. What design parameters are utilized for Target Mean Strength of concrete in the Zambian environment?
3. Is the applied margin for predicting Target Mean Strength appropriate for the concrete mix design model commonly employed in Zambia?

### *1.7. Scope and Limitation of Study*

The study was limited to normal concrete classes of C20, C25 and C30 classified with respect to characteristic cube compressive strength at 28 days [7]. The cement used for experimental mix designs was limited to Ordinary Portland cement Class of 42.5R manufactured by Lafarge Zambia. The coarse aggregates were limited to crushed 20mm size stone sourced from Oriental Quarries produced by Scirocco Enterprises located in Makeni, Lusaka. The crushed fine aggregates were sourced from United Quarries Ltd located in the Eastern part of Lusaka. The concrete mixes did not include admixtures. The laboratory room temperatures ranged between 24°C and 28°C during casting, curing and testing of the concrete cubes at the University of Zambia (UNZA) Civil Engineering Laboratory.

### *1.8. Study Overview*

The concrete composite material may vary in strength even when the same mix proportions are used in the mix design. In order to avoid compromise in strength demanded by concrete structural designers, modern concrete mix designs demand for five percent allowable defective. This is achieved by ensuring that an appropriate margin above the specified characteristic strength is used to predict the Target Mean Strength of specific concrete mixes. In this regard, the study was aimed at establishing appropriate margins for predicting Target Mean Strength of concrete mixes based on Zambian local materials. The aim was achieved through identifying concrete mix design models being practiced locally from the reviewed existing models in various parts of the world and then experimentally.

## 2. Materials and Methods

In order to achieve the aim and objectives of the study, mixed methods of research were employed i.e. qualitative and quantitative. The first stage involved literature review with a view to identify concrete mix design models and prediction criteria for Target Mean Strength employed worldwide. Thereafter, the information obtained from literature review was used as a basis for:

1) Secondary data collected through interviews by means of questionnaire,
2) Primary data collected through laboratory experiments and,
3) Data analysis to establish margins for prediction Target Mean Strength of concrete mixes using local materials.

### 2.1. Secondary Data

The secondary data was meant to identify a mix design model utilizing local materials that could be validated for Target Mean Strength prediction through laboratory experiments. After successful literature review, a semi structured questionnaire was developed and used for secondary data collection. Purposive sampling was used and minimum single sample size was targeted from a target group that deals with concrete mix designs for various clients in the Zambian construction industry. The single sample size was deemed sufficient as the response obtained was mainly for identification of concrete mix design model utilizing local materials and possible sources of materials. Six questionnaires were this issued to targeted institutions. Out of the six questionnaires, only two responses were obtained.

### 2.2. Primary Data

The BSI DOE method of concrete mix design recommends at least 20 consecutive concrete strength results for computing standard deviation to predict Target Mean Strength for the concrete class. For the BIS concrete mix design approach, recommends a minimum of 30 consecutive strength results for calculating standard deviation to predict TMS. Therefore, in this study, the minimum sample size of 30 for consecutive cube strength results for each concrete class, i.e. C30, C25 and C20 was adopted. Primary data collection for concrete cube strength followed the following steps:

1) Sourcing and delivery of mix materials to UNZA Laboratory,
2) Laboratory experiments of aggregate testing in accordance with BSI [12],
3) Concrete mix design for at least 30 mixes for each of the concrete classes of C20, C25 and C30 using BS-DOE method,
4) Casting of concrete cubes and slump testing for each mix in accordance with BSI [13],
5) Curing of the cubes at age of 28 days, and
6) Strength testing of cubes by crushing in accordance with BSI [13].

### 2.3. Constituent Materials Sources for Concrete

The constituent materials were sourced as follows:

1) Sixteen bags of 50kg Ordinary Portland cement Class 42.5R manufactured by Lafarge Zambia were acquired from the local market,
2) Two tons of crushed 20mm coarse aggregate was bought from Oriental Quarries located in Makeni Lusaka district,
3) Two tons of crushed fine aggregates was bought from United Quarries Limited Company located in the Eastern part of Lusaka district, and
4) Tap water supplied to the laboratory was used in the mixes.

### 2.4. Study Flow Chart

Figure 1 summarizes the research methodology.

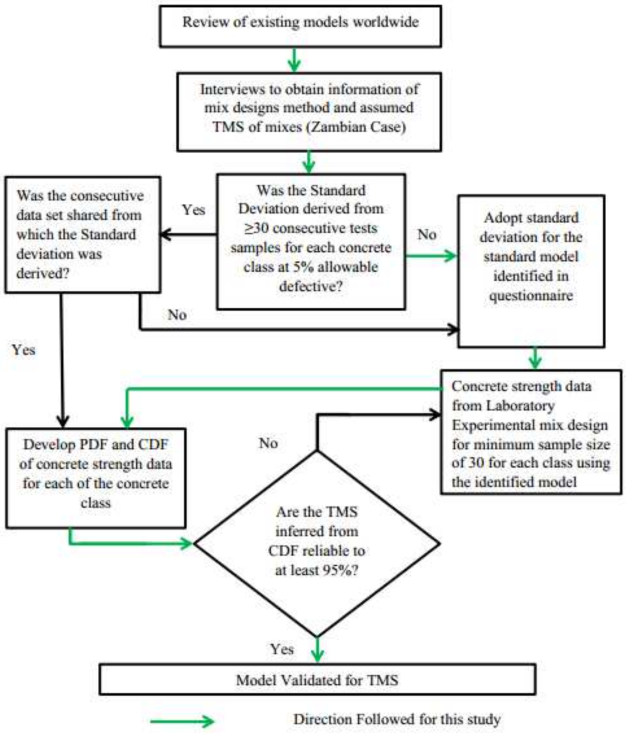



***Figure 1.*** *Flow Chart for Research Methodology.*

## 3. Results and Discussions

The results are based on interview questionnaires and laboratory experiments. The concrete strength data from laboratory experiments were analyzed to establish the appropriate predicting values for Target Mean Strength of concrete mixes. The procedure for data collection and analysis was as per BS DOE model of concrete mix design. Prediction values for Target Mean Strength were obtained from Probability Distribution Functions (PDFs) that derived from concrete strength results.

### 3.1. Concrete Mix Design Model Identification

The concrete design model validated for Target Mean Strength in this study was identified based on results from interview questionnaire. The two respondents from interview questionnaire (Table 1) indicated BS-DOE method as the method they used for their concrete mix design. Therefore, the BS-DOE method of concrete mix design was identified as one of the methods that could be validated for predicting TMS for local concrete mix materials in this study.

