A BLEND OF SODA-LIME SILICATE AND BOROSILICATE WASTE GLASS FOR PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

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AUGUST, 2018

Declaration

I declare that the work in this Dissertation entitled "A Blend of Soda-lime Silicate and Borosilicate Waste Glass for Partial Replacement of Cement in Concrete" has been carried out by me in the Department of Chemistry of Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Habibu GAMBO Isari _____ _____

Signature Date

Certification

This dissertation entitled "A BLEND OF SODA-LIME SILICATE AND BOROSILICATE WASTE GLASS FOR PARTIAL REPLACEMENT OF CEMENT IN CONCRETE" by HabibuIsari GAMBO meets the regulations governing the award of the degree of Master of Science in Polymer Science and Technology of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. P. A. P. Mamza Chairman, Supervisory Committee	_____ Signature	_____ Date
Dr. C. M. Gonah Member, Supervisory Committee	_____ Signature	_____ Date
Prof. A. O. Oyewale Head of Department	_____ Signature	_____ Date
Prof. S. Z. Abubakar Dean, School of Postgraduate Studies	_____ Signature	_____ Date

Dedication

This work is dedicated to my parents, Alh. GamboIsari and Haj. RahmaGamboIsari, may Allah (S.W.T) forgive their shortcomings! Amen.

Acknowledgment

All praises are due to Almighty Allah, the Creator and Sustainer of the universe for sparing my life, guarding and guiding me throughout the course of my studies, research work and write up in this great University. May His Peace and Blessings be onto His Noble Prophet (S. A. W), the Seal of Prophets.

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Table of Contents

List of Tables

List of Figures

List of Plates

List of Abbreviation

B.D	Bulk Density
BSG	Borosilicate Glass
C.F	Compacting Factor
FST	Final Setting Time
IST	Initial Setting Time
PCC	Portland Cement Concrete
SLG	Soda-lime Silicate Glass
SCM	Supplementary cementitious materials
S.G	Specific Gravity
OPC	Ordinary Portland Cement
GLS	Mixture of Borosilicate and Soda-lime silicate waste glass

List of Appendices

Abstract

This study evaluated the possibility of using Soda-lime Silicate and Borosilicate glass waste as an effective additives for improving the properties of cement-based cementitious materials with obvious advantages both from environmental and economic viewpoints after the ultimate strength (after 28 days of curing). Results show that the incorporation of various compositions (wt) of waste glass powder (2.5%, 5.0%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20%) increases the compressive strength by nearly 46%, while higher amounts have the opposite results. When waste glass particles are ball-milled to micro size powder, it is expected to undergo pozzolanic reactions with cement hydrates, forming secondary Calcium Silicate Hydrate. The research work looked at the chemical analysis using X-Ray fluorescence (XRF) technique and found some differences in the chemical composition of soda-lime silicate and borosilicate waste glass. The major oxides detected were combined proportion of SiO_2, Al_2O_3, and $Fe_2O_3$with percentage value of 73.202%, 72.998%, 0.411%, 0.201%, and 0.223%, 0.112% respectively.Workability was determined by slump test method the control had slump of 55 mm, the samples that contains 5% of waste glass powder had 47mm slump less than the control thereby reduces the slump value. The slump test correlates with the compacting factor, since the value of control mixes higher. It means that it is more workable than other mixes, however none of the mixes fall below the acceptable value for structural work. Control had 0.92 and all other mixes were 0.85. TheSetting time of the specimens that contains waste glass powder was also determined and found that it delayed initial and final setting time, and the effect increases as the percentage replacement of cement with waste glass powder increases,The microstructural characterization was also carried out using Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) to characterize the concrete samples. It was found that the morphology of concrete samples with

waste glass powder (10%) was denser than the control sample (0%). Also, XRD results indicated that the intensity of the peaks, in particular of portlandite, is significantly reduced in the 10% waste glass sample than the control (10% of portlandite in the control, 2% of portlandite in 10% waste glass replacement). Various compositions of the samples (Control 0%, 2.5%, 5.0%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20%) of concrete cube, cylinder and beam samples were prepared and tested for strength at 7, 14 and 28 days of curing. The compressive strength test results of the control and the 10% waste glass replacement were 20.95 N/mm^2, 16.44N/mm^2 for 7, 26.52 N/mm^2, 24.14 N/mm^2 14, and 31.38 N/mm^2, 28.82 N/mm^2 28 days respectively. The tensile strength test results of the control and the 10% waste glass replacement were 2.08 N/mm^2, 1.65N/mm^2 for 7, 2.65N/mm^2 , 2.41 N/mm^2 14, and 3.13N/mm^2, 2.89N/mm^2 28 days respectively.The flexural strength test results of the control and the 10% waste glass replacement were 3.96 N/mm^2, 3.17N/mm^2 for 7, 4.95N/mm^2, 4.58 N/mm^2 14, and 5.87N/mm^2, 5.27N/mm^2 28 days respectively.It can be concluded that all the samples can be used for structural purposes, this is because all the samples (except for 2.5% replacement which had 23.12 N/mm^2) which was less than the maximum strength specified by ASTM 24.2 N/mm^2 at 28 days.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Polymer blend is a mixture of at least two polymers or copolymers. Polymer blends are physical mixtures of two or more polymers with/without any chemical bonding between them. The objective of polymer blending is a practical one of achieving commercially viable products through either unique properties or lower cost than some other means might provide. Property of polymer blends is superior to those of component homopolymers. Blending technology also provides attractive opportunities for reuse and recycling of polymer wastes(Alexander,*et al.*,2016).

Inorganic polymers in this class constitute the majorcomponents of soil, mountains and sand, and they are also employed as abrasives and cutting materials (diamond, silicon carbide) fibres (fibrous glass, asbestos, boron fibres), coatings, flame retardants,building and construction materials (window glass, stone, Portland cement, brick and tiles), andlubricants and catalysts (zinc oxide, nickel oxide, carbonblack, silica gel,aluminium silicate, and clays) (Rahimi, 2004).Inorganic and organometallic polymers represent a rapidlygrowing field of chemical research and already have many applications and any classification is necessarily somewhat arbitrary. For simplicity and convenient a classification is used here which may be far from perfect. In the following, we will focus on four main classes of inorganic polymers which are: wholly inorganic polymers, inorganic-organic polymers, organometallic polymers, and hybrid organic-inorganicpolymers (Rahimi, 2004).

“Geopolymer” is the term often used to refer to a class of alumina-silica based inorganic materials which are processed like a polymer that undergoes polycondensation at low temperatures, but resembles ceramics in the resulting structure and high temperature resistant properties (Radford, *et al.*,2009).

The minerals that constitute this material are readily available. The name “geopolymer” was coined in 1978 during research efforts focused on the development of fire-resistant, non-toxic materials to be used in building structures (Mackenzie, 2003). This material evolved into a mineral-based binder for use as a high strength industrial cement with significantly shorter cure times than traditional Portland cements (Radford, *et al.*,2009). More recently there has been interest in utilizing the high-temperature resistant properties of this material and its very low density to replace heavier metallic components in high-temperature applications.

It has been shown that geopolymers represent a competitivealternative to Portland cement and they are beginning to be widely used in diverse applications. Geopolymer is a term used to describe inorganic polymers based on aluminosilicatesand produced by synthesizing pozzolaniccompounds or aluminosilicate source materials with highly alkaline solutions (Duxson, *et al.*, 2007). The ability to vary the Si/Al molar ratio, and therefore the structure and the physicochemical properties of the polymers, broadens the range of possible applications of these materials. However, most of the studies are limited to the use of certain mineral fines such as metakaolin, silica fume, fly ash or slag (Pacheco, 2008). All thesematerials share the ability to provide silica and aluminum to the reactional environment that is necessary for the polymerization reaction (Cyr, *et al.*,2012).

