THE EFFECT OF MIXING SEQUENCE ON THE PROPERTIES OF CONCRETE

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Declaration

I declare that the work in this dissertation entitled "THE EFFECT OF MIXING SEQUENCE ON THE PROPERTIES OF CONCRETE" was done by me in the Department of Building, Ahmadu Bello University, Zaria under the supervision of Prof. M. M. Garba and Dr. D. D. Dahiru. All information provided in the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation has been submitted for any degree award in any institution.

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Certification

This dissertation entitled "THE EFFECT OF MIXING SEQUENCE ON THE PROPERTIES OF CONCRETE" by Zahradeen Wala IBRAHIM, meets the regulation governing the award of the degree M. Sc. Construction Technology of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literacy presentation.

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Dedication

This work is dedicated to my parent (Mallam Ibrahim Wala and Aishatu Ibrahim Wala), to my child Ibrahim Zahradeen Wala, all my siblings, all members of my family and my supervisors, Prof. M. M. Garba and Dr. D. D. Dahiru.

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Abbreviations

National Concrete Pavement Technology Centre	NCPTC
American Concrete Institute	ACI
American Petroleum Institute	API
American Society for Testing and Materials	ASTM
British standard	BS
British Standard European Norm	BS EN
British Research Establishment	BRE
Et Cetera (other similar thing)	e.t.c
Et Alia (and others)	*et al*
Kilogram per Meter Cube	Kg/m^3
Indian Standard	IS
Interfacial Transition zone	ITZ
Meter Cube (unit of volume)	m^3
Millimeter	mm
National Concrete Pavement Technology Centre	NCPTC
Newton per Square Millimeter	N/mm^2
Quality Event Management Solutions	QEMS
Revolution per Minute	rpm
Sand Enveloped with Cement Concrete	SEC
Specific Gravity	S.G

Abstract

Concrete is the most demanded material only second to water as a substance, with this, it can only be imagined that huge expense and resources have been put into it. In consideration with the aforementioned fact on concretes' demands coming in tune with the advancements of the 21st century production researches, cost free methods are being optimized to boost production efficiency. This research entitled "The effect of mixing sequence on the properties of concrete" is about the latter statement, as it deals directly with finding the most suitable mixing sequence to optimize production efficiency without any added resources. The research focused on the fresh and hardened properties of concrete. British Research Establishment (BRE) Method of mix design was used. A total of 720 cubes were cast for tests at the following ages of 7, 14, 28 and 56 days. Twenty four (24) mixing sequences were assessed. Among the mixing sequences, two standardized mixing sequences from the ASTM and ACI were chosen. It was found that samples mixed using the standard mixing sequences of the ASTM and ACI passed all the standard requirements for all properties of concrete assessed. However the samples produced using ACI mixing sequence had better hardened concrete properties when compared with the samples of concrete made using ASTM mixing sequence. All the concrete batch samples from the various mixing sequences passed the standard conditions for compacting factor and plastic density. Samples mixed using mixing sequences (22, 19 and 17) did not pass the standard condition for slump. Samples mixed using mixing sequences (14 and 17) did not pass the standard condition for air content. Samples from mixing sequence 24 had optimum compressive strengths of 23.40N/mm^2, 25.52 N/mm^2, 30.84 N/mm^2 and 35.56 N/mm^2 for 7, 14, 28 and 56 days of testing respectively and

passed all the standard conditions for all properties tested. It surpassed samples from the standardized mixing sequences in grade by at least 4.7% for every test age. During concrete production, with all processes, materials and proportioning considered, two sets of concrete samples from two different mixing sequences can differ in average from 0.91% to 41.85% under water absorption while two sets of concrete samples from two different mixing sequences can differ in average from 0% to 100% under abrasion resistance. From the properties of concrete tested, the various mixing sequences used have the most positive effects on plastic density followed by air content then slump and finally compressive strength. Due to the differences in the properties of concrete samples under the influence of different mixing sequence, it is recommended that good mixing sequences, when used should be consistent under a particular job. Mixing sequence 24 had optimum compressive strengths and can be used to make the best concrete. Uniformity should be checked firstly for fresh concrete properties when determining which or what mixing sequence to use.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Concrete is the most useable building materials in today's construction industry. Its ability to be cast into infinite desirable shapes and fashion makes it applicable for most building purposes. Its relatively long life and low maintenance adds to its popularity. It is such that it does not rot, rust, decay, and resistant to wind, water, rodent and insects. It does not combust making it fire resistant and has the ability to withstand high temperatures (Assist, 2009). There are many factors that affects the properties of concrete. Mixing sequence as a factor amongst others affects the properties of concrete (Fitzpatrick and Serkin, 1949)

Mixing sequence is the order of introduction of constituents into the mixing process during concrete production. Mixing sequence is as old as concrete manufacture itself. It is an essential, integral and inevitable part of concrete production. Concrete has been formed in rigid molds since its invention in antiquity. (Malinowski and Garfinkel, 1991).

A stepping stone in the history of concrete was the invention of Portland cement by Joseph Aspdin, (Francis *et al.*, 1977). The way to go about how to mix this cement or other cementitious materials to get an improved and efficient concrete of high quality became essential and sustainable. This only requires at first research which is vital to every development.

Fitzpatrick and Serkin (1949) were the first persons recorded to investigate mix sequence of constituents. Their work found that, mixing sequence has a significant effect upon the

properties of concrete which includes workablity, strength, density, surface finish and absorption. These properties determine concrete quality.

The quality of concrete is determined by how suitable a concrete is in terms of its practicability to properly designed properties by influences of production techniques and by the homogeneity of the material after mixing and placement. The methodology to determine the quality of the concrete mixed is often referred to as the measurement of the efficiency of the mixer. The efficiency parameters of a mixer are affected by the mixing sequence, the type of mixer, and the mixing energy (power and duration) as pointed out by Ferraris (2001). Ferraris (2001) suggested that there should be methodology to check the quality of concrete produced, because only one attempt of standardization was found.

National Concrete Pavement Technology Centre (NCPTC, 2007) shows that concrete mixing is a complex process in which different factors influence the quality of produced concrete during production. These factors include loading sequence, mixing time, mixer type, and the time and rate of adding chemical admixtures.

The sequence of charging a mixer is a great factor of whether the constituents would mix properly or not, American Concrete Institute (ACI Committee 304, 2000). There are no general rules in mixing sequence of concrete (Neville and Brooks, 2010). The sequence of introduction of constituents into a mixer varies from plant to plant, (ACI Committee 304, 2000).

The American Society for Testing and Materials (ASTM, 1994a) specifies in its sequence that some water and aggregates should be mixed first, then cement should be added, and finally, the remaining portion of the water is added with not more than one-fourth of the

total mixing time elapsed. Any liquid admixture should be added together with water. (Mass, 1989) strongly suggested experimentally that, mixing cement and water into a paste before combining these materials with aggregates can increase the compressive strength of the resulting concrete. ACI Committee 304 (2000) specifies something different to (Mass 1989). The ACI Committee 304 (2000) says that coarse aggregates should be poured first, followed by the fine aggregates. Then add in sequence the required water and cement. ASTM C 305, (1998c) specifies a different order of sequence from above sequences. This sequence calls for first mixing water, cement and fine aggregate altogether until it produces a uniform mortar, then the coarse aggregate is added.

Then again, the mixing sequence developed by Tam *et al.*, (2005) called the *'two stage mixing approach'* is aimed at improving the quality of concrete. It indicates that all aggregate should be mixed first, then half of water after 60 seconds, cement after another 60 seconds and the other half of the required water after 30 seconds and then wait for 120 seconds for the concrete constituents to be properly mixed. Tam *et al.*, (2005) investigated in comparism to what they considered the normal mixing method, which is pouring fine aggregate, cement, coarse aggregate and water and mixing respectively.

Soga and Takagi, (1986) reported that the addition rate of the mixing water and the rotational speed of the mixing drum control fresh concrete characteristics. In particular, the bleeding rate of fresh concrete decreases as the rate of adding water decreases. The bleeding rate of fresh concrete decreases as the rotational speed of the mixer is increased.

Similarly, Tamimi (1994) and Mitsutaka and Yasuro (1982) studied the effects of mixing water but in two separate stages. In the first stage, aggregate and a weight of water equal to

25 percent of the weight of cement were mixed for 30 seconds. Next, cement was added and mixed for 60 seconds. And finally, the remaining water was added and mixed for 90 seconds. Concrete produced by this technique was labeled "*sand enveloped with cement concrete*" (SEC). The goal was to investigate the effectiveness of this mixing sequence in reducing the bleeding rate of fresh concrete and increasing the compressive strength at various stages of curing. Tamimi (1994), Mitsutaka and Yasuro (1982) concluded that this method did in fact reduce the bleeding rate of fresh concrete and improved the compressive strength over conventionally-mixed concrete. Tamimi (1994) took the research further to prove that adding water using this formula leads to a greater gel-to-space ratio in the interfacial transition zone (ITZ), creating a more intimate bond, lower porosity, and increased micro-hardness in the ITZ.

Gaynor (1996) studied the influence of concrete truck mixers on concrete properties. He concluded that non-uniformity in truck-mixed concrete is caused by agglomerations of concrete materials inside the mixer. This included head packs and cement balls. To remedy the non-uniformity problems, Gaynor suggested that one-fourth of the mixing water be added as the last ingredient and that the mixer rotate at 20–22 rpm.

Traditional concrete mixing practice is today regulated by a specific mixing time required to achieve specified performance of the fresh and hardened concrete. This mixing time is based on a long experience of developed correlations between the mixing process and the mixers performance, and is generally detailed in specifications, National Concrete Pavement Technology Centre (NCPTC, 2007).

ASTM (1998a) has shown that insufficient mixing time can lead to lower compressive strength and inhomogeneous concrete. Excessive mixing time can cause aggregate breakdown and decreased air content. Beitzel (1981) studied the influence of mixing time on the quality of concrete, where quality was defined as the uniform distribution of water, cement and fine aggregate. Results showed that the optimum mixing time is different for different concrete properties, and that there should be upper and lower limits on the mixing time. Beitzel (1981) developed a qualitative empirical representation of the optimum relationship between mix separation and uniformity.

Cable and McDaniel (1998) also investigated the effects of mixing time on a variety of concrete characteristics, including workability, the air content of cured concrete, and segregation caused by truck mixing. Cable and McDaniel (1998) concluded that a minimum mixing time of 60 seconds is effective for all mixer types; this is in order to achieve an acceptable level of concrete performance from the final product. And this time should only be reduced if measures are taken to ensure all aggregate particles are completely coated upon discharge from the mixer.

American Petroleum Institute (API) Specification 10A, (2002) states the requirements for a mixer which include mixing speed and time. Shetty (2005) says mixing more than 2 minutes would not very significantly increase strength. Assist (2009) says 1.5 to 3 minutes is sufficient to obtain a good mixture. Mixing more than 3 minutes will not improve the quality of the mixture. NCPTC (2007) indicates that the continued mixing of cement pastes can delay setting time and that the setting time could be delayed; although hydration does not stop, this slows bonding.

Generally speaking, mixing sequence needs to be studied in conformity with the parameters that bind it (such as mixing time, loading intervals e.t.c). The time and speed of rotation (mixing energy) is known to improve the quality of concrete (homogeneity) up to a certain level at which it becomes inconceivable after optimum time. The speed of rotation of a mixer affects the optimum time within closed limit for different mix proportion and water-cement ratios. Added variation in quality can be deduced from mixing sequence. The method of loading which primarily includes mixing sequence is the most influential variant in the process of concrete production and has the greatest effect on batch uniformity (Irtishad *et al*, 2002). Reasonably fixed time is needed to characterize the quality of different mixing sequence in relation to one another. All the other entities (optimum time, mixer efficiency, mixing energy e.t.c) could be measured and calibrated for optimum production, but only the mixing sequence cannot and needs to be determined. Lastly, Different sequences may need adjustments in the mixing time (kosmatka *et al.*, 2003).

Factors that affect mixing sequence in concrete production are basically, the constituent materials used, mixing time, type of mixer, speed of mixing (Debbie, 2017). Constituent materials affect mixing sequence because their properties determine how mixing sequence affects quality firstly which is empirical. The number of materials being introduced adds to the order of sequencing. The number of times a particular material is introduced into the mixing process affects the order of introduction of materials into the mixing process which exclusively is referred to as mixing sequence, hence the quality of concrete. Batch size in relation to size of aggregate also affects mixing sequence invariably (Debbie, 2017). This is because the physical properties of constituent materials is a general factor in determining how these materials are most preferably introduced into a mixing process in relations to

batch size, mixer type and mixing speed. Time, mixer type and mixing speed evidently affect mixing sequence (Debbie, 2017). The choice of mixing sequence is vital to concrete production and is primarily determined to a broader aspect by researches, relevant standards, specifications and experience. This cannot be overemphasized as mixing sequence is key to concrete production and mix uniformity which is used to assess concrete quality (Ferraris, 2001).

1.2 Statement of the Research Problem

With the advancements of the 21st century production researches, methods are being optimized to boost concrete production efficiency. It is true that concrete production is cunningly a complex process (NCPTC, 2007). Concrete structures are a great deal more than sand, gravel, cement and water blended and left to harden into useful shaped lumps. Considerable care, study and knowledge are needed to manufacture good quality concrete (Controls, 2014). Knowing good and proper sequence from poor ones prevents the manufacture of poor quality concrete moreover, provides the knowledge in the manufacture of good quality concrete.

Properly manufactured concrete is inherently an environmentally friendly material as it can be demonstrated readily with a life-cycle analysis. The challenge is derived mainly from the fact that Portland cement is not environmentally friendly, (Micheal *et al*, 2002). Someone could therefore reduce this problem by simply using as much concrete with as little cement as possible, (Meyer, 2005). This can be achieved through improved mechanical properties by harnessing the strength in concrete. One efficient way is by knowing the best mix sequence to use. This adds to the environmental friendliness for a

given quantity of cement in concrete by increased strength and durability, prolonging life circles of infrastructures or by reduced cement needed in production as per requirements.

Concrete is in fact, the most demanded material only second to water as a substance. Much effort is being used to provide target in the cost of concrete. This is especially as a result of its huge demand in comparative to its accumulated cost and overall price impact. The right sequence in which cement, aggregate and water are mixed could add to optimize concrete strength, mixer performance and production efficiency. This reduces the manufacturing cost of the most useable building material basically by reducing the amount of cement in concrete of a specified concrete grade and durability requirements needed for a particular job. This is met with needed quality, more so, without any added effort in production. The observation made could amount to much difference as the overall demand for concrete is huge. So to say, the above situations determine the case and criteria of this study and needs to be addressed proficiently.

1.2 Justification of the Study

The construction industry has gone far and great lengths to harness strength in concrete. Strength that could be got should be tapped especially if it causes no extra human, material, time or effort. Knowing the best sequence of mixing to be used adds to optimize strength and durability of concrete during concrete production processes.

Strength of concrete is considered the most important property of concrete as it denotes and relates the general quality of concrete and its overall internal structural arrangement. However, durability is nevertheless very important as from the onset of Portland cement concrete hitherto, structures are more and more being built in and/or to a toxic environment

injurious to concrete which require enough durability to resist, withstand and sustain these likely injuries. So to say, durability is critical as it is beneficial because durable concretes keep the useful life of structures by ensuring its internal mass and surfaces are not penetrated, degraded, worn or leached. These properties, strength and durability are of viable importance and so, immense consideration is needed to improve these properties in concrete effectively because they, on a major scale affect essential construction items like cost, sustainability, material and a related other useful items. These items are necessary and play a major role in determining key related activities in the construction industry.

Strength and durability, a primary determinant in the assessment of the most useable building material cannot be overstated. The improvement of these concrete properties; strength and durability can be achieved by knowing and using the proper mixing sequence. This does not result in the addition of any added effort of sort in concrete production. These rewarding benefits provided a platform for the need of study in this research work.

1.3 Aim and Objectives

1.4.1 Aim

The aim of this research is to investigate the effect of mixing sequence on the properties of concrete with a view to establishing an optimized mixing sequence in the properties of concrete.

1.4.2 Objectives

i. To determine the properties of the concrete ingredients such as specific gravity, density.

ii. To assess the fresh properties of concrete produced such as workability, air content, plastic density, with different mixing sequences.

iii. To assess the hardened properties of concrete produced such as strength and durability with different mixing sequences.

iv. To establish the effect of mixing sequence on the properties of concrete such as workability, air content, plastic density, strength and durability.

1.5 Scope and limitations

1.5.1 Scope

The research covered the manufacture of concrete using hand fed concrete mixer fed up to a reasonable capacity of 35 to 45 percent of gross drum volume, (ASTM, 1978) . Batches were mixed for 2 minutes in accordance with Indian Standard (IS 456, 2000), with 20 seconds charging intervals. Same batch size was used for each individual mixing sequence. Tests on specimens such as abrasion resistance test, water absorption test, air content test, plastic density test, workability and compressive strength test were carried out, on the fresh and hardened samples in accordance with the relevant standards.

Limitations

Fresh concrete tests like segregation and bleeding were not carried out because the mixes do not possess significant properties being assessed by such tests. Non-destructive test method is more accurate to assess uniformity using compressive strength test as all samples can be tested at once and reused and interference of hydration on uniformity can be monitored from subsequent ages across same batch samples but the equipment to be used was not available.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete

Concrete is the most useable building materials in today's construction industry. Its ability to be cast into infinite desirable shapes and fashion makes it applicable for most building purposes. Its relatively long life and low maintenance adds to its popularity. It is such that it does not rot, rust, decay, and resistant to wind, water, rodent and insects. It does not combust making it fire resistant and has ability to withstand high temperatures (Assist, 2009).