***Table 1.*** *Summary of Interview Questionnaires Response.*

| S/N | Questions | Respondent A | Respondent B |
|---|---|---|---|
| 1 | Method of Concrete Mix Design employed? | DOE | DOE |
| 2 | What Size of Coarse Aggregate? (mm) | 20mm | 20mm |
| 3 | What type of aggregates? | crushed | crushed |
| 4 | What is shape of concrete test samples? | cube | cube |
| 5 | What margin is used for C20? | 7.5 MPa | 15.2 MPa |
| 6 | What margin is used for C25? | 9.0 MPa | 20.3 MPa |
| 7 | What margin is used for C30? | 10.5 MPa | 18.2 MPa |

From the mix proportions provided by one respondent with similar cement material presented in Table 1, it was observed that the margin values for predicting TMS that were approximately 7.5 MPa, 9.0 MPa and 10.2 MPa for concrete classes C20, C25 and C30, respectively. It was however noted that the predicting margin values provided from interviews by respondent A were within range when compared with DOE mix design. In the DOE model, the theoretical standard deviation values are 4.0 MPa and 8.0 MPa which corresponding to margins of 6.56 MPa and 13.1 MPa, respectively, for the sample sizes of at least 20 and below 20, respectively. According to the British Research Establishment [1], the anticipated limits of standard deviation for concrete in the United Kingdom ranges between 2.5 and 8.5. However, in application of DOE method, a minimum standard deviation of 4.0 is recommended if similar past concrete data is available and if not available, a standard deviation of 8.0 is recommended.

It was, however difficult to validate the predicting values provided by respondents in the questionnaire owing to non-disclosure of data used to derive the predicting values. Therefore, primary laboratory experiments to generate the required concrete strength data for predicting Target Mean Strength were sought to validate the identified model.

### *3.2. Laboratory Experimental Results for Model Validation*

The data required to validate the model was obtained from experimental concrete strength cube tests results for each class of concrete. The required test results were not only for the cube compressive strength but also tests on aggregates used for concrete mixing, in order to ensure that the cast concrete cubes were made from standard materials and procedures. Therefore, the results presented include aggregate test results and PDFs produced from concrete strength test results for concrete classes C20, C25 and C30.

#### *3.2.1. Concrete Aggregate Tests*

The test results of concrete constituent materials used for the experiments were in conformity with the appropriate standards as presented in Tables 2 and 3. These material tests were confined to affirm compliance of the fine and coarse aggregates whilst the cement bought from the open market, manufactured by Lafarge Zambia, were assumed to meet the prescribed standard by the manufacturer.

***Table 2.*** *Coarse Aggregate Test Results Summary.*

| S/N | Test Conducted | Detailed Description | Parameter/Units | Limiting Range | Ref Standards | Value obtained | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | Sieve Analysis | Test Sieve Size 20mm | % cumulative passing | 85 to 100 | BS 882 | 100 | Acceptable |
| | | Test Sieve Size 14mm | % cumulative passing | 0 to 70 | BS 882 | 39.9 | Acceptable |
| | | Test Sieve Size 10mm | % cumulative passing | 0 to 25 | BS 882 | 0.28 | Acceptable |
| | | Test Sieve Size 5mm | % cumulative passing | 0 to 5 | BS 882 | 0 | Acceptable |
| 2 | Relative Density | Based on SSD | $Ton/m^3$ | 2.4 to 2.9 | BRE-DOE, Method | 2.73 | Acceptable |
| 3 | Bulk Density | rodded | $Ton/m^3$ | 1.28 to 1.92 | ACI 2011 | 1.627 | Acceptable |
| 4 | Aggregate Crushing Value (ACV) | Separating sieve 2.36mm | % | <30 | BS 812-110 | 16.6 | Acceptable |
| 5 | Elongation Index | | % | <45 | BS 882 | 10 | Acceptable |
| 6 | Flakiness Index | | % | <40 | BS 882 | 8 | Acceptable |

***Table 3.*** *Fine Aggregate Test Results Summary.*

| S/N | Test Conducted | Detailed Description | Parameter/Units | Limiting Range | Ref Standards | Value obtained | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | Sieve Analysis | Test Sieve Size 10mm | % cumulative passing | 100 | BS 882 | 100 | Acceptable |
| | | Test Sieve Size 5mm | % cumulative passing | 89 to 100 | BS 882 | 89.5 | Acceptable |
| | | Test Sieve Size 2.36mm | % cumulative passing | 60 to 100 | BS 882 | 65.6 | Acceptable |
| | | Test Sieve Size 1.18mm | % cumulative passing | 30 to 100 | BS 882 | 53.7 | Acceptable |
| | | Test Sieve Size 0.6mm | % cumulative passing | 15 to 100 | BS 882 | 40.6 | Acceptable |
| | | Test Sieve Size 0.3mm | % cumulative passing | 5 to 70 | BS 882 | 27.2 | Acceptable |
| | | Test Sieve Size 0.15mm | % cumulative passing | 0 to 20 | BS 882 | 14 | Acceptable |
| 2 | Relative Density | Based on SSD | $Ton/m^3$ | 2.4 to 2.9 | BRE-DOE, Method | 2.620 | Acceptable |

### *3.2.2. Concrete Strength Results*

The range and distribution of predicted Target Mean Strengths based on DOE Method that were used for the experiment and the corresponding actual strengths for each class is presented in form of PDF graphs (Figures 2, 4 and 6). The respective probabilities of these distribution are presented in form of Cumulative Distribution Function (CDF) graphs (Figures 3, 5 and 7). The concrete strength results distributions presented in these figures for concrete classes C20, C25 and C30 were found to follow a normal distribution pattern as anticipated from literature reviewed. The normality test conducted in Table 4 confirmed that the distributions for the three classes of concrete were within normal distribution patterns. The Z-Test was used to conduct this normality [14].