Glass in general is a highly transparent material formed by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperatures followed by cooling during which solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing. Glass has been indispensable to man's life due to such properties as pliability to take any shape with ease, bright surface, resistance to abrasion, safety and durability. The utility ranges of the glass increase the amount of the waste glass (WG) (Jagmeet and Rajindervir, 2016).

Solid wastes are substances and masses resulted by the various human activities that have to be dumped (Adeniyi, 2014). Wastes exist in different forms: municipal waste (including household and commercial waste), industrial waste (including manufacturing), hazardous waste, construction and demolition waste, mining waste, waste from electrical and electronic equipment (glasses), biodegradable municipal waste, packaging waste, and agricultural waste. Solid wastes can be solid, liquid, and semi-solid or containerized gaseous material. Also, there are various sources of waste: residential, industrial, commercial, institutional, construction and demolition waste; municipal services manufacturing process, agriculture etc(Adeniyi, 2014). This waste is composed of sand, stone, gravel, tiles, ceramic, marble, glass, aluminum, wood, plastic, paper, paints, plumbing pipes, electric parts and asbestos, and other materials (Adeniyi, 2014).

According to Sadiqu, *et al.*,(2016) as of 2005, the total global waste glass production estimate was 130 Mt, in which the European Union, China and USA produced

approximately 33 Mt, 32 Mt and 20 Mt, respectively being non-biodegradable in nature (Sadiqu, *et al.*,2016).

Soda-lime glass is transparent, easily formed and most suitable for window. It has a high thermal expansion and poor resistance to heat (500- 600 °C), while Borosilicate glasses stand heat expansion much better than window glass and use for chemical glassware, cooking glass, car head lamps, etc. Borosilicate glasses have as main constituent's silica and boron oxide. They have fairly low coefficients of thermal expansion of 3.25×10^{-6}/°C as compared to about 9×10^{-6}/°C for a typical soda-lime glass (Jagmeet and Rajindervir, 2016).

Pozzolan is an additive used in concrete to improve its quality, for example, reduces the temperature rise during initial hydration, and improves the strength development and durability of concrete materials (Rungrawee, and Boonchai, 2015). Several types of pozzolan are widely used, such as natural pozzolan, fly ash, blast furnace slag, and silica fume (microsilica). Many studies have shown that waste glass has potential for use in building material, for example, as an aggregate replacement, a filler in concrete, or a cement replacement. Specifically, finely ground glass powder (particle size of less than 38 μm) has potential for use as pozzolan, and glass powder has more reactive silica than fly ash, which is the most commonly used pozzolan in Thailand.

In addition, glass powder tends to improve the compressive strength more if it was more finely ground (Rungrawee, and Boonchai, 2015). Being amorphous and having relatively

high silicon and calcium contents, glass is pozzolanic or even cementitious especially when the fineness of glass powder is much greater than that of Portland cement (Kara, *et al.*,2016).

Many researchers have beenundertaken on the use of glass waste as partial replacement of cement, or fine aggregate in the production of concrete, it was reported by some authors that glass waste improves properties of concrete when it is grounded to a fines of less than 100µm, and pulverized glass waste could eliminate the risk of Aggregate Silicate Reaction (ASR). When waste glass is milled down to micro size particles, it is expected to undergo pozzolanic reactions with cement hydrates, forming secondary calcium silicate hydrate (C–S–H) (Sadiqul, *et al.*,2016).

Kara, *et al.*, (2016) conducted research on the performance of soda lime as partial replacement of cement and concluded that 20% replacement level gave higher strength than the control at later curing age, Rungraweeand Boonchai (2015) conducted research on the partial replacement of cement with sodalime glass and reported using 10% or 20% glass powder reduced the workability of fresh concrete and accelerated its setting time. However, concrete containing 10% finely ground glass powder exhibited greater compressive strength and improved resistance to the penetration of chloride ions than normal concrete and concrete containing fly ash at the same replacement level.

Concrete with 10% glass powder also had lower shrinkage than normal concrete and concrete containing fly ash but higher shrinkage than concrete with 10% silica

fume.Ramprashath and Chellakavitha, (2015) conducted research on the utilization of borosilicate glass powder as partial replacement of cement and concluded that beyond 20% replacement, compressive strength starts decreasing. Chirag and Ashok (2015) conducted research on suitability of crushed waste glass particles as partial replacement of fine aggregates on concrete properties and reported that the waste glass can effectively be used as a fine aggregate replacement (up to 40%) without substantial change in strength whereas the tensile strength will decrease with increasing waste glass content. Nurhayat, *et al.*,(2011) conducted research on utilization of waste glass as partial replacement of sand and reported that 10% replacement gave highest compressive and flexural strength than all other blended samples.

The use of finely divided glass powder as a cement replacement material has yielded positive results (Vijayakumar*et al.*, 2013). There still exist the need to determine if addition of borosilicate and soda-lime silicate glass powder at different proportions will improve the properties of concrete when used as partial replacement of cement because it remained anun explored area of research. The unfavorable properties of concrete include a relatively weak tensile strength as compared to its compressive strength and the ability to form cracks in unpredictable areas (Abdullah, 2007).

Cyr, *et al.*, (2012) conducted research on properties of inorganic polymer (geopolymer) mortars made of glass cullet and reported that the finest glass particles systematically led to the best performances in terms of compressive strength and durability: lower loss of strength and leaching of alkalis when conserved in water. However, coarser particles can

be used for some applications where only a few MPa are sufficient and durability is not a concern, for instance in a dry environment.

1.2Statement of Research Problem

As of 2005, the total global waste glass production estimate was 130 Mt, in which the European Union, China and USA produced approximately 33 Mt, 32 Mt and20 Mt, respectively. Beingnon-biodegradable in nature, glass disposal as landfill hasenvironmental impacts and also could be expensive (Sadiqul*et al.,*2016).Normally glass does not harm the environment in any way because it does not give off pollutants, but it can harm humans as well as animals, if not dealt carefully and it is less friendly to environment because it is non-biodegradable (Mane and Mane, 2012).

The amount of waste glass produced has gradually increased over the recent years due to an ever growing use of glass products. Most waste glass has and is being dumped into landfill sites. The land filling of waste glass is undesirable because waste glass is non-biodegradable which makes them environmentally less friendly (Iqbal, *et al.,*2013). According toKara, *et al.,*(2015) notwithstanding the glass waste recycling infrastructure still suffers from the lack of an adequate network of local recycling companies, therefore there exist the need to device and improvise methods and means of recycling glass waste, this is one of the vital area this research work focused on.

1.3 Significance of the Study

Glass is an inert material which could be recycled and used many times without changing its chemical property (Vijayakumar*et al.,* 2013). Glass is amorphous material with high silica content, thus making it potentially pozzolanic when particle size is less than 75μm (Vijayakumar*et al*., 2013).

Fine glass particles can exhibit pozzolanic reactivity, thereby improving the microstructure of paste and the strength and durability of concrete in the long term, the amorphous silica content in the glass would dissolve in an alkaline environment such as due to OH^- ions in the pore solution of cement paste. Thereafter, it could react with calcium hydroxide (CH) to form secondary calcium silicate hydrate (C-S-H), a process known as pozzolanic reaction (Qingke*et al*., 2014).

$$CH + S + H \rightarrow C\text{-}S\text{-}H \qquad 1.1$$

The use of waste products in concrete not only makes it economical, but also helps in reducing disposal problems. Reuse of bulky wastes is considered the best environmental alternative for solving the problem of disposal (Yvonne, 2016). This study attempted to overcome the problem of glass waste that is generated from construction and demolition activities and other human activities, in order to reduce the quantity of un-recycled glass

waste, it has been suggested to partially replace cement with waste glass powder and reduce problems associated with cement manufacture.

1.4 Aim and Objectives of the Research

The aim of this study is to determine the addition of borosilicate and soda-lime silicate waste glass to improve the properties of concrete and their suitability in concrete production.

