DETERMINATION OF THE SUITABILITY OF CASSAVA STARCH AS AN ADMIXTURE IN CEMENT PASTE AND CONCRETE

BY

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B.ENG (UNIVERSITY OF ILORIN 2008)

MSc/ENG/0859/2009-2010

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

JANUARY, 2016

DECLARATION

I hereby declare that the work in this dissertation entitled **Determination of the Suitability of Cassava Starch as an Admixture in Cement Paste and Concrete** has been carried out by me in the Department of Civil Engineering, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

_____ _____

Adeniyi Ibiyeye Date

M.Sc/ENG/0859/2009-2010

CERTIFICATION

The dissertation entitled **DETERMINATION OF THE SUITABILITY OF CASSAVA STARCH AS AN ADMIXTURE IN CEMENT PASTE AND CONCRETE** by Adeniyi IBIYEYE meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to The Almighty God, Giver of life and possessor of the earth, by whose grace, help and inspiration this research work was accomplished.

ACKNOWLEDGEMENTS

My profound appreciation goes to my Parents Hon. Justice and Hajia S.A. Ibiyeye for their unconditional love, encouragement and prayers. I couldn't have done it without you, may God allow you will live long to eat the fruit of your labour. To my immediate family Arch. and Mrs. S. A. Ibiyeye, Miss Yetunde, Engr. Boje, Mr. and Mrs. Olanbanji Opoola, Miss Adeshola and Master Abioye, thank you all for your support and care. To Kabir, Wale, Lami, Imaikop and mostly my love, Lola A. Morohunfola, thank you so much for your encouragement and support.

To my major supervisor, Prof. S.P. Ejeh, I thank you very much sir for your untiring efforts, patience and understanding and my minor supervisor Prof. J.A. Tanko, thank you very much sir. Dr. A. Ocholi, sir your support and believe in me cannot go unappreciated on this page, thank you very much.

I will also like to thank all the lecturers and students of the Civil Engineering department. A special thank you goes to Dr. Y.D. Amartey, Prof. O.S. Abejide and Prof. I. Abubakar. Prof. G. Kolawole and Dr. Ben Dauda of the department of Textile Science, sirs, thank you for the assistance rendered. Not forgetting Prof. M.A. Oyebode of Agricultural Engineering department, thank you so much sir and to all my Colleagues, Classmates and Friends; Folashade, Ebenezer, Taku, Terry, Yinka, Hamza, Shittu, Lazhi, Jafar; Thank you for your support

Not forgetting my Boss and Mentor Engr. (Chief) Victor O. Raydon, thank you very much sir for your understanding.

ABSTRACT

This research work was carried out to investigate the effects and suitability of Cassava starch as an admixture in cement paste and concrete. A standard consistency test was carried out on the cement paste with concentrations of the cassava starch at 0%, 0.5%, 1%, 2%, 3%, 4% and 5% by weight of the cement used in the paste. A prescribed concrete mix ratio of 1:2:4 concrete cubes (150mm by 150mm) and water-cement ratio of 0.5 were cast with the same concentrations as above. A total of eighty four (84) cubes were cast and cured for 3, 7, 14 and 28 days and compressive strength subsequently determined in comparison with the relevant specifications. Consistency test on the cement paste at the various concentrations exhibited an increase in the setting time as the concentration increases with the highest value recorded at 5% cassava starch concentration as 219 minutes for the initial setting time and 275 minutes for the final setting time as against the control specimen of 159 minutes and 234 minutes for both initial and final setting times respectively. The 28 days compressive strength of the concrete cubes; compared with that of the control; showed a slight increase in both strength values and strength gain at 0.5% and 1% starch concentrations with compressive strength of 21.24N/mm^2 and 21.63N/mm^2 and strength gain of 4% and 6% respectively. Also, the rate of strength development within the same concentration in terms of test ages was also realized to be higher at starch concentrations of 0.5%, 1% and 2% with the highest recorded as15% at 1% from 7 to 14 days.

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ABBREVIATIONS AND SYMBOLS

kN:	Kilo Newton
Kg:	Kilo Gramme
N/mm^2:	Newton per square millimeter
°C	degree Celsius
w/c:	Water Cement Ratio
m:	meter
mm:	millimeter
%:	Percentage

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

In most developed and developing countries concrete and mortar have been major construction/building and civil engineering materials alongside steel and wood. The use of concrete in the building industries cannot be overemphasized. Therefore, ways of improving or modifying some of its properties such as strength, setting characteristics and durability; in order to effectively maximize its use and most likely reduce the cost of construction; are constantly been developed. The use of admixtures in concrete works are some of the ways of improving the qualities of concrete (Mamlouk and Zaniewski, 2006).

Concrete as a construction material encompasses hydraulic cement, aggregate and water, each with its individual or unique properties but all acting together to form a composite structure. However, it is important to note that by improving or modifying some of the properties of the individual constituents of the concrete; it could provide a means of producing a new composite material with enhanced characteristics that complies with the demands of Engineers and Architects.

For several decades, admixtures have been widely used in concrete and mortar, providing advanced specific properties needed during construction. By definition, Admixtures are materials other than hydraulic cement, aggregates, water and fiber reinforcements used as an ingredient in a cementitious mixture to modify its properties, setting or hardening properties, and it is added to the batch before or during its mixing (Suchorski *et al.*, 2003).

Admixtures usually classified according to their intended use as Water Reducing, Set-controlling, Corrosion inhibiting; etc are some of the classes specified by the British standard; BS 8500 -1:2002, BS-EN 934 -2: 2001 etc. (Adamu, 2001). Materials used as admixtures could range from purpose designed chemicals or materials (either in solid or liquid form) to waste materials for which an outlet is sought (Afolayan, 1997). It is important to note that majority of admixtures for concrete are used primarily on the basis of experience or ad-hoc test (Neville, 1997). Therefore, the performance of admixtures is determined by using a control concrete mixture (one without the admixture).

Cassava (a chief source of starch) is grown in many tropical countries including Nigeria as one of her important commercial crops. Cassava is an attractive crop for industrial uses because of its low cost of production and for many industrial applications less cassava starch is required than maize starch to achieve a particular function (Ferris *et al*.,2005). Starch from cassava processing is a highly versatile, renewable natural resource which can be used in virtually all industrial sectors. In its natural state, starch is used as a binder, stabilizer, surfactant, texturizer and bulk agent (Ferris *et al.*, 2005). In this research, starch extracted from cassava is investigated to determine its effects as an admixture in cement paste and concrete.

1.2 STATEMENT OF RESEARCH PROBLEM

A major challenge faced by concrete users is its limited performance in unpredictable circumstances, such as changing climatic and jobsite conditions for instance, hot or cold weather concreting, underwater concreting, concreting in corrosive environments (acidic or

alkaline), delays in placing fresh concrete etc. Most of the conventional materials used as admixtures are too expensive and usually not readily available. Therefore, the use of locally available and renewable materials with unique properties, (say Cassava starch) is investigated to determine its suitability as concrete admixtures.

1.3 JUSTIFICATION OF RESEARCH

Cassava products like starch are multifaceted products finding many industrial applications and the increasing uses of this renewable resource is ecologically and economically of great interest since they are being and have been used in other technical areas such as textiles, paper production, adhesives etc. Generally, carbohydrates have been documented as excellent admixtures.

Nigeria as a nation is one of the major producers of cassava, a chief source of starch in the world, therefore seizing this advantage and harnessing the possible desirable contributions starch can offer to the concrete industry as an admixture may be a step forward.

1.4 AIM AND OBJECTIVES

The aim of this research is to determine the suitability of cassava starch as an admixture in concrete and cement paste mortar.

The objectives of this research work are:

a. D

etermination of some engineering properties of the constituent materials.

b. Starch characterization using X-Ray Diffraction (XRD) test.

c. Determination of the consistency and setting time (initial and final) of cement paste mixes with starch as an admixture.

d. Determination of the workability of concrete with various admixture (starch) concentrations at different concrete ages.

e. Determination of the compressive strength of concrete at various starch percentage concentrations.

f. Relating the results obtained in 3, 4 and 5 above with standard specifications according to ASTM C494 and/or BS 5075: Part 1: 1982 for admixtures.

1.5 SCOPE AND LIMITATION OF RESEARCH

1.5.1 Scope of Research

The scope of this research work is restricted to the use of cassava starch content of 0%, 0.5%, 1%, 2%, 3%, 4% and 5% of the cement weight. Effects of these starch concentrations are being considered on the consistency of the cement paste and on the workability of fresh concrete mixes. The workability will be based on results from the slump test and compaction factor test. Concrete cubes (150mm by 150mm) are cast with the same concentration as stated above.

1.5.2 Limitations of Research

The curing and compressive strength determination is limited to 3, 7, 14 and 28 days. Starch percentage concentration is limited to 5% based on section 5.2.6 of BS EN 206-1: 2000 on the use of admixtures in concrete.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Strength and durability may be considered as the most essential properties of concrete and should by all means not be compromised. Therefore, in order to achieve this, precautions should be taken right from the time of batching and mixing up to the time of placement and compaction. These properties (strength and durability) in addition are affected by the water-cement ratio of the concrete mix, chloride content of the concrete mix as well as the rate of stiffening of the mix (Setting) amongst other factors. Excess mixing water will lead to a weaker and less durable concrete while rapid rate of setting especially in hot weather conditions will lead to a less workable concrete and consequently reduction in the 28 day compressive strength of the concrete (Neville, 1997).

So many researches have been made to evaluate the addition of some admixtures in concrete so as to assess their activity. Some results from these research works turned out beneficial while some were disregarded (Adamu, 2001). Organic admixtures have been widely used in concrete and mortar for several decades, providing advanced specific properties needed during the construction.

2.2 HISTORICAL BACKGROUND AND REVIEW ON THE USE OF ADMIXTURES

Literature from the first century revealed that Vitruvius, a Roman engineer suggested the use of hog's lard or curdled milk in stucco (Cement paste) mixtures which he considered

will improve some of the mix properties and this was later checked and proved to be air entraining admixtures (Suchorski *et al.,* 2003). The Mayans also used bark extracts and other substances as set retarders to keep stucco workable for a long period of time. Another instance in the progressive use of admixtures in concrete was the use of carbohydrates and sugars as retarding admixtures, this was first discovered by Thomas in 1921, where he noticed that shortly after being laid, the concrete of his workshop floor began to disintegrate due to small amounts of sugar waste found in the mixing water (Thomas, 1921).

By the late thirties, it was generally accepted in both the civil and building engineering industries that little amounts of sugar will retard the setting time of cement effectively (Gonnerman, 1939). As at 1968, the influence of such admixtures on the Calcium aluminates phase (C_3A) of cement was studied by Young (1968) who showed that, interaction of sugars on C_3A prevents rapid formation of the cubic phase C_3AH_6 and promotes formation of the hexagonal phase C_4AH_{13} and Yamamuro (1999) showed that a polysaccharide derivative containing an ionic functional group and a hydrophobic group increases the viscosity of cement suspensions. Peschard *et al*., (2007) investigated the effects of polysaccharides on the hydration of cement pastes at early test ages. The results obtained clearly showed that the retardation increases with higher polysaccharide to cement weight ratio. The investigation also revealed that retardation effects of the polysaccharides are also dependent on the cement composition.

The experimental use of local materials like silica fume and fly ash has also not been left out as excellent mineral admixtures. In 2009, an experiment carried out in the University of Jordan to determine the effects of these local materials on the mechanical properties of high strength concrete produced remarkable results. In the experiment, various percentages of Silica Fume (SF) and Fly Ash (FA) were added at different water/cement (w/cm) ratios. Concrete specimens were tested and compared with plain concrete specimens at different ages. The results obtained indicated that compressive as well as flexural strengths increased with mineral admixture incorporation. SF contributed to both short and long-term properties of concrete, whereas, FA showed its beneficial effect in a relatively longer time. Adding of both SF and FA did not increase compressive strength in the short-term, but improvements were noticed in the long-term. Compared with compressive strength, flexural strength of SF concretes has exhibited greater improvements (Ismeik, 2009).

In 2003, Iman Satyarno of GadjahMada University, Indonesia presented a paper that reported the effects of cane sugar (also a carbohydrate) on the setting time of cement paste using the standard vicat apparatus. He investigated how effective cane sugar is as a retarding admixture. In the experiment cement paste was blended with various amounts of sugar extracted from cane sugar in Indonesia. The amounts varied from 0% to 0.2% of the weight of cement used. The test results showed that cane sugar can be used as a retarder because the cane sugar caused a delay of the setting time, ranging from 2 hours to almost 18 hours (Satyarno, 2003).

Recent advances on the use of cassava products or carbohydrate related substances in concrete and cement as admixtures have been conducted. In 2013 at the International Conference on Advances in Cement and Concrete Technology (ACCT), briefs and abstracts of various experimental works being carried out were stated including starch related works such as the use of Cassava Starch as an Alternative Binder in Cement Mortar by Naomi and Akindehinde, Influence of Some Starches on some Properties of Concrete by Akindehinde *et al.* Other admixtures related works stated at the conference include the study of the Engineering Properties of Sandcrete blocks using Cassava Peel Ash as Pozzolan by Olonade *et al.,* Controlled Superplasticizer addition by Hennings *et al,* Concrete with High Volume Metakaolin as Cement Replacement etc. (Herbert and Wolfram, 2013).

Okafor (2008) investigated the potentials of cassava flour (differs from cassava starch) as a set-retarding admixture in concrete and Okafor (2010) further investigated cassava flour as a water-reducing admixture. As a set retarding admixture, concrete mix proportion of 1:2:4 by weight of cement, sand and coarse aggregate and, water/cement ratio of 0.48 was made with six different dosage levels of cassava flour were tested included setting time, workability of the fresh concrete and compressive strength of the hardened concrete. These properties were compared with those of similar concrete mix made without cassava flour admixture. He observed that cassava flour considerably improved the workability of the fresh concrete and delayed the setting time of cement by up to 6 hours. Results of the tests also showed that while cassava flour reduced the early strength of concrete, the long-term

strength was improved. Cassava flour dosage level of 3% was also found to be the optimum level as an admixture.

Similarly, Akogu (2011) investigated the effects of sugar (a carbohydrate) on the physical properties of ordinary Portland cement and concrete and observed that the initial setting time of cement paste(with sugar admixtures) was delayed longest at 0.06% sugar content by weight of the cement in a grade 35 concrete mix. He concluded that the compressive strength of the modified concrete showed some marginal strength increase.

Studies carried out by Glenn also shows that starch based polymers used as admixtures can be used to produce Light weight concrete with density of fewer than $2g/cm^3$ .Light weight concrete is useful because it has low sound and thermal conductivity. In addition, the research also stated that starch addition is much cheaper to use in lightweight concrete than the use of light weight aggregates (Glenn *et al*., 1998).

2.3 CONCRETE

Concrete is a manufactured construction material that is heterogeneous and composed mostly of cement, aggregate and water. Concrete consist of aggregate bonded by a paste made from Portland cement and water. Each particle of aggregate is completely coated with paste and the paste fills the voids between the aggregates, after the newly mixed concrete is placed, it hardens to form a solid structural material that is good in compression and when reinforced with steel forms a good composite structure. The major ingredient in concrete is the hydraulic cement, which is used as a binding agent and strengthener.

Portland cement is primarily composed of calcium, silicon, aluminum, iron, and gypsum; these elements can be combined in various combinations to produce different types of Portland cement (Popovics, 1979). Cement is the most expensive ingredient in concrete and is generally the most reliable. The principal requirements are that the cement should be able to produce a strong, dense and durable concrete with definite setting and hardening characteristics.