Concrete has been cast in stiff molds since its first invention in antiquity. Some of the earliest examples of concrete slaps were built by Roman engineers. The oldest concrete recorded in history dates back to 7000BC discovered in Israel and was made from lime form. This art of the earliest concrete manufacture died 5000BC and reemerged 2500BC in Egypt. Over-time, this spreads from Egypt around the eastern Mediterranean and by 500BC was being used in Ancient Greece (Malinowski and Garfinkel, 1991).

Concrete in Rome was found 300BC old. The idea of concrete manufacture was borrowed and developed by the Romans from the Greeks. The very word concrete comes from the Latin word 'Concretus' meaning grown together or compounded. The Romans indeed accidentally discovered pozzolanic cement as they quarried the pink volcanic ash close to Pozzuoli and mixed it with lime thinking it was sand. The mixture resulted in anything

stronger to what they had previously manufactured. The discovery was to a far reaching effect in the construction industry for the subsequent next four centuries (Obe, 1999).

By the first century AD, concrete had come to be recognized as a structural material. This was so for over a period of 800 years, but with the decline of the Roman Empire, most knowledge gained of the use of concrete disappeared during the Dark Ages (Malinowski and Garfinkel, 1991).

Smeaton's experiments were the first scientific investigation that paved way to modern concrete through his cement work. Towards the end of the 18^{th} century there was revival of interest in the development of new types of cement, with many formulations which, in essence, were little a better than Smeaton's attempts (Francis *et al*, 1977).

A major breakthrough in the history of concrete was the invention of Portland cement by Joseph Aspdin. This discovery reinvented concrete as a structural material. The way to go about how to mix this cement or other cementitious materials to get an improved and efficient concrete of high quality became essential and sustainable, (Francis *et al*, 1977). This only requires at first research which is vital to every development. This gives way to a wide application of concrete and by so, concrete properties are needed within acceptable range of concrete performance. These are achieved by desired control measures during production and good material selection. These control measures can be more readily met by understanding the nature and properties of concrete and what affects them positively and otherwise. This is so for both hardened and freshly mixed concrete (Kosmatka *et al*, 2011).

2.1.1 Fresh concrete mix

Fresh concrete are in either plastic or semi fluid form and usually capable of being molded into different shapes. All the solid ingredients of fresh concrete are encased and held in suspension by fluid. These ingredients should not be made to segregate during transport. When a concrete is properly mixed and left to harden, it becomes a homogeneous mix of all the ingredients. During placement, concrete of good consistency does not segregate or crumble but has stability (Kosmatka *et al*, 2003)

2.1.1.1 Properties of fresh concrete mix

Workability: Workability is the ease of handling freshly mixed concrete and the difficulty at which it withstand segregation. Concrete workability is the quantity of effective internal work needed for complete compaction of fresh concrete. A good concrete does not separate during handling and is workable. The three factors having a huge effect on workability are water–cement ratio, aggregate–cement ratio and water quantity (Gordana *et al.*, 2010). Some concrete properties related to workability include consistency (flow) and stability (resistance to segregation).

The type of concrete, method of placement and consolidation type are factors that controls the degree of workability needed for proper placement. A proper example of the clarity of these factors is the self consolidating concrete which has a unique property of high workability and stability which allows for complex shapes and rigorous construction schedule (Scezy and Mohler, 2009).

Uniformity: The uniformity of a concrete affects its strength and economy collectively. The uniformity of concrete is determined by the accuracy of dispersion, proportioning, mixing

of ingredients according as specified. Each separate batch of concrete must be proportioned and mixed exactly the same to ensure that the total structural mass has uniform structural properties (United States Army Engineering Centre and School, 1992).

Consistency: Consistency is considered to be a close indication of workability. The slump test, (ASTM C143, 1990) is the most widely used method to measure the consistency of concrete as it is the most widely accepted. There are also other methods used to measure consistency. It is such that a stiff consistency has a low slump. A harsh consistency has the tendency to segregate. Excessive water in concrete mix produces high slumps and causes poor concrete performance. This leads to bleeding, segregation, and increased drying shrinkage. If a finished concrete surface is to be wear resistant, level, and especially uniform in appearance, it is an indication that all the batches of concrete placed on that surface definitely have nearly the same slump (Daniel, 2006).

Rheology: Rheology is a field of science that deals with deformation and flow of matter studied through the relationships of stress and rate of strain (Banfill, 2003). Cement slurry is able to flow as a result of the interaction of adjacent cement particles as they move over each other in suspension. The concentration, shape, and size of the particles in suspension affect this behavior. National Concrete Pavement Technology Centre (NCPTC, 2007).

Bleeding and settlement: Bleeding is the development of a layer of water on the surface of fresh concrete after placement. This occurs because water has the lowest specific gravity of all the ingredients. This causes the sedimentation of solid particles and the simultaneous upward movement of water. This is sometimes referred to as water-gain. Ordinarily,

bleeding is normal and does not retard the quality of concrete but excessive bleeding does and is abnormal (Shetty, 2005).

After the evaporation of all bled water on a floor, the hardened surface might become slightly lower than the initial fresh placed surface. This decrease in height from time of placement to initial setting of concrete is called settlement shrinkage. The bleeding rate and the bleeding capacity increases with the initial water content, concrete height, and pressure. Mass, structural or watertight concrete with a good bond should have low bleeding properties to avoid formation of water pockets (Kosmatka and Stephen, 2006).

Bleeding in concrete can be reduced efficiently by using less water or maximizing the use of cement. Increased fines in sand and the use of finer cemetitious materials also reduce bleeding. Lastly, it can be reduced by the use of air-entrained concrete and also by the use of blended cement. These are some of the ways to reduce bleeding in concrete (Kosmatka and Stephen, 2006).

Consolidation: When vibration is sets into particles of fresh concrete. Friction is reduced between them, and the mixture is given the mobile qualities of a thick fluid. The vibratory action allows the use of a stiffer mixture with optimum proportion of coarse aggregate. An optimally graded coarser aggregate concrete is easier to consolidate and place and it is known to likely improve quality and economy. With poor consolidation may come porous, weak concrete with poor durability. That creates the need for mechanical vibration in some instances for concretes that are impractical to consolidate by hand under normal condition (Kosmatka *et al*, 2003).

Setting of concrete: The onset of rigidity in fresh concrete is termed setting. It is different from hardening, which is described as the development of useful and measurable strength. Setting precedes hardening although both are controlled by the ongoing hydration of the cement. Setting, or the start of significant crystallization of hydration products, occurs at the end of the induction period, when the concentration of ions has reached a critical state (Panasyuk, 2014)

2.1.2 Hardened concrete

2.1.2.1 Properties of hardened concrete

Curing: Curing is the hydration of concrete after it had hardened. It is the increase in strength of concrete with age after hardening. For hydration to take place, the following must be present in concrete, they are; unhydrated cement, moistened concrete or a relative humidity of 80 percent and above, favorable concrete temperature, and sufficient space available for hydration products to form. If the temperature of concrete drops below freezing point, hydration or strength gain virtually stop (Kosmatka *et al*, 2003).

If concrete is saturated again after a drying period, hydration is resumed and strength will again increase. However, it is best to cure concrete continuously from the time it is placed until it has attained the desired quality; once concrete has dried out, it will be difficult saturate again.

Drying rate of concrete: Concrete does not harden or cure when dry. Concrete (or more precisely, the cement in it) needs moisture to hydrate and harden. When concrete dries out, it ceases to gain strength; the fact that it is dry is no indication that it has undergone sufficient hydration or has obtained the desired physical properties. Fresh concrete usually

has abundant water, but as drying progresses from the surface inward, strength gain will continue at each depth with a relative humidity of above 80%. While the surface of a concrete element dries quite rapidly, it takes a much longer time for mass to dry completely (Kosmatka *et al*, 2004). The moisture content of concrete depends on the concrete constituents, original water content, drying conditions, and the size of the concrete element (Hedenblad, 1997; 1998). The size and shape of a concrete mass or element significantly affect its rate of drying. Concrete elements with larger surface area to volume ratio dry faster than voluminous concrete members with relatively smaller surface areas (Kosmatka *et al*, 2011)

Strength: Strength of concrete is today usually considered by professionals as the most important property of concrete. In some practical cases, it can be true other characteristics like durability, impermeability and volume stability, may be in fact more important. Nevertheless, strength gives an overall picture of quality in concrete as it directly relates to the structure and distribution of cement paste which affects quality and uniformity. Strength primarily is more highly dependent on the physical structure of cement as a product of hydration than on its chemical composition. More specifically, it is the presence of flaws, pores and discontinuities that is significant to understanding strength. Unfortunately, these are difficult to quantify, so it is necessary to resort to an empirical study of the effect of various factors on strength (Neville and Brooks, 2010).

a. Compressive strength: Compressive strength of concrete specimen is known to be its measured maximum resistance to axial loading. It can be expressed in Newton per square millimeter (N/mm^2) at 28 curing days. The extent to which hydration has excelled, the curing condition, environmental conditions, and the age of the

concrete affects its compressive strength (Abrams, 1918). Generally, concrete study is conducted basically to exploit its good compressive strength. Compressive strength of concrete is approximately 8 times a factor of its direct tensile strength (Neville and Brooks, 2010). The control limits for compressive strength is recommended to be ±2 standard deviation or it can be obtained from past projects but if past projects are not available, a standard deviation of up to 3.5N/mm² is ok (Karthikeyan, 2015).

b. Tensile strength: The direct tensile strength of concrete is about 8% to 12% of the compressive strength and is often estimated as 0.4 to 0.7 times the square root of the compressive strength in N/mm². Splitting tensile strength is 8% to 14% of the compressive strength (Hanson, 1968).

Density: The density of concrete varies, depending on the amount and density of aggregate, the air content, water content and cementitious materials, which in turn are influenced by the maximum aggregate size. Reducing the amount of cement or increasing the volumn of aggregate is known to increase density especially with heavier aggregates. But this has to be that the aggregate is heavier than the cement gel because it is possible it might not work for light weight aggregate, especially if lighter than the cement gel. The weight of dry concrete equals the weight of the fresh concrete ingredients minus the weight of mix water that dries out into the air. Some of the mix water combines chemically with the cement during hydration adding to the weight of hardened concrete. Meanwhile, some of the water may tightly remain held in pores and capillaries which do not evaporate under normal conditions (Kosmatka *et al*, 2003).

Durability: The durability of concrete may be defined as the ability of concrete to resist abrasion and weathering action and withstand chemical attack within its desired functional characteristics (Shetty, 2005). Different concretes require different degrees of durability depending on the exposure environment and the desired properties. Considerable consideration for durability of modern concrete construction has assumed a much higher importance in building construction than it was formally practiced. This is as a result of good land being occupied and buildings constructions are swaying to hostile environment. Increment of chloride in cement as per specification requirement due to scarcity of quarries has also resulted in a more strict durability measure across countries (Shetty, 2005).

a. Abrasion resistance: Surfaces of floors, pavements, and hydraulic structures are prone to abrasion; therefore, in these applications, concrete if used must have high abrasion resistance. Abrasion resistance closely relates to compressive strength. So, generally speaking, a stronger concrete should have a higher abrasion resistance. Since compressive strength depends on water-cement ratio and curing, a low water-cement ratio and adequate curing are also necessary for abrasion resistance. The type of aggregate, surface finish and treatment also influence abrasion resistance. And lastly, harder aggregate are more resistance to wear than softer ones (Kosmatka et al, 2011).

b. Water absorption capacity: this is the rate at which water flow in an unsaturated porous concrete due to pressure difference produced by capillary or pressure difference and it is measured as a percentage of the mass of water to concrete. So, water absorption in concrete can be said to be a process which happens only as a result of capillary suction and in the absence of any external pressure. The process

is dependant on the following factors which are; surface tension, surface energy, capillarity and concrete sorptivity (Nolan, 1996)

2.2 Concrete Mixing

The process of stirring up or blending the constituents of concrete into a fine uniform mix is referred to as concrete mixing. Concrete is mixed either by hand or machine but in cases of large and medium scale project, it is especially done mechanically. The term 'concrete mixer' generally refers to mechanical methods of mixing as consideration is only paid to them in most literatures (Ferarris, 2001; NCPTC, 2007). There is a wide variety of the types of concrete mixer. But only a few non-special (general) types will be discussed in this literature review.

2.2.1 Categories of concrete mixing

The two main categories of concrete mixing are hand mixing and concrete mixers. Hand mixing involves the use of tools like shovel while the concrete mixers involved mechanical components, blades or fins and mixing compartment (Aguwa, 2010). These are discussed below in the subsequent sub-sections.

2.2.1.1 Hand mixing

This involves using tools like shovel to turn cement mixture with hand until a homogeneous uniform mix is acquired. Compressive strength of hand mixed concrete increases with increase in the amount of mixing in terms of number of turning concrete over from one end to another on a mixing tray. Aguwa (2010) investigated the effect of hand mixing on compressive strength and found that the optimum strength was recorded at

four times turning for all the ages and there was no significant increase in the compressive strength beyond four times of turning. He found that mixing below four turns is non-satisfactory. Lastly, increase in strength with age has been considered to be normal. Hand mixing is best used for small amounts and small project of less precision in concrete properties (Aguwa, 2010).

2.2.1.2 Mechanical mixer, concrete mixer or mixer

Mechanical mixer does a better job than hand mixing with large batches. Mechanical mixer involves mixing concrete with the use of machine. It is classified into two broad groups; continuous mixer and batch mixer. These classifications are based on the way in which they operate as it was explained in section 2.2.2.1 and 2.2.2.2. Mechanical mixer became necessary and essential in today's construction industry because of its ease in use, speed, size of production, mixing precision and mixer efficiency.

2.2.2 Classification of mixers

Classification of mixer only applies to mechanical mixer, it does not relate to hand mixing. It falls into two broad categories, Continuous mixer and batch mixer.

2.2.2.1 Continuous mixers

As the name indicates, in this class of mixer, materials are continuously fed into the mixer at the same rate the concrete is being discharged. When the output of the mixer equals to the input of materials and the mixer can be operated without interruption to charging or discharging of material, the mixer is said to be continuous (ACI Committee 304, 1992). These mixers are used for applications that require a short working time, long unloading

time, remote sites (not suitable for ready-mix) and in most cases, small deliveries (Ferraris, 2001). A major use of this class of mixer is for non flow-able, low slump concretes (ASTM, 1990). One example is pavement. Due to the short mixing time, the air content is not easily controlled even with the addition of air entraining admixtures (Ferraris, 2001). Some examples of the continuous mixer are the pugmill mixers and some central plants.

2.2.2.2 Batch mixers

This is one of the classes of mixer. The process of production in this class of mixer involves feeding the mixer to a reasonable capacity with concrete ingredients, mixing and discharging afterwards for another round. The two main types of batch mixer are distinguished by the orientation of the axis of rotation. This can be horizontal or inclined used for drum mixers or vertical used in pan mixers. This drum mixer comprises of drum and fixed blades hinged on the internal wall of the drum rotating about its axis. The pan mixer may have the blade on its central axis or fixed on the internal wall of the pan. For the pan mixer, either the pan and blade rotates about its axis or just the centre blades do (Ferraris, 2001).

2.2.3 Types of concrete mixers

The types of concrete mixers are distributed according to their mobility, orientation of the mixing compartment, their profile and functionality. Some basic examples of the different types of mixers are reviewed in the subsequent subsection below. They are drum mixer, pan mixer, pugmill mixer and truck mixer.

2.2.3.1 Drum mixers

Variation in the drum mixer includes the reversing drum mixer, the tilting drum mixer, and the non-tilting drum mixer. In the reversing drum mixer, the direction of rotation can be reversed. In the tilting drum mixer, the mixer discharges by tilting the axis of the drum. In mixing mode, the drum axis can either be horizontal or inclined at an angle. For the non-tilting drum mixer, it is a revolving drum mixer that charges, mixes, and discharges with the axis of the drum fixed horizontally (ACI 304, 2000).

2.2.3.2 Pan mixer

Pan mixers constitute of a low profile pan cylinder to hold the concrete ingredients. The pan is either stationary or rotating about its axis during the mixing process. If the pan is rotating, the blades are designed to rotate in opposite direction, if not, only the blades rotate in whatever direction the manufacturer has designed it to be.

There are large and small pan mixers. Large pan mixers are those with pans greater than $0.2\ m^3$. They typically discharge from a door at the bottom. Small pan mixers are those with pans less than $0.2\ m^3$ and they typically discharge by removing concrete materials from the top of the pan (NCPTC, 2007).

This type of mixer has significant advantage on rapid mixing. It also does an excellent job in mixing a relatively dry concrete. It is often used in laboratory and by manufacturers of concrete products for testing (ACI 304, 2000).

2.2.3.3 Pugmill mixers

These mixers are defined in ACI 304 (2000) as a mixer having a fixed cylindrical mixing compartment, a horizontal cylindrical axis, and one or more rotating horizontal shafts to which mixing blades or paddles are attached. The configuration and type may differ. They are designed to fold and move concrete during mixing process from one end to the other inside the cylinder. The pugmill mixers are suitable for harsh, stiff concrete mixtures. Usually for production of block units, roller compacted concrete e.t.c (ACI 304, 2000).

