Council for the Regulation of Engineering In Nigeria

CONCRETE MIX DESIGN MANUAL

SPECIAL PUBLICATION NO. COREN/2017/016/RC

FIRST EDITION: AUGUST 2017

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FOREWORD

It is with deep sense of joy that the Council for the Regulation of Engineering in Nigeria, **COREN**, present the Concrete Mix Design Manual for Nigeria. This is indeed historic, as sad as it is, we must admit that this is the first of its type as the nation had never had her own Concrete Mix Design Manual. Like in many areas of our national life, we had all these years depended on the Concrete Mix Design Manual of other nations irrespective of their sharp differences in their environmental and other factors.

The challenge was heightened when in 2014, controversies became pervasive as to classes and qualities of cement. Eventhough the issues on the subject were promptly put to rest with the conclusion that cement classification does not cause building collapse but rather its application.

This, and the need to take up a national industry challenge, compelled COREN to commence the project of producing the Concrete Mix Design Manual for Nigeria.

The journey has been chequered with various challenges all of which were proficiently surmounted in the course of the project.

It started with the formation of a Technical Committee with membership carefully selected from the academia and the industry. The work of the Committee included laboratory tests, the results of which were variously subjected to further confirmation tests carried out in various Universities in the geo-political zones of Nigeria. The work was further subjected to critique analysis to arrive at a document that has no doubt, met international standard and the test of time.

The Concrete Mix Design Manual for Nigeria, like any document of this nature must be subjected to periodic review. Every reference document goes obsolete if left to drift for eternity, that is, without review.

The Manual, for practitioners in Nigeria using concrete, must now replace the foreign manuals which has produced the danger of non-uniformity because of diverse sources. The Concrete Mix Design Manual for Nigeria, therefore, provides homogeneity for all concrete design.

In the application of this manual, a trial mix is mandatory for any major construction site in Nigeria.

On behalf of the COREN, I wish to express my profound appreciation to the Chairman and members of the Technical Committee, the various construction companies which readily gave their support to this project, the Universities ***(especially the University of Uyo, Uyo)*** which made their laboratories and personnel available, the Management and staff of the Nigerian Building and Road Research Institute, ***NBRRI, Lafarge Cement, Dangote Cement*** and those of COREN who committed so much of their time and energy to this project.

This is indeed a historic achievement but opening the window of challenges in our need to develop our indigenous Codes and standards as we take Engineering Practice to higher levels in Nigeria.

Engr. Kashim A. Ali, FNSE, mni
President, COREN
August, 2017

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Part one: Introduction to Concrete Mix Design

1.1. Scope

This manual provides guidelines for the determination of the appropriate concrete mixes required for various construction applications. It provides a step by step procedure required for deducing the appropriate quantities of constituents required to achieve concrete with specified characteristics in accordance to EN 206. This manual is applicable for designing concrete mixes using Portland Limestone Cements conforming to NIS 444-1 and natural aggregates in conformity to EN 12620. With the advent of various strength classes of cement for construction, it is now possible to use any strength class of cement to obtain concrete of a specified characteristic strength provided the mix design is carried out appropriately. This mix design manual sets out the guidelines for concrete mixes in Nigeria.

1.2. Concept of Mix Design

Concrete can be designed for strength ranging from 10MPa to 100MPa(note that MPa is used instead of N/mm^2 throughout this manual)making it an extremely versatile building material. In all these cases, the basic constituents remain the same, but it is their relative proportions that determine the properties.

In designing a concrete mix, the primary objective is to select suitable constituent materials and determine their required amounts in order to produce concrete of specific characteristics and properties as economically as possible. The characteristics typically specified are workability, strength and durability. Other characteristics that may be required includes; density, thermal characteristics, elastic modulus etc.

However, the mix design process only considers the factors which have a major effect on the properties of concrete i.e. workability, strength and durability. The proportioning of the constituent materials of concrete is dependent on the required performance of concrete in two states: the fresh/plastic and hardened states.

Four variable factors need to be considered in mix proportioning:

i. Water-cement ratio
ii. Cement content
iii. Gradation of aggregates
iv. Consistency

Typically, two or three factors are specified and the others are adjusted to achieve minimum workability and economy. In summary, the goal of mix proportioning is to use the minimum quantity of cement that will lubricate the mixture when fresh to allow for adequate placing and at the same time, bind the aggregates together and fill up the voids between them when the concrete has hardened. Any excess of paste results in a higher cost, higher drying shrinkage.

1.3. Requirements of Concrete Mix Design

At the mix design stage, available data for deriving the required proportions of constituent materials is usually limited. The data provided in this manual are estimates and should be replaced where there is more appropriate data with regards to the local materials.

The necessary data required can be classified into two categories viz a viz:

a. Specified variables: These are variables which are normally selected in the specifications based on intended use of the concrete. They include:

- The minimum compressive strength required for the intended use of the concrete
- Adequate workability required for placement and full compaction with the available compaction equipment
- Maximum water-cement ratio
- Maximum/minimum cement content required to provide adequate durability for the specified exposure conditions
- Strength class of cement
- Maximum aggregate size

b. Additional information: This refers to data on the available materials required for the concrete mix. They include:

- The standard deviation which is a measure of the variability from the specified characteristic strength
- The type of aggregate
- Specific gravity of aggregate
- Grading of fine aggregate

Understanding the basic concept of mix design is as significant as the actual calculations required for determining the mix proportions. In fact, the appropriate mix proportions are a consequence of the concrete mix design.

1.4. Variability of Concrete Strength

In the production of concrete, there are inevitable variations in the properties of the materials used as well as the construction methods. For instance, the quality of various batches of cement supplied may vary, or the grading and particle shape of the aggregates may vary. These variations may even be observed within a batch as a result of process of sampling, production, curing and testing of specimens even if they are conducted in accordance with the recommended standard. This results in variation of strength from batch to batch and also within a batch. This makes the strength of the final product difficult to assess.

In concrete mix design, it is now generally accepted that the variation in concrete strengths follow the normal distribution curve shown in Figure 1.1. The area under the curve represents the total number of test results. If a vertical line is drawn through a specified value, the proportion of results less than that value is represented by the area beneath the curve and to the left hand side of the vertical line as demonstrated in Figure 1.1. The normal distribution curve is defined by two parameters: its mean and standard deviation. The curve is symmetrical about its mean and the standard deviation is a measure of the variability. Typically at a given level of quality control, the standard deviation increases as the specified characteristic strength.

