ASSESSMENT OF EFFECTS OF SUGAR CANE MILL (SCM) AS AN ADMIXTURE ON THE PROPERTIES OF CONCRETE

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BY

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SPS/12/MCE/00013

A DISSERTAION SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, BAYERO UNIVERSITY, KANO. IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWADRD OF MASTER DEGREE IN CIVIL ENGINEERING (STRUCTURAL ENGINEERING)

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DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Engr. Dr. M.O.A Mtallib and has not been presented anywhere for the award of a degree or certificate. All sources have been duly acknowledged.

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MURTALA SANI Date

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write-up (MURTALA SANI; SPS/12/MCE/00013) were carried out under our supervision

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This dissertation has been examined and approved for the award of Master Degree in Civil Engineering (Structural Engineering).

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DEDICATION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This research work assesses the possibility of using sugar cane mill (SCM), from sugar cane waste as an admixture in concrete. Sugar cane waste was obtained from mashi local government market, katsina state and from the local sugar cane sellers in the area, prepared (cut to small pieces, air dried and pounded to mill) and were sieved using a local sieve. The mill was sieved with 75 µm BS sieve. The percentages of SCM used are 0.0%, 0.025%, 0.05%, 0.075%, 0.1%, 0.125%, 0.15% and 0.175%. Three (3) specimens were cast for each percentage of SCM at curing periods of 7, 14, 28 and 56 days. A total of 96 cubes and 96 cylinder specimens of SCM-Concrete cast and tested for both compressive and split tensile strengths respectively. The results showed that, the slump (workability) of the concrete increased with increased in SCM content and SCM delays the setting time of cement, while compressive and split tensile strengths also increased with increase in the mill content until at 0.075% of SCM, while it decreased with the increased in the SCM for the remaining percentages. The compressive strength of 44 N/mm^2 against the control of 35.7 N/mm^2 at 28 days of curing for a designed grade 30 concrete was obtained. The strengths also further increased at 56 days of curing i.e. 46.97 N/mm^2 against the control of 41.78 N/mm^2, both for 0.075% of SCM. It was recommended that, SCM is a good admixture and up to 0.075% of SCM (for strengths beyond the control) could be used as an admixture in concrete. Therefore it can also be used as a retarding admixture or a plasticizer as it increased the slump of the concrete significantly with a little or negligible increased in water.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical and chemical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties of the finished material (Zongjin, 2011).

Concrete when fresh, can be moulded into any desired shape and will develop strength to carry different loadings when hardened. This unique characteristic advantage of concrete made it to be the preferred material for application in the construction industry. The cement component, as a constituent of concrete is the main binder in translating the fresh concrete into a rigid strong concrete, (Pontip, 2013). Admixtures can therefore be used to modify one or more of its properties in its fresh or harden state, taking into consideration, its short and long term effect on the concrete.

Admixtures are materials other than the main constituents of concrete (cement, aggregates and water), used as an ingredients in a cementitious mixture to modify the properties of the concrete, such as setting characteristics, strength and durability; added to the batch before or during mixing (ACIE 4 – 03, 2004). It ranges from purposed designed chemicals or materials (solid or liquid), to waste materials for which an out let is sought (Afolayan, 1997). According to Neville (1997), majority of admixtures used in concrete are primarily on the basis of experience or ad-hoc test. Therefore, their performance is determined by using control concrete mixture. The use of admixtures (chemicals or mineral), polymers and adhesives added to the concrete during mixing are some of ways of modifying or improving the properties of concrete (Mamlouk and Zniewski, 2006).

Quick setting and strength gain are the properties that make Portland cement a desirable binder in the construction industry. These properties are so important that hydration, the process during which they occur, and factors affecting it have been extensively studied over the years. One of these factors, sugar, has been found to delay the setting of cement hydration. The agreement about that has led investigators to all have the same routine.

Recently, a variety of alternative building materials are available. The use of these new materials may provide better, efficient, durable and cost-effective construction-material resources with reduced degradation of environment. Some of the materials are manufactured by using waste materials, such as fly ash (by-product of burning coal), or agricultural waste ash as the raw material for their production (Mohamed and Samah, 2011). Due to limited availability of natural resources and rapid urbanisation, there is a shortfall of conventional construction materials. On the other hand, energy consumed for the production of conventional construction materials pollutes the air, water and land. Accumulation of unmanaged agro waste, especially from the developing countries, has an increased environmental concern. Therefore, development of new technologies to recycle and convert waste materials into reusable materials is important for the protection of the environment and sustainable development of the society (Mangesh, 2014).

With increasing demand and consumption of cement, researchers and scientist are in search of developing alternate binders that are eco-friendly and contribute towards waste management. The utilisation of industrial and agricultural waste produced by industrial processes has been the focus on waste reduction (Kawade *et al.*, 2013). Therefore many agricultural wastes have been investigated to check their effects on concrete. Such as saw dust ash, bagasse ash among others. So also in this research, sugarcane mill (peels, joints and ratoon) is to be investigated to determine its effects on cement and concrete.

1.2 BACKGROUND OF THE RESEARCH

Concrete performs and or behaves differently in unpredictable circumstances such as hot or cold weather, under water concreting, climate and site conditions and delays in placing fresh concrete. This becomes a serious or major challenge facing the concrete users. The use of admixtures or additives in concrete found to be effective in handling such related challenges. Yet, some of the materials usually used as admixture or additives found to be expensive or not readily available, depending on the nature and location of the work or the site. Also, literature has shown that, sugar has been found to delay the setting of cement hydration (retarder). Hence, found to be useful in concreting under hot temperatures in preventing pre-matured hardening of concrete before placing.

Most admixtures behaving as retarders have been found to be sugar related, for example lignin, borax, sugar, tartaric acid, and salt. Since sugar cane has a lot of sugar content it is worthwhile investigating whether sugar cane mill follow this trend. Therefore, the effect of locally available material, sugar cane mill, as an admixture will be checked on the properties of concrete. Retarders can be useful when concreting in hot weather, when the normal setting time of concrete is shortened by the higher ambient temperature. Sugar is used in producing retarders (Akogu, 2011). Commercial lignosulfonates used in admixture formulations are predominantly calcium-sodium based with sugar content of 1-30%. Molasses (sugar) as a retarder has been used in the England- France channel construction in the early 1990s to prevent the setting of residual concrete since washing out underground was no possible (Neville 1997; Akogu, 2011).

1.3 STATEMENT OF THE RESEARCH PROBLEM

Indiscriminate disposal of waste in dumpsites located within urban areas has proved to be a problem to nearby residents in most developing cities of the world, (Foday *et al.*, 2013). Open dump of solid waste is a common practice in Nigeria. While some employ the service of streams to transport their solid wastes out of their sight, some directly dump their solid wastes by the road sides. Mountains of mixed solid wastes in so-called designated places are set on fire, causing serious and dangerous environmental pollution, (Babayemi and Dauda, 2009). Similarly, the total world production of sugarcane rises to about 1, 877, 105 thousand metric tons, (TMT) (crop production, 2015). This large world's sugarcane production figure will in turn generates significant sugar cane waste worldwide, will poses great nuisance to environment. Utilisation of industrial and agricultural waste in the industry has been the focus of researches for economical, environmental and technical reasons; and also on waste reduction, (Shivakumar *et al*., 2014; Kawade *et al.*, 2013).

1.4 JUSTIFICATION OF THE RESEARCH

This research will help to reduce dumping of sugar cane waste if it is found that sugar cane mill (SCM) can effectively be used in concrete. This leads to an overall environmental improvement in terms of sanitation. Sugar cane mill if found to be useful in concrete could create the possibility of converting waste to wealth, and create an avenue for a cheap admixture in concrete.

1.5 AIM AND OBJECTIVES

1.5.1 Aim: To assess the possibility of using SCM in concrete with a view of finding a profitable means of disposing sugar cane waste.

1.5.2 Objectives: The objectives of this research are as follows:

(1) To determine the physical properties of the constituents of concrete.

(2) To determine the consistency and setting time the Cement-SCM paste.

(3) To determine the compressive and splitting tensile strengths of concrete containing SCM at various percentages.

1.6 SCOPES AND LIMITATION OF THE RESEARCH

1.6.1 Scope of the Research:

The percentages of SCM are 0%, 0.025%, 0.05%, 0.075%, 0.1%, 0.125%, 0.15% and 0.175%. This is as a result of various trial cubes cast which all dissolved in water during curing. The 0.15% and 0.175% also dissolved, but survived with two days of casting before demoulding. The curing ages are 3, 7, 28 and 56 days. Concrete cubes and cylindrical specimens with various concentrations of the mill will be casted and tested at each of the above mentioned curing periods. Therefore, this in line with (Akogu, 2011), Effects of sugar at concentrations of 0, 0.05, 0.06, 0.08, 0.10, 0.20, 0.40, 0.60, 0.80 and 1% by weight of cement on cement paste and grade C35 concrete cured at 3, 7, 14 and 28 days was investigated using ordinary Portland cement in the laboratory. The optimum was recorded at 0.06% with 42.36 N/mm^2 while 17.40 N/mm^2 at 1% was recorded, both at 28 days of curing.

1.6.2 Limitations of the Research:

This research is limited to the assessment of the effects of SCM on setting time of cement paste, workability, compressive and splitting tensile strengths. The maximum percentage of SCM was limited to 0.175% with maximum curing age of 56 days.

1.7 SIGNIFICANCE OF THE STUDY

Bagasse ash obtained from sugar cane waste, have been found to be useful additive in soil. Sugar cane mill which can also be obtained from sugar cane waste could as well be found useful in concrete. Furthermore, this will help to boost sugarcane farming, not only in Nigeria, but in the world in general. In Nigeria, the research will be very relevant in line with the mandate to boost sugarcane farming by the Federal Government of Nigeria, (Hassan, 2012).

1.8 CONTRIBUTION TO KNOWLEDGE

1. This study will widen the knowledge on the area of application of sugar cane waste in construction.
2. This study will increase the knowledge on conversion of waste to wealth.
3. This study could add to the existing admixtures in concrete.

CHAPTER TWO

LITERATURE REVIEW

2.1 CONCRETE IN GENERAL

Concrete is a “composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate, usually a combination of fine aggregate and coarse aggregate. In Portland-cement concrete, the binder is a mixture of Portland cement and water, with or without admixtures. Concrete is one of the most versatile, economical, and universally used construction material. It is among the few building materials produced directly on the job by the user. To know proper concrete mix, it is important for the user to identify the desirable properties and components, and to be able to use other considerations involved in producing concrete and the methods employed in concrete production, (Strategic Development Council; SDC, 2008).

2.1.1 Concrete Composition

Concrete is a mixture of aggregates held together by a hardened paste of cement and water. Although there are other kinds of cement, the word cement in common usage refers to Portland cement. A chemical reaction between the Portland cement and water, not drying of the mixture, causes concrete to harden to a stone like condition. This reaction is called hydration. Hydration gives off heat, known as the heat of hydration. When correctly proportioned, concrete is at first a plastic mass that can be cast or molded into nearly any size or shape. Upon hydration of the cement by the water, concrete becomes stone like in strength, durability, and hardness (Army Institute for Professional Development; AIPD, 1992).

2.1.2 Concrete as a Construction Material

Concrete has a great variety of applications because it not only meets structural demands but also lends itself readily to architectural treatment. In buildings, concrete is used for footings, foundations, columns, beams, girders, wall slabs, and roof units and all important building elements. Other important concrete applications are in road pavements, airport runways, bridges, dams, irrigation canals, water-diversion structures, sewage-treatment plants, and water-distribution pipelines. A great deal of concrete is used in manufacturing masonry units, such as concrete blocks and concrete bricks (Army Institute for Professional Development; AIPD, 1992).

2.1.3 Advantages of Concrete

Concrete and cement are among the most important construction materials. Concrete is fire proof, comparatively economical, and easy to make. It offers surface continuity (absence of joints) and solidity and bond with many other materials, (AIPD, 1992).

2.1.4 Limitations of Concrete

Certain limitations of concrete cause cracking and other structural weaknesses that affects the appearance, serviceability, and useful life of concrete structures (AIPD, 1992). Listed below are some principal limitations and disadvantages of concrete; Low tensile strength; Concrete members subject to tensile stress must be reinforced with steel (rebar) to prevent excess cracking and failure. Thermal movements; during setting and hardening, the heat of hydration raises the concrete temperature, and then gradually cools. These temperature changes can cause severe thermal strains and early cracking. In addition, hardened concrete expands and contracts with changes in temperature (at roughly the same rate as steel); therefore, expansion and contraction joints must be provided in many types of concrete structures to prevent failures. Drying shrinkage and moisture movements;

Concrete shrinks as it dries out and, even when hardened, expands and contracts with wetting and drying. These movements require that control joints be provided at intervals to avoid unsightly cracks. To prevent drying shrinkage in newly placed concrete, its surface is kept moist continuously during the curing process. Moisture is applied as soon as the concrete is hard enough to prevent damage to the concrete's surface. Creep; Concrete deforms creeps gradually under load, and this deformation does recover completely when the load is removed. Permeability; Even the best quality concrete is not entirely impervious to moisture. It contains soluble compounds that are leached out in varying amounts by water. Unless properly constructed, joints allow water to enter the mass. Permeability is particularly important in reinforced concrete because the concrete must prevent water from reaching the steel reinforcement (AIPD, 1992).

2.1.5 Importance of Concrete in Construction

Fresh concrete or plastic concrete is a freshly mixed concrete which can be molded into any shape. The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state. The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. In those cases where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties. Therefore, the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used as a qualitative measure for other properties of hardened concrete (Shetty, 2005).

For a long time, concrete was considered to be very durable material requiring a little or no maintenance. The assumption is largely true, except when it is subjected to highly aggressive environments. Concrete durability is a subject of major concern in many countries. Numbers of international seminars are held on concrete durability and numerous papers written on failures of concrete structures are discussed and state-of-the-art reports are written and disseminated, regularly (Shetty, 2005).

Concrete and other heavyweight building materials have a beneficial effect on the energy performance and thermal comfort of a building due to their high thermal mass. This effect has been the subject of a number of recent investigations (Biasoli and Oberg, 2007).

2.1.6 Solving Problems with Cement and Concrete

Concrete and cement can be used creatively to solve waste and pollution problems, to achieve energy efficient and comfortable buildings and to increase the service life. However, they can also be used to solve environmental problems, for example, stabilizing or encapsulating environmentally harmful substances, (Glavind *et al.,* 2006)

2.1.7 Life Cycle Aspects of Concrete

In the Nordic network, a consensus was reached regarding the definition of sustainable concrete structures. Sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs', (Concrete for the Environment, 2003; Glavind *et al*., 2006).

The definition of sustainable concrete structures reads:

An environmentally sustainable concrete structure is a structure that is constructed so the total environmental impact during the entire life cycle, including use of the structures, is reduced to a minimum. This means that the structure shall be designed and produced in a manner which is tailor-made for the use, i.e. to the specified lifetime, loads, environmental impact, maintenance strategy, heating need, etc. – or simply the right concrete for the right application. This shall be achieved by utilizing the inherently environmentally beneficial properties of concrete, e.g. the high strength, good durability and the high thermal capacity. Further-more, the concrete and its constituents shall be extracted and produced in an environmentally sound manner, (Glavind *et al*., 2006).

When assessing the environmental impact of concrete structures, it is essential to consider all life cycle phases, i.e. from cradle to grave. The life cycle of concrete products can be divided into the following life cycle phases, (Glavind *et al*., 2006):

- Extraction and processing of raw materials;
- Concrete production;
- Construction;
- Use;
- Demolition and recycling.

It is generally accepted that most sustainability aspects of concrete may be considered under one of the following categories, (Glavind *et al*., 2006):

- Natural resources;
- Energy consumption/greenhouse effect;
- Environmental effects;
- Health and safety.

2.2 ADMIXTURES

The history of admixtures is as old as the history of concrete. It is defined as a material, other than cement, water and aggregates that is used as an ingredient of concrete and is added to the batch immediately before or during mixing (AIPD, 1992).

2.2.1 Admixtures in Concrete

Admixtures are therefore, substances added to concrete during mixing to accelerate or retard the initial set, improve workability, reduce mixing water requirements, increase strength, or otherwise alter concrete properties. They usually cause a chemical reaction within the concrete. Admixtures are normally classified into accelerators, retarders, air-entraining agents, water reducers, and pozzolans. Many admixtures fall into more than one classification (AIPD, 1992). Additive is a material which is added at the time of grinding cement clinker at the cement factory.

These days, concrete is being used for wide varieties of purposes to make it suitable in different conditions. In these conditions ordinary concrete may fail to exhibit the required quality performance or durability. In such cases, admixture is used to modify the properties of ordinary concrete so as to make it more suitable for the intended situation.

It will be slightly difficult to predict the effect and the results of using admixtures because, many a time, the change in the brand of cement, aggregate grading, mix proportions and richness of mix alter the properties of concrete. Sometimes many admixtures affect more than one property of concrete. At times, they affect the desirable properties adversely. Sometimes, more than one admixture is used in the same mix. The effect of more than one admixture is difficult to predict. Therefore, one must be cautious in the selection of admixtures and in predicting the effect of the same in concrete (Shetty, 2005).