2.2.3.4 Truck mixers

There are two types of revolving drum truck mixers currently in use. These are the rear discharge and front discharge. The rear-discharge, inclined-axis mixer is the most commonly used. In both cases, the long spiral blades in the drum, mix concrete in the mixing mode and but discharge the concrete when drum rotation is reversed (ACI 304, 2000).

2.3 Mixing Sequence

Mixing sequence could easy be defined as the order of introduction of constituent material of concrete into the mixing process. The quality of order is constraint by the mixing time and charging intervals. Ferraris says the combination of both mixing sequence and mixing time is termed mixing method (Ferraris, 2001). But, other important components of mixing method include the type of mixer and the loading interval, the size of the mixer, and speed of rotation. Mixing sequence has a significant effect upon the properties of concrete as to workability, strength, density, surface finish and absorption (Fitzpatrick and Serkin, 1949).

Concrete mixing is a complex process in which many factors influence the quality of a final concrete product. These factors include loading sequence (NCPTC, 2007).

2.3.1 Importance of mixing sequence

As for all materials, the performance of concrete is determined by its microstructure. Its microstructure is determined by its mixing sequence and a range of whole other different parameters used in the process of concrete production (Ferraris, 2001). It is true that different mix sequence apply best for different methods of concrete production. This may be as a result of blade shape, mixer orientation and other important variable factors. This signifies the fact that proper mixing sequence varies from plant to plant. Proper mixing sequence has significant effect on uniformity of concrete which is used to test concrete quality; maximum allowable differences to evaluate mixing uniformity within a batch of ready mixed concrete are given in ASTM (ASTM C, 1994). The quality of concrete improves with uniformity. Uniformity improves with quality of sequencing. The best sequencing possible for a given method of production add to optimize concrete production resulting in better concrete performance and concrete quality.

2.3.2 Various mixing sequences

Shetty (2005) indicated a mixing sequence designed for charging a with a loading skip so as to get better efficiency in production while retaining concrete properties and it is as follows; 25 percent of water to be used is introduced into the mixer drum to wet the drum and to prevent any cement from sticking inside the drum. About half of coarse aggregate is then placed in the skip over which about half the quantity of fine aggregate is poured. On that, the full quantity of cement is poured. Over the cement, the remaining quantity of

coarse aggregate and fine aggregate is deposited in sequence; this prevents the spilling of cement or blowing away of cement in windy weather. The dry mix is charged into the drum. As soon as the dry mix has been charged completely, the remaining 75 percent of water is then added to the drum. If the mixer has got an arrangement for independent feeding of water, it is desirable that the remaining 75 percent of water is admitted simultaneously with the other materials. Mixing time is counted from the moment all the quantities; especially the complete quantity of water is fed into the drum. If plasticizer or superplasticizer was to be used, a litre of water would be held back, mixed with and added to the drum after one minute of mixing. If so, the mix would be prolonged, half a minute for the plasticizing effect to be fully achieved by proper dispersion (Shetty, 2005).

The half-wet system: it involves premixing sand, cement and water to form a slurry. This is then poured into a truck of already placed aggregate. This type of system has significant impact on batching time and reduces wear and tear in central mixer units (John and Ban, 2003).

Gaynor studied the influence of concrete truck mixers on concrete properties. He concluded that non-uniformity in truck-mixed concrete is caused by agglomerations of concrete materials inside the mixer, including head packs and cement balls. To remedy the non-uniformity problems, Gaynor suggested that one-fourth of the mixing water be added as the last ingredient and that the mixer rotate at 20 to 22 rpm (Gaynor, 1996).

In this paragraph, the mixing sequence only considers for air content and proffered the following clue based on cement applied firstly. It says that simultaneous batching lowers air content and cement first increases air content (Kosmatka *et al*, 2011).

Assist (2009) states that the following procedure is recommended for loading concrete mixers: place a part of the water into the mixer to clean the drum wall for any concrete left from the previous mix; half the volume of coarse gravel is charged. The gravel will also assist in cleaning the inner surfaces of the drum; the prescribed amount of sand and finer gravel is added; the cement is added; the remainder of the coarse gravel is added; mixed dry for one minute; when the aggregate and the cement have been thoroughly mixed, the remaining quantity of water is added and was mixed wet for two minutes.

Neville and Brooks (2010) suggested in their book, '*concrete technology'* the mixing sequence of a drum mixer. It says that a small amount of water should be fed first, followed by all aggregates and cement; fed preferably uniformly and simultaneously into the mixer. If possible, the greater part of water should be fed during the same time as the solid materials, the remainder being added afterwards. They also suggested that when using very dry mixes in the drum mixers, it is necessary to feed the coarse aggregate just after the small initial water has been fed. This is to ensure the aggregate surface is sufficiently wetted. In case of a small laboratory pan mixer and very stiff mixes, the sand should be fed first, then a part of the coarse aggregate, cement and water, and finally the remainder of the coarse aggregate so as to break up any nodules of mortar.

Under this paragraph, the sequence calls for obtaining a preblending or ribboning effect. This is considered by Gaynor and Mullarky to be essential. This calls for charging cement and aggregates simultaneously as the stream of materials to flow into the mixer (Gaynor and Mullarky, 1975).

This particular mixing sequence was designed to avoid packing of material, particularly sand and cement, in the head of the drum during charging of a truck mixer; it states that probability of packing is decreased when approximately 10% of the coarse aggregate and water in the mixer drum is placed before sand and cement. Approximately ¼ to 1/3 of the water should be added to the discharge end of the drum after all the solids have been charged. Water-charging pipes should be of proper design and of sufficient size so that water can enter at a point well inside the mixer. Lastly, charging should be complete within the first 25% of the mixing time (Gaynor and Mullarky 1975). This last part is an ACI Committee standard (ACI Committee 304, 2000).

This sequence is by the US Army Engineering Centre and School, for a skip loading: aggregate, cement and sand is to be deposited into the skip in that sequence, and then it should be discharged into the mixer while the mixing water is put into the mixing drum. Sand can be placed on the pile in the skip so that not too much cement is lost as the batch dumps into the mixer (United States Army Engineering Centre and School, 1992).

Two stage mixing method: It was a study made in relation to what the study considers a conventional mixing method. The study involved aggregate, recycled aggregate and natural aggregate mixed for 60 seconds after which half of water was added and mixed for another 60 seconds, then cement was added and mixed for another 30 seconds and half of the remaining water required was added and mixed for 2 minutes. This was with the aim of improving strength of recycled aggregate concrete. The conventional mixing method basically involved mixing fine aggregate, cement, recycled and natural coarse aggregate, water and mixing for 2 minutes (Tam *et al*., 2005).

In this section, the mixing sequence was used as aid to avoid cement balls in truck mixing. It indicated that 4000 pounds of coarse aggregate was loaded, three-quarter of the water was added, cement was ribbon loaded together with sand, and the rest of the coarse aggregate. One-quarter of the water was added lastly (Irtishad *et al.*, 2002). Irtishad *et al.*, indicated, Gaynor (1996) found that concrete ball was as a result of improper mixing sequence (Gaynor, 1996).

To avoid cement ball, Zuhlke in (Irtishad *et al*., 2002) suggested that water should be added over the full period of charging the mixer with dry material. Dry material should be ribbon fed at the same time. The mixer must be clean and in good condition, not over loaded, and operating at optimum speed; also to be made sure is that the mixer blades are not worn more than 10%.

(Gaynor, 1996) Gaynor believes that ribbon loading is prone to form head-packs and concrete lumps. To avoid this problem, Gaynor suggested that coarse aggregate and some water should be placed prior to sand and cement during the sequence of loading.

Recommended mixing sequence for Rinker concrete plant: This mixing sequence is a comparative study to improve Rinker concrete plant mixing sequence. The standard mixing sequence used by Rinker concrete plant was headwater, ribbon-fed cement, aggregate, all initially mixed at 12 rpm (Revolution per minute), tailwater was then added with 30 additional revolution at 12 rpm, concrete then discharged and lumps sieved if found. The following mixing sequence was then recommended; Aggregates should be charged first then headwater. After these, cemetitious materials should be ribbon fed into the aggregate stream. Discharge of cementitious material should be completed prior to the completion of

aggregate charge. Finally, the tailwater should be charged. The drum should rotate for 90-100 initial mixing revolutions at a speed of 12rpm. Once the initial mixing is complete, the jobsite water should be added to increase the slump of concrete. The concrete should then be mixed for an additional 30 revolutions at 12 rpm. The process was recommended because it was not very different from the original mixing sequence as it could easily be applied (Irtishad *et al.*, 2002).

A two-stage mixing sequence: This involves mixing slurry of cementitious materials and water, then adding the slurry to a coarse and fine aggregate to form concrete. It is believed that the pre-mixing process might facilitate dispersion of cementitious material and improve cement hydration, concrete homogeneity, and the interfacial transition zone (ITZ) between aggregate and paste. The two stage mixing sequence has increased concrete strength by 8 to 20 percent and improves uniformity significantly over conventional method (NCPTC, 2007).

Hydromix: this mixing sequence is a continuous mixing process. Once the cementitious materials are batched and ribbon fed into slurry after which the aggregate belt starts to charge the awaiting ready mix truck. Admixtures such as air entraining agent and water reducer are sprayed on aggregate as it is being charged into the ready mix truck (NCPTC, 2007).

The Hybrid Mixing sequences: the hybrid mixing sequence is a concept just like the two-stage mixing sequence. The hybrid mixing sequence involves mixing in several partial quantities but with varying mixing intensity. In this, the speed of the mixer is adjusted

based on respective requirements. A scheme graph of a hybrid mixing sequence has been developed for further reduction of optimum mixing time in (Lowke and Schiessl, 2005).

The two-stage slurry premixing sequence: Pope and Jennings experimented with a two-stage slurry premixing process of sequencing. In the study, cement and water were initially mixed in a large bench-top mixer, then added to fine aggregate in a large rotary mixer and mixed into a mortar. The researchers came to the conclusions that the microstructure and the paste-aggregate bond were improved by limiting the amount of direct water contact with the aggregate during mixing, and the 28 days compressive strengths of the premixing process samples were greater than the samples prepared by delaying the order of mixing water (Pope and Jennings, 1992).

Soga and Takagi reported that rate of adding the mixing water and the speed of revolution of the mixing drum control fresh concrete characteristics. In particular, the bleeding rate of fresh concrete decreases as the addition rate of water decreases and the speed of rotation of the mixer is increased (Soga and Takagi, 1986).

Sand enveloped with cement concrete mixing sequence: This is a mixing sequence created and studied by Mitsutaka and Yasuro. Mitsutaka and Yasuro (1982) studied the effects of adding mixing water at two separate times during mixing process. In the first stage, the aggregate and a weight of water equal to 25 percent of the weight of the cement were mixed for 30 seconds. The cement was added next and mixed altogether for 1 minute. In the final stage, the remaining water required was added and mixed for 1 minute 30 seconds. Concrete produced by this technique was labeled “sand enveloped with cement concrete” (SEC). The goal of the studies was to investigate the effectiveness of this new

mixing technique in reducing the bleeding rate of fresh concrete and increasing the compressive strength at various stages of curing (Mitsuka and Yasuro, 1982). They concluded that this method did in fact reduce the bleeding rate of fresh concrete and improved the compressive strength over conventionally-mixed concrete. Tamini (1994) took the research further to prove that adding water using the mixing sequence formula leads to a greater gel-to-space ratio in the interfacial transition zone (ITZ), thereby creating a greater intimate bond, lower porosity, and increased micro-hardness in the ITZ.

(Mass, 1989) strongly suggested that experimental works have shown that mixing cement and water into a paste before combining these materials with aggregates can increase the compressive strength of the resulting concrete.

The Standardized Mixing Sequence: The standard mixing sequences available are those of the ASTM (1994a); ASTM (1998c), the American Concrete Institute Committee ACI (2000) and the (BS 1881-125, 1986).

a. ASTM (1994a) outlines guidelines for standard mixing sequence of concrete. ASTM (1994a) specifies that some water and all aggregates should be added and mixed firstly. Secondly, cement should be added and mixed, and finally, the remaining portion of the water is added with no more than one-fourth of the total mixing time elapsed. Liquid admixtures are to be added with the mixing water.

b. ASTM C 305 (1998c) specifies a different order for mixing constituents. The sequence calls for initially mixing the water, cement and fine aggregate into a uniform mortar, then adding the coarse aggregates.

c. ACI (2000) states that coarse aggregates should be placed in the mixer first, followed by the fine aggregates. Then add in sequence the required water, cement.

d. British mixing sequence for drum mixer using dry aggregate content: it specifies that all aggregate should be put in one amount if single aggregate type is used but if separate fine and coarse aggregates are used, about half the coarse aggregate is added, next all the fine aggregate is added and in sequence the remaining coarse aggregate is added after which the mixer is started and made to mix between 15 seconds to 30 seconds. As the mixer is mixing, about half the mixing water is added during a period of 15 seconds after which the mixer is left to mix for 2 minutes to 3 minutes before stopping and the contents is covered for 5 minutes to 15 minutes. Then cement and additives is added on the aggregates and mixed for 30 seconds. After that the remaining water is added and continue to mix for not less than 2 minutes and not more than 3 minutes after all the materials have been added. After mixing is complete, the concrete is discharged onto a clean non-absorbent surface and turned over using a hand tool to ensure uniformity of mix before sampling (BS 1881-125, 1986).

e. The BS 1881-125 (1986) mixing sequence for drum mixer using saturated aggregates: It specifies that if an all-in aggregate is used, about half the aggregate should be added before the other materials and the remainder after them. If separate fine and coarse aggregates are used, about half the coarse aggregate is added, all of the fine aggregate is added next, the cement and any ground granulated blast-furnace slag, pulverized-fuel ash, pigment or other powders is/are added after the fine aggregate and the remaining coarse aggregate is added in sequence. The mixer

is started and all the water added during the first 30 seconds of mixing. Mixing should continue after all the materials have been added for at least 2 minutes and not more than 3 minutes. After completion of mixing, concrete is discharged onto a clean non-absorbent surface and turned over using a hand tool to ensure uniformity before sampling (BS 1881-125, 1986).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

In the course of this research, materials that were used include fine aggregate, coarse aggregate, cement and water.

3.1.1 Fine aggregate (sharp sand)

The fine aggregate used in this research work was fine river sand supplied to the Department of Building, Ahmadu Bello University Zaria from Ahmadu Bello University Dam conforming to ASTM C778 (2013) and BS 812 part 2 (1995)

3.1.2 Coarse aggregate (gravel)

A load of crushed granite stone was obtained from Zaria-Sokoto road quarry site, which passes through 20mm sieve and is retained on 5mm sieve, was used for the study which was in accordance with BS 812 part 2 (1995) and ASTM C 127 (1993).

3.1.3 Cement

The cement used for this research work was Portland cement manufactured by Dangote Cement Company which was gotten from Sabon Gari Market, Zaria, with standards conforming to ASTM C1084 (2010).

3.1.4 Water

Water from Ahmadu Bello University, Zaria water main supply was used for this study. The quality of water conformed to BS EN 1008-2 (2002) standard.

3.2 Methods

3.2.1 Physical properties of Portland cement

All tests carried out were in accordance to the standard codes of practice used at the Department of Building, Ahmadu Bello University (A.B.U) Zaria. They are as follows:

3.2.1.1 Specific gravity test for cement

Specific gravity test was conducted to determine the values used in the batching of the mix.

Materials: Dangote Portland cement

Apparatus: Density bottle (pyknometer) and stopper, weighing balance, funnel and spatula

Procedure: In accordance to the ASTM C311 (2005).

3.2.1.2 Bulk density test for cement

The compacted bulk density of the cement was determined by using the cylinder method.

Materials: Dangote Portland cement

Apparatus: cylinder, Metal rammer, electronic scale.

The Bulk density was calculated using the formula below:

$$\text{Bulk density} = \frac{W}{V} \quad \text{.....(3.1)}$$

Where; W= weight of the material

V= volume of the metal ring

3.2.2 Physical properties of aggregates

The physical properties of coarse and fine aggregate was determined based on oven-dry and saturated surface dry condition in accordance to the standard at the Department of Building, Ahmadu Bello University Zaria; in order to find the parameters to be used in concrete mix design

3.2.2.1 Bulk density of aggregates

The bulk densities of the fine and coarse aggregates were determined base on saturated surface dry condition when compacted.

Materials: Fine aggregates (sand), Coarse aggregates (gravel)

Apparatus: An empty box container**,** Weighing balance and BS sieves, Tamping rod**.**

Procedure: in accordance to BS 812 part 2 (1995).

3.2.2.2 Specific gravity of aggregates

The specific gravity (Gs) was determined for the aggregate using pykonometer method in accordance to the standard.

Materials: Coarse aggregates**,** fine aggregates and water

Apparatus: Pykonometer, Oven**,** BS sieves

Procedure: in accordance to ASTM C 127 (1993):

3.2.3 Mixing sequences used and concrete samples produced

Table 3.1 shows the detail number of cubes that were cast and the ages they were tested. The samples from the mentioned mixing sequences were used to cast concrete cube specimens of size 100mmm by 100mm by 100mm. A number of 240 specimens were produced for both water absorption and abrasion resistance tests, 480 cubes were produced for compressive strength test. A total of 720 test cubes were produced and tested in all. Five (5) numbers of samples were used for each test carried out, Quality Event Management Solutions (QEMS, 2011). The mixing sequences used in this research work presented on table 3.1 were gotten from the four factorial of the major ingredients of concrete used, each poured into the mixing process a single time. A four-factorial which is 24, provides the bases for the 24 individual mixing sequences used in this work.