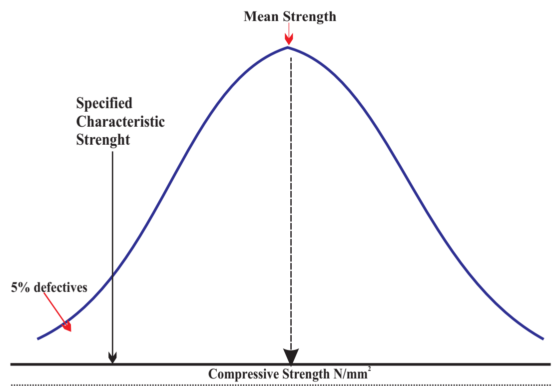

Figure 1: Normal Distribution of Concrete Strengths

This statistical quality control method provides a scientific approach to understanding the variations that are encountered on site so as to provide proper tolerance to allow for inevitable variations. To obtain the standard deviation on site, the minimum number of test samples should be between 20 to 30. The standard deviation used for any calculation should be based on either result obtained from the site, or in the absence of such data, assumed values are specified in different standards.

Most producers of concrete in Nigeria do not have the quality control ability to have small standard deviations. To this end it is suggested that producers without adequate records start with a standard deviation of 6MPa, if thereafter a consecutive result of 30 tests is available, the standard deviation should be based on the result from the 30 consecutive tests. Whenever the producer is convinced that he can achieve a lower standard deviation, he can use that new value for mix design.

1.5. Selecting Mix Characteristics

The primary objective of the mix design is to achieve the specified properties in the most economical manner.

Only with proper selection of the constituent materials and mixture characteristics can the specified properties be obtained in concrete construction. As a result, adequate knowledge of the constituent material properties and properties of concrete in the plastic condition is a prerequisite for a proper mix design. Also, the exposure conditions and the intended use of the concrete are also factored in whilst carrying out the mix design as the characteristics of the concrete should reflect the needs of the structure.

Once the required characteristics have been selected, the mixture is proportioned using data obtained from the field or the laboratory to achieve the specified requirements.

1.6. Decision Variables in Mix Design

The following are the key decision variables when estimating the proportions in a concrete mix:

1.6.1. Water Cement ratio

The water cement ratio is the single most important parameter that determines the strength and durability of concrete. The strength of concrete is dependent on the water cement ratio and not totally on the cement content. According to Abram's law, the higher the water cement ratio, the lower the strength of concrete. It is generally accepted as a rule of thumb that every 1% increase in quantity of water added reduces the strength of concrete by 5%. Theoretically, a water cement ratio of 0.25 is required for the complete hydration of cement. Hence, it is very important to control the water cement ratio on site.

1.6.2. Cement Content

Cement is the binder material in concrete which imparts strength to the concrete. With regards to durability, conditions of exposure govern the maximum cement contents required. For a given workability, a certain water content is required. This implies that a higher cement content would be required to achieve a desired workability at a lower water cement ratio. Based on the relationship between cement content and water cement ratio, we see that a greater water cement ratio would require a lower cement content. Details on properties and types of cement and how they relate to concrete properties are presented in chapter two of this manual.

1.6.3. Relative Proportion of Aggregates

Aggregates in concrete are of two types:

Coarse aggregates which refer to materials retained on 4.75mm sieve size; and Fine aggregates which are materials passing through 4.75mm sieve size. The proportion of fine aggregates to coarse aggregate in a concrete mix depend on the fineness of the fine aggregate, size/shape of coarse aggregates and the cement content. Details of the effect of properties of aggregates on properties of concrete mixes are presented in chapter three

1.7. Factors Affecting Concrete Mix Pro- portions

The process of designing a concrete mix consists of selecting the appropriate proportions of cement, fine aggregate, coarse aggregate and water to produce concrete having specified properties. The most fundamental way of specifying mix proportions is in terms of the mass of material in a unit volume of fully compacted concrete.

The various factors affecting the choice of mix proportions include:

1.7.1. Compressive Strength

The compressive strength of concrete is the most universally used measure for concrete quality. It influences other properties of hardened concrete. Studies have shown that the compressive strength of concrete is inversely proportional to the water cement ratio within practical limit. The strength of the cement paste binder in concrete is dependent on the quality and quantity of the reaction of the paste components and the extent to which the hydration reaction has progressed. The strength of concrete increases with time as long as there is sufficient hydration water/moisture at a favorable temperature. Hence, the strength at a particular age is dependent on both the original water-cement ratio as well as the degree to which the cementitious materials have hydrated. The mean compressive strength at a specific age,

typically 28 days, determines the water-cement ratio of the mix. (Except in pozolanic cement where ages 56 to 90 days may be specified)

1.7.2. Workability

The workability required for various types of construction is dependent on various factors. The Slump test is typically used to determine the degree of workability. For a given proportion of cement and aggregates, the higher the slump, the wetter the mixture and higher the workability.

1.7.3. Durability

Typically, high strength concrete is generally more resistant to adverse conditions as compared to low strength concrete. However, in conditions where high strength is not required but the concrete would be exposed to adverse conditions, the durability requirement will determine the water-cement ratio to be used. See EN 206-1 Concrete - Part 1: Specification, performance, production and Conformity.

Part Two: Nigerian Cement, Aggregate, Admixture And Concrete Standards

2.1. CEMENT.

The Nigerian cement standard NIS 444-1 Cement - Part 1: Composition, specifications and conformity criteria for common cements. This standard defines 27 product in the family of common cement that are grouped into 5 main types.

The types of cements commonly used in Nigeria are Portland Limestone Cements which is in the CEM II class of cement as defined in NIS 444-1. This cement composes of limestone as a blended addition to clinker and gypsum.

Table 1 shows the strengths of various cements available in Nigeria.