The objectives of this study is to:

i. obtain samples anddetermine the physicaland chemical properties of cement, soda-lime silicate and borosilicate waste glass

ii. prepare and determine the fresh properties of concrete test samples

iii. determine the strength properties, durability propertiesand microstructural characterizationof hardened concrete samples

1.5 Scope and Limitations

Soda-lime silicate and borosilicate waste glasses, ordinary Portland cement etc. were used to determine Slump and Compacting factors of the fresh properties of concrete samples, the properties of hardened concrete that were determine include strength properties (compressive strength, tensile strength and flexural strength test), the durability property was assessed with water absorption, other properties such as sorptivity, shrinkage test and fire resistance tests were not determined.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete

In construction industry, the most widely used material is concrete which is obtained by mixing cementitious materials, water and aggregates. The mixture when placed in forms and allowed to cure hardens into a rock like mass known as hardened concrete. The hardening is caused by chemical reaction between water and cement and it continues for a long time.

It may also be considered as an artificial stone in which the voids of larger particles (coarse aggregate) are filled by the smaller particles (fine aggregates) and the voids of fine aggregates are filled with cement (Olubisi, 2013).

2.1.1 Composition of concrete

A good quality concrete is essentially a homogeneous mixture of cement, coarse and fine aggregates and water which solidifies into a hard mass as a result of chemical action between the cement and water. Each of the four constituents has a specific function. The coarser aggregate acts as a filler. The fine aggregate fills up the voids between the paste

and the coarse aggregate. The cement in conjunction with water acts as a binder (Duggal, 2008).

2.1.2 Chemical composition of cement

The chemical composition is the basis for the characterization of cement. The materials used for the manufacture of cement consists mainly of lime, silica and aluminates.

These oxides interacts with one another in the kiln at high temperature to form more complex compounds (Shetty, 2009). Cement with higher content of certain compound relative to each other could cause retardation or accelerate the rate of setting and hardening. These compounds could also affect the rate of heat evolution as the content hydrates. Chemical like calcium chloride and calcium sulphate are used to accelerate or retard the rate of setting of cement paste. Table 2.1 shows the oxide composition of cement while table 2.2 shows the chemical composition of cement.

Table 2.1: Oxide composition of cement

Oxide	Function	Composition (%)
CaO	Controls strength and soundness	60-65
SiO_2	Gives strength, excess causes slow setting	17-25
Al_2O_3	Responsible for quick setting, excess lower strength	3-8
Fe_2O_3	Gives colour and fussion of different ingredients	0.5-6
MgO	Impart colour and hardness excess cause cracking	0.5-4

$Na_2O+ K_2O$	These are residue, and in excess cause	0.5-1.3
TiO_2	efflorescence	0.1-0.4
P_2O_5	and cracking	0.1-0.2
SO_3	Makes cement sound	1-2

Source: Duggal (2008)

Table 2.2: Chemical composition of cement

Principal compounds In Portland cement	Mineral Formulae	Name	Symbol
Tricalcium silicate	$3CaO.SiO_2$	Alite	C_3S
Dicalcium silicate	$2CaO.SiO_2$	Belite	C_2S
Tricalcium aluminate	$3CaO.Al_2O_3$	Celite	C_3A
Tricalciumalumino ferrite	$3CaO.Al_2O_3.Fe_2O_3$	Ferrite or Braunmillerite	C_3AF

Source: Duggal (2008)

2.2 Aggregates

Aggregates constitute a skeleton of concrete. Approximately three-quarters of the volume of conventional concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should contribute important properties to both the fresh and hardened product. Aggregate is usually viewed as an inert dispersion in the cement paste. However, strictly speaking, aggregate is not truly inert because physical, thermal, and, sometimes, chemical properties can influence the performance of concrete. Aggregates can be divided into several categories according to different criteria, such as size, source, and unit weight (Zongji, 2011).

2.2.1. In accordance with size

a) Coarse aggregate

Aggregates predominately retained on a No. 4 (4.75-mm) sieve are classified as coarse aggregate. Generally, the size of coarse aggregate ranges from 5 to 150 mm. For normal concrete used for structural members such as beams and columns, the maximum size of coarse aggregate is about 25 mm. For mass concrete used for dams or deep foundations, the maximum size can be as large as 150 mm (Zongji, 2011).

b) Fine aggregate (sand)

Aggregates passing through a No. 4 (4.75 mm) sieve and predominately retained on a No. 200 (75 um) sieve are classified as fine aggregate. River sand is the most commonly used fine aggregate. In addition, crushed rock fines can be used as fine aggregate. However, the finish of concrete with crushed rock fines is not as good as that with river sand. There are other method of classifications e.g classification by weight, by size and source (Zongji, 2011).

2.3 Fresh Concrete

Fresh concrete can be viewed as a concentrated suspension of solid particles (aggregates) in a viscous medium, i.e. cement paste. The behaviour of a specimen of fresh composite material is defined in terms of its workability and is measured by numerous consistency methods (Zongji, 2011).

2.3.1 Workability

Workability of concrete is defined in ASTM C125 as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity (uniform). The term manipulate includes the early-age operations of placing, compacting, and finishing. The ease of placement, consolidation and finishing of freshly mixed concrete and degree to which it resist segregation is termed workability, the ingredients of workable concrete should not fall apart during transport and handling. Shetty (2009) defines workability as internal useful work necessary to produce full compaction, ease with which concrete can be compacted 100 percent having regard to mode of compaction and place of deposition.

2.3.2 Factors affecting workability

a) Water content
b) Mix proportion
c) Size of aggregate
d) Shape of aggregate
e) Surface Texture of Aggregate
f) Grading of aggregate
g) Use of Admixture

2.3.3 Measurement of workability

The most widely used test, which mainly measures the consistency of concrete, is called the slump test. For the same purpose, the second test in order of importance is the Vebe

test, which is more meaningful for mixtures with low consistency. The third test is the compacting factor test, which attempts to evaluate the compactability characteristic of a concrete mixture. The fourth test method is the ball penetration test that is somewhat related to the mechanical work (Zongji, 2011).

1) Slump Test
2) Compacting Factor Test
3) Vebe Test
4) Flow Table Test
5) Penetration Test

2.3.4 Slump test

The equipment for the slump test is indeed very simple. It consists of a tamping rod and a truncated cone, 300mm in height, 100mm in diameter at the top, and 200mm in diameter at the bottom. To conduct a slump test, first moisten the slump test mould and place it on a flat, nonabsorbent, moist, and rigid surface. Then hold it firmly to the ground by foot supports (Zongji, 2011).

Next, fill 1/3 of the mould with the fresh concrete and rod it 25 times uniformly over the cross section. Likewise fill 2/3 of the mold and rod the layer 25 times, then fill the mold completely and rod it 25 times. If the concrete settles below the top of the mold, add more. Strike off any excessive concrete. Remove the mold immediately in one move. Measure

and record the slump as the vertical distance from the top of the mold to average concrete level (Zongji, 2011).

Three types of slump usually observed:

1. True slump

True slump is observed with cohesive and rich mixes for which the slump is generally sensitive to variation in workability.

2. Shear slump

Shear slump occurs more often in leaner mixes than harsh mixes. Whenever shear slump is obtained the test should be repeated and, if persistent, this fact should recorded together with test result.

3. Collapse slump

Is usually associated with very wet mixes and is generally indicative of poor quality concrete and most frequently result from segregation of its constituents materials. The standard slump apparatus is only suitable for concretes in which the maximum aggregate size does not exceed 37.5mm.

2.3.5 Compaction factor

This test measures the degree of compaction for standard amount of work and thus offers a direct and reasonably reliable assessment of the workability of concrete (Rahim, 2010).

It consists of two hoppers and one cylindrical mould stacked in three levels. To perform an experiment, the upper hopper is first fully filled with fresh concrete. Then the hinged door is slid open and hence the concrete will fall into the lower hopper by gravity. Next, the hinged door of the power hopper is slid open and the concrete free falls into the 150 × 300mm cylindrical mold. After the excessive concrete is struck off on the top of the mould, the weight of the cylinder is measured and noted as Mp, representing a partially compacted cylinder mass. Another cylinder is made with same concrete by three layers with 25 times rodding on each layer and striking off any excessive concrete.The weight of the cylinder is measured as Mf, representing the fully compacted cylinder mass.