Since the early 1980's, there has been an enormous demand for the mineral admixture and in future this demand is expected to increase even more (Chan, 2000). Also in this modern age every structure has its own intended purpose(s) and hence to meet this purpose(s) modification in traditional cement concrete has become essential. This situation has led to the extensive research on concrete resulting in mineral admixture to be partly used as cement replacement to increase workability in most structural application (Payá *et al.*, 2007). If some of raw material having similar composition to cement can be replaced by weight of cement in concrete, then cost could be reduced without affecting its quality

(Cordeiro *et al*., 2008). For this reason Sugarcane Bagasse Ash (SCBA) is one of the main by-products that can be used as mineral admixture due to its high content in silica (SiO2), (Bhalchandra and Rajesh, 2011).

2.2.2 Classification of Admixtures

(a) Classification of admixtures on the basis of Shetty, M.S., (2005)

According to Shetty (2005), admixtures can be classified as follows:

Plasticizers, Super plasticizers, Retarders, Accelerators, Air-entraining Admixtures, Pozzolanic or Mineral Admixtures, Damp-proofing and Waterproofing Admixtures, Gas forming Admixtures, Air-detraining Admixtures, Alkali-aggregate Expansion Inhibiting Admixtures, Workability Admixtures, Grouting Admixtures, Corrosion Inhibiting Admixtures, Bonding Admixtures, Fungicidal, Germicidal, Insecticidal Admixtures and Coloring Admixtures

(b) Classification of admixtures on the basis of (ASTM C 494)

The American Society of Testing and Materials (ASTM C 494, 1999) specification presents eight (8) types of chemical admixtures:

Type A – Water-reducing admixtures

Type B – Retarding admixtures

Type C – Accelerating admixtures

Type D – Water-reducing and retarding admixtures

Type E – Water-reducing and accelerating admixtures

Type F – Water-reducing admixtures

Type G – Water-reducing, high-range, and retarding admixtures

Type S – Specific performance admixtures

2.2.3 Types of Admixtures

(a) Accelerating admixtures

An accelerating admixture is used to accelerate the rate of hydration (setting) and strength development of concrete at an early age. The strength development of concrete can also be accelerated by other methods: (1) Using Type III or Type HE high-early-strength cement. (2) Using a water reducer, or (3) Curing at higher temperatures.

Accelerators are designated as Type C admixtures under (ASTM C 494, 1999; AASHTO M 194, 2000). Calcium chloride ($CaCl_2$) is the chemical most commonly used in accelerating admixtures, especially for non-reinforced concrete. It should conform to the requirements of (ASTM D 98, 1998; AASHTO M 144, 1996) and should be sampled and tested in accordance with ASTM D 345, (1997). The widespread use of calcium chloride as an accelerating admixtures has provided much data and experience on the effect of this chemical on the properties of concrete. Besides accelerating strength gain, calcium chloride causes an increase in drying shrinkage, potential reinforcement corrosion, discoloration (a darkening of concrete), and an increase in the potential for scaling.

(b) Retarding admixtures

A delay in the setting of cement paste can be achieved by adding a retarder to the concrete mix. Retarders generally slow down the hardening of the cement paste by stopping the rapid set shown by tricalcium aluminate but do not alter the composition of hydration products. The delay in setting of the cement paste can be exploited to produce architectural finish of exposed coarse aggregate. Sugar, carbohydrate derivatives and some salts exhibit retarding action. It is believed that retarders modify crystal growth or morphology, becoming absorbed on rapidly formed membrane of hydrated cement and slowing down the growth of calcium hydroxide nuclei thus forming a more efficient barrier to further hydration than is the case without a retarder (Akogu, 2011).

2.2.4 Sugar as an Admixture

Sugar is used as a set-retarding admixture in concrete. It slows down the rate of early hydration of C_3S by extending the length of the cement dormant period. The extension of the dormant period is proportional to the amount of retarding admixture used. When concentration of sugar exceeds 0.5 g/l, the C_3S hydration will never proceed beyond the dormant period and the cement paste will never set. In the United States, truck drivers carrying unset concrete in situations where setting must be delayed often take advantage of this fact by adding a bag of table sugar to the concrete batch (Medjo and Riskowski, 2001).

Sugar belongs to the type of retarders that can hold up setting and hardening indefinitely and Forsén called them ‘cement destroyers’ (Akogu, 2011).

2.2.5 Efforts done by others on Admixtures in Concrete

With increasing demand and consumption of cement, researchers and scientist are in search of developing alternate binders that are eco-friendly and contribute towards waste management. The utilization of industrial and agricultural waste produced by industrial processes has been the focus of waste reduction. One of the agro-waste is sugar cane bagasse ash (SCBA) which is a fibrous waste product obtained from sugar mills as a by-product. Juice is extracted from sugar cane, after which the ash is produce by burning the bagasse in uncontrolled condition and at very high temperature (Kawade *et al*, 2013).

Concrete is a construction material that allows the ingress of water, oxygen, and aggressive ions, such as chlorides, can cause the passive layer on reinforced steel to break down. Additives, such as fly ash, microsilica, rice husk ash, and cane sugar bagasse ash, have a size breakdown that allows the reduction of concrete pore size and, consequently, may reduce the corrosion process, (Núñez-Jaquez *et. al*, 2012). Ash from sugar cane bagasse is one of the main waste products generated worldwide and can be used as a mineral additive, mainly due to its high content of silica (SiO_2).

2.3 SUGAR CANE AND ITS PRODUCTION

Sugar cane: The grass, Saccharum officinarum, is grown to produce sugar. Sugar cane is a tall, thick-stemmed grass that stores sugar in the stem. Products extracted from sugar cane at the sugar mill are raw sugar, Massecuite (molasses), bagasse (a source of fuel that may be used to power the sugar mill), and water. Federal Crop Insurance Corporation (FCIC, 2007).

Sugar cane Plant: A plant also referred to as a stool, ratoon or cluster and consists of the primary or original shoot, and the secondary and tertiary shoots. The primary shoot develops from a single node (“bud” or “eye”) on the mother stalk or seed piece. The secondary shoot develops from the buds on the underground part of the stalk. A tertiary shoot may also originate from a secondary shoot (FCIC, 2007).

Figure 2.1 is a sketch of a billet of sugar cane showing the bast, vascular bundles and pith regions of the plant.

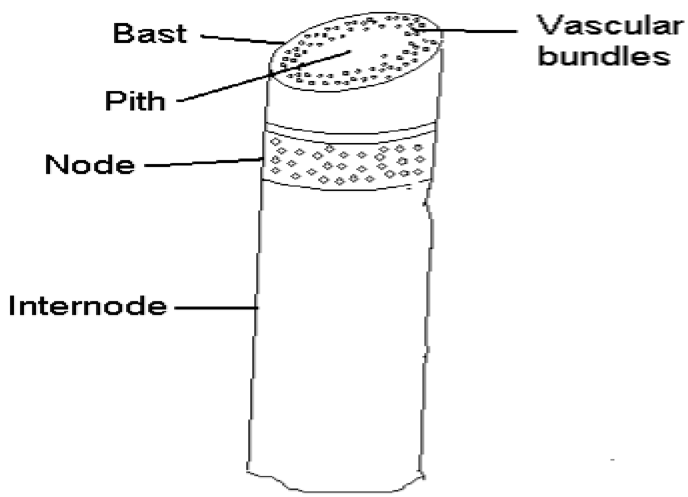

Figure 2.1 Sugar cane billet, (Thomas, 2009).

The ‘Bast’ is the external part of the plant and the ‘Pith’ is the internal part of the plant.

The billets are crushed in a sugar factory to extract the juice which contains the sugar (13% - 15% of the plant). The juice is concentrated and sugar crystals are produced. The fluid surrounding the sugar crystals, (i.e. molasses), has a high sugar content (around 40%) which is sold for cattle feed or converted into fuel ethanol. The fibre left over from the crushing process, i.e. bagasse, constitutes around 14% of the plant, (Thomas, 2009).

Australia produces 10 million tonnes of bagasse annually. The production of sugar and bagasse is shown in Figure 2.2 below

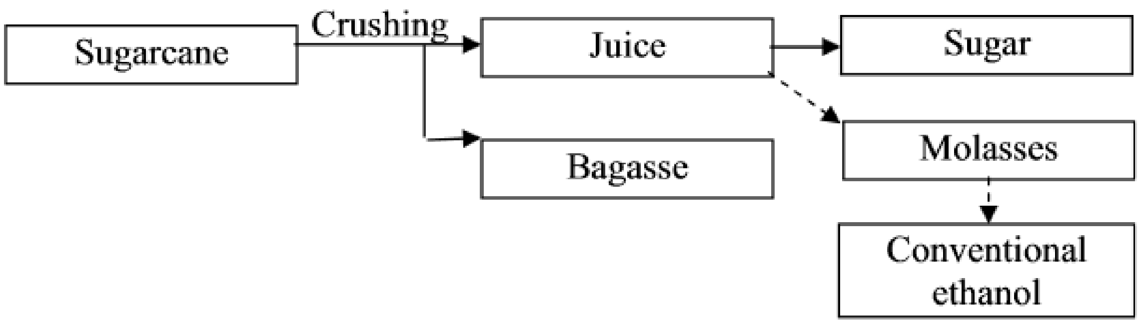

Figure 2.2 Schematic Flow Chat of Sugarcane Processing and Bagasse Utilization Options, (Thomas, 2009).

There are two main methods of extracting juice from cane; Sugar 'mills' are used almost exclusively in Australian raw sugar factories while Sugar 'diffusers' are not common in Australia but are commonly used overseas, (Thomas, 2009).

Bagasse fibers are severely damaged by sugar milling. A typical sugar milling roller unit is shown in Figure 2.3. Sucrose is extracted after opening up the parenchyma cells (mainly in the pith). The opening up of the pith occurs when the sugarcane is initially shredded in the hammer mills, when it is processed in the subsequent roller mills (typically, six roller mills) and also in the final dewatering mill. However, some shear forces are also exerted in the roller mills in between the hammer mills and the dewatering mill in a sugar mill that uses only a milling train (Rainey *et al*, 2008; Thomas, 2009).

Sugar cane production in the world was summarized in the Table 2.1 below in ranking order of production capacity per country.

Table 2.1 Top Ten Sugarcane Producers in the World

Country	Production (thousand metric tons, TMT)
Brazil	739, 267
India	341, 200
China	125, 536
Thailand	100, 096
Pakistan	63, 750
Mexico	61, 182
Colombia	34, 876
Indonesia	33, 700
Philippines	31, 874
United States	27, 906
Total world production	1, 877, 105

Source; (Crop Production, 2015).

Over the years, sugar cane is one of the major crops grown in over 110 countries and its total production is over 1500 million tons. Sugarcane is one of the major crops grown in over 110 countries and its total production is over 1500 million tons. Sugarcane production in India is over 300 million ton/year leaving about 10 million tons of SCBA as un-utilized and hence waste material, (Shivakumar *et al*, 2014).

Five largest sugar cane producers in the world are related to Nigeria in terms of yield, in tones per hectare as given in Table 2.2 below.

Table 2.2 Yield of Five Largest Sugar Cane Producers in the World Compared to Yield in Nigeria in Tones Per Hectare, (Oni, 2016).

Countries	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Brazil	71	74	74	73	75	78	79	80	79	76	74	75	76
India	67	64	59	65	67	69	69	65	70	69	71	67	67
China	65	64	65	64	67	71	71	68	66	67	69	69	67
Thailand	61	67	58	48	51	65	71	72	70	76	77	76	66
Mexico	72	74	75	77	75	75	74	70	72	70	69	78	73
Nigeria	19	19	20	21	21	24	20	19	19	20	20	20	20

Source: FAOSTAT, 2015.

The summary of output, area and yield for Sugarcane in Nigeria, 1999-2011 was given in Table 2.3.

Table: 2.3 Trends in Output, Area Planted and Yield of Sugarcane in Nigeria, 1999-2011, (Oni, 2016).

Year	Output		Area Planted		Yield	
	Actual in tonnes	Growth in %	Actual in hectare	Growth in %	Actual tonnes/ha	Growth in %
1999	682,000		24,000		28.42	
2000	695,000	1.91	24000	0.00	28.96	1.91
2001	705,000	1.44	23000	-4.17	30.65	5.85
2002	750,000	6.38	40000	73.91	18.75	-38.83
2003	798,000	6.40	42000	5.00	19.00	1.33
2004	854,000	7.02	43000	2.38	19.86	4.53
2005	914,000	7.03	44000	2.33	20.77	4.59
2006	987,000	7.99	47000	6.82	21.00	1.09
2007	1,506,000	52.58	63000	34.04	23.90	13.83
2008	1,412,070	-6.24	71890	14.11	19.64	-17.83
2009	1,401,680	-0.74	73060	1.63	19.19	-2.33
2010	1,478,180	5.46	77550	6.15	19.06	-0.65
2011	1,429,570	-3.29	76380	-1.51	18.72	-1.81
Average	1,047,115	7.16	49,914	12	22.15	-2.36

Source: FOSTAT, 2014, National Bureau of Statistics and Central Bank of Nigeria Annual Report, 2015. Abuja, Nigeria.

With an average yield of 80 to 100 tons of cane per hectare, the annual yield of sugarcane in Nigeria is two to three (3) million tons; about 45% of which ends up as bagasse, a ligno-cellulose material left after the removal of fluids (sugar and moisture) from sugarcane, (Omoniyi, 2014). In 2010, Nigeria was the 2nd largest producer of sugar cane in West Africa after Ivory Coast and the 19th in Africa (Gourichon, 2013).

In Nigeria, sugarcane is the major raw-material for sugar production as it is in other tropical countries. Although there are vast potentials for the commercial production of this crop, its processing industry did not come into existence in Nigeria until the early 1960's, (Afolami *et al*, 2014). Large quantities of biomass residues are generated from agricultural processing in Nigeria yearly and these had been poorly utilized which invariably become menace to the environment. Research efforts are currently being geared towards effective management of these enormous wastes. Presently, sugarcane is grown on 25-30 thousands hectares in the country, of which industrial cane covers about 12 thousands hectares (Omoniyi, 2014).

From next year, 2013, sugar cane farmers will have a cause to smile as the Federal Ministry of Agriculture and Rural Development (FMARD) has been mandated to develop industrial sugar cane in addition to the present sugar cane farms in the farmers' possession. This is to help boost the production of sugar cane in the country. Apart from developing cuttings suitable for planting in different geographical areas, (FMARD) has been mandated to help the sugar cane farmers get more money for their toil through exploitation of sugar cane for sugar, ethanol and feed production (Hassan, 2012).

2.3.1 The Essential Elements of Sugarcane

The "essential elements" of a healthy sugarcane crop include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, boron, chlorine, copper, iron, manganese, molybdenum, sulphur and zinc, (Miller *et al.*, 2012). Silicon, although not strictly needed for the sugarcane plant to complete its life cycle, may enhance sugarcane production significantly. An over-abundance of one element may cause a deficiency or toxicity of another. Hence, there is a need for a good nutritional balance to produce the healthiest plants. Since relatively large quantities of Nitrogen, Potassium, Phosporous, Sulphur, Magnesium, and Calcium are needed by the plants, these are referred to as "macronutrients"; the remainders of the elements are usually called "micronutrients" (Miller *et al.*, 2012).

2.3.2 Relevance of Assessing Sugar Cane Mill (SCM) as an Admixture in Concrete

A lot of researches were undertaken by different researchers on sugars and sugar cane wastes (sugar cane bagasse and sugar cane bagasse ash). Some of these researches are highlighted as follows:

- Asma *et al*., (2014): Compressive Strength and Microstructure of Sugar Cane Bagasse Ash Concrete.
- Kawade *et al*., (2013): Effect of Use of Bagasse Ash on Strength of Concrete.
- Rainey et al *et al*., (2008): An Experimental Study of Australian Sugarcane Bagasse Pulp Permeability.
- Aigbodion *et al*., (2010): Potential utilization of solid waste (Bagasse Ash).
- Akogu, (2011): Effects of Sugar on Physical Properties of Ordinary Portland cement Paste and Concrete.
- Frías *et al*., (2011): Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture.
- Madurwar *et al*., (2013): Application of Agro-Waste for Sustainable Construction Materials: a review of Building Construction Materials.
- Medjo, (2001): "A Procedure for processing Mixtures of Soil, Cement and Sugar Cane Bagasse".
- Omoniyi, (2014): Experimental Characterisation of Bagasse Biomass Material for Energy Production

From the foregoing, most of the previous works are on baggase ash, and no much work has been done on SCM.