CEMENT GRADE	EARLY STRENGTH		STANDARD STRENGTH RANGE		INITIAL SETTING TIME (MINS)	SOUNDNESS (EXPANSION) MM
	2DAYS	7DAYS	28 DAYS			
32.5	-	≥16	≥32.5	≤ 52.5	≥ 60	≥10
32.5R	≥10		≥32.5	≤ 52.5	≥ 60	
42.5	≥10		≥42.5	≤62.5	≥ 60	
42.5R	≥20		≥42.5	≤ 62.5	≥ 60	
52.5	≥20		≥52.5	-	≥ 45	
52.5R	≥20		≥52.5	-	≥ 45	

The above table presents the following facts that should be of interest to the user of concrete products:

A bag of cement labeled Grade 32.5 may contain cement whose strength at 28days is higher than that contained in a bag labeled Grade 42.5 because of the overlap of the strength of the two grades between 32.5MPa and 42.5MPa. What one can then safely say is that the cement in a Grade 32.5 bag has strength of not less than 32.5MPa. Similarly, one can also say that the cement in a Grade 42.5 bag has strength of not less than 42.5MPa. This is important in that those not familiar with this fact could jump to the false conclusion that a particular cement is substandard;

The bag of cement labeled Grade 42.5 may contain cement whose strength at 28days is higher than that contained in a bag labeled Grade 52.5 because of the overlap of the strength of the two grades between 52.5MPa and 62.5MPa. What one can then safely say is that the cement in a Grade 42.5 bag has strength of not less than 42.5MPa. Similarly, one can also say that the cement in a Grade 52.5 bag has strength of not less than 52.5MPa.

This is a very important issue to remember when dealing with cements under this new standard. It should therefore be noted that the actual strength of cement in any bag can only be determined by test – not from the label on the bag. The label only guarantees minimum strength, but a concrete mix design ensures the use of the actual cement strength.

2.1.1. Strength Classes of Cement

The strength classes of cement (i.e 32.5 MPa or 42.5MPa) refer to the minimum strength of cement mortar after 28 days curing and testing as per standard conditions as specified in the NIS 445:2003. The relationship between compressive strength and water cement ratio has been established as a set of curves for the various strength classes of cement. Various types and strength of classes of cements require varying water contents to produce pastes of standard consistency. Hence the water-cement ratio required to achieve the target mean strength is also dependent on the strength class of cement. A higher strength class of cement would produce a higher strength of concrete at the same water cement ratio. Based on the relationship between compressive strength of concrete and the water to cement ratio for the various cement classes, it can be deduced that a lower water to cement ratio would be required to produce a concrete of a specific characteristic strength when using a lower strength class of cement. That is to say, a specified grade of concrete can be produced using any strength class of cement provided the mix design procedure is followed.

2.2. AGGREGATES

Aggregates are the main constituents of concrete because they do not only give the body to the concrete, but they also have a significant effect on the properties of fresh and hardened concrete based on their shape, size, texture, grading and crushing value.

The overall mechanical property of concrete depends on certain properties of aggregates itself. These aggregate properties include the source of aggregates, size of aggregate, shape of aggregate, crushing type of aggregates, angularity index, surface texture, modulus of elasticity, bulk density, specific gravity, absorption and moisture content, grading of aggregates.

For a good concrete mix, aggregates need to be clean, hard, and strong with the particles free of absorbed chemicals or coatings of clay and other fine materials that are likely to interfere with the process of hydration.

2.2.1. Types of Aggregates

Aggregate characteristics have a significant effect on the behavior of fresh and hardened properties of concrete. Aggregate characteristics are function of particle size and as such, the following classification is used in accordance to common practice: material retained in the No.4 sieve (4.75mm) is considered as coarse aggregate; material passing No.4 sieve (4.75mm) and retained in the No. 200 sieve (75µm) is considered as fine aggregate; and material passing No. 200 sieve is referred to as micro-fines.

2.2.2. Properties of Aggregates

The main characteristics of aggregate that affect the performance of fresh and hardened concrete, even though some variation in aggregate properties is expected, are as follows:

Table 2: Aggregate properties and its influence on concrete performance.

Properties	Influence on Concrete Performance
Shape and texture	Bonding, Water Demand, Absorption
Grading	Cohension, Water Demand (Strength)
Mineralogy and coatings	Strength, Water demand
Strength and stiffness	Strength
Maximum size	Strength and Water Demand
Specific gravity or relative density	Strength and Absorption

2.2.3. Shape and Texture

The shape and texture of both coarse and fine aggregates play a significant role in the properties fresh and hardened concrete. The shape and texture of coarse aggregate play an important role on the behavior of fresh and hardened concrete as they affect the demand for fine aggregate.

Table 3: Impact of aggregates shape and texture in concrete.

Aggregate Shape and Texture	Impact
Flaky	Bond Grip, Water Demand.
Angular	High Voids, Requires More Fines, Increases Water Demand.
Elongated	High voids, Poor Bond Grip, Bleeding.
Rough	Good Bond Grip
Poorly shaped aggregates	Increase segregation, Finishing
Cubical or Rounded	Cement saving between 4 or 5%

Flaky and elongated particles should be limited to between 35 to 40 percent, or the shape coefficient determined by Equation 3.1 which should not be less than 0.20.

where is the volume of particle I

is the size of particle I

$$\infty = \frac{V_1 + V_2 + ...V_n}{\frac{\pi}{6}[d_1^3 + d_2^3 + ...d_n^3]} \text{ --------- } 3.1$$

2.2.4. Maximum Size of Aggregate

Maximum size of aggregate, MSA, influences workability, strength, shrinkage, and permeability. Mixtures with large maximum size of coarse aggregate tend to produce concrete with better workability, probably because of the decrease in specific surface. There is an optimal maximum size of coarse aggregate that produces the highest strength for a given consistency and cement content. In high-performance concrete (HPC) with low water-cement ratio and high cement content, a high value of MSA tends to reduce strength. This can be explained by the observation that bond with large particles tends to be weaker than with small particles due to smaller surface area-to-volume ratios. Mixtures with coarse aggregates having large maximum size tends to have reduced shrinkage and creep. Finally, for a given water-cement ratio, the permeability increases as the maximum size of the aggregate increases.

2.2.5. Limit on Deleterious Matter.

In natural sands, deleterious particles like clay minerals and organic matter, mostly present in the minus 63µm portion, increase significantly the demand for water.

It is recommended that the limit of 5% passing 63µm be adopted for use in concrete mix design.

2.2.6. Aggregates in Nigerian Construction Industry

The aggregates commonly available in the Nigerian construction industry are the fine aggregates [sharp sand and stone dust] and coarse aggregates [natural gravel and crushed rock]. In selecting aggregates for use in concrete, the grading curve for such an aggregate is an important parameter for determining its suitability for use.

EN 12620 Aggregate for Concrete provides grading limits within which suitable aggregates are expected to lie.