The compaction factor is defined as

$$\text{compaction factor} = \frac{MP}{MF} \quad \ldots\ldots 2.1$$

Usually, the range of compaction factor is from 0.78 to 0.95 and concrete with high fluidity has a higher compaction factor (Zongji, 2011). For the normal range of concretes the compaction factor lies between 0.8 and 0.92. The test is particularly useful for drier mixes for which the slump test is not satisfactory, and is appropriate for concrete with a maximum size of aggregate up to 40mm (Rahim, 2010).

2.3.6 Uniformity and stability

Fresh concrete, properly designed, batched and mixed, needs to be sensibly uniform and to remain reasonably so through the remaining normal processes of transporting, placing, compacting, finishing and thereafter, until the stiffening process of hydration provides the

necessary rigidity (Dewar and Anderson, 2004). Extreme construction conditions may require additional precautions. The range of relative densities of the normal materials used, 1 for water to over 3 for cement, means that there is always a tendency for segregation to take place, particularly at high workability. This tendency will generally be smaller for richer mixes, finer cementitious materials, finer sands, higher sand contents, lower water demand concretes, in warm weather, and when air-entraining and certain water-reducing admixtures are used. Agitation during transport or remixing before discharge of medium- and high-workability concrete may be necessary to maintain uniformity, whereas for low-workability mixes, agitation may be detrimental, causing aggregation or 'balling' of the fine components (Dewar and Anderson, 2004).

2.3.7 Segregation

According to Neville and Brooks (2011) segregation can be defined as separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. In the case of concrete, it is the differences in the size of particles and in the specific gravity of the mix constituents that are the primary causes of segregation, but its extent can be controlled by the choice of suitable grading and by care in handling.

2.3.8 Bleeding

Bleeding is sometimes referred to as water gain, it is a particular form of segregation, in which some of the water from the concrete ascends to the concrete top, being of the lowest specific gravity among all the constituent materials used in concrete production, it is moe pronounced in highly wet mix, disproportionate and insufficient mixed concrete, in thin

members like roof or road slabs and when concrete is placed under sunny weather. Due to this water come up and accumulates at the surface. Sometimes, along with certain quantity of cement (Shetty, 2009).

Water while travelling from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmentedby the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete (Shetty, 2009).

2.3.9 Setting time of concrete

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which concrete is made of. The setting time of concrete depends upon the w/c ratio, temperature condition, type of cement, use of mineral admixture, use of plasticizer. The setting parameter of concrete is more of practical significance for site engineers than setting time of cement. When retarding plasticizers are used, the increase in setting time, the duration up to which the concrete remain in plastic state is of significance interest. The setting time of concete is determined by penetrometer test. This method of test is prescribed by ASTMC-403.

2.3.10 Rheology

Rheology is the science of the deformation and flow of matter .The need to define and control the properties and performance of materials is part of technological development and the rheology of cement-based materials is no exception to this process. Applying Kelvin's condition to the meaning of "understand", namely that a phenomenon is not

properly understood unless it can be measured, three levels of understanding may be identified. These may or may not coincide with a chronological progression. Considering the phenomenon of workability, in level 1, the property is described in comparative terms only, using subjective assessments such as "stiff".

In level 2, a quantitative numerical scale based on an empirical measurement, such as slump, is established. In level 3, the property is rigorously defined in terms of physical constants, derived from the fundamental quantities of mass, length and time, which describe the material itself and do not depend on the circumstances of the test or the use of the material. This last level involves the use of sound scientific methods, such as rheology, in which physical and analytical models are developed and applied to the situation under consideration (Banfill, 2006). Fresh concrete that is not under vibration begins to flow only when the yield stress value is exceeded (Sandra, 2012). Many authors have concluded that, when vibration is applied, the yield stress is reduced to the extent that concrete can flow due to its own weight.

2.4 Properties of Hardened Concrete

Concrete is most widely used construction material today. Concrete has attained the status of a major building material in all the branches of modern construction. It is difficult to point out another material of construction which is as variable as concrete. Concrete is the best material of choice where strength, durability, impermeability, fire resistance & absorption resistance are required (Sathish, 2012).

2.4.1 Curing

All concrete requires curing in order that cement hydration can proceed so as to allow for development of strength, durability and other mechanical characteristics (Akeem, *et al.*, 2013). To obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment, especially during the early stages of hardening. Curing is the name given to procedures used for promoting hydration of cement, and consists of a control of temperature and moisture movement from and into the concrete. Curing as the process of protecting concrete for a specified period of time after placement, to provide moisture for hydration of the cement, to provide proper temperature and to protect the concrete from damage by loading or mechanical disturbance (Akeem *et al.*, 2013). Proper curing application has significant impact on density and compressive strength of concrete (Shohanna, 2015).

2.4.2 Importance of curing to concrete

The longer the moist curing period the higher the strength (Mehta and Monteirro, 2006); continuous water curing resulted in an improved microstructure of the concrete specimens (Abalaka and Okoli, 2013). Adequate curing at early ages as well as at later ages is essential in the strength development of PCC concrete.

2.4.3 Strength

Strength of concrete is commonly considered to be its most valuable property, strength usually give an overall picture of the quality of concrete because it is directly related to the structure of cement paste. The strength of a material is defined as the ability to resist stress without failure (Mehta and Monteiro, 2006). Cement paste strength is typically defined in

three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, curing conditions, size and shape of specimen, loading conditions and age (Vignesh*et al.,* 2014).

2.4.4Compressive strength test

The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. Concrete strength up to 80 N/mm^2 can be achieved by selective use of the type of cement, mix proportion, method of curing conditions. Concrete structures, except for road pavements, are normally designed on the basis that concrete is capable of resisting only compression, the tension being carried by steel reinforcement. The standard method described in BS 1881: Part 3 requires that the test specimen should be cured in water at 20 ^{0}C and crushed immediately after it has been removed from the curing tank (Rahim, 2010).

$$Fct = \frac{P}{A} \quad \text{.....2.2}$$

Where:

P = Applied load

A= Surface Area

2.4.5 Tensile strength test

The tensile strength of concrete is of importance in the design of concrete roads and runways. However, in the design of some structures that are required to contained liquids the tensile strength is taken into consideration (Omotola and Idowu, 2011). Concrete members are also required to withstand tensile stresses resulting from any restraint to

contraction due to drying or temperature variation. Unlike metals, it is difficult to measure concrete strength in direct tension and indirect methods have been developed for assessing this property (Rahim, 2010).

2.4.6 Split cylinder test

This is the simplest and most widely used. This test is fully described in BS 1881 Part 4 and entails diametrically loading a cylinder in compression along its entire length. This form of loading induces tensile stresses over the loaded diametrical plane and the cylinder split along the loaded diameter. The magnitude of the induced tensile stress

fctat failure is given by:

$$f_{ct} = \frac{2F}{\pi ld} \qquad \text{.....2.3}$$

Where:

F = the maximum applied load

l = the cylinder length

d = the diameter of the cylinder

2.4.7 Flexural strength test

The flexure strength of concrete is another indirect tensile value which is also commonly used (BS 1881: Part 4). In this test a simple supported plain concrete. Beam is loaded at is third points, the resulting bending moments inducing compressive and tensile stresses in

the top and bottom of the beam respectively. The beam fails in tension and the flexure strength (modulus of rupture) fcris defined by:

$$f_{cr} = \frac{FL}{bd^2} \quad \text{.....2.4}$$

where:

F = the maximum applied load

L = the distance between the supports

b& d = are the beam breadth and depth respectively at the section which failure occurs.