Accumulation of unmanaged agro-waste, especially from the developing countries, has an increased environmental concern. Therefore, development of new technologies to recycle and convert waste materials into reusable materials is important for the protection of the environment and sustainable development of the society (Mangesh *et al.*, 2014). Example of such waste materials, includes sugarcane bagasse ash (SBA) (Madurwar *et al.*, 2013), recycled paper mill waste (Raut *et al.*, 2012) etc. Recycling of such wastes by incorporating them into building materials is a practical solution to the pollution problem (Mangesh *et al*., 2014).

The beneficial utilization of industrial and agricultural wastes has been the focus of many researchers on waste reduction. Also every structure has its own intended purpose(s); working under water or ambient temperature or where the concrete will be exposed to a harsh environment like acid. And to meet such purpose(s), modification in traditional cement concrete has become essential (Kawade *et al*., 2013). Also this beneficial utilization of industrial and agricultural wastes has focused on has been the focus of research for economical, environmental and technical reasons (Shivakumar *et al*., 2014). In Nigeria, sugarcane is the major raw-material for sugar production as it is in other tropical countries (Afolami, 2014).

Therefore, dumping of sugar cane waste will be reduced or even eliminated as well as overall environmental improvement in terms of sanitation will be achieved, if it is found that sugar cane mill can effectively be used in concrete. Also, a means of creating wealth from waste will developed especially to the sugar cane farmers.

2.4 SUGAR CANE BAGASSE

Bagasse is an abundant waste produced in sugar factories after extraction of juice from Sugarcane. The huge supply of bagasse needs meaningful disposal. Burning of bagasse as fuel leaves bulk quantity of ash called sugarcane bagasse ash or SCBA. Therefore, an average annual production bagasse is estimated as 600 Million tons, which is a bulky waste from sugar industry. Sugarcane plantations cover one-fifth of the arable land in Sudan, also having the highest potential among the countries of eastern and southern Africa of producing electricity from bagasse and over 40% of its electricity can be produced from bagasse co-generation (Asma *et al*., 2014).

2.4.1 Uses of Bagasse

Bagasse is used for several purposes (Deepchand, 2005):

- fuel for the boilers and kilns,
- production of paper, paperboard products, and reconstituted panel board,
- agricultural mulch, and
- As a raw material for production of chemicals.

The primary use of bagasse and bagasse residue is as a fuel source for the boilers in the generation of process steam in sugar plants. Dried filtercake is used as an animal feed supplement, fertilizer, and source of sugarcane wax, (Thomas, 2009). Other uses of bagasse are shown in Figure 2.3 below.

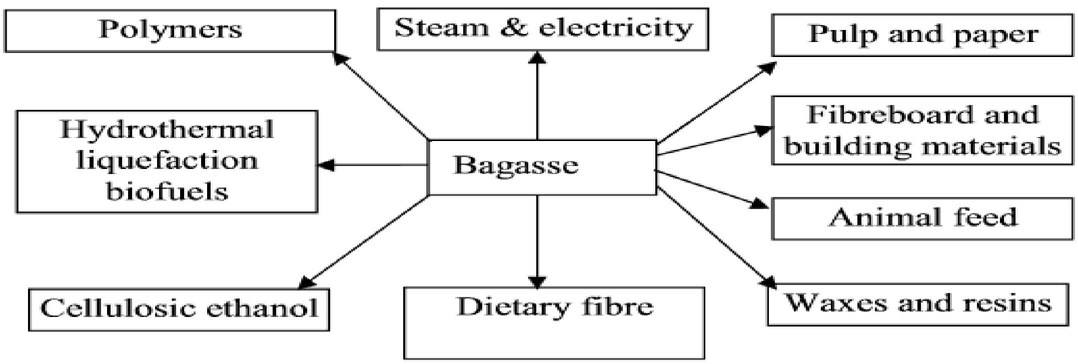

Figure 2.3 Other Uses of Sugar Cane Bagasse, (Thomas, 2009).

Bagasse fiber is also used in building products. It is often used as a cheap raw material in fibreboard or used as filler in other products including composite materials. Sometimes it is combined with cement and sand to make reinforced concrete. These building products are common in India. There has been considerable interest for using lignocellulosic material, including bagasse, for the production of fuel ethanol (Shu *et al*., 2006)

2.5 SUGAR CANE BAGASSE ASH

Sugarcane Bagasse Ash is a waste from burning sugarcane bagasse or obtained directly as a waste product from electricity cogeneration plants using sugarcane bagasse as fuel by sugar producing companies. The utilization of sugarcane bagasse ash in concrete production will help protect the environment by not dumping this waste in dump sites and water bodies (Shuaibu *et al.*, 2014).

To obtain Sugarcane Bagasse Ash (SCBA), burning was carried out in two stages-open burning followed by controlled burning at 600°C for 5 hours (actual procedure), but the SCBA used for our project is collected from Bilagi Sugarcane factory where the burning temperature of SCBA was around 900-1100°C. SCBA so obtained was not fine enough to be blended with the cement; therefore to achieve fineness compared to OPC, the ash obtained after burning was grounded in a ball mill and subsequently screened through 45μ sieve (Shivakumar *et al.*, 2014).

The major advantages of the bagasse ash is that it is cheaper to produce, needs much lower or even negligible capital inputs to get started, and requires far fewer imported technological equipment because it is produced by already available machines in sugar mill. It can also be produced on a small scale to supply a local market resulting in greatly reduced transportation costs, (Mohamed and Samah, 2011).

2.5.1 Need of Sugarcane Bagasse Ash (SCBA) Usage

- When used as replacement for cement in concrete, it reduces the problem associated with their disposal, (Gaona-Tiburcio, 2011).
- Also according to, (Shivakumar *et al*., 2014);
- It is used as Mineral Admixture
- It is used as Partial Replacement for Sand
- It is used as Partial Replacement for Cement
- It is used for the Extraction of Silica
- It is used in the manufacture of Tiles in Ceramic industry
- It is used as fuel in the same sugarcane industry to stoke boilers that produce steam for electricity generation.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 MATERIALS

The materials used for the laboratory tests in this research are ordinary Portland cement (OPC), coarse aggregates, fine aggregates, cement, sugar cane mill, and water.

3.1.1 Cement

The cement used in this research work is the ordinary Portland cement (3x), manufactured by Dangote group. The cement was obtained from a dealer at Bakar-Lamba, Gwarzo road, Kano State and care was taken to ensure that it was of recent supplies.

3.1.2 Sugar Cane Mill (SCM)

The sugar cane mill was from sugar cane waste (the peels, joints and the ratoon). It was cut to small pieces for easy drying. It was then crushed and powdered manually by pounding. Mechanical grinding was not used, because the friction between machine teeth generates heat that in turn re-activates the sugar content and make it wet again.

3.1.3 Fine Aggregate

Naturally occurring clean sand obtained from a dealer at Rijiyar-Zaki was used, and care was taken to ensure that it was free of adulteration.

3.1.4 Coarse Aggregate

The coarse aggregate used in this research work was crushed granite of 20 mm maximum size, obtained from a standard quarry site of Abduljalil Hajaig & Sons Ltd. located along Gwarzo road in Lambu village, Tofa Local Government area of Kano State. The aggregate was purchased from a dealer at Rijiyar-Zaki, Kano.

3.1.5 Water

The water used in this research was clean tap water fit for drinking and assumed to be free of threats that can adversely affect the important properties of the concrete.

3.2 TESTS ON MATERIALS

3.2.1 Aggregates

3.2.1.1 Sieve analysis

Sieve analysis for the samples was conducted in accordance with BS EN 933-1, (2003). The detailed calculation of the results of sieve analysis for fine and coarse aggregates are presented in Appendix A, Tables A1, A2, A3 and A4 respectively.

3.2.1.2 Test for crushing value aggregate (ACV)

The test was performed on the material passing the 14mm sieve and retained on the 10.0 mm sieve. The aggregate used in this test were obtained from a bulk sample that was initially taken and prepared in the manner described in BS EN 932-1, 1997. The value of ACV was determined using the following formula:

$$\text{Aggregate crushing value} = (W_2 \text{ x } 100) / (W_1\text{-}W) \quad (3.1)$$

W= Mass of mould

W_1 = Mass of mould + sample.

W_1-W = Mass of surface dry sample.

W_2 = Mass of fractions passed through 2.36 mm BS sieve.

The ratio of weight of fines formed to the weight of total sample in each test shall be expressed as a percentage, the result being recorded to the first decimal place.

The results of the ACV test are given in Appendix A, Table A5, while the detailed calculations are presented and summarized in Appendix A, Table A6.

3.2.2 Specific Gravity of SCM, Cement, Fine and Coarse Aggregate

Specific gravity is the ratio of the density (mass per unit volume) of a substance to the density of (mass of the same unit volume) of a reference substance (water at 4^0C).

Specific gravity test on the SCM, cement, fine and coarse aggregate was conducted according to BS 812-103:1985, BS 812, (1989), and BS EN 12620, (2002) respectively. The test results for specific gravity of the materials are shown in Appendix B, Tables B1, B2, B3, B4 and B5 respectively. Detail calculations for the specific gravity of the materials were presented and summarized in Table B6 of the Appendix.

The specific gravity of the materials was calculated using the following relations

$$Gs = \frac{\text{weight of solids}}{\text{weight of equal volume of water}}$$

$$G_s = \frac{(W2 - W1)}{(W4 - W1)(W3 - W2)} \tag{3.2}$$

$$G_s = \frac{(W4 - W1)}{(W5 - W1)} \tag{3.3}$$

Where;

w_1 = weight of empty pycnometer bottle

w_2 = weight of pycnometer bottle + sample

w_3 = weight of pycnometer bottle + sample + water

w_4 = weight of empty pycnometer bottle + water

w_5 = weight of empty pycnometer bottle + kerosene

3.2.3 Standard Consistency Test for Cement

The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate to a depth of 33-35 mm from the top of the mould or 5-7 mm from the bottom of the mould, BS EN 196-3, (2003). The results of consistency test for 0 %, 0.025 %, 0.05 %, 0.075 %, 0.1 %, 0.125 %, 0.15 % and 0.175% of SCM are presented in Appendix A, Tables A7, A8, A9, A10, A11, A12, A13 and A14 respectively.

3.2.4 Setting Time for Cement and SCM-Cement Pastes

The setting time test was carried out in accordance with BS EN 196-3, 2003. The results are presented in Appendix A, Tables A7-A14 and summarized in Table 4.2.

3.3 CONCRETE MIX DESIGN

The process of selecting suitable ingredients of concrete and determining their relative amount with the objective of producing a concrete of required strength, durability, workability as economically as possible is termed the concrete mix design (Shivarkumar *et al.,* 2014). In order to determine quantities of the concrete mix constituents, a mix design was carried out based on DoE (1975) method. The details for the design assumptions and calculations are given in Appendix A, item number four. The design charts (Figures and Tables) are given in Appendix C, as indicated various stages of the design process. The designed results are summarized in Table 3.1 below.

Table 3.1 Concrete Mix Design Summary

Material	Water	Cement	Fine aggregate	Coarse aggregate
Quantity (kg/m^3)	190	358.5	600	1226.5

3.4 BATCHING OF THE CONCRETE

3.4.1 Quantities of Materials required for Production of Concrete Cubes

The detailed calculation of the quantity of materials required for SCM-concrete cubes specimens are presented in Appendix A, item number five and summarized in Table 3.2

Table 3.2 Summary of Materials Required for SCM-Concrete Cubes Specimens

SCM (%)	0	0.025	0.05	0.075	0.1	0.125	0.15	0.175
SCM (g)	0	4.17	8.35	12.52	16.70	20.87	25.05	29.22
Water (kg)	8.849	9.008	8.927	8.897	8.885	8.867	8.945	9.054
Cement (kg)	16.697	16.697	16.697	16.697	16.697	16.697	16.697	16.697
Fine aggregate (kg)	30.740	30.740	30.740	30.740	30.740	30.740	30.740	30.740
Coarse aggregate (kg)	57.124	57.124	57.124	57.124	57.124	57.124	57.124	57.124

3.4.2 Quantities of Materials required for Production of Concrete Cylinders

The detailed calculation of the materials required for SCM-concrete cylinder specimens are presented in Appendix A, item number six and summarized in Table 3.3

Table 3.3 Summary of Materials Required for SCM-Concrete Cylinders Specimens

SCM (%)	0	0.025	0.05	0.075	0.1	0.125	0.15	0.175
SCM (g)	0	1.49	2.98	4.46	5.95	7.44	8.92	10.41
Water (kg)	3.153	3.210	3.180	3.170	3.166	3.159	3.187	3.226
Cement (kg)	5.949	5.949	5.949	5.949	5.949	5.949	5.949	5.949
Fine aggregate (kg)	10.952	10.952	10.952	10.952	10.952	10.952	10.952	10.952
Coarse aggregate (kg)	20.353	20.353	20.353	20.353	20.353	20.353	20.353	20.353

3.5 pH VALUE TEST FOR WATER USED IN MIXING AND CURING THE CONCRETE

The pH value of the used in mixing and curing the concrete was determined in accordance with BS EN ISO 10523, (2012). The results are presented in Appendix B, Tables B7 and B8 respectively.

3.6 SLUMP TEST

The test was carried out in accordance with British Standard for conducting slump test (EN 12350-2, 2000). The results are presented in Table 4.3.

3.7 CASTING AND CURING OF SCM-CONCRETE

3.7.1 Casting of SCM-Concrete Cubes

The operation was carried out in accordance to BS 1881-108, (1985). Each cube was given identification mark which includes the date of casting, percentage of SCM and the expected curing duration, and cured in water tank in the laboratory for 7, 14, 28 and 56 in accordance with BS 1881-3, (1970).

3.7.2 Casting of SCM-Concrete Cylinders

The operation was carried out in accordance to BS 1881-108, (1985). Each cylinder was given an identification mark and cured as described in 3.8.1.

3.8 COMPRESSIVE STRENGTH TEST

The test was carried out in accordance with BS EN 12390-3 (2003). The cubes were tested at four different ages of curing i.e. 7, 14, 28 and 56 days. The compressive strength of each cube at each percentage of SCM and curing days was computed. The details were presented in item number seven, Appendix B, Tables B9, B10, B11 and B12 respectively.

The compressive strength is calculated as:

Compressive strength = $\frac{\text{Load at failure}}{\text{Area of specimen}}$ (N/mm^2) (3.4)

Cube size = 150 mm x 150 mm x 150 mm

Area of the cube = 150 mm x 150 mm = 22500 mm^2

3.9 SPLIT TENSILE STRENGTH TEST

The split tensile strength test was carried out in accordance with BS EN 12390-6, (2003). The concrete cylinders cast were tested at four different ages of 7, 14, 28 and 56 curing days. The tensile strength of each cylinder at each percentage of SCM was computed. The details were presented in item number eight, Appendix B, Tables B13, B14, B15 and B16 respectively.

The split tensile strength was calculated as:

Split tensile strength = $\frac{2 \times F}{\pi \times l \times d}$ ………………………… (3.5)

Where;

Diameter of the cylinder (d) = 8 cm = 80 mm

Height of the cylinder (l) = 25 cm = 250 mm

F = Load at failure;

$\pi = \frac{22}{7}$

CHAPTER FOUR

PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 PRESENTATION OF THE RESULTS

Table 4.1 show the summary of the result of the tests carried out on the materials; the sieve analysis of fine aggregate, crushing value of coarse aggregate, specific gravity of SCM and cement, pH value of the mixing and curing water for concrete. Table 4.2 present the consistency and setting time test for the cement.

Figure 4.1 shows the graph of zone of fine aggregate while Figure 4.2 indicates the graphical presentation of slump test results. Table 4.3 present the results of the slump test, while Tables 4.4 and 4.5 presented the summary of the compressive strength and the percentage change in the compressive strength relative to the control respectively. For Figures 4.3 and 4.4 shows the graphical presentation of the information in the Tables 4.4 and 4.5 above, for both, curing periods and percentages of SCM respectively. Tables 4.6 and 4.7 presented the summary of the splitting tensile strength and the percentage change in the splitting tensile strength relative to the control respectively. For Figures 4.5 and 4.6 shows the graphical presentation of the information in the Tables 4.6 and 4.7 above, for both, curing periods and percentages of SCM respectively.

4.2 ANALYSIS AND DISCUSSION OF RESULTS

4.2.1 Results on Materials

The results obtained from test on materials are summarized in Table 4.1 from both Appendix A and Appendix B.

Table 4.1 Summary of Standard Tests for Materials

Material property	Value obtained	Standard ranges	BS Code or Organization	Remark
Fine aggregate zone	2	1 – 4	BS EN 933-1	Okay
Aggregate crushing value (%)	24.7	≤ 30 %	BS EN 12620	Okay
Specific gravity of SCM	1.57	-	-	-
Specific gravity of cement	3.13	(3.10 – 3.15)	BS 4550-3	Okay
Specific gravity of fine aggregate	2.64	(2.3–2.9)	BS EN 12620	Okay
Specific gravity of coarse aggregate	2.73	(2.4–2.9)	BS EN 12620	Okay
pH of water for casting	8.23	6.5 – 8.5	WHO	Okay
pH of water for curing before immersion	8.27	6.5 – 8.5	WHO	Okay

4.2.1.1 Fine aggregate zone

Further analysis of fine aggregate, particle size analysis results to determine the zone using software GEOBUK2015, (Abubakar, 2015) is detailed in Appendix A. Table A1 and A2 are plotted to identify the zone of the fine aggregate shown in Figure 4.1 below.

