# Prediction of Target Mean Strength of Concrete Mixes

**By**

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**A dissertation submitted to the University of Zambia in partial fulfillment of the requirements for the degree of Master of Engineering in Structural Engineering**

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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 C30 and 35 for each of the C25 and C20 classes. The mix materials used were Ordinary Portland cement 42.5R manufactured by Lafarge Zambia, 20mm crushed coarse aggregates and crushed fine aggregates. 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 (kxs) 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*

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ACI | American Concrete Institute |
| ACV | Aggregate Crushing Value |
| BIS | Bureau of Indian Standards |
| BS | British Standards |
| CDF | Cumulative Density Function |
| DOE | Department of Environment |
| E.I | Elongation Index |
| FI | Flakiness Index |
| FM | Fineness Modulus |
| JSCE | Japanese Society of Civil Engineers |
| PDF | Probability Density Function |
| SD | Standard Deviation |
| SSA | Specific Surface Area |
| SSD | Saturated Surface Dry |
| TMS | Target Mean Strength |

# CHAPTER 1: INTRODUCTION

## 1.1 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 (BRE, 2010). 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 (Izabela and Marta, 2019). However, concrete specimens cured for prescribed 28 days may exhibit variation in strength from batch to batch and within the batch (ACI, 2011). In order to take care of these exhibited variations, modern concrete mix designs are targeted at strength higher than the specified minimum characteristic strength (ACI, 2019). This targeted strength is commonly known as Target Mean Strength (TMS).

## 1.2 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 (Hakim et al., 2020). 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 (Shetty and Jain, 2019). According to BS 8500-1+A2:2019, 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 (Shetty and Jain, 2019).

It is generally accepted from the various codes of practice that the variation in concrete strength follows a normal distribution pattern (BRE, 2010). 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 (Shekhar and

Kushal, 2020). 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 (Shetty and Jain, 2019).

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, IS 10262:2019. 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 (Abebe, 2022).

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.

### 1.3 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 (BSI, 2019). According to Indian Standards, IS 10262:2019, 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 (Uche et al., 2019). Zambia had adopted British standard of concrete mix design and is being practiced even today by industry. However, application of British Model (BS-DOE) of concrete mix design without it being verified for local mix materials, may not guarantee achieving desired strength at 95% reliability as demanded by the code BS 8500-1+A2:2019. Therefore, the need for appropriate prediction of Target Mean Strength of local mixes so as to provide quality control in hardened concrete strength.

## 1.4 Significance of 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 British Standard Institution (BSI, 2019), 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.

## 1.5 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.

## 1.6 Objectives

1. To review existing concrete mix design approaches in various regions of the world so as to identify models of concrete mix designs that can be validated for Target Mean Strength using local mix materials.
2. To establish a concrete mix design model that utilizes local design parameters for Target Mean Strength of normal concrete grades
3. To validate the established concrete mix design model with local materials through experimental cube casting, curing and testing for compressive strength at age of 28 days.

## 1.7 Research Question

1. What types of 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?

## 1.8 Scope and Limitation of the Study

The study was limited to normal concrete classes of C20, C25 and C30 classified with respect to characteristic compressive strength at 28 days of 150mm cubes (BSI, 2019). The cement used for experimental mix designs was limited to Ordinary Portland cement strength 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 coarse aggregates properties were in compliance with BS 882 in terms of particle size distribution, relative density based on saturated and surface dried, Aggregate Crushing Value Elongation and Flakiness indexes. The crushed fine aggregates were sourced from United Quarries Ltd located in the Eastern part of Lusaka. The fine aggregate properties were in compliance with BS 882 in terms of particle size distribution and relative density based on saturated and surface dried. The mix proportions did not include admixtures. The laboratory room temperatures ranged between 24$^{o}$C and 28$^{o}$C during casting, curing and testing of the cubes at the University of Zambia Civil Engineering Laboratory.

## 1.9 Summary

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 validate it with local materials for TMS. The study was limited to normal concrete classes of C20, C25 and C30 as well as the mix materials in section 1.8.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

In order to successfully establish the predicting parameters for Target Mean Strength of concrete mixes using local materials, it was imperative to understand: criteria for TMS prediction employed worldwide, concept and methods of concrete mix designs worldwide, and positive strides made to overcome challenges in concrete mix design. Therefore, the reviewed literature in this study addresses the aforementioned aspects.

## 2.2 Criteria for Predicting TMS of Concrete Worldwide

In international popular codes of practice, such as BS EN 206-1, ACI 214R-11 and IS 456-2000, it is assumed that concrete strength follows a normal distribution pattern. Target Mean Strength is thus predicted statistically in two approaches with application of standard normal distribution properties. The two methods are either by use of standard deviation or coefficient of variation approach. The critical parameters required for predicting TMS in this regard are the allowable percentage of defectives and Standard deviation or Coefficient of Variation. Equations 2.2-1 and 2.2-2 are general forms for predicting TMS based on ACI 214R-11.

$$F_m = F_c + KS \qquad \text{...Equation 2.2-1}$$

$$F_m = \frac{F_c}{(1-KV)} \qquad \text{... Equation 2.2-2}$$

$where$:

$F_m = Target\ Mean\ Strength$

$F_c = Characteristic\ Strength$

$V = coefficient\ of\ variation = \frac{S}{Xm}$

$K = risk\ factor\ (Z\ score) coreponding\ to\ \%\ defective\ allowed$

$S = sample\ standard\ deviation = \sqrt{\frac{\sum(X_i - X_m)}{n-1}}$

$where: X_m = sample\ mean, \quad n = sample\ size\ and\ X_i = \ strength\ test\ result$

## 2.3 Guide Values used for Predicting TMS Worldwide

Most of the statistical values used for predicting TMS used worldwide are enshrined in respective National or Regional Standards of Practices. This section outlines the actual guide values used for predicting Target Mean Strength of mixes from selected different National/Regional guidelines of concrete mix designs.

In the United States of America, the predicted Target Mean Strength is based on cylinder strength for normal concrete at 5% allowable defective where there is no sufficient historical data is as illustrated in equations 2.3-1, 2.3-2 and 2.3-3 (ACI, 2011).

If the specified cylinder compressive strength (Fc) is less than 21MPa ($Fc < 21MPa$), then the Target Mean Strength (Fm) is as given by Equation 2.3-1.

$$Fm = Fc + 7 \qquad \textit{...Equation 2.3-1}$$

If the specified cylinder compressive strength (Fc) is greater or equal to 21MPa $but\ less\ or\ equal\ to\ 35MPa,$ $(21 \leq Fc \leq 35MPa)$, then the Target Mean Strength (Fm) is as given in Equation 2.3-2.

$$Fm = Fc + 8 \qquad \textit{...Equation 2.3-2}$$

If the specified cylinder compressive strength (Fc) is greater than 35MPa ($Fc > 35MPa$), then the Target Mean Strength (Fm) is as given in Equation 2.3-3.

$$Fm = Fc + 5 \qquad \textit{...Equation 2.3-3}$$

In Europe, the prediction of Target Mean Strength is as per European Standards EN 206-1:2000. The criterion adopted in the code for initial tests for standardized prescribed concrete in obtaining Target Mean Strength (Fm) from the specified Characteristic Strength (Fc) at 5% significance is as given in Equation 2.3-4. The margin between specified characteristic strength and TMS ranges between 6MPa and 12Mpa, which is twice the expected standard deviation depending on production facilities, material constituents and background information of variation (BSI, 2019).

$$Fm \geq Fc + 12 \qquad \textit{...Equation 2.3-4}$$

The relationship between cylinder and cube strengths classes of concrete grades as provided in British Standard, BS-EN 206-1:2000 is as shown in Table 2.3-1.

***Table 2.3-1: Compressive Strength Classes for Normal and Heavyweight Concrete***

| **Compressive Strength Class** | **Minimum Characteristic Cylinder Strength $f_{ck,cyl}$ N/mm$^2$** | **Minimum Characteristic Cube Strength $f_{ck,cube}$ N/mm$^2$** |
|---|---|---|
| C8/10 | 8 | 10 |
| C12/15 | 12 | 15 |
| C16/20 | 16 | 20 |
| C20/25 | 20 | 25 |
| C25/30 | 25 | 30 |
| C30/37 | 30 | 37 |
| C35/45 | 35 | 45 |
| C40/50 | 40 | 50 |
| C45/55 | 45 | 55 |
| C50/60 | 50 | 60 |
| C55/67 | 55 | 67 |
| C60/75 | 60 | 75 |
| C70/85 | 70 | 85 |
| C80/95 | 80 | 95 |
| C90/105 | 90 | 105 |
| C100/115 | 100 | 115 |

*Source: BS-EN 206-1:2000, Table 7*

L'Hermite also suggested the relationship between cylinder and cube strength as shown in Equation 2.3-5. However, it was noted that some secondary factors affecting the strength might influence the strength of the specimens (Neville, 2000).

$$Ratio\ of\ Cylinder\ to\ Cube\ strength = 0.76 + 0.2log\frac{fcu}{2840} \qquad \textit{...Equation 2.3-5}$$

$where$:

$fcu = Cube\ Strength\ in\ pound\ per\ square\ inch$

In South Africa, application of Equation 2.3-4 is used for the prediction of TMS as the South African Standard (SAN-50206) adopts the European Standards, EN 206-1. In this South African standard, normal designed concrete strength specifications conform to BS-EN 206-1. Therefore, specifications of designed concrete should contain compressive strength class, exposure class, maximum nominal upper aggregate size and chloride content class (SABS, 2015). For the Zambian case, there are no localized standards of concrete mix design. Therefore, it is common practice for many industries in Zambia to adopt the British code of practice BS-EN 206-1 for their concrete mix design specifications.

In India, the Prediction of Target Mean Strength is as per Bureau of Indian Standards IS 456:2000. The predicted Target Mean Strength (Fm) at 5% allowable defective is calculated as shown in Equation 2.3-6. The standard deviation ($\sigma$) used in Equation 2.3-6 is obtained from Table 2.3-2. (BIS, 2019).

$$Fm \geq Fc + 1.65\sigma \qquad \textit{...Equation 2.3-6}$$

***Table 2.3-2: Assumed Standard Deviation as Per Indian Standard IS 456:2000***

| Grade of Concrete | Assumed Standard Deviation (MPa) |
|---|---|
| M10 | 3.5 |
| M15 | |
| M20 | 4 |
| M25 | |
| M30 | 5 |
| M35 | |
| M40 | |
| M45 | |
| M50 | |

*Source: BIS, 2000-IS 456:2000, Table 8*

In Japan, prediction of TMS at 5% of allowable defectives as per Japanese Society of Civil Engineers (2010) as shown in Equation 2.3-7. The Target Mean Strength (Fm) is determined from the specified characteristic strength (Fc) and overdesign factor ($\alpha$). The coefficient of variation of 25% is recommended in situation where there is no available historical data and later deduces the actual coefficient after carrying out the tests. The over design factor ($\alpha$) is obtained from Figure 2.3-1 (JSCE, 2010).

$$Fm = Fc \times \alpha$$ ...Equation 2.3-7

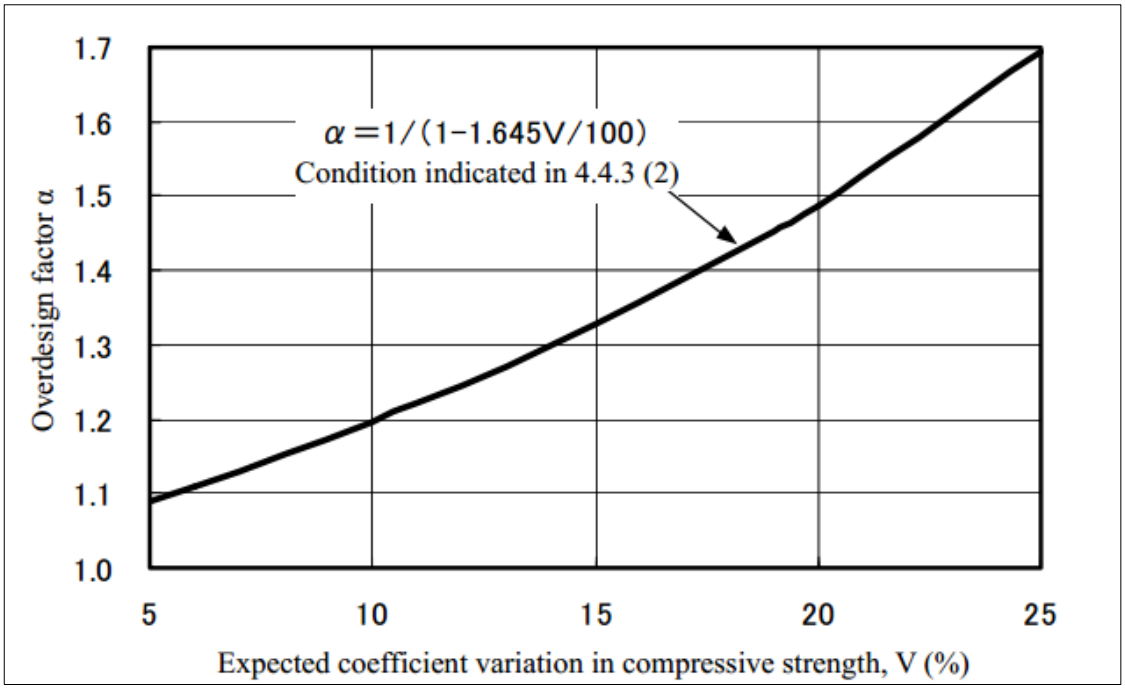



***Figure 2.3-1: Over design factor***

*(Source: JSCE, 2010- Guidelines for Concrete No.16, Fig C4.4.4)*

In New Zealand, Target Mean Strength from plant concrete production is obtained from Table 2.3-3 extracted from paper titled "The New Zealand Guide to Concrete Construction" published by the Cement & Concrete Association of New Zealand.

***Table 2.3-3: Evaluation Criteria for Plants Opting for not Less than 10 tests per Month***

| Specified Strength $f'_c$ MPa | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Grade MPa | 17.5 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| Max. C of V% | 12.5 | 11.5 | 11 | 10.5 | 10 | 9.5 | 9 | 8.5 |
| Min. Target Mean Strength Mix MPa | 22 | 24.5 | 30.5 | 36 | 42 | 47 | 53 | 58 |
| **Cautionary limit to be equaled or exceeded by the mean of any consecutive group of 6 Results (b)** | | | | | | | | |
| MPa | 20 | 22.5 | 28.5 | 34.5 | 39.5 | 44 | 50 | 55 |
| **Cautionary limit to be equaled or exceeded by the mean of any consecutive group of 30 Results (c)** | | | | | | | | |
| MPa | 21.5 | 24 | 29.5 | 35 | 40.5 | 46 | 51.5 | 56.5 |
| **Rejection Limit (a) Individual Result** | | | | | | | | |
| Rep. Sample MPa | 15 | 17 | 21.5 | 26.5 | 31.5 | 36.5 | 41.5 | 46.5 |
| Snatch Sample Size | 14 | 16 | 20.5 | 25.5 | 30.5 | 35.5 | 40.5 | 45.5 |

*(Source:* Cement & Concrete Association of New Zealand, 2010*: NZS, 3104)*

## 2.4 Concept of Optimal Concrete Mix Design

Most of concrete mix design processes are based on aggregate packing theory and/or excess paste/water layer theories (Ghasemi, 2017). Proportioning between the coarse and fine aggregates in optimal mix design require the dense proportions of the mixtures. Therefore, from the principle of aggregate packing theory, gradation of fine and coarse aggregate is of great concern in this regard (Mohammed et al, 2012). Fuller and Thompson (1907) suggested empirical formula illustrated in Equation 2.4-1 for calculating percentage of fine aggregate that would achieve maximum density when combined with coarse aggregates.

$$Percentage\ of\ Finer\ = 100 \times (\frac{d}{D})^{0.5} \qquad \textit{...Equation 2.4-1}$$

$where$:

$d = diameter\ of\ the\ current\ sieve\ and$

$D = Maximum\ size\ of\ \ aggregates$

The excess paste layer theory firstly suggested by Kennedy (1940) and later developed by other researchers, suggests that after the cement paste in mix design fills in the void spaces, excess of it surrounding the aggregate surface area is utilized for workability

requirement. Combining the packing and excess paste theories, optimal mix deign can be attained in the sense that the packing theory would allow for maximum density and leaving minimal void spaces that would in turn be filled in with cement paste and excess for workability from the excess cement paste theory (Ghasemi, 2017; Mohammed. et. al, 2012).

Concrete mix design is aimed at balancing between economy and requirements for workability, strength, durability and density (Al-Zuhairi, 2017). The minimal usage of cement paste strives to achieve the economy as well as reduce on the shrinkage and creep in concrete mix design. The desired strength and durability aspect are achieved through control of water cement ratio and obtaining most possible dense concrete. The lower the water-cement ratio is, the higher the strength and durability but less workability (Mohammed et.al, 2012). From extensive laboratory works, Abram (1919) developed the empirical relationship between compressive strength and water-cement ratio, Equation 2.4-2, however the challenges with the formula are on determining the appropriate coefficient for the particular material (Al-Attar et al., 2003).

$$Qc = \frac{A}{B^{(w \div c)}} \qquad \textit{...Equation 2.4-2}$$

$where$

$Qc = Compressive\ strength\ based\ on\ cylinder\ tests\ of\ 150mm\ by\ 300mm$

$A = Empirical\ constant\ \ depending\ on\ cement\ properties$

$B = Constant\ depending\ on\ cement\ properties$

$\frac{w}{c} = \frac{water}{cement}\ ratio, by\ volume$

Figure 2.4-3 shows the established relationship between compressive strength and water-cement ratio from Abram's experimental results.

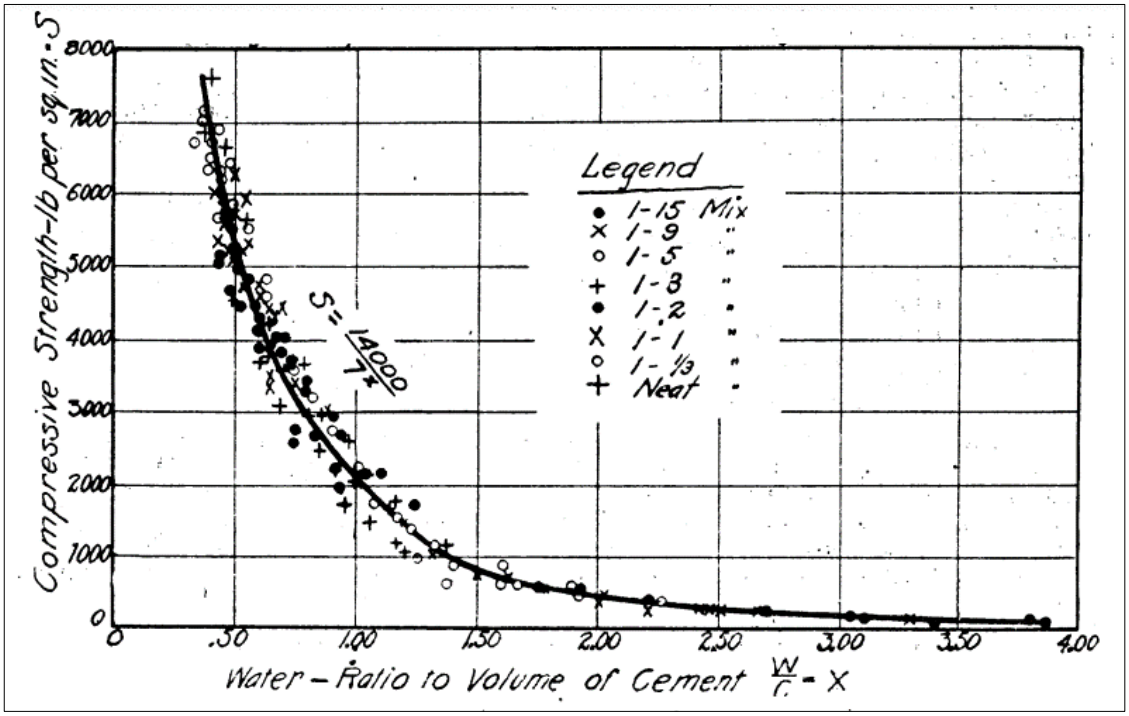



***Figure 2.4-1: Relationship between Compressive Strength and Water-Cement ratio***

*(Source: Abram, 1919)*

The unknown parameters A and B in Equation 2.4-2 established to be 14000 and 7, respectively from Abram's experimental results as shown in Figure 2.4-1. Hence, Equation 2.4-2 is rewritten as Equation 2.4-3.

$$Qc = \frac{14000}{7^{(\frac{W}{C})}} \qquad \text{...Equation 2.4-3}$$

## 2.5 Proportioning of Concrete Mixes

Proportioning of concrete mixes with use of local materials can primarily be achieved in two ways. It can either be done from existing statistical data of the same material mixes, proportions and concreting condition or by laboratory trial mixtures in situations where there are no existing or insufficient records (Kett, 2010).

### 2.5.1 Laboratory Trial Mixes Approach

The trial mixes proportioning is applied in situations where there are no available or insufficient past record data of concrete mix design. This method as the name states, there are based on trial to achieve the desired slump with predetermined water-cement ratios, strength results at 28-day curing and maximum coarse aggregate sizes, (Kett, 2010). The number of three trial batch mixes with varying slump of ±20mm and entrained air of within ±0.5% can be used. The mix proportions are obtained by field experience or guided either by arbitrary or minimum void ratio or fineness modulus or surface area of aggregate methods (Kosmatka et al, 2003).

### 2.5.2 Field Method-Past Record Statistical Data

This method is the quickest and with no cost if the, readily available statistical past record data is free. However, there are conditions to be met if the available data is to be accepted. According to the ACI 214R-11 report, conformity criteria, the available past record statistical data should be of the same type of material mixes for which strength test data and standard deviations were obtained. The record data should also represent at least 30 consecutive tests of which each test is a representative of average of at least two samples of the same proportion. The ACI 214R-11 report provides for adjustment of the standard deviation if only the available consecutive test record data is less than 30 but more than 14. This is done by multiplying the standard deviation (S.D) with appropriate modification factors. For tests numbers equal or greater than 30, 25, 20 and 15, the S.D. values are multiplied with modification factors of 1.00, 1.03, 1.08 and 1.16, respectively. If the consecutive tests are less than 15, the method of trial mix is recommended, as non-existence of sufficient available record of past data would be assumed. To apply this method, caution should be taken to ensure that the desired characteristic strength should be within the 7MPa in comparison with the historical record of the same characteristic strength. (Kosmatka et.al, 2003)

## 2.6 Concrete Mix Design Methods for Normal Concrete

The various methods of concrete mix designs include absolute volume, minimum voids, Arbitrary, Fineness Modulus, Maximum Density, Specific Surface area, Indian Road Congress, ACI committee, BS-DOE, Indian recommended standard method and Rapid mix design methods. However, some methods have drawbacks in achieving the desired proportions, (Shetty, 2007).