The tensile strength of concrete is usually taken to be about one- tenth of its compressive strength. This may vary, however, depending on the methods used for measuring tensile strength and the type of concrete. In general the direct tensile strength and the splitting strength vary from 5 to 13 per cent and the flexure strength from 11 to 23 per cent of the concrete cube compressive strength. In each case, as the strength increases the percentage decrease (Rahim, 2010).

2.4.8 Density

The mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength and fewer amount of voids and porosity. Smaller the voids in concrete, it becomes less permeable to water and soluble elements. So water absorption will also be less and better durability is expected from this type of concrete (Shohanna, 2015). The density and compressive strength of concrete cement paste are affected by several parameters like water cementitious materials ratio, supplementary cementitious materials, use of admixture, curing, cement type (Shohanna, 2015).

2.5Concrete Durability

A long service life is considered synonymous with durability. As durability under one set of conditions does not necessarily mean durability under another, it is customary to include a general reference to the environment when defining durability. According to ACI Committee 201, *durability* of portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. In other words, a durable concrete will retain its original form, quality, and serviceability when exposed to its intended service environment. No material is inherently durable. As a result of environmental interactions.

The microstructure and consequently the properties change with time (Mehta and Monteirro, 2006). A material is assumed to reach the end of service life when its properties, under given conditions of use, have deteriorated to an extent that its continued use is ruled either unsafe or uneconomical (Mehta and Monteirro, 2006).

Durability of concrete is considered as important as concrete strength, since conditions such as temperature changes, humidity, loading characteristics and frequency are determinant of a quality product meeting predetermined expectation (Jose*et al*., 2010). In many cases, the effect of harmful conditions on the durability of concrete can be evaluated only qualitative, since mathematical models that allow prediction of the magnitude of deterioration with time have been investigated during the last decades, without the scientific community agreeing in one model in particular that satisfy all possible considerations (Jose*et al*., 2010).

2.5.1 Water as an agent of deterioration

Water in its various forms, such as seawater, groundwater, river water, lake water, snow, ice, and vapour, is undoubtedly the most abundant fluid in nature. Water molecules are very small and, therefore, are able to penetrate into extremely fine pores or cavities. As a solvent, water is noted for its ability to dissolve more substances than any other known liquid. This property accounts for the presence of many ions and gases in some waters which, in turn, become instrumental in causing chemical decomposition of solid materials (Mehta and Monteirro, 2006).

The durability of concrete subjected to aggressive environments depends largely on transport properties, which are influenced by the pore (Javier, *et al.*, 2011). Three main mechanisms govern transport in cementitious systems: permeability, diffusion and absorption (Javier, *et al.*,2011). Therefore it will become necessary to discuss pore structure in concrete before transportation in concrete will be discussed.

As a porous media, cement and concrete materials adopt a pore structure with broad pore size distribution from nanometer to micrometer scales (Jun *et al.*, 2014). Generally speaking, the pores of concrete are classified into four major types (Jun *et al.*, 2014).

2.5.2 Forms in which water exist in concrete

Water may be present in hydrated cement paste in many forms that may be classified on the basis of the degree of difficulty in eliminating it.

2.5.3 Capillarity water

The water contained in the capillarity pores account for the greatest part of water. Water retained by capillarity tension in pores of diameter smaller than 50nm (nano micro meter) will evaporate at when the value of relative humidity is lower as the diameter of capillarity pore decreases from 50nm to 5nm (Luca, *et al.*,2004).

2.5.4Adsorbed water

Some water will still remain adsorbed to the inner surface in the form of a very thin layer of adsorbed water even when water has evaporated from the capillarity pores. This water can be removed if the external humidity falls below 30%. It contributes little to transport processes, it has insignificant effect on corrosion of reinforcement. Its elimination give rise to shrinkage of the cement paste and influences creep behavior (Luca *et al.*, 2004).

2.5.5 Interlayer water

Concrete losses retained water between the C-S-H layers, if the external humidity falls below 11%. This water do not contribute to corrosion of reinforcement because the gel pores are too small to allow transport processes at any level but rather influences shrinkage (Luca *et al.*, 2004).

2.5.6Chemically combined water

This is the water form integral part of C-S-H or other hydration products. It is not lost on drying. It can only be released when the hydration decompose on heating at temperature

that exceed 1000^0C, it does not contribute to any transport phenomenon (Luca *et al.*, 2004).

2.5.7 Concrete porosity

The pore structure of cement-based materials contains air voids, capillary pores, and gel pores, and the pores are randomly sized, arranged, and connected. It is a well-established fact that porosity is one of the important parameters which directly affect the strength and durability of cement-based materials. Lower porosity in concretes with sufficient binding material content enhances higher strength concretes. The traditional classification of pores in concrete, gel pores (<10 nm), which are associated with the formation of hydration products, and capillary pores (10 nm~10000 nm), which dominate transport processes. And the existence of diffusivity of concrete on pore structure attributes mainly to the effect of capillary porosity and connectivity of these capillary pores (Haito, *et al.*,2014). Since concrete porosity relates with concrete strength and durability it is necessary to discuss types of pores that exist in concrete.

2.5.8The gel pores

The gel pores, which are mostly of 1.5–2.0 nm(nano micro meter) size gel pores (diameter < 10 nm), do not influence the strength of concrete adversely through its porosity, although these pores are directly related to creep and shrinkage (Rakesh andBhattacharjee, 2003). Gel pores basically are smaller in size and numerous, created by existing cavities in the hydration products of the cement. The gel pores are really interconnected interstitial spaces

between gel particles. Although the gel pores constitute a network of communicating pores, it seems that the permeability of this network, by calculation of Power's Law, it is very low: 7.10-16 m/s (Meter/Second) (Rakesh and Bhattacharjee, 2003).

2.5.9 Transitional pores (diameter 10–100 nm)

The coarse aggregate surface has an interfacial transition zone (ITZ) of about 100-Am depth. This ITZ includes two layers: One is a duplex film at the surface of the coarse aggregate, about 1 Am deep. Its components are CH crystals and C –S –H gels, the other layer is the porous transition zone, about 20– 100 Am deep, which contains more CH crystals, some C –S–H gels and little ettringite. These weak faces will influence the durability of concrete. With the progress of hydration, the discontinued pores of cement particles will be gradually filled with hydration products (Kuo-Yu, *et al.*,2004).

2.5.10 Capillary pores

Capillary pores are responsible for reduction in strength and elasticity (capillary pores diameter, 100–1000 nm) (Rakeshand Bhattacharjee, 2003). It is generally larger in size in which the formation depends on the evaporation of the water used in the pastes. The volume of the capillary system will reduce with the progress of hydration. In any stage of hydration the capillary pores filled the part of the gross volume, which has not been filled by the products of hydration. The average volume and size of the pores decreases, and the network progressively breaks down (segmentation of the capillaries).

2.5.11 Macropores (diameter > 1000 nm)

Pores whose diameter of 100 nm is defined as threshold, since the size of the pores are assumed to be detrimental to durability for cement and concrete composites (Jun *et al.*, 2014). Such greater porosity also makes cement pastes more vulnerable to chemical attack by aggressive agents, reducing the service life of structures.

2.6 Causes of Deterioration of Concrete

Deterioration of concrete can be as a result of internal causes and external causes (Sulaiman, 2016).

2.6.1 Internal causes

These are causes within the concrete composition itself. Adequate test and meticulate material selection are means of correcting internal causes of deterioration, the causes of internal deterioration can be attributed to type of cement, alkali aggregate reaction, aggregate type, permeability of concrete, thermal properties of aggregate and cement paste (Sulaiman, 2016).

2.6.2 The external causes

The external causes of concrete deterioration are classified into physical and chemical causes. The deterioration effects of external causes can be corrected through appropriate

assessment of the environment which the concrete is exposed to and application of adequate protection techniques (Balim, 2012).