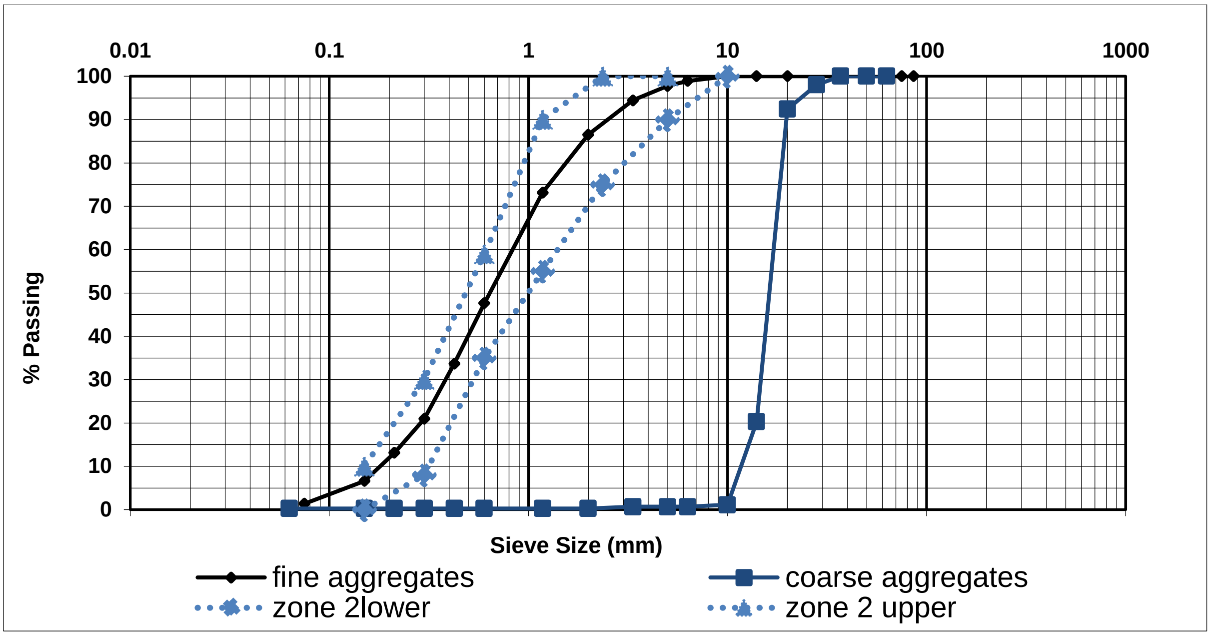

Figure 4.1 Particles Size Distribution Curve for Fine Aggregate

From figure 4.1, the fine aggregate is identified to be in zone 2.

As shown in Table 4.1, the fine aggregate was found to be in zone 2. This indicate that the fine aggregate is suitable for concreting, BS EN 933-1, (2003).

4.2.1.2 Aggregate crushing value test (ACV)

The aggregates crushing value of the coarse aggregate found to be 24.7% as given in Table 4.1. This satisfies the requirements of BS EN 12620, (2013) which specifies that ACV for coarse aggregate to be used in concrete should be less than or equal to 30%.

4.2.1.3 Specific gravity of the materials

The specific gravity of SCM as presented in Table 4.1 is 1.57. It indicates how dense a substance is by comparing it to the density of water. Therefore SCM is found to be very light due to its lower value of specific gravity compared to that of both aggregates (2.3–2.9), BS EN 12620, (2000), and that of cement (3.1–3.15), BS 4550: Part 3, (1978). The cement also is denser than the aggregate as its specific gravity is higher than that of the aggregate. Hence, SCM is less dense and this indicates how light SCM is, in terms of weight. That is why the percentages of the SCM to that of cement appeared to be very small. Even fractions of one gram (1g) can be measured or weighed and looks voluminous.

4.2.1.4 pH value of mixing water

The pH value of the water used in mixing the concrete was found to be 8.23 as shown in Table 4.1. This satisfies the requirements of World Health Organization (WHO), (2012) that the pH value for a drinking water should be within 6.5–8.5. Therefore the water is suitable for concreting since clean water is required for concreting. Impurities present in water are reacting differently with different constituent of cement. These reactions mostly affect the setting time, compressive strength and may also cause straining of concrete surface. In general, acid solutions which attack cement mortars or concrete by dissolving part of the cement do not cause any expansion, but progressively weaken the material by removal of cementing constituents forming soft and mushy mass remains. But, drinking water may be unsuitable as mixing water when the water contains a high concentration of sodium or potassium which leads to danger of alkali-aggregate reaction. While the use of potable water is generally safe, water not fit for drinking may also be satisfactorily used in making concrete. As a rule, any water with pH of 6.0 to 8.0 which does not taste saline or brackish is suitable for use, (Kucche *et al*., 2015).

4.2.1.5 pH value of curing water before immersion of the concrete specimens

The pH value of the water used in curing the concrete was found to be 8.27 as shown in Table 4.1 i.e. before the curing. With similar reference in section 4.2.1.4, the water is good for curing concrete.

4.2.2 Consistency and Setting Time of Cement- SCM Pastes

The standard consistency test results for cement-SCM pastes at various percentages of the SCM are given in Appendix A, Tables A7-A14 and summarized in Table 4.2.

Table 4.2 Summary of Consistency and Setting for Cement-SCM Pastes

SCM (%)	Water content (% of cement)	Change in Water content (% of cement)	Change in Water content (g)	Initial setting time (minutes)	Final setting time (minutes)
0	30.5	0	0	100	250
0.025	32.30	1.8	7.2	119	266
0.05	31.38	0.88	3.5	120	263
0.075	31.04	0.54	2.16	127	268
0.1	30.91	0.41	1.64	134	265
0.125	30.70	0.20	0.8	139	270
0.15	31.58	1.08	4.32	146	276
0.175	32.85	2.32	9.28	152	279

Table 4.2 shows the consistency of cement paste at various percentage contents of SCM, as well as the corresponding initial and final setting times. The results indicate that the consistency satisfies the range given by BS EN 196-3, (2003) which specifies the consistency should be between 26-32% of cement weight.

According to BS EN 196-3, (2003), the initial setting time of a cement paste should be ≥ 45 minutes while the final setting time should be ≤ 600 minutes. Therefore Table 4.2 satisfies the requirements.

ASTM C 494, (1999) classified any material that retard the setting time of cement paste as a ‘Type B’ admixture, (Retarding admixture). Others are ‘Type A’, water reducing admixture, ‘Type C’, accelerating admixture, for example. Therefore, SCM is a retarding admixture and also a ‘Type B’ admixture.

4.2.3 Slump Test Results

Table 4.3 Results for Slump Test

SCM (%)	0.0	0.025	0.05	0.075	0.1	0.125	0.15	0.175
Water (kg)	8.849	9.008	8.927	8.897	8.885	8.867	8.945	9.054
Slump (mm)	35	40	45	50	55	60	65	75

Figure 4.2 gives a bar chart derived from Table 4.3 above for more clearer or pictorial view of how slump varies with respect to variations of percentage of SCM in the concrete.

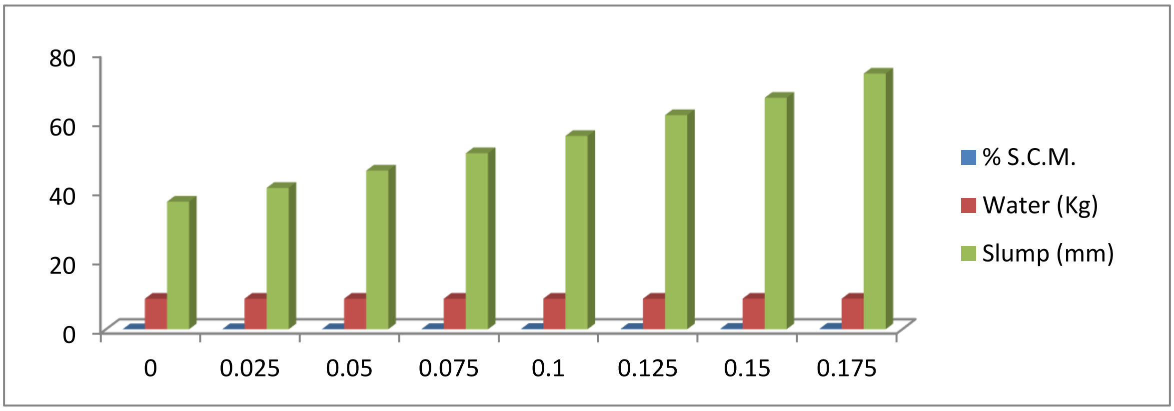

Figure 4.2 Variation of Slump with Respect to Percentage Increase in SCM

Workability is the ability of the concrete to flow and fill forms or mould to achieve the required shape by compaction. And this becomes very important for every concrete work and determines how well or otherwise is the designed concrete. Slump test is used to determine the workability of concrete. Concrete with poor slump cannot be cast and compacted easily or take the required shape. Hence, the concrete is highly workable due to the continuous increase in the slump by each percentage increase in SCM. Therefore, it can be used in special concretes such as self compacted concrete where highly workable concrete is required with less or no compaction.

4.2.4 Compressive Strength of SCM-Concrete

4.2.4.1 Variation of compressive strength with curing period

The compressive strength at various ages of curing periods are presented in item number seven, Appendix B, Tables B9, B10, B11, and B12 is summarized in Table 4.4.

Table 4.4 Compressive Strength of SCM-Concrete

Compressive strength test (N/mm^2)				
SCM (%)	Curing period (days)			
	7	14	28	56
0.0	31.11	32.59	35.7	41.78
0.025	32.44	33.48	39.85	43.56
0.05	33.78	34.52	42.81	45.93
0.075	31.11	36.59	44	46.97
0.1	28.59	30.79	38.82	39.41
0.125	27.56	28.15	33.04	33.78
0.15	18.09	21.51	26.07	27.41
0.175	11.99	18.52	22.27	24.62

Compressive strength of the concrete increased relative to the control with an increase in the SCM. The highest strength was recorded as 44 N/mm^2 for 0.075 % of the SCM at 28 days of curing while 35.7 N/mm^2 was recorded at same age of curing for the control specimen i.e. about 23.25 % increased in strength. Also the highest strength was recorded as 46.97 N/mm^2 for 0.075 % of the admixture at 56 days of curing while 41.78 N/mm^2 was recorded at same age of curing for the control specimen i.e. about 12.42 % increased in strength. The strength reduces as the percentage of the SCM is increased above 0.075%. The percentage increase in the strength is higher for 28 days of curing (23.25 %) than that of 56 days (12.42 %).

The compressive strengths increased with an increased in curing ages (days). For all curing ages, the compressive strength of concrete increased from 0 % SCM to 0.175 % SCM, the only exception is at 7 days curing period for 0.075 % SCM. Above 0.075 % SCM, the compressive strength of concrete decreased for all durations of curing. Within the study duration of 56 days of curing, the highest compressive strength values occur at 56 days for 0.075 % SCM. The SCM is made up of two components, bagasse powder and the sugar contents, with a very smaller percentage of sugar compared to that of the bagasse i.e. by weight as indicated by the specific gravity of the SCM. The bagasse powder increase the binding property to cement while the sugar reduces the binding means as it is an enemy to cement, (Akogu, 2011). That is why the strength starts reducing beyond 0.075% of SCM where the accumulation or concentration of the sugar begins to affect the binding properties of the cement, and this continues with increase in SCM until no more strength will be obtained.

Figure 4.3 gives the graphical presentation of the information in the Table 4.4. It gives the graph of compressive strength of the SCM-concrete with respect to the curing periods.

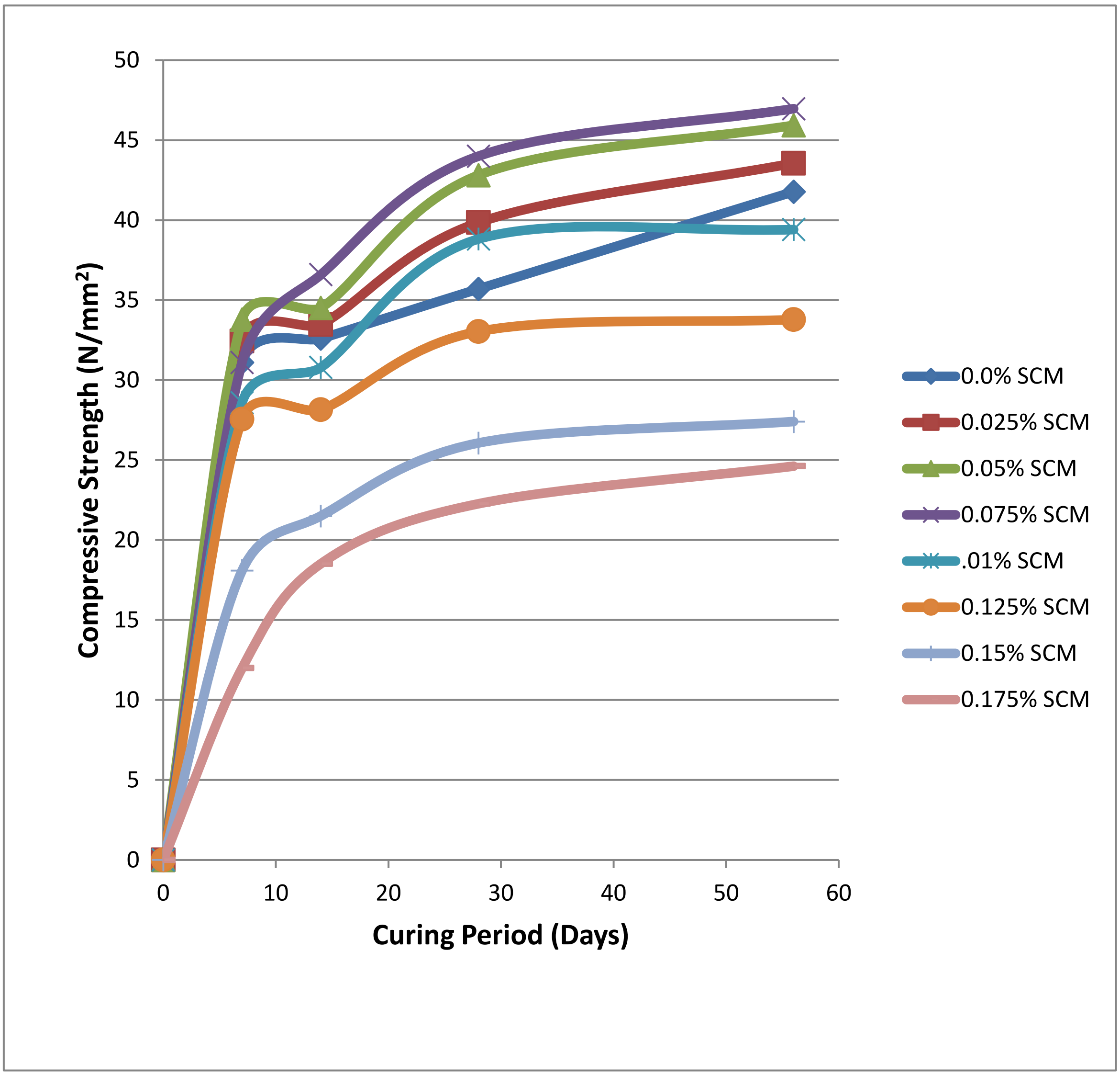

Figure 4.3 Compressive Strength Vs Curing Period at Varying SCM Contents

4.2.4.2 Variation compressive strength with percentage of SCM

Figure 4.4 gives the graphical presentation of the information in Table 4.4. It gives the graph of compressive strength of the SCM-concrete with respect to the SCM content.