Fresh concrete is a mixture of water, cement, aggregate and probably admixtures which may be used in certain cases to control rheology, rate of setting and hardening and durability. It is important that they remain uniformly distributed within the concrete mass during the various stages of its handling and that full compaction is achieved. When either of these conditions is not satisfied the properties of the resulting hardened concrete; say its strength or durability may be affected adversely (Neville and Brooks, 1994).

Some properties of concrete which may be affected with the use of admixtures in the mix include setting characteristics, rate and heat of hydration, workability, compressive and flexural strengths, concrete durability etc.

2.3.1 Setting times (initial & final)

The setting characteristics of concrete is the term used to describe the stiffening of the cement paste (cement and water), although the definition of the stiffness of the paste which is known as setting is somewhat arbitrary. Broadly speaking, setting refers to a change from a fluid to a rigid state. Although, during setting, the paste acquires some strength, it is convenient to distinguish setting from hardening, which refers to the gain of strength of a

set cement paste (Glon, 2010). Based on cement specifications by BS EN 197:Pt 1:2000, the initial setting time of ordinary Portland cement is limited to minimum of about 75 minutes under normal ambient conditions while the final setting time is approximately less or equal to 10 hours. The setting time of cement usually decreases with a rise in temperature and at low temperatures setting is retarded.

2.3.2 Heat of hydration:

This is the heat generated when Portland cement reacts with water. It is majorly as a result of the Tricalciumsulphate (C_3S) and Tricalcium Aluminate (C_3A) content, C_3S is believed to undergo hydrolysis producing a calcium silicate of lower basicity, ultimately $C_3S_2H_3$ with the released lime separating out as Calcium hydroxide ($Ca(OH)_2$) (Neville and Brook, 1997). Making the appropriate assumption that $C_3S_2H_3$ is the final product of hydration of both silicates, the reaction of hydration and corresponding specific energy dissipated according to Winter (2012) can be written as follows

$$2C_3S + 6H \text{ ---------- } C\text{-}S\text{-}H + 3CH \ (120cal/g) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

$$2C_2S + 4H \text{ ---------- } C\text{-}S\text{-}H + CH \ (62cal/g) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

$$C_3A + 3CSH_2 + 26H \text{ ------} C_6A\hat{S}_3H_{32} \ (300cal/g) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

$$2C_3A + C_6AS_3H_{32} + 4H \text{ ---------- } 3C_4A\hat{S}H_{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

$$C_4AF + 10 + 2CH \text{ ---------- } 3C_4A\hat{S}H_{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

- C-S-H ….$C_3S_2H_3$ (Tobomerite)
- CH ……. $Ca(OH)_2$ (Calcium hydroxide)

- $C_6AS_3H_{32}$ ……. (Ettringite)
- $C_4A\hat{S}H_{12}$…… (Monosulfate)

2.3.3: Workability of Concrete

Workability of concrete has never been precisely defined. For practical purposes, it generally implies the ease with which a concrete mix can be handled from the mixer to its final compacted shape. The three main characteristics of the properties are consistency, mobility and compactness. Consistency is a measure of wetness or fluidity, Mobility defines the ease with which a mix can flow into and completely fill the formwork or mould while compactness is the ease with which a given mix can be fully compacted to remove all trapped air (Neville and Brooks, 1994).

The degree of workability of concrete mix is selected based on the methods of mixing, transportation and compaction. For highly congested reinforced sections, medium or high workability is necessary. This is also applied to concrete transported by pumping or placed without compaction. For highly reinforced section of average size and when powerful vibration is available, low workability could be adequate. The degree of workability of a mix plays an important role in determining the strength of hardening concrete. Sufficient workability helps in the adequate compaction of concrete. Various factors are known to influence the workability of a freshly mixed concrete, factors such as the Cement, Water, Admixture and Size, Grading, Surface area of Aggregate. Other Factors include ambient conditions, temperature, humidity, mixing time etc. (Neville, 1997). The slump test has

been very useful in measuring the workability as given by any of the definition stated in this research project.

2.3.3.1 Slump test

This is a test used extensively for site work all over the world. The slump test does not measure the workability of concrete because ACI 116R (1990) describe it as a measure of consistency, but the test is very useful in detecting variations in the uniformity of a mix of a given nominal proportions. This test was developed by Chapman in the United States in 1913.

The slump test is prescribed by ASTM C-90 and BS 1881: 102 (1983). The mould for the slump test is a frustum of a cone, 300mm high, placed on a smooth surface with the smaller opening at the top, and filled with the concrete in three layers. Each layer is tamped 25 times with a standard 16mm diameter steel rod, rounded at the end, and the top surface is struck of by a means of a sawing and rolling motion of tamping rod. The mould is then slowly lifted up from the concrete cone. The slump is the difference between the height of the concrete in the mould and the greatest height of it after lifting the mould.

2.3.3.2 Compaction factor test

Although there is no generally accepted method of measuring the amount of work needed to achieve full compaction but using the inverse approach may be an alternative means of

the measurements. The test known as the compaction factor test was developed in the UK and it's described in BS 1881: 103 (1993). The degree of compaction called the Compaction factor is measured by the density ratio that is the ratio of the density actually achieved in the test to the density of the same concrete fully compacted. The apparatus consists essentially of two hoppers each in the shape of a frustum of a cone and one cylinder, the three being above one another and the hoppers have hinged doors at the bottom. Unlike the slump test, the variation in the workability of dry concrete mixes are reflected in a large change in the compacting factor, that is the test is more sensitive at the low workability end of the scale than at high workability. The compaction factor apparatus is not very convenient to use on site although it provides a good measure of workability. (Neville and Brooks, 1994).

2.3.4 Compressive Strength

The compressive strength of concrete is the maximum compressive load it can carry per unit area. Concrete structures, except for road pavements, are normally designed on the basis that concrete is capable of resisting only compression, the tension being carried by steel reinforcement. The compressive strength of concrete is carried out using cylinders or cores (ASTM C 39, 1999). Cube specimens of size 150 mm is often used to determine the compressive strength. BS 1881:108 (1983) recommended that the test specimen for compressive strength should be cured in water at a temperature of $20\pm5^{o}C$ and crushed immediately it is removed from water.

2.3.5 Flexural Strength

Flexural strength is also known as modulus of rupture, bend strength, or fracture strength. This is a mechanical parameter for brittle material and is defined as a material's ability to resist deformation under load. The primary parameter used in assessing pavement strength is flexural strength, or modulus of rupture (MOR), because that is the critical mode of loading. Flexural strength is determined in accordance with ASTM C 78 (third-point loading). Some agencies use the center-point flexural strength test ASTM C 293 particularly to assess whether the pavement can be opened to traffic (Peter *et al*., 2007).

According to Hodgkinson (2000) and Callister (2003), the transverse bending test is most frequently employed in measuring the flexural strength of members. In flexural or bending strength test, a beam or rod specimen having either a circular or rectangular cross-section is bent until fracture/failure using either a centre point, three point, or four point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is usually measured in terms of stress.

It is known that the compressive strength and tensile strength are closely related, both characteristics are functions of cement type, aggregate type and mix design, although, there is no direct proportionality between the two tests (Mehta and Monteiro, 1995).

However, according to CEB-FIP model code (1993), the tensile strength (f_t) has been related to compressive strength (f_c) within a range of

Lower limit = $ft = 0.95(\frac{fc}{10})^{2/3}$ and Upper Limit = $ft = 1.85(\frac{fc}{10})^{2/3}$

These limits approximate the flexural strength to about 10 to 20 percent of the compressive strength.

2.4 ADMIXTURES

Admixtures may be defined as any material other than water, hydraulic cement, aggregates and fiber reinforcement used as an ingredient of a cementitious mixture to modify its freshly mixed, setting or hardened properties and that it is added to the batch before or during its mixing (Suchorski *et al.,* 2003). This modification may result in improvement of workability, acceleration or retardation of setting time, control of strength development, and enhancement of resistance to frost action, thermal cracking, alkali-aggregate expansion, and acidic and sulfate solutions. Except in special cases such as high-strength concrete, the maximum dosage of concrete admixtures is limited by 5.2.6 of BS EN 206–1 (2000) to 50 g/kg cement (about 5% by weight of the cement). For low dosages of less than 2 g/kg cement, the admixture has to be dispersed in part of the mixing water.

There are so many admixtures currently present which are commonly classified by their function in concrete but often they exhibit some additional action. Generally speaking, based on functionality, the following standards BS 5075, BS EN 934, ASTM C494, BS EN 206, classifies admixtures into

a. Water Reducers (Plasticizers and Super plasticizers)

b. Set- Controlling (Retarders and Accelerators)

c. Retarding plasticizers and Accelerating Plasticizers

d. Air-entraining Admixtures

e. Mineral Admixtures

f. Other specialty admixtures include; Corrosion- inhibiting admixtures, admixtures for controlling Alkali-Silica reactivity, Shrinkage-reducing admixtures etc.

2.4.1 Water Reducers:

Water reducers, water-reducing admixtures or plasticizers are mostly aqueous solutions that are added to a concrete mix to lower the amount of water required for the cement particles to hydrate fully. The advantages of using water-reducers include lower density, higher workability and consistency, lower bleeding, and lower water to cement ratio. However, water-reducing admixtures have a relatively high cost when compared to other materials in a concrete mix (Ramachandran, 1995). Water reducers may include lignosulfonates, carbohydrates and hydroxycarboxylic acids. Examples of water reducers are plastiment BV 40, plastol 341, daracem 19, etc.

2.4.2 High Range Water Reducers:

These types of admixtures are also known as Super plasticizers but differs from water reducers (Plasticizers) as they in their own case can further reduce the amount of water needed in a concrete mix by as much as 30% without inducing excessive retardation on the setting characteristic of the concrete mix as well as compromising the strength and

workability integrity of the mix (Kourd and Hammad, 2010). Super plasticizers are mostly organic products that may either be sulfonated melamine formaldehyde condensates, sulfonated naphthalene formaldehyde condensates, lignosulfonates or polycarboxylates.

2.4.3 Air Entraining Admixtures:

This type of admixture allows a controlled quantity of small uniformly distributed air bubbles to be incorporated in a mortar/concrete and which remain after hardening. The advantages of using air-entrained concrete include lower weight, higher workability and consistency, lower bleeding, lower frost-damage, and higher resistance to sulfate deterioration. However, air-entrained concrete generally has a lower compressive strength than normal concrete (Ramachandran, 1995). Consequently, air-entraining agents are mostly used in extremely cold climates where concrete mixes would crack without the admixtures. Air-entraining agents may be; salts of wood resins (vinsol resin), some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, alkyl benzene sulfonates, and salts of sulfonated hydrocarbons. Some of the most important air entraining agents that has at one time enjoyed world-wide market is vinsol resin and darex.

2.4.4 Retarders:

Retarders or retarding admixtures are used to delay the rate of setting of concrete. High temperatures of fresh concrete (30°C or 86°F) are often the cause of an increased rate of hardening that makes placing and finishing difficult. Retarders do not decrease the initial temperature of concrete. The bleeding rate and bleeding capacity of concrete is increased

with retarders. Retarding admixtures are useful in extending the setting time of concrete, but they are also often used in attempts to decrease slump loss and extend workability, especially prior to placement at elevated temperatures (Whiting and Dziedic, 1992). Retarders generally may be lignin, borax, sugars and carbohydrates, tartaric acid and salts.

2.4.5 Accelerators:

These groups of admixtures are not generally used in mortar and screed production; however some proprietary screed mixes incorporate an accelerating admixture. They achieve their effect by increasing the rate of chemical reaction between the Portland cement and water (hydration) within the mix. This is achieved by either increasing the rate of dissolution of the silica and alumina phases of the cement or by dissolving the lime. An accelerator that was formerly widely used was based on calcium chloride; this was added at a dosage of between 1 and 2% by weight of cement. However, calcium chloride was found to increase the rate of corrosion of reinforcing metal. Chloride free accelerators based on triethanolamine, calcium formate and sodium thiocyanates are widely available. However, generally they are not as effective as calcium chloride.

2.4.6 Pozzolanic or Mineral Admixtures

The use of Pozzolanic materials is as old as that of the art of concrete construction. It was recognized long time ago, that suitable pozolans used in appropriate amount modify certain properties of fresh and hardened mortars and concretes. Ancient Greeks and Romans used certain finely divided siliceous materials which when mixed with lime produced strong cementing material having hydraulic properties and such cementing materials were

employed in the construction of aqueducts, arches, bridges, etc. One of such material was consolidated volcanic ash, other examples of mineral admixtures include fly ash, silica fume, and ground granulated blast furnace slag amongst many others. It has been amply demonstrated that the best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as: Lower the heat of hydration and thermal shrinkage, increase the water tightness, lower susceptibility to dissolution and leaching, improve workability etc (Ramachandran, 1995).

2.4.7 Retarding Plasticizers and Accelerating Plasticizers:

These admixtures are usually a blend of water reducers and set- controlling admixtures. It may be interesting to note that all the plasticizers and super plasticizers by themselves show certain extent of retardation. Many a time this extent of retardation of setting time offered by admixtures will not be sufficient. Instead of adding retarders separately, retarders are mixed with plasticizers or super plasticizers at the time of commercial production. Such commercial brands are known as retarding plasticizers or retarding super plasticizers. Also, certain ingredients may be added to plasticizers or super plasticizers in order to accelerate the strength development of concrete. Such accelerating super plasticizers, when added to concrete result in faster development of strength. The accelerating materials added to plasticizers or super plasticizers are triethanolamine chlorides, calcium nitrite, nitrates and fluosilicates etc. The accelerating plasticizers or accelerating super plasticizers manufactured by well known companies are usually chloride free.

2.5 CASSAVA

Cassava (*Manihot esculentacrantz* or *Manihot utilissima*) is a perennial tuber plant widely grown in many tropical countries including Nigeria as one of the most important commercial crops. Cassava is an important high energy traditional food crop. The edible fleshy portion makes up 80-90% of the tube. The tuber flesh is composed of about 62% water, 35% carbohydrate, 1-2% protein, 0.3% fat, 1-2% fiber and 1% mineral matter. Most of the carbohydrate fraction is starch which makes up 25-30% of the tuber flesh (Purseglove, 1968).

The cassava tuber does best when rainfall is about 100-150 cm per annum and well distributed. Compared to other tuber or root crops, cassava also draws its uniqueness from the fact that it is well adapted for cultivation under conditions of drought and can be profitably grown in areas of 50cm annual rainfall and mean temperature ranges of 25-29^{o}C (Onwueme, 1978). These environmental conditions usually determine the level of toxicity, yield of the crop and to an extent the quality and yield of the starch extracted from them (Charles *et al*., 2005).

Cassava and to a small extent, sweet potato (*Ipomoea batatas*) are used for starch extraction in countries such as India, Brazil, Thailand, Indonesia, Philippines and China. Based on the statistics from the FAO of the United Nations, Thailand is the largest exporting country of dried cassava with a total of 77% of world export in 2005. The second largest exporting country is Vietnam, with 13.6%, followed by Indonesia (5.8 %) and Costa Rica (2.1 %) (Adejumo *et al*., 2011).

In terms of production, Nigeria currently is the largest producer of cassava in the whole world with an annual output of about 30 million tons of tuberous root and it plays a dominant role in the rural economy in the southern agro-ecological zone (Adeniji *et al.*, 2001). Comparing the output of various crops in Nigeria, cassava production ranks first at over 30 million tonnes, followed by yam production in 2004, sorghum at 7 million tonnes, millet at 6 million tonnes and rice at 5 million tonnes (FAO, 2004). Fig 2.1 shows the distribution of crops grown in Nigeria. Also, Fig 2.2 shows the production output of cassava across Nigeria. By zone, the North Central zone produced over 7 million tonnes of cassava a year (1999 to 2006). South-South produces over 6 million tonnes a year while the South West and South East produce just less than 6 million tonnes a year.