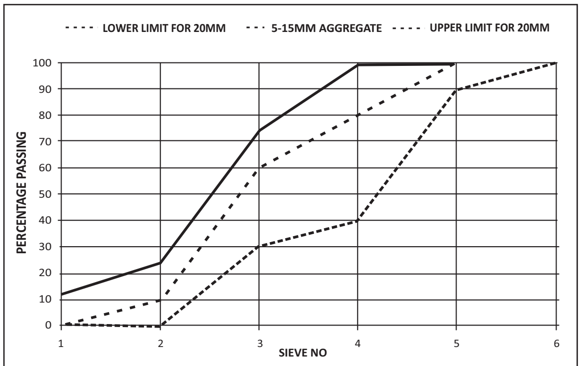

Fig. 2 - Grading curve for 5-15 coarse aggregate

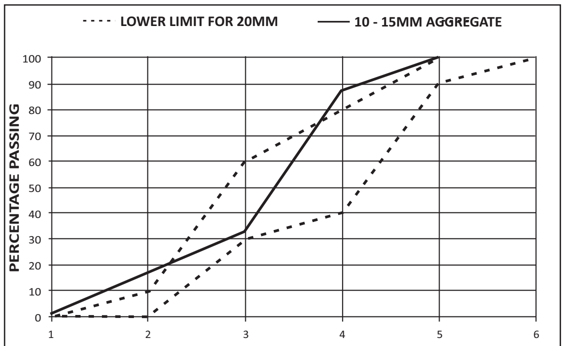

Fig. 3 - Grading curve for 10-15 coarse aggregate

2.2.7. Maximum Nominal Size of Aggregate

The maximum size of coarse aggregate is the standard sieve size through which at least 90% of the coarse aggregates would pass. Typical maximum sizes of aggregate in use in Nigeria are 40mm, 20mm and 10mm with 20mm being the most common. The maximum size of aggregate affects the workability and strength of the concrete. It also affects the required water content for a certain workability and fine aggregate content required for achieving a cohesive mix.

The larger the size of the maximum aggregate, the lower the surface area of the coarse aggregates. With a higher surface area, a higher water content is required to coat the particles and develop workability. Also, a higher maximum size of aggregate would require a lower fine aggregate content to coat the particles and maintain cohesiveness of the concrete mix. This implies that for the same workability, coarse aggregate with maximum size of 40mm would require a lower water cement ratio and thus higher strength compared to coarse aggregate with maximum size of 20mm. However, maximum size of aggregate is restricted by the clear cover and the minimum distance between reinforcement bars. See EN 12620 Aggregates for Concrete.

2.2.8. Grading and Type of Aggregate

Typically, aggregates can be single sized or graded in terms of particle size distribution. The grading of aggregate is significant in achieving a dense and cohesive concrete mix. The voids created by the larger coarse aggregates are filled by the smaller coarse aggregates and hence, the volume of cement-sand-water paste required to fill the final voids is minimum. By proper grading of coarse aggregate, the compactibility of concrete is improved and segregation is minimized especially for higher workability.

The type and source of aggregate also has a significant effect on the compressive strength of concrete. Typical aggregates in use in Nigeria can be categorized in the crushed and uncrushed classes. It is widely accepted that concrete produced from crushed aggregate has a higher strength compared to concrete produced from uncrushed aggregates. This can be attributed to the rough surface texture of the crushed aggregates which gives it a better bonding with the cement gel. The grading of aggregate is significant in attaining an economical mix as it affects the amount of concrete that can be obtained with a given amount of cement and water.

2.3. ADMIXTURES

Admixtures are constituent materials other than Portland cement, aggregate and water added to concrete mixture before or during mixing to modify one or more characteristic of concrete either in the wet or hardened state. Admixtures can be group into two major group as Mineral admixtures and Chemical Admixtures.

2.3.1. Mineral Admixtures

Mineral admixtures are either naturally occurring or as by-product of industrial processes. They are known as supplementary cementing materials, which could be blended with clinker to produce blended or composite cement as specified in NIS 444-1 Mineral admixture could also be added during production of cement to alter characteristic performance of concrete.

2.3.1.1. Types of Mineral Admixtures

- Ground Granulated Blast Furnace Slag
- Fly Ash (Siliceous or Calcareous)
- Silica Fume
- Rice husk Ash and Metakaolin which are the result of controlled calcination of rice husk and kaolinite clay falls under the calcined pozolana etc.

2.3.2. Chemical Admixtures

Chemical Admixture are chemical additives added to concrete to alter the characteristic either at the wet or hardened state. The composition and the performance criteria are listed in EN 934-2 Admixtures for Concrete Mortar and Grout.

2.3.2.1. Types of Chemical Admixtures

- Water reducing/Plasticizing
- High-range water reducing/super-plasticizing
- Water retaining (Reduces Bleeding)
- Water resisting (for Waterproofing)
- Air Entraining
- Set Retarding
- Set Accelerating
- Hardening Accelerating

Others are;

- Set retarding/water reducing/ plasticizing.
- Set retarding/high-range water reducing/super-plasticizing.
- Set Accelerating/water reducing/ plasticizing.

Admixture could be used singularly or in combinations to attain any desired performance effect in concrete.

2.4. CONCRETE GRADES

Concrete is generally designed in grades which, in Nigeria, correspond to classes of strength and therefore categories of concrete below those shown in the Table 5 should never be used. Consequently, the single most important deleterious effect on building strength and durability is poor concreting. The concrete should be 'designed' OR 'designated'. In a 'designated concrete', the producer who is generally the constructor (not necessarily the same as a contractor) is required to produce a material to satisfy the designated strength and consistency (workability) using a particular aggregate size. Designated concretes are designated as Grade 30, for example, based on the cube strength up to Grade 50, according to the application involved. A designed concrete, on the other hand, is the one whose strength class, cement type, and limits to composition including water/cement ratio, cement content (mix ratio) are specified.

The symbol f_{ck} generally denotes characteristic strength based on cylinder strength of the concrete. The term f_{cu} denotes cube strength.