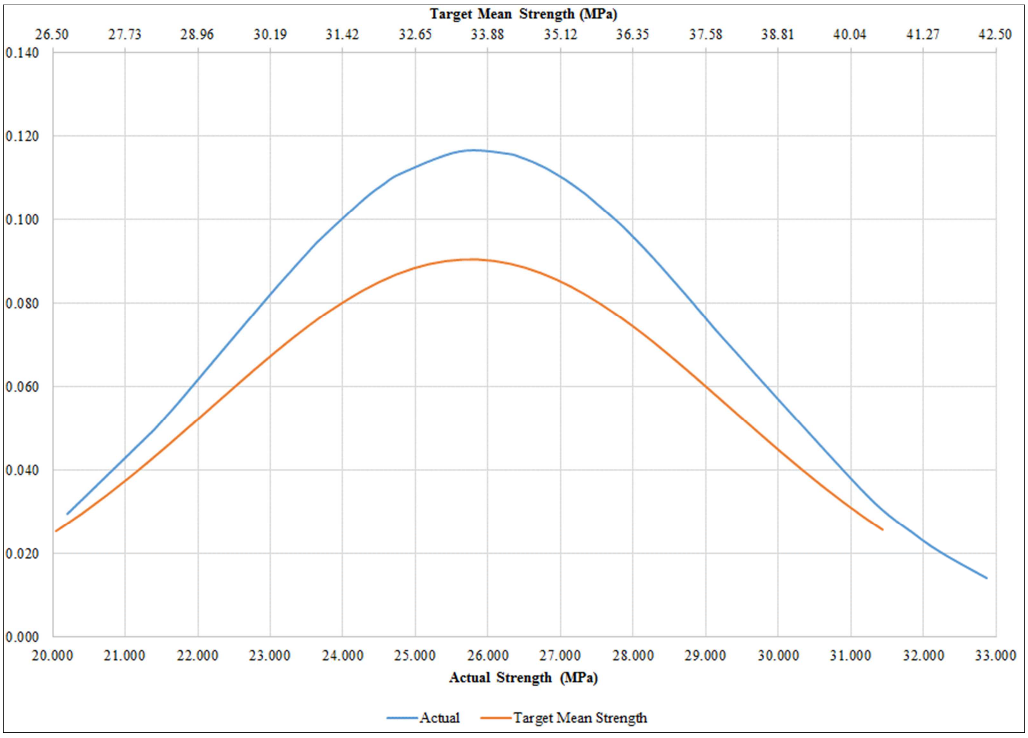
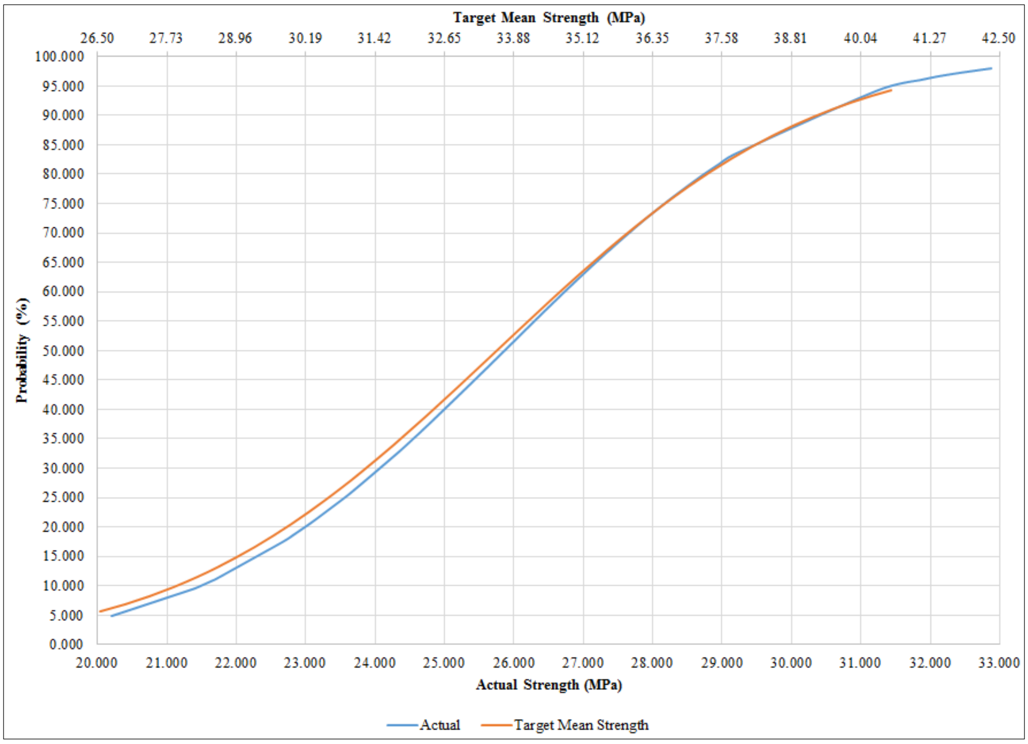