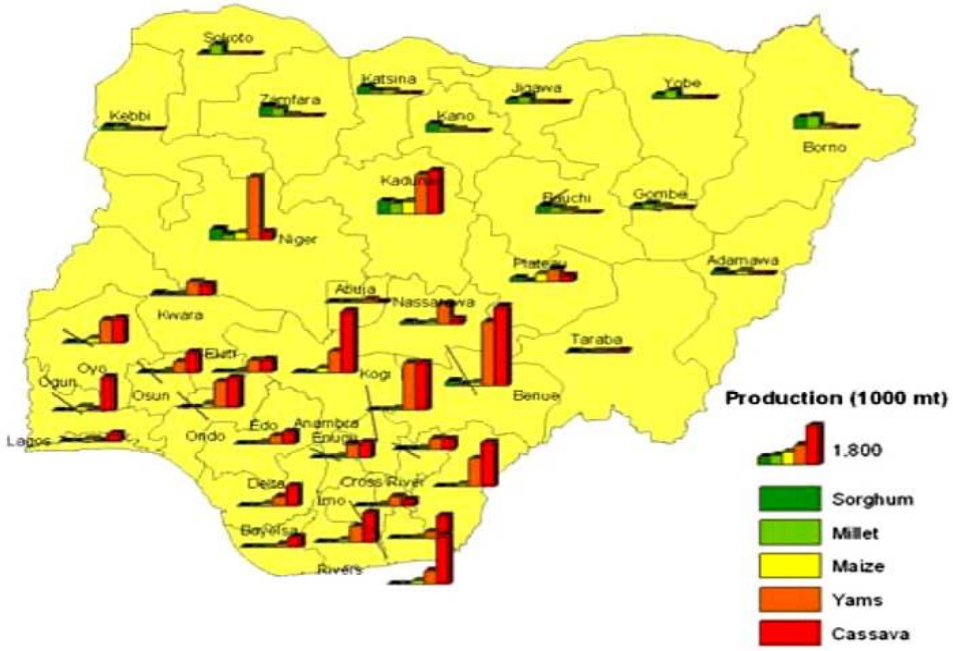

Fig 2.1 Various Crop Production outputs in Nigeria.
Source: NFRA, Nigeria (2007)

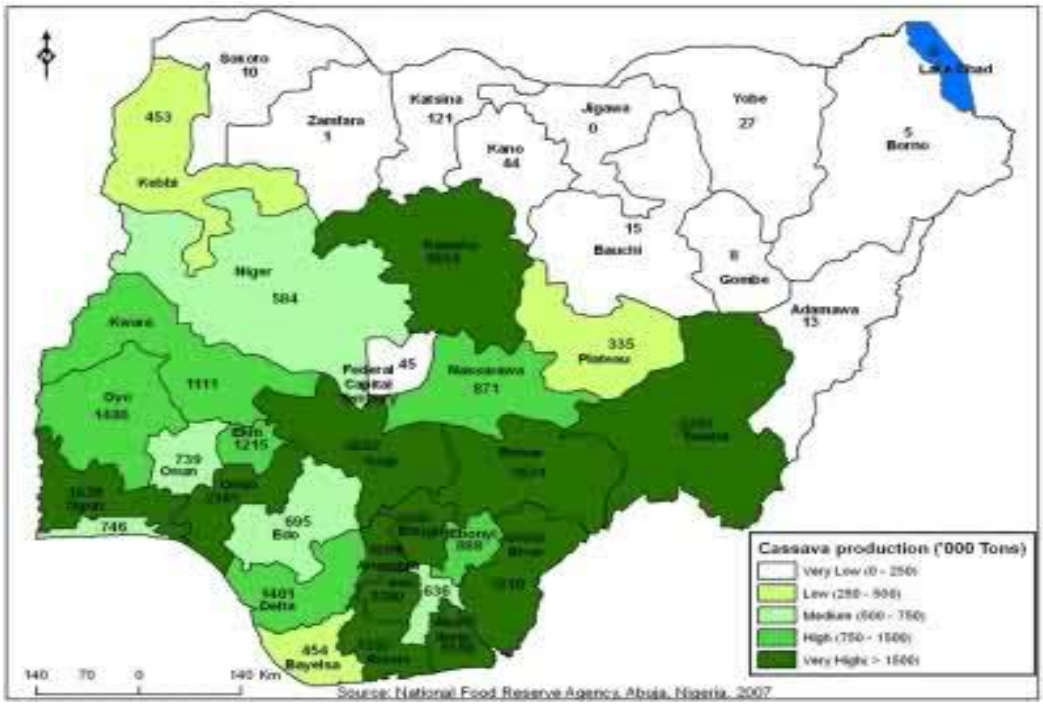

Fig 2.2: Cassava Production in various states of Nigeria.
Source**:** NFRA, Nigeria (2007).

Table 2.1 shows that the North West and North East are small by comparison at 2 and 0.14 million tonnes respectively while the north-central and south-south have the highest productions.

Table 2.1 Cassava Production by Zone 2000-2005 (tonnes)

Region	**2000**	**2002**	**2005**
South-West	4 993 380	5 663 614	6 883 805
South- South	6 268 114	6 533 944	7 321 674
South- East	5 384 130	5 542 412	6 846 310
North- West	2 435 211	2 395 543	3 140 000
North- Central	7 116 920	7 243 970	8 405 640
North- East	165 344	141 533	840 620

Total	26 363 099	27 521 016	33 438 049

Source: IITA (2006)

2.6 PROPERTIES OF STARCH

Starch is a highly versatile renewable natural resource which is used in virtually all industrial sectors. In the natural state, starch is used as a binder, stabilizer, surfactant, texturizer, and bulking agent. Starch is also processed into a range of products including adhesives, sweeteners, and other more specialized products, such as biodegradable plastics and superabsorbent polymers. Essentially, starch is a carbohydrate polymer of glucose found as a nutritive reserve in plants. With a specific gravity of about 0.56, starch is composed of 2 types of polysaccharide molecules, one linear (amylose) and the other branched (amylopectin). In natural starch, these molecules are closely associated in structured microscopic granules, and in cassava starch, amylose content typically lies within the range of 16– 18% relative to amylopectin (Shipman *et al.*,1993).

2.6.1 Rheological Properties of Starch

Starches in general have unique properties like gelatinization temperature, swelling capacity; solubility, paste clarity, viscosity etc, and these properties are known as Rheological Properties.

i. **Gelatinization temperature**. When an aqueous suspension of starch is heated, water molecules around the granule disrupt the hydrogen bonding and enter the granules which then swell. This swelling and absorption of water are an irreversible process,

termed gelatinization. The gelatinization process leads to the preparation of a viscous suspension and this determines the temperature at which a starch paste takes on the desired processing qualities. Due to the differences in starch granules' size and their heterogeneous structure, gelatinization does not occur at a specific temperature but across a temperature range. For cassava, this is from 58 to 70^{o}C.

ii. **S**

welling capacity and solubility. Swelling capacity can be defined as the maximum increase in volume and weight which starch undergoes when allowed to swell freely in water. Solubility is a measure of the solutes which are leached from starch granules when tested for swelling capacity. Swelling capacity of starch is dependent upon the strength and nature of the associate forces within the network of the starch granule. Cassava starch has a higher solubility than the other tuber crop starches and the higher solubility can be attributed partly to the high swelling cassava starch undergoes during gelatinization. The solubility of starch of different cassava varieties varied from 17.2 to 27.2 %.

iii. **V**

iscosity. When an aqueous concentrated suspension of starch is heated to the gelatinization temperature, starch granules swell by rapidly absorbing the available water. As the starch granules absorb water, soluble are leached from the granules into the aqueous phase. When the available volume of water has been absorbed, these solubles diffuse back into the granules until equilibrium is reached.

2.6.2 Cassava Starch

Cassava starch has been used to fill some of the high demand for starch in industry. The process of starch extraction is relatively simple as there are only small amounts of secondary substances, such as protein in the roots. Tubers arriving at the production plant are first peeled and washed then crushed to produce a pulp which is suspended in water and by means of revolving sieves; the fibrous materials are removed leaving the starch milk. The starch is allowed to settle from its milk and then dried and bagged (Williams, 1969). Fig 2.3 shows the schematic diagram of cassava starch production process.

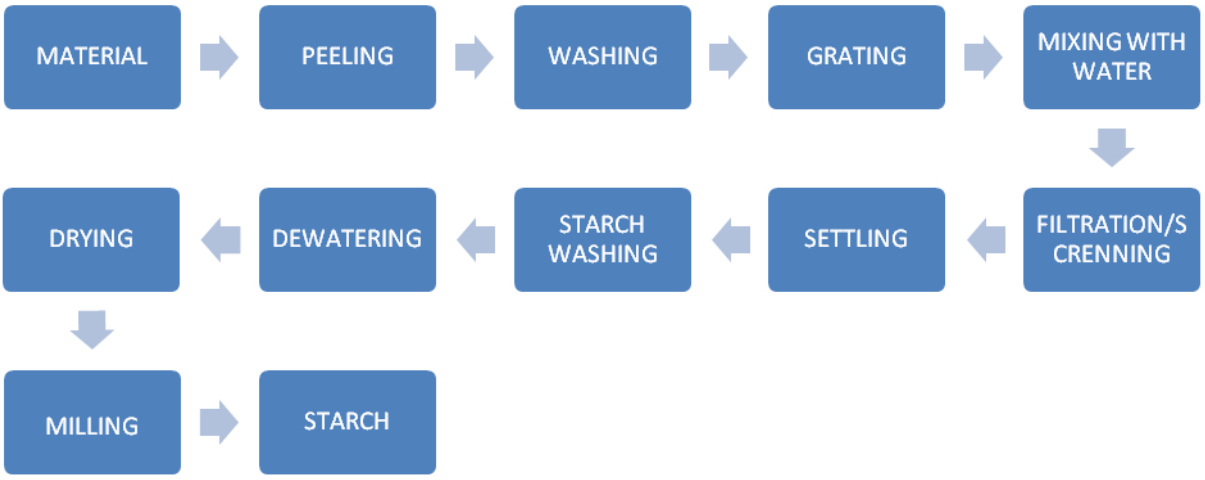

Fig 2.3: Starch Production Process.

Cassava starch is usually white in color, odourless and in powdery form with grain sizes varying from less than 1 μm to more than 100 μm. Generally, granule size is expressed as the average spherical equivalent diameter (Bagalapolan, 1988). Cassava starch granules are mainly round with a flattened surface on one side containing a conical pit. For high quality starch, its pH ranges between 6.3 - 6.5.

CHAPTER THREE

MATERIALS AND METHODS

3.1 PREAMBLE

This chapter has to do with the materials used in this work and how the test and methods were carried out in accordance to the various codes. Consistency, setting time and soundness test were determined using appropriate procedures on the cement. Fine and Coarse aggregates were also subjected to test in accordance with relevant standards.

Concrete and Cement paste were cast in two categories each; one without the cassava starch and the other with the cassava starch in different percentages. Workability and Compressive strength test were also determined using recommended test procedures on the prepared specimen.

3.2 MATERIALS

The materials used for the research are

i. Cement (Ordinary Portland Cement)
ii. Fine Aggregate (Sand)
iii. Coarse Aggregates
iv. Water
v. Cassava Starch

i. Cement

Cement obtained from a reputable dealer in Samaru market, Zaria was used and subjected to XRF (X-ray Fluorescence) test to determine its chemical composition and the following physical property tests:

a. Consistency
b. Initial setting time and final setting time
c. Soundness.

ii. Fine Aggregates

The fine aggregate (river sand) used in this research work was bought from a supplier at Samaru, Zaria and examined for conformity with the standard requirements. Test carried out on the sand included:

a. Sieve analysis (particle size distribution)
b. Specific gravity
c. Bulk density
d. Water absorption
e. Moisture content

iii. Coarse Aggregates

Coarse aggregates used in this research work was obtained a quarry site within Zaria metropolis and subjected to the following tests:

a. Particle size distribution
b. Specific gravity
c. Bulk density
d. Moisture content

e. Flakiness and Elongation

f. Aggregate Impact Value and Aggregate Crushing Value

The coarse aggregates used were nominal size of twenty millimeters (20 mm).

iv. Cassava Starch

The cassava tubers used in this study were obtained from a local dealer at the Samaru market, Zaria and the starch was then extracted from it. The extracted cassava starch with a specific gravity of about 0.56 was then sun dried and milled into powdered form of less than 75 microns and then subjected to X-Ray diffraction test

v. Water

Clean tap water, fit for drinking was used in this research.

3.2.1 Cement

a. Chemical Composition

Chemical composition and characterization of cement were determined using X-ray fluorescence (XRF) in accordance to, BS 12 (1978). It was carried out at Centre for Energy Research and Training, Ahmadu Bello University, Zaria in Kaduna state.

b. Consistency

The consistency of the cement was carried out in accordance with BS EN 196: Pt 3 (1994) using the vicat apparatus. 400g of cement was weighed and mixed with water (30% initial mass of dry cement sample) for an average of 5 minutes mixing time. The vicat mould was then filled with the paste and placed under the plunger of the apparatus. The plunger was brought in close contact to the top surface of the paste and

then released. The plunger penetrates to point 5mm to 7mm above the bottom of the mould.

c. Initial and Final Setting Time

The initial setting time was determined by placing the vicat mould filled with cement paste under the apparatus and instead of a plunger, a needle of 1mm diameter is brought in contact with the surface of the paste and released quickly. The needle was allowed to sink to the bottom of the mould and the same procedure repeated in different positions on the mould until the needle cannot penetrate more than 5mm above the bottom of the mould. Initial setting time was then recorded as the time elapsed since mixing water with cement till until the last reading.

Final setting time on the other hand was determined by replacing the round needle above with a 1mm square needle fitted with a metal annular attachment and this was brought in contact with the surface of the paste every 15 to 20mins. Final setting time was recorded when the needle makes an impression on the surface but the annular cutting edge fails to do so.

d. Soundness

A cement paste of standard consistency was prepared and filled into the 'Le chatelier mould'. The mould was covered with a piece of glass and immediately immersed in water. After 24 hours the mould was removed from water and the distance between the pointers was measured. The mould was re-immersed in water again and boiled for 1 hour, the mould was the removed, allowed to cool and the distance between the

pointers measured again. The difference between the 2 measurements represents the expansion of the cement.

3.2.2 Aggregates

Both fine and coarse aggregates were examined in accordance with BS 812; testing of aggregates.

i. Particle Size Distribution

A sample of the aggregates was shaken mechanically through a series of wire-cloth sieves with openings, nested one above the other in order of size, with the sieve having the largest openings on top, the one having the smallest openings at the bottom, and a pan underneath to retain material passing the finest sieve. Coarse and fine aggregates are generally sieved separately.