Table 4: Strength Classes of Concrete according to EN 206-1

Compressive Strength Class	Minimum Characteristic Cylinder Strength $f_{ck,cyl}$ or f_{cy} MPa	Minimum Characteristic Cube Strength $f_{ck,cube}$ or f_{cu} MPA	Normal lowest for application as specified
C8/10	8	10	Plain concrete
C12/15	12	15	Plain concrete
C16/20	16	20	Reinfoced concrete
C20/25	20	25	Reinforced concrete
C25/30	25	30	Reinforced concrete in foundations
C30/37	30	37	Prestressed & Reinforced concrete subject to chlorides
C35/45	35	45	Special concretes and constructions
C40/50	40	50	Special concretes and constructions
C45/55	45	55	Special concretes and constructions
C50/60	50	60	Special concretes and constructions
C55/67	55	67	Special concretes and constructions
C60/75	60	75	Special concretes and constructions
C70/85	70	85	Special concretes and constructions
C80/95	80	95	Special concretes and constructions
C90/105	90	105	Special concretes and constructions
C100/115	100	115	Special concretes and constructions

PART THREE: MIX DESIGN PROCEDURE

3.1. Introduction to mix design

For ease of calculation, the mix design procedure is divided into five stages. Each step by step procedure deals with a particular aspect and ends with an important parameter. The step by step procedure is as follows:

Step 1: Determination of target mean strength
Step 2: Determination of Water-cement ratio
Step 3: Determination of water content
Step4: Determination of cement content
Step5: Determination of aggregate content

3.2. Determination of Target Mean Strength

As a result of the variability of concrete in production, it is necessary to design the mix to have a mean strength greater than the specified characteristic strength. Hence, the target compressive strength is obtained from the equation:

$$f_m = f_c + ks$$

where f_m = the target mean strength

f_c = the specified characteristic strength

k = a constant (taken as 1.64 for a 5% defective level)

s = standard deviation

Typically, the standard deviation is obtained from the field by carrying out tests on a minimum of 20-30 samples taken from the site as early as possible. In cases of significant changes in production of concrete batches, the standard deviation value should be calculated for new batches. The standard deviation recommended in this manual is 6MPa. Where however a producer is able to achieve lesser value, he can use his own value.

3.3. Determination of Water-Cement ratio

Different cements and aggregates of various maximum size, grading and other characteristics may produce concretes of different compressive strengths at the same water-cement ratio. Hence, the relationship between strength and water cement ratio should be established for the materials to be used. If this is not available, the free water-cement ratio corresponding to the target strength may be obtained from Fig. 4.1 The water cement ratio selected should be checked against the maximum water cement ratio for the requirements of durability and the lower of the two values is recommended.

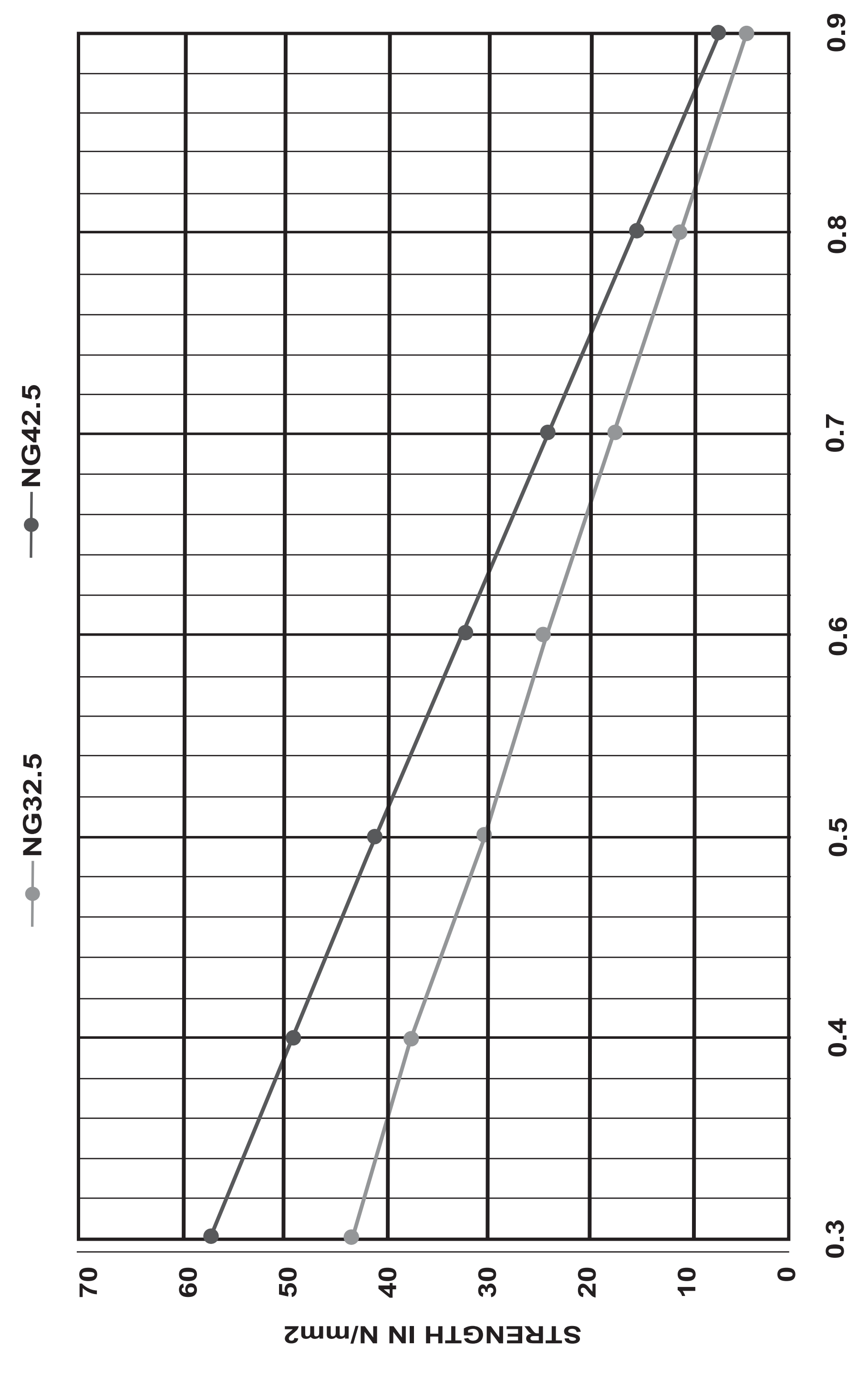

Fig. 4.1 - strenghth versus Water/Ceement Ratio for Nigerian Cements

Alternatively, the equation of the strength versus water/cement graph for Grade 32.5 cement is for $[0.3 \le r \le 0.9]$

$$\sigma = -64r + 62 \quad \text{..........[5.1]}$$

Where

σ is the target mean strength of the mix;

r is the water/cement ratio

From equation 4.1, we have:

$$r = \frac{62 - \sigma}{64} \quad \text{..........[5.2]}$$

The equation of the strength versus water/cement graph for Grade 42.5 cement is[for]:

$$\sigma = -84r + 83 \quad \text{..........[5.3]}$$

Where

σ is the target mean strength of the mix;

r is the water/cement ratio

From equation 4.3, we have:

$$r = \frac{83 - \sigma}{84} \quad \text{..........[5.4]}$$

It should be noted here that the procedure adopted limits the target mean strength for concrete using Grade 32.5 cement to 44MPa while that of Grade 42.5 cement is limited to 57MPa for water/cement ratios between 0.3 and 0.9.