***Figure 2.*** *Probability Density Function for Class C20.*




***Figures 3.*** *Cumulative Density Function for Class C20.*

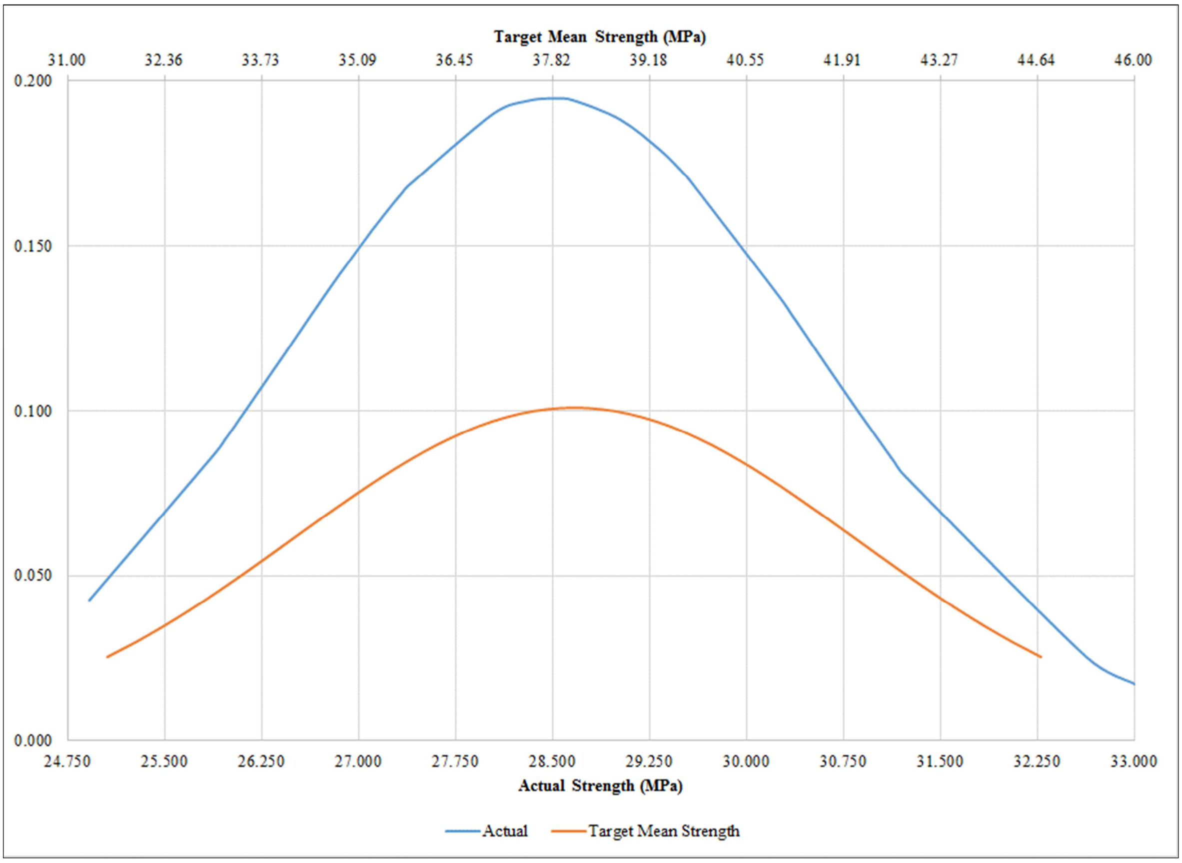



***Figure 4.*** *Probability Density Function for Class C25.*

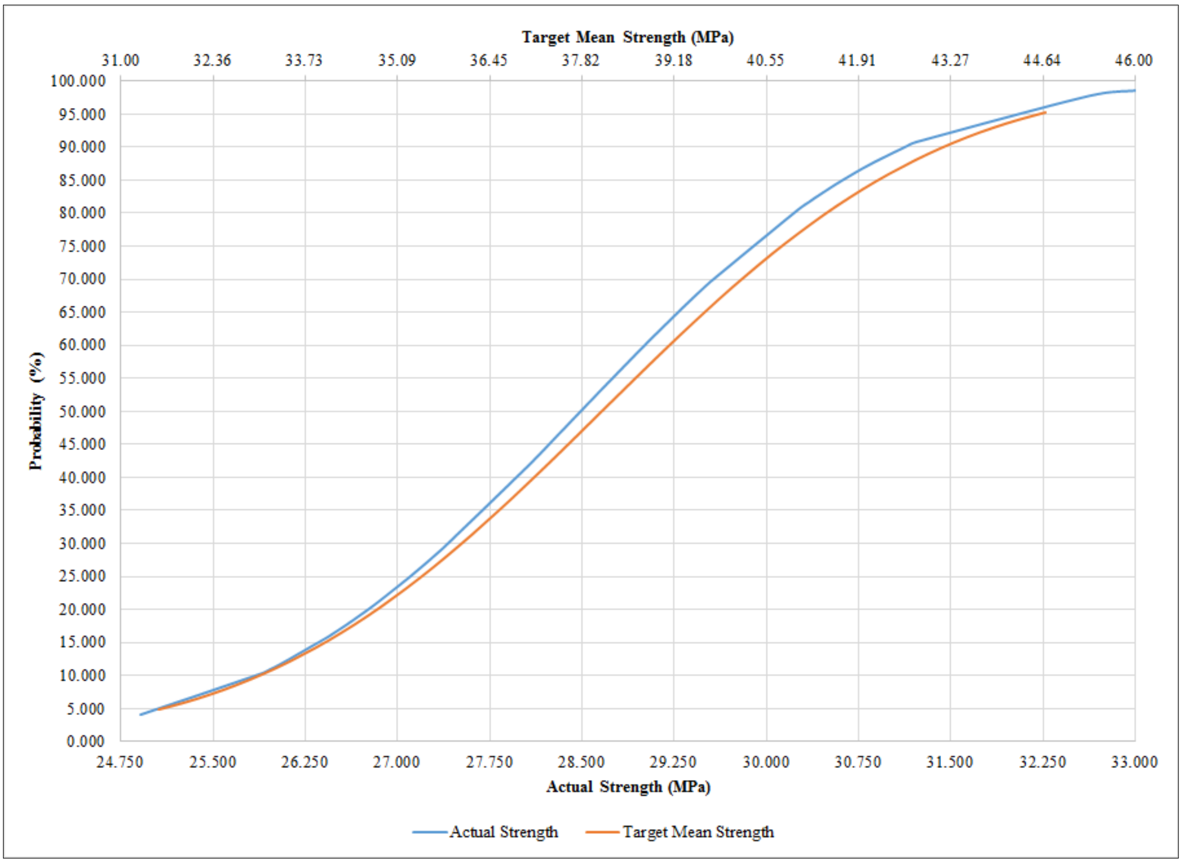



***Figure 5.*** *Cumulative Density Function for Class C25.*

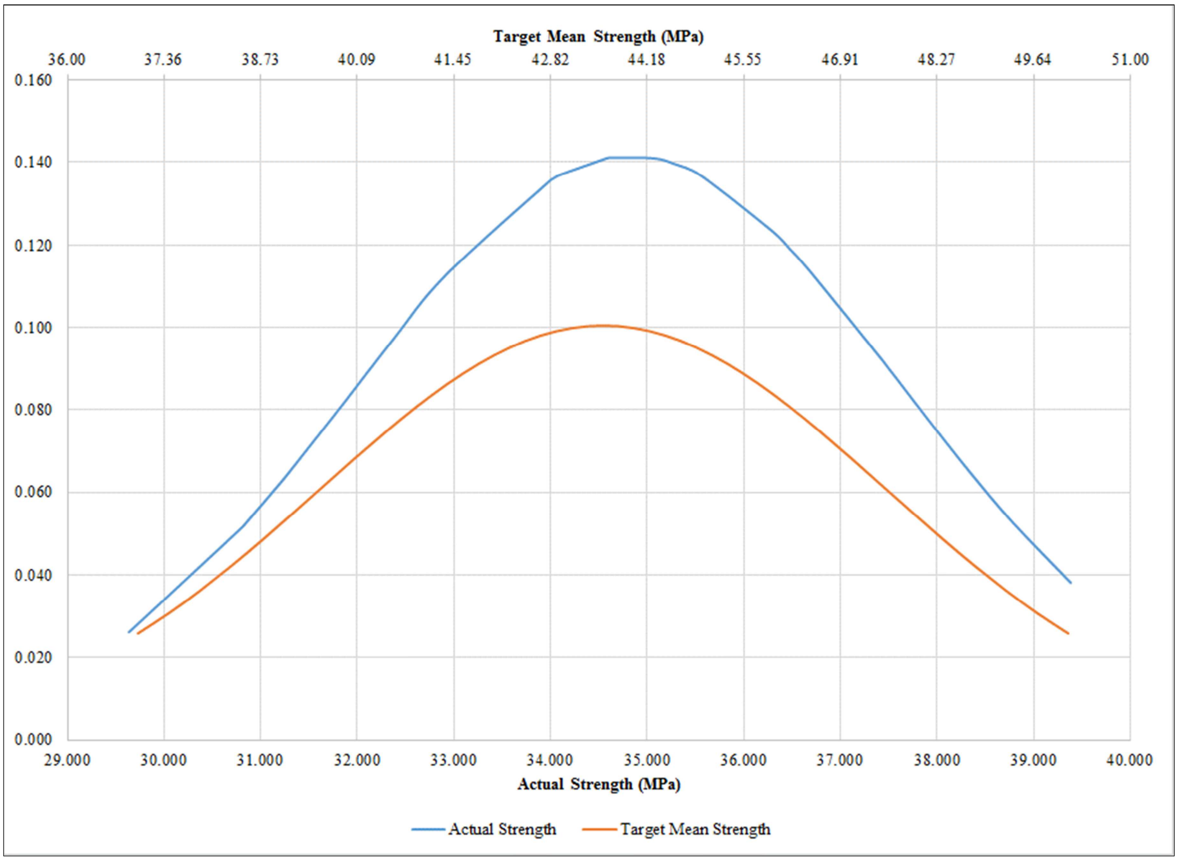



***Figure 6.*** *Probability Density Function for Class C30.*

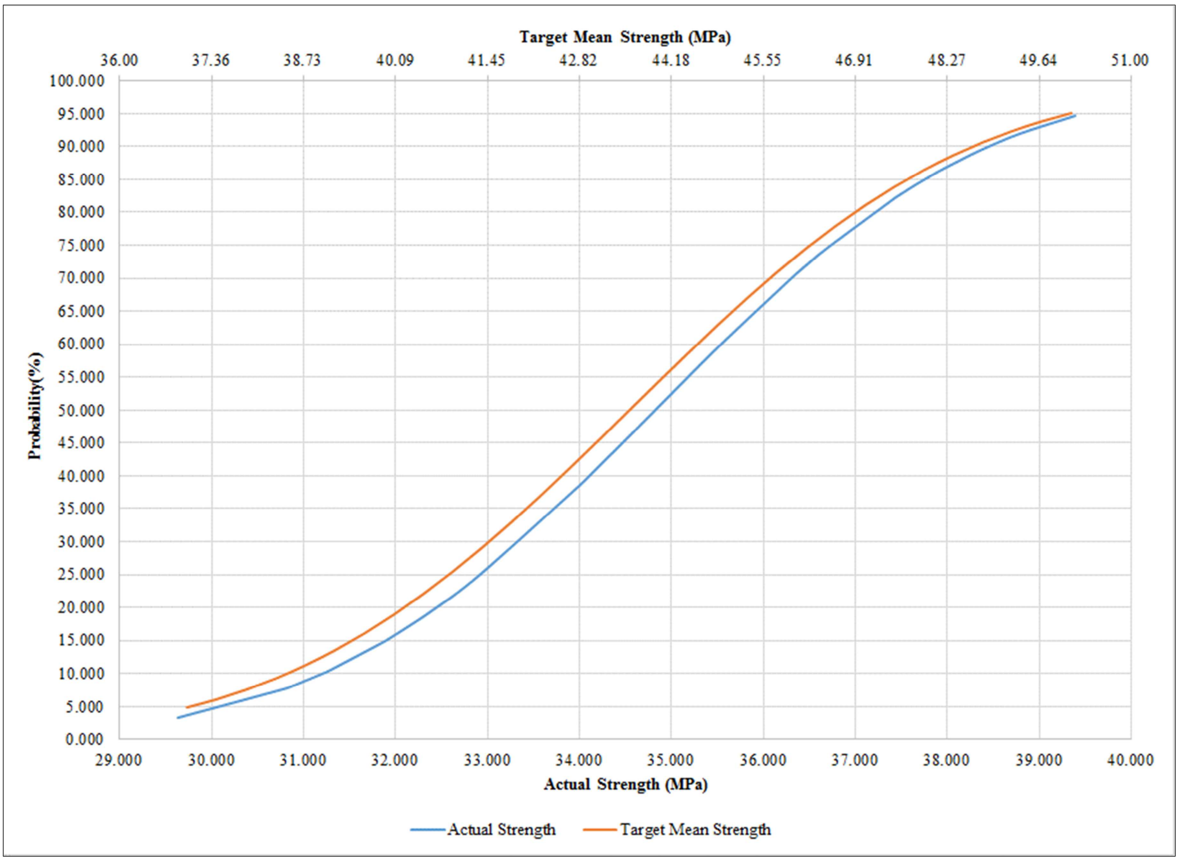



***Figure 7.*** *Cumulative Density Function for Class C30.*

***Table 4.*** *Normality Tests for the Distributions Using the Z-Test.*

| Concrete Class | C20 | C25 | C30 |
|---|---|---|---|
| Sample Size (n) | 35 | 35 | 31 |
| Mean for Null Hypothesis (μ) | 26.54 | 28.96 | 34.51 |
| Sample Mean (x) | 25.86 | 28.49 | 34.82 |
| Confidence Level (%) | 95 | 95 | 95 |
| Critical P-Value (α) | 0.05 | 0.05 | 0.05 |
| Lower bound Z-Critical Value | -1.96 | -1.96 | -1.96 |
| Upper bound Z-Critical Value | 1.96 | 1.96 | 1.96 |
| Standard Deviation (S) | 3.42 | 2.05 | 2.82 |
| Calculated value of Z | -1.18 | -1.37 | 0.61 |
| Comments | Z calculated within bounds | Z calculated within bounds | Z calculated within bounds |

Equation (1) was used to calculate the value of Z in Table 4.

$$Z = (x - \mu)/(s \div \sqrt{n}) \quad (1)$$

$where$:

$z = number\ of\ standard\ deviations\ (Z - score)$
$x = sample\ mean$
$s = standard\ deviation$
$\mu = mean\ for\ null\ hypothesis$
$n = sample\ size$