Table 3.1: Mixing sequences used, number of cube specimens produced and ages of testing.

Mixing Sequences	S/N	Abrasion Resistance and Water Absorption Capacity Tests		Compressive Strength Test			
		Curing Ages of Samples for Tests in Days					
		28	56	7	14	28	56
Water, coarse aggregate, cement, sand	**1**	5	5	5	5	5	5
Water, sand, cement, coarse aggregate	**2**	5	5	5	5	5	5
Water, cement, sand, coarse aggregate	**3**	5	5	5	5	5	5
Water, coarse aggregate, sand, cement	**4**	5	5	5	5	5	5
Water, sand, coarse aggregate, cement	**5**	5	5	5	5	5	5
Water, cement, coarse aggregate, sand	**6**	5	5	5	5	5	5
Sand, water, cement, coarse aggregate	**7**	5	5	5	5	5	5
Sand, cement, water, coarse aggregate	**8**	5	5	5	5	5	5
Sand, cement, coarse aggregate, water	**9**	5	5	5	5	5	5
Sand, coarse aggregate, cement, water	**10**	5	5	5	5	5	5
Sand, water, coarse aggregate, cement	**11**	5	5	5	5	5	5
Sand, coarse aggregate, water, cement	**12**	5	5	5	5	5	5
Cement, water, sand, coarse aggregate	**13**	5	5	5	5	5	5
Cement, sand, water, coarse aggregate	**14**	5	5	5	5	5	5
Cement, sand, coarse aggregate, water	**15**	5	5	5	5	5	5
Cement, coarse aggregate, sand, water	**16**	5	5	5	5	5	5
Cement, coarse aggregate, water, sand	**17**	5	5	5	5	5	5
Cement, water, coarse aggregate, sand	**18**	5	5	5	5	5	5
Coarse aggregate, water, sand, cement	**19**	5	5	5	5	5	5
Coarse aggregate, sand, water, cement	**20**	5	5	5	5	5	5
Coarse aggregate, sand, cement, water	**21**	5	5	5	5	5	5
Coarse aggregate, cement, sand, water	**22**	5	5	5	5	5	5
Coarse aggregate, cement, water, sand	**23**	5	5	5	5	5	5
Coarse aggregate, water, cement, sand	**24**	5	5	5	5	5	5

Source; laboratory research work (2016)

3.2.4 Production and testing of concrete sample specimen

3.2.4.1 Mix design

BRE Method of mix design was used. A concrete grade of 25 N/mm^2 was designed for at 28 days of curing base on the fact that it is a commonly used grade in Nigeria (kazeem *et al*, 2015). The mix ratio (1:2.25:2.44) was deduced, the quantity of materials used were 15kg for cement, 33.74kg for sand, 36.56kg for crushed stone, and 8.69kg of water. A water cement ratio of 0.58 was used. Concrete samples produced from each batch of materials were at least 35 cubes of 100 mm x 100 mm x 100 mm.

3.2.4.2 Production method

A hand fed concrete mixer was used. Twenty-four different mixes were sequenced. Each mixing sequence was used to mix concrete for a period of 2 minutes at a charging interval of 20 seconds. The mixings start and finish while the mixer was running for at least 2 minutes.

3.2.5 Testing of fresh concrete

3.2.5.1 Slump test

The slump test was used to assess the workability of the mix

Materials: Fresh concrete mix

Apparatus: Scoop, Tamping rod**,** Base plate, hand scoop, trowel and Slump testing cone

Procedure: in accordance to BS 1881-102 (1983).

3.2.5.2 Compacting factor

Before the concrete sample specimen is poured into mould, workability test for compacting factor was carried out in accordance to BS 1881: 103 (1983).

3.2.5.3 Plastic density

Tests on plastic density were carried out in accordance with ASTM, (2001a). It was conducted at the Department of Building, ABU Zaria.

3.2.5.4 Air content

Tests on air content were carried out in accordance with ASTM, (2001a). It was conducted at the Department of Building, ABU Zaria.

3.2.6 Testing of hardened concrete

Destructive method of testing was used in this study. These included compressive strength and durability tests on cubes.

3.2.6.1 Compressive strength test

The test was conducted according to British Standard European Norm (BS EN) 12390:3. (2002). A total of 480 concrete cubes of size, 100 mm x100 mm x100 mm were crushed at saturated surface dry condition. The crushing was carried out at 7, 14, 28 and 56 days using a hydraulic crushing machine of 1000 KN capacity.

3.2.6.2 Water absorption capacity test

The water absorption capacity tests were carried out in accordance with BS 1881-122: (1983). 240 concrete samples were used for both 28 and 56 days of curing. The absorption capacities were evaluated as the increase in mass resulting from the immersion of the concrete specimen in water tank and express as the percentage of the specimen.

3.2.6.3 Abrasion resistance test

Abrasion resistance test was carried out using cubes at the age of 28 and 56 days of curing. 240 concrete cube samples of size, 100mm by 100mm by 100mm were tested for abrasion and they were done in using steel wire brushes. Abrasion resistance was computed as percentage abraded using the following formula.

Percentage abraded = $\left[\frac{(wb-wa)}{wb}\right] 100$ ……...(3.2)

Weight before abrasion = wb

Weight after abrasion = wa

3.3 Method of Data Analysis

The data obtained were analyzed using simple statistical tools like standard deviation and mean. Standard deviation is used by standard codes to check uniformity between concrete samples and they are limits codes adhere to depending on the concrete property involved and these uniformities were checked and used according to standard codes of practice. The results were compared for the different concrete mixes. The following are the formulae of the statistical tools; mean and standard deviation respectively.

Average Measurement = $\frac{x1+x2+\cdots+xn}{n}$ ……..…….(3.3)

x1, x2,…xn = Individual Measurements

n = No of Individual Tests

Standard Deviation = $\sqrt{\left[\frac{(x1-x)^2+(x2-x)^2+\cdots+(xn-x)^2}{(n-1)}\right]}$ ……...(3.4)

x1, x2,…xn = Individual Measurements

n = No of Individual Tests

x = Average measurement

CHAPTER FOUR

4.0 DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

4.1 Presentation of Results of Preliminary Test

The results presented in this chapter were for various tests carried out on the concrete samples produced using 24 different mixing sequences. Results were presented on both fresh and hardened concrete. Six (6) properties of concrete were tested, these include; workability, plastic density, air content, compressive strength, abrasion resistance and water absorption capacity. Under workability tests carried out, results were presented on slump and compacting factor.

4.1.1 Fresh concrete test results

4.1.1.1Workability

This was carried out in terms of slump and compacting factor to assess the consistency of the mix. It is an important property to consider because it measures the amount of useful work to obtain full compaction without excessive bleeding or undue segregation.

Slumps of concrete samples: Fig 4.1 shows the relationship between concrete batch samples mixed using the ACI standard mixing sequence, the ASTM standard mixing sequence and the rest of the 22 unstandardized mixing sequences. Mix done using ACI mixing sequence had an average slump of 37.25mm and a standard deviation of 13.55mm. Batches mixed using ASTM mixing sequence had an average slump of 43mm and a standard deviation of 15.49mm. They both fall within the range the concrete mixes were designed for. All concrete batches mixed using standardized mixing sequences satisfy the

ASTM C09 conditions. Out of the 22 unstandardized mixing sequences, 7 mixing sequences (24, 23, 18, 16, 15, 10, and 6) had a mix with lower average slump than the standardized mixing sequences. The concrete batches mixed using 3 mixing sequences (15, 16 and 18) had a low degree of workability which is not satisfactory because the mixes were designed for a medium degree of workability. Concrete batches of 3 mixing sequences (4, 11, and 13) had a high degree of workability which is satisfactory. The 3 concrete batches mixed using mixing sequences (22, 19 and 17) were found to be unsatisfactory in accordance with the ASTM C09 (2003). This indicates that some mixing sequence have bad effect on consistency and uniformity of fresh concrete in terms of slump. The BRE method of design is compatible to both the ASTM and the ACI standard mixing sequences but not to all mixing sequences.

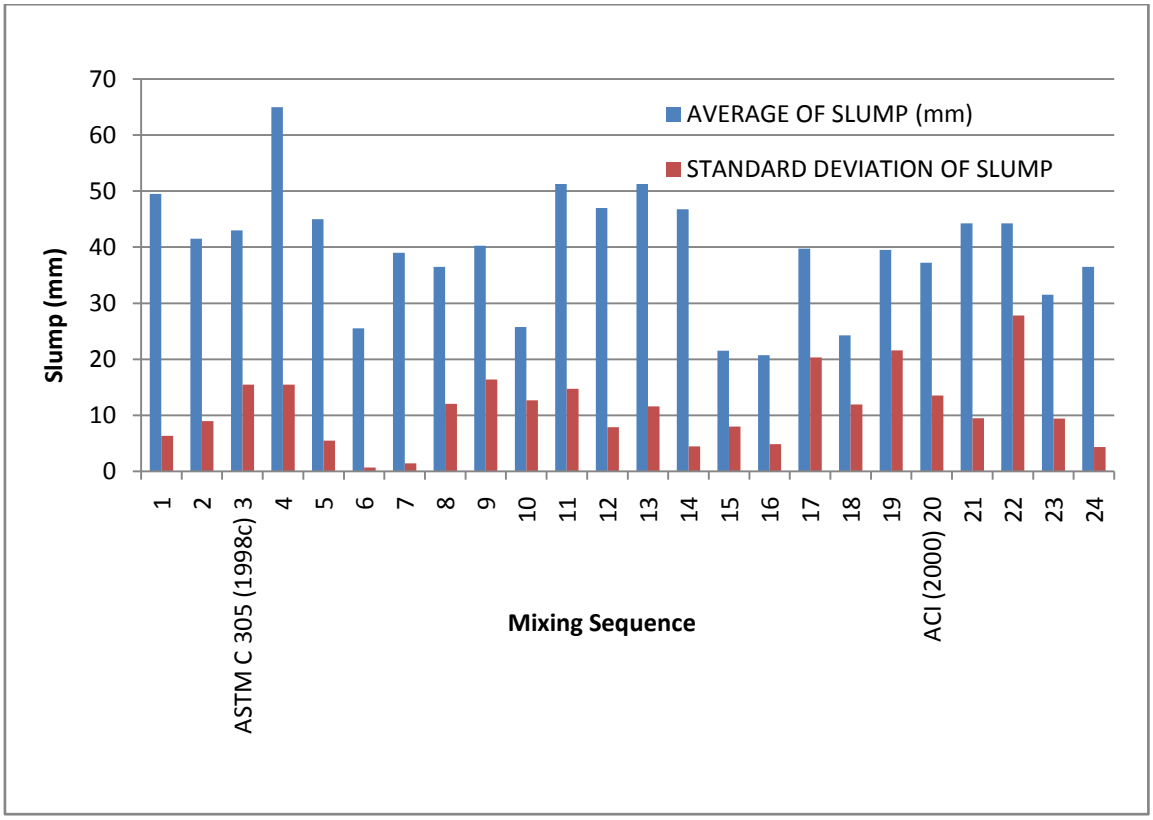


Figure 4.1: Slumps of concrete samples

Average compacting factors of fresh concrete samples are presented in Figure 4.2. the results shown using the average compacting factors for concrete batches mixed using 24 various mixing sequences range from 0.90 to 0.96. The mix done using ACI mixing sequence was found to be slightly more workable than that done using ASTM mixing sequence and having an average compacting factors of 0.94 and 0.93 respectively. Mixes produced using the two standardized mixing sequences both fall within a medium degree of workability under compacting factor which is satisfactory. Up to 12 mixing sequences (2, 4, 5, 7, 9, 11, 13, 14, 17, 21, 22, and 24) used were found to have a more workable mix than those of the standardized mixing sequences under compacting factor. Mix done using mixing sequence number one had a low degree of workability under compacting factor. This indicates that mixing sequence has a poor effect on compacting factor. For the 24 mixing sequences assessed, slump test had two poor concrete batches morethan compacting factor test. This is evident, there is more likely chance to observe poor effect of mixing sequence in slump test than in compacting factor test as far as workability is concerned.

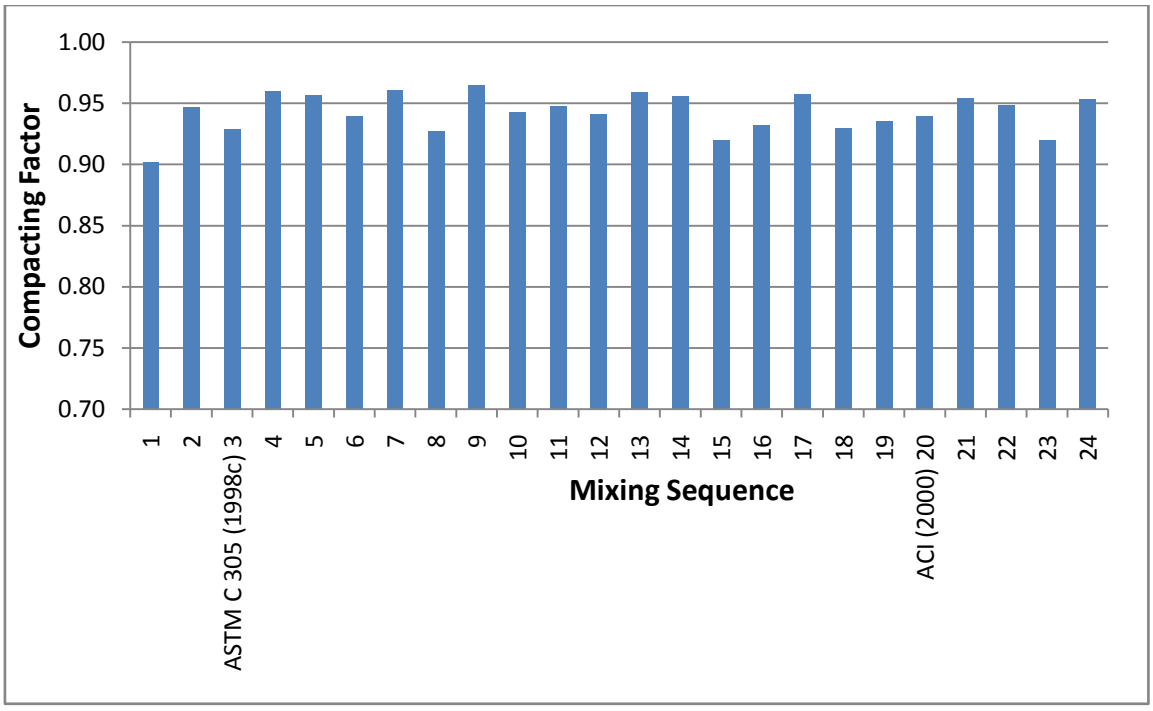


Figure 4.2: Average compacting factor of concrete samples

Standard deviations for compacting factor of fresh concrete samples: According to figure 4.3, all batches mixed using the various mixing sequences fulfilled the reproducibility condition of not more than 0.04 standard deviation of compacting factor as prescribed in BS 1881: 103 (1983). Batches mixed using the ACI standard mixing sequence had 0.003 standard deviation for compacting factor and batch mixed using ASTM standard mixing sequence had 0.001 standard deviation for compacting factor.

With all concrete samples fulfilling standard requirements under compacting factor test, it is safe to assume that mixing sequence has no negative effect on compacting factor as far as standard deviation is concerned. It is only that, some samples have better uniformity than others which is proof of the effect of mixing sequence on compacting factor.

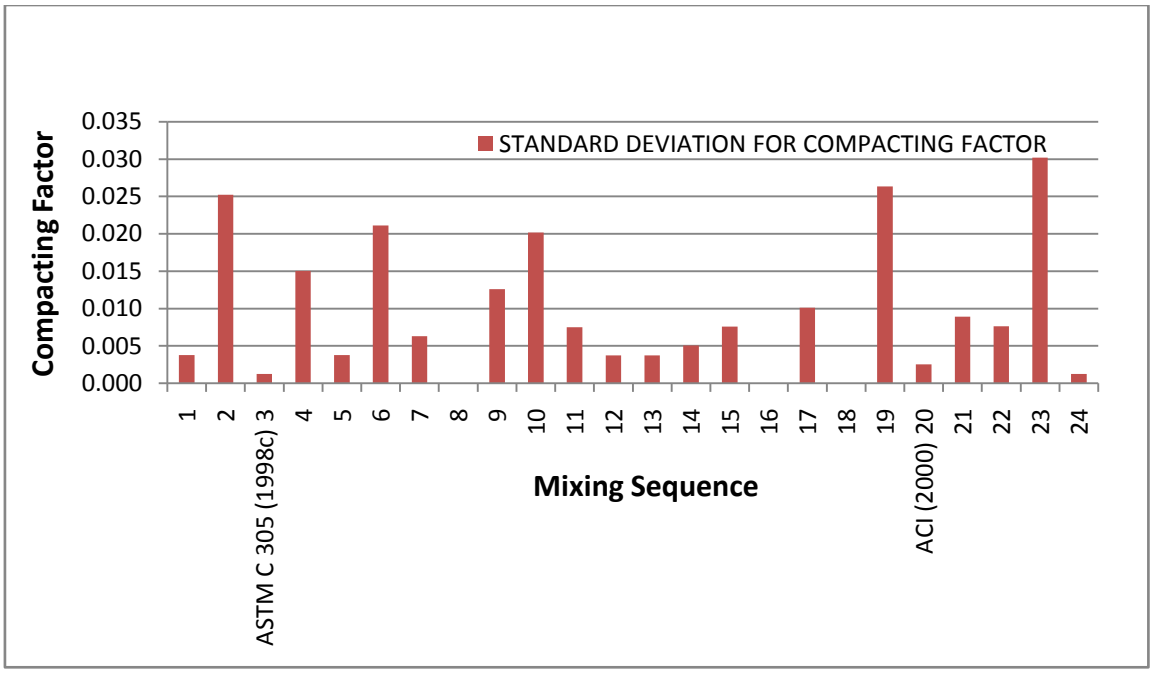


Figure 4.3: Standard deviations for compacting factors of samples

4.1.1.1.2 Plastic densities of concrete samples

Average plastic densities of fresh concrete samples: Figure 4.4 shows the average plastic densities of batch samples produced using 24 individual mixing sequences. The number of fresh concrete batches produced using individual mixing sequence that produced higher average plastic density than those of the two standardized mixing sequences is 5. They were mixes from mixing sequences (4, 5, 7, 8 and 12) and their average plastic densities were (2269 kg/m^3, 2267 kg/m^3, 2264 kg/m^3, 2248 kg/m^3 and 2252 kg/m^3) respectively. The average plastic density of all concrete batches range from 2182kg/m^3 to 2269kg/m^3 with the batch mixed using ACI mixing sequence at 2239kg/m^3 and the batch mixed using ASTM mixing sequence at 2248kg/m^3. The concrete batch mixed using ASTM mixing sequence has higher average plastic density than that mixed using ACI mixing sequence and was closer to design value of 2270kg/m^3. This indicates that the concrete batch mixed using ASTM mixing sequence has more stability compared with concrete batch produced using

ACI mixing sequence and is more compatibility with BRE method of mix design under plastic density.