2.6.3 Physical deterioration

(1) Abrasion (2) Fire (3) Erosion (4) Cavitation(5)Freezing

A. Abrasion of Concrete

Under many circumstances, concrete surfaces are subjected to wear. This may be due to attrition by sliding, scraping or percussion. In the case of hydraulic structures, the action of the abrasive materials carried by water leads to erosion. Another cause of damage to concrete in flowing water is cavitation (Neville and Brooks, 2011). Abrasion damage to concrete may be caused by the sliding or scraping of equipment across the concrete (Nagesh, 2012).

1. That abrasion resistance is clearly related to the compressive strength of the concrete, Strong concrete has more resistance than weak concrete (Mehta and Monteiro, 2006).

1. Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance (Jose*et al*., 20010).
2. Hard aggregates are more abrasion resistant than soft aggregates (Tarun and Muhammad 2012).
3. Steel-trowelled surfaces resist abrasion more than a surface that is not trowelled (Tarun and Muhammad 2012).
4. Incorporation of pozzolana into mix increases abrasion resistance (Jose*et al*., 20010: Tarun and Muhammad 2012).

B. Fire

When concrete is subjected to elevated temperature, concrete responds not just in instantaneous physical changes, such as expansion, but by undergoing various chemical changes. This response is especially complex due to the non-uniformity of the material. Concrete contains both cement and aggregate elements, and these may react to heating in a variety of ways (Fletcher, *et al.*,2010).

First of all, there are a number of physical and chemical changes which occur in the cement subjected to heat. Some of these are reversible upon cooling, but others are irreversible and may significantly weaken the concrete structure after an exposure. Most porous concretes contain a certain amount of liquid water in them. This will obviously vaporize if the temperature significantly exceeds the moisture plateau range of 100-140°C or so, normally causing a build-up of pressure within the concrete. If the temperature reaches about 400°C, the calcium hydroxide in the cement will begin to dehydrate, generating further water vapour and also bringing about a significant reduction in the physical strength of the material. Other changes may occur in the aggregate at higher temperatures, for example quartz-based aggregates increase in volume, due to a mineral transformation, at about 575°C and limestone aggregates will decompose at about 800°C. In isolation, the thermal response of the aggregate itself is more straightforward but the overall response of the concrete due to changes in the aggregate may be much greater (Fletcher*et al.*, 2010).

These physical and chemical changes in concrete will have the effect of reducing the compressive strength of the material. Generally, concrete will maintain its compressive strength until a critical temperature is reached, above which point it will rapidly drop off. This generally occurs at around 600°C (Fletcher *et al.*, 2010). Several factors influence the behavior of concrete at high temperatures. These factors include concrete moisture content, aggregate type and stability, cement content, duration of concrete exposure, the rate that temperatures rise, the age of the concrete, and any restraint (Nagesh, 2012).

C. Erosion

Erosion refers to wearing of the concrete surface by the abrasive action of fluids and suspended solids as well as by wind-borne sand particles. Erosion is therefore a special case of abrasion (Balim, 2012: Emily, 2014). Erosion which provokes the removal of material from the surface of concrete. It depends on the speed, the content of hard dust particles and the quality of the concrete. In this case, the only remedy is to take special care when mixing the concrete.

D. Cavitation

Cavitation can be a problem in any open channel where the velocity of the flowing water is higher than 12 mls (meter/second) (39.4 ft/s) feet/second. In a closed pipe or conduit, cavitation can occur at velocities as low as 7.5 mls (24.6 ft/s). Concrete damage that is due

to cavitation can be minimized if irregularities in the flow of the water are eliminated or if the velocity of the flowing water is reduced. Concretes that have the best resistance to cavitation damage have a high strength, a low water-cement ratio, a small aggregate size that does not exceed 20 mm (3/4 inch), and a good paste aggregate bond (Nagesh, 2012).

E. Freezing

Problems caused by freezing of concrete are seldom encountered in Southern Africa because of the relatively mild climate in this region. However, there are some applications, such as cold rooms or cold liquid storage facilities, in which concrete is exposed to very low temperatures and could be damaged by the freezing of water in the pore structure (Balim, 2012).

According to Balim (2012) damage by freezing is derived from the fact that water undergoes a 9% volume increase when it turns to ice. Hence, damage occurs when the water in the pore structure expands upon freezing and there is not enough empty space in the pore structure to accommodate this expansion. Tensile stresses are then set up and microcracking of the cement paste occurs. In freeze-thaw deterioration, the cracks are propagated by the cyclic freezing and thawing actions.

2.6.5 Chemical deterioration

a) Sulphate Attack on Concrete

Sulfate attack is one of the most aggressive environmental deteriorations that affect the long-term durability of concrete structures. The sulfate attack of concrete leads to

expansion, cracking, and deterioration of many civil engineering structures exposed to sulfate environment such as piers, bridges, foundations, concrete pipes, etc. The sulfate ions in the solution, which come from soil, ground water, and seawater, are found in combination with other ions such as sodium, potassium, magnesium and calcium ions. The sulfate ions react with C_3A and $Ca(OH)_2$ to produce expansive and softening types of deterioration (Collerpadi, 2003).

2.6.5 Sulphate Attack

Sulphate attack is one of the most aggressive environmental factors that affect long term durability of concrete structures. It can result in cracking, expansion and deterioration of concrete structures. Sulphate attack is the reaction of sulphate ions with calcium hydroxide and calcium aluminate hydrate to form ettringite and gypsum, these products are voluminous and lead to expansion, cracking, deterioration, and deformation of concrete structures when formed after concrete has hardened (Collerpadi, 2003).

Sulphate attack can also lead to leaching of calcium compounds, degradation of calcium silicate hydrate (C-S-H), and overall deterioration of cement paste matrix (Bolanle and adeshina, 2014). One of the most severe conditions for durability of concrete is the sulphate or acid environment caused by industrial wastes or chemical residues at re-

claimed grounds (Bolanle and adeshina, 2014). Deterioration of concrete as a result of sulphate attack can be in form of internal attack due to sulphate content of the cement, and external attack due to exposure of concrete to sulphate environment. Both forms of sulphate attack are manifested by expansion and cracking of concrete (Bolanle and Adeshina, 2014).

The effects of sulphate attack in cementitiousmaterials visible to naked eye include spalling, dilapidation, macro cracking and possible loss of cohesion.

These are the repercussory outcome of complex chemical reaction and processes between the components of hydrated cement and sulphate compounds. The reactions that take place are as follow absorption, dissolution or precipitation and crystallization reaction (Collarpardi, 2003).

2.6.6Damage mechanisms due to sulphate attack

Three kinds of macroscopic damage due to sulfate ion interaction with the cementitious matrix have been reported: expansion (cracking, spalling), softening and decohesion (Aude, 2010).

A) *Expansion*

Sulfate attack is generally associated with, and even defined, in the literature as the formation of sulfate-bearing products within the cement paste leading to macroscopic expansion. Expansion is generally attributed to ettringite formation (Aude, 2010). Cement is known to perform very well in compression but very badly under tension with a failure criterion in the range of few MPa (e.g.; in the order of 4 MPa). Hence, any

microstructural effects responsible of macroscopic expansion should be able to generate stresses in such a range. Various different theories exist regarding the mechanism of expansion: increase in solid volume; topochemical reaction;swelling; crystal growth pressure (Aude, 2010).

b) Softening

Gypsum is mainly found as precipitates in macroscopic cracks. Nevertheless, it may also be found intermixed in the cement matrix. This suggests that gypsum can form from portlandite and also from calcium in C-S-H which becomes decalcified. Monosulfoaluminate is usually assumed to be the source of aluminium for ettringite formation but a source of calcium is also needed. In ordinary Portland cement paste, the experimentally determined Ca/Si-ratio is around 1.7-1.8, compared to the upper limit of synthetic C-S-H of 1.5 (Aude, 2010). This implies that in real cement matrix the C-S-H has an excess of calcium, which become available for gypsum and ettringite formation. Both gypsum and ettringite formation therefore lead to a relative decalcification of C-S-H, which is the main hydrate of cement matrix and stands for its cohesive property. This would result in a softening of this phase.

c) De cohesion

De cohesion mainly occurs when thaumasite formation is observed. Thaumasite is indeed a very brittle material whose fracture produces small conchoidal fragments: It does not possess the cohesive properties proper to the cementitious matrix. Thaumasite forms in presence of carbonate from a sulfate source and drawing silicon from

the C-S-H, the consumption of the silica of the C-S-H can lead to a loss of its binding properties. There is no evidence that ettringite is theoretically required as a precursor to thaumasite formation, but thermodynamically as sulfate concentration increases, ettringite forms first (Aude, 2010). Ettringite and thaumasite can also enter into partial solid solution (Aude, 2010).