### 2.6.1 Absolute Volume Method

The popular models of concrete mix design i.e. ACI, DOE and BIS are based on the absolute method. In this method, the proportions of ingredients are obtained as absolute volumes mixed in fixed volume of $1m^3$. The absolute volume of a granular material is the volume occupied by the solid matter, i.e. excluding voids between the particles (Kosmatka et.al, 2003). This implies that, the absolute volume sum of ingredients excluding absorbed water in aggregates is equal to density of fresh concrete.

The water and cement contents are obtained with reference to specified minimum cement content and water-cement ratios specified in the code practices for particular concrete grades. To obtain the absolute volume, the cement and water mass contents are divided by their particle densities. The absolute volume of coarse aggregate in a $1m^3$ volume is obtained by dividing bulk density of coarse aggregate by the material particle density. The bulk volume of fine aggregates is obtained by subtracting the sum volume of cement, water and coarse aggregate from $1m^3$. To effectively apply this method, it is required that aggregates are well graded as confirmed by sieve analysis (Kosmatka et.al, 2003).

### 2.6.2 Arbitrary Method

The proportioning of the constituents under this method is based on nominal volume ratios. The method is prone to yielding great variation in concrete strength owing to its

non-consideration of constituent material properties. Arbitrary method is used for low grades of concrete. i.e. M20 or lower (BIS, 2000).

### 2.6.3 Fineness Modulus Method

The fineness modulus is an index number that describes the relative size of the coarse and fine aggregates. It is determined by dividing the cumulative percentage sum of retained aggregate masses on the different sieves during sieve analysis by 100, (Abrams, 1919). The method is achieved by first determining the fineness modulus of coarse aggregate, fine aggregate and then combined fineness modulus of the coarse and fine aggregates. The sieves sizes used for the coarse aggregates are 80mm, 40mm, 20mm and 4.75mm whilst for fine aggregates are 1mm, 600µmm, 300 µmm, 212 µmm, 150 µmm and 75 µmm.The percentage composition of the fine aggregate is determined by Equation 2.6-1.

$$Fine\ Aggregate\ (\%) = \left(\frac{Pc-Pcf}{Pcf-Pf}\right) \times 100 \qquad \textit{...Equation 2.6-1}$$

$where$:

$Pcf = Fineness\ Modulus\ of\ combined\ coarse\ and\ fine\ aggregate$

$Pc = Fineness\ Modulus\ of\ coarse\ aggregates, and$

$Pf = Finenes\ \ Modulus\ of\ fine\ aggregates$

For the strength relating to water-cement ratio are obtained by making use of formula developed by Abram (1919) shown in Equation 2.4-3. The desired workability is achieved by using Equation 2.6-2 when determining the quantity of water required in mixing concrete developed by Abram (1919).

$$X = R[\frac{3}{2}P + \left(\frac{0.3}{1.26^m} + a - c\right)n] \qquad \textit{...Equation 2.6-2}$$

$where$:

$X = Water - cment\ ratio\ by\ volume$

$R = Relative\ consistency\ (workability\ factor),$

$$If\ \ R = 1, concrete\ is\ said\ to\ be\ of\ normal\ consistency$$

$P = Normal\ Consistency\ of\ cement\ by\ weight\ (assume\ P = 0.23)$

$m = Fineness\ Modulus\ of\ aggregate$

$n = Volume\ of\ mixed\ aggregate\ to\ one\ volume\ of\ cement$

$a = Absorption\ of\ aggregate, ratio\ water\ absorbed\ to\ volume\ of\ aggregate$

$c = moisture\ in\ aggregate, ratio\ of\ water\ contained\ to\ volume\ of\ aggregate$

### 2.6.4 Minimum Void Method

This method works on the principle that the fine aggregates quality used in the mix design should fill the voids left in between the coarse aggregate. The method also assumes that the voids left between the fine aggregates would in turn be filled in by the cement quantity so as to produce a dense concrete material with minimal voids. Practically, the quantity of the fine aggregate is taken to be approximately 10% above total voids in coarse aggregate. The cement content is also taken to be approximately 15% above the voids in the fine aggregates. The quantity of water added in this method would depend on the desired workability. This method may have some drawbacks in achieving the desired strength due to non-specification of fixed water/cement ratio and gradation of aggregates (Raj et al., 2014).

### 2.6.5 Maximum Packing Density Method

The method is used in the proportioning of fine and coarse aggregates. In this method, various formulations of course to fine aggregate fractions are prepared. The proportions of the two are done in definite proportions by weight such as 90:10, 80:20 70:30 and 60:40. The bulk density of each of the mixture is determined by means of weighing the mixture in a known volume. The graph is then plotted of bulk density against the mixing fractions. The optimal proportions of fine and coarse aggregates are achieved by taking note of the fraction that yields maximum bulk density, i.e. peak bulk density value from graph plotted. The proportion that gives the densest is adopted as the proportion to be used in the mix design (Kore and Vyas, 2017).

### 2.6.6 Surface Area Method

This method is based on established relationship between the coarse aggregate specific area and water requirement for desired workability. The theory behind is that the film of water added to concrete mix firstly surrounds the fine cement during hydration to form cement paste that in turn covers the fine aggregate to form mortar. The formed mortar is tangential to the surfaces area of the coarse aggregate to form the workability of entire fresh concrete. The cement content is obtained from the water-cement ratio to strength relation using the established water content relating to SSA (Rahma, 2013). It is suggested that the optimum compressive strength is achieved between 22 and 26 $cm^2/gm$. The higher the cement is in the mix, the lower the optimum specific surface area (Helmy, 1998).

### 2.6.7 ACI Method

The American Concrete Institute mix design method was first published in 1944 (Shetty, 2007). The method has undergone various revisions to include modification. Application of this method require first to obtain the data of fine modulus of fine aggregates, dry rodded volume of coarse aggregate, specific gravity of cement, absorption characteristic of coarse aggregate and SSD of fine aggregates. The water/cement ratio in relation to desired strength, water content, and slump are obtained from provided tables in the code of practice. The proportions of the mixes are obtained by absolute method (ACI, 2011).

### 2.6.8 Rapid Method

This method is outlined in the Indian standard IS: 9013-1978. The rapid method makes use of an established chart of correlations between the accelerated cured concrete at 3 days using boiling water and the concrete strength attained at 28 days of curing. To apply this method, trial mixes are cured at 3 days and their strength at 28 days is obtained from

the graph of correlation. This method is applicable for all types of cement in India as the development of the relationship took care of all types of cement by then (Shetty, 2007).

### 2.6.9 British, DOE Method

The BS-(DOE) method was developed by The Building Research Establishment of Department of Environment (DOE) U.K in 1975, revised in 1988 and republished in 1997 and 2010 (BRE, 2010). The method had replaced the Road Note No. 4, which was popularly used up to 1970. The method is based on absolute volume method. The initial required information for proportioning the mixes are: desired (characteristic) strength, Target Mean Strength, size of coarse aggregates, type of cement, relative density of coarse aggregate based on saturated and surface dry condition (SSD), percentage of fine aggregates passing through the 600μm test sieve, type of aggregates (crushed or uncrushed) and desired range of slump. The small percentage of entrapped air is ignored in this method. From this information, the proportions of the mix design are obtained from Standard tables and charts as outlined in the code of practice (BRE, 2010).

### 2.6.10 Indian Recommended Method

The Indian Standard Recommended method of concrete mix design is based on the Indian National Laboratory works. The method is applicable for both medium and high strength concrete. The minimum cement content and water-cement ratio for respective concrete Grades are obtained from table tabulated in the Indian code of practice. The total aggregate content is calculated by absolute volume method. The percentage of fine aggregates are selected from the table in the code indicating Zone categories dependent on the grading curve obtained by sieve analysis of the fine aggregate (BIS, 2019).

## 2.7 Positive Strides to Overcome Challenges in Concrete Mix Design

Abram, (1919), established relationship between compressive strength and water-cement ratio. This Abram's rule has been the basis for today's models of concrete mix designs,

(Al-Attar et al., 2003). Despite establishing relationships of strength against water-cement ratios in modern concrete mix designs, variation in strength may occur even for the same water-cement ratio (Newman & Choo, 2003).

The aggregate particle shape and surface texture are some of the two characteristic of aggregates particles that affects the properties of concrete. The particle shape affects the workability whilst surface texture mainly affects the bond between the matrix and aggregate particles (BRE, 2010). The different cement types and different aggregates sizes as well as other aggregate characteristics may produce concrete of different compressive strength even though the same free water-cement ratio is used (BIS, 2019). It is worth noting that, from the many properties of aggregates that influence either plastic or hardened properties of concrete, it is difficult to point to any of these properties that could be directly responsible for the changes in performance of concrete in plastic or hardened state (Day et al., 2014).

Therefore, it is challenging to predict the magnitude of change in concrete performance especially for a wide range of aggregates and mix designs (Day et al., 2014). Thus, it is recommended to establish the relationship between compressive strength and water-cement ratio for the actual materials to be used (BIS, 2019).

Arising from the complexity of the prediction, some scholars have sought for machine learning methods. Ziolkowski and Niedostatkiewicz (2019) in their study focused on machine learning application in concrete mix design. It was revealed in the study that the method employed allowed for checking composition mix ingredients to achieve the desired class. However, it was noted that the mathematical expression presented was not adequate to reflect the relationships between the constituents and their boundary conditions.

Therefore, predicting strength of concrete from new mixing material can be challenging (DE Rousseau, et al, 2019). However, Statistical prediction models are effective, provided large samples are used for the same material source and care is taken note for generalization (Osborne, 2000).

It is thus from above that some of today's popular models of concrete mix design worldwide such as BS-DOE, ACI and Indian Recommended Method, emphasize the need for experimental trial mixes for new materials. These methods are based on absolute volume method of proportioning (BRE, 2010; ACI, 2011; BIS, 2019). In order to address these challenges, compressive strength is normally specified in terms of characteristic strength value below which a minimum proportion of 5% is permitted to occur (Newman & Choo, 2003). For mix designs purposes, the relationship between strength and water-cement ratio is based on Target Mean Strength for any given specified strength (Newman & Choo, 2003). This provides for quality control in concrete mix designs by taking care of the properties of mix materials that causes variations in strength but cannot be accurately measured (BRE, 2010).

## 2.8 Summary

From the literature reviewed, it was revealed that concrete strength follows a normal distribution pattern. The Target Mean Strength is predicted by either use of a margin or overdesign factor. The margin is determined from standard deviation whilst the overdesign factor is from coefficient of variation of the concrete strength data. In both approaches, the prediction levels are commonly set at five percent probabilities of allowable defective. The minimum sample size of strength data ranging between 20 and 30 is acceptable as per various codes of practice reviewed. The margins applied in various parts of the world range between 6.0 and 14.0 whilst the overdesign factor range between 1.0 and 1.7.

The prediction of Target Mean Strength goes hand in hand with concrete mix design. The models of concrete mix designs do not only allow for an optimal design but also allow for strength prediction at particular significance level. Some of these reviewed models of concrete mix design included the BS-DOE, ACI and Indian Recommended methods. These provides with them the various standard deviations for predicting Target Mean Strength for various respective concrete classes. These methods are based on absolute volume method for proportioning the mixes. They utilize existence of empirical

relationship between strength and water-cement ratio for predicting Target Mean Strength of concrete mixes. The existence of such a relationship was firstly proved by Abram (1919). The aggregate properties such as size, texture, shape, strength, densities and grading may affect strength of concrete. Therefore, aggregates for concrete required to meet specific standards. The water and cement contents do not only affect strength but also workability of the fresh concrete.

# CHAPTER 3: METHODOLOGY

## 3.1 Introduction

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 was to review literature with a view to identifying concrete mix design models and prediction criteria's for TMS employed worldwide. Thereafter, the information obtained from literature review was used as basis for the following:

- The secondary data collected through interviews by means of questionnaire,
- The primary data collected through laboratory experiments and
- The data analysis employed to establish margins for prediction Target Mean Strength of concrete mixes using local materials

## 3.2 Secondary Data Collected

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. The minimum single sample size was targeted from a target group institution that deal with concrete mix designs meant for various clients in the Zambian construction industry. The single sample size 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 issued to some targeted institutions. Out of the six issued questionnaires, only two responses were obtained and the same two did not agree to provide the data that can be used to verify information provided. This poor response to interview questionnaire could have been due to potential respondents regarding their concrete mix design information to be confidential for their business. The target group were unwilling to respond to the questioning, as they would have regarded concrete mix

design information as confidential for their business. This made it difficult to validate the predicting values provided by the two respondents in 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. BS-DOE model was identified based on availability of concrete testing equipment at University of Zambia Civil Engineering Laboratory. The sample questionnaire is attached in appendix A

### 3.3 Primary Data Collected

The BS-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 (BRE, 2010). For the Indian Recommended Method of concrete mix design as per IS: 456:2000, recommends a minimum of 30 consecutive strength results for calculating standard deviation to predict Target Mean Strength. Therefore, in this study, the minimum sample size of 30 of consecutive cube strength results for each of the concrete classes, i.e. C30, C25 and C20 were used. The concrete strength results were obtained through laboratory experiments carried out at the University of Zambia Civil Engineering laboratory.

The steps undertaken to obtain primary data of concrete cube strength results were as follows:

i. Sourcing and delivery of mix materials to the Laboratory
ii. Laboratory experiments of aggregate testing,
iii. Concrete mix design for at least 30 mixes for each of the concrete class of C20, C25 and C30 using BS-DOE method,
iv. Making of concrete cubes and slump testing for each mix,
v. Curing of the cubes at age of 28 days and
vi. Strength testing of cubes by crushing

### 3.3.1 Sourced Materials for the Experiments

The material quantities bought and their sources for the experiments were as follows:

- Sixteen (16) bags of 50kg Ordinary Portland cement strength class of 42.5R manufactured by Lafarge Zambia were bought from the local market,
- Two (2) tones of crushed 20mm coarse aggregates were bought from Oriental Quarries produced by Scirocco Enterprise located in Makeni Lusaka district,
- Two tones (2) of crushed fine aggregates were bought from United Quarries Limited Company located in the Eastern part of Lusaka district and
- Tap water in laboratory pumped from boreholes was used in the mixes.

### 3.3.2 Aggregate Tests

Prior to undertaking the proportioning of the mixes, experimental tests of the aggregates were conducted in order to check whether the properties of the aggregates bought were within the required standards for concrete mix. The other reason for aggregate testing was to determine properties such as relative density based on saturated surface dry condition and percentage of fine aggregates passing through 600μm sieve which was used in the concrete mix design. The tests conducted included: Aggregate Crushing Value (ACV), Elongation Index (E.I), Flakiness Index (F.I.), particle size distribution through sieve analysis, compacted bulk density and relative density based on Saturated Surface Dry condition.

#### *3.3.2.1 Particle Size Distribution of Aggregates*

The objective of the analysis was to ascertain the particle size distribution of the aggregates and fillers with a view to ensuring that the aggregate grading was within acceptable standards. The dry sieving of the aggregates was performed in accordance with BS 812.

#### *3.3.2.2 Elongation Index (EI) and Flakiness Index (FI)*

Aggregate particles are classified elongated when they have length dimension of more than 1.8 of their mean sieve sizes. For flakiness, aggregate particles are classified flaky

when they have thickness dimension of less than 0.6 of their mean sieve sizes according to BS 812. The elongation and flakiness test help to prevent use of elongated (long) and flaky (flat) coarse aggregates in the mix design mix. If the major constituency of the aggregate are long and or flat, means that they can easily break and there will be difficulties in mixing them with the binder (Newman & Choo, 2003). Not only this but there would also be increased void spaces in the mix as compared to the round and angular aggregates.

Therefore, the objectives of the experiment were to determine the elongation and flakiness index in order to ascertain suitability of the aggregates for use in concrete with reference to BS 812 standards.

#### *3.3.2.3 Bulk Density of the aggregates*

The bulk density is the mass of the granular material per unit volume. When a tempered rod is used in placing the aggregates in a known volume for bulk density determination, the resulting density is referred as compacted bulk density (Newman & Choo, 2003). The test procedure was done in accordance with BS 812 standards.

#### *3.3.2.4 Relative Density of Aggregates and Water Absorption*

The relative density on a saturated surface dry basis is one of the properties of the aggregates used in concrete mix design (BRE, 2010). The water absorption tests were conducted with a view to comparing with standard limits of aggregate absorptions for concrete mix design. Therefore, the objective of the experiment was to determine the relative density and water absorption of the aggregates for the concrete mix design in line with BS 812 standards.

#### *3.3.2.5 Aggregate Crushing Value (ACV)*

The strength of coarse aggregates is normally measured by Aggregate Crushing Test. The Aggregate Crushing Value (ACV) is a relative measure of the resistance of an aggregate to crushing under a gradually applied load. It is determined by measuring the material passing a specified sieve after crushing under a load of 400 KN. The test is

applicable to a standard fraction aggregates passing a 14mm sieve and retained on a 10mm sieve and using a separating sieve of 2.36mm as per BS 812 standards.

Therefore, the objective of the experiment was to determine the aggregate crushing value so as to assess the suitability by strength of the aggregate if to be used for concrete. The ACV test procedure was conducted in accordance with BS 812:1990.

### 3.3.3 Concrete Mix Design-BS DOE method

Based on the respondents from the administered questionnaires, it was reviewed that the BS-DOE method of concrete mix design was one of the methods that is applied in the Zambian construction industry. Therefore, this method was chosen to validate it with laboratory experiments for Target Mean Strength predictions using the local materials. The steps undertaken in the concrete mix design using this method were as outlined in the Building Research Establishment literature titled Design of Normal Concrete Mixes (BRE, 2010).

### 3.3.4 Concrete Cube Casting and Curing

After successful proportioning of the mixes using the DOE method of concrete mix design, the stage was followed by making the test cubes from fresh concrete. The cubes were made with reference procedure outlined in BS 1881:1983.

### 3.3.5 Slump Testing

The objective of slump test was to determine the workability of the concrete. The slump test was measured by filling fresh concrete in a conical mold measuring 200mm base diameter, 100mm top diameter and 300mm height. The mold was then removed slowly and slump measured after removal of mold. The test procedure was in accordance with BS 1881: Part 102:1983.

### 3.3.6 Cube Curing

The procedure and standard followed for cube curing process was with reference to BS 1881: Part 108:1983.

### 3.3.7 Concrete Cube Strength Tests

This was the final test procedure undertaken to ascertain the compressive strength of the cured cubes at the age of 28 days. The strength results were then later analyzed to accomplish aim of the study. The tests procedure was done in accordance with BS 1881: Part 116:1983.

## 3.4 Data Analysis

The data analysis procedure to validate model involved statistical approach in obtaining the prediction parameters for TMS which included standard deviation and mean strength obtained from the Probability Density Function (PDF) at 5% significance level of the characteristic strength. The PDF distributions with their corresponding Cumulative Distribution Functions (CDF) were produced for each of the concrete strength class with an aid of Microsoft Excel application. The standard deviation and margin for predicting TMS of concrete mixes for each class was obtained using Equations 3.3-1 and 3.3-2, respectively.

$$Standard\ deviation = \frac{Target\ Mean\ Strength - Characteristic\ Strength}{1.64} \quad \textit{...Equation 3.4-1}$$

$$Margin = standard\ deviation \times 1.64 \quad \textit{...Equation 3.4-2}$$

## 3.5 Summary

The interview questionnaire was used to identify concrete mix design model applied locally. The identified model was validated for Target Mean Strength using primary data. Table 3.3-1 presents tests conducted and associated standards, to collect primary data. The flow chart in Figure 3-4-1 summarizes the Methodology of the study.