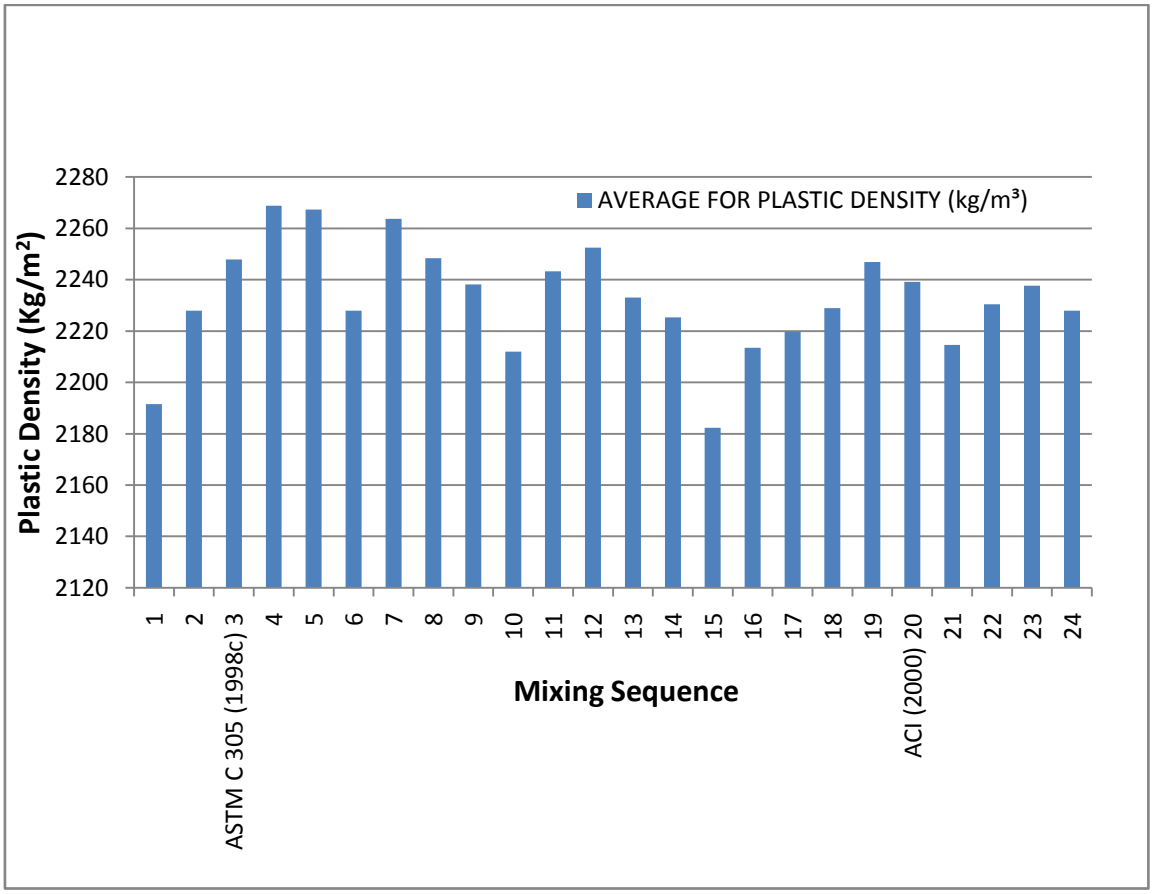


Figure 4.4 Average plastic densities of concrete samples

Standard deviations for plastic density of concrete samples: Figure 4.5 shows the standard deviation of plastic densities for concrete batches mixed using 24 different mixing sequences. Batch mixed using ACI mixing sequence had a standard deviation of 17.6kg/m^3 while batch mixed using ASTM mixing sequence had a standard deviation of 18.5kg/m^3 all for plastic density. It indicates an acceptable range of standard deviation for plastic density in concrete batches for both standardized mixing sequences which states that it should not differ by more than 37.0kg/m^3. Only concrete sample of mixing sequence number one has been found to have a better standard deviation than samples mixed using the two standard

mixing sequences. No concrete sample has been found to be incoherent to the limits set in ASTM, (2001a). As it can be seen from the standard deviation of plastic density of concrete samples, no any mixing sequence has a poor effect on plastic density. This means no any order involved in the process of mixing sequence has a poor effect on plastic density of concrete.

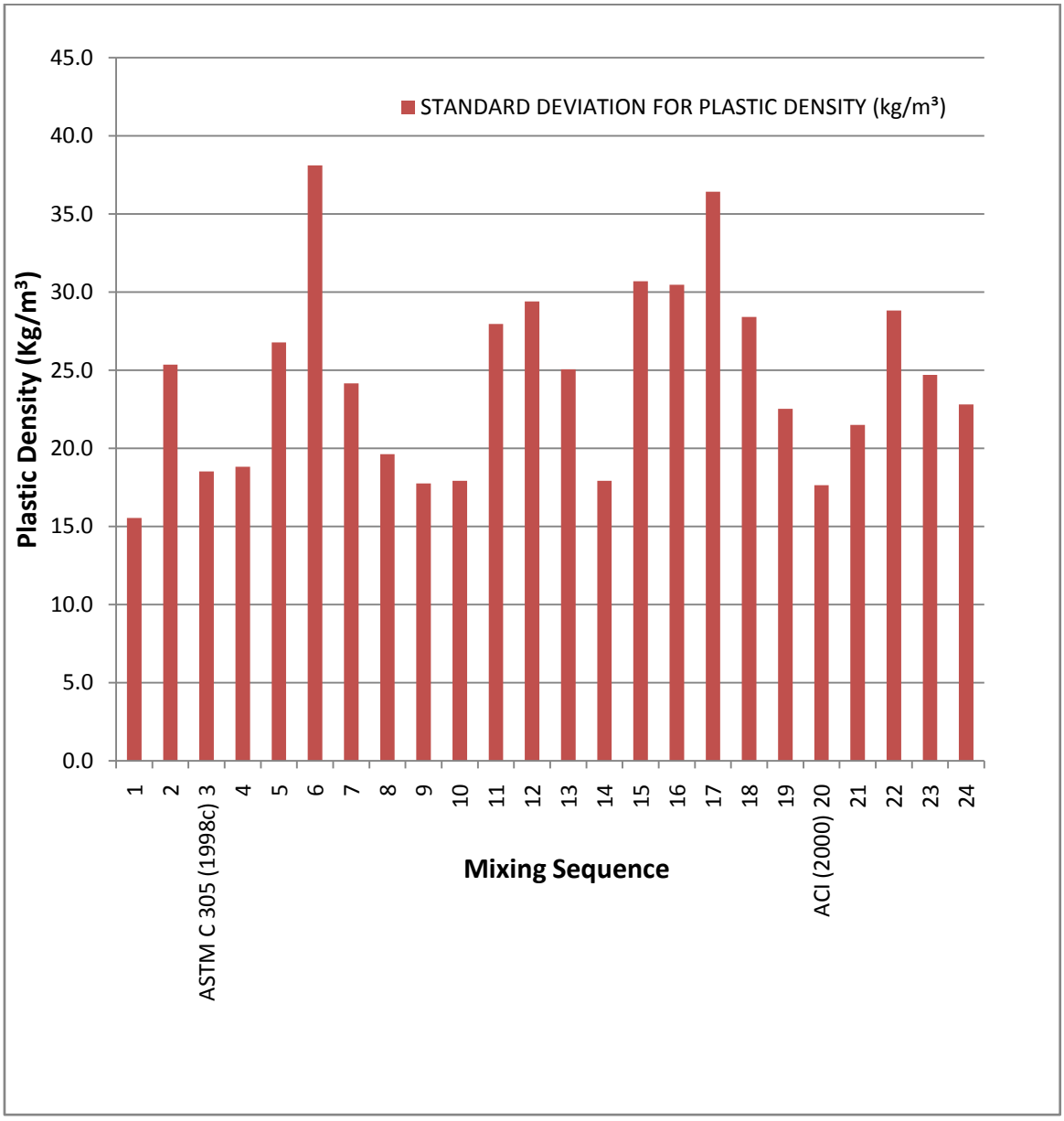


Figure 4.5: Standard deviations for plastic density of samples

4.1.1.1.3 Air contents of concrete samples

Figure 4.6 shows the average air content of concrete batches mixed using 24 different mixing sequences. The average air contents for all concrete samples ranged from 1.09% to 4.80%. The concrete batch mixed using ACI mixing sequence had an average air content of 2.3% while concrete batch mixed using ASTM mixing sequence had an average air content of 1.94%. The number of concrete batches that had higher average air content than those of the two standard mixing sequences is fifteen (15). They were batches mixed using mixing sequences (1, 2, 6, 9, 10, 13, 14, 15, 16, 17, 18, 21, 22, 23 and 24) and their average air contents were (4.39%, 2.81%, 2.81%, 2.36%, 3.50%, 2.58%, 2.92%, 4.80%, 3.43%, 3.16%, 2.76%, 3.39%, 2.70%, 2.38% and 2.81%) respectively. This indicates that concrete batches mixed using standard mixing sequences had relatively low air content. The fact that the average air content in all batches had a difference of 77.29% across samples means that mixing sequence has an effect on air content of concrete.

The standard deviations for air content of concrete samples range from 0.6% to 1.65% for all concrete samples mixed using the mixing sequences produced. Samples mixed using ACI mixing sequence had standard deviation of air contents to be 0.65% while those mixed using ASTM mixing sequence had a standard deviation of air content of 0.81%. The samples mixed using ACI mixing sequence had samples mixed using mixing sequences (8, 9 and 10) to have lower standard deviations of air content while samples mixed using ASTM mixing sequence had samples mixed using mixing sequences (1, 4, 8, 9, 10, 20 and 24) to have lower standard deviation of air content. Samples produced using mixing sequences (14 and 17) did not satisfy the precision statement for standard deviation of air content in BS 1881: 106. (1983). This indicates that some mixing sequence have poor

effect on air content of concrete. The two standard mixing sequences ACI and ASTM had satisfactory air content uniformity.

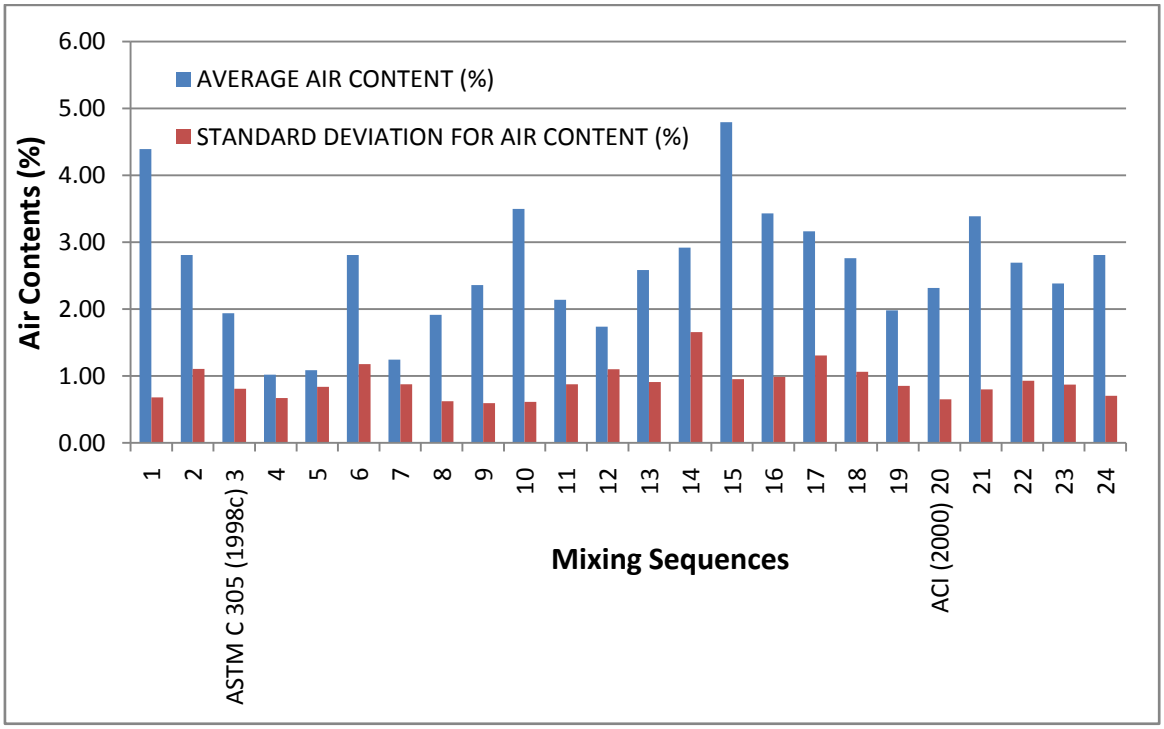


Figure 4.6: Standard deviations and average air contents of samples

4.1.2 Hardened concrete test results

4.1.2.1 Compressive strength of concrete samples

The test for compressive strength was carried out on the various concrete samples as described in chapter three; tests were carried out for 4 curing ages which were at 7, 14, 28, 56 days. The results were presented on different figures for each age of testing due to the needed clarity it provided.

Compressive strength of concrete samples at 7 days of curing: Figure 4.7 shows the relationship between average and standard deviation of compressive strengths at seven

days of curing. Concrete cube sample with lower standard deviation and higher average compressive strength is considered better especially if this pattern followed up at subsequent testing ages. The average compressive strength of cubes produced using ACI mixing sequence was 20.34N/mm^2 while the average compressive strength of cubes produced using ASTM mixing sequence was 22.36N/mm^2. The standard deviation of compressive strength for cubes produced using ACI mixing sequence was 2.5N/mm^2 while that for those produced using ASTM mixing sequence was 2.50N/mm^2. It can be seen that despite good average strength, samples produced using a particular mixing sequence can have low standard deviation signifying a probable improved strength using that mixing sequence.