For fine aggregate, a sample of approximately 1kg is sampled for the sieve analysis, a set of sieve opening sizes were stacked as follows 4.76mm, 2.36mm, 600µm, 300µm, 150µm and pan while for coarse aggregates approximately 3kg is sampled with different sieve sizes which are staked as follows: 50mm, 38.1, 25.4, 19.05, 12.7, 9.52 and 6.25mm.

ii. Specific gravity

A pycnometer of known capacity was filled with water and the weight was recorded (A).A known weight (B); 500g for the fine or 1kg for the coarse aggregates; was poured into the pycnometer filled with distilled water. The surface of the apparatus was dried and weighed (C). The apparent specific gravity of the surface dry sample is then computed from

$$\text{Specific Gravity} = \frac{B}{(A+B-C)} \quad \text{..... (3.1)}$$

This test was repeated 2 more times and the average specific gravity of each of the aggregates were determined.

iii. Bulk density

Two cylinders of about 2.83litres and 14.15 litres capacity for the fine and coarse aggregates respectively were used. Each cylinder was first calibrated to determine its actual volume (V); the mass of water in kg required to fill the cylinder was used to deduce the volume, then the appropriate cylinder was filled to overflowing with the surface dry aggregate. The net mass of the aggregate in the cylinder was measured (M) and the bulk density calculated from

$$\text{Bulk Density} = \frac{M}{V} \quad \text{..... (3.2)}$$

Where M denotes the mass of the aggregate in kg and V denotes the corresponding volume of the cylinder in m^3.

iv. Aggregate Crushing Value

About 5kg of coarse aggregate passing through B.S sieve size of 12.7mm and retained on sieve size 9.52mm was used for this test. A 152mm diameter open-ended steel cylinder was filled with the aggregate in 3 equal layers giving 25 blows to each layer. The sample was then tested in a compression machine at 40KN/min to a load of 400KN. The material was removed from the cylinder and sieved through a 2.4mm B.S test sieve. The weight of the fines passing through the 2.4mm sieve was then determined and expressed as a percentage of the total weight of aggregate used. The value equals the Aggregate Crushing Value. This test was repeated twice and average crushing value for coarse aggregate is then recorded.

v. Aggregate Impact Value

Sufficient amount of coarse aggregate passing through B.S sieve size 12.7mm and retained on the 9.52mm sieve was prepared. The prepared sample was used to fill a 7.6mm diameter cylinder in 3 layers giving 25 strokes of a 23cm tamping rod to each layer. The whole sample was firmly placed in the cup of the impact machine and then subjected to 15 blows by allowing the hammer fall freely. The crushed aggregates were then sieved on the 2.4 mm sieve and the percentage passing by weight was determined. The impact value was expressed as the percentage of fines passing the 2.4mm sieve to the total weight of the sample.

3.2.3 Cassava Starch

Cassava starch was extracted as explained in Fig 2.3. The cassava species from which the starch was extracted is referred to as "TME 7 or OKO-IYAWO (BRIDEGROOM)" in local terms. The wet and sticky like boluses of the starch was subjected to a moisture content test. XRD characterization of the starch was carried out at the National Geoscience Research Lab, Kaduna.

3.3 SPECIMEN PREPARATION AND TESTING

Cassava starch was added to cement paste and concrete in various proportions in accordance to 5.2.6 of BS EN 206–1 on the dosage of admixtures to 50 g/kg cement (About 5% by weight of the cement). For low dosages of less than 2 g/kg cement, the admixture has to be dispersed in part of the mixing water.

3.3.1 Cement Paste (Consistency Test)

The starch was added to the cement paste in proportions of 0, 0.5, 1, 2, 3, 4 and 5 percents by weight of the cement. Each of the weight of the corresponding starch proportion was measured on a scale and mixed with the dry cement sample and then a standard consistency test was carried out on the cement paste with each of the above named proportions of cassava starch. 400g of cement was weighed and mixed with a water-cement ratio of 0.5 in a mixing bowl for a period of about 5 minutes and then placed under the vicat apparatus and tested for consistency as well as setting times.

3.3.2 Concrete

Freshly prepared concrete mixture was prepared with a prescribed mix ratio of 1:2:4 and water cement ratio of 0.50 for both the control (concrete specimen without the cassava starch) and test specimen (concrete specimen with the various starch concentrations). Starch concentrations of 0, 0.5, 1, 2, 3, 4 and 5 % of weight of cement in concrete mixture were added in the concrete mix. The prepared test specimen were labeled COT-0, COT-1, COT-2 …and COT-6, where COT-0 implies concrete test specimen mix with 0% (by weight of the cement in the concrete mix) of the cassava starch, where COT-1 implies concrete test specimen mix with 0.5% (by weight of the cement in the concrete mix) of the cassava starch etc.

3.4 BATCHING AND MIXING OF CONCRETE MATERIALS.

Batching of aggregates and cements is best done by weight, since dispensing of solids on a volume basis can lead to gross errors. Only water and liquid admixtures can be measured

accurately by volume. Thorough mixing is essential for the complete blending of the materials that are required for the production of homogeneous, uniform concrete.

The desired concrete compressive strength of 20N/mm^2 with a prescribed concrete mix ratio of 1:2:4 was used in this research work that is, 1 part of cement, 2 parts of fine aggregate and 4 parts of Coarse aggregate. The water cement ratio of 0.5 is used based on the desired workability and slump value of 50 – 75mm. Based on the prescribed mix ratio, the various weights of the constituent materials in the concrete were determined using Equation 3.3.

$$\frac{W}{1000} + \frac{C}{1000Lc} + \frac{A1}{1000L1} + \frac{A2}{1000L2} = 1 \quad \text{..... (3.3)}$$

where L with appropriate suffix represents the specific gravity of each material. The mix proportioning gives the values of W/C, C/ (A_1 + A_2) and A_1/A_2, hence the values of W, C, A_1 and A_2 can be found.

Having obtained the various weights, the ingredients were thoroughly mixed manually according to BS 1881 -3 (1970) and then tested for workability (Slump and Compaction factor tests). See appendix D4.

Plate I: Batching by Weight of Concrete Constituents

3.5 WORKABILITY TEST

The slump test and compaction factor test were used in this research as an assessment for the workability of the concrete mix.

3.5.1 Slump test

The already mixed concrete was used to fill the 300mm high slump cone in 4 approximately equal layers tamping each layer 25 times with the standard 16mm diameter steel rod. Upon filling, the top surface of the concrete cone was leveled and the mould lifted up off the concrete. The height difference between the mould and that of the concrete cone after lifting the mould was recorded to the nearest 5mm as the Slump value. The slump test was repeated for each of the admixed concrete specimens.

Plate II: Slump Test Being Carried Out

3.5.2 Compaction Factor Test

The upper hopper of the compaction factor apparatus was gently filled with the mixed concrete so that no work is done on the concrete to produce compaction. Two minutes after filling, the door at the bottom of the upper hopper was released and the concrete was allowed to fall into the second but smaller hopper and then the door of the second hopper was also released and the concrete falls into the cylinder. Excess concrete was cut by two floats slid across the top of the mould.

The weight of the concrete in the mould which is partially compacted was determined to the nearest 10g. Correspondingly, the weight of a fully compacted concrete was

determined by refilling the cylinder with concrete in four layers with each layer tampered 25 times with a tamping rod.

Plate III: Compaction Factor Test Being Carried Out

3.6 COMPRESSIVE STRENGTH TEST

Compressive strength was determined with the use concrete cubes. 3 sets each of concrete cubes (150mm x150mm x 150mm dimensions) were cast and cured for 3, 7, 21 and 28 days, each of these cubes were admixed with cassava starch of 0, 0.5, 1, 2, 3, 4 and 5% (by weight of the cement in the concrete mix), giving a total of 84 cubes. Curing was done in water by complete immersion and removed at the respective ages above. Each of the cubes was air dried for about an hour and weighed accordingly. Each of the cubes was placed in the testing machine (Plate 4) crushed and the load at failure recorded. The compressive strength was calculated by dividing the crushing load (failure load) by the area of the cube.

Plate IV: Compressive Strength Test Specimen in Crushing Machine

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 PREAMBLE

This chapter deals with the analysis and discussion of results from tests carried out in chapter three, in order to arrive at reasonable conclusions and recommendations.

4.2 CEMENT

4.2.1 X-Ray Fluorescence (XRF) Test on Cement

Figure 4.1 shows the XRF chemical or oxide composition test of the Dangote cement used in this research in comparison with the specification of ordinary Portland cement as stated in BS EN 197 (2000) and ASTM C 150 (2007)

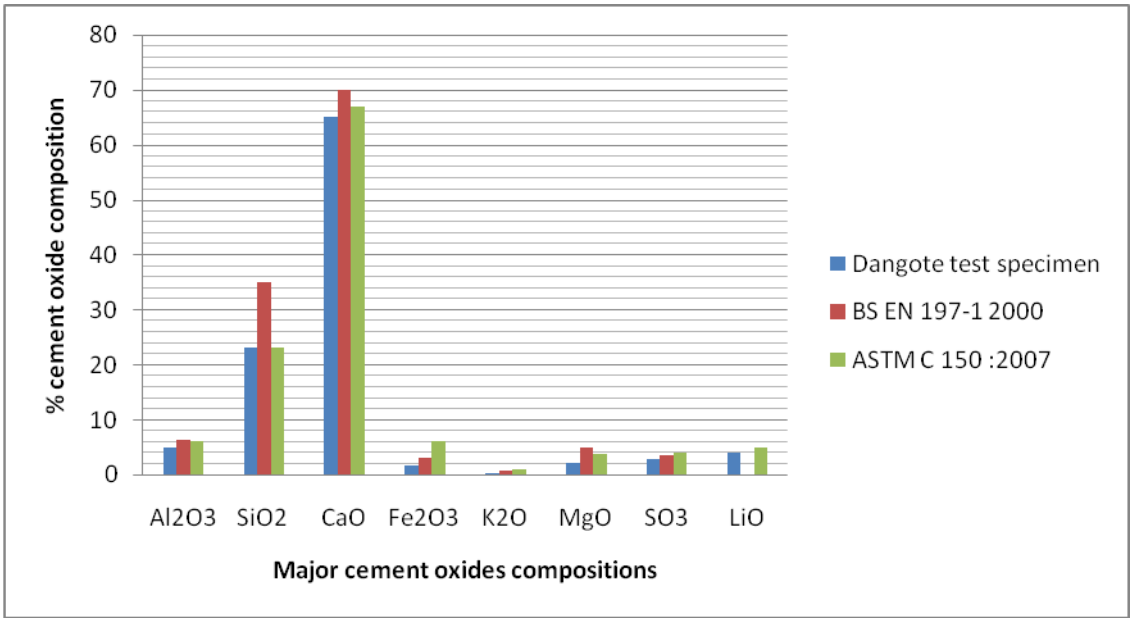

Fig 4.1: Major Oxide Composition of Cement

The Dangote cement oxide compositions compared with the code specifications indicate the values are within the specified limits for ordinary Portland cement. Note that the upper

or maximum value of the each of the code specification is used as the basis of comparison. Hence the Dangote cement used is an ordinary Portland cement and its quality good and is of standard.

4.2.2 Soundness

The soundness of the cement was carried out in accordance to BS 4550 (1978) clause 3.7 and the result is presented in table 4.1

Table 4.1: Soundness of Cement

	Test 1	**Test 2**
Sample No.	SOT-01	SOT-02
Distance between the pointer before heating(mm)	4.0	3.0
Distance between the pointer after heating (mm)	5.5	4.5
Soundness: – Expansion (mm)	**1.5**	**1.5**
Average(Mean) soundness	**1.5**	

Other tests carried out on the cement sample include the consistency and setting time test. Results obtained are represented in appendix A2 and A3. Summarized in table 4.2 shows a comparison between the results of the properties of the Dangote cement used and code specification BS EN 197-1 2000.

Table 4.2: Comparison of cement parameters with code specifications

S/No.	Parameter	Values forDangote	BS EN 197-1 (2000)
01	Consistency	30.3%	26 – 32%
02	Initial Setting time	159 minutes	≥ 45 minutes
03	Final Setting time	234 minutes	≤ 600 minutes
04	Soundness	1.5 mm	≤ 10 mm

Having looked at Table 4.2, it can be inferred that the Dangote cement conforms to the specification as stated in BS EN 197-1 2000 for Ordinary Portland Cement, hence the Dangote cement is an Ordinary Portland Cement.

4.3 FINE AGGREGATES

4.3.1 Particle Size Distribution

The particle size distribution was carried out in accordance to BS 812 (1989) clause 102. The sieve analysis results is presented in appendix B1 and plotted as shown in Fig 4.2.

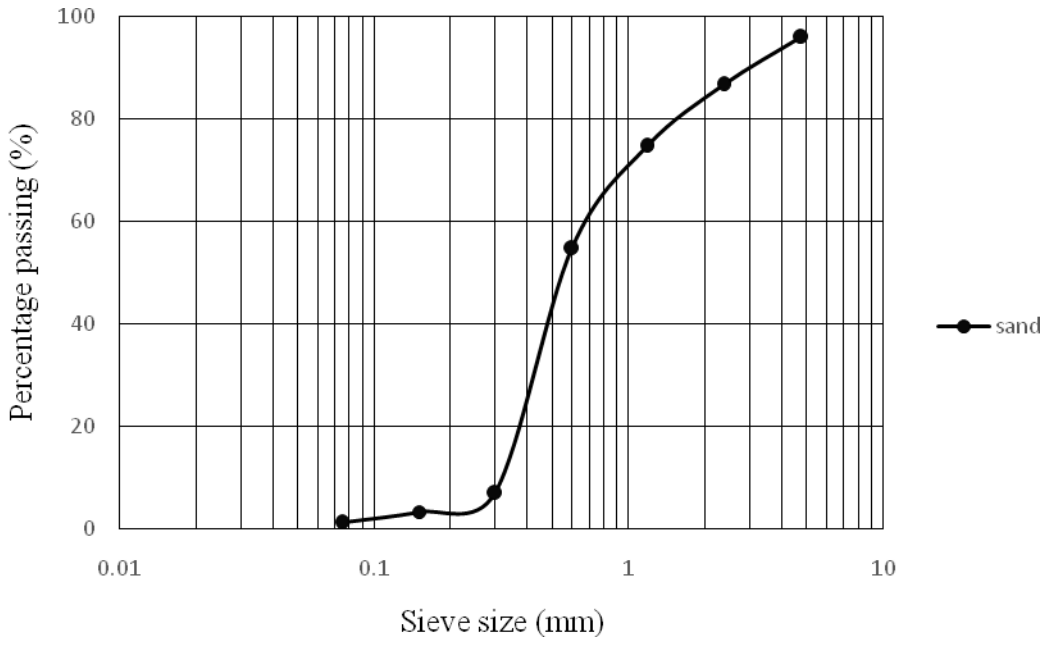

Figure 4.2 Particle Size Distributions Curve of Fine Aggregates (Sand)

Also, Fig 4.3 shows that the gradation of sand is within zone grading No. 2. And it's suitable for concrete works. The gradation of particles falls within the fine aggregates (F) specified gradation limits in (BS882:1992) which was later replaced by BS EN 12620: 2002.