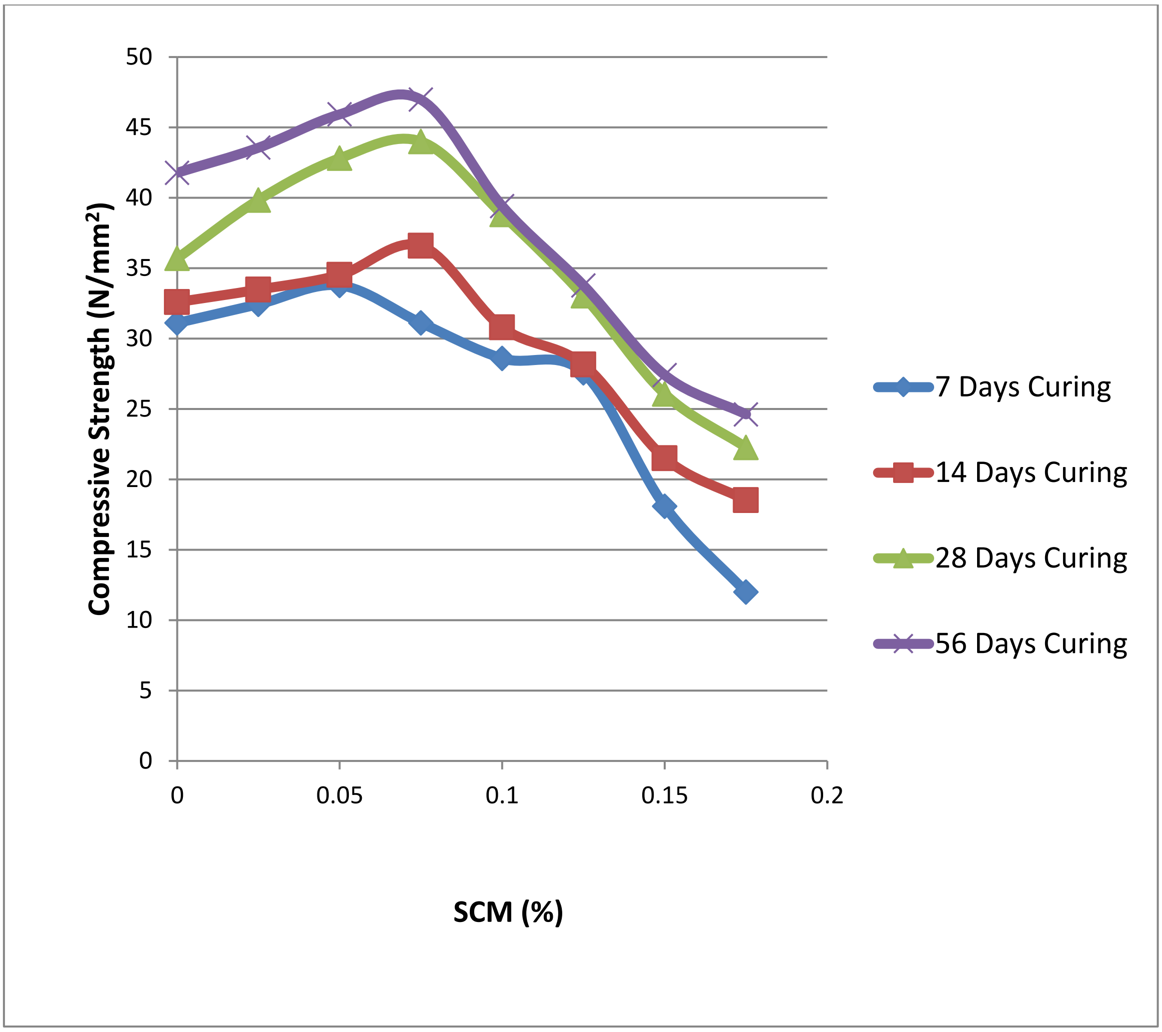

Figure 4.4 Compressive strength Vs SCM (%) at varying curing ages.

Table 4.5 shows the percentage change in SCM-Concrete strengths at each curing days obtained from Table 4.4.

Table 4.5 Percentage Change in SCM-Concrete Strengths at each Curing Days

Change in compressive strength (%)				
SCM (%)	Curing period (days)			
	7	14	28	56
0.0	0	0	0	0
0.025	4.28	2.73	11.63	4.45
0.05	8.58	5.92	19.92	9.93
0.075	0	12.27	23.25	12.42
0.1	-8.10	-5.52	8.74	-5.67
0.125	-11.41	-13.62	-7.45	-19.15
0.15	-41.85	-34	-26.98	-34.40
0.175	-61.56	-43.17	-37.62	-41.07

ASTM C 494, 1999 states that the decrease in the strength of concrete with admixture should not be more than 10 percent of the control strength. Therefore, those percentages of SCM with strengths decrease more than 10% should not be considered in structural concrete work i.e. 0.125%, 0.15% and 0.175% but can still be used for non-structural purposes. But 0.125% SCM can be used at 7 and 28 days of curing.

Also, ASTM C 618, 2009 states that the decrease in strength of concrete with admixture or partial replacement of cement, (the Pozzolanic or organic activity index of the material) should not be more than 25 percent of the control. Therefore, 0.15% and 0.175% SCM should not be considered in structural concrete works but can find application in non-structural concretes.

For the compressive strengths at all ages and SCM content of up to 0.125%, the strength of concrete is satisfied. Above 0.125% SCM, the strength of concrete is satisfied at 28 days and above for 0.15% SCM, and only at 56 days for 0.175% SCM.

4.2.5 Splitting Tensile Strength of SCM-Concrete

4.2.5.1 Splitting tensile strength results for the duration period

The splitting tensile strength at various ages of curing periods presented in Appendix B, item number eight, Tables B13, B14, B15 and B16 is summarized in Table 4.6.

Table 4.6 Splitting tensile strength of SCM-Concrete

Splitting tensile strength test (N/mm^2)				
SCM (%)	Curing period (days)			
	7	14	28	56
0.0	1.38	1.72	2.06	2.42
0.025	1.62	1.86	2.22	2.52
0.05	1.82	1.96	2.26	2.72
0.075	1.76	2.01	2.18	2.8
0.1	1.38	1.78	1.96	2.48
0.125	1.12	1.62	1.82	2
0.15	1.10	1.54	1.76	1.86
0.175	0.99	1.41	1.59	1.71

The splitting tensile strength increased with increased in curing period (days).An increased in tensile strength of 5.83% at 28 days and 15.70% at 56 days of curing for 0.075% SCM. This is similar to that compressive strength with higher results obtained same percentage of SCM (0.075%), only that higher increased occurred at 56 days of curing.

For all curing periods, the tensile strength of concrete increased from 0 % SCM to 0.075 % SCM, with the exceptions occurring only at 7 and 28 days curing period for 0.075 % SCM. Above 0.075 % SCM, the tensile strength of concrete decreased for all durations of curing. Within the study duration of 56 days of curing, the highest tensile strength values occur at 56 days for 0.075 % SCM.

SeshaPhani *et al.*, (2013) developed a relationship between compressive and splitting tensile strength of concrete as $f_t = 0.043f_{ck}^{1.064}$ with coefficient of variation $R^2 = 0.990$. Therefore this relationship will be used to justify splitting tensile strength results in Table 4.6. Using this relationship with the highest value of compressive strength obtained in Table 4.4, (46.97 N/mm^2) to determine the corresponding value of the split tensile strength and then compare it with the value obtained in Table 4.6

Given $f_t = 0.043f_{ck}^{1.064}$ with $f_c =$ 46.97 N/mm^2.

$f_t = 0.043(46.97)^{1.064} = 2.58$ N/mm^2

Split tensile strength = 2.8 N/mm^2 (From Table 4.6, for 0.075% SCM)

Difference = 2.8 – 2.58 = 0.22 N/mm^2

Percentage increase = 7.86%

Therefore, the results in Table 4.6 are even more than the values obtained from this relationship. Hence, it is acceptable.

Figure 4.5 gives the graphical presentation of the information in the Table 4.6. It gives the graph of tensile strength of the SCM-concrete with respect to the curing period.

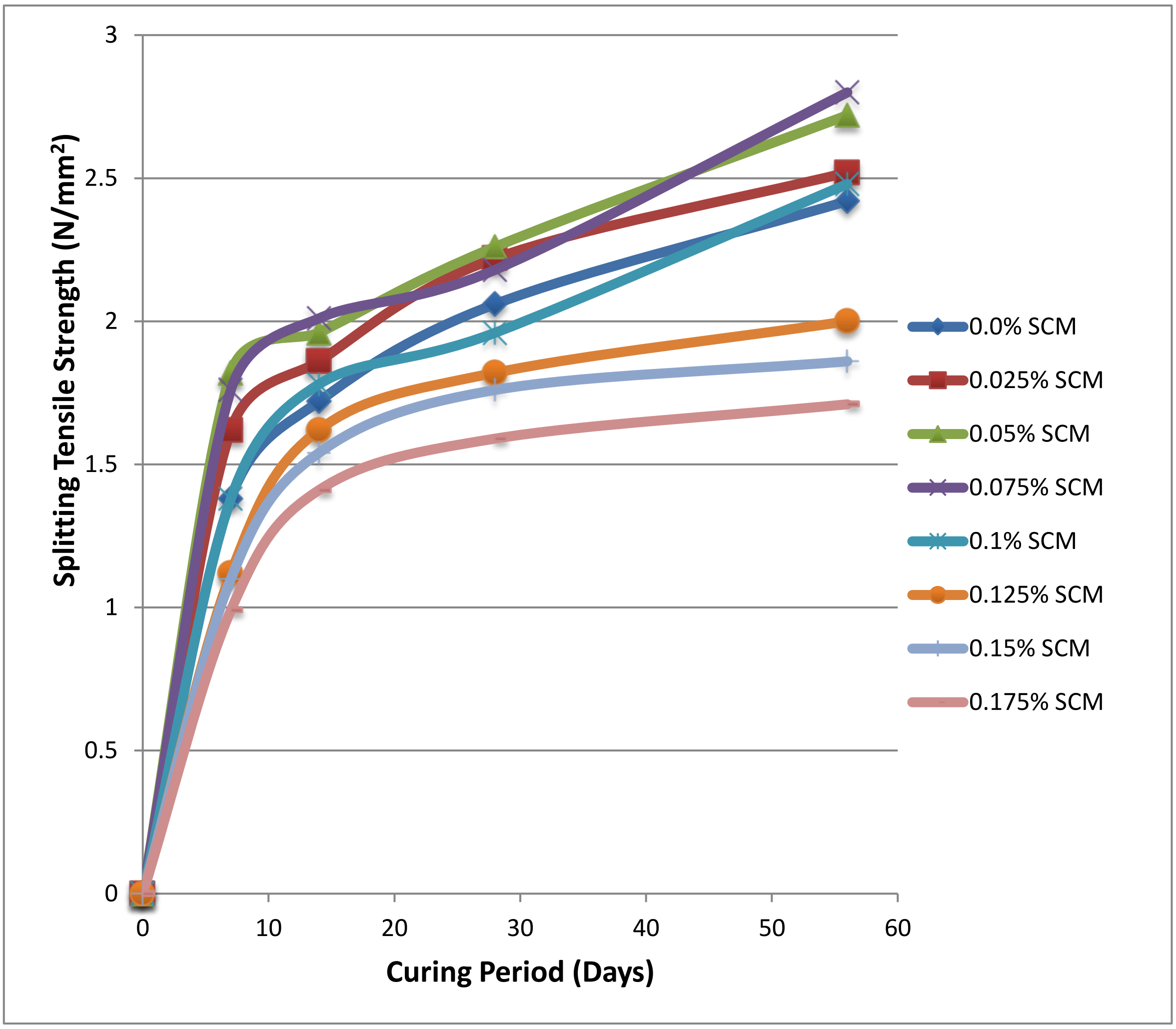

Figure 4.5 Splitting Tensile Strength Vs Curing age at Varying SCM Contents

4.2.5.2 Splitting tensile strength results for the SCM-Concrete

Figure 4.6 gives the graphical presentation of the information in Table 4.6. It gives the graph of splitting tensile strength of the SCM-concrete with respect to the SCM content.

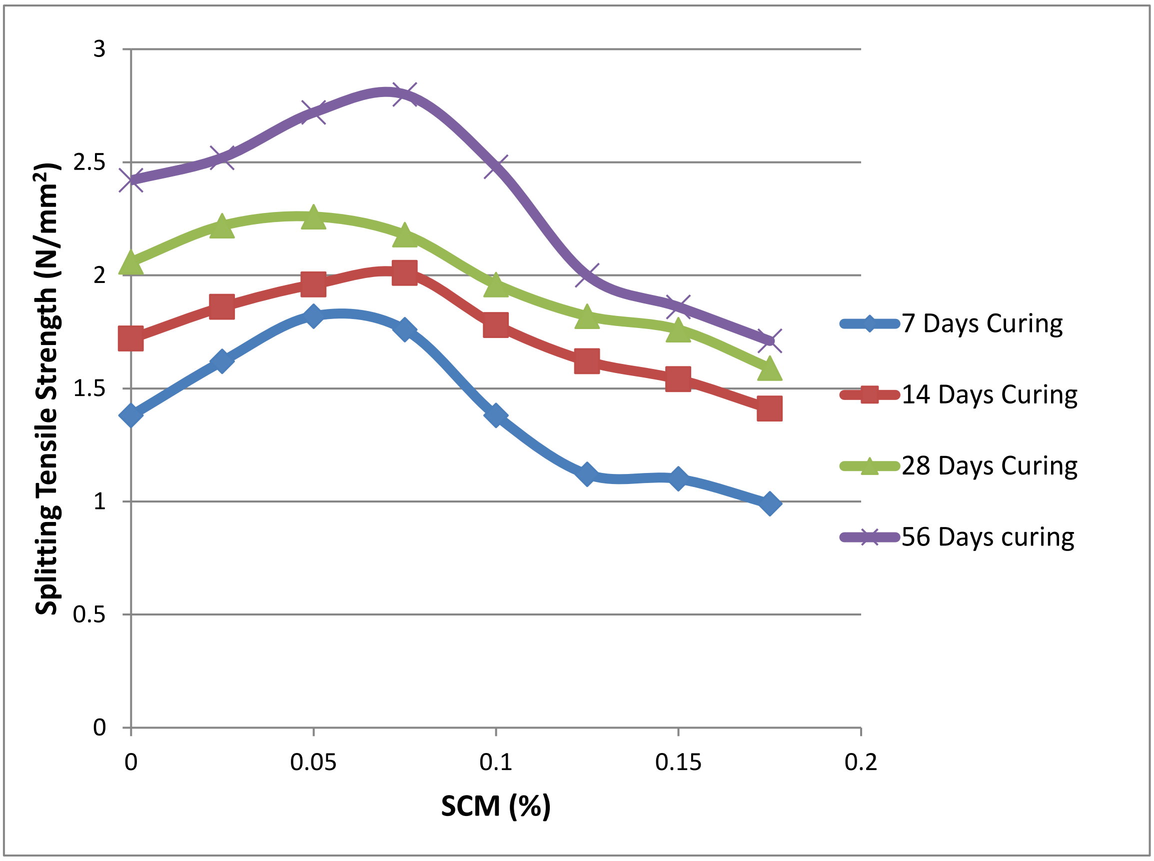

Figure 4.6 Splitting tensile strength Vs SCM (%) at varying curing ages.

Table 4.7 shows the percentage change in SCM-Concrete strengths at each curing days as calculated from Table 4.6.

Table 4.7 Percentage Change in SCM-Concrete Strengths at Each Curing Days

Change in splitting tensile strength (%)				
SCM (%)	Curing period (days)			
	7	14	28	56
0.0	0	0	0	0
0.025	17.39	8.14	7.77	4.13
0.05	31.88	13.95	9.71	12.40
0.075	27.54	16.86	5.83	15.70
0.1	0	3.49	-4.85	2.48
0.125	-18.84	-5.81	-11.65	-17.36
0.15	-20.29	-10.47	-14.56	-23.14
0.175	-28.26	-18.02	-22.82	-29.34

ASTM C 494, 1999 states that the decrease in the strength of concrete with admixture should not be more than 10 percent of the control strength. Therefore, those percentages of SCM with strengths decrease more than that should not be considered in structural concrete work i.e. 0.125%, 0.15% and 0.175% but can still be used for non-structural purposes. But ASTM C 618; 2009 states that the decrease in the strength of concrete with admixture or partial replacement of cement, (the Pozzolanic or organic activity index of the material) should not be more than 25 percent of the control. Therefore, 0.175% SCM should not be considered in structural concrete works for 7 and 56 days curing period or can find application in non-structural concretes. But can consider for 14 and 28 days of curing.

For the tensile strengths at all ages and SCM content of up to 0.125 %, the strength of concrete is satisfied. Above 0.125 % SCM, the strength of concrete is satisfied at 28 days and above for 0.15 % SCM, and only at 56 days for 0.175 % SCM.

CHAPTER FIVE

CONCLUSIONS AND RECOMMMENDATIONS

Based on the results obtained, and discussed, the following conclusions are drawn and recommendations made as follows:

5.1. CONCLUSIONS

1. The physical properties of the constituents of the concrete are suitable for concreting as it satisfies the recommendations of the respective Standards and Organizations.
2. SCM retards the setting time and improves or increases the workability of the cement-SCM paste.
3. SCM increases the compressive and splitting tensile strength of the concrete up to 0.075% of SCM, while the strength reduces beyond.

5.2 RECOMMENDATIONS

From the results of this study, the following recommendations are made.

1. Sugar cane mill could be used as retarding admixture in concrete.
2. The SCM could be used as plasticizer, as it highly increased the workability of concrete with negligible increased in water content.
3. Due to the plasticizing behavior of the admixture, it can be used in special concretes; particularly where a highly workable concrete is required, such as light weight or self-compacted concrete i.e. where compaction is not required.
4. The 0.075 % of SCM could be used in concrete, if more strength is required with respect to the designed concrete’s strength.