**Table 3.5-1: Laboratory Tests Conducted**

| S/N | Description of Test/Method | Standard Procedure/Reference Document |
|---|---|---|
| **1** | **Aggregate Testing** | |
| 1.1 | Sieve Analysis | BS 812-103: Part 1:1985 |
| 1.2 | Elongation Index (E.I) | BS 812-105 Part 2:1990 |
| 1.3 | Flakiness (F.I) | BS 812-105 Part 1:1989 |
| 1.4 | Relative Density/Water Absorptions | BS 812 Part 2:1995 |
| 1.5 | Bulk Density | BS 812 Part 2:1995 |
| 1.6 | Aggregate Crushing Value (ACV) | BS 812-110:1990 |
| **2** | **Concrete Mix Design** | |
| 2.1 | BS-DOE Method | BRE, 2010; BS 8500-1+A2:2019 |
| **3** | **Concrete Cube Making, Curing & Testing** | |
| 3.1 | Cube Making and Curing | BS 1881-108:1983; BS 1881-125:2013 |
| 3.2 | Slump testing | BS 1881-102:1983; BS 1881-125:2013 |
| 3.3 | Cube strength test | BS 1881-116:1983; BS 1881-125:2013 |

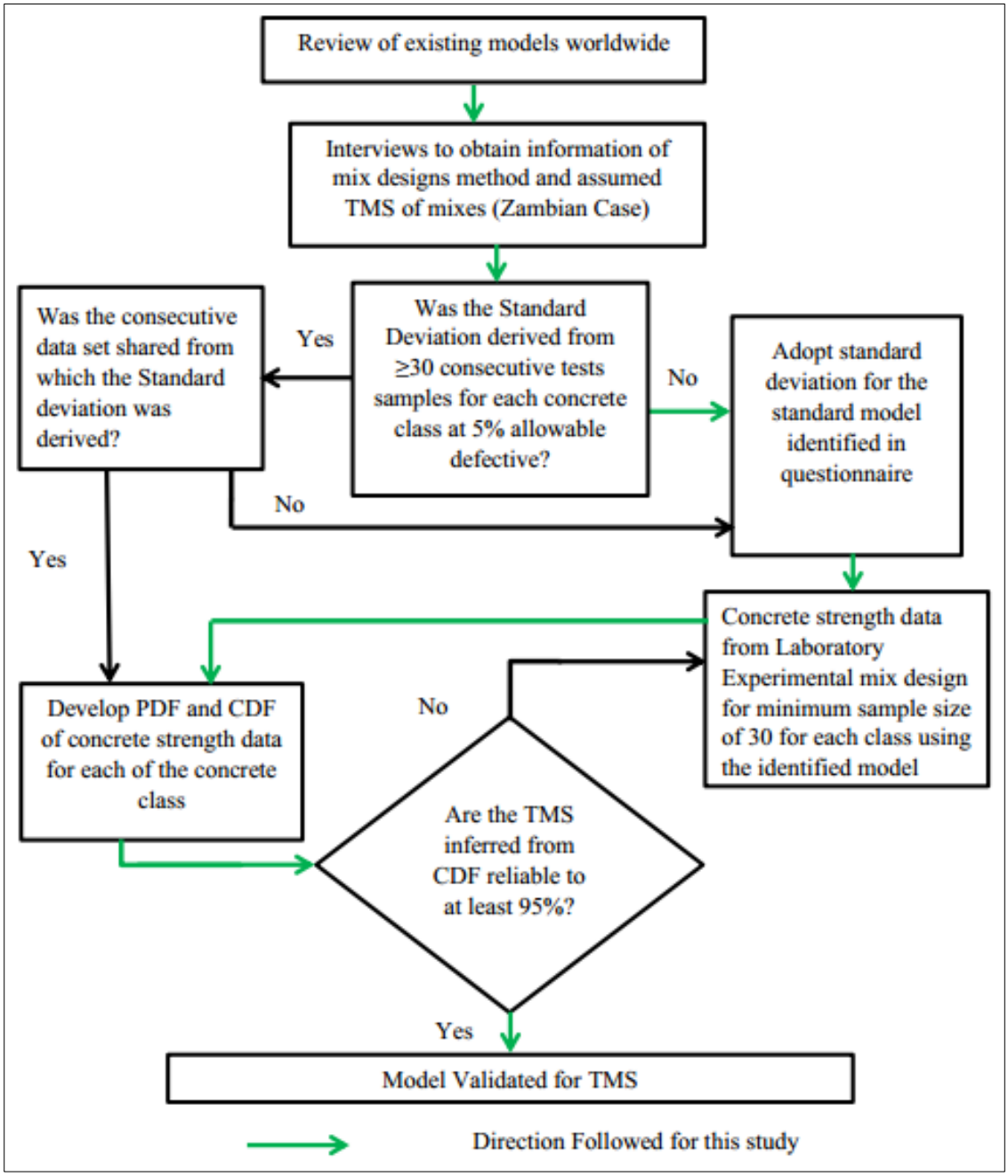



***Figure 3.5-1: Flow Chart for Establishing Adequate Margins for TMS***

# CHAPTER 4: RESULTS

## 4.1 Introduction

This chapter presents the results from interview questionnaires and laboratory experiments. The concrete strength data from laboratory experiment were analyzed to establish the appropriate predicting values for Target Mean Strength of concrete mixes. The procedure for data collection and analysis were as per reviewed literature of concrete mix design model adopted. This was in order to achieve the aim of the study, which was to establish an appropriate margin for predicting Target Mean Strength of concrete mixes based on Zambian local materials. Prediction values for Target Mean Strength were obtained from Probability Distribution Functions that were plotted from concrete strength results.

## 4.2 Concrete Mix Design Model Identification

The concrete design model validated for TMS in this study was identified based on testing equipment available aligned to British Standards, which Zambia had adopted, from independence and response from two interview questionnaires. The sample questionnaire used in the study is attached in Appendix A.

## 4.3 Laboratory Experimental Results for Model Validation

The data required to validate model were obtained from experimental concrete strength cube tests casted for each class of concrete. The required test results were not only for the cube strength but also the material tests of aggregates used for concrete mixing in order to ensure that the casted concrete cubes were made from standard materials and procedures. Therefore, the results presented include aggregate test results and Probability Distribution Functions produced from concrete strength test results for concrete classes C20, C25 and C30. The quality of water used for the mixes were assumed to be of good quality for concrete mixes as the same water was used as portable water for the University of Zambia. According to BS-EN 1008:2002, the quality of water

that meet standards of drinking water referred to as portable water needs no testing when used for concrete mixes.

### 4.3.1 Aggregate Tests Results

The aggregate tests results were compared with respective standards as indicated in *Tables 4.3-1* and *4.3-2* as well as *Figures 4.3-1* and *4.3-2*

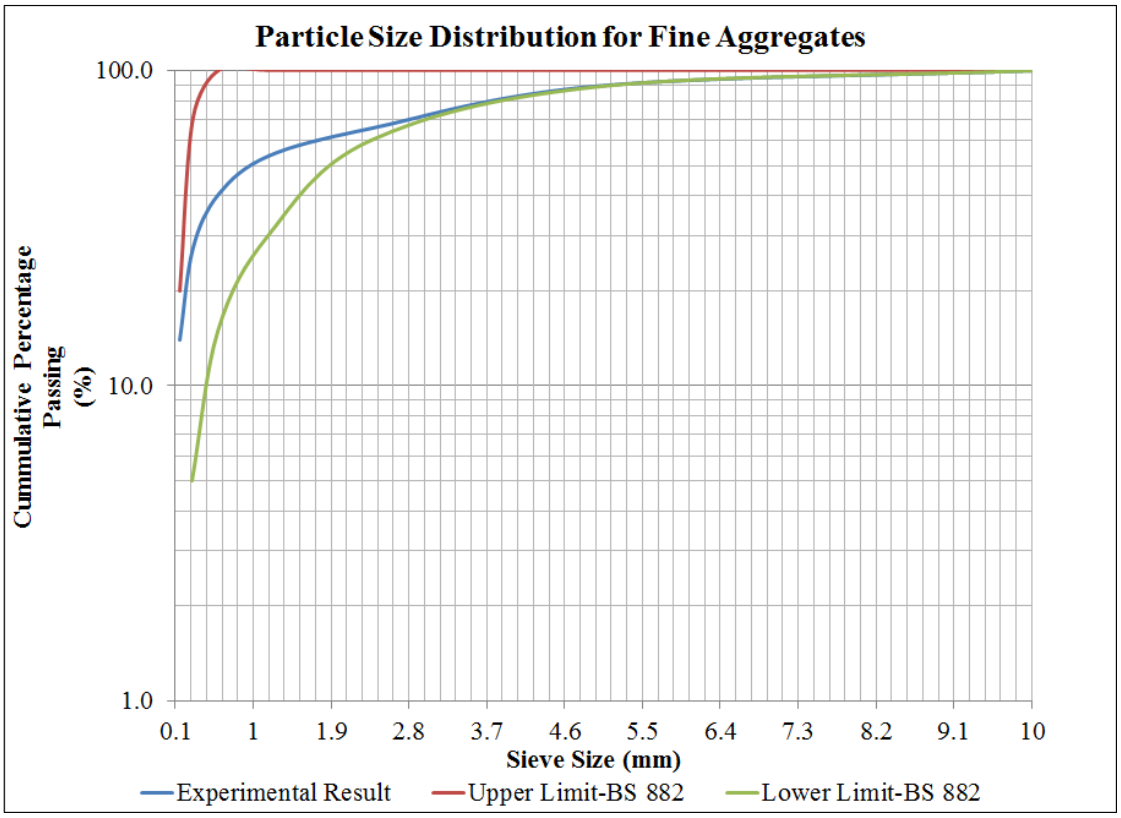



***Figure 4.3-1: Particle Size Distribution for Fine Aggregates***

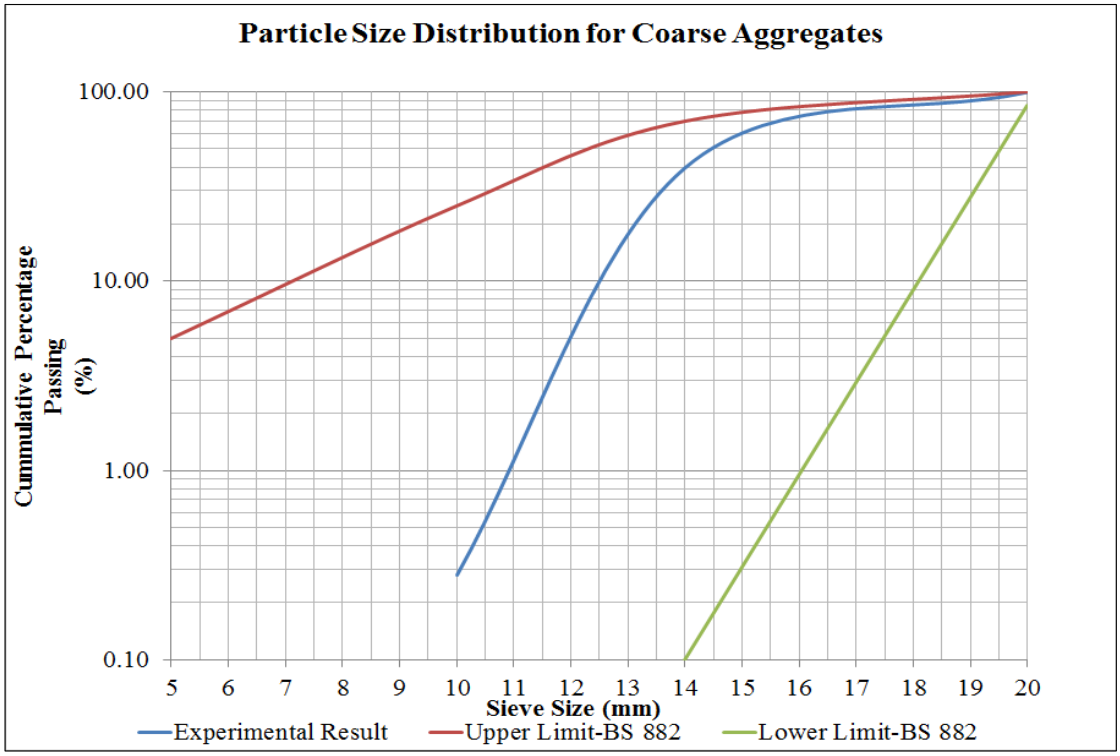



*Figure 4.3-2: Particle Size Distribution for Coarse Aggregates*

***Table 4.3-1: Summary of Coarse Aggregate Test Results***

| S/N | Test Conducted | Detailed Description | Parameter/Units | Limiting Range | Ref Standards/Document | Test 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, 2010 | 2.73 | Acceptable |
| 3 | Bulk Density | rodded | $Ton/m^3$ | 1.28 to 1.92 | ACI, 2011 | 1.627 | Acceptable |
| 4 | 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 4.3-2: Summary of Fine Aggregate Test Results***

| S/N | Test Conducted | Detailed Description | Parameter/Units | Limiting Range | Ref Standards | Test 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, 2010 | 2.620 | Acceptable |

The laboratory data for the aggregate test results from which Table 4.3-1 and 4.3-2 as well as figures, 4.3-1 and 4.3-2 were generated from the data attached in Appendices B to J.

### 4.3.2 Concrete Strength Results

Figures 4.3-3, 4.3-5 and 4.3-7 show the probability distributions for the concrete strength results as well as their Target Mean Strength employed for the concrete classes C20, C25 and C30 respectively. Figures 4.3-4, 4.3-6 and 4.3-8 show the Cumulative Density Function meant for obtaining the percentage probabilities for Figures 4.3-3, 4.3-5 and 4.3-7, respectively. The concrete compressive strength data used to produce these figures are attached in Appendix P.

#### *4.3.2.1 Concrete Strength Results for C20*

The concrete mix design was based on BS-DOE model. The first step during concrete mix design were to establish characteristic strengths for the required data set. For concrete class C20, the sample size was 35. From this set of characteristic strengths, the Target Mean Strengths were calculated using equation 2.2-1 with adopted standard deviation value of 4 and risk factor of 1.64, which represent 5% allowable defective. Therefore, the distribution for the resulting data set of Target Mean Strength were plotted as indicted in figure 4.3-3. The distribution of compressive strength resulting from the actual hardened concrete cubes at age of 28days were plotted as indicted in graph for actual in in figure 4.3-3. The target Mean Strength results for C20 were consistently higher than the actual strength owing to the possible differences between properties of local mix materials and those materials used in experiments to develop the BS-DOE. The corresponding probability values for the Target Mean Strength and actual strengths for C20 is presented in figure 4.3.4. From these graphs, it can be observed that the actual strength of 20MPa representing the class of concrete C20 were sitting at approximately 5% allowable defective whilst the Predicted Target Mean Strength value of 33.43MPa sitting at 50% probability.

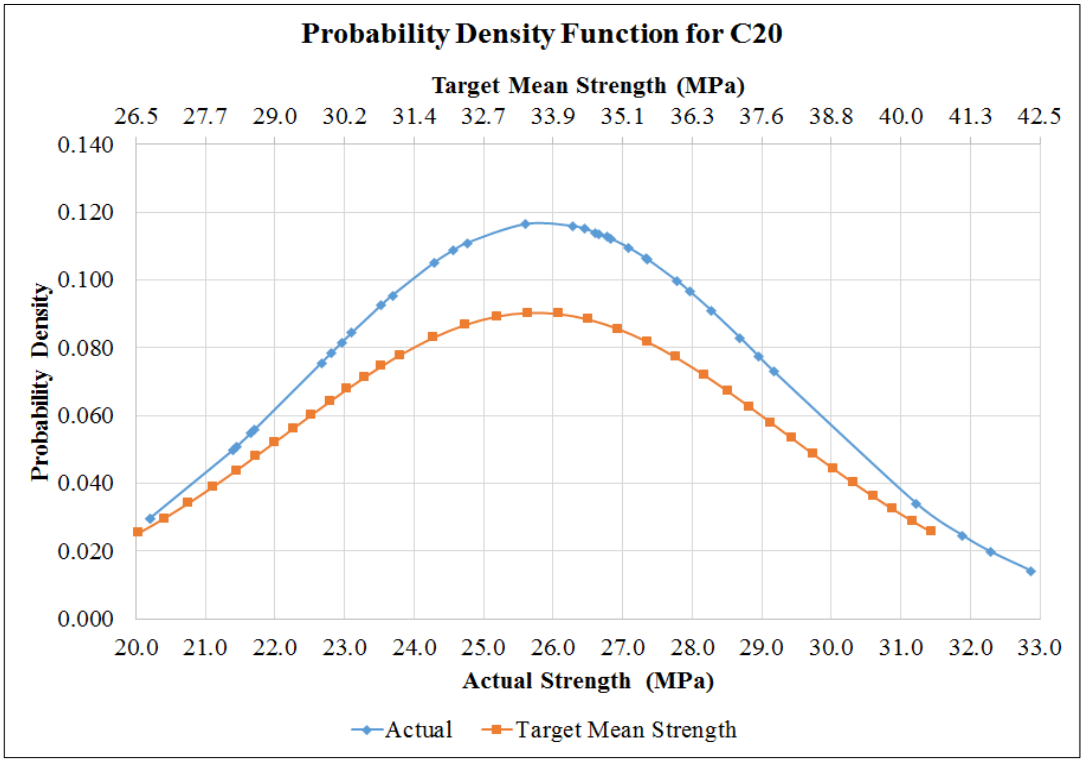



*Figure 4.3-3: Probability Density Function for Class C20*

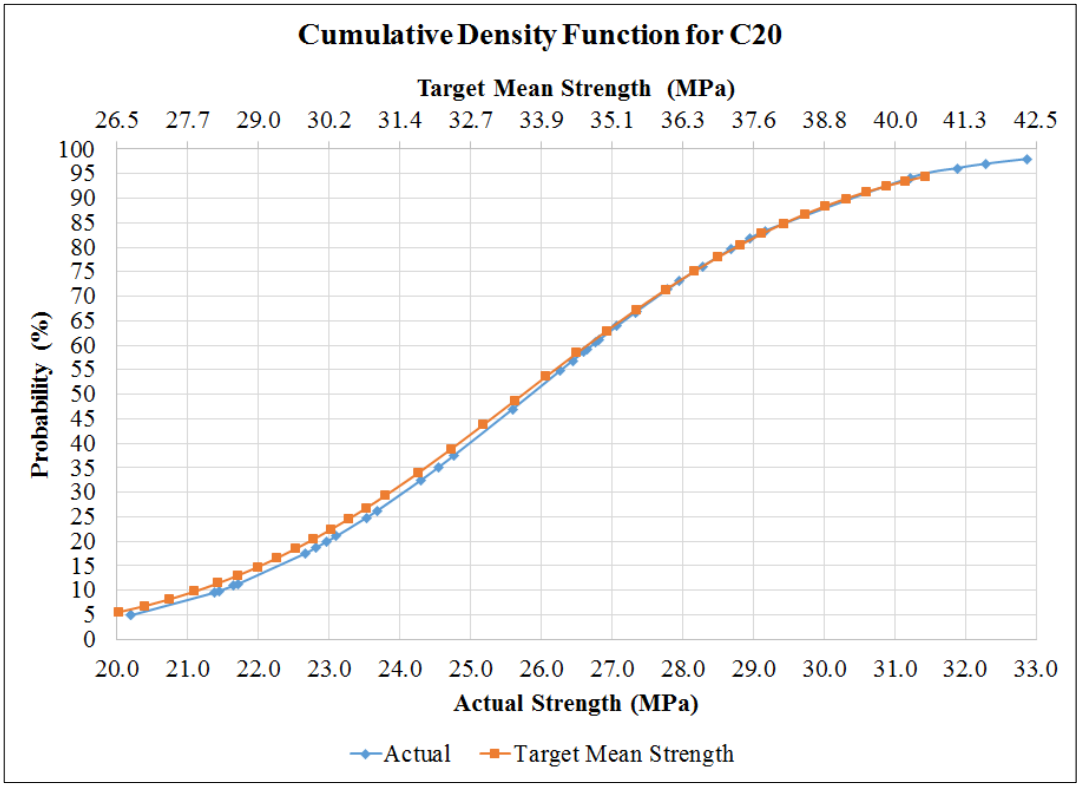



*Figure 4.3-4: Cumulative Density Function for Class C20*

### *4.3.2.2 Concrete Strength Results for C25*

Similarly, the data set for concrete class C25 were developed using the process outlined for concrete class C20. For concrete class C25, the data sample size was 35 and the distribution for the resulting data set of Target Mean Strength were plotted as indicted in figure 4.3-5. The distribution of compressive strength resulting from the actual hardened concrete cubes at age of 28days were plotted as indicted in graph for actual in in figure 4.3-5. The target Mean Strength results for C25 were consistently higher than the actual strength owing to the possible differences between properties of local mix materials and those materials used in experiments to develop the BS-DOE. The corresponding probability values for the Target Mean Strength and actual strengths for C25 is presented in figure 4.3.6. From these graphs, it can be observed that the actual strength of 25MPa representing the class of concrete C25 were sitting at approximately 5% allowable defective whilst the Predicted Target Mean Strength sitting at 50% probability was 38.1MPa.