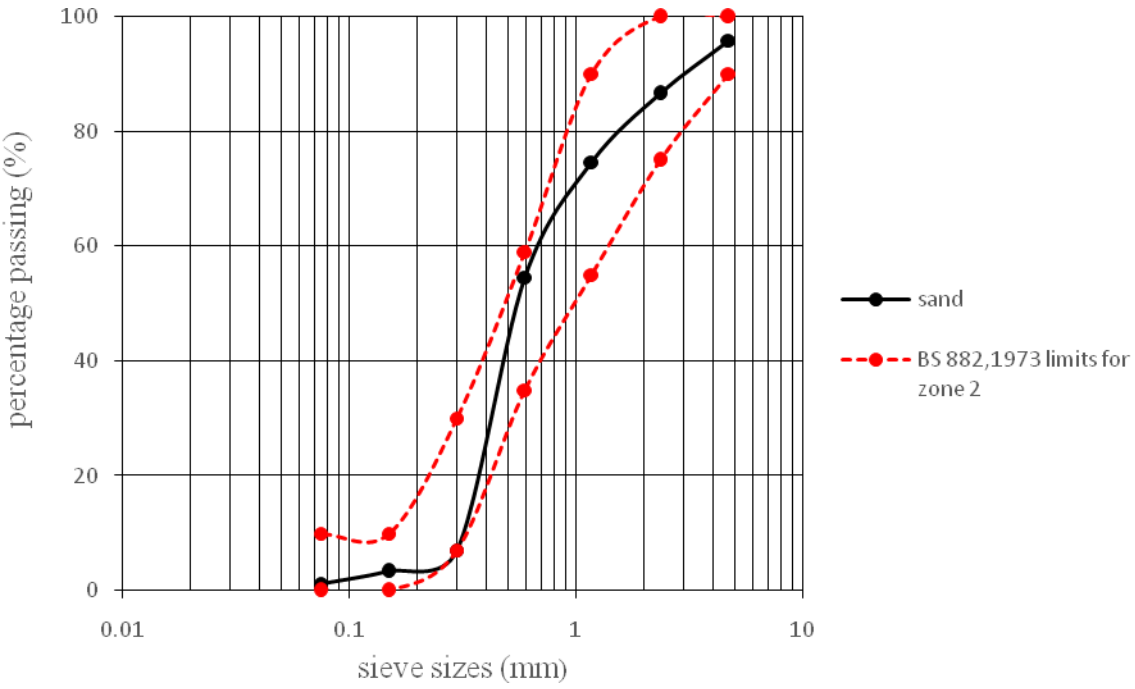

Figure 4.3: Particle Size Distributions Curve of Fine Aggregate (Sand) Compared with the Zone 2 Limits

4.3.2 Fines Content of the Fine Aggregates

Fines are defined in British standards as materials passing a 75μm test sieve. From the particle size distribution analysis, the fines content of sand is 1.2% and falls in Class I which is within the specification limit for fines in sand of (0 – 16.0%) in (BS 882, 1992) and 0 -10% in BS EN 12620.

4.3.3 Fineness Modulus of the Fine Aggregate

Using the sieve analysis results, a numerical index called the fineness modulus (FM) was computed. The fineness modulus is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100. The coarser the aggregate, the higher the fineness modulus, for fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in (ASTM C 33, 2003). Table 4.3 shows the result of the fineness modulus of sand. The FM for sand is within the range specified in (ASTM C 33, 2003).

Table 4.3: Fineness modulus of Fine Aggregates (FA)

Sieve size	Cumulative % retained for FA
No. 4	4.2
No. 8	13.4
No. 16	25.4
No.30	45.4
No. 50	93

No. 100	96.6
Sum	278
Fineness modulus	278/100= 2.78

4.3.4 Properties of the Fine Aggregates

Tests on some of the engineering properties of the fine aggregates such as the apparent specific gravity, bulk density, moisture content and absorption were carried out in accordance to BS 812 specifications and the detailed results are presented in appendix B1, B2, B3, B4 and B5. The result of these test carried out compared with BS EN 12620 code specifications are summarized in Table 4.4

Hence, based on the values of Table 4.4 the river sand used in this research conforms to specifications for fine aggregates to be used in concrete.

Table 4.4: Comparison of Sand parameters with code specifications

S/No.	Parameter	Values for Sand	BS EN 12620 (2000)
01	Fines Content	1.2	Class I (0-10%) Class II (>10 but <14)
02	Finess Modulus	2.78	2.2 – 3.1
03	Bulk Denisty	1352	1350 - 1660
04	Specific Gravity	2.63	2.3 – 2.9
05	Absorption	1.04	0 – 8

06	Moisture Content	8.1	0 – 10

4.4 COARSE AGGREGATES

4.4.1 Particle Size Distribution of Coarse Aggregates

The particle size distribution of the coarse aggregate is plotted in figure 4.4. The graph shows that the gradation of the coarse aggregates is within the limits of gradation specified for aggregates with nominal sizes of 20 to 5mm and is therefore suitable for concrete works (ASTM C33-78).

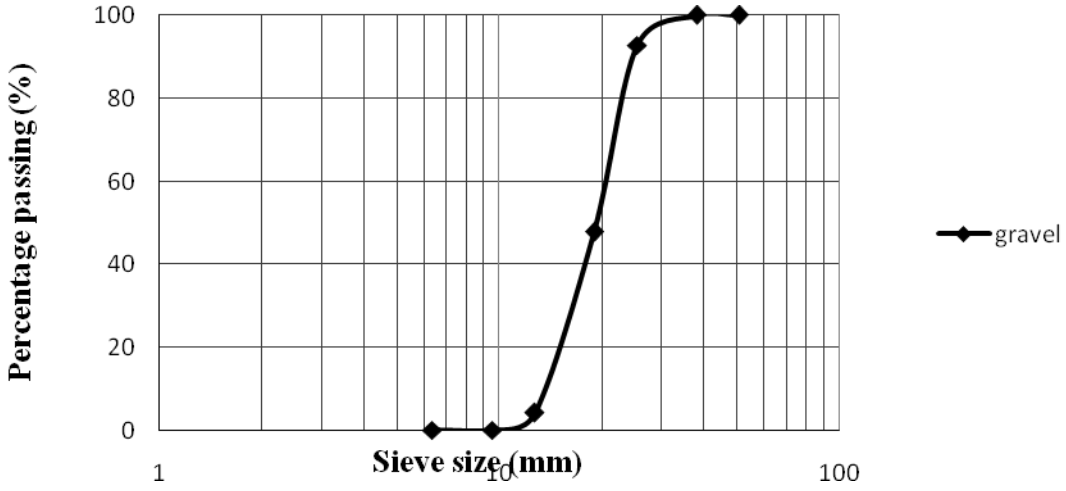

Figure 4.4 Particle size distribution of Coarse aggregates (Gravel)

4.4.2 Geometrical Properties of Coarse Aggregates

Other physical and geometrical tests carried out on the coarse aggregates such as the Bulk density, Flakiness index, Aggregate Impact Value, Aggregate Crushing Value, Elongation Index, Absorption and Moisture Content are presented in Appendix C2 to C13.

The summarized results of the Geometrical and physical requirements test on coarse aggregates is shown in Table 4.5 and compared with Code specifications of BS EN 12620 (2002).

Table 4.5: Comparison of results of Coarse aggregates tests with Code specifications

S/No.	Parameter	Value	Code Specifications BS EN12620 (2002)
01	Specific gravity	2.85	2.4 – 2.9
02	Flakiness Index	13.38%	30% Max.
03	Elongation Index	14.87%	35% Max.
04	Aggregate Impact Value	26%	≤30%
05	Aggregate Crushing Value	20.5%	30% Max.
06	Absorption	0.7%	0.8% Max.
07	Moisture content	0.1%	2% Max

(Each value is an average (mean) of three test results. See Appendix C)

It is observed from the table 4.5 that the Specific Gravity, Flakiness Index, Elongation Index, Aggregate Impact Value, Aggregate Crushing Value and Absorption values all fall

within the range specified in BS EN 12620 (2002). Hence the coarse aggregate used is good for concrete work used for rigid pavement.

4.5 STARCH

4.5.1 X- Ray Diffraction

The X-Ray diffraction test was used as a rapid analytical technique for phase identification, material characterization and structural analysis. Table 4.6 shows the characteristics of the starch sample as obtained from the XRPD test.

Table 4.6: Characteristics of Cassava Starch from X- Ray Powder Diffraction Test

Name and Formula	Compound name	Starch (Cassava)
	PDF (Index name)	Starch (Cassava)
	Empirical formula	$C_6H_{10}O_5$
	Chemical formula	$(C_6H_{10}O_5)n$
Subfiles	Subfiles	Organic Polymer
Analysis	Amylose	18%
	Amylopectin	82%

It will be observed in the table 4.6 that the characterization of the starch compound using the XRD Test shows the empirical as well as chemical formulae of the starch compound. It also states the Amylose and Amylopectin content of the starch sample used. The

compound is a Polymer as well as an amorphous solid. The figure 4.5 below shows the starch structure as obtained from the XRPD test.

Table 4.6a: Chemical Composition of Cassava Starch

Element	Weight %	Atomic %
Carbon	49.99	57.18
Oxygen	49.76	42.73
Potassium	0.25	0.09
Total	100	

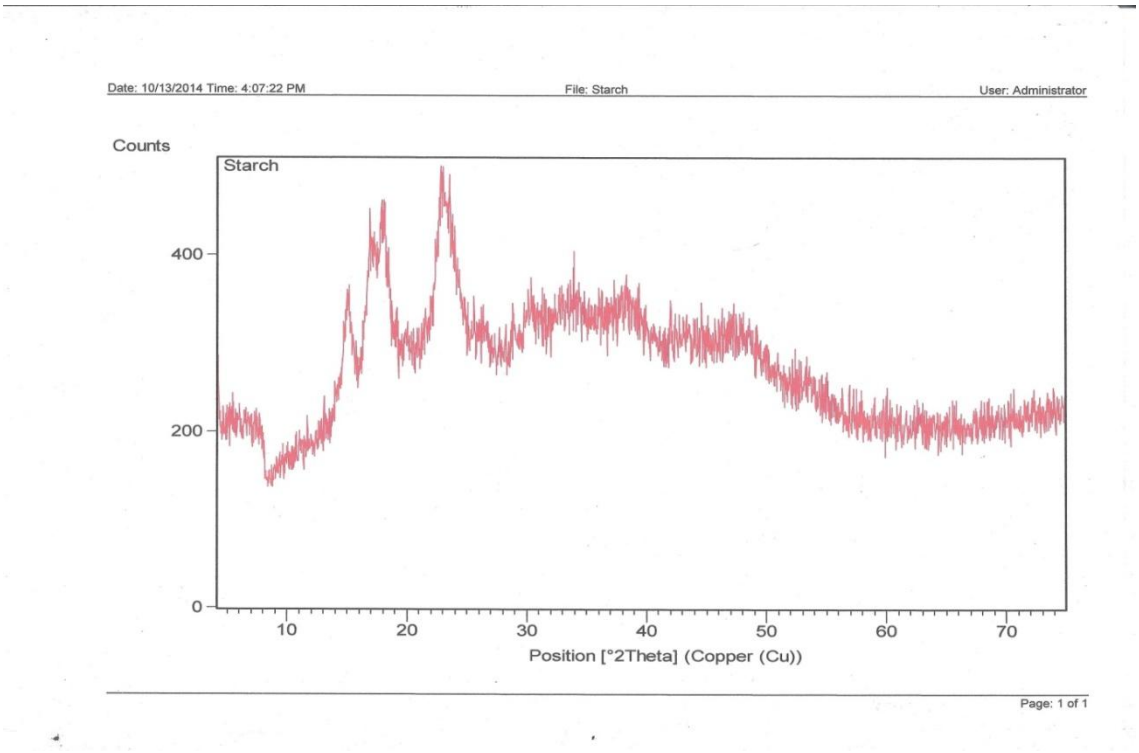

Fig 4.5: Starch Structure using X-Ray Powder Diffraction

4.6 CONSISTENCY TEST

The results of the consistency test or vicat test for setting times carried out in accordance to ASTM C494 and as described in section 3.3.1 is presented in of appendix D1. The proportions of the cassava starch in the cement paste are labeled CNT-0, CNT-1, CNT-2…, and CNT-7. Where CNT-0 implies consistency test specimen (cement paste) mix with 0% (by weight of cement) of the cassava starch, CNT-1 implies consistency test specimen (cement paste) mix with 0.5% (by weight of cement) of the cassava starch; CNT-2 implies consistency test specimen (cement paste) mix with 1% (by weight of cement) of the cassava starch etc.

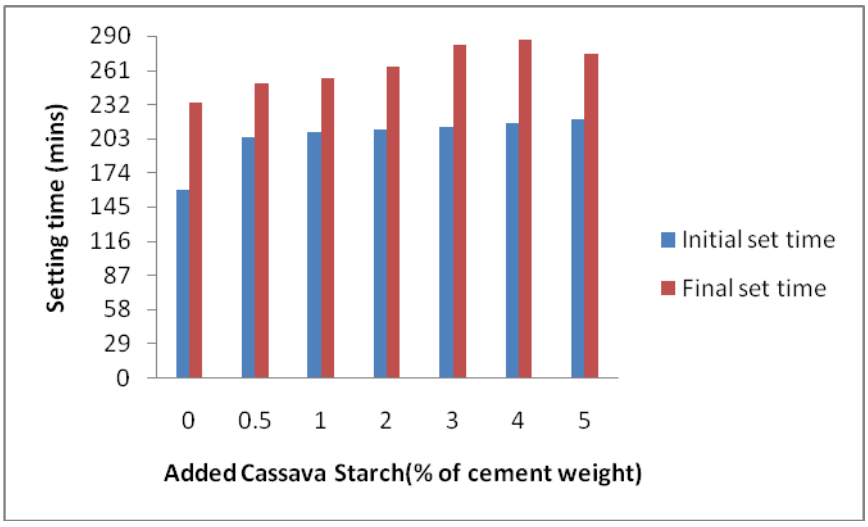

Fig 4.6: Initial and Final Setting Times of Admixed and Non Admixed Cement Paste

Fig 4.6 above shows the initial and final setting time as cassava starch is added to the cement paste mix. At 0% that is the control sample, initial and final setting times were recorded as 159 and 234 minutes respectively, comparing this value with that of the admixed cement paste, it will be observed that increase in the addition of the cassava starch

increases the setting time, the more starch is added to the paste the more delay in setting this causes, this is as a result of the starch molecule forming complexes (R - $^{-}$O – Ca^{+}- $^{-}$ OH) with the calcium ions in the solution thereby increasing their solubility and discouraging the formation of the nuclei of Calcium Hydroxide by inhibiting the growth of the Calcium and Hydroxyl ions which will not be able to precipitate, hence retardation occurs (Bazid and Muhammad, 2004).

Alternatively, the retardation may be as a result of Adsorption of the starch compound on the surface of cement particles, forming a protective skin which slows down hydration.

The retarder (starch) is believed to be finally removed from solution by being incorporated into the hydrated material without necessarily forming different complex hydrates (Young 1972).

The specifications for various chemical admixtures according to ASTM C494: 1992 and for Accelerating/Retarding Water Reducing admixtures of BS 5075:1: 1982 for initial and final setting times is shown in appendix E1 and E2 respectively.

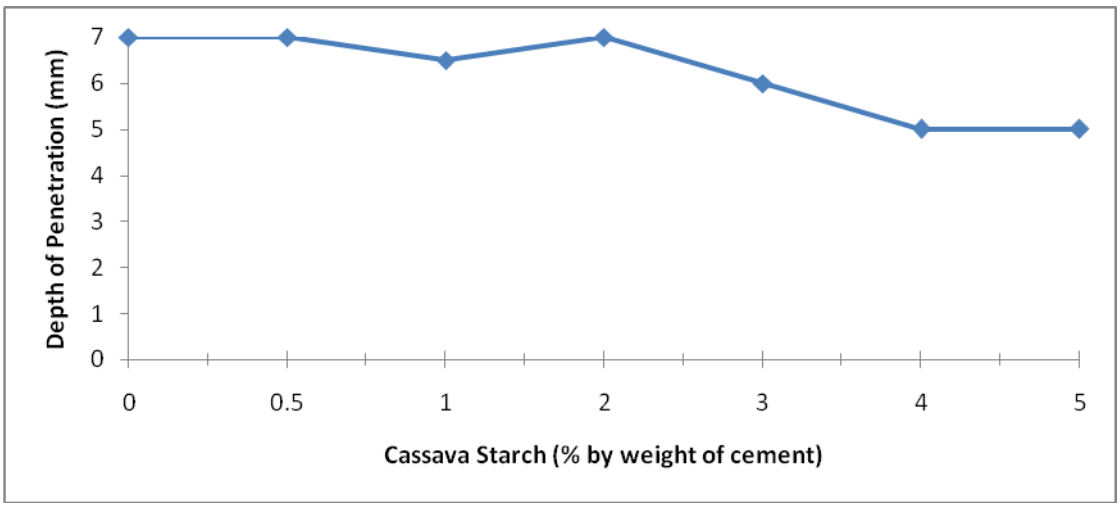

Fig 4.7: Depth of Penetration During Consistency Test.