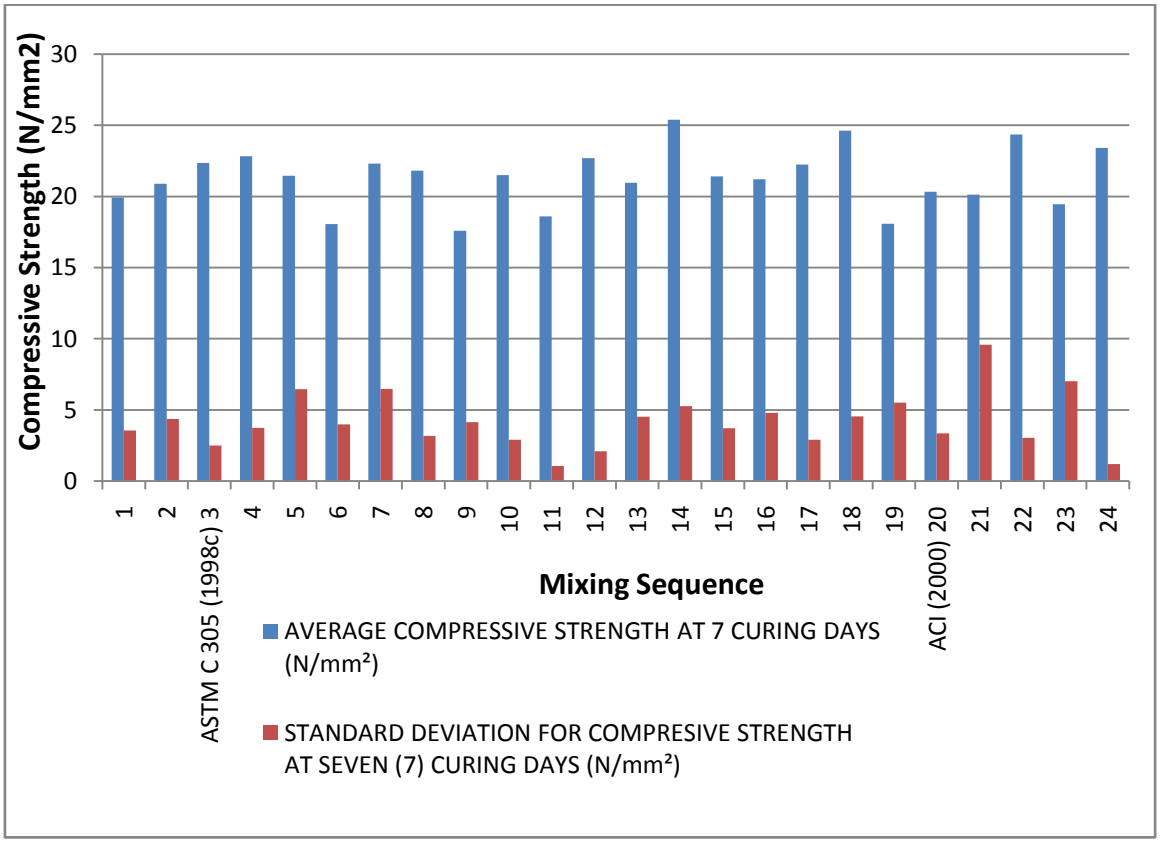


Figure 4.7: Compressive strengths of samples at 7 days of curing

Compressive strength of concrete samples at 14 days of curing: Figure 4.8 shows the average and standard deviation for compressive strength at 14 days of concrete cube samples produced using different mixing sequences. The average compressive strength for cube samples produced using ACI mixing sequence was 24.12N/mm^2. The average compressive strength for samples produced using ASTM mixing sequence was 22.74N/mm^2. The standard deviation for samples produced using ACI mixing sequence and samples produced using ASTM mixing sequence was 1.62 and 2.72 respectively. The standard deviations of compressive strengths of cube samples were generally lower at 14 days that those at 7 days. The cube samples made using ACI mixing sequence had higher grade than the cube samples made using ASTM mixing sequence by 5.72% at 14 curing days. This gives a good idea as to the likely subsequent strength development.

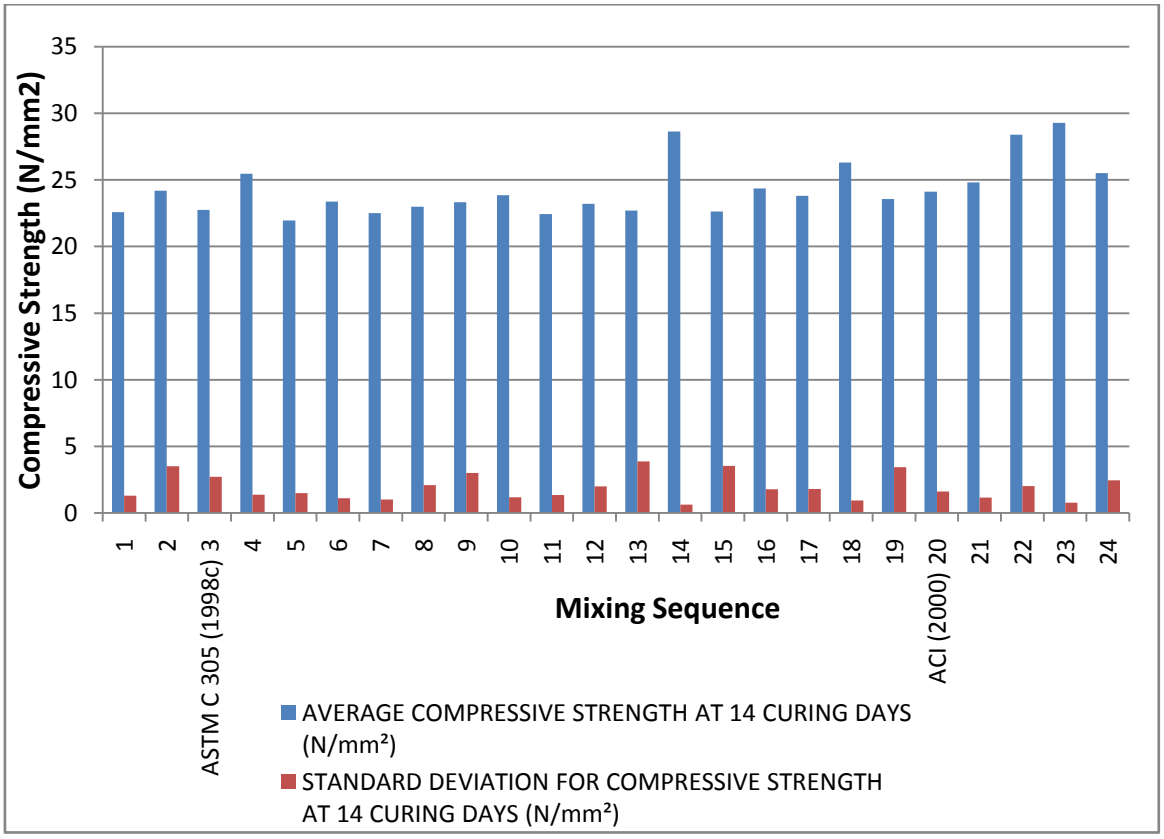


Figure 4.8: Compressive strength of samples at 14 days of curing

Compressive strength of concrete samples at 28 days of curing: Figure 4.9 shows the averages and standard deviations of cube samples for compressive strength tests at 28 days of curing. It shows the average compressive strength for cube samples mixed using ASTM mixing sequence was 24.9N/mm^2. The average compressive strength of cube samples mixed using ACI mixing sequence was 27.24N/mm^2. It shows the standard deviations of compressive strengths was 2.94N/mm^2 for cube samples mixed using ASTM mixing sequence and 2.12N/mm^2 for cube samples mixed using ACI mixing sequence. This means that cube samples mixed in accordance with ACI mixing sequence had higher grade than cube samples mixed in accordance with ASTM mixing sequence by 8.59%. This suggests that cube samples mixed in accordance with ACI mixing sequence has gained more strength than cube samples mixed in accordance with ASTM mixing sequence over the course of 28 days of curing.

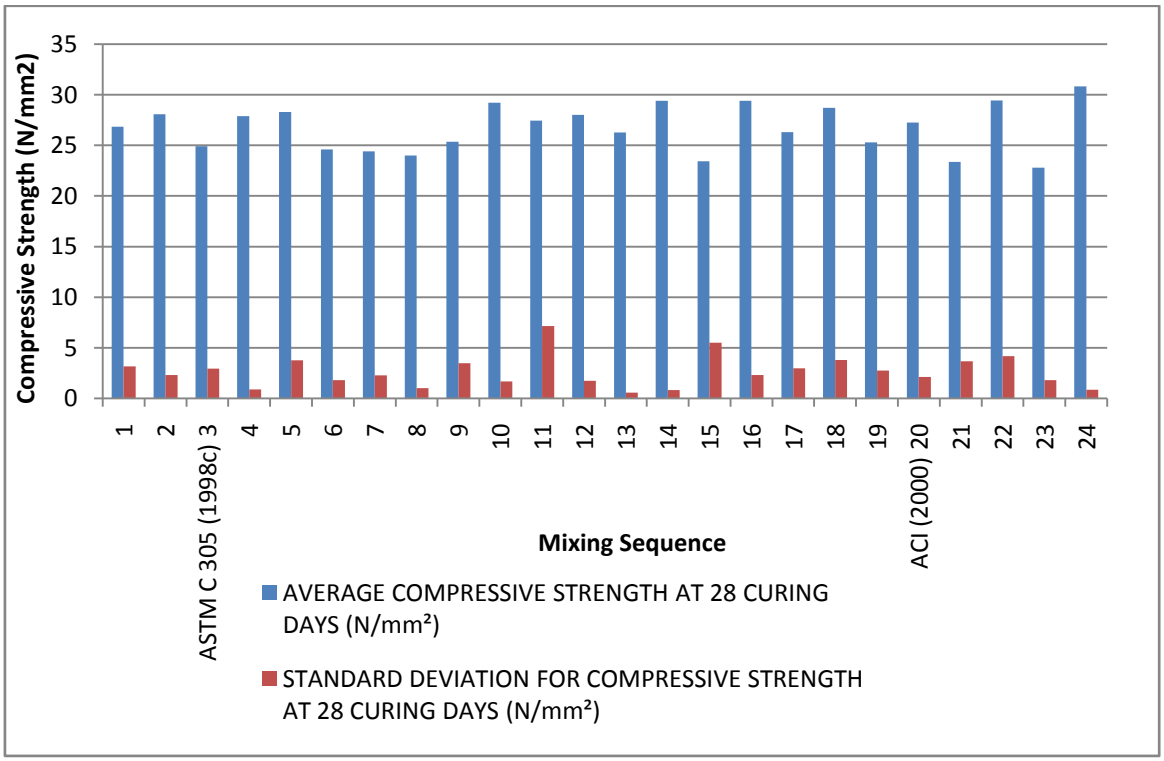


Figure 4.9: Compressive strengths of samples at 28 days of curing

Compressive strength of concrete samples at 56 days of curing: Figure 4.10 shows the averages and standard deviations of compressive strengths at 56 days for the various cube samples mixed using different mixing sequences. The average compressive strength for cube specimens mixed using ACI mixing sequence and ASTM mixing sequence was 30.48N/mm^2 and 25.2N/mm^2 respectively. The standard deviation of compressive strength for cube samples mixed using ACI mixing sequence and ASTM mixing sequence was 0.79N/mm^2 and 0.91N/mm^2 respectively. The cube samples mixed using ACI mixing sequence had higher grade than the cube samples mixed using ASTM mixing sequence by 17.32%. At this point, it can be said that cube samples mixed using ACI mixing sequence gained strength faster than the cube samples mixed using ASTM mixing sequence. Cube specimens mixed using ACI mixing sequence kept to increase more in strength compared with cube samples mixed using ASTM mixing sequence by 66.13% between 7 and 56 curing days. This indicates that mixing sequence affects strength development. Only cube samples from mixing sequences 3, 8, 10, 12, 17, 20 and 24 have passed the generally accepted precision statement for compressive strength in all testing ages.

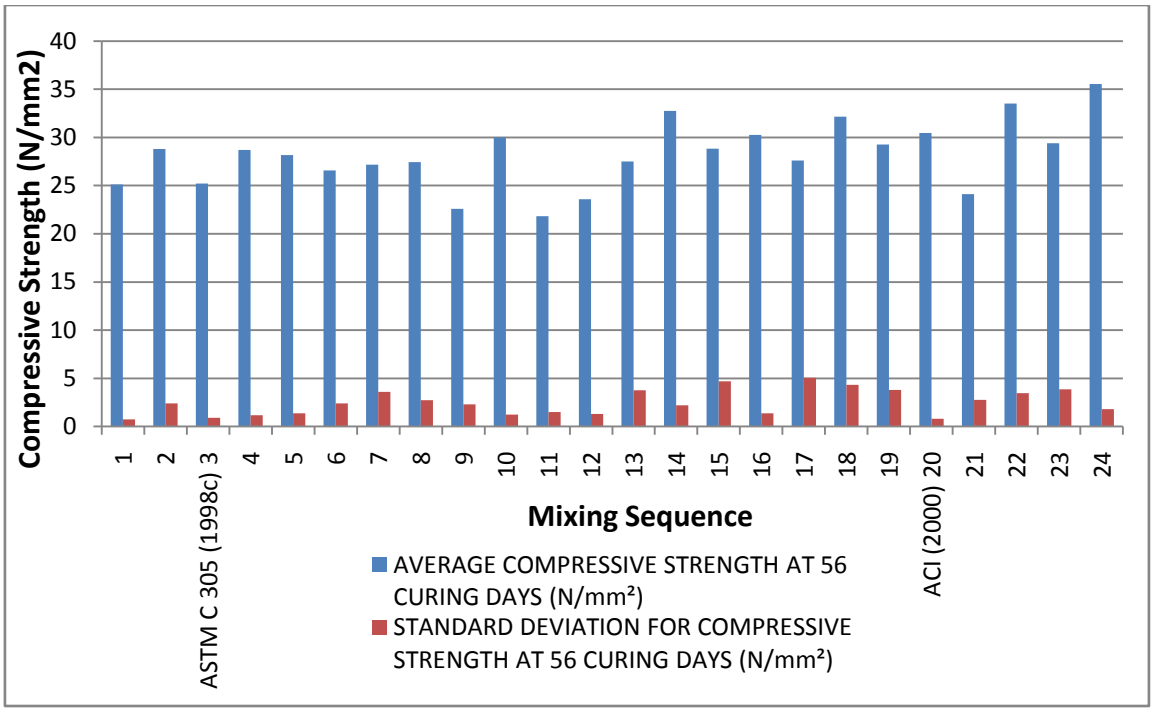


Figure 4.10: Compressive strength of samples at 56 days of curing

4.1.2.2 Water absorption capacities of concrete samples

Figure 4.11 shows that due to random sampling used in the hardened concrete tests which is in accordance with the ASTM C 823 (2000), it was possible for properties affected by mixing sequence to appear to reduce in quality over time under normal curing conditions. This is not a depiction of quality loss but an idea of uniformity affecting quality of concrete samples along ages. This can be explained because samples used were not reused but different samples with higher, lower or uniform strength were continued with along curing ages in testing a particular property of cube samples mixed in one batch. Water absorption can be seen to vary from 3.4% to 6.3% for the 28 and 56 days of curing for all cubes samples involved. Cubes samples mixed using ASTM mixing sequence had average water absorption capacity of 6.09% and 4.99% for 28 and 56 days respectively. Concrete cubes samples mixed using ACI mixing sequence had average water absorption capacity of

3.64% and 3.57% for 28 and 56 days respectively. This indicates that cube samples mixed using ACI mixing sequence had lower average water absorption capacity compared with cube samples mixed using ASTM mixing sequence by 40.23% and 28.46% for 28 and 56 days of curing respectively.

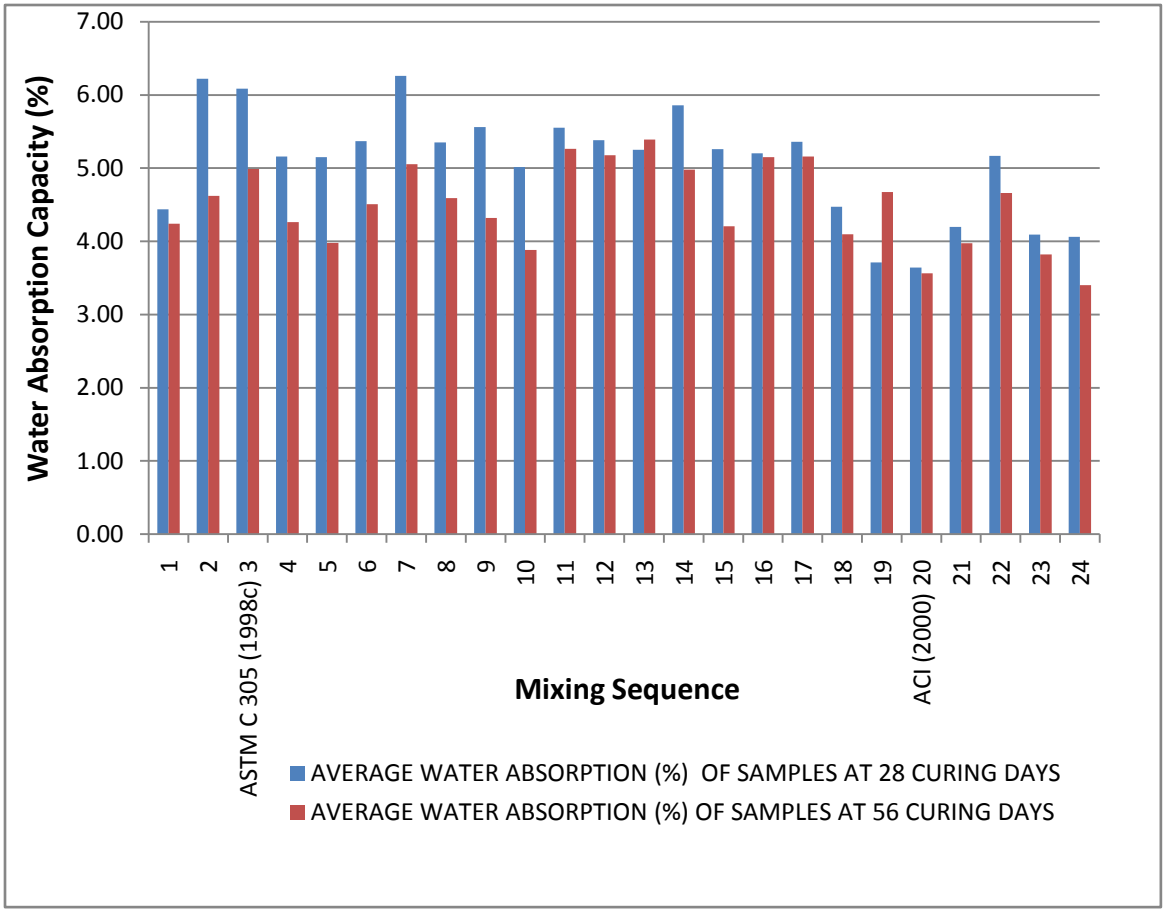


Figure 4.11: Water absorption capacities of concrete samples

4.1.2.3 Abrasion Resistance of concrete samples

Figure 4.12 shows cube samples of ASTM mixing sequence and ACI mixing sequence with an average abrasion of 0.09% and 0.07% for 28 days and 0.07% and 0.07% for 56 days respectively. It differs by not more than 0.01% to 0.18% at both 28 and 56 curing

days, jointly. Relationship between ages for affected properties like abrasion can only be deduced for samples with good uniform quality. Other samples with bad standard deviations or poor uniformity can alter true relationship giving a false sense of high quality increase over time or even reversing the phenomena giving a sense of reduced quality over time. The cube samples mixed using ACI mixing sequence had lower abrasion compared to those mixed using ASTM mixing sequence at 28 days of curing by 22.22%