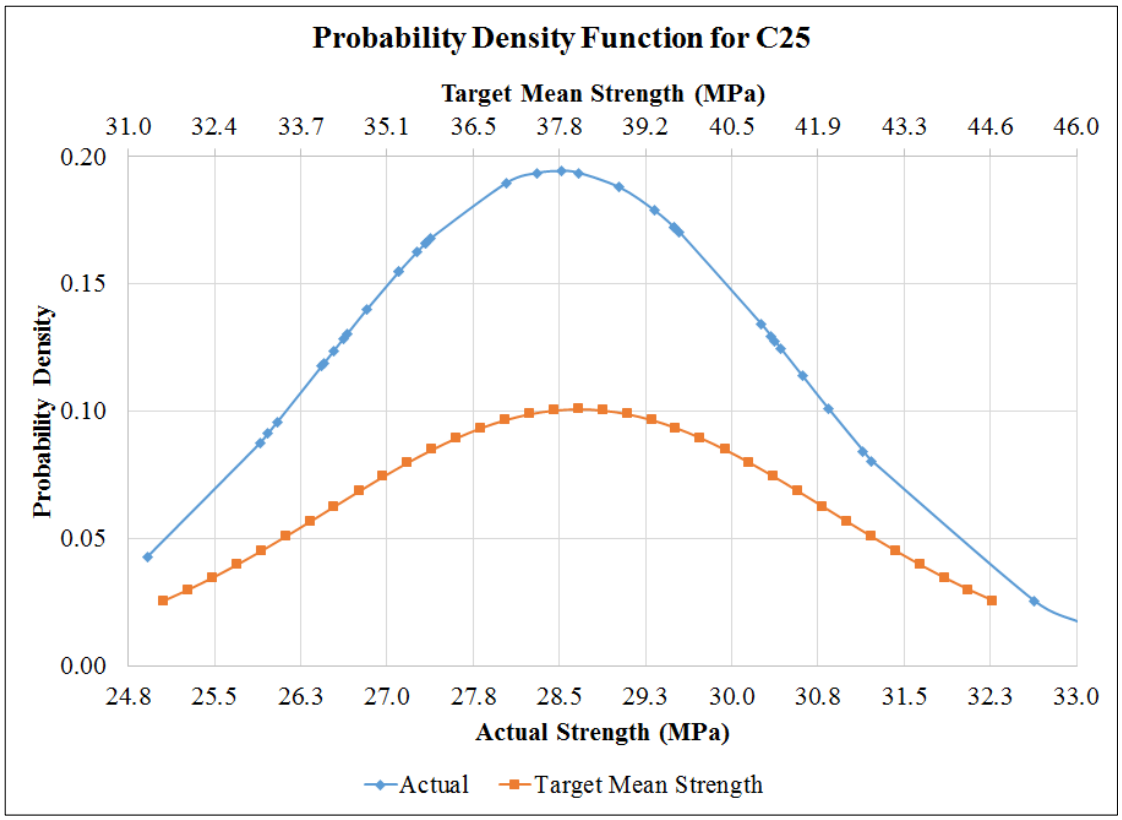



***Figure 4.3-5: Probability Density Function for Class C25***

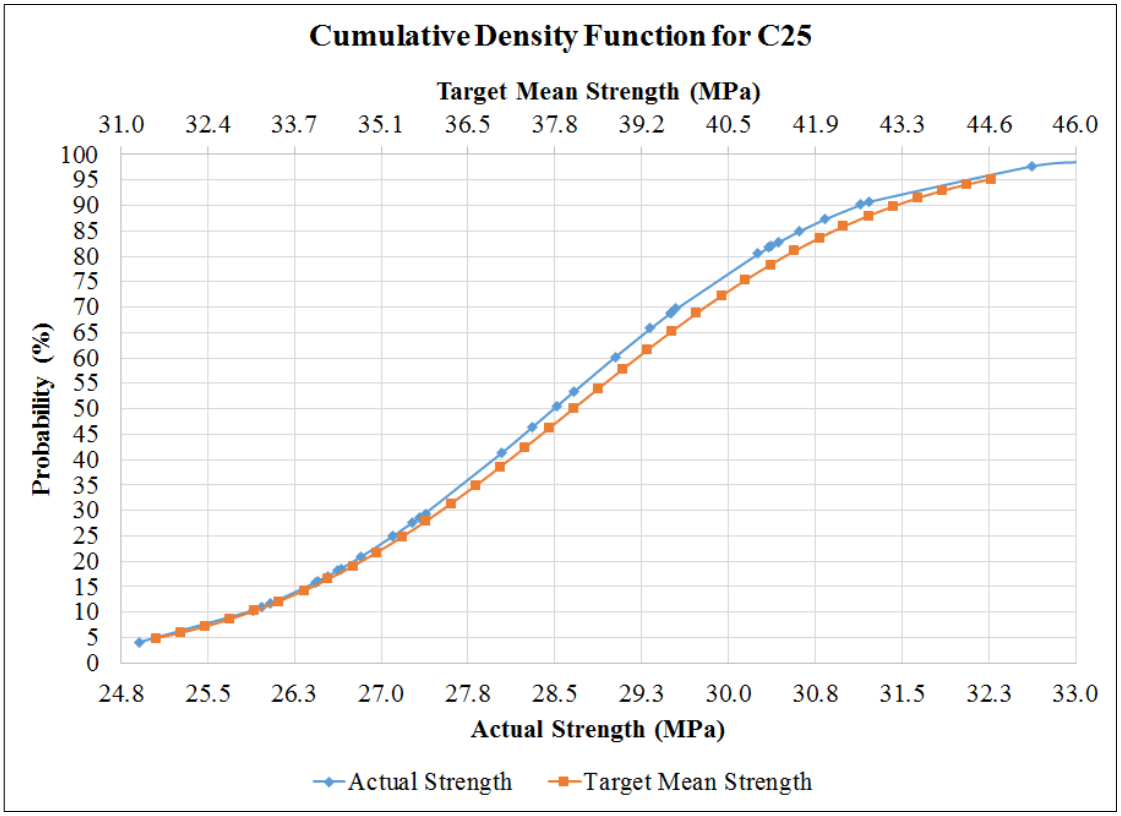



***Figure 4.3-6: Cumulative Density Function for Class C25***

#### *4.3.2.3 Concrete Strength Results for C30*

Similarly, the data set for concrete class C30 were developed using the process outlined for concrete class C20. For concrete class C30, the sample size was 31 and the distribution of Target Mean Strength results were plotted as indicted in figure 4.3-7. The distribution of compressive strength results for the actual hardened concrete cubes at age of 28days were plotted as indicted in graph for actuals in figure 4.3-7. The target Mean Strength results for C30 were consistently higher than the actual strength owing to the possible differences between properties of local mix materials and those materials used in experiments to develop the BS-DOE. The corresponding probability values for the Target Mean Strength and actual strengths for C30 is presented in figure 4.3.8. From these graphs, it can be observed that the actual strength of 30MPa representing the class of concrete C30 was at approximately 5% allowable defective whilst the Predicted Target Mean Strength was at 50% probability was 43.6MPa.

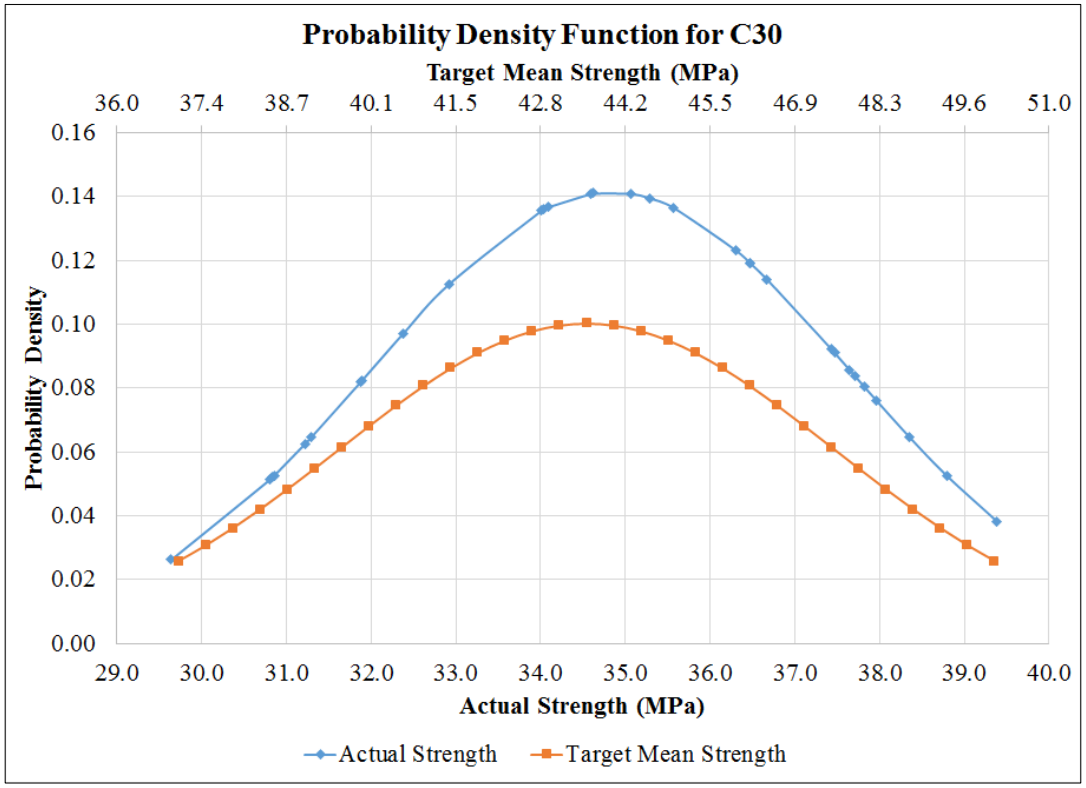



*Figure 4.3-7: Probability Density Function for Class C30*

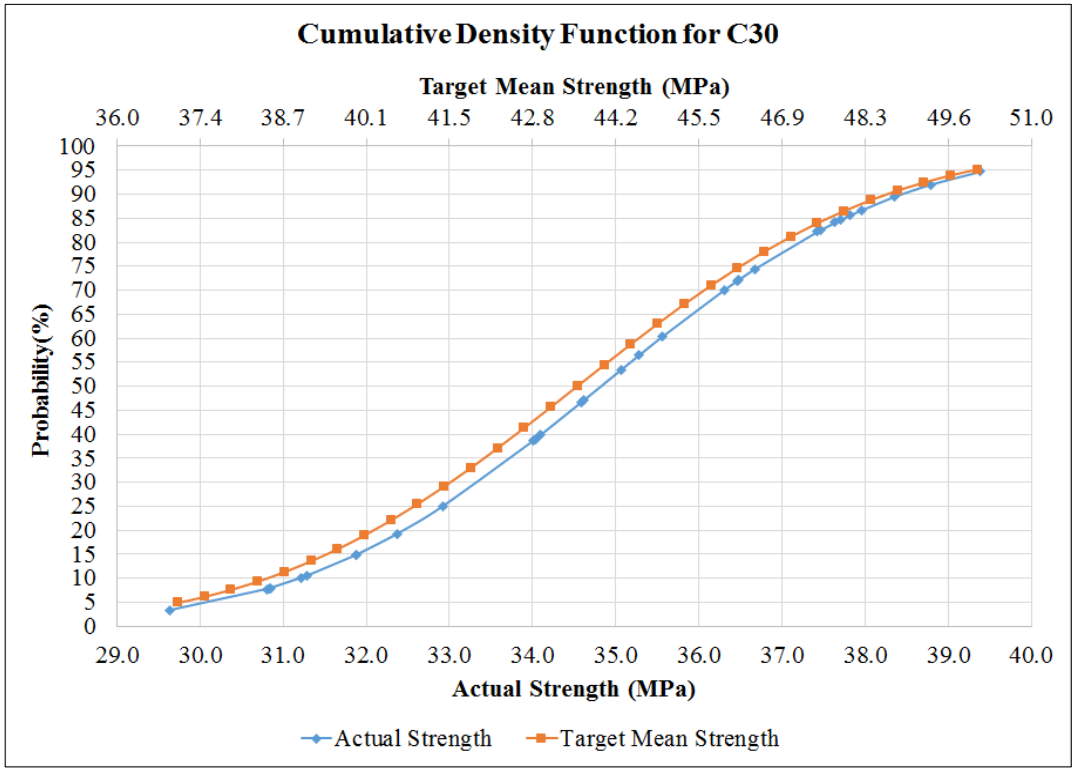



*Figure 4.3-8: Cumulative Density Function for Class C30*

### 4.3.3 Normality Test for Concrete Strength Results

The null hypothesis of concrete strength results being normally distributed was tested to affirm the distribution. Table 4.3-3 shows the distribution test using the Z-test.

***Table 4.3-3: Normality Tests for the Distributions Using the Z-Test***

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

*$z = number\ of\ standard\ deviations\ (Z - score)$

$x = sample\ mean$

$s = standard\ deviation$

$\mu = mean\ for\ null\ hypothesis$

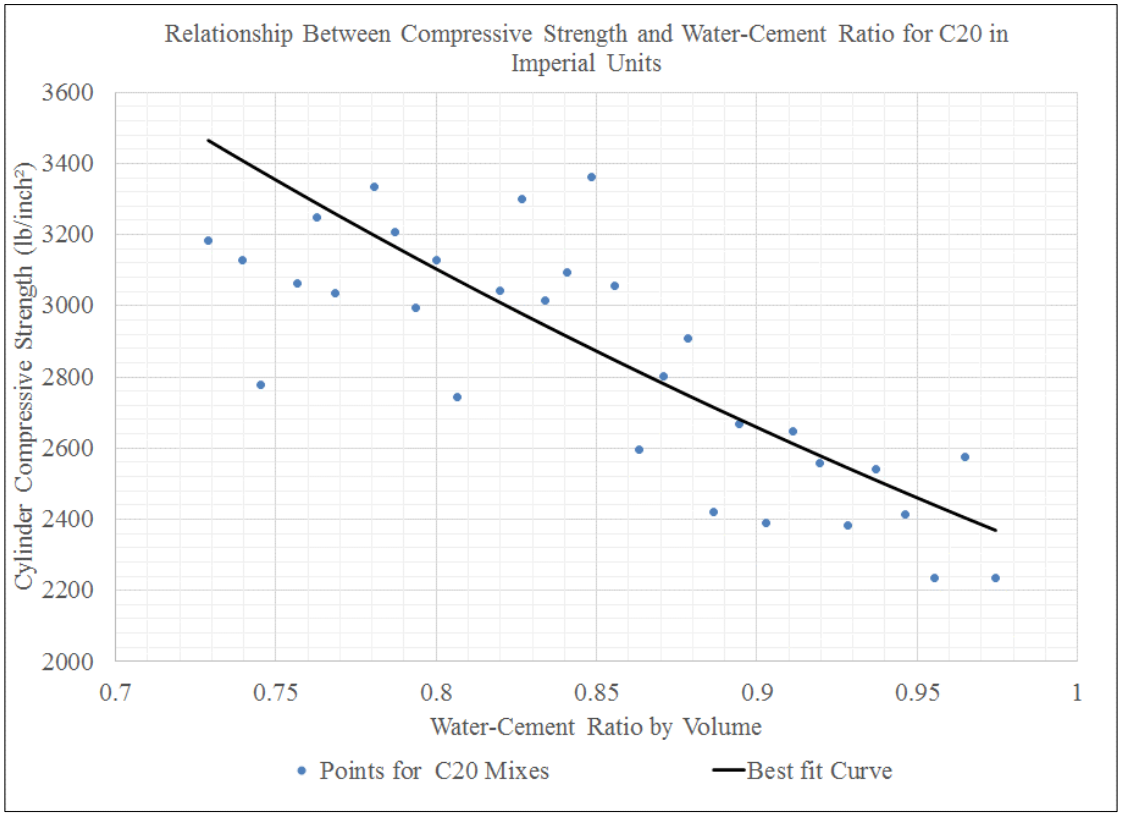
$n = sample\ size$

### 4.3.4 Relationship between Compressive Strength and Water-Cement Ratio obtained from Experimental Results

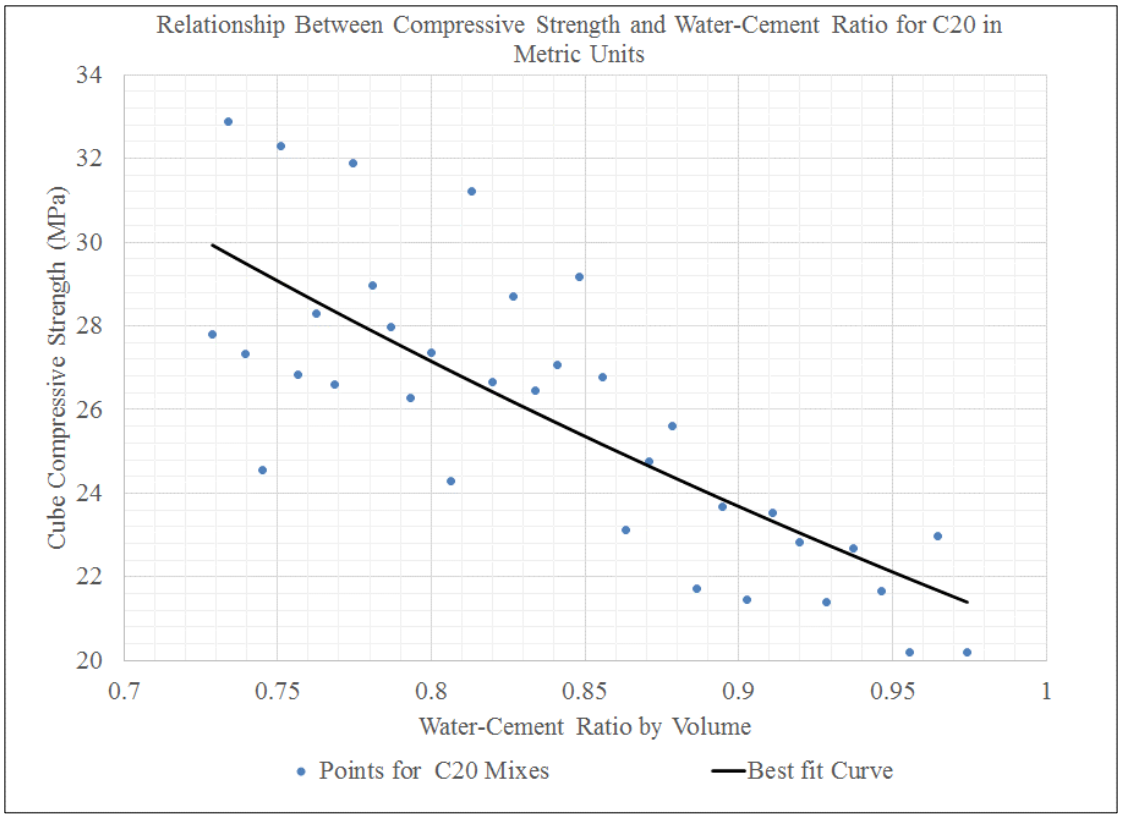
The relationships between compressive strength and water-cement ratios were established for concrete classes C20, C25, C30 and the general relationship for all the 3 classes.

#### *4.3.4.1 Relationship between Compressive Strength and Water-Cement Ratio for C20*

Figure 4.3-9(a) and 4.3-9(b) present the plotted points and corresponding best fir curves for C20 classes of concrete cube strength results obtained against the water cement ratios, in Imperial and Metric units, respectively...




*(a) Imperial units*




*(b) Metric Units*

***Figure 4.3-9: Relationship between Compressive Strength and Water-Cement Ratio for C20 Laboratory Experimental Results***

The mathematical relationship of the best-fit curve in figure 4.3-9(a) is represented in equation 4.3-1.

$$Qc = \frac{10700}{4.7^{(\frac{W}{C})}} \qquad \text{...Equation 4.3-1}$$

Where:

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

$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

The mathematical relationship of the best-fit curve in figure 4.3-9(b) is represented in equation 4.3-2.

$$Qcu = \frac{81}{3.92^{(\frac{W}{C})}}$$ ...Equation 4.3-2

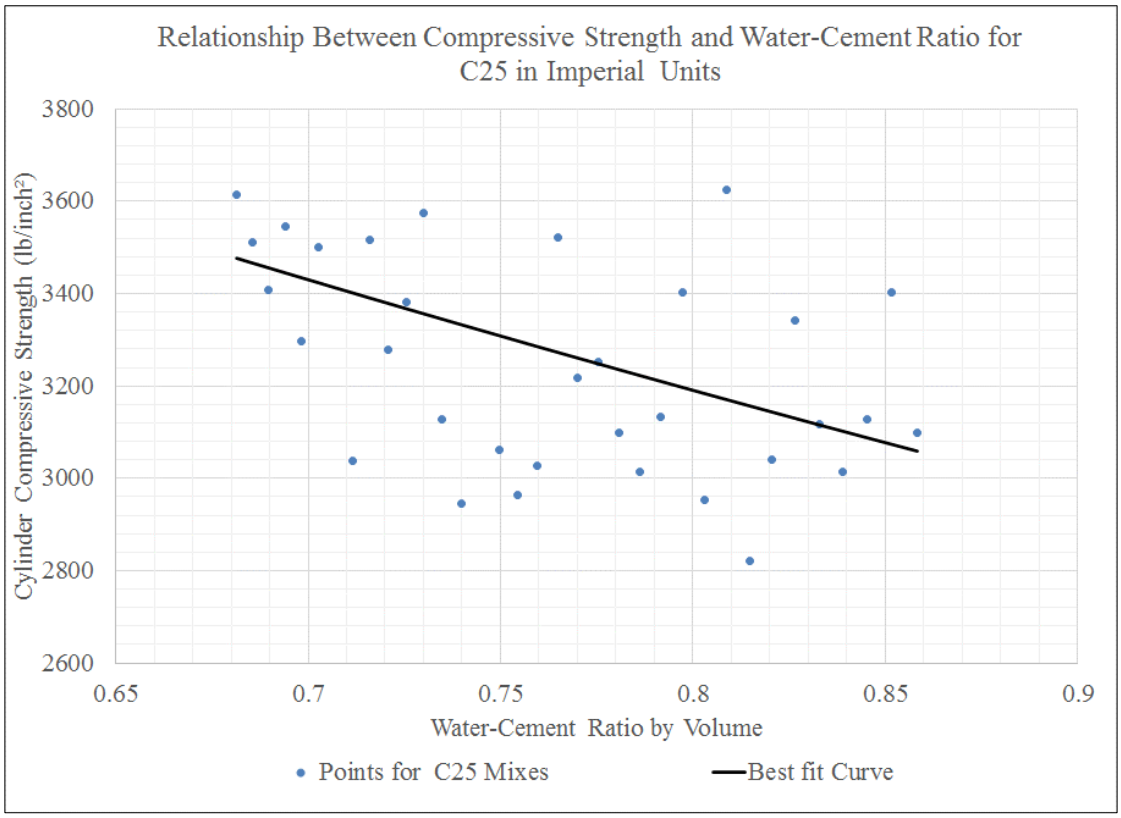
Where:

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

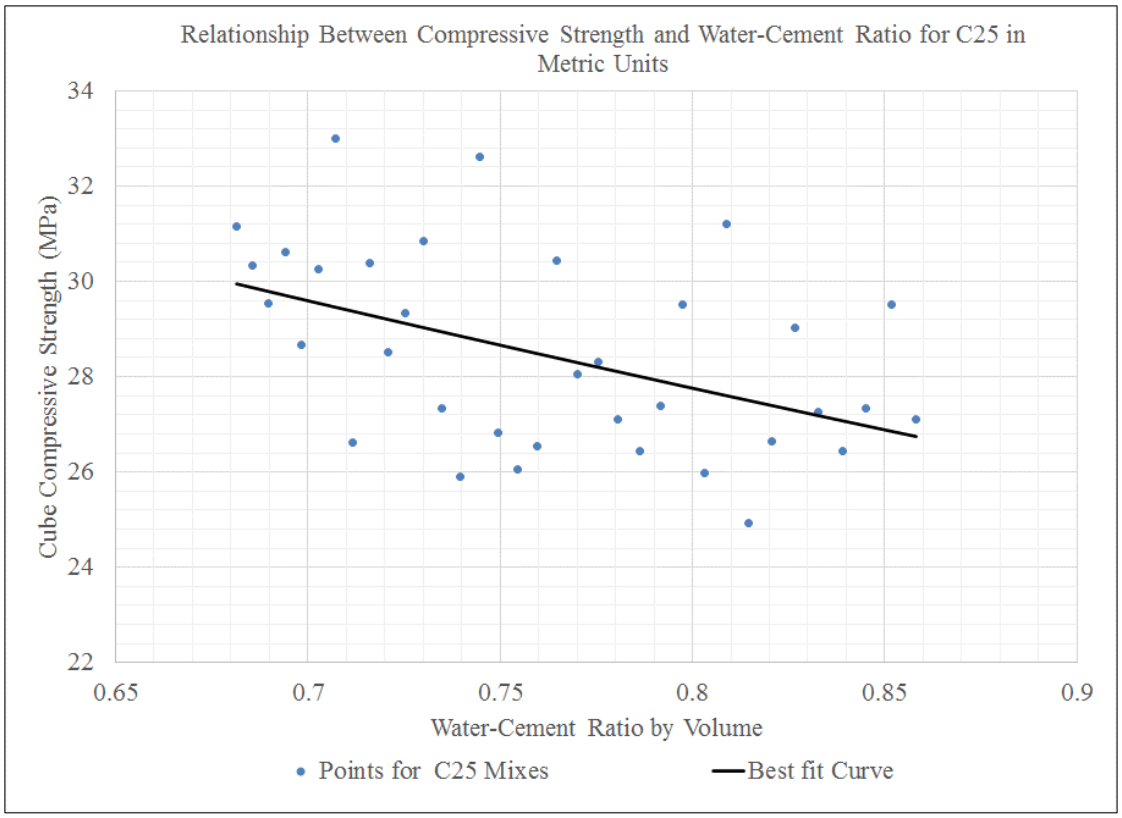
$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

### *4.3.4.2 Relationship between Compressive Strength and Water-Cement Ratio for C25*

Figure 4.3-10(a) and 4.3-10(b) presents the plotted points and the corresponding best fit curves for C25 classes of concrete cube strength results obtained against the water cement ratios.