Fig 4.7 shows the depth of penetration of the vicat plunger during the consistency test, it is noticed that the depth of penetration starts reducing after 2% starch content, this is an indication of the cement paste being stiffer as more than 2% cassava starch is being added with the same water to cement ratio. Although still within the requirements of standard consistency, the stiffness could be associated with the swelling capacity of the starch granules which tends to absorb water, hence with a constant water to cement ratio and more starch content, the granules takes in some of the water required for cement paste hydration.

4.7 WORKABILITY

The workability parameters; slump value and compaction factor of the concrete mix used are shown in appendix D2.

4.7.1 Slump Test

Figure 4.8 illustrates the slump value with respect to the cassava starch admixed with the concrete. It will be observed that as more cassava starch is added to the concrete mix with a constant water-cement ratio, the slump value starts to decrease after starch content of 1%. Consequently this results in a stiffer and less workable mix due to the increase of the surface area of the dry mix.

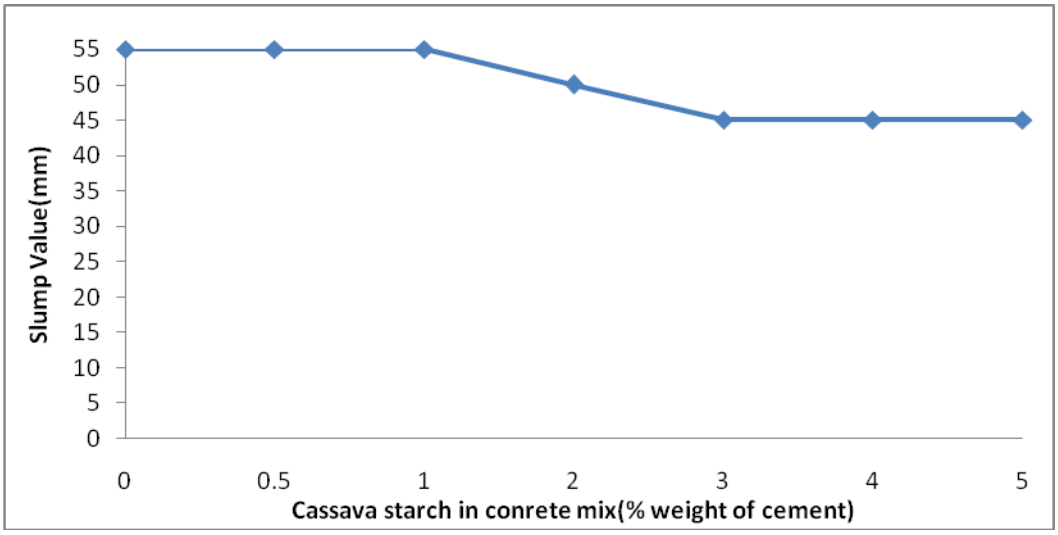

Fig 4.8: Slump Value Test for the Concrete Mix

4.7.2 Compaction Factor Test

Fig 4.9 also shows the compaction factor as the concrete mix is admixed with the cassava starch. The compaction factor or the degree of compaction is the amount of work necessary to achieve full compaction and this is measured by the density ratio that is the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

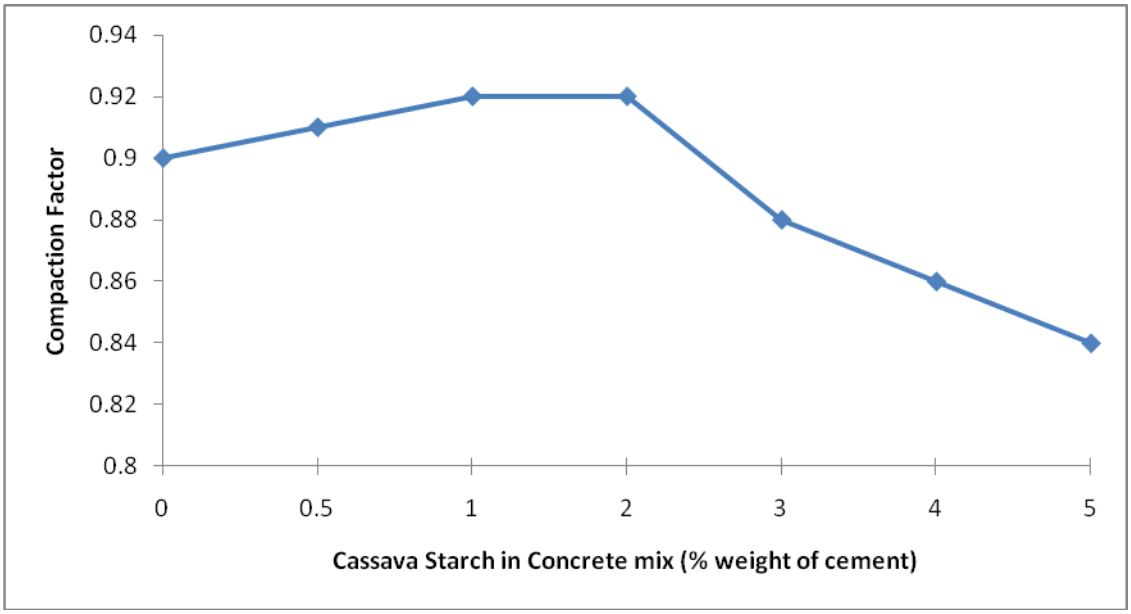

Fig 4.9: Compaction Factor for the Concrete Mix

From the figure 4.9, it will be observed that at cassava starch proportions of 0.5, 1 and 2% additions to the mix, an increase in compaction factor occurs. However, as more cassava starch is added to the mix the less the compaction factor becomes which indicates that the more starch in the mix the less dense the concrete mix becomes, hence more work is required for instance concrete specimen 'CON 5 or 6' than it is required for 'CON 1 or 2'. Unlike the slump test, the variations in the workability of dry concrete mix are reflected in a large change in the compaction factor that is the test is more sensitive at the low workability end of the scale than at high workability. However, very dry mixes tend to stick to one or both hoppers and the material has to be eased gently by poking with a steel rod which implies that the assumption that all mixes with the same compaction factor require the same amount of useful work is not always justified. Appendix E3 shows the degree of workability, slump and compaction factor of concrete mix with size of aggregate within 19mm to 38mm and the suitable uses of such concrete mixes.

4.8 COMPRESSIVE STRENGTH

Freshly prepared concrete mixture was prepared with a prescribed mix ratio of 1:2:4 and water cement ratio of 0.50 for both the control (concrete specimen without the cassava starch) and test specimen (concrete specimen with the various starch concentrations). Starch concentrations of 0, 0.5, 1, 2, 3, 4 and 5 % of weight of cement in concrete mixture were added in the concrete mix. The prepared test specimen were labeled CON-0, CON-1, CON-2 …and CON-6, where CON-0 implies concrete test specimen mix with 0% (by weight of the cement in the concrete mix) of the cassava starch, where COT-1 implies concrete test specimen mix with 0.5% (by weight of the cement in the concrete mix) of the cassava starch etc . The compressive strength of the concrete cubes was determined as described in chapter 3 section 3.6 and the results obtained are tabulated of appendix D5 to D11. Appendix D12 shows an average of the compressive test results obtained.

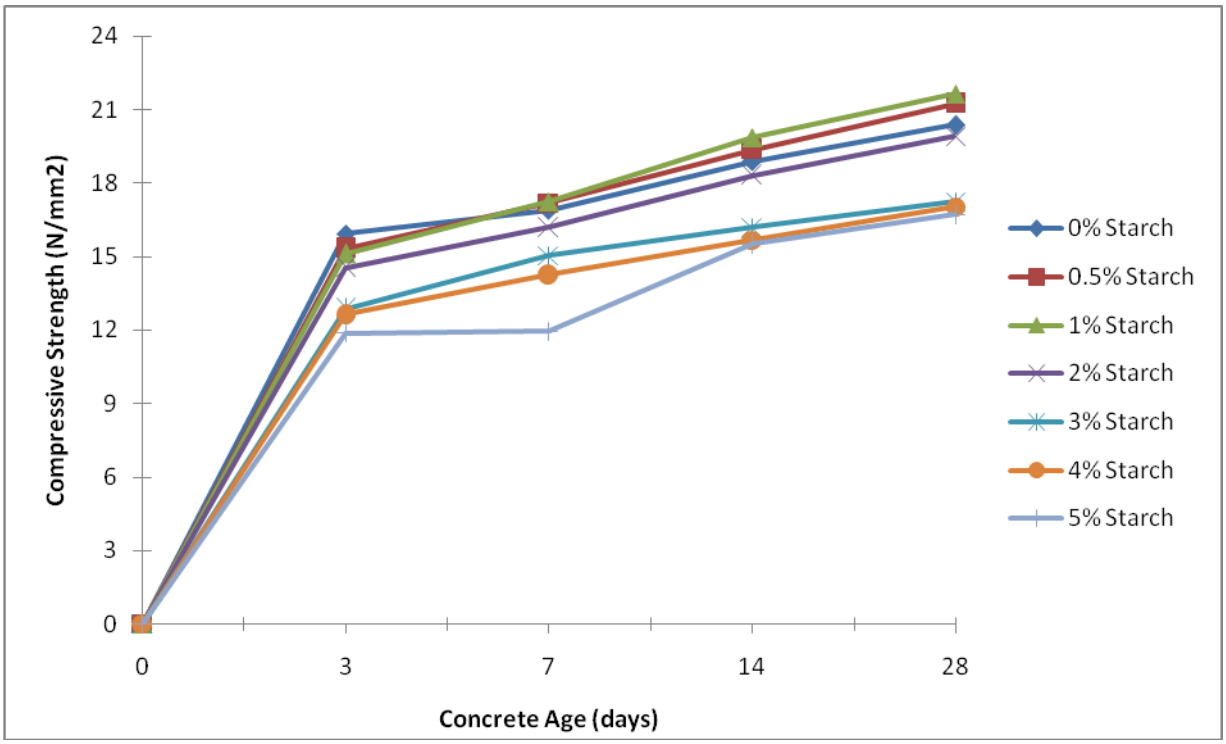

Fig 4.10: Compressive Strength Test for the Concrete Mixes

Figure 4.10 illustrates the effects of the cassava starch on the compressive strength of the concrete mix. It will be observed that concrete test specimens CON 1 and CON 2 (0.5% and 1%) exhibit increasing compressive strength compared to the control sample (CON 0) except at 3 days. Maximum compressive strength value of 21.63N/mm^2 at 28 days was recorded at concrete specimen CON 2; about 6% gain in strength compared to the control sample.

The major factor contributing to the higher strength development is improved degree of compaction achieved by the addition of cassava starch in concrete. Other factors may include the effect of dispersion of cement particles, high degree of polymerization of the cassava starch thereby resulting to a greater binding force of the starch and cement complex (Swinkels, 1985) and the formation of denser gel (increased viscosity) due to

delayed setting as also may be observed from the density test results (Neville and Brooks, 1994).

However, as a result of an increase in the starch to cement ratio, compressive strengths beyond CON 2 shows significant strength loss compared to the control sample due to the biodegradable nature of starch (Abilash and Sivapragash, 2013) and possibly due to the prolonged retarding action of the cassava starch high dosage levels.

In addition, a close look at the strength gain from 3 days to 7 days, 7 days to 14 days and 14 days to 28 days for concrete samples CON 1, CON 2 and CON 3 shows an increase in strength gain when compared to the control sample (CON 0) with the highest values recorded as 15% at 7 days to 14 days for concrete sample CON 2; concrete with 1% starch content, while samples CON 4, CON 5 and CON 6 shows strength gain values lower than the control sample.

Strength gain between 7 to 14 days at 5% starch content indicates a value of 30%. This may be regarded as an "Outlier" because it exceeds the Upper Outer Fence of the data. An *outlier* is an observation that lies an abnormal distance from other values in a random sample from a population. Appendix D13 and figure 4.11 shows the strength gain from consecutive or preceding test ages.

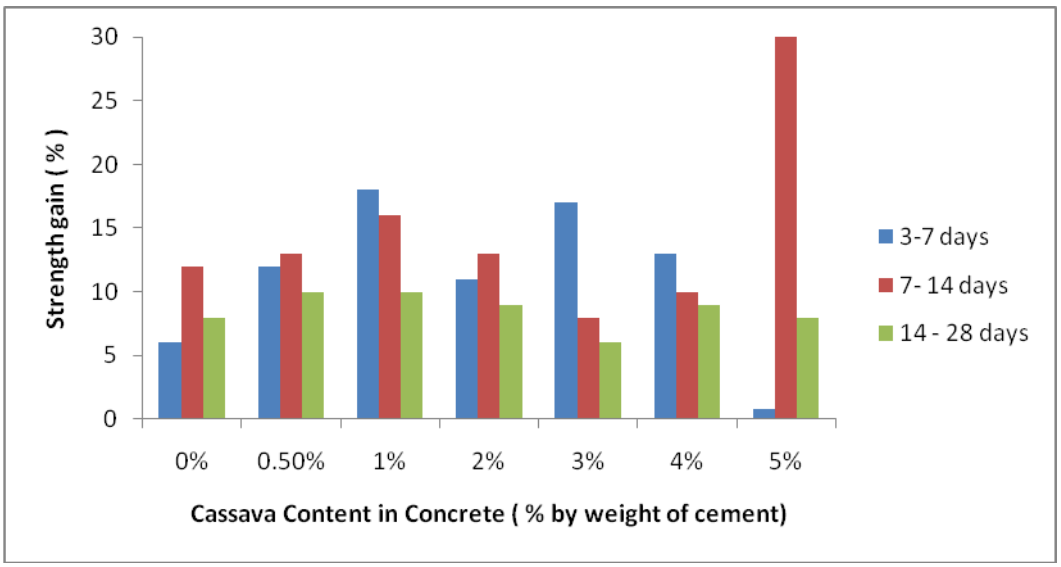

Fig 4.11: Compressive strength gain from preceding test ages

According to ASTM C494: 1992, the compressive test of concrete containing retarding admixtures (Type B) will have a minimum of 90% of the control value at any test age. Table 4.7 tabulates each compressive strength value expressed as a percentage of the control sample. Appendix E1 shows the specification for various types of admixtures according to ASTM C494- 1992.

Table 4.7: Compressive strength result expressed as percentage of control sample

Mix No	Starch content present (% by weight of cement)	Strength at 3days (% of control)	Strength at 7days (% of control)	Strength at 14days (% of control)	Strength at 28days (% of control)
CON-1	0.5	96	101	103	104
CON-2	1	95	102	105	106
CON-3	2	91	96	97	98

CON-4	3	81	89	86	85
CON-5	4	79	84	83	84
CON-6	5	74	71	82	82

The Table 4.7 shows that at 28 days, the concrete test specimen CON 1, CON 2 and CON 3 have percentage values higher than the required minimum of 90% for retarding admixtures at all test ages. Concrete test specimen CON 4, CON 5 and CON 6 however have percentage values lower than the required minimum for retarding admixtures and all other types of admixtures.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Based on the results of the findings in this research work, the following conclusions are drawn:

1. The cement used in this research work conforms to the relevant specifications for Ordinary Portland Cement (OPC) and good for concrete works. The Fine and Coarse aggregates used also conform to the respective specifications for aggregates.
2. The X- ray diffraction test characterizes the starch material as an organic polymer with an Amylose content of 18% and Amylopectin content of 82%.
3. The depth of penetration in the consistency test reduced relatively from 7mm to 5mm as cassava starch content was increased from 0% to 5% (by weight of cement) while the initial setting time at 0% starch content increased from 159 minutes to 219 minutes at 5% starch content and the final setting time increased from 234minutes at 0% to 275 minutes at 5% starch content. Hence, the admixed cement paste exhibited setting time retardation.
4. The workability of the concrete shows that slump value remains constant from 0% starch content at 55mm starts to decrease after 1% starch content.