### *3.2.3. Relationship Between Compressive Strength and Water-Cement Ratio Obtained from Experimental Results*

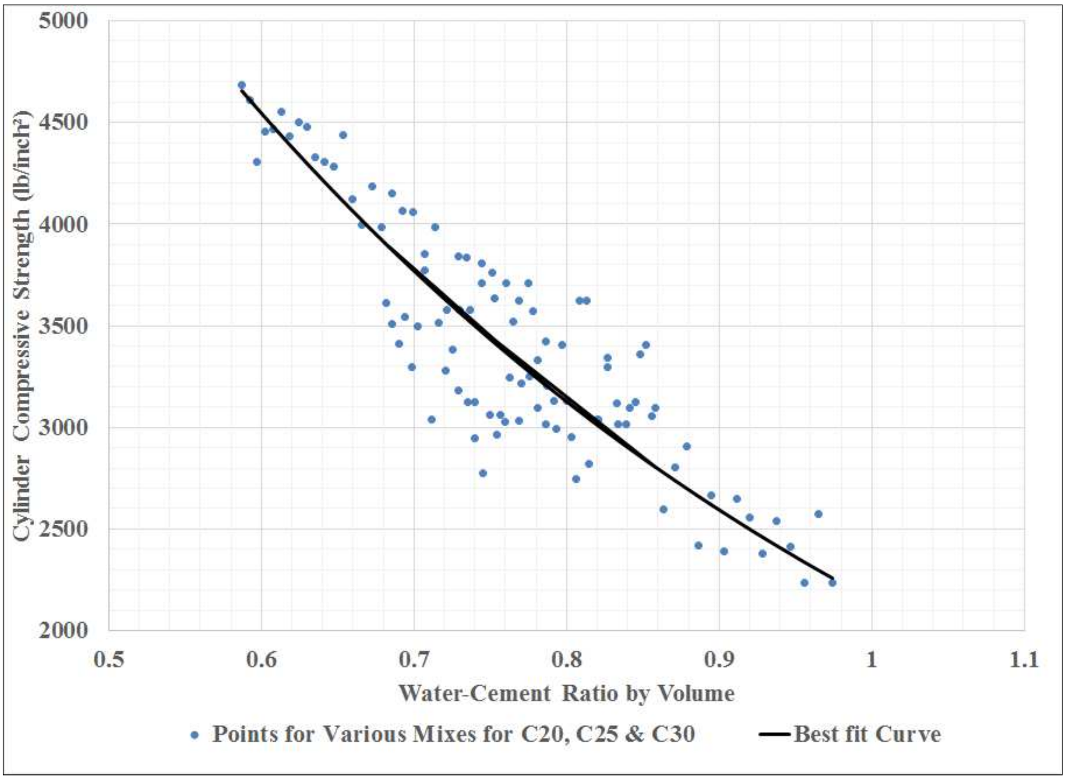
The established relationship between compressive strength and water-cement ratio presented in Figure 8 (a) and Equation (3), was deliberately expressed in imperial system units in order to compare study results with results established by Abram in 1918 and is still applicable today [15]. Abram established the general equation for the relationship between compressive strength and water-cement ratio presented in Equation (2).

$$Qc = (A \div (B^{WC})) \quad (2)$$

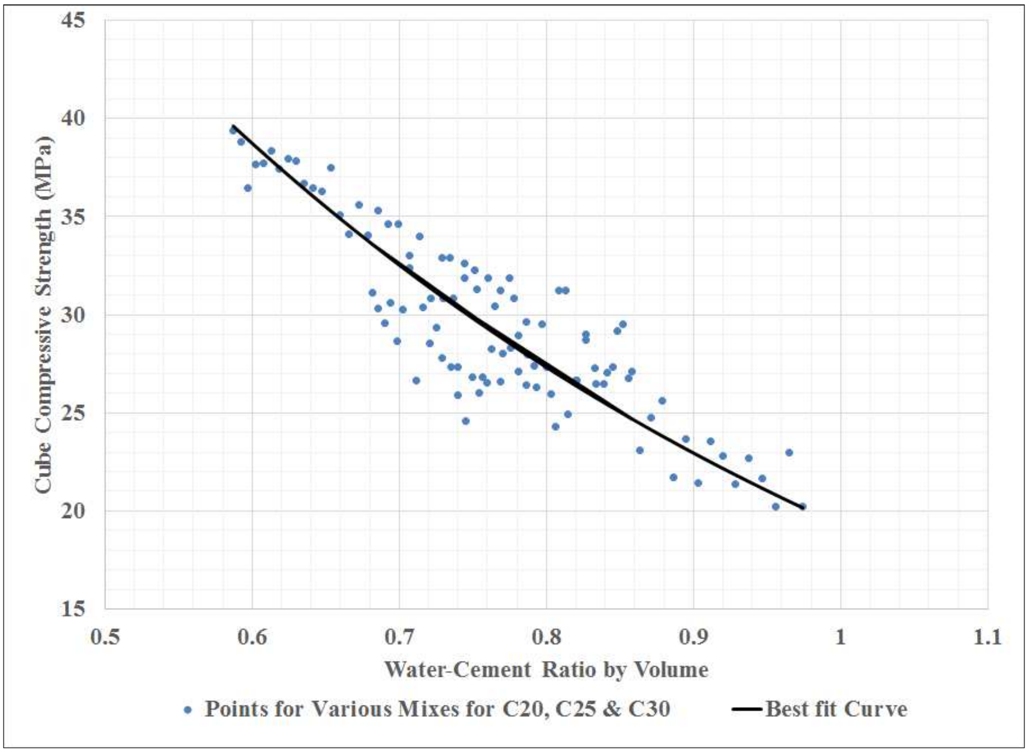
$where$

$Qc =$ Compressive strength based on cylinder tests of 6inch by 12inch
$A =$ Empirical constant depending on cement properties
$B =$ Constant depending on cement properties

$$WC = water - cement\ ratio\ by\ volume$$




(a)




(b)

***Figure 8.*** *Relationship between Compressive Strength and Water-Cement Ratio by volume.*

The constant A and B in equation (2) are specific for particular mix materials. Abram in his experiments established the value of A and B to be equal to 14000 and 7, respectively. In this study, the value of A was established to be equal to 13980 whilst the value of B was 6.5 as expressed in Equation (4). These constant values established in this study were approximately the same as those established by Abram 1919. Therefore, the study confirmed that the relationship between compressive strength and water-cement ratio established by Abram was applicable for the local materials in the study. The Figure 8 (b) and equation (5) presents study established relationship between concrete compressive strength concrete and water-cement ratio in metric system units which is equivalent to the one established by Abram in 1919.