*(a) Imperial units*




*(b) Metric Units*

***Figure 4.3-10: Relationship between Compressive Strength and Water-Cement Ratio for C25 Laboratory Experimental Results***

The mathematical relationship of the best-fit curve in figure 4.3-10(a) is represented in equation 4.3-3.

$$Qc = \frac{5710}{2.07^{(\frac{W}{C})}} \qquad \text{...Equation 4.3-3}$$

Where:

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

$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

The mathematical relationship of the best-fit curve in figure 4.3-10(b) is represented in equation 4.3-4.

$$Qcu = \frac{46.4}{1.9^{(\frac{W}{C})}}$$ *...Equation 4.3-4*

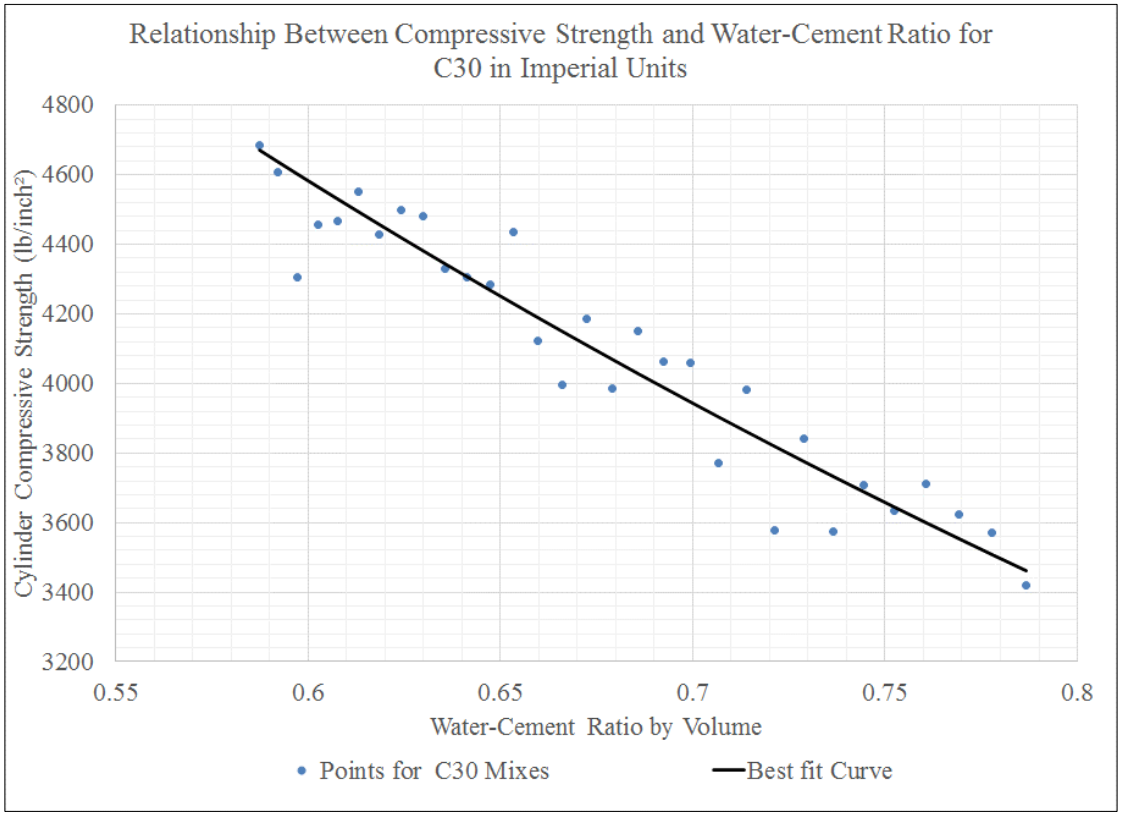
Where:

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

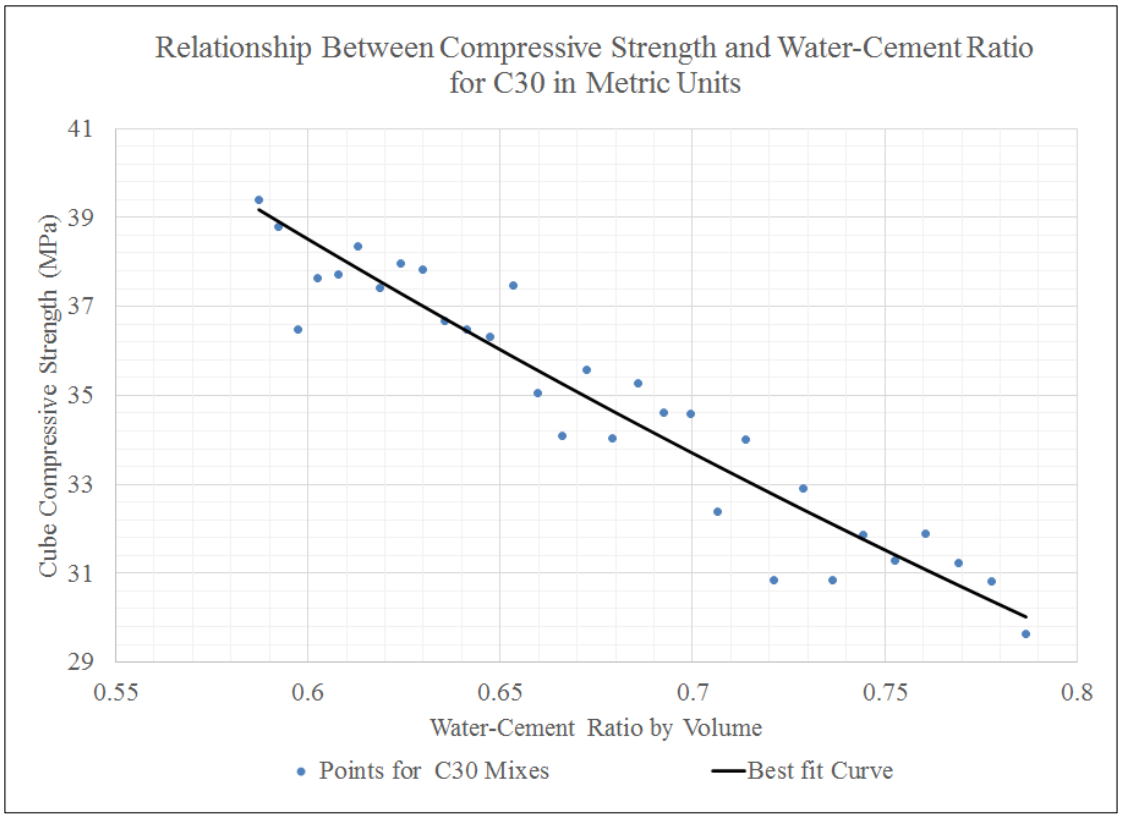
$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

### *4.3.4.3 Relationship between Compressive Strength and Water-Cement Ratio for C30*

Figure 4.3-11(a) and 4.3-11(b) presents the plotted points and tte corresponding best fit curves for C25 classes of concrete cube strength results obtained against the water cement ratios.




*(a) Imperial units*




*(b) Metric Units*

***Figure 4.3-11: Relationship between Compressive Strength and Water-Cement Ratio for C30 Laboratory Experimental Results***

The mathematical relationship of the best-fit curve in figure 4.3-11(a) is represented in equation 4.3-5.

$$Qc = \frac{11300}{4.5^{(\frac{W}{C})}} \qquad \text{... Equation 4.3-5}$$

Where:

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

$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

The mathematical relationship of the best-fit curve in figure 4.3-11(b) is represented in equation 4.3-6.

$$Qcu = \frac{85.8}{3.8^{(\frac{W}{C})}} \quad \text{...Equation 4.3-6}$$

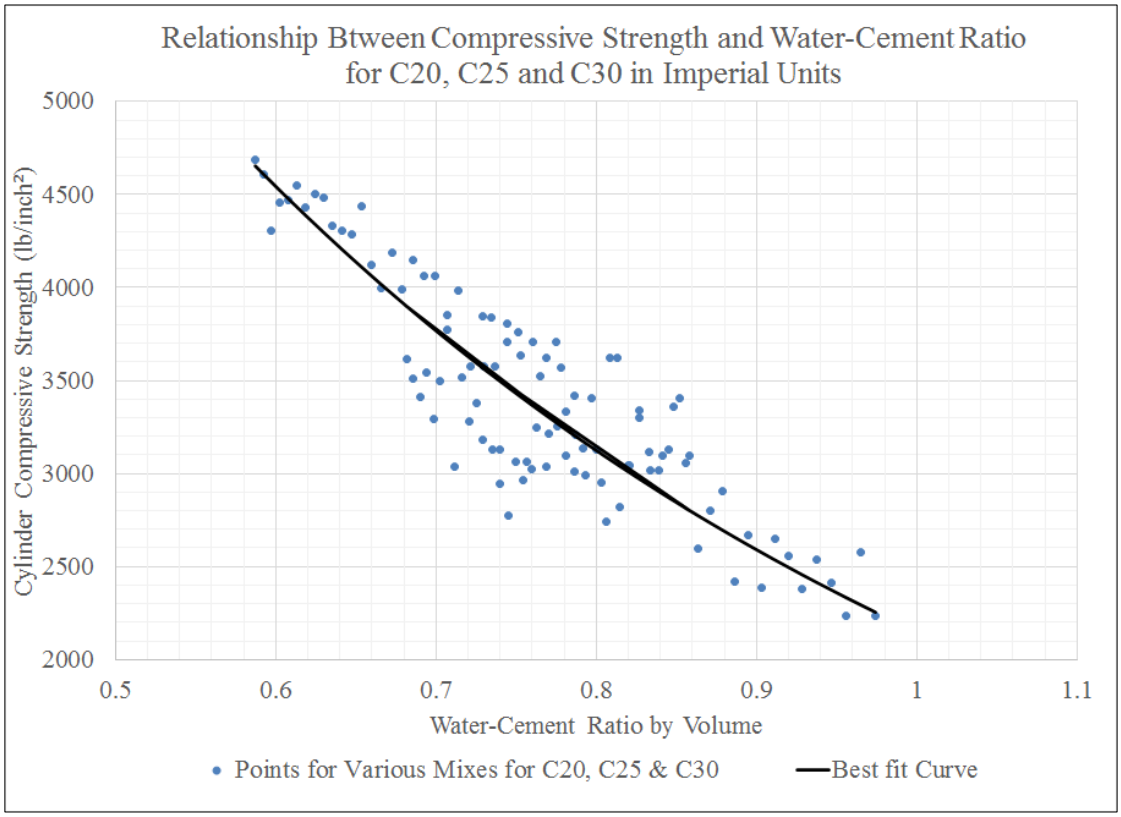
Where:

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

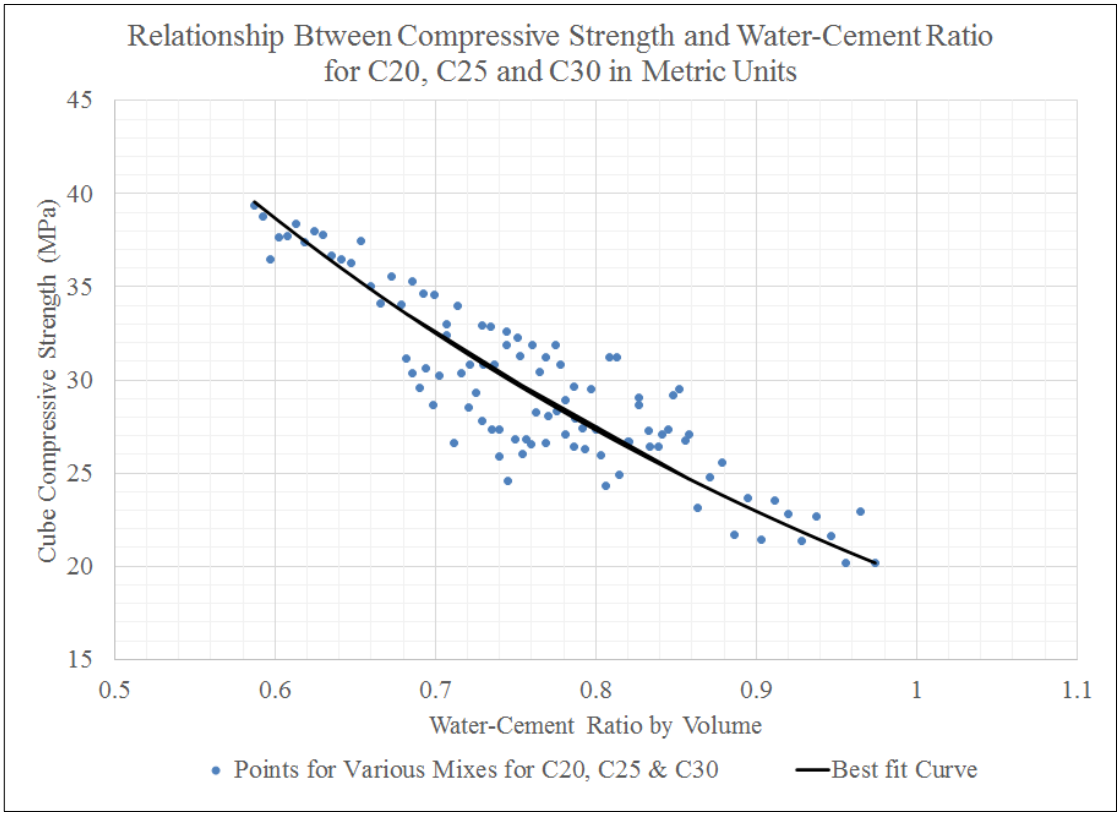
$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

#### *4.3.4.4 Relationship between Compressive Strength and Water-Cement Ratio for all Concrete Classes C20, C25 and C30*

Figure 4.3-12(a) and 4.3-12(b) presents the plotted points and their curve of best fit for all the classes of concrete cube strength results obtained against the water cement ratios.




*(a) Imperial Units*




*(b) Metric Units*

***Figure 4.3-12: Relationship between Compressive Strength and Water-Cement Ratio from Laboratory Experimental Results***

The mathematical relationship of the best-fit curve in figure 4.3-12(a) is represented in equation 4.3-7.

$$Qc = \frac{13980}{6.5^{(\frac{W}{C})}} \quad \text{...Equation 4.3-7}$$

Where:

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

$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

The mathematical relationship of the best-fit curve in figure 4.3-12(b) is represented in equation 4.3-8.

$$Qcu = \frac{110}{5.7^{(\frac{W}{C})}} \quad \text{... Equation 4.3-8}$$

Where:

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

$\frac{W}{C} = water\ cement\ ratio\ by\ volume$

### 4.3.5 Target Mean Strength Values

Table 4.3-4 indicates the established appropriate standard deviation for predicting Target Mean Strength based on local concrete mix materials when using BS-DOE method for the classes C20, C25 and C30. It further shows the respective mix proportions for these classes based on the validated Target Mean Strength.

*Table 4.3-4: Established Target Mean Strength Prediction Values for local Concrete Mixes*

| Method of Concrete Mix Design | Concrete Class | Characteristic Strength-Fc (MPa) | Target Mean Strength-$F_m$ (MPa) | Standard deviation (σ) (MPa) | Margin (M) (MPa) | Mixing Proportions (kg/m$^3$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $\sigma = \frac{Fm - Fc}{1.64}$ | $M = 1.64 \times \sigma$ | Cement | Fine Aggregates | Coarse Aggregates | Water |
| BS-DOE Method | C20 | 20 | 33.4 | 8.2 | 13.4 | 328 | 743 | 1139 | 190 |
| | C25 | 25 | 38.1 | 8.0 | 13.1 | 360 | 718 | 1162 | 190 |
| | C30 | 30 | 43.6 | 8.3 | 13.6 | 407 | 673 | 1160 | 190 |
| **Average Standard deviation & Margin** | | | | **8.15** | **13.37** | | | | |

Where: Fm=Target Mean Strength, Fc=Characteristic strength, σ=Standard deviation and M= margin

The concrete mix design data used to produce strength results for the concrete classes in Table 4.3-4 are attached in Appendix K, L and M.

## 4.4 Summary

Figure 4.4-1 presents the established standard deviation for classes C20, C25 and C30 in comparison with anticipated limits of standard deviation in BS-DOE method of concrete mix design. According to the literature Building Research Establishment (BRE, 2010), limits of standard deviation in United Kingdom for normal concrete mixes is anticipated to range between 2.5 and 8.5.

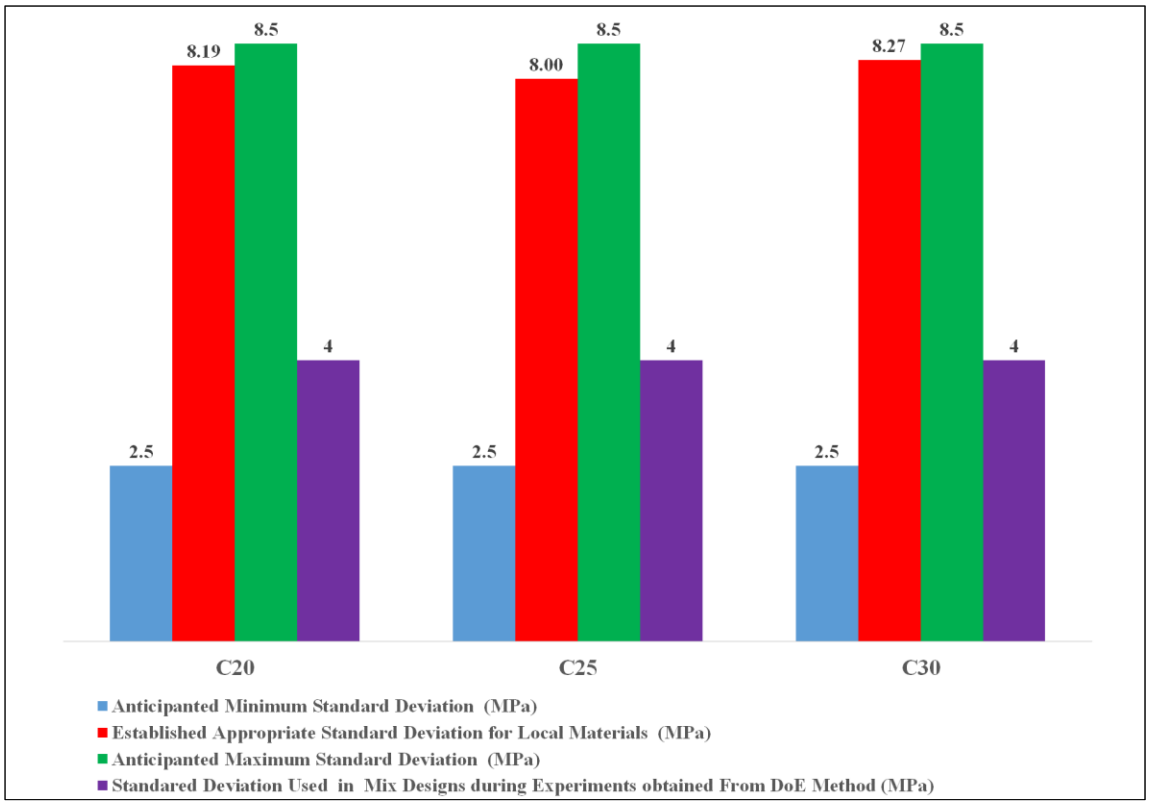



***Figure 4.4-1: Established Standard Deviation in Comparison with DOE Method***

Figure 4.4-2 presents the established Target Mean Strengths for classes C20, C25 and C30 in comparison with limits of Target Mean Strength in BS-DOE method.

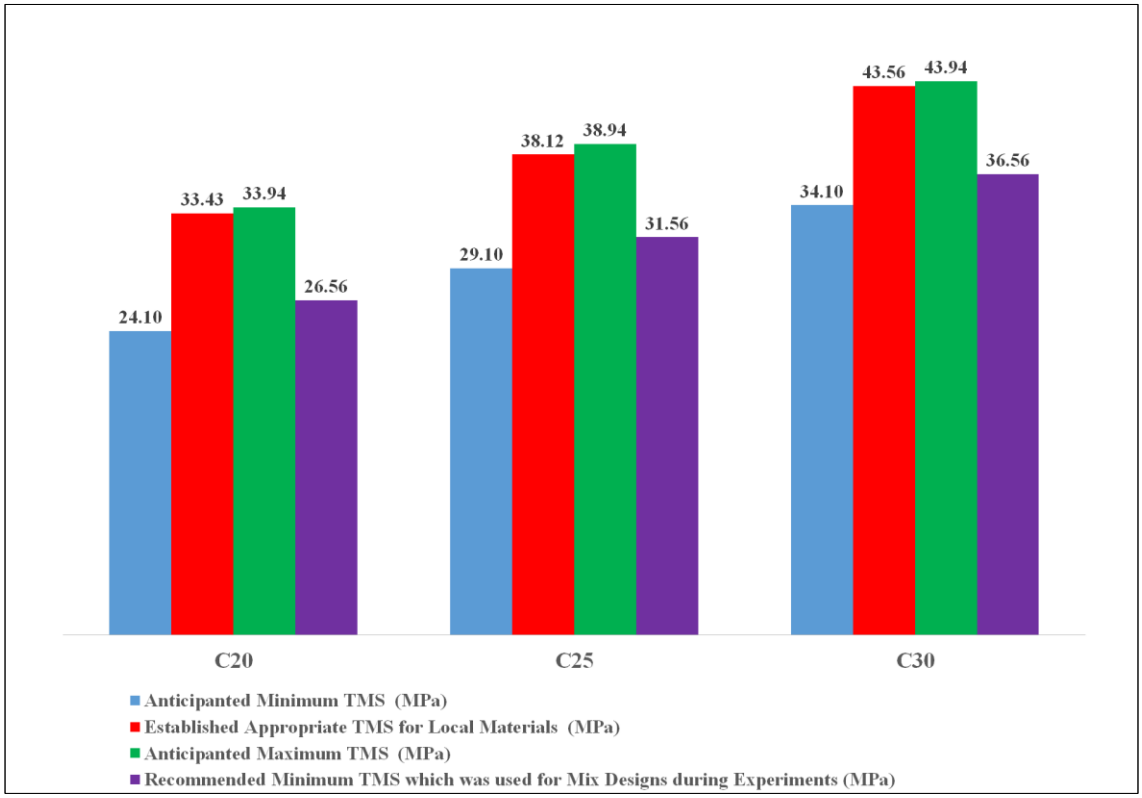



***Figure 4.4-2: Established Target Mean Strength in Comparison with DOE Method***

From the established Target Mean Strengths in figure 4.4-2, the established mix proportions of concrete per cubic meter for local materials for the classes C20, C25 and C30 at 5% allowable defective are presented in Figure 4.4-3 (a), (b) and (c).