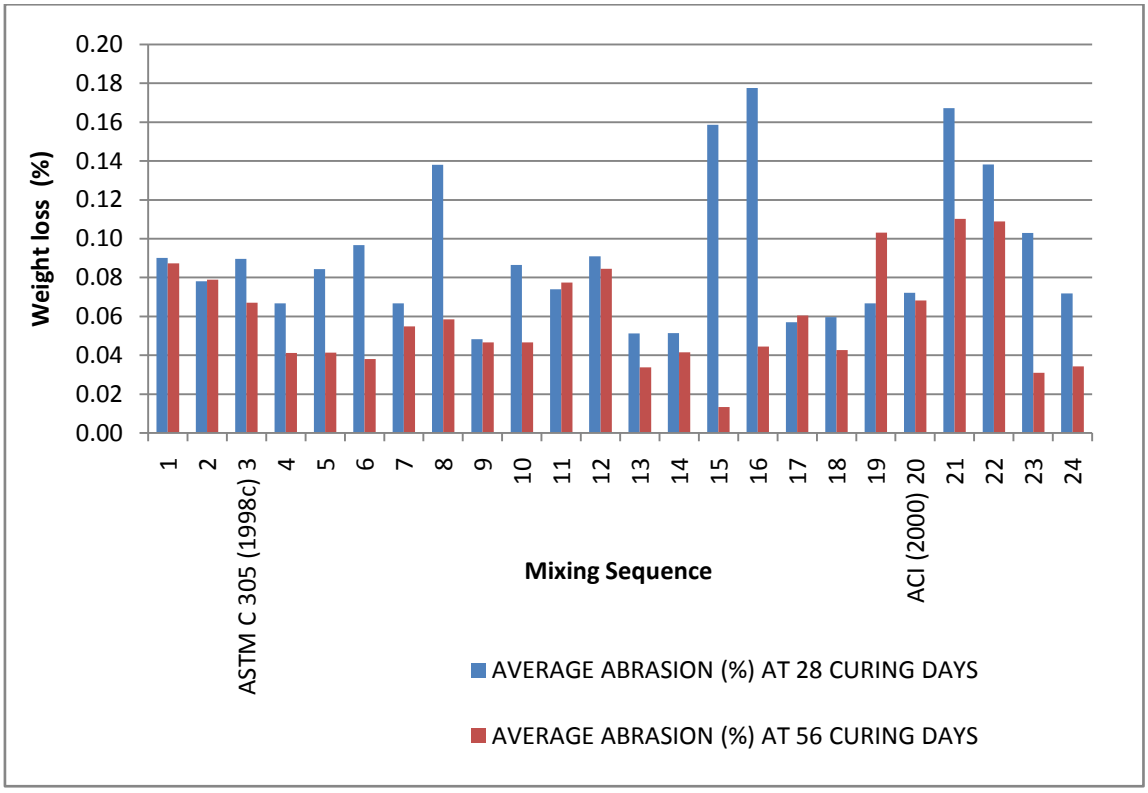


Figure 4.12: Abrasion resistance of concrete sample

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary of the Research Findings

A study of the effect of mixing sequence on the properties of concrete was carried out. 24 mixing sequences were investigated. Out of the 24, two were from the ACI and ASTM standards. A series of tests were carried out on them. The tests carried out were slump, compacting factor, plastic density, air content, compressive strength, abrasion resistance and water absorption. The major findings from the research were as follows.

1. It was found that the fresh concrete mixed produced using ASTM mixing sequence has an average slump of 43mm and the fresh concrete mixed using ACI mixing sequence has an average slump of 37mm. 3 mixing sequences (15, 16 and 18,) had concrete mix at low degree of workability with values (21.5mm, 20.75mm, and 24.25mm) respectively. Another 3 mixing sequences (4, 11, and 13) had concrete mix with high degree of workability. 3 fresh concrete batch samples with mixing sequences (22, 19 and 17) had slumps with standard deviation of 44.25mm, 39.5mm and 39.75mm respectively which do not comply with ASTM C09 (2003) precision statement.

2. The fresh concrete mixed using ACI mixing sequence was found to fall within the same degree of medium workability as concrete mix produced using ASTM mixing sequence and having an average compacting factor of 0.94 and 0.93 respectively. Fresh concrete batches produced using 12 mixing sequences (2, 4, 5, 7, 9, 11, 13, 14, 17, 21, 22, and 24) with average compacting factors of (0.95, 0.96, 0.96, 0.96,

0.96, 0.95, 0.96, 0.96, 0.96, 0.95, 0.95, and 0.95) were found to have more workable mixes than those of both standardized mixing sequences. Mix of mixing sequence (1) falls under low degree of workability under compacting factor.

3. It was found that the number of fresh concrete batches from individual mixing sequence that produced higher average plastic density than those of the two standardized mixing sequences is 5. They were mixed using mixing sequences (4, 5, 7, 8 and 12) and their average plastic densities were (2269 kg/m^3, 2267 kg/m^3, 2264 kg/m^3, 2248 kg/m^3 and 2252 kg/m^3) respectively. The plastic density of concrete batch mixed using ACI mixing sequence was at 2239kg/m^3 and that of the batch mixed using ASTM mixing sequence at 2248kg/m3.

4. It was found that batches of concrete mixed using ACI and ASTM mixing sequence had an average air content of 2.3% and 1.94% respectively and standard deviations of 0.65 and 0.81 in order. The number of concrete batches that had higher average air content than those of the two standardized mixing sequences is fifteen (15). They were batches mixed using mixing sequences (1, 2, 6, 9, 10, 13, 14, 15, 16, 17, 18, 21, 22, 23 and 24) and their average air contents were (4.39%, 2.81%, 2.81%, 2.36%, 3.50%, 2.58%, 2.92%, 4.80%, 3.43%, 3.16%, 2.76%, 3.39%, 2.70%, 2.38% and 2.81%) respectively. Samples produced using mixing sequence (14 and 17) did not satisfy the precision statement for standard deviation of air content in BS 1881: 106. (1983).

5. It was found that concrete cube samples produced using mixing sequence 24 had higher compressive strength than those produced using the ACI and ASTM

standardized mixing sequences by at least 4.7%, 5.8%, 13.2% and 16.7% for 7, 14, 28 and 56 days respectively.

6. It was found that cube samples produced using ASTM mixing sequence had higher average water absorption capacity compared with cube samples mixed using ACI mixing sequence by 67.31% and 39.78% at 28 and 56 days of curing respectively and their average water absorption capacity were 6.09% and 3.64% at 28 days of curing and 4.99% and 3.57% at 56 curing days respectively

7. It was found that the concrete cube samples of ASTM mixing sequence and ACI mixing sequence had an average abrasion of 0.09% and 0.07% at 28 curing days and 0.07% and 0.07% at 56 curing days respectively. The cube samples mixed using ACI mixing sequence had lower abrasion compared with those mixed using ASTM mixing sequence at 28 days of curing by 22.22% and were of the same value at 56 days of curing.

5.2 Conclusion

From the research carried out, the following conclusions were drawn;

1. Sieve Analysis test was carried out for fine aggregates . Bulk density and specific gravity tests were carried out for coarse and fine aggregates which conform to BS 812 part 2 (1995) and ASTM C 127 (1993) standards respectively .

2. The concrete batch samples produced using the ASTM and ACI standard mixing sequences passed all standard conditions for properties of fresh concrete tested. Mixes from mixing sequences (22, 19 and 17) did not pass the standard conditions

for slump. All batch samples produced using the various mixing sequences passed the standard conditions for compacting factor and plastic density. Two batch samples from mixing sequences (14 and 17) did not pass the standard requirements for air content. Mixing sequence has effect on all the properties of fresh concretes tested.

3. Concrete cube samples produced using ACI mixing sequence had better hardened concrete properties compared with those produced using ASTM mixing sequence under compressive strength, water absorption capacity and abrasion resistance. Samples from mixing sequence 24 had higher strengths compared to samples of the standardized mixing sequences at all test ages. Only samples from mixing sequences 3, 8, 10, 12, 17, 20 and 24 adhered to the control limit for compressive strength. Mixing sequence evidently has effect on all hardened concrete properties assessed. Mixing sequence not only affects uniformity but strength development in concrete.

4. From the properties of concrete tested, mixing sequence has the most positive effect on plastic density followed by air content then slump and finally compressive strength.

5.3 Recommendations

Based on the established test results, the following specified recommendation were made;

1. It is recommended that the mixing sequence used for testing and adjusting properties of concrete in laboratory should be the same mixing sequence used to produce that concrete type on site.
2. It is recommended that uniformity should be checked firstly for concrete properties when determining which or what mixing sequence to use.
3. It is recommended that, the ACI standard mixing sequence is preferable in the production of concrete than the ASTM standard mixing sequence.
4. it is recommended that mixing sequence (24) should be use of all the mixing sequences to make the best hardened concrete.

5.4 Recommendations for Further Studies

1. More standard mixing sequences like the British mixing sequence (BS 1881-125, 1986) can be compared with some already existing mixing sequences like the hydromix, the two stage mixing sequence and the hybrid mixing sequence.
2. Some other properties of concrete like segregation, tensile strength, flexural strength and so on could be explored.
3. Durability tests in aggressive environments can be carried out to assess how mixing sequence affects such conditions.
4. Mixing sequences can be assessed with respect to other types of mixers.

5. Some other concrete types like the self compacting concrete can be evaluated based on different mixing sequences.

5.5 Contribution to Knowledge

1. The ACI (2000) and ASTM C305 (1998c) mixing sequences were fully compatible with the British Research Establishment (BRE) method of mix design.

2. ACI (2000) and ASTM C305 (1998c) mixing sequences have no mixing time but were found to be coherent with Indian standard mixing time.

3. Mixing sequence (24) was found to give optimum strengths better than the existing standard mixing sequences assessed and has no fault whatsoever.

4. It was found that mixing sequence can create parallax in concrete samples greater than rate of strength development.

5. Mixing sequence has effect on slump, compacting factor, plastic density, air content, compressive strength, water absorption capacity and abrasion resistance.

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APPENDIX A

Specific gravity (S.G) of materials

1. Specific gravity of coarse aggregate

Weights;

a = container = 202g; b = Container + water = 780g; c = coarse aggregate + container = 685g; d = coarse aggregate + container + water = 1078g.

$$\text{S.G of coarse aggregate} = \frac{c - a}{(b - a) - (d - c)} = \frac{685 - 202}{(780 - 202) - (1078 - 685)} = 2.6108$$

2. Specific gravity of fine aggregate

Weights;

a = container = 202g; b = Container + water = 780g; c = fine aggregate + container = 601g; d = fine aggregate + container + water = 1012g.

$$\text{S.G of coarse aggregate} = \frac{c - a}{(b - a) - (d - c)} = \frac{601 - 202}{(780 - 202) - (1012 - 601)} = 2.389$$

3. Specific gravity of fine aggregate

Weights;

a = container = 202g; b = Container + water = 1166g; c = cement + container = 454g; d = cement + container + water = 1344g.

$$\text{S.G of coarse aggregate} = \frac{c - a}{(b - a) - (d - c)} = \frac{454 - 202}{(1166 - 202) - (1344 - 454)} = 3.405$$

Table 1: Sieve analysis for sand

Sieve size	Weight retained (gramm)	Weight passing	% passing
5mm	2	1998	99.9
2.36mm	164	1834	91.7
1.18mm	495	1339	66.95
600µm	917	422	21
300µm	356	66	3.3
150µm	39	27	1.35
pan	17	10	0.5

1.1 Design of Concrete Using BRE Method

1. Data on strength of specimen

Specific strength; fc

Target strength; fm

Constant; K

Standard deviaton; S

$Fm = fc + KS$

$Fc = 25\ N/mm^2$; K = 1.64; S = 8;

$Fm = 25 + (1.64 * 8)$

$Fm = 38.12\ N/mm^2$

2. Data on materials

Table 2: Specific gravity and density of ingredients

materials	Specific gravity (S.G)	Density (SSD) (kg/m^3)
Cement	3.41	1355
Sand	2.39	1614
Crushed stone	2.61	1526
Water	1.0	1000

   a. Max aggregate size = 20mm

3. Percentage passing 600µm is 21%

4. w/c = 0.58

5. Workability is medium of slump range, 25-50mm.

6. Water content is 210 kg/mm^3 of concrete

7. Cement content is C, which is 210/C = 0.58; C = 210/ 0.58 = 362.07 kg/m^3

8. Average combined specific gravity of aggregate = $\frac{\text{S.G of fine + S.G of coarse}}{2}$ = $\frac{2.39 + 2.61}{2}$ = 2.5

9. Wet density of concrete or plastic density (D) = 2270 kg/m^3

10. 48% of fine aggregate

11. Total aggregate = D – C – W (C = cement content; W = water content)

    = 2270 – 362 – 210

12. Total aggregate = 1698 kg/m^3

13. Fine aggregate = 1698 * (48/100)

Fine aggregate = 815.04

14. Coarse aggregate = total aggregate – fine aggregate

Coarse aggregate = 1698 – 815.04

Coarse aggregate = 882.96 kg/m^3

15. Mix proportion = $\frac{368}{362} : \frac{815}{362} : \frac{883}{362}$

    = 1: 2.25: 2.44

16. No of cubes is 36, percentage waste is 15.

17. Volume of cube is 0.001m^3

18. Volume of materials = 36 * 0.001 + (15/100 * 0.036) = 0.0414 m^3

19. Quantity of materials

a. Cement = 362 * 0.0414 = 15kg

b. Sand = 815 * 0.0414 = 33.74kg

c. Crushed stone = 883 * o.o414 = 36.56kg

d. Water = 210 * 0.0414 = 8.69kg

APPENDIX B

Table 3: Compressive strength test results at 7 days of curing

Mixing sequences	Compressive strength (N/mm^2)							
	s/n	1	2	3	4	5	AVR	S.D
Water, coarse aggregate, cement, sand	1	17	20	20	19	24	19.92	3.55
Water, sand, cement, coarse aggregate	2	18	23	20	20	24	20.90	4.37
Water, cement, sand, coarse aggregate	3	26	23	22	22	19	22.36	2.50
Water, coarse aggregate, sand, cement	4	23	22	23	26	21	22.82	3.74
Water, sand, coarse aggregate, cement	5	23	18	20	26	20	21.46	6.46
Water, cement, coarse aggregate, sand	6	20	19	15	19	17	18.06	3.98
Sand, water, cement, coarse aggregate	7	21	27	19	20	25	22.32	6.47
Sand, cement, water, coarse aggregate	8	24	21	24	21	20	21.82	3.18
Sand, cement, coarse aggregate, water	9	19	17	21	15	17	17.58	4.14
Sand, coarse aggregate, cement, water	10	21	20	24	21	22	21.50	2.90
Sand, water, coarse aggregate, cement	11	18	19	19	19	19	18.60	1.07
Sand, coarse aggregate, water, cement	12	23	22	21	23	24	22.68	2.08
Cement, water, sand, coarse aggregate	13	27	23	15	19	20	20.96	4.52
Cement, sand, water, coarse aggregate	14	28	26	26	21	26	25.40	5.26
Cement, sand, coarse aggregate, water	15	18	22	22	22	22	21.40	3.72
Cement, coarse aggregate, sand, water	16	20	19	25	20	22	21.20	4.79
Cement, coarse aggregate, water, sand	17	23	22	24	20	22	22.24	2.90
Cement, water, coarse aggregate, sand	18	26	21	27	24	26	24.62	4.54
Coarse aggregate, water, sand, cement	19	22	19	16	20	13	18.08	5.51
Coarse aggregate, sand, water, cement	20	23	22	18	19	20	20.34	3.36
Coarse aggregate, sand, cement, water	21	16	13	22	22	28	20.12	9.57
Coarse aggregate, cement, sand, water	22	24	24	27	25	22	24.36	3.03
Coarse aggregate, cement, water, sand	23	17	17	18	25	21	19.46	7.02
Coarse aggregate, water, cement, sand	24	24	22	23	24	25	23.40	1.19