Equation (3) suggested by L' Hermite was used to convert experimental compressive strength results from cube-based test to cylinder-based strength test [16].

$$Cylinder\ Strength/Cube\ strength = 0.76 + 0.2 log\ fcu/2840 \quad (3)$$

$where$:

$fcu = Cube\ Strength\ in\ pound\ per\ square\ inch$ (psi)

The mathematical relationship of the best fit curve in Figure 8 (a) is represented in Equation (4).

$$Qc = 13980 \div 6.5^{WC} \quad (4)$$

where:

Qc = Compressive strength based on cylinder test strength in lb/inch$^2$

wc=water cement ratio by volume

The mathematical relationship of the best fit curve in Figure 8 (b) is represented in equation (5).

$$Qcu = 110 \div 5.7^{WC} \quad (5)$$

where:

$Qcu$ = Compressive strength based on cube test strength in MPa,

$wc = water\ cement\ ratio\ by\ volume$

### *3.2.4. Established Target Mean Strength Values*

The Target Mean Strength of concrete mixes was determined by the value of compressive strength corresponding to 50% probability on the CDF graphs. The respective characteristic strength corresponded approximately to 5% probability of the actual strength CDF graphs. Figures 3, 5 and 7 are the CDF graphs for concrete classes C20, C25 and C30, respectively. The prediction margin was simply the difference between the characteristic strength and the Target Mean Strength. The margins were divided by a factor k (1.64) to obtain standard deviations as presented in Figure 9.

Figure 9 compares the established standard deviations in this study with the anticipated values of concrete in the United Kingdom where the DOE was developed. From this Figure, it was observed that the established standard deviations of 8.19, 8.0 and 8.27MPa were within the anticipated limits, though closer to the upper bound of 8.5MPa. The initial minimum standard deviation of 4.0MPa was used during concrete mix design for the experiment. Figure 10 compares the Target Mean Strengths calculated from standard deviations in Figure 9. Figures 11 (a), (b) and

(c) present established concrete mix proportions per cubic meter volume for classes C20, C25 and C30, respectively. The results of the study were also in conformity when compared with Rüsch's work. According to Rüsch, the standard deviation varies from 1 to 10Mpa depending on constituent materials and general condition of concrete production [17]. In this work, it was further suggested that if the distribution is Gaussian, at 5% fractile, the k-factor is 1.64 and standard deviation is almost 8 MPa.

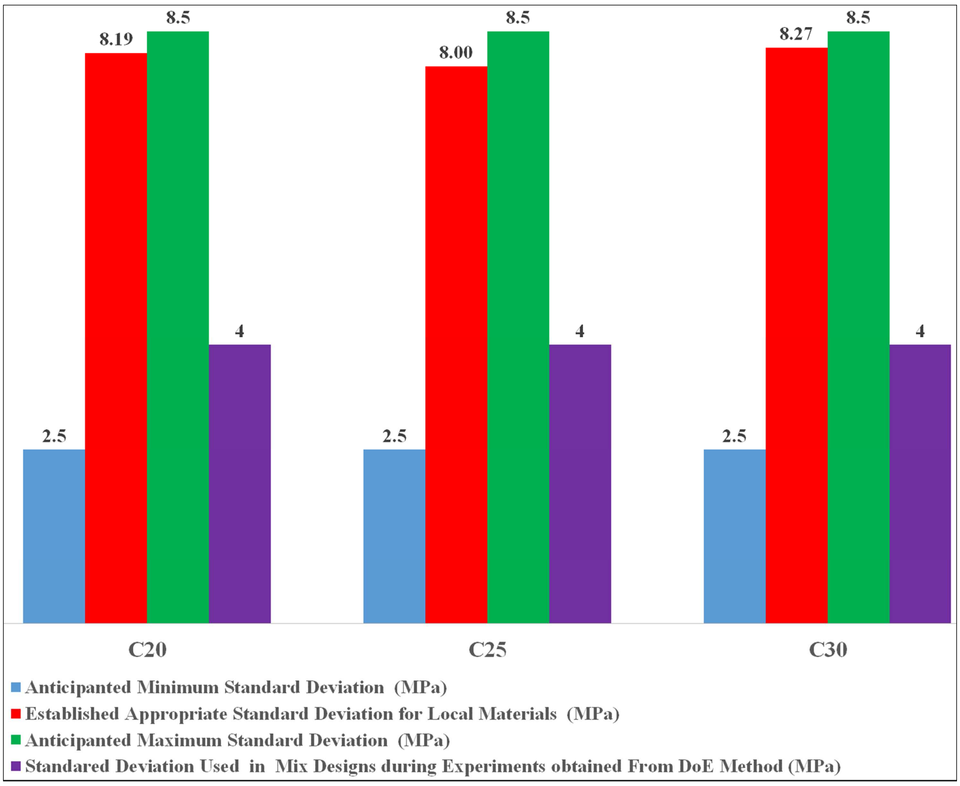



***Figure 9.*** *Established Standard Deviation in Comparison with DOE.*

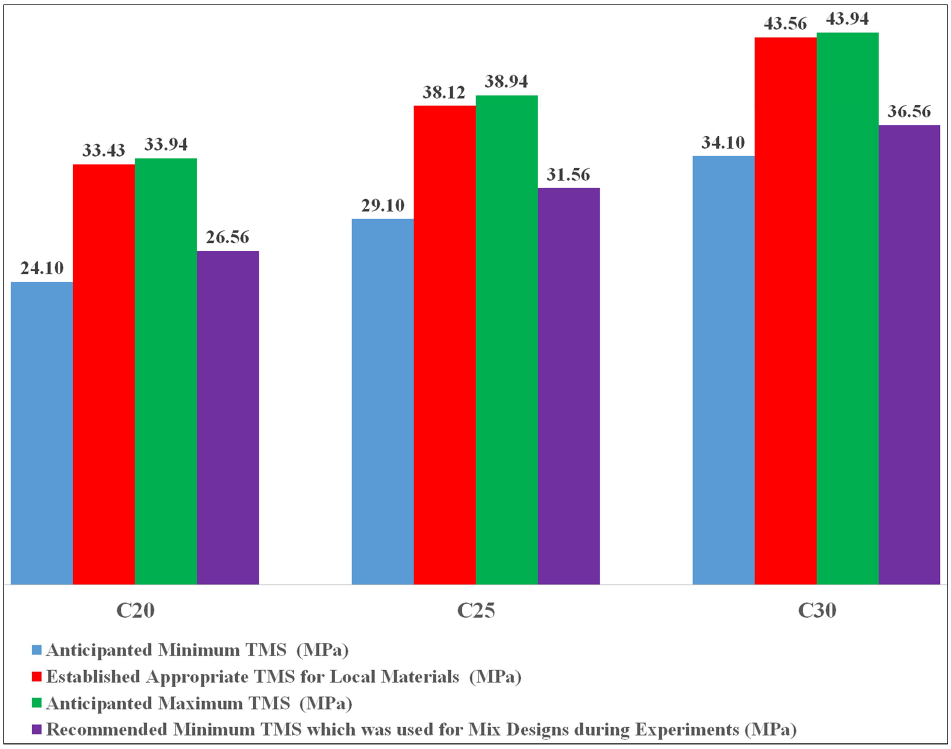
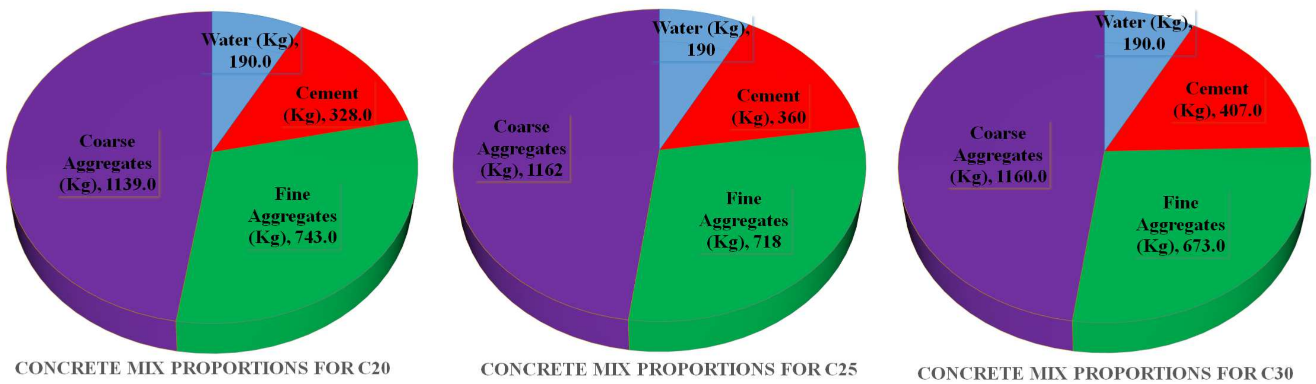