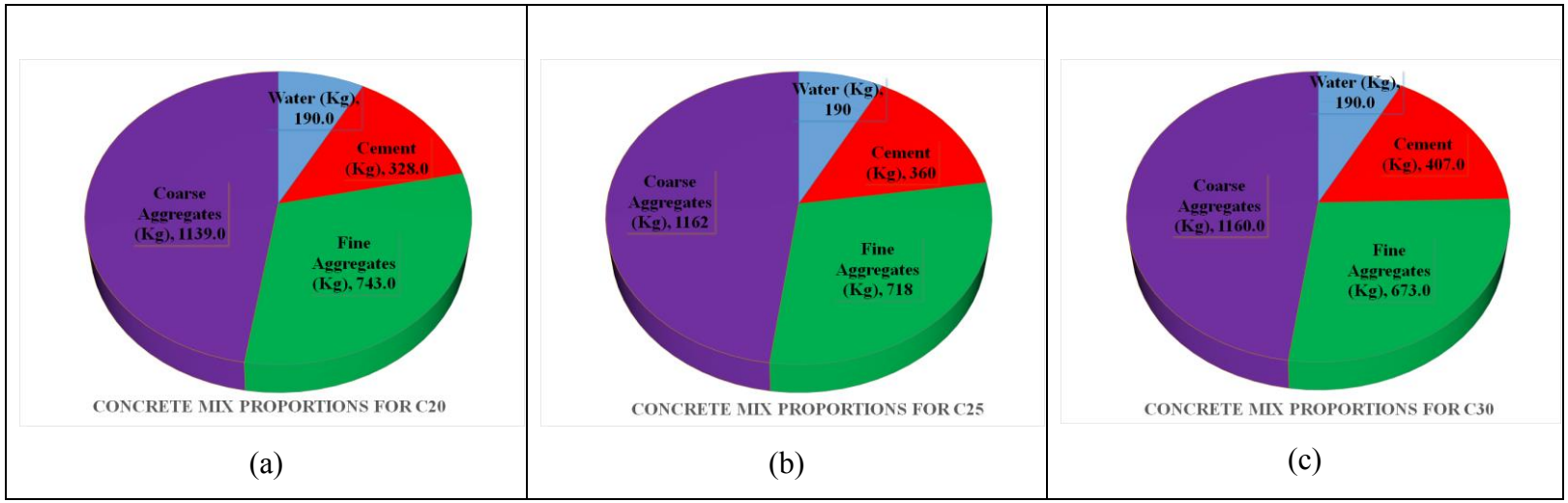



***Figure 4.4-3: Established Concrete Mix Proportions for Class C20, C25 and C30***

# CHAPTER 5: DISCUSSION OF RESULTS

## 5.1 Introduction

This chapter explains and interprets the results of the study with reference to reviewed literature and laboratory investigations. The discussion was limited to the response from interview questionnaire, laboratory experimental results and their analysis. The interview questionnaire was used to identify appropriate concrete mix design method commonly applied locally. The laboratory experiments were carried out using the identified concrete mix design method. The concrete strength yielded from laboratory experiments was analyzed to validate the mix design for Target Mean Strength for the local mix materials.

## 5.2 Reviewed Concrete Mix Design Models that Utilizes Target Mean Strength

Literature reviewed that BS-DOE, ACI and Indian Recommended method of concrete mix design are some of the methods can be validated for Target Mean Strength using local materials. In all of these three models, concrete strength results are assumed to follow a normal distribution pattern and Target Mean Strength is predicted based on the properties of this distribution. From the three models, the BS-DOE model was found suitable for the study because of the available laboratory testing equipment aligned to the British standards. In all the three models, either standard deviation or coefficient of variation of the concrete strength results can be used to predict Target Mean Strength for particular type of materials. Equations 2.2-1 and 2.2-2 are used for predicting Target Mean Strength when using standard deviation and coefficient of variation respectively. When using the standard deviation, a margin above the characteristic is determined whilst for coefficient of variation an over design factor is determined. In this study, the approach of using standard deviation was adopted.

## 5.3 Concrete Mix Design Model Identification

Despite obtaining a poor response to an interview questionnaire, in Zambia, it is known that the British standard codes of practice were adopted as far as independence era and were currently being applied by some industries. The two respondents interviewed by

means of questionnaire indicated that the they were using BS-DOE method for their concrete mix designs. Most of the laboratory testing equipment available at the University of Zambia for concrete works are aligned to British standards. Therefore, in this study, the B.S-DOE method of concrete mix design was identified for validation in Predicting Target Mean Strength using local materials.

### 5.4 Model Validation for Target Mean Strength through Experimental Results

The test results of concrete constituent materials used for the experiments were in conformity with the appropriate standards as presented in Tables 4.3-1 and 4.3-2. These material tests were confined to affirm compliance of the fine and coarse aggregates whilst the cement bought from the open market were assumed to meet the prescribed standard by the manufacturer.

The range and distribution of predicted Target Mean Strengths based on DOE Method that were used for the experiment and the corresponding actual strengths yielded for each class is presented in form of Probability Density Function (PDF) graphs (Figures: 4.3-3, 4.3-5 and 4.3-7). The respective probabilities of these distribution are presented in form of Cumulative Distribution Function (CDF) graphs (Figures: 4.3-4, 4.3-6 and 4.3-8). 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 review. The normality test conducted in Table 4.3-3 confirmed that the distributions for the three classes of concrete were within normal distribution patterns. The Z-Test was used to conduct this normality (Kanji, 2006).

The established relationship between compressive strength and water-cement ratio presented in figure 4.3-9(a) and equation 4.3-1, was deliberately expressed in imperial system units in order to compare study results with results established by Abram (1919) and is still applicable today (Li et al., 2020). The equation 2.3-5 was used to convert experimental compressive strength results from cube-based test to cylinder-based strength test. Abram (1919) established the general equation for the relationship between compressive strength and water-cement ratio presented in equation 2.4-2. The constant

values A and B in equation 2.4-2 are specific for particular mix materials as per reviewed literature in chapter 2. Abram (1919) 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 4.3-7. 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 (1919) was applicable for the local materials in the study. The figure 4.3-12(b) and equation 4.3-7 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 (1919).

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. These CDF graphs are presented in Figures 4.3-4, 4.3-6 and 4.3-8 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 Table 4.3-4.

Figure 4.4-1 compares the established standard deviation 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, 8.00 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.

### 5.5 Summary

In summary, the BS DOE method of concrete mix design was validated for Target Mean Strength using the local mix materials. The established standard deviation for predicting

Target Mean Strength for all the three classes were higher than the recommended minimum standard deviation of 4.0 in DOE method but slightly less than the anticipated upper limit values in the United Kingdom. Therefore, usage of standard deviation, which are less than the ones, established in this study for similar local mix materials when using BS-DOE method may not be appropriate in achieving the desired strength. The results in this study affirms DOE model as an appropriate concrete mix design for the local mixes materials. However, to guarantee 95% reliability in achieving desired concrete strength results, the limitations of the study should be taken into account. The study also validated the relationship between concrete compressive strength and water-cement ratio developed by Abram (1919).

# CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

## 6.1 Introduction

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 Zambia. 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.

## 6.2 Conclusions

### 6.2.1 Reviewed Concrete Mix Design Models

Literature revealed that the BS DOE, ACI and Indian Recommended methods are some models of concrete mix designs that utilizes Target Mean Strength for concrete mixes (BRE, 2010; ACI, 2011; BIS, 2019). 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 (JSCE, 2010). 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. The ACI is provided with margins based on cylinder strength ranging between 5.0 and 8.0 MPa as detailed in Section 2.2. 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. 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.

### 6.2.2 Concrete Mix Design Model Applied Locally

Despite the poor response from the interview questionnaire, in Zambia, it is known that the British Standard codes of practice which were adopted as far back as Zambia's Independence (1964) were currently being applied by some industries as per response obtained from questionnaire. The two respondents interviewed by means of questionnaire indicated that they were using BS-DOE method for their concrete mix designs. Based on this, the study proceeded to validate BS-DOE model for Target Mean Strength using local mix materials.

### 6.2.3 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.

### 6.2.4 Limitations of the Study

1. The concrete strength results used in the study were only based on laboratory experimental mixes and were not compared with similar strength obtained from mixes used for actual construction by industry. This was attributed to the poor response to the administered questionnaire.
2. There were no local standards of concrete mix designs that could be validated for Target Mean Strength. The study validated BS-DOE model, which was developed in another region of the world. This could have led to high margin differences between the Target Mean Strengths and actual strength results.

## 6.3 Recommendations

Industry should make use of the findings of this study to optimize concrete mix designs for classes C20, 25 and C30. Further, Design and Supervising Engineers, and National Council for Construction should undertake further consultations with stakeholders, and support further studies on the subject matter, with a view to standardize concrete mix design models in Zambia.

## 6.4 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.

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## APPENDICES

### Appendix A: Sample Questionnaire

**The University of Zambia**
**School of Engineering**
**Department of Civil & Environmental Engineering**
**Research Topic: Prediction of Target Mean Strength of Concrete Mixes**
**Date of Interview……..**

**Section A: Details of Respondent**

Name of Respondent (optional)……
Designation……..
Name of Institution being represented…….
Institution Type of business…….

**Section B: Concrete Mix design Information Required**
**Please tick where appropriate**

1. What cement brand do you normally use for your mix design?
    a) Lafarge
    b) Dagonte
    c) Zambezi Portland
    d) Sinoma
    e) Others, Specify……..
2. What is the specific gravity and bulk density of the cement type selected in question one? Specific gravity……..Bulk density:…….
3. What value of standard deviation and % of allowable defective is used for your prediction of Target Mean Strength for normal concrete?.....
4. Was the above standard deviation derived from local material mixes of at least 30 consecutive samples cured at 28 days for normal concrete?
    a) Yes
    b) No
5. If the answer in question 4 is No, Specify assumptions made for standard deviation value…….
6. If the answer in question 4 is Yes, is it possible to share the data used to derive the standard deviation?
    a) Yes
    b) No

7. What mix design methods (s) are employed for your proportioning of normal concrete mixes?
    a) BS-DOE method
    b) ACI Method
    c) Indian Standards
    d) Others
8. If your answer to Question 7 includes d) Others, specify……..
9. Which are your normal sources for coarse and fine aggregates?

    Name (s) of Coarse Aggregate source (s)……
    Name (s) of fine aggregate source (s)…….
10. What are the maximum sizes of coarse aggregates used for your mix designs?
    a) 20mm
    b) 40mm
    c) Others, specify……..
11. State the proportion ratios you normally use for achieving your Target Mean Strength for the following grades of concrete?

| Concrete Grade | Target Mean Strength | Mixing Proportion Ratios | | | |
|---|---|---|---|---|---|
| | | Water | Cement | Fine aggregate | Coarse Aggregate |
| C20 | | | | | |
| C25 | | | | | |
| C30 | | | | | |
| C35 | | | | | |
| C40 | | | | | |

12. What type of concrete compressive strength tests do you conduct to obtain TMS for concrete classes in 11?
    a) Cube
    b) Cylinder
    c) Others, specify…….
13. On average, how may construction companies/concrete suppliers request for your mix designs annually?
    Answer: .....

## Appendix B: Relative Density and Moisture Absorption Test Results for Coarse Aggregates

| TEST METHOD-Ref BS 812 | | | | | |
|---|---|---|---|---|---|
| Specimen Reference | Parameter/Formula | unit | T-1 | T-2 | Mean |
| Mass of saturated surface dry aggregate in air | A | g | 2002 | 2002 | |
| Mass of Vessel +Sample in water | B | g | 1762 | 1760 | |
| Mass of empty basket in water | C | g | 492 | 492 | |
| Mass of oven dried aggregate in air | D | g | 2000 | 2000 | |
| Relative density on an oven dry basis | $\rho d = \frac{D}{A-(B-C)}$ | t/m³ | 2.732 | 2.725 | 2.73 |
| Relative density on a saturated and surface dry basis | $\rho s = \frac{A}{A-(B-C)}$ | t/m³ | 2.735 | 2.73 | 2.73 |
| Apparent Relative density | $\rho a = \frac{D}{D-(B-C)}$ | t/m³ | 2.740 | 2.73 | 2.74 |
| Water Absorption | $\rho abs = \frac{(A-D)}{D} \times 100$ | % | 0.10 | 0.10 | 0.10 |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 7 December 2021 | | | |
| **Checked By:** Masala Mwiko | | **Date:** 7 December 2021 | | | |

## Appendix C: Relative Density and Moisture Absorption Test Results for Fine Aggregates

| TEST METHOD-Ref BS 812 | | | | | |
|---|---|---|---|---|---|
| Specimen Reference | Parameter/Formula | unit | T-1 | T-2 | Mean |
| Mass of saturated surface dry aggregate in air | A | g | 300 | 300 | |
| Mass of Vessel +Sample in water | B | g | 954 | 955 | |
| Mass of empty basket in water | C | g | 769 | 769 | |
| Mass of oven dried aggregate in air | D | g | 294.3 | 294 | |
| Relative density on an oven dry basis | $\rho d = \frac{D}{A-(B-C)}$ | t/m³ | 2.559 | 2.579 | 2.569 |
| Relative density on a SSD | $\rho s = \frac{A}{A-(B-C)}$ | t/m³ | 2.61 | 2.63 | 2.620 |
| Apparent Relative density | $\rho a = \frac{D}{D-(B-C)}$ | t/m³ | 2.69 | 2.72 | 2.707 |
| Water Absorption | $\rho abs = \frac{(A-D)}{D} \times 100$ | % | 1.94 | 2.04 | 1.989 |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 7 December 2021 | | | |
| **Checked By:** Masala Mwiko | | **Date:** 7 December 2021 | | | |

## Appendix D: Bulk Density Test Results for Coarse Aggregates

| Measurement of Vessel | | | |
|---|---|---|---|
| Diameter | m | 0.265 | |
| Height | m | 0.182 | |
| Volume | $m^3$ | 0.010 | |
| Bulk Density Test Results | | | |
| Description | Unit | T-1 | T-2 |
| Mass of Vessel | kg | 6.736 | 6.736 |
| Mass of Vessel+Sample | kg | 23.169 | 23.069 |
| Mass of Sample | kg | 16.433 | 16.333 |
| Bulk Density | $kg/m^3$ | 1,637 | 1,627 |
| Avg. Bulk Density | $kg/m^3$ | 1,632 | |
| | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 7 December 2021 | |
| **Checked By:** Masala Mwiko | | **Date:** 7 December 2021 | |

## Appendix E: Bulk Density Test Results for Fine Aggregates

| Measurement of Vessel | | | |
|---|---|---|---|
| Diameter | m | 0.18 | |
| Height | m | 0.178 | |
| Volume | $m^3$ | 0.0045 | |
| Bulk Density Test Results | | | |
| Description | Unit | T-1 | T-2 |
| Mass of Vessel | kg | 3.861 | 3.861 |
| Mass of Vessel+Sample | kg | 13.625 | 13.653 |
| Mass of Sample | kg | 9.764 | 9.792 |
| Bulk Density | $kg/m^3$ | 2,156 | 2,162 |
| Avg. Bulk Density | $kg/m^3$ | 2,159 | |
| | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 7 December 2021 | |
| **Checked By:** Masala Mwiko | | **Date:** 7 December 2021 | |

## Appendix F: Aggregate Crushing Value (ACV) Test Results

| **Fraction Tested** | | 14-10mm | | | |
|---|---|---|---|---|---|
| **Separating Sieve** | | 2.36mm | | | |
| | | **Measured Quantities** | | | |
| **Description** | **Symbol/Formula** | **Test 1** | **Test 2** | **Test 3** | **Test 4** |
| Mass of Tray + specimen (g) | | 3,554 | 3,554 | 3,554 | 3,554 |
| Mass of tray alone (g) | | 554 | 554 | 554 | 554 |
| Mass of original test specimen (g) | M1 | 3,000 | 3,000 | 3,000 | 3,000 |
| Mass of Tray +Material Passing | | 1,053 | 1,070 | 1,013 | 1,076 |
| Mass of tray alone (g) | | 554 | 554 | 554 | 554 |
| Mass of Material Passing separating | M2 | 499 | 516 | 459 | 522 |
| Mass of Tray +Material retained on | | 3,054 | 3,038 | 3,093 | 3,031 |
| Mass of tray alone (g) | | 554 | 554 | 554 | 554 |
| Mass of material Retained separating | M3 | 2,500 | 2,484 | 2,539 | 2,477 |
| Mass retained and passing on | $M2 + M3$ | 2,999 | 3,000 | 2,998 | 2,999 |
| Aggregate Crushing Value (%) | $\frac{M2}{M1} \times 100$ | 16.6 | 17.2 | 15.3 | 17.4 |
| **ACV-Mean Value (%)** | | **16.6** | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 8 December 2021 | | | |
| **Checked By:** Masala Mwiko | | **Date:** 8 December 2021 | | | |

## Appendix G: Elongation Index (EI) Test Results

| **Sieve Sizes on which Aggregates Retained** | **Unit** | **Gauging** | | |
|---|---|---|---|---|
| | | **Passing** | **Retained** | |
| 14 | mm | 144 | 18 | |
| 10 | mm | 1218 | 121 | |
| 6.3 | mm | 889 | 102 | |
| Fraction Gauged | | | | |
| Passing Sieve | mm | 20 | 14 | 10 |
| Retained on Sieve | mm | 14 | 10 | 6.3 |
| Gap Between pins | mm | 30.6 | 21.6 | 14.7 |
| Fraction Gauged | | 0.1111111 | 0.0903659 | 0.1029263 |
| Before Gauging | | | | |
| Mass of Aggregate Fraction (Mo) | g | 169 | 1338 | 999 |
| Individual Percentage ((Mo/M1)*100) | % | 6.7438148 | 53.39186 | 39.864326 |
| Sum of Aggregate Mass (M1) | g | 2506 | | |
| Sum of Fraction less than 5% of M1 | g | 0 | | |
| Remaining sum of aggregate mass M2 | g | 2506 | | |
| After Gauging | | | | |
| Sum of aggregate mass not passing gaps (M3) | g | 243 | | |
| Elongation Index ((M3/M2)*100) | % | 9.677207603 | | |
| E.I is acceptable since it is less than 15% | | 9.67 < 15% | | |
| | | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 8 December 2021 | | |
| **Checked By:** Masala Mwiko | | **Date:** 8 December 2021 | | |

## Appendix H: Flakiness Index (FI) Test Results

| Sieve Sizes on which Aggregates were Retained | Unit | Gauging | | |
|---|---|---|---|---|
| | | Passing | Retained | |
| 14 | mm | 47 | 114 | |
| 10 | mm | 136 | 1202 | |
| 6.3 | mm | 4 | 995 | |
| Fraction Gauged | | | | |
| Passing Sieve | mm | 20 | 14 | 10 |
| Retained on Sieve | mm | 14 | 10 | 6.3 |
| Slots width | mm | 10.2 | 7.2 | 4.9 |
| Fraction Gauged | | 0.292 | 0.102 | 0.004 |
| Before Gauging | | | | |
| Mass of Aggregate Fraction (Mo) | g | 169 | 1338 | 999 |
| Individual Percentage ((Mo/M1)*100) | % | 6.74381484 | 53.3918595 | 39.8643256 |
| Sum of Aggregate Mass (M1) | g | 2506 | | |
| Sum of Fraction less than 5% of M1 | g | 0 | | |
| Remaining sum of aggregate mass M2 | g | 2506 | | |
| After Gauging | | | | |
| Sum of aggregate mass passing slots (M3) | g | 189 | | |
| Flakiness Index ((M3/M2)*100) | % | 7.555283469 | | |
| F.I is acceptable since it is less than 30% | | 7.55 < 30% | | |
| | | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | **Date:** 8 December 2021 | | |
| **Checked By:** Masala Mwiko | | **Date:** 8 December 2021 | | |

## Appendix I: Sieve Analysis Test Results for Coarse Aggregates

| Test Method Ref: BS812 | | | | |
|---|---|---|---|---|
| Initial Dry Mass ($M_1$) | | | 2507g | |
| Sieve Test Results | | | | |
| Test Sieve | Mass Retained (M) (g) | Percentage Retained $(\frac{M}{M1} \times 100)$ | Cumulative Percentage Passing | Standard Limits (BS 882) |
| 20 | 0 | 0.0 | 100.00 | 85 to 100 |
| 14 | 1507 | 60.1 | 39.89 | 0 to 70 |
| 10 | 993 | 39.6 | 0.28 | 0 to 25 |
| 5 | 7 | 0.3 | 0.00 | 0 to 5 |
| 2.36 | 0 | 0.0 | 0.00 | |
| Total | 2507 | | | |
| | | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | | **Date:** 7 December 2021 | |
| **Checked By:** Masala Mwiko | | | **Date:** 7 December 2021 | |

## Appendix J: Sieve Analysis Test Results for Fine Aggregates

| Test Method Ref: BS812 | | | | |
|---|---|---|---|---|
| Initial Dry Mass ($M_1$) | | | 1000g | |
| Sieve Test Results | | | | |
| Test Sieve | Mass Retained (M) (g) | Percentage Retained $(\frac{M}{M1} \times 100)$ | Cumulative Percentage Passing | Standard Limits (BS 882) |
| 10 | 0 | 0.0 | 100.0 | 100 |
| 5 | 105 | 10.5 | 89.5 | 89 to 100 |
| 2.36 | 239 | 24.0 | 65.6 | 60 to 100 |
| 1.18 | 119 | 11.9 | 53.7 | 30 to 100 |
| 0.6 | 131 | 13.1 | 40.6 | 15 to 100 |
| 0.3 | 134 | 13.4 | 27.2 | 5 to 70 |
| 0.15 | 132 | 13.2 | 14.0 | 0 to 20 |
| Pan | 137 | 13.7 | 0.0 | |
| Total | 997 | | | |
| | | | | |
| **Tested By:** Chimpipa Kaeimbwe & Irvin Nchinga Chingumbe | | | **Date:** 7 December 2021 | |
| **Checked By:** Masala Mwiko | | | **Date:** 7 December 2021 | |