AVR=Average

S.D = Standard deviation

Table 4: Compressive strength test results at 14 days of curing

Mixing sequences	Compressive strength (N/mm^2)							
	s/n	**1**	**2**	**3**	**4**	**5**	**AVR**	**S.D**
Water, coarse aggregate, cement, sand	**1**	21	22	25	22	23	22.58	1.30
Water, sand, cement, coarse aggregate	**2**	26	20	21	28	26	24.20	3.50
Water, cement, sand, coarse aggregate	**3**	25	19	24	21	25	22.74	2.72
Water, coarse aggregate, sand, cement	**4**	25	27	25	24	27	25.46	1.38
Water, sand, coarse aggregate, cement	**5**	22	23	23	19	23	21.96	1.48
Water, cement, coarse aggregate, sand	**6**	23	24	24	25	22	23.38	1.10
Sand, water, cement, coarse aggregate	**7**	23	21	22	24	23	22.50	1.00
Sand, cement, water, coarse aggregate	**8**	21	24	21	25	25	23.00	2.08
Sand, cement, coarse aggregate, water	**9**	28	21	22	22	23	23.32	3.01
Sand, coarse aggregate, cement, water	**10**	23	26	23	24	24	23.86	1.18
Sand, water, coarse aggregate, cement	**11**	23	21	23	21	24	22.44	1.35
Sand, coarse aggregate, water, cement	**12**	22	26	23	23	21	23.20	2.00
Cement, water, sand, coarse aggregate	**13**	21	27	27	20	19	22.70	3.88
Cement, sand, water, coarse aggregate	**14**	29	28	28	29	28	28.64	0.62
Cement, sand, coarse aggregate, water	**15**	22	23	20	20	29	22.62	3.53
Cement, coarse aggregate, sand, water	**16**	24	22	24	27	24	24.36	1.77
Cement, coarse aggregate, water, sand	**17**	24	22	26	26	22	23.80	1.80
Cement, water, coarse aggregate, sand	**18**	27	25	27	26	26	26.30	0.94
Coarse aggregate, water, sand, cement	**19**	26	22	21	29	20	23.56	3.44
Coarse aggregate, sand, water, cement	**20**	24	25	23	27	23	24.12	1.62
Coarse aggregate, sand, cement, water	**21**	25	24	26	25	24	24.82	1.15
Coarse aggregate, cement, sand, water	**22**	29	26	31	28	27	28.40	2.01
Coarse aggregate, cement, water, sand	**23**	28	30	29	29	30	29.28	0.77
Coarse aggregate, water, cement, sand	**24**	21	26	26	27	27	25.52	2.45

AVR=Average

S.D = Standard deviation

Table 5: Compressive strength test results at 28 days of curing

Mixing sequences	Compressive Strength (N/mm^2)							
	s/n	1	2	3	4	5	AVR	S.D
Water, coarse aggregate, cement, sand	1	32	24	27	27	25	26.84	3.17
Water, sand, cement, coarse aggregate	2	29	25	26	29	31	28.08	2.30
Water, cement, sand, coarse aggregate	3	24	25	23	23	30	24.90	2.94
Water, coarse aggregate, sand, cement	4	29	27	27	29	28	27.90	0.89
Water, sand, coarse aggregate, cement	5	33	25	27	32	25	28.30	3.78
Water, cement, coarse aggregate, sand	6	25	22	27	25	24	24.60	1.81
Sand, water, cement, coarse aggregate	7	28	24	22	24	25	24.40	2.26
Sand, cement, water, coarse aggregate	8	24	23	25	25	23	24.00	1.00
Sand, cement, coarse aggregate, water	9	22	25	22	30	27	25.36	3.47
Sand, coarse aggregate, cement, water	10	31	28	30	30	27	29.22	1.67
Sand, water, coarse aggregate, cement	11	19	22	34	27	35	27.44	7.13
Sand, coarse aggregate, water, cement	12	28	29	26	30	26	28.00	1.74
Cement, water, sand, coarse aggregate	13	27	27	26	26	26	26.28	0.56
Cement, sand, water, coarse aggregate	14	29	29	30	31	29	29.40	0.82
Cement, sand, coarse aggregate, water	15	28	25	18	17	29	23.44	5.50
Cement, coarse aggregate, sand, water	16	28	30	27	33	29	29.40	2.30
Cement, coarse aggregate, water, sand	17	26	27	23	31	25	26.32	2.98
Cement, water, coarse aggregate, sand	18	29	24	33	26	32	28.72	3.80
Coarse aggregate, water, sand, cement	19	26	27	24	29	22	25.28	2.76
Coarse aggregate, sand, water, cement	20	26	25	27	27	31	27.24	2.12
Coarse aggregate, sand, cement, water	21	28	27	20	21	21	23.36	3.66
Coarse aggregate, cement, sand, water	22	25	33	32	25	32	29.44	4.18
Coarse aggregate, cement, water, sand	23	21	21	23	24	25	22.80	1.79
Coarse aggregate, water, cement, sand	24	31	32	30	31	30	30.84	0.85

AVR=Average

S.D = Standard deviation

Table 6: Compressive strength test results at 56 days of curing

Mixing sequences	Compressive Strength (N/mm^2)							
	s/n	1	2	3	4	5	AVR	S.D
Water, coarse aggregate, cement, sand	1	25	26	24	26	25	25.10	0.74
Water, sand, cement, coarse aggregate	2	32	29	26	27	30	28.80	2.39
Water, cement, sand, coarse aggregate	3	26	24	26	26	25	25.20	0.91
Water, coarse aggregate, sand, cement	4	28	28	31	29	28	28.70	1.15
Water, sand, coarse aggregate, cement	5	27	29	30	27	28	28.18	1.37
Water, cement, coarse aggregate, sand	6	23	27	29	27	27	26.58	2.38
Sand, water, cement, coarse aggregate	7	31	21	26	29	29	27.18	3.59
Sand, cement, water, coarse aggregate	8	28	27	30	28	23	27.44	2.73
Sand, cement, coarse aggregate, water	9	19	22	23	24	25	22.60	2.30
Sand, coarse aggregate, cement, water	10	29	29	30	32	30	30.00	1.22
Sand, water, coarse aggregate, cement	11	21	24	22	22	20	21.84	1.51
Sand, coarse aggregate, water, cement	12	22	23	25	24	25	23.58	1.28
Cement, water, sand, coarse aggregate	13	23	25	27	33	29	27.52	3.76
Cement, sand, water, coarse aggregate	14	35	32	31	31	35	32.76	2.20
Cement, sand, coarse aggregate, water	15	21	32	28	31	32	28.84	4.68
Cement, coarse aggregate, sand, water	16	31	30	32	28	30	30.28	1.37
Cement, coarse aggregate, water, sand	17	36	24	23	28	27	27.60	5.06
Cement, water, coarse aggregate, sand	18	25	32	33	36	35	32.16	4.33
Coarse aggregate, water, sand, cement	19	26	26	28	35	31	29.28	3.78
Coarse aggregate, sand, water, cement	20	30	29	31	31	31	30.48	0.79
Coarse aggregate, sand, cement, water	21	23	20	25	27	26	24.12	2.75
Coarse aggregate, cement, sand, water	22	30	30	35	36	37	33.52	3.45
Coarse aggregate, cement, water, sand	23	27	33	34	25	28	29.40	3.84
Coarse aggregate, water, cement, sand	24	36	38	35	33	35	35.56	1.81

AVR=Average

S.D = Standard deviation

Table 7: Water absorption test results

MIXING SEQUENCES	S/N	AVERAGE WATER ABSORPTION (%) FOR 28 DAYS	AVERAGE WATER ABSORPTION (%) FOR 56 DAYS
Water, coarse aggregate, cement, sand	1	4.44	4.24
Water, sand, cement, coarse aggregate	**2**	6.22	4.62
Water, cement, sand, coarse aggregate	ASTM C 305 (1998c) 3	6.09	4.99
Water, coarse aggregate, sand, cement	4	5.16	4.26
Water, sand, coarse aggregate, cement	5	5.15	3.98
Water, cement, coarse aggregate, sand	6	5.37	4.51
Sand, water, cement, coarse aggregate	7	6.26	5.06
Sand, cement, water, coarse aggregate	8	5.35	4.59
Sand, cement, coarse aggregate, water	9	5.56	4.32
Sand, coarse aggregate, cement, water	10	5.01	3.88
Sand, water, coarse aggregate, cement	11	5.55	5.26
Sand, coarse aggregate, water, cement	12	5.38	5.18
Cement, water, sand, coarse aggregate	13	5.25	5.39
Cement, sand, water, coarse aggregate	14	5.86	4.98
Cement, sand, coarse aggregate, water	15	5.26	4.21
Cement, coarse aggregate, sand, water	16	5.20	5.15
Cement, coarse aggregate, water, sand	17	5.36	5.16
Cement, water, coarse aggregate, sand	18	4.47	4.10
Coarse aggregate, water, sand, cement	19	3.71	4.67
Coarse aggregate, sand, water, cement	ACI (2000) 20	3.64	3.57
Coarse aggregate, sand, cement, water	21	4.20	3.98
Coarse aggregate, cement, sand, water	22	5.17	4.66
Coarse aggregate, cement, water, sand	23	4.09	3.82
Coarse aggregate, water, cement, sand	24	4.06	3.40

Table 8: Abrasion resistance test results

MIXING SEQUENCES	S/N	AVERAGE ABRASION (%) AT 28 DAYS	AVERAGE ABRASION (%) AT 56 DAYS
Water, coarse aggregate, cement, sand	1	0.09	0.09
Water, sand, cement, coarse aggregate	**2**	0.08	0.08
Water, cement, sand, coarse aggregate	ASTM C 305 (1998c) 3	0.09	0.07
Water, coarse aggregate, sand, cement	4	0.07	0.04
Water, sand, coarse aggregate, cement	5	0.08	0.04
Water, cement, coarse aggregate, sand	6	0.10	0.04
Sand, water, cement, coarse aggregate	7	0.07	0.05
Sand, cement, water, coarse aggregate	8	0.14	0.06
Sand, cement, coarse aggregate, water	9	0.05	0.05
Sand, coarse aggregate, cement, water	10	0.09	0.05
Sand, water, coarse aggregate, cement	11	0.07	0.08
Sand, coarse aggregate, water, cement	12	0.09	0.08
Cement, water, sand, coarse aggregate	13	0.05	0.03
Cement, sand, water, coarse aggregate	14	0.05	0.04
Cement, sand, coarse aggregate, water	15	0.16	0.01
Cement, coarse aggregate, sand, water	16	0.18	0.04
Cement, coarse aggregate, water, sand	17	0.06	0.06
Cement, water, coarse aggregate, sand	18	0.06	0.04
Coarse aggregate, water, sand, cement	19	0.07	0.10
Coarse aggregate, sand, water, cement	ACI (2000) 20	0.07	0.07
Coarse aggregate, sand, cement, water	21	0.17	0.11
Coarse aggregate, cement, sand, water	22	0.14	0.11
Coarse aggregate, cement, water, sand	23	0.10	0.03
Coarse aggregate, water, cement, sand	24	0.07	0.03

Table 9: Slump test results

MIXING SEQUENCES	S/N	AVERAGE OF SLUMP (mm)	STANDARD DEVIATION OF SLUMP
Water, coarse aggregate, cement, sand	1	49.5	6.36
Water, sand, cement, coarse aggregate	**2**	41.5	8.99
Water, cement, sand, coarse aggregate	ASTM C 305 (1998c) 3	43	15.49
Water, coarse aggregate, sand, cement	4	65	15.49
Water, sand, coarse aggregate, cement	5	45	5.48
Water, cement, coarse aggregate, sand	6	25.5	0.71
Sand, water, cement, coarse aggregate	7	39	1.41
Sand, cement, water, coarse aggregate	8	36.5	12.02
Sand, cement, coarse aggregate, water	9	40.25	16.41
Sand, coarse aggregate, cement, water	10	25.75	12.68
Sand, water, coarse aggregate, cement	11	51.25	14.75
Sand, coarse aggregate, water, cement	12	47	7.87
Cement, water, sand, coarse aggregate	13	51.25	11.61
Cement, sand, water, coarse aggregate	14	46.75	4.44
Cement, sand, coarse aggregate, water	15	21.5	7.97
Cement, coarse aggregate, sand, water	16	20.75	4.87
Cement, coarse aggregate, water, sand	17	39.75	20.34
Cement, water, coarse aggregate, sand	18	24.25	11.95
Coarse aggregate, water, sand, cement	19	39.5	21.58
Coarse aggregate, sand, water, cement	ACI (2000) 20	37.25	13.55
Coarse aggregate, sand, cement, water	21	44.25	9.47
Coarse aggregate, cement, sand, water	22	44.25	27.80
Coarse aggregate, cement, water, sand	23	31.5	9.43
Coarse aggregate, water, cement, sand	24	36.5	4.339739

Table 10: Compacting factor test results

MIXING SEQUENCES	S/N	AVERAGE FOR COMPACTING FACTOR	STANDARD DEVIATION FOR COMPACTING FACTOR
Water, coarse aggregate, cement, sand	1	0.90	0.004
Water, sand, cement, coarse aggregate	**2**	0.95	0.025
Water, cement, sand, coarse aggregate	ASTM C 305 (1998c) 3	0.93	0.001
Water, coarse aggregate, sand, cement	4	0.96	0.015
Water, sand, coarse aggregate, cement	5	0.96	0.004
Water, cement, coarse aggregate, sand	6	0.94	0.021
Sand, water, cement, coarse aggregate	7	0.96	0.006
Sand, cement, water, coarse aggregate	8	0.93	0.000
Sand, cement, coarse aggregate, water	9	0.96	0.013
Sand, coarse aggregate, cement, water	10	0.94	0.020
Sand, water, coarse aggregate, cement	11	0.95	0.007
Sand, coarse aggregate, water, cement	12	0.94	0.004
Cement, water, sand, coarse aggregate	13	0.96	0.004
Cement, sand, water, coarse aggregate	14	0.96	0.005
Cement, sand, coarse aggregate, water	15	0.92	0.008
Cement, coarse aggregate, sand, water	16	0.93	0.000
Cement, coarse aggregate, water, sand	17	0.96	0.010
Cement, water, coarse aggregate, sand	18	0.93	0.000
Coarse aggregate, water, sand, cement	19	0.94	0.026
Coarse aggregate, sand, water, cement	ACI (2000) 20	0.94	0.003
Coarse aggregate, sand, cement, water	21	0.95	0.009
Coarse aggregate, cement, sand, water	22	0.95	0.008
Coarse aggregate, cement, water, sand	23	0.92	0.030
Coarse aggregate, water, cement, sand	24	0.95	0.001

Table 11: Plastic density test results

MIXING SEQUENCES	S/N	AVERAGE FOR PLASTIC DENSITY (kg/m3)	STANDARD DEVIATION FOR PLASTIC DENSITY (kg/m3)
Water, coarse aggregate, cement, sand	1	2192	15.5
Water, sand, cement, coarse aggregate	**2**	2228	25.3
Water, cement, sand, coarse aggregate	ASTM C 305 (1998c) 3	2248	18.5
Water, coarse aggregate, sand, cement	4	2269	18.8
Water, sand, coarse aggregate, cement	5	2267	26.8
Water, cement, coarse aggregate, sand	6	2228	38.1
Sand, water, cement, coarse aggregate	7	2264	24.2
Sand, cement, water, coarse aggregate	8	2248	19.6
Sand, cement, coarse aggregate, water	9	2238	17.7
Sand, coarse aggregate, cement, water	10	2212	17.9
Sand, water, coarse aggregate, cement	11	2243	28.0
Sand, coarse aggregate, water, cement	12	2252	29.4
Cement, water, sand, coarse aggregate	13	2233	25.1
Cement, sand, water, coarse aggregate	14	2225	17.9
Cement, sand, coarse aggregate, water	15	2182	30.7
Cement, coarse aggregate, sand, water	16	2214	30.5
Cement, coarse aggregate, water, sand	17	2220	36.4
Cement, water, coarse aggregate, sand	18	2229	28.4
Coarse aggregate, water, sand, cement	19	2247	22.5
Coarse aggregate, sand, water, cement	ACI (2000) 20	2239	17.6
Coarse aggregate, sand, cement, water	21	2215	21.5
Coarse aggregate, cement, sand, water	22	2230	28.8
Coarse aggregate, cement, water, sand	23	2238	24.7
Coarse aggregate, water, cement, sand	24	2228	22.8

Table 12: Air content test results

MIXING SEQUENCE	S/N	AVERAGE AIR CONTENT (%)	STANDARD DEVIATION FOR AIR CONTENT
Water, coarse aggregate, cement, sand	1	4.39	0.678
Water, sand, cement, coarse aggregate	**2**	2.81	1.11
Water, cement, sand, coarse aggregate	ASTM C 305 (1998c) 3	1.94	0.81
Water, coarse aggregate, sand, cement	4	1.02	0.67
Water, sand, coarse aggregate, cement	5	1.09	0.84
Water, cement, coarse aggregate, sand	6	2.81	1.18
Sand, water, cement, coarse aggregate	7	1.24	0.87
Sand, cement, water, coarse aggregate	8	1.91	0.62
Sand, cement, coarse aggregate, water	9	2.36	0.60
Sand, coarse aggregate, cement, water	10	3.50	0.61
Sand, water, coarse aggregate, cement	11	2.14	0.87
Sand, coarse aggregate, water, cement	12	1.73	1.10
Cement, water, sand, coarse aggregate	13	2.58	0.91
Cement, sand, water, coarse aggregate	14	2.92	1.65
Cement, sand, coarse aggregate, water	15	4.80	0.95
Cement, coarse aggregate, sand, water	16	3.43	0.99
Cement, coarse aggregate, water, sand	17	3.16	1.31
Cement, water, coarse aggregate, sand	18	2.76	1.06
Coarse aggregate, water, sand, cement	19	1.98	0.85
Coarse aggregate, sand, water, cement	ACI (2000) 20	2.32	0.65
Coarse aggregate, sand, cement, water	21	3.39	0.80
Coarse aggregate, cement, sand, water	22	2.70	0.93
Coarse aggregate, cement, water, sand	23	2.38	0.87
Coarse aggregate, water, cement, sand	24	2.81	0.70