It should be noted here that the procedure adopted limits the target mean strength for concrete using Grade 32.5 cement to 52MPa while that of Grade 42.5 cement is limited to 68MPa.

3.4. Determination of Water content

The water content of concrete is dependent on the type and maximum size of concrete to give a specified workability. The ranges of slump covered in this manual are 30 to 60mm and 60 to 180mm. Maximum aggregate sizes are also limited to 20 and 40mm. The recommended water content are as shown on Table 4.1.

Table 4. : Approximate Free water contents required to give various levels of workability

Maximum size of coarse aggregate	Aggregate Type	Slump 30-60	Slump 60-180
20	Uncrushed	180	205
	Crushed	210	235
40	Uncrused	160	185
	Crused	190	215

3.5. Determination of cement content

The cement content is determined from the water-cement ratio and the quantity of water.

$$\textit{Cement content} = \frac{\textit{free water content}}{\textit{free water/cement ratio}}$$

The resulting value should be checked against the maximum and minimum value specified

If the specified maximum cement content is exceeded, a higher cement grade should be used to enable the producer meet this requirement. Alternatively, super plasticizers could be used to meet other requirement at the determined cement content.

If the minimum cement content is higher that the earlier calculated value, this minimum value should be adopted and the water content should be recalculated to provide the same water/cement ratio at the specified minimum cement content.

3.6. Determination of aggregate content

To determine the total aggregate content, an estimate of the density of the fully compacted concrete should be known. From tests carried out, a density value of 2400kg/m3 is recommended for use for all mixes using normal weight aggregates. The total aggregate is obtained from the relationship:

The fine and coarse aggregate content are determined by obtaining the proportion of fine aggregate in the total aggregate content. Due to the fact that many coarse aggregates available from the quarries in Nigeria do not fit into the BS882 envelopes for coarse aggregates, the use of combined aggregate grading envelope is recommended. Two methods are recommended for determining the proportion of fine aggregates in the concrete.

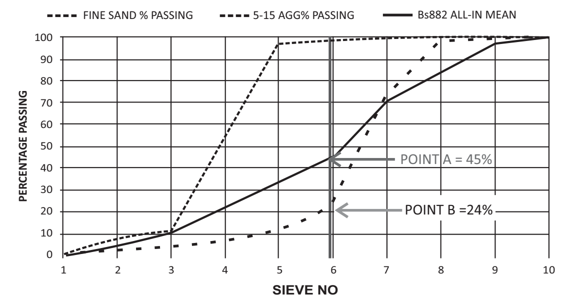

Fig. 4.2 - Combined aggregate curves for fine sand and 5-15 coarse aggregate

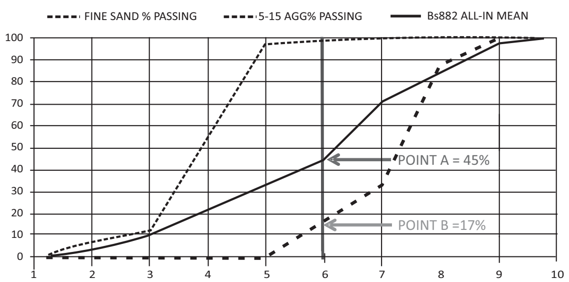

Fig. 4.3 - Combined aggregate curves for fine sand and 10-15 coarse aggregate

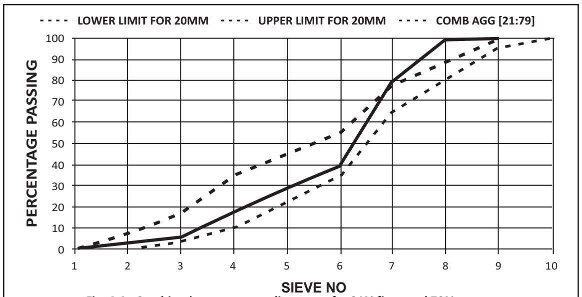

Fig. 4.4 - Combined aggregate grading curve for 21% fines and 79% coarse

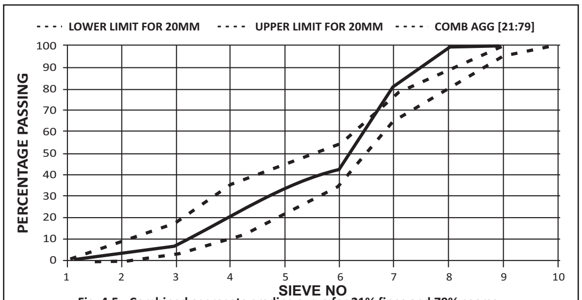

Fig. 4.5 - Combined aggregate grading curve for 21% fines and 79% coarse
[USING COMBAG 16]

The first involves plotting the grading curves of the fine and coarse aggregates on the same axis on the graph paper and determining the percentage combinations of the two aggregates which gives a grading very close to the median of the BS882 envelope.

Fig. 4.5. Involves using [COMBA] a software developed by Professor Charles Uko of the University of Uyo, Uyo, Nigeria which automatically determines the most suitable combination once values of percentages passing different sieve sizes are provided for the two aggregates.

The fine aggregate and coarse aggregate contents are calculated from the relationships

3.7. Trial Mixes

The mix proportions obtained should be checked using trial batches. The workability of the first trial mix should be measured and if it's different from the stipulated value, the water content should be adjusted suitably. With the adjusted water content, the mix design should be recalculated with the original water-cement ratio. Two more trial mixes should be made with this adjusted water content but at varying water cement ratios of ±10% of the original value. The last three mixes provide sufficient information on the relationship between compressive strength and water-cement ratio. This can be used to carry out mix proportions for field trials using actual methods of concrete production on site.