## Appendix K: Mix Design Results Developed for C20

| Sample No. | TMS (MPa) | Water (kg/m³) | Cement (kg/m³) | Fresh Concrete Density (kg/m³) | % of Fine (kg/m³) | F.A (kg/m³) | C.A (kg/m³) | Date of Casting | Laboratory Room Temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|
| C20-1 | 26.55 | 190 | 280.769 | 2400 | 41.918 | 808.691 | 1120.540 | 10-Dec-21 | |
| C20-2 | 27.00 | 190 | 283.554 | 2400 | 41.752 | 804.323 | 1122.123 | 10-Dec-21 | |
| C20-3 | 27.43 | 190 | 286.338 | 2400 | 41.589 | 800.027 | 1123.635 | 10-Dec-21 | |
| C20-4 | 27.86 | 190 | 289.123 | 2400 | 41.429 | 795.800 | 1125.077 | 10-Dec-21 | |
| C20-5 | 28.27 | 190 | 291.908 | 2400 | 41.272 | 791.640 | 1126.452 | 10-Dec-21 | |
| C20-6 | 28.63 | 190 | 294.692 | 2400 | 41.119 | 787.546 | 1127.762 | 10-Dec-21 | |
| C20-7 | 28.96 | 190 | 297.477 | 2400 | 40.968 | 783.515 | 1129.008 | 10-Dec-21 | |
| C20-8 | 29.29 | 190 | 300.262 | 2400 | 40.820 | 779.546 | 1130.192 | 11-Dec-21 | |
| C20-9 | 29.61 | 190 | 303.046 | 2400 | 40.674 | 775.638 | 1131.316 | 11-Dec-21 | |
| C20-10 | 29.93 | 190 | 305.831 | 2400 | 40.531 | 771.788 | 1132.382 | 11-Dec-21 | |
| C20-11 | 30.24 | 190 | 308.615 | 2400 | 40.391 | 767.994 | 1133.390 | 11-Dec-21 | |
| C20-12 | 30.55 | 190 | 311.400 | 2400 | 40.254 | 764.257 | 1134.343 | 11-Dec-21 | |
| C20-13 | 30.85 | 190 | 314.185 | 2400 | 40.118 | 760.573 | 1135.243 | 11-Dec-21 | |
| C20-14 | 31.17 | 190 | 316.969 | 2400 | 39.986 | 756.941 | 1136.090 | 11-Dec-21 | |
| C20-15 | 31.75 | 190 | 319.754 | 2400 | 39.855 | 753.361 | 1136.885 | 11-Dec-21 | |
| C20-16 | 32.32 | 190 | 322.538 | 2400 | 39.727 | 749.830 | 1137.631 | 12-Dec-21 | |
| C20-17 | 32.89 | 190 | 325.323 | 2400 | 39.601 | 746.348 | 1138.328 | 12-Dec-21 | |
| C20-18 | 33.44 | 190 | 328.108 | 2400 | 39.477 | 742.914 | 1138.979 | 12-Dec-21 | 24 to 28 |
| C20-19 | 33.98 | 190 | 330.892 | 2400 | 39.355 | 739.525 | 1139.583 | 12-Dec-21 | |
| C20-20 | 34.51 | 190 | 333.677 | 2400 | 39.235 | 736.181 | 1140.142 | 12-Dec-21 | |
| C20-21 | 35.03 | 190 | 336.462 | 2400 | 39.118 | 732.882 | 1140.657 | 12-Dec-21 | |
| C20-22 | 35.55 | 190 | 339.246 | 2400 | 39.002 | 729.625 | 1141.129 | 12-Dec-21 | |
| C20-23 | 36.05 | 190 | 342.031 | 2400 | 38.888 | 726.409 | 1141.560 | 12-Dec-21 | |
| C20-24 | 36.55 | 190 | 344.815 | 2400 | 38.775 | 723.234 | 1141.950 | 13-Dec-21 | |
| C20-25 | 36.97 | 190 | 347.600 | 2400 | 38.665 | 720.099 | 1142.301 | 13-Dec-21 | |
| C20-26 | 37.35 | 190 | 350.385 | 2400 | 38.557 | 717.003 | 1142.612 | 13-Dec-21 | |
| C20-27 | 37.73 | 190 | 353.169 | 2400 | 38.450 | 713.945 | 1142.886 | 13-Dec-21 | |
| C20-28 | 38.11 | 190 | 355.954 | 2400 | 38.344 | 710.923 | 1143.123 | 13-Dec-21 | |
| C20-29 | 38.48 | 190 | 358.738 | 2400 | 38.241 | 707.938 | 1143.324 | 13-Dec-21 | |
| C20-30 | 38.84 | 190 | 361.523 | 2400 | 38.139 | 704.988 | 1143.489 | 13-Dec-21 | |
| C20-31 | 39.20 | 190 | 364.308 | 2400 | 38.038 | 702.072 | 1143.620 | 13-Dec-21 | |
| C20-32 | 39.55 | 191 | 369.024 | 2400 | 37.940 | 698.078 | 1141.898 | 22-Dec-21 | |
| C20-33 | 39.89 | 192 | 373.770 | 2400 | 37.842 | 694.111 | 1140.118 | 22-Dec-21 | |
| C20-34 | 40.24 | 193 | 378.546 | 2400 | 37.746 | 690.171 | 1138.283 | 22-Dec-21 | |
| C20-35 | 40.57 | 194 | 383.350 | 2400 | 37.652 | 686.257 | 1136.393 | 22-Dec-21 | |
| | **Mix Design Developed By:** | | | | Masala Mwiko | | | | |
| | **Concrete mixing & Cube casting carried out by:** | | | | Chimpipa Kaeimbwe, Irvin Nchinga Chingumbe & Masala Mwiko | | | | |

## Appendix L: Mix Design Results Developed for C25

| Sample No. | TMS (MPa) | Water (kg/m³) | Cement (kg/m³) | Fresh Concrete Density (kg/m³) | % of Fine (kg/m³) | F.A (kg/m³) | C.A (kg/m³) | Date of Casting | Laboratory Room Temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|
| C25-1 | 31.56 | 190 | 318.831 | 2430 | 39.898 | 766.512 | 1154.658 | 14-Dec-21 | |
| C25-2 | 31.95 | 190 | 321.262 | 2430 | 39.785 | 763.379 | 1155.360 | 14-Dec-21 | |
| C25-3 | 32.33 | 190 | 323.692 | 2430 | 39.674 | 760.284 | 1156.024 | 14-Dec-21 | |
| C25-4 | 32.72 | 190 | 326.123 | 2430 | 39.565 | 757.226 | 1156.650 | 14-Dec-21 | |
| C25-5 | 33.10 | 190 | 328.554 | 2430 | 39.457 | 754.205 | 1157.241 | 14-Dec-21 | |
| C25-6 | 33.49 | 190 | 330.985 | 2430 | 39.351 | 751.219 | 1157.796 | 14-Dec-21 | |
| C25-7 | 33.88 | 190 | 333.415 | 2430 | 39.246 | 748.268 | 1158.317 | 14-Dec-21 | |
| C25-8 | 34.26 | 190 | 335.846 | 2430 | 39.143 | 745.350 | 1158.804 | 14-Dec-21 | |
| C25-9 | 34.65 | 190 | 338.277 | 2430 | 39.042 | 742.466 | 1159.257 | 15-Dec-21 | |
| C25-10 | 35.03 | 190 | 340.708 | 2430 | 38.942 | 739.614 | 1159.678 | 15-Dec-21 | |
| C25-11 | 35.42 | 190 | 343.138 | 2430 | 38.843 | 736.794 | 1160.067 | 15-Dec-21 | |
| C25-12 | 35.80 | 190 | 345.569 | 2430 | 38.745 | 734.005 | 1160.425 | 15-Dec-21 | |
| C25-13 | 36.19 | 190 | 348.000 | 2430 | 38.649 | 731.247 | 1160.753 | 15-Dec-21 | |
| C25-14 | 36.58 | 190 | 350.431 | 2430 | 38.555 | 728.519 | 1161.051 | 15-Dec-21 | |
| C25-15 | 36.96 | 190 | 352.862 | 2430 | 38.461 | 725.819 | 1161.319 | 15-Dec-21 | |
| C25-16 | 37.35 | 190 | 355.292 | 2430 | 38.369 | 723.149 | 1161.559 | 15-Dec-21 | |
| C25-17 | 37.73 | 190 | 357.723 | 2430 | 38.278 | 720.506 | 1161.771 | 16-Dec-21 | |
| C25-18 | 38.12 | 190 | 360.154 | 2430 | 38.189 | 717.891 | 1161.955 | 16-Dec-21 | 24 to 28 |
| C25-19 | 38.51 | 190 | 362.585 | 2430 | 38.100 | 715.303 | 1162.113 | 16-Dec-21 | |
| C25-20 | 38.89 | 190 | 365.015 | 2430 | 38.013 | 712.741 | 1162.244 | 16-Dec-21 | |
| C25-21 | 39.28 | 190 | 367.446 | 2430 | 37.927 | 710.205 | 1162.349 | 16-Dec-21 | |
| C25-22 | 39.66 | 190 | 369.877 | 2430 | 37.842 | 707.694 | 1162.429 | 16-Dec-21 | |
| C25-23 | 40.05 | 190 | 372.308 | 2430 | 37.758 | 705.208 | 1162.484 | 16-Dec-21 | |
| C25-24 | 40.44 | 190 | 374.738 | 2430 | 37.676 | 702.747 | 1162.515 | 16-Dec-21 | |
| C25-25 | 40.82 | 190 | 377.169 | 2430 | 37.594 | 700.309 | 1162.522 | 17-Dec-21 | |
| C25-26 | 41.21 | 190 | 379.600 | 2430 | 37.513 | 697.895 | 1162.505 | 17-Dec-21 | |
| C25-27 | 41.59 | 190 | 382.031 | 2430 | 37.434 | 695.504 | 1162.465 | 17-Dec-21 | |
| C25-28 | 41.98 | 190 | 384.462 | 2430 | 37.355 | 693.135 | 1162.403 | 17-Dec-21 | |
| C25-29 | 42.36 | 190 | 386.892 | 2430 | 37.277 | 690.789 | 1162.319 | 17-Dec-21 | |
| C25-30 | 42.75 | 190 | 389.323 | 2430 | 37.201 | 688.464 | 1162.213 | 17-Dec-21 | |
| C25-31 | 43.14 | 190 | 391.754 | 2430 | 37.125 | 686.161 | 1162.085 | 17-Dec-21 | |
| C25-32 | 43.52 | 191 | 396.259 | 2430 | 37.050 | 682.739 | 1160.002 | 17-Dec-21 | |
| C25-33 | 43.91 | 192 | 400.790 | 2430 | 36.976 | 679.333 | 1157.877 | 22-Dec-21 | |
| C25-34 | 44.29 | 193 | 405.347 | 2430 | 36.903 | 675.942 | 1155.711 | 22-Dec-21 | |
| C25-35 | 44.68 | 194 | 409.929 | 2430 | 36.831 | 672.566 | 1153.505 | 22-Dec-21 | |
| | **Mix Design Developed By:** | | | | Masala Mwiko | | | | |
| | **Concrete mixing & Cube casting carried out by:** | | | | Chimpipa Kaeimbwe, Irvin Nchinga Chingumbe & Masala Mwiko | | | | |

## Appendix M: Mix Design Results Developed for C30

| Sample No. | TMS (MPa) | Water (kg/m³) | Cement (kg/m³) | Density of Fresh Concrete (kg/m³) | % of Fine (kg/m³) | F.A (kg/m³) | C.A (kg/m³) | Date of Casting | Laboratory Room Temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|
| C30-1 | 37.00 | 190 | 347.846 | 2430 | 38.7 | 732.264 | 1159.890 | 18-Dec-21 | |
| C30-2 | 37.44 | 190 | 351.781 | 2430 | 38.5 | 726.964 | 1161.255 | 18-Dec-21 | |
| C30-3 | 37.87 | 190 | 355.715 | 2430 | 38.4 | 723.565 | 1160.719 | 18-Dec-21 | |
| C30-4 | 38.31 | 190 | 359.650 | 2430 | 38.2 | 718.294 | 1162.056 | 18-Dec-21 | |
| C30-5 | 38.75 | 190 | 363.585 | 2430 | 38.1 | 714.914 | 1161.501 | 18-Dec-21 | |
| C30-6 | 39.19 | 190 | 367.519 | 2430 | 37.9 | 709.670 | 1162.811 | 18-Dec-21 | |
| C30-7 | 39.62 | 190 | 371.454 | 2430 | 37.8 | 706.310 | 1162.236 | 18-Dec-21 | |
| C30-8 | 40.06 | 190 | 375.388 | 2430 | 37.7 | 702.959 | 1161.653 | 18-Dec-21 | |
| C30-9 | 40.50 | 190 | 379.323 | 2430 | 37.5 | 697.754 | 1162.923 | 19-Dec-21 | |
| C30-10 | 40.94 | 190 | 383.258 | 2430 | 37.4 | 694.422 | 1162.321 | 19-Dec-21 | |
| C30-11 | 41.37 | 190 | 387.192 | 2430 | 37.3 | 691.097 | 1161.710 | 19-Dec-21 | |
| C30-12 | 41.81 | 190 | 391.127 | 2430 | 37.1 | 685.932 | 1162.941 | 19-Dec-21 | |
| C30-13 | 42.25 | 190 | 395.062 | 2430 | 37.0 | 682.627 | 1162.311 | 19-Dec-21 | |
| C30-14 | 42.69 | 190 | 398.996 | 2430 | 36.9 | 679.330 | 1161.673 | 19-Dec-21 | |
| C30-15 | 43.12 | 190 | 402.931 | 2430 | 36.8 | 676.041 | 1161.028 | 19-Dec-21 | |
| C30-16 | 43.56 | 190 | 406.865 | 2430 | 36.7 | 672.760 | 1160.374 | 19-Dec-21 | 24 to 28 |
| C30-17 | 44.00 | 190 | 410.800 | 2430 | 36.6 | 669.487 | 1159.713 | 20-Dec-21 | |
| C30-18 | 44.43 | 190 | 414.735 | 2430 | 36.5 | 666.222 | 1159.044 | 20-Dec-21 | |
| C30-19 | 44.87 | 190 | 418.669 | 2430 | 36.3 | 661.143 | 1160.188 | 20-Dec-21 | |
| C30-20 | 45.31 | 190 | 422.604 | 2430 | 36.2 | 657.897 | 1159.499 | 20-Dec-21 | |
| C30-21 | 45.75 | 190 | 426.538 | 2430 | 36.1 | 654.660 | 1158.802 | 20-Dec-21 | |
| C30-22 | 46.18 | 190 | 430.473 | 2430 | 36.0 | 651.430 | 1158.097 | 20-Dec-21 | |
| C30-23 | 46.62 | 190 | 434.408 | 2430 | 35.9 | 648.208 | 1157.385 | 20-Dec-21 | |
| C30-24 | 47.06 | 190 | 438.342 | 2430 | 35.8 | 644.993 | 1156.664 | 20-Dec-21 | |
| C30-25 | 47.50 | 190 | 442.277 | 2430 | 35.7 | 641.787 | 1155.936 | 21-Dec-21 | |
| C30-26 | 47.93 | 190 | 446.212 | 2430 | 35.6 | 638.589 | 1155.200 | 21-Dec-21 | |
| C30-27 | 48.37 | 190 | 450.146 | 2430 | 35.6 | 637.188 | 1152.666 | 21-Dec-21 | |
| C30-28 | 48.81 | 190 | 454.081 | 2430 | 35.5 | 634.001 | 1151.918 | 21-Dec-21 | |
| C30-29 | 49.25 | 190 | 458.015 | 2430 | 35.4 | 630.823 | 1151.162 | 21-Dec-21 | |
| C30-30 | 49.68 | 190 | 461.950 | 2430 | 35.3 | 627.652 | 1150.398 | 21-Dec-21 | |
| C30-31 | 50.12 | 190 | 465.885 | 2430 | 35.2 | 624.489 | 1149.627 | 21-Dec-21 | |
| | **Mix Design Developed By:** | | | | Masala Mwiko | | | | |
| | **Concrete mixing & Cube casting carried out By:** | | | | Chimpipa Kaeimbwe, Irvin Nchinga Chingumbe & Masala Mwiko | | | | |

## Appendix N: Concrete Strength Results for Class C20

| Sample No. | Measured slump (mm) | Avg. Mass of cured cube at 28 day (kg) | Strength of Specimen @ 28 day (MPa) | | | Avg. Strength (MPa) | Date of Crushing | Laboratory Room Temperature (°C) |
|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | | | |
| C20-1 | 50 | 8.43 | 21.800 | 19.620 | 19.184 | 20.201 | 08-Jan-22 | 24 to 28 |
| C20-2 | 49 | 8.60 | 21.364 | 21.800 | 25.724 | 22.963 | 08-Jan-22 | |
| C20-3 | 46 | 8.26 | 20.056 | 20.056 | 20.492 | 20.201 | 08-Jan-22 | |
| C20-4 | 46 | 8.48 | 22.672 | 20.928 | 21.364 | 21.655 | 08-Jan-22 | |
| C20-5 | 45 | 8.57 | 23.544 | 21.800 | 22.672 | 22.672 | 08-Jan-22 | |
| C20-6 | 45 | 8.52 | 20.928 | 21.364 | 21.887 | 21.393 | 08-Jan-22 | |
| C20-7 | 44 | 8.54 | 22.846 | 23.370 | 22.236 | 22.817 | 08-Jan-22 | |
| C20-8 | 45 | 8.39 | 22.585 | 23.108 | 24.896 | 23.529 | 09-Jan-22 | |
| C20-9 | 44 | 8.53 | 20.492 | 21.887 | 21.974 | 21.451 | 09-Jan-22 | |
| C20-10 | 44 | 8.63 | 24.067 | 22.062 | 24.939 | 23.689 | 09-Jan-22 | |
| C20-11 | 43 | 8.46 | 20.666 | 23.544 | 20.928 | 21.713 | 09-Jan-22 | |
| C20-12 | 45 | 8.59 | 25.724 | 26.160 | 24.914 | 25.599 | 09-Jan-22 | |
| C20-13 | 44 | 8.63 | 24.678 | 24.852 | 24.765 | 24.765 | 09-Jan-22 | |
| C20-14 | 45 | 8.59 | 23.108 | 21.800 | 24.416 | 23.108 | 09-Jan-22 | |
| C20-15 | 44 | 8.51 | 25.811 | 27.032 | 27.468 | 26.770 | 09-Jan-22 | |
| C20-16 | 42 | 8.70 | 29.910 | 27.468 | 30.128 | 29.168 | 10-Jan-22 | |
| C20-17 | 43 | 8.55 | 29.604 | 25.288 | 26.334 | 27.076 | 10-Jan-22 | |
| C20-18 | 43 | 8.86 | 26.596 | 25.724 | 27.032 | 26.451 | 10-Jan-22 | |
| C20-19 | 40 | 8.64 | 29.386 | 29.648 | 27.032 | 28.689 | 10-Jan-22 | |
| C20-20 | 39 | 8.42 | 27.642 | 26.596 | 25.724 | 26.654 | 10-Jan-22 | |
| C20-21 | 39 | 8.62 | 30.084 | 32.526 | 31.043 | 31.218 | 10-Jan-22 | |
| C20-22 | 42 | 8.55 | 26.160 | 23.980 | 22.759 | 24.300 | 10-Jan-22 | |
| C20-23 | 41 | 8.53 | 26.247 | 27.904 | 27.904 | 27.352 | 10-Jan-22 | |
| C20-24 | 40 | 8.52 | 25.201 | 26.422 | 27.206 | 26.276 | 11-Jan-22 | |
| C20-25 | 40 | 8.53 | 28.514 | 27.468 | 27.904 | 27.962 | 11-Jan-22 | |
| C20-26 | 37 | 8.46 | 27.555 | 29.474 | 29.822 | 28.950 | 11-Jan-22 | |
| C20-27 | 36 | 8.63 | 32.264 | 29.386 | 34.008 | 31.886 | 11-Jan-22 | |
| C20-28 | 35 | 8.67 | 28.340 | 26.204 | 25.288 | 26.611 | 11-Jan-22 | |
| C20-29 | 38 | 8.55 | 27.555 | 29.648 | 27.642 | 28.282 | 11-Jan-22 | |
| C20-30 | 33 | 8.59 | 26.683 | 26.770 | 27.032 | 26.829 | 11-Jan-22 | |
| C20-31 | 32 | 8.35 | 33.310 | 30.869 | 32.700 | 32.293 | 11-Jan-22 | |
| C20-32 | 31 | 8.52 | 23.980 | 23.544 | 26.160 | 24.561 | 20-Jan-22 | |
| C20-33 | 29 | 8.58 | 28.514 | 26.552 | 26.945 | 27.337 | 20-Jan-22 | |
| C20-34 | 30 | 8.39 | 33.136 | 33.659 | 31.828 | 32.874 | 20-Jan-22 | |
| C20-35 | 29 | 8.71 | 26.509 | 28.776 | 28.078 | 27.788 | 20-Jan-22 | |
| **Tested By:** | Chimpipa Kaeimbwe, Irvin Nchinga Chingumbe and Masala Mwiko | | | | | | | |
| **Checked By:** | Masala Mwiko | | | | | | | |