2.6.7Magnesium sulphate

In the presence of magnesium sulphate, the products of reaction differ from those exhibited in other forms of sulphate attack. Conventionally, ettringite and gypsum are products of the attack. In addition to these, the presence of the Mg^{2+} cation in the gypsum's reaction kinetics leads to the formation of magnesium hydroxide ($Mg(OH)_2$), and eventual substitution of the calcium component in the C-S-H by magnesia (Julie, 2008). Therefore, this is the most disruptive form of sulphate attack and more disruptive than either calcium or sodium sulphate (Julie, 2008).

$Mg^{2+}+SO_4^{2-}+Ca(OH)_2+ 2H_2O \rightarrow Mg(OH)_2\ (s) + CaSO_4 \bullet 2H_2O$ ……2.7

This additional salt is also called brucite ($Mg(OH)_2(s)$).

.In this environment, the stability of C-S-H is reduced and its decomposition begins. At a progressed stage of the attack, "all the calcium content of the binder may be substituted by magnesium,non-cementitious magnesium silicate hydrate (M-S-H) is thus produced until equilibrium is reached causing disintegration of the paste (Julie, 2008).

2.6.8Methods of controlling sulphate effects on concrete

According to Shetty (2009) the following steps may be adopted for controlling effects of sulphate on concrete:

a. Use of Pozzolana: replacing part of cement by some pozzolanas reduces the sulphate attack. Incorporation of pozzolanic material into the concrete convert the leachable calcium hydroxide ($Ca(OH)_2$) into insoluble non leachable cementitious product. The pozzolanic action improves the impermeability of concrete. The reduction in $Ca(OH)_2$ reduces the possibility of sulphate attack on concrete.

b. Use of Sulphate Resistance Cement: In order to control or resist the sulphate effects on concrete the most effective and sufficient method is the use of low calcium aluminates (C_3A).

c. Quality of concrete: A well designed, prepared dense and impermeable concrete exhibits better resistance to sulphate attack. Similarly a concrete prepared with reduced water cement ratio exhibits a high resistance to sulphate.

d. The Use of High alumina Cement: The use of high alumina cement has been found to check the sulphate attack partly due to the absence of any free $Ca(OH)_2$ in the set concrete in contrast to Portland cement. High alumina cement contains approximately 40% aluminate.

e. Quality Concrete : A well designed placed and compacted concrete which is dense and impermeable exhibit higher resistance to sulphate attack, also concrete with low water cement ratio also offer high resistance to sulphate attack.

f. Use of Air Entrainment: Use of air entrainment around 6% has beneficial effects on the sulphate resisting qualities of concrete.

g. High pressure Steam Curing: High pressure steam curing improve the resistance to sulphate attack.

2.7Pozzolana

Pozzolana are siliceous materials which though not cementitious but contains materials which when combine with lime at ordinary temperature in the presence of water to form a compound which have low solubility and possess cementing properties. In other words Pozzolana is a siliceous and aluminous material which in itself possesses little or no cementitious quality, but will, in finely divided form and in presence of moisture, chemically reacts with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (Karim, *et al.*,2014).

2.7.1 Types of pozzolana

Pozzolanascan be divided into two groups: natural pozzolana (such as volcanic ash and diatomite) and artificial pozzolana (such as calcined clay, pulverized fuel ash, and ash from burnt agricultural waste). Many plant ashes have high silica content and are therefore suitable as a pozzolana(Shetty, 2009)

Table 2.3: Types of pozzolana

Natural pozzolana	Artificial Pozzolana
Clay and Shale	Fly ash

Opalinccherts	Blast furnace slag
Diatomaceous earth	Silica fume
Volcanic tuffs and pumicites	Rice husk ash
	Metakaoline

Source: Shetty (2009)

CHAPTER THREE

3.0 MATERIALS AND METHODS

Chapterthree gives a detail description of all the materials used in the experimental programme and the methods used for conducting the various tests.

3.1. Materials

The materials used in this research include the following: ordinary Portland cement, fine aggregate, coarse aggregate, water sealant cement, soda-lime silicate, borosilicate waste glass powder and water.

3.1.1 Cement

Ordinary Portland cement was used for the experimental work (OPC, Dangote Brand) conforming to the requirement of BS EN 197-1: (2011)

3.1.2 Borosilicate glass and soda-lime silicate glass waste

These two glass wastes were obtained from damaged glass, windows, doors and fluorescence waste glass. The glasses were cleaned in water and dried under sun, they were then ground in a ball milling machine up to fineness of 75 µm.The ground samples were then sieved with 75µm sieve size, in order to eliminate particles that were larger than 75µm. The pulverized glass samples were then mixed in the ratio of 1:1.

3.1.3 Fineaggregate

The fine aggregate used was natural sand. It was sieved with a 4.75mm BS sieve so as to remove impurities and larger aggregates. The fine aggregate was obtained from nearby river (ABU Dam). It complies with provisions of BS EN 1260: (2013)

3.1.4 Coarse aggregate

The coarse aggregates used were crushed gravels which were obtained from single quarry. It is in conformity with the requirement of BS EN 1260: (2013)

3.1.5 Water

The water that was used for mixing the concrete was clean fresh tap water free from injurious oils, chemicals and vegetable matters or other impurities complying with the provisions of BS EN 1008: (2002).

3.2 ExperimentalProgramme

The experiments were conducted as follow

3.2.1Preliminary investigation

The tests carried out include the physical, mechanical and chemical properties of materials used for the research such as: particle size distribution, specific gravity, bulk density, water absorption capacity, moisture content, setting time and soundness.

i. Particle Size Distribution

The particle size distribution for the coarse aggregate, fine aggregate and combined aggregate was carried out by sieve analysis as described in conformity to BS 812-103.1 :(1985). This was done in order to determine the grading of the aggregate.

ii. Specific Gravity

The specific gravity of cement, fine aggregate, coarse aggregate, borosilicate and sodalime glass were determined by using pyconometer method in conformity to BS 1377:2(1970).

The apparatus used include density bottle and stopper, funnel, spatula and weighing balance. The relationship used to find the specific gravity is given by:

Specific Gravity = $\frac{W2-W1}{(W4-W1)(W3-W1)}$ 3.1

Where:

W_1= Weight of density bottle

W_2 = Weight of density bottle + Sample

W_3 = Weight of density bottle + Water (full) + Sample

W_4 = Weight of density bottle + Water (full)

iii. Bulk Density

This was determined in conformity to BS 812: Part 2 (1995) for the borosilicate and sodalime glass, cement, and fine aggregate, coarse aggregate. The relation below was used to determine the bulk density of the sample:

Bulk Density = $\frac{W1-W}{V}$ 3.2

Where:

W_1 = Weight of container + sample

W = Weight of empty container

V = Volume of container

iv. Water absorption capacity

The absorption capacity test was carried out (i.e. the coarse and fine aggregate). This was done as stipulated by BS 1881-122 (1983).

v. Moisture content.