The issue of trial mix must be taken very seriously in view of the variables involved in

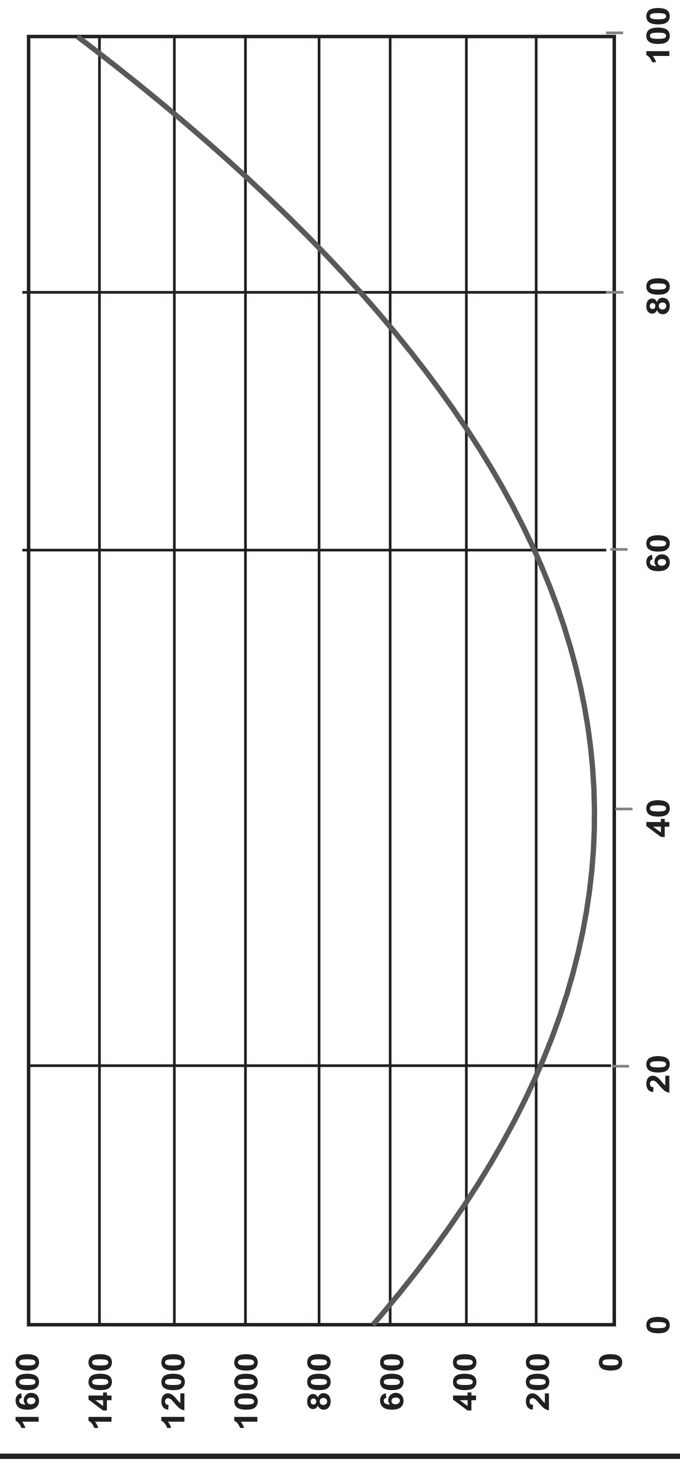

Fig. 5 : Plot of Standard Deviation from BS882 Mean against Percentage Fines

concrete production.

3.8. **Worked Examples**

The worked examples presented below are for the design of grade 30 concrete, using both grade 32.5 cement and grade 42.5 cements respectively. the coarse aggregate was crushed rock with maximum aggregate size 20mm. Fine aggregate was sharp sand and the percentage fines used was determined after sieve analysis and combination of aggregate using the method recommended or the software COMBA (see Fig. 5)

MIX DESIGN EXAMPLE FOR GRADE 30 CONCRETE [USING GRADE 32.5 CEMENT]			
S/NO	**ITEM**	**UNITS**	
1	**STAGE 1**		
1.1	Characteristic Strength	MPa	30
1.2	Standard Deviation	MPa	4
1.3	Margin	MPa	6.56
1.4	Target Mean Strength	MPa	36.56
1.5	Cement Grade		32.5
1.6	Aggregate Type: Coarse		Crushed
1.7	Aggregate type: Fine		Uncrushed
1.8	Free water/cement ratio		0.40
19	Maximum free water/cement ratio		NONE
2	**STAGE 2**		
2.1	Slump	mm	60 - 180
2.2	Maximum aggregate size	mm	20
2.3	Free-water content	kg/m^3	235
3	**STAGE 3**		
3.1	Cement Content	kg/m^3	591
3.2	Maximum cement content [specified]	kg/m^3	NONE
3.3	Minimum cement content [specified]	kg/m^3	NONE
3.4	Modified free-water/cement ratio		NONE
4	**STAGE 4**		
4.1	Concrete density	kg/m^3	2400
4.2	Total aggregate content	kg/m^3	1574
5	**STAGE 5**		
5.1	Grading of fine aggregate		Zone 2
5.2	Proportion of fine aggregate [%]		35
5.3	Fine aggregate content	kg/m^3	551
5.4	Coarse aggregate content	kg/m^3	1023
6	**STAGE 6 - Trial Mix Quantities**	**100mm cube**	**150mm cube**
6.1	Water [kg]	2.9	5.9
6.2	Cement [kg]	7.4	14.8
6.3	Fine aggregate [kg]	6.9	13.8
6.4	Coarse aggregate [kg]	12.8	25.6

MIX DESIGN EXAMPLE FOR GRADE 30 CONCRETE [USING GRADE 42.5 CEMENT]			
S/NO	ITEM	UNITS	
1	**STAGE 1**		
1.1	Characteristic Strength	MPa	30
1.2	Standard Deviation	MPa	4
1.3	Margin	MPa	6.56
1.4	Target Mean Strength	MPa	36.56
1.5	Cement Grade		42.5
1.6	Aggregate Type: Coarse		Crushed
1.7	Aggregate type: Fine		Uncrushed
1.8	Free water/cement ratio		0.55
19	Maximum free water/cement ratio		NONE
2	**STAGE 2**		
2.1	Slump	mm	60 - 180
2.2	Maximum aggregate size	mm	20
2.3	Free-water content	kg/m^3	235
3	**STAGE 3**		
3.1	Cement Content	kg/m^3	425
3.2	Maximum cement content [specified]	kg/m^3	NONE
3.3	Minimum cement content [specified]	kg/m^3	NONE
3.4	Modified free-water/cement ratio		NONE
4	**STAGE 4**		
4.1	Concrete density	kg/m^3	2400
4.2	Total aggregate content	kg/m^3	1740
5	**STAGE 5**		
5.1	Grading of fine aggregate		Zone 2
5.2	Proportion of fine aggregate [%]		35
5.3	Fine aggregate content	kg/m^3	609
5.4	Coarse aggregate content	kg/m^3	1131
6	**STAGE 6 - Trial Mix Quantities**	**100mm cube**	**150mm cube**
6.1	Water [kg]	2.9	5.9
6.2	Cement [kg]	5.3	10.6
6.3	Fine aggregate [kg]	7.6	15.2
6.4	Coarse aggregate [kg]	14.1	28.3