5. Correct percentage of SCM in concrete must be correctly chosen as too much of SCM in concrete will be detrimental to the concrete.
6. Further research could investigate the microscopic properties of the concrete with higher percentages of the SCM i.e. beyond 0.175 % which were found to be dissolving in water during curing for several trials cast.

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APPENDICES; APPENDIX A, APPENDIX B AND APPENDIX C

APPENDIX A

TESTS ON MATERIALS, CONCRETE DESIGN AND BATCING DETAILED CALCULATIONS

1. Sieve Analysis for Fine and Coarse Aggregate

Further analysis of results of fine and coarse aggregate test was carried out to determine the zone and particle size distribution from Tables A1 and A2 also from Tables A3 and A4 respectively.

Table A1 Sieve Analysis Test Results for Fine Aggregate

Sieve size (mm / µm)	Mass retained (g)	Cumulative Mass retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage passing (%)
14	0	0	0	0	100
10	0	0	0	0	100
6.4	11	11	1.1	1.1	98.9
5.0	11.42	22.42	1.42	2.52	97.48
3.35	33.39	55.81	3.34	5.86	94.14
2	79.01	134.82	7.90	13.76	86.24
1.18	133.54	268.36	13.35	27.11	72.89
600 µm	255.37	523.73	25.54	52.65	47.35
425 µm	139.33	663.06	13.93	66.58	33.42
300 µm	127.30	790.36	12.73	79.31	20.69
212 µm	78.43	868.79	7.84	87.15	12.85
150 µm	65.11	933.9	6.51	93.66	6.34
75 µm	52.48	986.38	5.25	98.91	1.09
Receiver	12.64	999.02	1.09	100	0

Table A2 Further Analysis of Sieve Test Results for Fine Aggregate

			Initial Weght (gm)		1000
Particle Description		Diameter (mm)	Weight (gm)	Retained %	Passing %
Cobbles		86	0	0.00	100.00
		75	0	0.00	100.00
		63	0	0.00	100.00
Gravel	Coarse	50	0	0.00	100.00
		20	0	0.00	100.00
		14	0	0.00	100.00
		10	0	0.00	100.00
		6.3	11	1.10	98.90
	Fine	5.0	11.42	1.14	97.76
		3.4	33.4	3.34	94.42
		2.0	79.0	7.90	86.52
Sand	Coarse	1.2	133.5	13.35	73.16
		0.6	255.4	25.54	47.63
	Medium	0.425	139.3	13.93	33.69
		0.3	127.3	12.73	20.96
		0.212	78.4	7.84	13.12
	Fine	0.15	65.1	6.51	6.61
		0.075	52.5	5.25	1.36
	clay or Silt	Pass 75 microns	12.6	1.26	0.00
			999.02	0	

Gravel =	14.16%	
Coarse Sand =	40.85%	Sand 84.51%
Medium Sand =	36.25%	
Fine Sand =	7.41%	
Fines =	1.33%	

Table A3 Sieve Analysis Test Results for Coarse Aggregate

Sieve size (mm)	Mass retained (g)	Cumulative Mass retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage passing (%)
28	31.21	31.21	1.56	1.56	98.44
20	482.6	513.81	24.13	25.96	74.31
14	1070.99	1584.8	53.55	79.24	20.76
10	391.96	1976.76	19.60	98.84	1.16
6.30	14.73	1991.49	0.74	99.58	0.42
5.0	0.33	1991.82	0.02	99.6	0.4
3.3	3	1994.82	0.15	99.75	0.25
2	2	1996.82	0.1	99.85	0.15
R	3.16	1999.98	0.15	100	0

Table A4 Further Sieve Analysis Test Results for Coarse Aggregate

			Initial Weght (g)		2000
Particle Description		Diameter (mm)	Weight (gm)	Retained %	Passing %
Cobbles		86	0	0.00	100.00
		75	0	0.00	100.00
		63	0	0.00	100.00
Gravel	Coarse	28	31.21	3.12	98.0
		20	482.16	7.60	92.40
		14	1070.98	72.10	20.30
		10	391.94	19.20	1.10
		6.3	14.73	0.45	0.65
	Fine	5.0	0.33	0	0.65
		3.4	3.0	0	0.65
		2.0	5.45	0.40	0.25
Sand	Coarse	1.2	0	0.0	0
		0.6	0	0	0
	Medium	0.425	0	0	0
		0.3	0	0	0
		0.212	0	0	0
	Fine	0.15	0	0	0
		0.075	0	0	0
	clay or Silt	Pass 75 microns	0	0	0.00
			1999.8	0	

Cobbles =	0.0%	
Coarse Gravel=	25.68%	Gravel 99.58%
Medium Gravel =	73.90%	
Fine Gravel =	0.0%	
Fine Sand=	0.42%	

2. Aggregate Crushing Value Detailed Calculation

The coarse aggregates crushing value test results were obtained in the laboratory and the detailed calculations of the aggregate crushing value are carried out using the following relationship.

$$\text{Aggregate crushing value} = (W_2 \times 100) / (W_1 - W) \quad (3.1)$$

W = Mass of mould

W_1 = Mass of mould + Sample

W_1-W = Mass of surface dry sample.

W_2 = Mass of fractions passed through 2.36 mm sieve.

The mean of three results to nearest whole number is the aggregate crushing value.

Aggregate crushing value = (W_2 x 100) / (W_1-W). (3.1)

Table A5 Aggregate Crushing Value Test Results

Description	Coarse aggregate samples		
	A	B	C
Mass of mould (W)	3183.4	3183.4	3183.4
Mass of mould + sample (W_1)	6031.1	6007.1	6016.1
Mass of sample (W_1-W)	2847.7	2823.7	2832.7
Mass passing 2.36 mm sieve (W_2)	676.5	698.4	724.5

<u>For sample A</u>

Mass of mould (W) = 3183.4 g

Mass of mould + sample (W_1) = 6031.1 g

Mass of sample (W_1-W) = 6031.1 - 3183.4 = 2847.7 g

Mass passing 2.36 mm sieve (W_2) = 676.5 g

Aggregate crushing value = $\frac{676.5}{2847.7}$ x 100% = 23.8 %

<u>For sample B</u>

Mass of mould (W) = 3183.4 g

Mass of mould + sample (W_1) = 6007.1 g;

Mass of sample (W_1-W) = 6007.1 - 3183.4 = 2823.7 g

Mass passing 2.36 mm sieve (W_2) = 698.4 g

Aggregate crushing value = $\frac{698.4}{2823.7}$ x 100% = 24.7 %

<u>For sample C</u>

Mass of mould (W) = 3183.4 g

Mass of mould + sample (W_1) = 6016.1 g

Mass of sample (W_1-W) = 6016.1 - 3183.4 = 2832.7 g

Mass passing 2.36 mm sieve (W_2) = 724.5 g

Aggregate crushing value = $\frac{724.5}{2832.7}$ x 100% = 25.6 %

Average aggregates crushing value = $\frac{(23.8 + 24.7 + 25.6)}{3}$

Average aggregate crushing value = $\frac{74.1}{3}$ = 24.7 % . Therefore ACV = 24.70 %

Appendix A, Table A6 presents the summary of the above calculated ACV values

Table A6 Summary of Aggregate Crushing Value

Aggregate crushing value (%)	Samples		
	A	B	C
	23.8	24.7	25.6
Average ACV (%)	24.7		

3. Standard Consistency Test Results

Table A7 Consistency Test Results (0 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	26.46	105.84	7.8	Inconsistent
2	400	37.78	151.12	4.6	Inconsistent
3	400	30.5	122	6	Consistent
4	Setting time (Minutes)			Initial	100
				Final	250

Table A8 Consistency Test Results (0.025 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	23.6	94.4	7.8	Inconsistent
2	400	35.4	141.6	5.2	Consistent
3	400	31.38	125.52	5.9	More consistent
4	Setting time (Minutes)			Initial	119
				Final	266

Table A9 Consistency Test Results (0.05 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	27.23	108.92	7.2	Inconsistent
2	400	39.40	157.6	4.7	Consistent
3	400	31.38	125.52	5.8	More consistent
4	Setting time (Minutes)			Initial	120
				Final	163

Table A10 Consistency Test Results (0.075 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	38.8	155.2	4.7	Inconsistent
2	400	34.49	137.96	5.4	Consistent
3	400	31.04	124.16	6	More consistent
4	Setting time (Minutes)			Initial	127
				Final	168

Table A11 Consistency Test Results (0.1 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	39.03	156.12	4.8	Inconsistent
2	400	27.15	108.60	6.9	Consistent
3	400	30.91	123.64	6.1	More consistent
4	Setting time (Minutes)			Initial	134
				Final	265

Table A12 Consistency Test Results (0.125 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	26.54	106.16	7.2	Inconsistent
2	400	37.68	150.72	5	Consistent
3	400	30.7	122.8	6.3	More consistent
4	Setting time (Minutes)			Initial	139
				Final	270

Table A13 Consistency Test Results (0.15 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	27.07	108.28	7	Consistent
2	400	31.58	126.32	6	More consistent
3	Setting time (Minutes)			Initial	146
				Final	276

Table A14 Consistency Test Results (0.175 % SCM)

Test number	Weight of cement (g)	Water content (% of cement)	Equivalent volume of water (ml)	Plunger penetration above the bottom of the sample (mm)	Remark
1	400	35.88	143.52	4.7	Inconsistent
2	400	32.85	131.4	5.8	Consistent
3	Setting time (Minutes)			Initial	152
				Final	279

4. DoE Method of Concrete Design

DoE Method Requirements:

(1) Characteristic strength = 30 N/mm^2 at 28 days to CP 110 (5% defective, K = 1.64)

(2) Cement type is ordinary Portland cement (OPC)

(3) Slump = 10 – 30 mm (assumed)

(4) Maximum aggregate size = 20 mm

(5) Maximum free water/cement ratio = 0.55 (assumed)

(6) Minimum Cement content = 300 kg/m^3 (assumed)

(7) Aggregate (a) fine –natural sand with relative density (SSD) of 2.6 (assumed)

(b) Coarse – crushed granite with relative density (SSD) of 2.7 (assumed)

(8) Standard deviation, S = 8 N/mm^2

Step one

(i) Characteristic strength = 30 N/mm^2 at 28 days

(ii) Standard deviation, S = 8 N/mm^2

(iii) Margin = K x S

= 1.64 x 8

= 13 N/mm^2

(iv) Target mean strength = 30 + 13 = 43 N/mm^2

(v) Cement type is ordinary Portland cement (OPC).

(vi) From Table C1 (Appendix C), for ordinary Portland cement and crushed coarse aggregate the 28-day strength is 47 N/mm^2. From Figure C1 (Appendix C), the water/cement ratio = 0.53

(vii) Specified maximum free water/cement ratio = 0.55

The lower of the values from (vi) and (vii) should be used. Therefore, the free water/cement ratio for the mix design is 0.53.

Step two

(i) Specified Slump = 10 – 30 mm

(ii) Specified Maximum aggregate size = 20 mm

(iii) From Table C2 (Appendix C), the free water content = 190 $kg/m^{3.}$

Step three

(i) The cement content is 190/0.53 = 358.5 kg/m^3

(ii) Maximum cement content not specified

(iii) Minimum cement content = 300 kg/m^3

(iv) Modified free water/cement =Nil (358.5 > 300)

Step four

(i) Relative density of aggregate (SSD) = 2.7 (Appendix C, Figure C2)

(ii) Free water content = 190 kg/m^3 (Appendix C, Table C2)

Concrete density = 2435 kg/m^3

(iii) Total aggregate content = 2435 – 358.5 – 190

= 1886.5 kg/m^3

Step five

(i) Grading of fine aggregate = Zone 2 (Figure 3.1)

(ii) Proportion of fine aggregate = 30.5 to 38 % (Appendix C, Figure C3)

= say 35 %

(iii) Fine aggregate content = 0.35 x 1886.5

= 660.27 kg/m^3

= say 660 kg/m^3

(iv) Coarse aggregate content = 1886.5 – 600 = 1226.5 kg/m^3

The results of the above concrete mix design is tabulated in Table 3.1 above.

5. Batching of Constituents for Compressive Strength Test

For compressive strength test, the batching of the concrete was carried out as follows:

Volume of cube mould = 150 mm x 150 mm x 150 mm = 0.003375 m^3

Add 15% for waste, the volume of materials mixed is obtained as follows:

Volume of materials mixed = 0.003375 + 0.15 x 0.003375

= 3.88125×10^{-3} m^3

(i) For 12 cubes with 0% of sugar cane mill

Free water content = 190 x 3.88125×10^{-3} m^3 x 12 = 8.849 kg

Cement = 358.5 x 3.88125×10^{-3} m^3 x 12 = 16.697 kg

Coarse aggregate = 1226.5 x 3.88125×10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125×10^{-3} m^3 x 12 = 30.740 kg

(ii) For 12 cubes with 0.025% of sugar cane mill

Free water content = 190 x 3.88125×10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A8)

= 8.849 kg + (1.8/100) x 8.849 kg

= 8.849 kg + 0.159282 kg = 9.008 kg

Cement = 358.5 x 3.88125×10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.025/100) x 16.697 kg = 4.17 g

Coarse aggregate = 1226.5 x 3.88125×10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125×10^{-3} m^3 x 12 = 30.740 kg

(iii) For 12 cubes with 0.05% of sugar cane mill

Free water content = 190 x 3.88125×10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A9)

= 8.849 kg + (0.88/100) x 8.849 kg

= 8.849 kg + 0.0778712 kg = 8.927 kg

Cement = 358.5 x 3.88125 x 10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.04/100) x 16.697 kg = 8.35 g

Coarse aggregate = 1226.5 x 3.88125 x 10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125 x 10^{-3} m^3 x 12 = 30.740 kg

(iv) For 12 cubes with 0.075% of sugar cane mill

Free water content = 190 x 3.88125 x 10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A10)

= 8.849 kg + (0.54/100) x 8.849 kg

= 8.849 kg + 0.0477846 kg = 8.897 kg

Cement = 358.5 x 3.88125 x 10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.075/100) x 16.697 kg = 12.52 g

Coarse aggregate = 1226.5 x 3.88125 x 10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125 x 10^{-3} m^3 x 12 = 30.740 kg

(v) For 12 cubes with 0.1% of sugar cane mill

Free water content = 190 x 3.88125 x 10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A11)

= 8.849 kg + (0.41/100) x 8.849 kg

= 8.849 kg + 0.0362809 kg = 8.885 kg

Cement = 358.5 x 3.88125 x 10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.1/100) x 16.697 kg = 16.70 g

Coarse aggregate = 1226.5 x 3.88125 x 10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125 x 10^{-3} m^3 x 12 = 30.740 kg

(vi) <u>For 12 cubes with 0.125% of sugar cane mill</u>

Free water content = 190 x 3.88125 x 10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A12)

= 8.849 kg + (0.20/100) x 8.849 kg

= 8.849 kg + 0.017698 kg = 8.867 kg

Cement = 358.5 x 3.88125 x 10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.125/100) x 16.697 kg = 20.87 g

Coarse aggregate = 1226.5 x 3.88125 x 10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125 x 10^{-3} m^3 x 12 = 30.740 kg

(vii) <u>For 12 cubes with 0.15% of sugar cane mill</u>

Free water content = 190 x 3.88125 x 10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A13)

= 8.849 kg + (1.08 /100) x 8.849 kg

= 8.849 kg + 0.0955692 kg = 8.945 kg

Cement = 358.5 x 3.88125 x 10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.15/100) x 16.697 kg = 25.05 g

Coarse aggregate = 1226.5 x 3.88125 x 10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125 x 10^{-3} m^3 x 12 = 30.740 kg

(viii) <u>For 12 cubes with 0.175% of sugar cane mill</u>

Free water content = 190 x 3.88125 x 10^{-3} m^3 x 12 + percentage increase of water (From Appendix A, Table A14)

= 8.849 kg + (2.32 /100) x 8.849 kg

= 8.849 kg + 0.2052968 kg = 9.054 kg

Cement = 358.5 x 3.88125 x 10^{-3} m^3 x 12 = 16.697 kg

Sugar cane mill = (0.175/100) x 16.697 kg = 29.22 g

Coarse aggregate = 1226.5 x 3.88125 x 10^{-3} m^3 x 12 = 57.124 kg

Fine aggregate = 660 x 3.88125 x 10^{-3} m^3 x 12 = 30.740 kg

6. Batching of Constituents for Split Tensile Strength Test

For tensile splitting test, the batching of concrete was carried out as follows:

Diameter of the cylinder = 8.0 cm = 0.08 m

Radius of the cylinder = 4.0 cm = 0.04 m

Length or height of the cylinder = 25 cm = 0.25 m

Therefore, Volume of cylinder = $\pi r^2 h$

$$= \frac{22}{7} \text{ x } (0.04)^2 \text{ x } 0.25 \text{ m}^3 = 0.0012571429 \text{ m}^3$$