5. The compaction factor increases at 0.5, 1 and 2 percent starch content with the highest value recorded as 0.92 at 1% and 2% starch contents, therefore workability in terms of compaction is increased up to 2% starch content.
6. 28 days compressive strength values obtained at 0% starch content was 20.37N/mm^2 and this was increased to 21.63N/mm^2 at 1% cassava starch content, which is about 6% more than the control sample.
7. 3 days strength of admixed concrete specimen is reduced at all starch percent contents. At 0.5, 1, and 2% starch content, strength gain from preceding test ages increases more than that of the control specimen; the highest value was obtained as 15% at 1% starch content from 7 to 14 days.
8. Based on the specification for admixtures in ASTM C494 (1992) and/or BS 5075-1:1982, the setting times, the compaction factor and the compressive strength for 1% starch contents conforms to properties of a retarding admixture.

5.1 RECOMMENDATION

The recommendation made as regards this research work is that cassava starch is suitable for use as a retarding admixture which can be used in concrete with an optimum limit of 1% (by weight of the cement).

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APPENDICES

Appendix A1: Chemical Comparison of Dangote Cement and Specification of Ordinary Portland cement

Chemical composition	Dangote cement (% Concentration)	BS EN 197-1:2000	ASTM C 150
Al_20_3	4.8	Max 6.3	2.5 to 6.0
SiO_2	23	Max 35	19 to 23
CaO	65.12	Max 70	61 to 67
Fe_2O_3	1.57	Max 3.0	0 to 6
K_2O	0.24	Less than 0.6	_
MgO	2.01	Max 5.0	2.4-3.8
SO_3	2.75	Max 3.5	1.5 to 4.5
TiO_2	0.16	_	_
V_2O_5	0.06	_	_
Cr_2O_3	0.038	_	_
LiO	4.05	Max 5.0	_

Appendix A2: Consistency of Cement

Sample No.	Test 1	Test 2	Test 3
	CM-01	CM-02	CM-03
Weight of sample (g)	400	400	400
Volume of water (ml)	124	120	120
Depth of penetration (mm)	7.0	7.0	7.0
Average consistency (mm)	31	30	30

Appendix A3: Initial and final setting time of Cement

	Test 1	Test 1	Test 2
Sample No.	ISET-01	ISET-02	ISET-03
Time test started	9:32 am	10:50 am	12:20 pm
Time at Initial setting	12:12 pm	1:25 pm	3:02 pm
Initial setting time (minutes)	**160**	**155**	**162**
Average(Mean) initial setting time (minutes)		**159**	
Time at Final setting	1:40 pm	2:38 pm	4:06 pm
Final setting time (minutes)	**248**	**228**	**226**
Average (Mean) final setting time (minutes)		**234**	

Appendix B1: Particle Size Analysis of Fine Aggregates

Mass of sample used (g)	Sieve No:	Sieve size (mm)	Mass retained (g)	% retained	% passing
	4	4.76	21	4.2	95.8
	8	2.36	46	9.2	86.6
	16	1.18	60	12.0	74.6
500	30	0.600	100	20.0	54.6

	50	0.300	238	47.6	7
	100	0.150	18	3.6	3.4
	200	0.075	11	2.2	1.2
		pan	6	1.2	-

Appendix B2: Moisture content of sand (fine aggregate) used

Appendix B3: % absorption by sand (fine aggregate) used

Aggregate used	**Bottle no/I.D**	**A** **Mass before drying** **(g)**	**B** **Mass after oven drying** **(g)**	**moisture content** $\frac{\text{A-B}}{\text{A}} \times 100\%$	**AVG moisture content**
Fine Aggregates (FA)	MCS-01	85	78	8.2	8.1
	MCS-02	66	60	9.1	
	MCS-03	92.5	87	7.0	

Aggregate used	**Bottle no**	**A** **Mass before drying** **(g)**	**B** **Mass after oven drying** **(g)**	**% absorption** $\frac{\text{A-B}}{\text{A}} \times 100\%$	**AVG % absorption**
Fine Aggregates	WA-01	80	79.0	1.25	1.04
	WA-02	56	55.5	0.89	

(FA)	WA-03	51	50.5	0.98	

Appendix B4: Specific Gravity result for sand

Bottle no	Weight of cylinder+ water (P) (kg)	Weight of fine aggregate (B) (Kg)	Weight of fine aggregate + water (P_s) (Kg)	Apparent specific gravity $\frac{B}{(P+B-P_S)}$	AVG S.G
SPG-01	1.59	0.500	1.9	2.63	
SPG-02	1.59	0.500	1.9	2.63	2.63
SPG-03	1.59	0.502	1.902	2.64	

Appendix B5: Bulk density of sand (fine aggregate) used.

Bottle number	Wt. of cylinder+ water (kg)	Wt. of cylinder (kg)	Volume of cylinder \(x10^{-3}) (m^3)	Wt. of cylinder+ aggregate (kg)	Wt. of aggregate (kg)	Bulk density (Kg/m^3)
BD-01	4.100	1.400	2.7	5.05	3.65	1352
BD-02	4.100	1.400	2.7	5.02	3.62	1341
BD-03	4.100	1.400	2.7	5.08	3.68	1363

Appendix C1: Sieve Analysis of Coarse Aggregate

Aggregate Sieve size	Sieve Size(mm)	Bottle no/I.D	Weight Passing (g) Mass before drying (g)	Mass retained (g) Mass after oven drying (g)	% retained A-B x 100% - A -	% moisture content Passing	AVG moisture content
	50.8		3000	-	-	100	
	38.1		3000	-	-	100	
	25.4		2785	215	7.2	92.8	
	19.05		1435	1350	45.0	47.8	
	12.7		130	1305	43.5	4.3	
	9.52		5	125	4.2	0.17	
	6.35		4	1	0.03	0.13	
	Pan		-	4	0.13	0	

Appendix C2: Moisture content of Coarse Aggregates used

Gravel	MCG-01	577.5	577	0.1	
	MCG-02	685.0	684.5	0.1	0.1
	MCG-03	600.0	599	0.17	

Appendix C3: % absorption by coarse aggregate used

Aggregate used	Bottle no	A Mass before drying (g)	B Mass after oven drying (g)	% absorption A-B x 100% A	AVG % absorption
Gravel	CA-01	725	720	0.69	
	CA-02	650	645	0.77	0.7
	CA-03	725	720	0.69	

Appendix C4: Specific Gravity for coarse aggregate used

Bottle no.	Weight of cylinder+ water (P) (kg)	Weight of fine aggregate (B) (Kg)	Weight of fine aggregate + water (P_s) (Kg)	Apparent specific gravity B (P+B-P_S)	AVG S.G
SG-07	2.5	1.0	3.15	2.85	
SG-08	2.5	1.0	3.15	2.85	2.85

SG-09	2.5	1.0	3.15	2.85

Appendix C5: Bulk Density of coarse aggregates used.

Bottle no.	Wt. of cylinder (kg)	Volume of cylinder \(x10^{-3}) (m^3)	Wt. of cylinder+aggregate (kg)	Wt. of aggregate (kg)	Bulk density (Kg/m^3)	Average bulk density (Kg/m^3)
BD-07	9.7	10	25.7	16	1600	
BD-08	9.7	10	25.0	15.5	1550	
BD-09	9.7	10	26.4	16.7	1670	1600

Appendix C6: Aggregate Impact Value test result.

Bottle no.	Initial weight (A) (kg)	Leftover weight after impact (B) (kg)	Weight passing 2.36mm sieve (C) (kg)	AIV %	Average aggregate impact value. (%)
AIV-01	500	135	97.5	26.7	
AIV-02	500	150	90	25.7	
AIV-03	500	143	93.5	26.2	26

Appendix C7: Aggregate Crushing Value Test Result.

Bottle no.	Initial weight	Leftover weight after impact	Weight passing 2.36mm sieve	ACV	Average aggregate crushing

	(A) (kg)	(B) (kg)	(C) (kg)	%	value. %
ACV-01	5000	1150	802.5	20.8	
ACV-02	5000	1100	790	20.3	
ACV-03	5000	1125	796.3	20.5	20.5

Appendix C8: Elongation index of coarse aggregate used (sample no EI-01)

Mass of material in tray (M_1) (g)	Gap between pins of length gauge (mm)	Weight passing each subdivision (g)	% passing each subdivision	Mass of fraction >5% of M_1 (M_2) (g)	Mass of all elongated particles. (M_3) (g)	Elongation index $\frac{M_3}{M_2} \times 100$
	50 - 38.1	-	-	-		
	38.1 - 25.4	173	17.3	173		
	25.4 - 19.05	573	57.3	573		
1000					104	11.87%
	19.05 - 12.7	130	13.0	130		
	12.7 - 9.52	20	2.0	-		
	9.52 - 6.25	-	-	-		

Appendix C9: Elongation index of coarse aggregate used (sample no EI-02)

Mass of material in tray (M_1) (g)	Gap between pins of length gauge (mm)	Weight passing each subdivision (g)	% passing each subdivision	Mass of fraction >5% of M_1 (M_2) (g)	Mass of all elongated particles. (M_3) (g)	Elongation index $\frac{M_3}{M_2} \times 100$
1000	50 - 38.1	-	-	-	104	11.87%
	38.1 - 25.4	173	17.3	173		
	25.4 - 19.05	573	57.3	573		
	19.05 - 12.7	130	13.0	130		
	12.7 - 9.52	20	2.0	-		
	9.52 - 6.25	-	-	-		

Appendix C10: Elongation index of coarse aggregate used (sample no EI-03)

Mass of material in tray (M_1) (g)	Gap between pins of length gauge (mm)	Weight passing each subdivision (g)	% passing each subdivision	Mass of fraction >5% of M_1 (M_2) (g)	Mass of all elongated particles. (M_3) (g)	Elongation index $\frac{M_3}{M_2} \times 100$
1000	50 - 38.1	-	-	-	104	11.87%
	38.1 - 25.4	173	17.3	173		
	25.4 - 19.05	573	57.3	573		
	19.05 - 12.7	130	13.0	130		
	12.7 - 9.52	20	2.0	-		
	9.52 - 6.25	-	-	-		

Appendix C11: Flakiness index of coarse aggregate used (sample no. FI-01)

Mass of material in tray (M_1) (g)	Width of slot in thickness gauge or special sieve (mm)	Weight passing each subdivision (g)	% passing each subdivision	Mass of fraction >5% of M_1 (M_2) (g)	Particles passing each gauge. (M_3) (g)	Flakiness index $\frac{M_3}{M_2} \times 100$
	50 - 38.1	-	-			

	38.1 - 25.4	100	10.0	100		
	25.4 - 19.05	595	59.5	595		
1000	19.05 - 12.7	150	15.0	150	105	12.43%
	12.7 - 9.52	50	5.0	-		
	9.52 - 6.25	-	-	-		

Appendix C12: Flakiness index of coarse aggregate used (sample no. FI-02)

Mass of material in tray **(M_1)** **(g)**	**Width of slot in thickness gauge or special sieve** **(mm)**	**Weight passing each subdivision** **(g)**	**% passing each subdivision**	**Mass of fraction >5% of M_1** **(M_2)** **(g)**	**Particles passing each gauge.** **(M_3)** **(g)**	**Flakiness index** $\frac{M_3}{M_2} \times 100$
	50 - 38.1	-	-			
	38.1 - 25.4	-	-			
	25.4 - 19.05	695	69.5	695		
1000	19.05 - 12.7	175	17.5	175	80	9.2%
	12.7 - 9.52	50	5.0	-		
	9.52 - 6.25	-	-	-		

Appendix C13: Flakiness index of coarse aggregate used (sample no. FI-03)

Mass of material in tray	**Width of slot in thickness gauge or special sieve**	**Weight passing each subdivision**	**% passing each**	**Mass of fraction >5% of M_1**	**Particles passing each**	**Flakiness index**

(M_1) (g)	(mm)	(g)	subdivision	(M_2) (g)	(M_3) (g)	$\frac{M_3}{M_2} \times 100$
	50 - 38.1	-	-			
	38.1 - 25.4	-	-			
	25.4 - 19.05	605	60.5	605		
1000	19.05 - 12.7	205	20.5	205		
	12.7 - 9.52	40	4.0	-	150	18.52%
	9.52 - 6.25	-	-	-		

Appendix D1: Quantities of Cement, Cassava starch (CS), initial & final setting time and consistency value in each cement paste mix.

S/NO	Mix No	% ofcassava starch (CS)	Weight of cement (grms)	Weight of cassava starch added (grms)	Total Weight of cement + starch sample(grms)	Initial setting time (mins)	Final setting time(mins)	Consistency (mm)
1	CNT-0	0	400	0	400	159	234	7
2	CNT-1	0.5	400	2	402	204	250	7
3	CNT-2	1.0	400	4	404	209	254	6.5
4	CNT-3	2.0	400	8	408	211	264	7
5	CNT-4	3.0	400	12	412	213	282	6.5
6	CNT-5	4.0	400	16	416	216	287	5
7	CNT-6	5.0	400	20	420	219	275	5

Appendix D2: Workability test result for the concrete mix

Mix No	Cassava starch content (%) by weight of the cement.	Water-cement ratio (w/c)	Compaction factor values	Slump (mm)
CON-0	0	0.50	0.90	55.00
CON-1	0.5	0.50	0.91	55.00
CON-2	1	0.50	0.92	55.00
CON-3	2	0.50	0.92	50.00
CON-4	3	0.50	0.88	45.00
CON-5	4	0.50	0.86	45.00
CON-6	5	0.50	0.84	45.00

Appendix D3: Compressive strength test result for trial mixes

Age (days)	Sample ID No.	Mass (kg)	Volume ($x 10^{-3}$) (m^3)	Density ($x 10^3$) (kg/m^3)	Slump (mm)	Failure load ($x10^3$) (N)	Actual strength (N/mm^2)	Average Compressive strength (N/mm^2)
28	TM-01	7.9	3.375	2.341	55	455	20.22	20.81
	TM-02	8.5	3.375	2.518		485	21.55	
	TM-03	8.0	3.375	2.370		465	20.66	

Appendix D4: Estimation of weight of various constituent materials by the Absolute Volume

Applying the absolute volume formulae

$$\frac{c}{1000\rho c} + \frac{w}{1000\rho w} + \frac{a}{1000\rho a} + \frac{f}{1000\rho f} = 1$$

Where
w = weight of water per m^3 of concrete

a = weight of coarse aggregate per m^3 of concrete

c = weight of cement per m^3 of concrete

f = weight of fine aggregate per m^3 of concrete

ρ_c, ρ_a, ρ_f, and ρ_w represent the specific gravities of cement, coarse aggregate, fine aggregate and water respectively.