***Figure 10.*** *Established Target Mean Strength in Comparison with DOE.*




(a) (b) (c)

***Figure 11.*** *Established Concrete Mix Proportions per meter cubic for concrete Class C20, C25 and C30.*

# 4. Conclusion and Recommendations

The study aimed at reviewing concrete mix design models, identification of local model through interviews and validation of local model for Target Mean Strength. In the review of concrete mix design models worldwide, it was established that notable popular design models that utilize Target Mean Strength included BS-DOE, ACI and Bureau of Indian Standards recommended methods. In these methods, TMS is predicted based on standard deviation derived from historical concrete strength distribution data. The interview questionnaire developed on the basis of these three models, revealed that the BS-DOE model was one of the methods that was being employed in Zambian. The concrete strength results based on this method were experimentally validated for TMS of local mixing materials. The established Target Mean Strengths from laboratory experiments were within limits as anticipated in DOE model.

## *4.1. Conclusion*

### *4.1.1. Reviewed Concrete Mix Design Models*

Literature revealed that the BS DOE, ACI and Indian Recommended methods are the popular models of concrete mix designs that utilizes Target Mean Strength for concrete mixes [1, 3, 8]. The standard deviation or margin values are used in these three models to predict Target Mean Strength of concrete mixes for normal concrete classes. Besides the standard deviation and margin, the coefficient of variation and overdesign factor is alternative for prediction of Target Mean Strength as used in other parts of the world such as Japan [18]. The BS DOE is provided with standard deviations of 4.0 and 8.0 MPa resulting from data set of at least twenty (20) and less than twenty (20), respectively [1]. The ACI is provided with margins based on cylinder strength ranging between 5.0 and 8.0 MPa [3]. The Bureau of Indian Standards method provides standard deviations ranging between 3.5 and 5.0 resulting from the data set of not less than thirty (30) for the classes C20, C25 and C30 [8]. The concrete tests for the BS DOE and BIS are based on cube strength test whilst the ACI are based on cylinder strength test. The margins for the BS DOE and Indian recommended methods are obtained by multiplying the provided standard deviations with factors of 1.64 and 1.65, respectively. The Target Mean Strength in the three models is obtained by adding the margin to the characteristic strength.

### *4.1.2. Concrete Mix Design Model Applied Locally*

From the interview questionnaire conducted, it was indicated that the BS DOE method of concrete mix design was one of the models that were being utilized for local design parameters. It was further established that the margin values employed locally for this model were approximately 7.5 MPa, 9.0 MPa and 10.2 MPa for concrete classes C20, C25 and C30, respectively. These margins were based on a respondent who utilized similar concrete mix materials with the ones used in this study.

### *4.1.3. Model Validation for Target Mean Strength*

The BS DOE concrete mix design model was used to design the mixes for the laboratory experiments. The concrete strength results obtained from experiments were analyzed by means of producing Probability Density Functions for each of the concrete classes, i.e. C20, C25 and C30. The obtained margins at 5% defective for classes C20, C25 and C30 were 13.43 MPa, 13.12 MPa and 13.56 MPa, respectively. The respective corresponding standard deviations for these margins were 8.19MPa, 8.00MPa and 8.27MPa. For class C20, the established TMS was 33.43MPa. and the corresponding mix proportions were 328kg/m$^3$ cement, 743kg/m$^3$ fine aggregate, 1139kg/m$^3$ coarse aggregate and 190kg/m$^3$ for water. For class C25, the TMS was 38.1MPa with corresponding mix proportions of 360kg/m$^3$ cement, 718kg/m$^3$ fine aggregates, 1162kg/m$^3$ coarse aggregate and 190kg/m$^3$ water. For class C30, the established TMS was 43.6MPa and the corresponding mix proportions were 407kg/m$^3$ cement, 673kg/m$^3$ fine aggregate, 1160kg/m$^3$ coarse aggregate and 190kg/m$^3$ of water. The established margins provided for prediction of Target Mean Strength at 95% reliability provided the BS-DOE model is applied and constituent material properties are similar to those used in the study.

## *4.2. Recommendations*

Industry should make use of the findings of this study in standardizing concrete mix designs. Further, Design and

Supervising Engineers, and National Council for Construction undertake further consultations with stakeholders, and support further studies on the subject matter, with a view to standardize concrete mix design models in Zambia.

### *4.3. Study Summary*

The initial standard deviation of 4.0 was used to predict TMS during concrete mix design for the experiment. The mix materials were proportioned using BS DOE concrete mix design method as this is the method that was identified from interview questionnaire. The concrete strength data from the experiment were used to produce PDFs and CDFs for each class of concrete. The Target Mean Strengths were deduced from these graphs and their corresponding standard deviations were calculated. The average established standard deviation was 8.15MPa for predicting TMS of local mixes for classes C20, C25 and C30. This standard deviation falls within range when compared to the anticipated standard deviations in the BS DOE model. Industry should make use of the findings of this study in standardizing concrete mix design in Zambia.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