Add 10% for waste, the volume of material mixed was obtained as follows:

Volume of material mixed = 0.0012571429 m^3 + 0.1 x 0.0012571429 m^3

= 0.0012571429 m^3 + 0.00011257143 m^3

= 1.3828572 x 10^{-3} m^3

(i) <u>For 12 cylinders with 0% of sugar cane mill</u>

Free water content = 190 x 1.3828572 x $10^{-3}$$m^3$ x 12 = 3.153 kg

Cement = 358.5 x 1.3828572 x $10^{-3}$$m^3$ x 12 = 5.949 kg

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(ii) For 12 cylinders with 0.025% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A8)

= 3.153 kg + (1.8 /100) x 3.153 kg

= 3.153 kg. + 0.056754 kg = 3.210 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.025/100) x 5.949 kg = 1.49 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(iii) For 12 cylinders with 0.05% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A9)

= 3.153 kg + (0.88/100) x 3.153 kg

= 3.153 kg. + 0.0277464 kg = 3.181 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.05/100) x 5.949 kg = 2.98 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(iv) For 12 cylinders with 0.075% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A10)

= 3.153 kg + (0.54/100) x 3.153 kg

= 3.153 kg. + 0.0170262 kg = 3.170 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.075/100) x 5.949 kg = 4.46 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(v) For 12 cylinders with 0.1% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A11)

= 3.153 kg + (0.41/100) x 3.153 kg

= 3.153 kg. + 0.0129273 kg = 3.166 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.1/100) x 5.949 kg = 5.95 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(vi) For 12 cylinders with 0.125% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A12)

= 3.153 kg + (0.20/100) x 3.153 kg

= 3.153 kg. + 0.006306 kg = 3.159 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.125/100) x 5.949 kg = 7.44 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(vii) For 12 cylinders with 0.15% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A13)

= 3.153 kg + (1.08 /100) x 3.153 kg

= 3.153 kg + 0.0340524 kg = 3.187 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.15/100) x 5.949 kg = 8.92 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

(viii) For 12 cylinders with 0.175% of sugar cane mill

Free water content = 190 x 1.3828572 x 10^{-3} x 12 + percentage increase of water (From Appendix A, Table A14)

= 3.153 kg + (2.32 /100) x 3.153 kg

= 3.153 kg. + 0.0731496 kg = 3.226 kg

Cement = 358.5 x 1.3828572 x 10^{-3} m^3 x 12 = 5.949 kg

Sugar cane mill = (0.175/100) x 5.949 g = 10.41 g

Coarse aggregate = 1226.5 x 1.3828572 x 10^{-3} m^3 x 12 = 20.353 kg

Fine aggregate = 660 x 1.3828572 x 10^{-3} m^3 x 12 = 10.952 kg

APPENDIX B

SPECIFIC GRAVITY, pH VALUE AND STRENGTH TESTS DETAILED CALCULATIONS

1 - Specific Gravity of SCM

The specific gravity test results obtained in the laboratory was presented in Table 3.4 above. The detailed calculations of the specific gravity value are carried out using the following relationship.

$$Gs = \frac{\text{weight of solids}}{\text{weight of equal volume of water}}$$

$$G_s = \frac{(W2 - W1)}{(W4 - W1) - (W3 - W2)} \qquad (3.2)$$

Where;

w_1 = weight of empty pycnometer bottle

w_2 = weight of pycnometer bottle + sample

w_3 = weight of pycnometer bottle + sample + water

w_4 = weight of empty pycnometer bottle + water

Table B1 Specific Gravity Test Results for SCM

Weight Wn (g)	Sugar cane mill (SCM) samples		
	A	B	C
w_1	1016	1016	1016
w_2	1124	1136	1106
w_3	2339	2346	2302
w_4	2317	2317	2317

For sample A:

w_1 = 19.09 g w_2 = 26.89 g w_3 = 72.73 g w_4 = 69.89 g

$$G_s = \frac{(26.89 - 19.09)}{(69.89 - 19.09) - (72.73 - 26.89)} = \frac{7.8}{50.8 - 54.84} = \frac{7.8}{4.96}$$

$G_s = 1.57$

For sample B

w_1 = 19.24 g w_2 = 26.19 g w_3 = 72.39 g w_4 = 69.89 g

$$G_s = \frac{(26.19 - 19.24)}{(69.89 - 19.24) - (72.39 - 26.19)} = \frac{6.95}{50.65 - 46.2} = \frac{6.95}{4.45}$$

$G_s = 1.56$

For sample C:

w_1 = 19.27 g w_2 = 28.17 g w_3 = 73.10 g w_4 = 69.86 g

$$G_s = \frac{(28.17 - 19.27)}{(69.86 - 19.27) - (73.10 - 28.17)} = \frac{8.9}{50.59 - 44.93} = \frac{8.9}{5.66} \quad G_s = 1.57$$

Average specific gravity (G_s) $= \frac{(1.57 + 1.56 + 1.57)}{3} = \frac{(4.7)}{3}$

Therefore, the specific gravity of SCM (G_s) = 1.57

2 - Specific Gravity of Kerosene

$G_s = \frac{(W2 - W1)}{(W3 - W1)}$

(3.3)

Where;

w_1 = weight of empty pycnometer bottle

w_2 = weight of pycnometer bottle + kerosene

w_3 = weight of pycnometer bottle + water

Table B2 Specific Gravity Test Results for Kerosene

Weight Wn (g)	Kerosene samples		
	A	B	C
w_1	19	19	19
W_4	60	60	60
W_5	69	69	68

<u>For sample A:</u>

w_1 = 19 g w_2 = 60 g w_3 = 69 g

$G_s = \frac{(60-19)}{(69-19)} = \frac{41}{50} = 0.82$ ∴ $G_s = 0.82$

<u>For sample B</u>

w_1 = 19 g w_2 = 60 g w_3 = 69 g

$G_s = \frac{(60-19)}{(69-19)} = \frac{41}{50} = 0.82$

$G_s = 0.82$

<u>For sample C:</u>

$w_1 = 19$ g $w_2 = 60$ g $w_3 = 68$ g

$$G_s = \frac{(60 - 19)}{(68 - 19)} = \frac{41}{49} = 0.84$$

$G_s = 0.84$

Average specific gravity (G_{sk}) = $\frac{(0.82 + 0.82 + 0.84)}{3} = \frac{(2.48)}{3}$

Therefore, the specific gravity of kerosene (G_{sk}) = 0.83

3 - Specific Gravity of Cement

$$G_s = \frac{(W2 - W1)}{(W4 - W1) - (W3 - W2)} \times (G_{sk}) \quad (3.4)$$

Where;

w_1 = weight of empty pycnometer bottle

w_2 = weight of pycnometer bottle + sample

w_3 = weight of pycnometer bottle + sample + kerosene

w_4 = weight of empty pycnometer bottle + kerosene

(G_{sk}) = Specific gravity of kerosene

Table B3 Specific Gravity Test Results for Cement

Weight Wn (g)	Cement samples		
	A	B	C

w_1	19	19	19
w_2	42	49	45
w_3	77	82	79
w_4	60	60	60

<u>For sample A:</u>

w_1 = 19 g w_2 = 42 g w_3 = 77 g w_4 = 60 g

$$G_s = \frac{(42 - 19)}{(60 - 19) - (77 - 42)} = \frac{23}{41 - 35} = \frac{23}{6}$$

G_s = 3.83 × 0.83 = 3.1789

G_s = 3.18

<u>For sample B</u>

w_1 = 19 g w_2 = 49 g w_3 = 82 g w_4 = 60 g

$$G_s = \frac{(49 - 19)}{(60 - 19) - (82 - 49)} = \frac{30}{41 - 33} = \frac{30}{8}$$

G_s = 3.75 × 0.83 = 3.1125

G_s = 3.11

<u>For sample C:</u>

w_1 = 19 g w_2 = 45 g w_3 = 79 g w_4 = 60 g

$$G_s = \frac{(45 - 19)}{(60 - 19) - (79 - 45)} = \frac{26}{41 - 34} = \frac{26}{7}$$

G_s = 3.71 × 0.83 = 3.0793

G_s = 3.10

Average specific gravity (G_s) = $\frac{(3.18 + 3.11 + 3.10)}{3}$ = $\frac{(9.39)}{3} = 3.13$

Therefore, the specific gravity of cement (G_s) = 3.13

4 - Specific Gravity of Fine Aggregate

$$G_s = \frac{(W2 - W1)}{(W4 - W1) - (W3 - W2)} \qquad (3.2)$$

Where;

w_1 = weight of empty gas jar

w_2 = weight of gas jar + sample

w_3 = weight of gas jar + sample + water

w_4 = weight of gas jar + water

Table B4 Specific Gravity Test Results for Fine Aggregate

Weight Wn (g)	Fine aggregate samples		
	A	B	C
w_1	1049	1049	1049
w_2	1549	1549	1549
w_3	2640	2644	2646
w_4	2333	2333	2333

For sample A:

w_1 = 1049 g w_2 = 1549 g w_3 = 2640 g w_4 = 2333 g

$$G_s = \frac{(1549 - 1049)}{(2333 - 1049) - (2640 - 1549)} = \frac{500}{1284 - 1091} = \frac{500}{193}$$

$G_s = 2.59$

For sample B

w_1 = 1049 g w_2 = 1549 g w_3 = 2644 g w_4 = 2333 g

$$G_s = \frac{(1549 - 1049)}{(2333 - 1049) - (2644 - 1549)} = \frac{500}{1284 - 1095} = \frac{500}{189}$$

$G_s = 2.65$

<u>For sample C:</u>

w_1 = 1049 g w_2 = 1549 g w_3 = 2646 g w_4 = 2333 g

$$G_s = \frac{(1549 - 1049)}{(2333 - 1049) - (2646 - 1549)} = \frac{500}{1284 - 1095} = \frac{500}{187} \qquad G_s = 2.67$$

Average specific gravity (G_s) = $\frac{(2.67 + 2.65 + 2.59)}{3} = \frac{(7.91)}{3}$

Therefore, the specific gravity of fine aggregate (G_s) = 2.64

5 - Specific Gravity of Coarse Aggregate

Table B5 Specific Gravity Test Results for Coarse Aggregate

Weight Wn (g)	Coarse aggregate samples		
	A	B	C
w_1	1049	1049	1049
w_2	2049	2049	2049
w_3	2969	2962	2966
w_4	2333	2333	2333

<u>For sample A:</u>

w_1 = 1049 g w_2 = 2049 g w_3 = 2969 g w_4 = 2333 g

$$G_s = \frac{(2049 - 1049)}{(2333 - 1049) - (2969 - 2049)} = \frac{1000}{1284 - 920} = \frac{1000}{364}$$

$G_s = 2.75$

<u>For sample B</u>

w_1 = 1049 g w_2 = 2049 g w_3 = 2962 g w_4 = 2333 g

$$G_s = \frac{(2049 - 1049)}{(2333 - 1049) - (2962 - 2049)} = \frac{1000}{1284 - 913} = \frac{1000}{371}$$

$G_s = 2.70$

<u>For sample C:</u>

w_1 = 1049 g w_2 = 2049 g w_3 = 2966 g w_4 = 2333 g

$$G_s = \frac{(2049 - 1049)}{(2333 - 1049) - (2966 - 2049)} = \frac{1000}{1284 - 917} = \frac{1000}{367}$$

$G_s = 2.73$

Average specific gravity (G_s) = $\frac{(2.75 + 2.70 + 2.73)}{3} = \frac{(8.18)}{3}$

Therefore, the specific gravity of coarse aggregate (G_s) = 2.73

Table B6 presents the summary of the calculated specific gravity values for SCM, cement, fine and coarse aggregate.

Table B6: Summary of the specific gravity values for SCM, cement, fine and coarse aggregate

Material	Samples			Average specific gravity
	A	B	C	

SCM	1.57	1.56	1.57	1.57
Kerosene	0.82	0.82	0.84	0.83
Cement	3.18	3.11	3.10	3.13
Fine aggregate	2.59	2.65	2.67	2.64
Coarse aggregate	2.75	2.70	2.73	2.73

6 - pH Value Test Results for Casting and Curing Water

Table B7 pH Test Results for Water Used in Casting the Concrete

Sample No.	Temperature of sample (ºC)	pH
1	32	8.3
2	32	8.2
3	32	8.2
Average pH	8.23	

Table B8 pH Test Results for Water Used in Curing the Concrete, (Before the curing)

Sample No.	Temperature of sample (ºC)	pH
1	34	8.2
2	34	8.4
3	34	8.2
Average pH	8.27	

7 - Compressive Strength Detail Calculations

The compressive strength tests results at 7, 14, 28 and 56 curing periods are analyzed and presented in Tables B9, B10, B11 and B12 respectively.

Table B9 Compressive Strength Test Results at 7-Day Curing Period

SCM (%)	Cube identity mark	Weight (g)	Failure load (kN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Change in compressive strength (N/mm^2)	Change in compressive strength (%)
0	A7	7788	730	32.44	31.11	0	
	B7	8720	670	29.78			
	C7	8354	700	31.11			0
0.025	D7	8632	710	31.56	32.44	1.33	
	E7	8380	750	33.33			
	F7	8256	730	32.44			4.28
0.05	G7	8192	740	32.89	33.78	2.67	8.58
	H7	8621	780	34.67			
	I7	8654	760	33.78			
0.075	J7	8868	690	30.67	31.11	0	0
	K7	8649	700	31.11			
	L7	7975	710	31.56			
0.1	M7	8592	660	29.33	28.59	-2.52	-8.10
	N7	8917	640	28.44			
	O7	8184	630	28			
0.125	P7	8686	600	26.67	27.56	-3.55	-11.41
	Q7	7928	610	27.11			
	R7	8621	650	28.89			
0.15	S7	8289	439	19.51	18.09	-13.02	-41.85
	T7	8472	372	16.53			
	U7	8567	410	18.22			
0.175	V7	8414	270	12	11.99	-19.12	-61.56
	W7	8394	275	12.22			
	X7	8408	264	11.73			

Table B10 Compressive Strength Test Results at 14-Day Curing Period

SCM (%)	Cube identity mark	Weight (g)	Failure load (kN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Change in compressive strength (N/mm^2)	Change in compressive strength (%)
0	A14	8855	720	32	32.59	0	0
	B14	8661	750	33.33			
	C14	8893	730	32.44			
0.025	D14	8720	750	33.33	33.48	0.89	2.73
	E14	8372	720	32			
	F14	8243	790	35.11			
0.05	G14	8232	760	33.78	34.52	1.93	5.92
	H14	8537	820	36.44			
	I14	8246	750	33.33			
0.075	J14	8676	880	39.11	36.59	4	12.27
	K14	8456	760	33.78			
	L14	8845	830	36.89			
0.1	M14	8426	760	33.78	30.79	-1.8	-5.52
	N14	8227	660	29.33			
	O14	7858	658	29.44			
0.125	P14	8765	620	27.56	28.15	-4.44	-13.62
	Q14	8769	640	28.44			
	R14	8762	640	28.44			
0.15	S14	8624	540	24	21.51	-11.08	-34
	T14	8337	439	19.51			
	U14	8581	473	21.02			
0.175	V14	8397	372	16.53	18.52	-14.07	-43.17
	W14	8772	540	24			
	X14	8823	338	15.02			

Table B11 Compressive Strength Test Results at 28-Day Curing Period

SCM (%)	Cube identity mark	Weight (g)	Failure load (kN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Change in compressive strength (N/mm^2)	Change in compressive Strength (%)
0	A28	8660	770	34.22	35.70	0	0
	B28	8870	850	37.78			
	C28	8676	790	35.11			
0.025	D28	8947	890	39.56	39.85	4.15	11.63
	E28	8656	840	37.33			
	F28	8700	960	42.67			
0.05	G28	8834	970	43.11	42.81	7.11	19.92
	H28	8687	950	42.22			
	I28	8329	970	43.11			
0.075	J28	8855	900	40	44	8.3	23.25
	K28	8636	1020	45.33			
	L28	8617	1050	46.67			
0.1	M28	8628	820	36.44	38.82	3.12	8.74
	N28	8580	905	40.22			
	O28	8790	895	39.78			
0.125	P28	8926	730	32.44	33.04	-2.66	-7.45
	Q28	8027	750	33.33			
	R28	8623	750	33.33			
0.15	S28	8567	610	27.11	26.07	-9.63	-26.98
	T28	8665	580	25.78			
	U28	8440	570	25.33			
0.175	V28	8573	490	21.78	22.27	-13.43	-37.62
	W28	8559	574	25.51			
	X28	8809	439	19.51			

Table B12 Compressive Strength Test Results at 56-Day Curing Period

SCM (%)	Cube identity mark	Weight (g)	Failure load (kN)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)	Change in compressive strength (N/mm^2)	Change in compressive Strength (%)
0	A56	8710	860	38.22	41.78	0	0
	B56	8675	1000	44.44			
	C56	8697	960	42.67			
0.025	D56	8842	980	43.56	43.56	1.78	4.45
	E56	8312	990	44			
	F56	8378	970	43.11			
0.05	G56	8581	960	42.67	45.93	4.15	9.93
	H56	8523	1075	47.78			
	I56	8730	1065	47.33			
0.075	J56	8735	1010	44.89	46.97	5.19	12.42
	K56	7982	1060	47.11			
	L56	8652	1100	48.89			
0.1	M56	8468	890	39.56	39.41	-2.37	-5.67
	N56	8611	880	39.11			
	O56	8422	890	39.56			
0.125	P56	8083	700	31.11	33.78	-8	-19.15
	Q56	8529	750	33.33			
	R56	8151	830	36.89			
0.15	S56	8829	600	26.67	27.41	-14.37	-34.40
	T56	8414	642	28.53			
	U56	8944	608	27.02			
0.175	V56	8809	570	25.33	24.62	-17.16	-41.07
	W56	8256	529	23.51			
	X56	8772	563	25.02			

8 - Splitting Tensile Strength Detail Calculations

The splitting tensile strength tests results at 7, 14, 28 and 56 curing periods are analyzed and presented in Tables B13, B14, B15 and B16 respectively.