Based on the prescribed mix ratio of 1:2:4 and water –cement ratio of 0.5, the various weights of the materials per m^3 are

$$\frac{c}{1000(3.15)} + \frac{0.5c}{1000(1)} + \frac{4c}{1000(2.85)} + \frac{2c}{1000\,(2.63)} = 1$$

The weight is given as

$$3.17\ x\ 10^{-4}c + 5.00\ x\ 10^{-4}c + 1.40\ x\ 10^{-3}c\ +\ 7.60\ x\ 10^{-3}c = 1\text{m}^3$$

Therefore cement weight per m^3 is

$2.98x\ 10^{-3}c = 1$. Hence c = 336kg
Total volume of cubes cast = volume of cubes x number of cubes per starch content x 10% waste.

0.15 x 0.15 x 0.15x 12 x 1.10 = $0.045m^3$

Scaling down weights of materials to $0.045m^3$ from $1m^3$, the weights of the various materials at 0% starch content are
Cement = 336 x 0.045= 15.12 kg

Fine Aggregates = 2 x 336 x 0.045= 30.24 kg

Coarse Aggregates = 4 x 336 x 0.045= 60.48 kg

Water = 0.5 x 336 x 0.045= 7.56 kg

The weights of the constituent materials at other starch content are presented below

S/No	Starch Content (%)	Cement weight (kg)	Fine Aggregate (kg)	Coarse Aggregates (kg)	Water (kg)	Starch Weight (g)
1	0	15.12	30.24	60.48	7.56	-
2	0.5	15.12	30.24	60.48	7.56	75.60
3	1	15.12	30.24	60.48	7.56	151.2
4	2	15.12	30.24	60.48	7.56	302.4
5	3	15.12	30.24	60.48	7.56	453.6
6	4	15.12	30.24	60.48	7.56	606.0
7	5	15.12	30.24	60.48	7.56	756.0

Appendix D5: Concrete compressive strength test results (0% Starch Content, CON-0)

Age (days)	Sample ID No.	Mass (kg)	Volume ($x10^{-3}$) (m^3)	Density ($x10^3$) (kg/m^3)	Failure 1oad ($x10^3$) (N)	Actual strength (N/mm^2)	Average compressive strength (N/mm^2)
	CS_0 (3)	8.30	3.375	2.459	355	15.77	
3	CS_0 (3)	8.00	3.375	2.370	340	15.11	15.92
	CS_0 (3)	8.20	3.375	2.430	380	16.88	
	CS_0 (7)	8.80	3.375	2.607	400	17.78	
7	CS_0 (7)	8.40	3.375	2.489	375	16.67	16.91
	CS_0 (7)	7.50	3.375	2.222	366	16.27	

	CS_0 (14)	8.20	3.375	2.430	425	18.89	
14	CS_0 (14)	8.00	3.375	2.370	420	18.67	18.89
	CS_0 (14)	8.50	3.375	2.519	430	19.11	
	CS_0 (28)	8.50	3.375	2.519	455	20.22	
28	CS_0 (28)	8.00	3.375	2.370	465	20.67	20.37
	CS_0 (28)	8.35	3.375	2.474	455	20.22	

Appendix D6: concrete compressive strength test results (0.5% Starch Content, CON-1)

Age (days)	Sample ID No.	Mass (kg)	Volume ($x10^{-3}$) (m^3)	Density ($x10^3$) (kg/m^3)	Failure 1oad ($x10^3$) (N)	Actual strength (N/mm^2)	Average compressive strength (N/mm^2)
	$CS_{0.5}$ (3)	8.50	3.375	2.519	355	15.78	
3	$CS_{0.5}$ (3)	8.40	3.375	2.488	335	14.89	15.33
	$CS_{0.5}$ (3)	8.20	3.375	2.430	345	15.33	
	$CS_{0.5}$ (7)	8.30	3.375	2.459	385	17.11	
7	$CS_{0.5}$ (7)	8.40	3.375	2.488	392	17.42	17.19
	$CS_{0.5}$ (7)	8.20	3.375	2.430	384	17.06	
	$CS_{0.5}$ (14)	8.00	3.375	2.370	435	19.33	
14	$CS_{0.5}$ (14)	8.20	3.375	2.430	438	19.46	19.37
	$CS_{0.5}$ (14)	8.00	3.375	2.370	435	19.33	
	$CS_{0.5}$ (28)	8.50	3.375	2.518	480	21.33	
28	$CS_{0.5}$ (28)	8.50	3.375	2.518	495	22.00	21.24
	$CS_{0.5}$ (28)	8.00	3.375	2.370	460	20.44	

Appendix D7: concrete compressive strength test results (1% Starch Content, CON-2)

Age (days)	Sample ID No.	Mass (kg)	Volume ($x10^{-3}$) (m^3)	Density ($x10^3$) (kg/m^3)	Failure 1oad ($x10^3$) (N)	Actual strength (N/mm^2)	Average compressive strength (N/mm^2)
	CS_1 (3)	8.00	3.375	2.370	340	15.11	
3	CS_1 (3)	8.00	3.375	2.370	340	15.11	15.11
	CS_1 (3)	8.20	3.375	2.430	340	15.11	
	CS_1 (7)	8.30	3.375	2.459	384	17.06	
7	CS_1 (7)	8.40	3.375	2.488	395	17.56	17.24
	CS_1 (7)	8.20	3.375	2.430	385	17.11	
	CS_1 (14)	8.45	3.375	2.504	448	19.91	
14	CS_1 (14)	8.40	3.375	2.490	448	19.91	19.85
	CS_1 (14)	8.40	3.375	2.490	444	19.73	
	CS_1 (28)	8.35	3.375	2.474	488	21.69	
28	CS_1 (28)	8.20	3.375	2.430	484	21.51	21.63
	CS_1 (28)	8.50	3.375	2.519	488	21.69	

Appendix D8: concrete compressive strength test results (2% Starch Content, CON-3)

Age (days)	Sample ID No.	Mass (kg)	Volume ($x10^{-3}$) (m^3)	Density ($x10^3$) (kg/m^3)	Failure 1oad ($x10^3$) (N)	Actual strength (N/mm^2)	Average compressive strength (N/mm^2)
	CS_2 (3)	8.00	3.375	2.370	328	14.58	

3	CS_2 (3)	8.00	3.375	2.370	324	14.40	14.55
	CS_2 (3)	7.80	3.375	2.311	330	14.67	
	CS_2 (7)	8.20	3.375	2.430	364	16.18	
7	CS_2 (7)	8.30	3.375	2.459	362	16.08	16.18
	CS_2 (7)	8.30	3.375	2.459	366	16.27	
	CS_2 (14)	8.30	3.375	2.459	410	18.22	
14	CS_2 (14)	8.30	3.375	2.459	415	18.44	18.32
	CS_2 (14)	8.30	3.375	2.459	412	18.31	
	CS_2 (28)	8.40	3.375	2.488	445	19.78	
28	CS_2 (28)	8.60	3.375	2.548	448	19.91	19.92
	CS_2 (28)	8.50	3.375	2.519	452	20.08	

Age	**Sample ID No.**	**Mass**	**Volume**	**Density**	**Failure 1oad**	**Actual strength**	**Average compressive strength**
(days)		**(kg)**	**(x10 $^{-3}$) (m^3)**	**(x10^3) (kg/m^3)**	**(x10^3) (N)**	**(N/mm^2)**	**(N/mm^2)**
	CS_3 (3)	7.50	3.375	2.222	285	12.67	
3	CS_3 (3)	7.80	3.375	2.311	292	12.97	12.87
	CS_3 (3)	7.60	3.375	2.252	292	12.97	
	CS_3 (7)	8.00	3.375	2.370	340	15.11	
7	CS_3 (7)	8.00	3.375	2.370	340	15.11	15.05
	CS_3 (7)	7.90	3.375	2.341	336	14.93	

	$CS_3(14)$	8.30	3.375	2.459	365	16.22	
14	$CS_3(14)$	8.20	3.375	2.430	364	16.17	16.20
	$CS_3(14)$	8.40	3.375	2.488	365	16.22	
	$CS_3(28)$	8.20	3.375	2.430	390	17.33	
28	$CS_3(28)$	8.20	3.375	2.430	386	17.15	17.24
	$CS_3(28)$	8.20	3.375	2.430	388	17.24	

Appendix D9: concrete compressive strength test results (3% Starch Content, CON-4)

Appendix D10: Concrete Compressive strength test results (4% Starch Content, CON-5)

Age	**Sample ID No.**	**Mass**	**Volume**	**Density**	**Failure 1oad**	**Actual strength**	**Average compressive strength**
(days)		**(kg)**	**($x10^{-3}$ m^3)**	**($x10^3$ kg/m^3)**	**($x10^3$ N)**	**(N/mm^2)**	**(N/mm^2)**
	$CS_4(3)$	7.50	3.375	2.222	285	12.67	
3	$CS_4(3)$	7.50	3.375	2.222	272	12.08	12.62
	$CS_4(3)$	7.80	3.375	2.311	296	13.15	
	$CS_4(7)$	7.90	3.375	2.341	322	14.31	
7	$CS_4(7)$	8.00	3.375	2.370	315	14.00	14.24
	$CS_4(7)$	8.00	3.375	2.370	324	14.40	
	$CS_4(14)$	7.90	3.375	2.341	352	15.64	
14	$CS_4(14)$	8.20	3.375	2.430	355	15.78	15.66
	$CS_4(14)$	8.20	3.375	2.430	350	15.56	
	$CS_4(28)$	8.00	3.375	2.370	385	17.11	
28	$CS_4(28)$	8.20	3.375	2.430	390	17.33	17.04
	$CS_4(28)$	8.00	3.375	2.370	375	16.67	

Appendix D11: concrete compressive strength test results (5% Starch Content, CON-6)

Age (days)	Sample ID No.	Mass (kg)	Volume ($x10^{-3}$) (m^3)	Density ($x10^3$) (kg/m^3)	Failure 1oad ($x10^3$) (N)	Actual strength (N/mm^2)	Average compressive strength (N/mm^2)
	CS_5 (3)	7.50	3.375	2.222	268	11.91	
3	CS_5 (3)	7.50	3.375	2.222	268	11.91	11.86
	CS_5 (3)	7.50	3.375	2.222	265	11.77	
	CS_5 (7)	7.30	3.375	2.162	255	11.33	
7	CS_5 (7)	7.40	3.375	2.193	252	11.20	11.96
	CS_5 (7)	7.70	3.375	2.281	300	13.33	
	CS_5 (14)	8.20	3.375	2.430	350	15.56	
14	CS_5 (14)	8.00	3.375	2.370	346	15.38	15.50
	CS_5 (14)	8.40	3.375	2.488	350	15.56	
	CS_5 (28)	8.30	3.375	2.459	384	17.06	
28	CS_5 (28)	7.90	3.375	2.341	365	16.22	16.72
	CS_5 (28)	8.30	3.375	2.459	380	16.89	

Appendix D12: Compressive strength result for concrete

Mix No	Starch content present (% of weight of cement)	Strength at 3days (N/mm^2)	Strength at 7days (N/mm^2)	Strength at 14days (N/mm^2)	Strength at 28days (N/mm^2)

CON-0	0	15.92	16.91	18.89	20.37
CON-1	0.5	15.33	17.19	19.37	21.24
CON-2	1	15.11	17.79	20.57	22.63
CON-3	2	14.55	16.18	18.32	19.92
CON-4	3	12.87	15.05	16.20	17.24
CON-5	4	12.62	14.24	15.66	17.04
CON-6	5	11.86	11.96	15.50	16.72

(Each value is an average of three test results.)

Appendix D13: Strength gain from preceding test ages

Mix No	Starch content present (% of weight of cement)	Strength gain from 3 to 7 days (%)	Strength gain from 7 to 14 days (%)	Strength gain from 14 to 28 days (%)
CON-0	0	6	12	8
CON-1	0.5	12	13	10
CON-2	1	18	16	10
CON-3	2	11	13	9
CON-4	3	17	8	6
CON-5	4	13	10	9
CON-6	5	0.84	30	8

ApppendixE1: Specification for various types of Admixtures according to ASTM C494-1992.

`	Type A	Type B	Type C	Type D	Type E	Type F	Type G
Water Content, max % of Control	95			95	95	88	88
Time of Setting, allowable deviation from control,(Min)							
Initial : at least	-	60 later	60 earlier	60 later	60 earlier	-	60 later
: Not more than	60 earlier	210 later	210 earlier	210 later	210 earlier	60 earlier	210 later
Final : at least	-	-	60 earlier	-	60 earlier	-	-
:Not more than	60 earlier	210 later	-	210 later	-	60 earlier	210 later
Compressive Strength, (Min % of Control)							
1 day						140	125
3 days	110	90	125	110	125	125	125
7 days	110	90	100	110	110	115	115
28 days	110	90	100	110	110	110	110
6 months	100	90	90	100	100	100	100
1 year	100	90	90	100	100	100	100
Flexural Strength, (Min % of Control)[a]							
3 days	100	90	110	100	110	110	110
7 days	100	90	100	100	100	100	100
28 days	100	90	90	100	100	100	100
Length change Max Shrinkage (alternative requirements).[b]							
% of Control	135	135	135	135	135	135	135

Increase over Control	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Relative durability factor ,(Min)[c]	80	80	80	80	80	80	80

Note : Type A (Water reducing), Type B (Retarding), Type C (Accelerating), Type D (Water reducing and retarding), Type E (Water reducing and Accelerating), Type F (Water reducing high range) and Type G (Water reducing, high range and retarding)

[a] The compressive and flexural strength of the concrete containing the admixture under test at any test age shall be not less than 90 percent of that attained at any previous test age. The objective of this limit is to require that the compressive or flexural strength of the concrete containing the admixture does not decrease with age.

[b.] Alternative requirements, percent of control limit applies when length change of control is 0.030 per cent or greater; increase over control limit applies when length change of control is less than 0.030 percent

[c] This requirement is applicable only when the admixture is to be used in air – entrained concrete which may be exposed to freezing and thawing while wet.

Appendix E2: Specification for Retarding/Accelerating and Water Reducing Retarding/Accelerating Admixtures according to BS 5075: Pt 1- 1982.

Type of Admixture	**Water Reduction, %**	**Compacting Factor**	**Stiffening time** **Time from completion of mixing to reach a resistance to penetration of**		**Compressive Strength**	
			0.5MPa	**3.5MPa**	**Min % of Control mix**	**Age**
Accelerating	-	Not more than 0.02 below control mix	More than 1 hour	At least 1 hour less than control mix	125 95	24hrs 28 days
	8	-	-	-	-	-
Retarding	-	Not more than 0.02 below control mix	At least 1 hour longer than control mix	-	90 95	7 days 28 days
	8	-	-	-	-	-

Normal Water Reducing	-	At least 0.03 above control mix	-	-	90 90	7 days 28 days
	8	Not more than 0.02 below control mix	Within 1 hr of control mix	Within 1 hr of control mix	110 110	7 days 28 days
Accelerating Water Reducing	-	At least 0.03 above control mix	-	-	125 90	24 hrs 28 days
	8	Not more than 0.02 below control mix	More than 1 hour	At least 1 hour less than control mix	125 110	24 hrs 28 days
Retarding Water Reducing	-	At least 0.03 above control mix	-	-	90 90	7 days 28 days
	8	Not more than 0.02 below control mix	At least 1 hr longer than control mix	-	110 110	7 days 28 days

Appendix E3: Workability, Slump and Compacting factor of concrete with 19 or 38 mm maximum size of aggregates.

Degree of workability	Slump		Compacting factor	Use for which concrete is suitable
	mm	In.		
Very low	0 – 25	0 - 1	0.78	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand- operated machines.
Low	25 – 50	1 - 2	0.85	Roads vibrated by Hand-operated machines. At the

				more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	50 – 100	2 - 4	0.92	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibrations.
High	100 – 175	4 - 7	0.95	For sections with congested reinforcement. Not normally suitable for vibration.

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