MIX DESIGN FOR GRADE ___ CONCRETE ________________________________			
S/NO	ITEM	UNITS	
1	**STAGE 1**		
1.1	Characteristic Strength	MPa	
1.2	Standard Deviation	MPa	
1.3	Margin	MPa	
1.4	Target Mean Strength	MPa	
1.5	Cement Grade		
1.6	Aggregate Type: Coarse		
1.7	Aggregate type: Fine		
1.8	Free water/cement ratio		
19	Maximum free water/cement ratio		
2	**STAGE 2**		
2.1	Slump	mm	
2.2	Maximum aggregate size	mm	
2.3	Free-water content	kg/m^3	
3	**STAGE 3**		
3.1	Cement Content	kg/m^3	
3.2	Maximum cement content [specified]	kg/m^3	
3.3	Minimum cement content [specified]	kg/m^3	
3.4	Modified free-water/cement ratio		
4	**STAGE 4**		
4.1	Concrete density	kg/m^3	
4.2	Total aggregate content	kg/m^3	
5	**STAGE 5**		
5.1	Grading of fine aggregate		
5.2	Proportion of fine aggregate [%]		
5.3	Fine aggregate content	kg/m^3	
5.4	Coarse aggregate content	kg/m^3	
6	**STAGE 6 - Trial Mix Quantities**	**100mm cube**	**150mm cube**
6.1	Water [kg]		
6.2	Cement [kg]		
6.3	Fine aggregate [kg]		
6.4	Coarse aggregate [kg]		

RECOMMENDATIONS

The following important points should be noted when carrying out a mix design:

1. All cement brands to be used must be clearly labeled indicating the strength class
2. A site trial mix design should be carried out to ensure the suitability of the mix on site. Cubes should be cast during the trial and should be tested prior to the commencement of concreting works
3. Concrete mix design procedure assumes that aggregates are in the saturated surface dry condition. Hence, coarse aggregates should be wetted before use to bring them to this condition
4. Water cement ratio must be strictly controlled on the site as it governs the strength and workability of the concrete.
5. Ensure cement is stocked properly in a waterproof area and is not in direct contact with floor or walls
6. Cubes should always be cast for every batch of concrete. Ensure that a minimum of three cubes are produced for 28days testing.
7. The following are essentials for a site laboratory:
    - Set of 12 cube moulds of size 150mm
    - A slump cone, tamping rod and a scale
    - Weighing balance of 5kg
    - Set of sieves comprising of 40mm, 25mm, 20mm, 12.5mm, 10mm, with a pan for coarse aggregates and 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm, 75µm with a pan and lid.
    - Batching equipment
    - Compression testing machine.

However, if a laboratory is not available on site, a suitable one should be identified close to the site.

CONCRETE MIX DESIGN MANUAL

APPENDIX

A.1. TESTING FRESH CONCRETE (SLUMP TEST) PROCEDURE

A.1.1. Apparatus.

- Slump cone
- Base plate.
- Compacting rod
- Funnel
- Ruler
- Scoop
- Timer
- Shovel
- Moist cloth

A.1.2. Testing Procedure

- Mix or remix the concrete sample thoroughly.
- Dampen the inside of the slump cone, the funnel and the base plate by wiping with a damp cloth.
- Clamp the slump cone to the base plate or stand firmly on the foot pieces to hold the slump down and in place.
- Fill the slump cone in 3 equal layer compacting each layer with 25 stroke of the tamping rod, distributing the strokes uniformly all over the surface of the layer. Repeat this for the second and the third layer tampering each layer through to the surface of the underlining layer.
- After compacting the third layer remove the funnel and strike off any excess concrete by means of sawing and the rolling motion of the tampering rod.
- Remove spilled concrete from the base plate and around the slump cone.
- Remove the slump cone by raising it vertically in a gentle manner within 5 to 10 seconds.
- The operation from filling to the remover of the slump cone should be done within 150 seconds.
- Immediately after the removal of the slump cone, measure and record the slump as the difference between the highest point on the concrete and the height of the slump cone to the nearest 10mm.

The result is valid only if the specimen yields a true slump.

See EN 12350-2 Testing fresh concrete. Slump-test for more detail.

A.2. TESTING HARDENED CONCRETE (COMPRESSIVE TEST) PROCEDURE

A.2.1. Sample Preparation

- Wipe the excess moisture on the test specimen with a clean towel
- Wipe the surface of the platen on the testing machine clean of any particle especially from previous tests.
- Do not use any packaging other than auxiliary platen or spacing blocks between the specimen and the platens of the testing machine.
- Position the cube specimen on its side so that the load is applied on the smooth surfaces and not on the trowel surface.
- Position the cube specimen to align with the center of the upper and the lower platen of the testing machine.

A.2.2. Loading Specimen

- A constant rate of loading should be maintain within the rate of 0.2 MPa/s to 1.0 MPa/s
- Apply load on the specimen without shock in an increasing manner, until sample fractures.
- Report the maximum load.
- The result is express as Fc = F/Ac.

Where Fc = the compressive strength in MPa

- o F = the maximum load at failure (N)
- o Ac = the cross sectional area of the specimen.

Check EN 12390-3 Testing hardened concrete - Part 3: Compressive strength of test specimen for more detail.

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REFERENCE STANDARDS

EN 206:2013 Concrete. Specification, performance, production and conformity.

NIS 444-1: 2003 Cement Part 1: Composition, specifications and conformity criteria for common cements.

NIS 445:2003 Methods of testing cement-Chemical analysis of cement.

EN 12620:2002+A1:2008 Aggregate for concrete.

EN 934-2:2009+A1:2012 Admixture for concrete, mortar and grout. Concrete admixture. Definition, requirements, conformity, marking and labeling.

EN 12350-2:2009 Testing fresh concrete. Slump-test.

EN 12390-3:2009 Testing hardened concrete. Compressive strength of test specimens.


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