Table B13 Splitting Tensile Strength Test Results at 7-Day Curing Period

SCM (%)	Cylinder identity mark	Weight (g)	Failure load (kN)	Split tensile strength (N/mm^2)	Average Split tensile strength (N/mm^2)	Change in split tensile strength (N/mm^2)	Change in split tensile strength (%)
0	A7	3410	49	1.56	1.38	0	0
	B7	3429	36	1.15			
	C7	3420	45	1.43			
0.025	D7	3317	54	1.73	1.62	0.24	17.39
	E7	3323	50	1.60			
	F7	3320	48	1.53			
0.05	G7	3280	61	1.94	1.82	0.44	31.88
	H7	3258	54	1.72			
	I7	3269	56	1.78			
0.075	J7	3338	60	1.91	1.76	0.38	27.54
	K7	3257	55	1.75			
	L7	3298	50	1.60			
0.1	M7	3373	41	1.31	1.38	0	0
	N7	3333	47	1.50			
	O7	3353	42	1.34			
0.125	P7	3237	34	1.08	1.12	-0.26	-18.84
	Q7	3219	36	1.15			
	R7	3228	36	1.15			
0.15	S7	3215	39	1.24	1.10	-0.28	-20.29
	T7	3210	30	0.96			
	U7	3248	35	1.11			
0.175	V7	3131	35	1.11	0.99	-0.39	-28.26
	W7	3255	28	0.80			
	X7	3302	30	0.96			

Table B14 Splitting Tensile Strength Test Results at 14-Day Curing Period

SCM (%)	Cylinder identity mark	Weight (g)	Failure load (kN)	Split tensile strength (N/mm^2)	Average Split tensile strength (N/mm^2)	Change in split tensile strength (N/mm^2)	Change in split tensile strength (%)
0	A14	3433	47	1.50	1.72	0	0
	B14	3285	60	1.91			
	C14	3359	55	1.75			
0.025	D14	3233	60	1.91	1.86	0.14	8.14
	E14	3284	62	1.97			
	F14	3259	53	1.67			
0.05	G14	3224	64	2.04	1.96	0.24	13.95
	H14	3343	57	1.81			
	I14	3284	63	2.00			
0.075	J14	3358	64	2.04	2.01	0.29	16.86
	K14	3234	60	1.91			
	L14	3296	65	2.07			
0.1	M14	3230	59	1.88	1.78	0.06	3.49
	N14	3258	56	1.78			
	O14	3244	53	1.69			
0.125	P14	3235	51	1.62	1.62	-0.1	-5.81
	Q14	3413	54	1.72			
	R14	3324	48	1.53			
0.15	S14	3132	49	1.56	1.54	-0.18	-10.47
	T14	3248	54	1.72			
	U14	3226	42	1.34			
0.175	V14	3352	44	1.40	1.41	-0.31	-18.02
	W14	3243	38	1.21			
	X14	3223	51	1.62			

Table B15 Splitting Tensile Strength Test Results at 28-Day Curing Period

SCM (%)	Cylinder identity mark	Weight (g)	Failure load (kN)	Split tensile strength (N/mm^2)	Average Split tensile strength (N/mm^2)	Change in split tensile strength (N/mm^2)	Change in split tensile strength (%)
0	A28	3296	65	2.07	2.06	0	0
	B28	3268	62	1.97			
	C28	3351	67	2.13			
0.025	D28	3334	75	2.39	2.22	0.16	7.77
	E28	3353	70	2.23			
	F28	3325	65	2.07			
0.05	G28	3211	70	2.23	2.26	0.2	9.71
	H28	3400	64	2.04			
	I28	3343	79	2.51			
0.075	J28	3234	73	2.32	2.18	0.12	5.83
	K28	3312	62	1.97			
	L28	3388	70	2.23			
0.1	M28	3323	64	2.04	1.96	-0.1	-4.85
	N28	3252	60	1.91			
	O28	3278	61	1.94			
0.125	P28	3366	57	1.81	1.82	-0.24	-11.65
	Q28	3245	52	1.66			
	R28	3315	63	2.01			
0.15	S28	3193	57	1.81	1.76	-0.3	-14.56
	T28	3099	59	1.88			
	U28	3225	50	1.59			
0.175	V28	3370	52	1.66	1.59	-0.47	-22.82
	W28	3181	48	1.53			
	X28	3256	50	1.59			

Table B16 Splitting Tensile Strength Test Results at 56-Day Curing Period

SCM (%)	Cylinder identity mark	Weight (g)	Failure load (kN)	Split tensile strength (N/mm^2)	Average Split tensile strength (N/mm^2)	Change in split tensile strength (N/mm^2)	Change in split tensile strength (%)
0	A56	3398	70	2.23	2.42	0	0
	B56	3250	83	2.64			
	C56	3389	75	2.39			
0.025	D56	3316	92	2.93	2.52	0.1	4.13
	E56	3247	80	2.55			
	F56	3287	75	2.39			
0.05	G56	3262	91	2.90	2.72	0.3	12.40
	H56	3662	85	2.71			
	I56	3498	80	2.55			
0.075	J56	3351	88	2.80	2.80	0.38	15.70
	K56	3242	85	2.71			
	L56	3249	90	2.86			
0.1	M56	3499	89	2.83	2.48	0.06	2.48
	N56	3239	74	2.36			
	O56	3399	70	2.23			
0.125	P56	3382	63	2.01	2.0	-042	-17.36
	Q56	3281	60	1.91			
	R56	3360	65	2.07			
0.15	S56	3135	55	1.75	1.86	-0.56	-23.14
	T56	3180	62	1.97			
	U56	3155	58	1.85			
0.175	V56	3348	59	1.88	1.71	-.71	-29.34
	W56	4256	52	1.66			
	X56	3198	50	1.59			

APPENDIX C

DoE METHOD OF CONCRETE DESIGN CHARTS

Table C1: Approximate Compressive Strength (N/mm^2) of Concrete Mixes Made with a Free- Water/Cement Ratio of 0.5

Types of cement	Types of coarse aggregate	Compressive strength (N/mm^2)			
		Curing age (Days)			
		3	7	28	91
Ordinary Portland cement (OPC) Or Sulphate resisting Portland cement (SRPC)	Uncrushed	18	27	40	48
	Crushed	21	33	47	55
Rapid hardening Portland cement (RHPC)	Uncrushed	25	34	46	53
	Crushed	30	40	53	60

Table C2: Approximate Free-Water Contents (kg/m^3) required to give Various Levels of Workability

Slump (mm)		0 - 10	10 - 30	30 - 60	60 - 180
Vebe time (s)		>12	6 - 12	3 - 6	0 – 3
Maximum size of aggregate (mm)	Type of aggregate	Water content (kg/m^3)			
10	Uncrushed	150	180	205	255
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

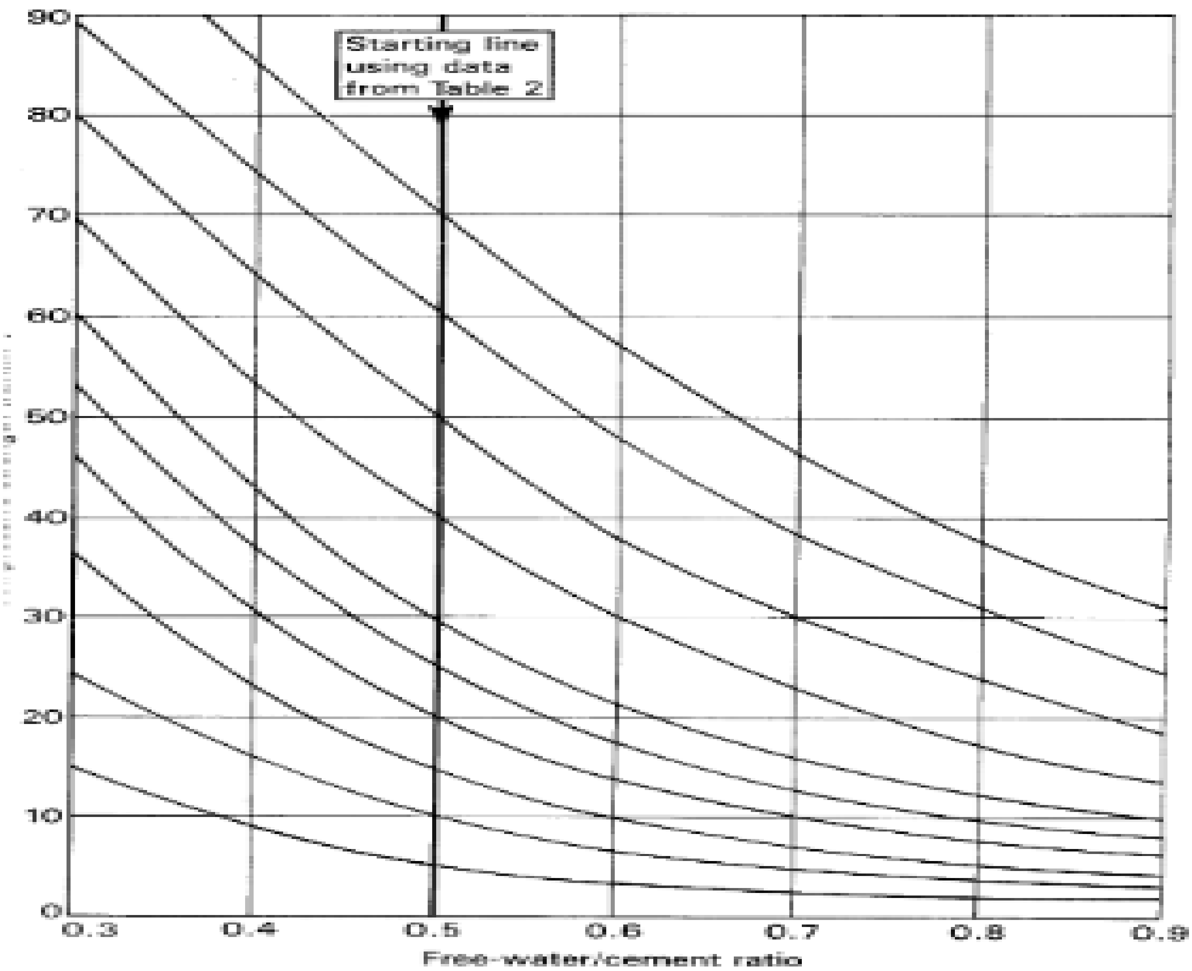

Figure C1: Relationship between Compressive Strength and Free-Water/Cement ratio

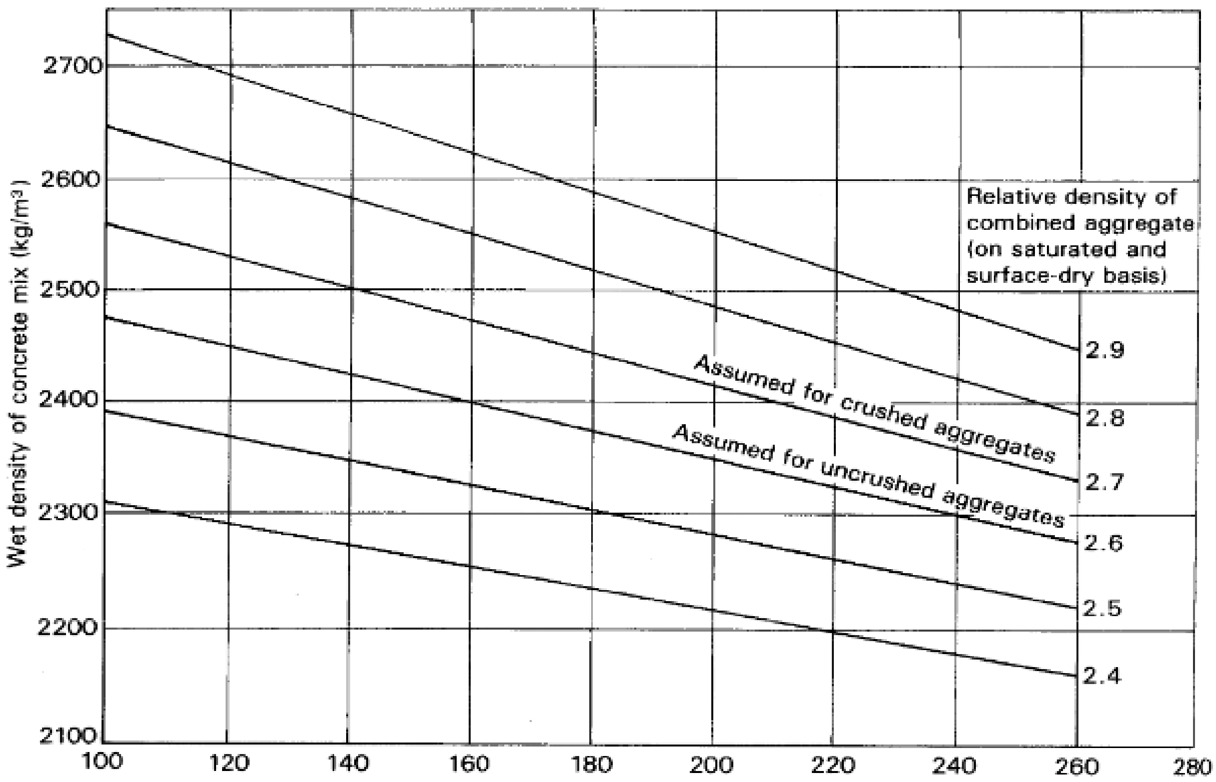

Figure C2: Estimated wet density of fully compacted concrete

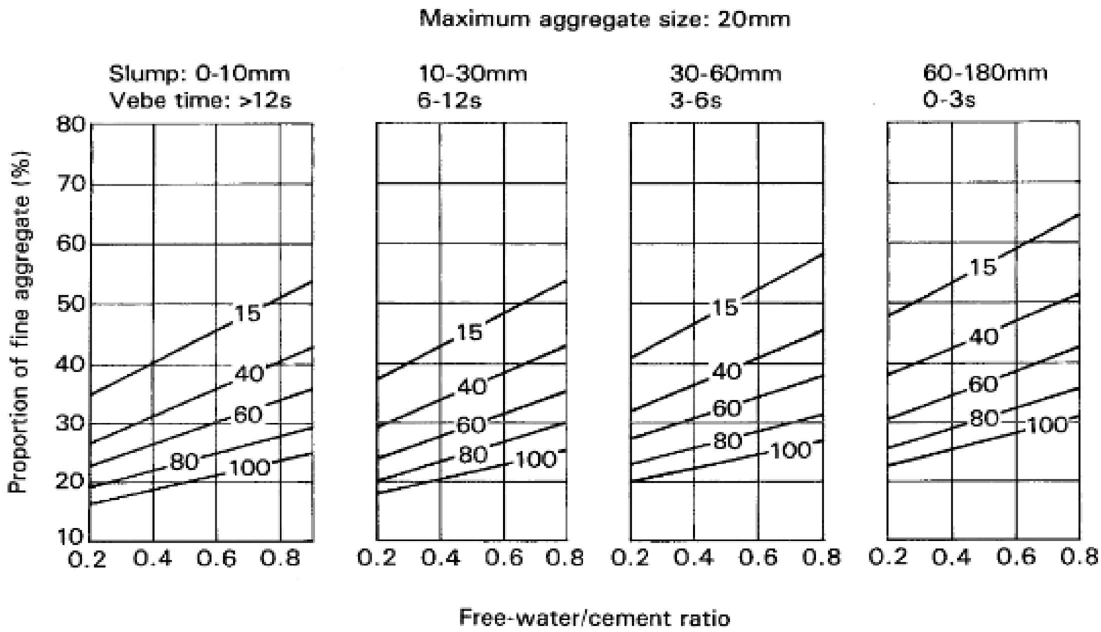

Figure C3: Recommended proportions of fine aggregate according to percentage passing 600 μm sieve.