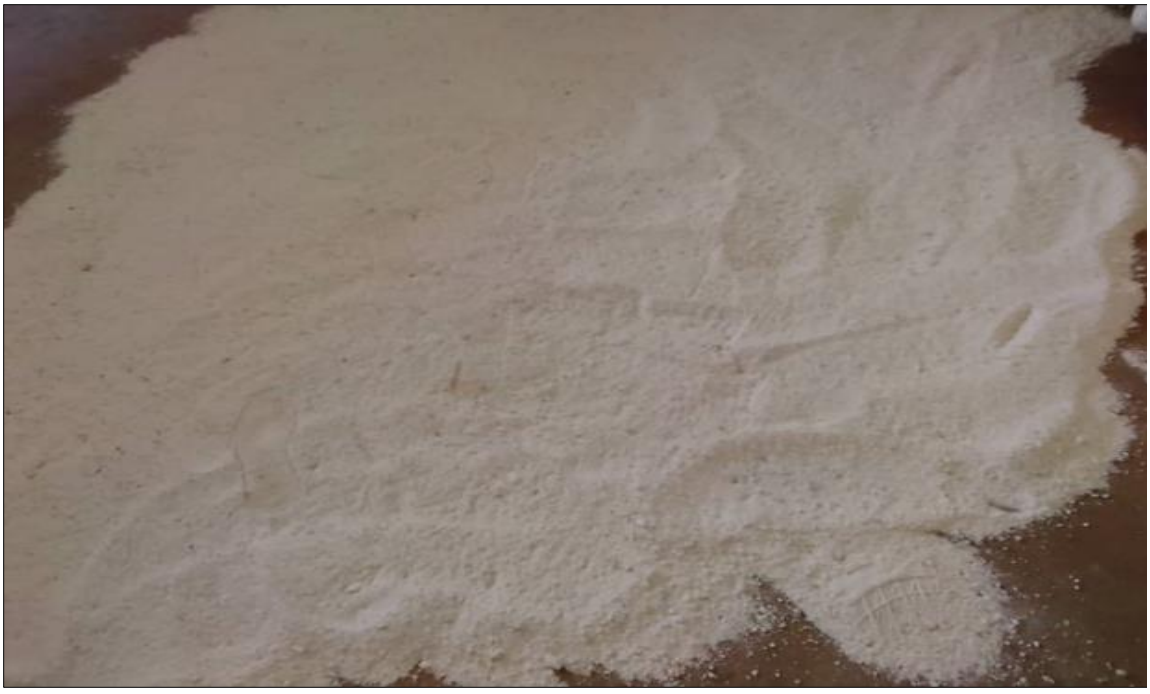
## Appendix O: Concrete Strength Results for Class C25

| Sample No. | Measured slump (mm) | Avg. Mass of cured cube at 28 day (kg) | Strength of Specimen @ 28 day (MPa) | | | Avg. Strength (MPa) | Date of Crushing | Laboratory Room Temperature (°C) |
|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | | | |
| C25-1 | 41 | 8.51 | 26.811 | 27.032 | 27.468 | 27.104 | 12-Jan-22 | 24 to 28 |
| C25-2 | 40 | 8.70 | 29.910 | 28.468 | 30.128 | 29.502 | 12-Jan-22 | |
| C25-3 | 40 | 8.42 | 28.514 | 26.334 | 27.163 | 27.337 | 12-Jan-22 | |
| C25-4 | 40 | 8.86 | 26.596 | 25.724 | 27.032 | 26.451 | 12-Jan-22 | |
| C25-5 | 39 | 8.57 | 26.160 | 28.602 | 27.032 | 27.265 | 12-Jan-22 | |
| C25-6 | 38 | 8.64 | 29.386 | 29.648 | 28.032 | 29.022 | 12-Jan-22 | |
| C25-7 | 38 | 8.42 | 27.642 | 26.596 | 25.724 | 26.654 | 12-Jan-22 | |
| C25-8 | 37 | 8.47 | 25.084 | 24.726 | 24.936 | 24.915 | 12-Jan-22 | |
| C25-9 | 37 | 8.62 | 30.084 | 32.526 | 31.043 | 31.218 | 13-Jan-22 | |
| C25-10 | 36 | 8.55 | 26.160 | 25.980 | 25.759 | 25.966 | 13-Jan-22 | |
| C25-11 | 36 | 8.62 | 30.694 | 28.078 | 29.735 | 29.503 | 13-Jan-22 | |
| C25-12 | 33 | 8.65 | 27.206 | 28.166 | 26.770 | 27.381 | 13-Jan-22 | |
| C25-13 | 34 | 8.54 | 27.119 | 26.509 | 25.680 | 26.436 | 13-Jan-22 | |
| C25-14 | 34 | 8.73 | 26.073 | 27.770 | 27.468 | 27.104 | 13-Jan-22 | |
| C25-15 | 35 | 8.79 | 29.648 | 26.596 | 28.689 | 28.311 | 13-Jan-22 | |
| C25-16 | 33 | 8.67 | 27.940 | 28.904 | 27.288 | 28.044 | 13-Jan-22 | |
| C25-17 | 33 | 8.63 | 30.032 | 29.863 | 31.392 | 30.429 | 14-Jan-22 | |
| C25-18 | 32 | 8.46 | 27.119 | 26.160 | 26.334 | 26.538 | 14-Jan-22 | |
| C25-19 | 32 | 8.43 | 26.247 | 25.724 | 26.160 | 26.044 | 14-Jan-22 | |
| C25-20 | 30 | 8.59 | 26.683 | 26.770 | 27.032 | 26.829 | 14-Jan-22 | |
| C25-21 | 30 | 8.35 | 33.310 | 31.869 | 32.700 | 32.626 | 14-Jan-22 | |
| C25-22 | 31 | 8.52 | 25.980 | 25.544 | 26.160 | 25.895 | 14-Jan-22 | |
| C25-23 | 30 | 8.58 | 28.514 | 26.552 | 26.945 | 27.337 | 14-Jan-22 | |
| C25-24 | 29 | 8.40 | 30.084 | 30.607 | 31.828 | 30.840 | 14-Jan-22 | |
| C25-25 | 28 | 8.58 | 30.433 | 28.163 | 29.386 | 29.327 | 15-Jan-22 | |
| C25-26 | 29 | 8.64 | 28.340 | 29.735 | 27.468 | 28.514 | 15-Jan-22 | |
| C25-27 | 27 | 8.68 | 29.648 | 31.392 | 30.084 | 30.375 | 15-Jan-22 | |
| C25-28 | 26 | 8.43 | 26.770 | 27.032 | 26.073 | 26.625 | 15-Jan-22 | |
| C25-29 | 25 | 8.49 | 33.180 | 32.700 | 33.136 | 33.005 | 15-Jan-22 | |
| C25-30 | 23 | 8.39 | 30.520 | 29.735 | 30.520 | 30.258 | 15-Jan-22 | |
| C25-31 | 24 | 8.41 | 28.912 | 27.684 | 29.401 | 28.666 | 15-Jan-22 | |
| C25-32 | 23 | 8.70 | 31.451 | 29.530 | 30.862 | 30.614 | 15-Jan-22 | |
| C25-33 | 24 | 8.63 | 30.258 | 29.168 | 29.212 | 29.546 | 20-Jan-22 | |
| C25-34 | 25 | 8.57 | 30.072 | 29.030 | 31.933 | 30.345 | 20-Jan-22 | |
| C25-35 | 20 | 8.32 | 31.525 | 31.405 | 30.500 | 31.143 | 20-Jan-22 | |
| **Tested By:** | Chimpipa Kaeimbwe, Irvin Nchinga Chingumbe and Masala Mwiko | | | | | | | |
| **Checked By:** | Masala Mwiko | | | | | | | |

## Appendix P: Concrete Strength Results for Class C30

| Sample No. | Measured slump (mm) | Avg. Mass of cured cube at 28 day (kg) | Strength of Specimen @ 28 day (MPa) | | | Avg. Strength (MPa) | Date of Crushing | Laboratory Room Temperature (°C) |
|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | | | |
| C30-1 | 30 | 8.630 | 30.357 | 29.260 | 29.304 | 29.640 | 16-Jan-22 | 24 to 28 |
| C30-2 | 29 | 8.535 | 30.185 | 30.986 | 31.260 | 30.810 | 16-Jan-22 | |
| C30-3 | 28 | 8.393 | 31.582 | 28.821 | 33.250 | 31.218 | 16-Jan-22 | |
| C30-4 | 28 | 8.686 | 33.515 | 31.904 | 30.239 | 31.886 | 16-Jan-22 | |
| C30-5 | 27 | 8.698 | 32.164 | 30.165 | 31.550 | 31.293 | 16-Jan-22 | |
| C30-6 | 33 | 8.300 | 31.042 | 32.357 | 32.224 | 31.874 | 16-Jan-22 | |
| C30-7 | 30 | 8.716 | 30.577 | 31.022 | 30.920 | 30.840 | 16-Jan-22 | |
| C30-8 | 28 | 8.698 | 32.739 | 33.085 | 32.930 | 32.918 | 16-Jan-22 | |
| C30-9 | 29 | 8.575 | 31.412 | 30.816 | 30.335 | 30.854 | 17-Jan-22 | |
| C30-10 | 27 | 8.491 | 32.139 | 33.613 | 36.264 | 34.005 | 17-Jan-22 | |
| C30-11 | 27 | 8.681 | 32.639 | 31.367 | 33.118 | 32.375 | 17-Jan-22 | |
| C30-12 | 28 | 8.387 | 33.663 | 34.558 | 35.554 | 34.592 | 17-Jan-22 | |
| C30-13 | 30 | 8.482 | 35.551 | 34.006 | 34.286 | 34.614 | 17-Jan-22 | |
| C30-14 | 26 | 8.629 | 35.630 | 34.736 | 35.480 | 35.282 | 17-Jan-22 | |
| C30-15 | 25 | 8.569 | 34.311 | 34.872 | 32.912 | 34.032 | 17-Jan-22 | |
| C30-16 | 24 | 8.393 | 34.579 | 35.260 | 36.860 | 35.566 | 17-Jan-22 | |
| C30-17 | 25 | 8.350 | 34.318 | 34.728 | 33.232 | 34.093 | 18-Jan-22 | |
| C30-18 | 27 | 8.367 | 35.408 | 34.375 | 35.408 | 35.064 | 18-Jan-22 | |
| C30-19 | 25 | 8.657 | 39.461 | 35.325 | 37.620 | 37.469 | 18-Jan-22 | |
| C30-20 | 25 | 8.639 | 34.803 | 38.042 | 36.068 | 36.304 | 18-Jan-22 | |
| C30-21 | 20 | 8.776 | 38.189 | 36.359 | 34.857 | 36.468 | 18-Jan-22 | |
| C30-22 | 18 | 8.483 | 37.749 | 38.160 | 34.108 | 36.672 | 18-Jan-22 | |
| C30-23 | 20 | 8.655 | 38.083 | 36.470 | 38.899 | 37.817 | 18-Jan-22 | |
| C30-24 | 15 | 8.525 | 39.141 | 35.254 | 39.494 | 37.963 | 18-Jan-22 | |
| C30-25 | 15 | 8.726 | 35.713 | 37.893 | 38.682 | 37.429 | 19-Jan-22 | |
| C30-26 | 14 | 8.616 | 38.323 | 35.341 | 41.402 | 38.355 | 19-Jan-22 | |
| C30-27 | 13 | 8.249 | 39.452 | 37.314 | 36.368 | 37.711 | 19-Jan-22 | |
| C30-28 | 12 | 8.692 | 37.347 | 39.650 | 35.929 | 37.642 | 19-Jan-22 | |
| C30-29 | 10 | 8.589 | 35.460 | 37.908 | 36.068 | 36.479 | 19-Jan-22 | |
| C30-30 | 10 | 8.792 | 38.930 | 35.195 | 42.245 | 38.790 | 19-Jan-22 | |
| C30-31 | 11 | 8.748 | 39.191 | 39.288 | 39.677 | 39.385 | 19-Jan-22 | |
| **Tested By:** | Chimpipa Kaeimbwe, Irvin Nchinga Chingumbe and Masala Mwiko | | | | | | | |
| **Checked By:** | Masala Mwiko | | | | | | | |

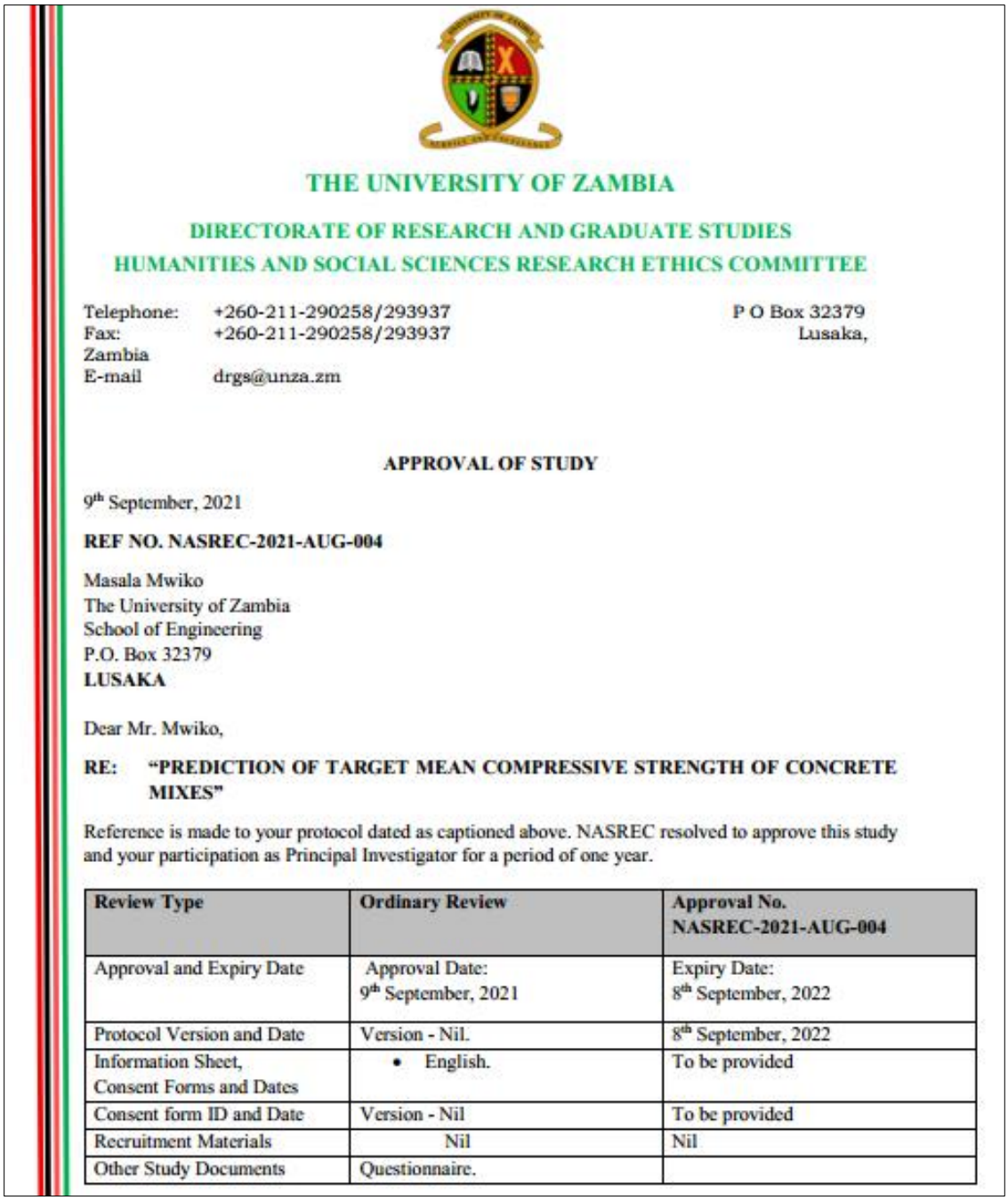
## Appendix Q: Pictures of Aggregate Materials used for Laboratory Experiments



(a) Fine Aggregates

(b) Coarse Aggregates

## Appendix R: Approval of Study Letter



THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

HUMANITIES AND SOCIAL SCIENCES RESEARCH ETHICS COMMITTEE

Telephone: +260-211-290258/293937
Fax: +260-211-290258/293937
Zambia
E-mail drgs@unza.zm

P O Box 32379
Lusaka,

**APPROVAL OF STUDY**

9th September, 2021

**REF NO. NASREC-2021-AUG-004**

Masala Mwiko
The University of Zambia
School of Engineering
P.O. Box 32379
**LUSAKA**

Dear Mr. Mwiko,

**RE: "PREDICTION OF TARGET MEAN COMPRESSIVE STRENGTH OF CONCRETE MIXES"**

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

| **Review Type** | **Ordinary Review** | **Approval No. NASREC-2021-AUG-004** |
|---|---|---|
| Approval and Expiry Date | Approval Date: 9th September, 2021 | Expiry Date: 8th September, 2022 |
| Protocol Version and Date | Version - Nil. | 8th September, 2022 |
| Information Sheet, Consent Forms and Dates | • English. | To be provided |
| Consent form ID and Date | Version - Nil | To be provided |
| Recruitment Materials | Nil | Nil |
| Other Study Documents | Questionnaire. | |

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

**Conditions of Approval**

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled "late submissions" and will incur a penaltyfee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.
- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO),both NASREC
- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.
- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.
- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.
- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

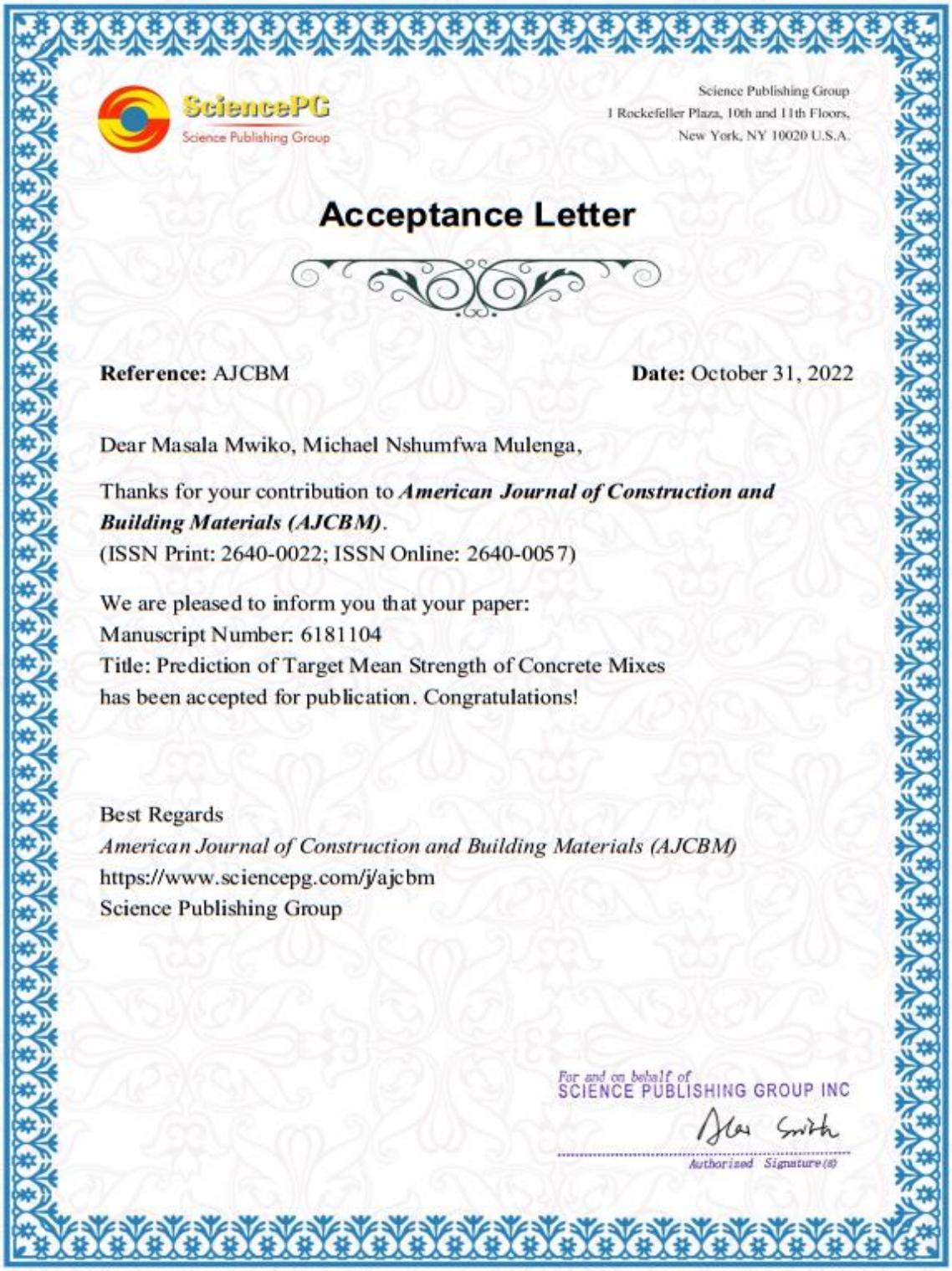
Yours faithfully,

Dr. Mususu Kaonda

**VICE CHAIRPERSON**
**THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB**

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies

**Appendix S: Acceptance Letter for Publication**



SciencePG
Science Publishing Group

Science Publishing Group
1 Rockefeller Plaza, 10th and 11th Floors,
New York, NY 10020 U.S.A.

## Acceptance Letter

**Reference:** AJCBM **Date:** October 31, 2022

Dear Masala Mwiko, Michael Nshumfwa Mulenga,

Thanks for your contribution to ***American Journal of Construction and Building Materials (AJCBM)***.
(ISSN Print: 2640-0022; ISSN Online: 2640-0057)

We are pleased to inform you that your paper:
Manuscript Number: 6181104
Title: Prediction of Target Mean Strength of Concrete Mixes
has been accepted for publication. Congratulations!

Best Regards
*American Journal of Construction and Building Materials (AJCBM)*
https://www.sciencepg.com/j/ajcbm
Science Publishing Group

For and on behalf of
SCIENCE PUBLISHING GROUP INC

Authorized Signature (s)

## Appendix T: Certificate of Publication

SciencePG
Science Publishing Group

Science Publishing Group
1 Rockefeller Plaza, 10th and 11th Floors,
New York, NY 10020 U.S.A.

**Certificate of Publication**

**Reference:** AJCBM **Date:** December 15, 2022

The certificate is awarded to

**Masala Mwiko**

In recognition of the publication of your paper titled "Prediction of Target Mean Strength of Concrete Mixes"
in ***American Journal of Construction and Building Materials*** (Vol. 6, Issue Number 2, December 2022)
ISSN Print: 2640-0022; ISSN Online: 2640-0057
JOURNALWEBSITE

For and on behalf of
SCIENCE PUBLISHING GROUP INC
Authorized Signature(s)