This test was determined in accordance to BS 812:109 (1995). The procedure for the test was carried out as stipulated by Gambo (2014)

vi. Setting time

The setting time of the pastes were carried out according to the procedures highlighted by ASTM C 451 -89 and the apparatus used was Vicat apparatus. This was conducted for each percentage replacement.

vii. Chemical properties

The chemical analysis was conducted at the Centre for Minerals Research and Development Kaduna Polytechnic Kaduna state of Nigeria using X-ray florescence test to determine the percentages of chemical composition of oxide such as silicon oxide (SiO_2), aluminum oxide (Al_2O_3), iron trioxide (Fe_2O_3) and others. To investigate if they are in line with the ASTM C 618-05 classes of pozzolana because the ASTM standard stipulated that for any material to be used as pozzolana, it should fall within the following classes Class *N*, Class *F*, Class *C*.

3.2.1 Production of concrete samples

i. Mix design

Grade 30 concrete was designed because the target strength was 30N/mm^2. This was done in order to determine the ability of designing for a particular strength of concrete. In this

case, building research establishment (BRE) method of mix design was used for designing the grade of concrete. Details are shown in appendix A2

ii. Mixing and casting of the concrete samples

The constituent materials required for each sample were measured and weighed on a digital weighing balance i.e cement, sand and aggregate, (borosilicate and sodalime glass). After mixing, the fresh concrete was casted into 100mm X 100 mm X100 mm moulds in two layers and was compacted manually by giving it 25 blows with a tapping rod in order to achieve smooth and level compaction for each sample.

iii Curing of samples

Samples were allowed to set for 24hours before demoulding and immersed in a pool of water tank for 7days, 14days and 28days.

iv. Concrete Specimens Produced

Nine different specimens were produced and tested at various ages of (7 days, 14 and 28,). They included specimen A which is control, specimen B samples replaced with borosilicate and soda-lime silicate glass. The variation in the percentage replacement of cement with borosilicate and soda-lime silicate glass was to have a stronger basis for comparison, A total of 108 cubes were casted, 81 cylinders and 81 beams for this research, detail of specimen casted are shown in table 3.1 and 3.2.

Table 3.1: Breakdown of the crushed samples used in this research

Tests	Curing Period	Samples								
		Control	2.5% GLS	5% GLS	7.5% GLS	10 % GLS	12.5% GLS	15% GLS	17.5% GLS	20% GLS
Compressive Strength		3	3	3	3	3	3	3	3	3
Tensile Strength	7days	3	3	3	3	3	3	3	3	3
Flexural Strength		3	3	3	3	3	3	3	3	3
Compressive Strength		3	3	3	3	3	3	3	3	3
Tensile Strength	14 days	3	3	3	3	3	3	3	3	3
Flexural Strength		3	3	3	3	3	3	3	3	3
Compressive Strength		3	3	3	3	3	3	3	3	3
Tensile Strength	28 days	3	3	3	3	3	3	3	3	3
Flexural Strength		3	3	3	3	3	3	3	3	3
Absorption Test		3	3	3	3	3	3	3	3	3

Source: Experimental Research work (2017)

Table 3.2: Summary of tested samples

Type of Test	Type of Specimen and Size	No of Specimen
Compressive Strength	Cubes	81
Tensile Strength	Cylinders	81
Flexural Strength	Beams	81
Absorption Capacity	Cubes	27
Total Samples		**270**

Source: Laboratory Research Work (2017)

3.2.3 Testing of fresh concrete specimens

a. Workability test

i. Slump

The slump value of the fresh concrete was measured in order to determine the workability of each mix. This was done as recommended by BS 1881-102 (1983). The apparatus used in carrying out the slump test includes steel tamping rod, base plate, hand scoop, trowel and metal cone.

ii. Compacting factor test

The compacting factor of fresh concrete was measured in order to determine the degree of workability and possible area of applications. This was done as recommended by BS 1881: Part

103(1947). The apparatus used in carrying out the compacting factor include the following, compacting factor apparatus, digital weighing balance, tamping rod, base plate and metal cone.

The compacting factor was determined using the formulae

$$C.F = \frac{W1}{W2} \quad \text{.....3.3}$$

iii. Setting time test

The Setting time test was conducted with Vicat apparatus, and the procedure stipulated by ASTM C 451 was strictly observed, nine samples were prepared which include the control and all the samples that contain glass powder as partial replacement of cement

3.2.2 Testing of hardened concrete specimens

After curing the samples they were subjected to the following tests at the end of each curing ages which include:

i. Compressive strength test

Compressive strength was carried out after different curing ages of 7, 14, and 28 days for all the concrete samples (control, and samples that contain glass powder as partial replacement of cement). A total of 81 specimens were tested for compressive strength and it was done as stipulated by ASTM C 39-05. Three cubes were tested to failure for all specimens. The maximum failure load was then recorded and the compressive strength was calculated using the relation:

$$\text{Compressive strength} = \frac{\text{Maximum load (KN)X1000}}{CrossSectionalArea}\,(\text{mm2}) \quad \text{.....3.4}$$

ii. Tensile strength test

Tensile strength was carried out after different curing ages of 7, 14, and 28 days for all the concrete samples (control, and Samples that contain glass powder as partial replacement of cement). A total of 81 specimens were tested for tensile strength and it was done as stipulated by BS 1881 (part 117). Three cubes were tested to failure for all specimens. The maximum failure load was then recorded and the tensile strength was calculated using the relation:

$$\text{Tensile Strength} = \frac{\text{Load}}{\text{Failure Area}} X \frac{2}{3.14} \quad \ldots\ldots 3.5$$

iii. Flexural strength test

Flexural strength was carried out after different curing ages of 7, 14, and 28 days for all the concrete samples (control, and Samples that contain glass powder as partial replacement of cement). A total of 81 specimens were tested for Tensile strength and it was done as stipulated by BS 1881 (part 118). Three cubes were tested to failure for all specimens. The maximum failure load was then recorded and the flexural strength was calculated using the relation:

$$\text{Tensile strength} = \frac{\text{Load}}{\text{Failure Area}} X \frac{2}{3.14} \quad \ldots\ldots 3.6$$

iv. Water absorption test

The water absorption tests were carried out in accordance to BS 1881-122(1983). The apparatus used for carrying out the experiment include weighing balance, oven and water tank. Three specimens from each sample were placed in an oven at temperature of 105^0C for 72 hours. The specimen were then removed and allowed to cool down to room temperature in an airtight

container. The specimens were weighed (W_1) and submerged in a water tank for 24 hours. After 24 hours the specimens were removed from the water tank and were surface dried with cloth. The specimens were then re weighed and the values recorded. The results were evaluated as the increase in mass resulting from the submersion of the concrete specimens in the water tank and expressed as the percentage of the dried specimen.

Water absorption = $\frac{(W2-W1)}{W2}$ x 100 ……3.7

Where:

W_1 = Oven dry weight of cylinder in grams

W_2 = after 24 hours wet weight of cylinder in grams.

CHAPTER FOUR

4.0 RESULTS

4.1 Presentation of Results

The results presented in this chapter are obtained from the tests carried out on the type of materials and concrete samples used for this research. Physical properties and chemical analysis tests for the materials used in the experiment as well as the test results for both the fresh and hardened concretes are presented in this chapter.

4.2.1 Particle size distribution of aggregates (fine)

Table 4.1: Particle size distribution of fine aggregate

BS Sieve Size	Weight Retained (g)	Weight passing (%)	Percentage passing (%)	Cumulative Retained Passing(%)	Fineness Modulus
20mm	0.00	500	100	0	0
10mm	0.00	500	100	0	0
5mm	0.00	500	100	0	0
2.36mm	37.0	463	92.6	37	25.87
1.18mm	106	357	71.4	143	38.75
600 µm	226	131	26.2	369	77.35
300 µm	108	23	4.6	477	97.1
150 µm	14.0	9	1.8	491	98.2
Pan	9.0	0	0	500	337.2

Source: Laboratory Research Work (2017)

Figure 4.1 presents the grading curve for combined aggregate (Coarse and Fine aggregate). It can be seen that the combined aggregate fell between zone 1 and zone 4. This means that the aggregate are suitable for general structural work. Details of the results are presented in appendix A.1.

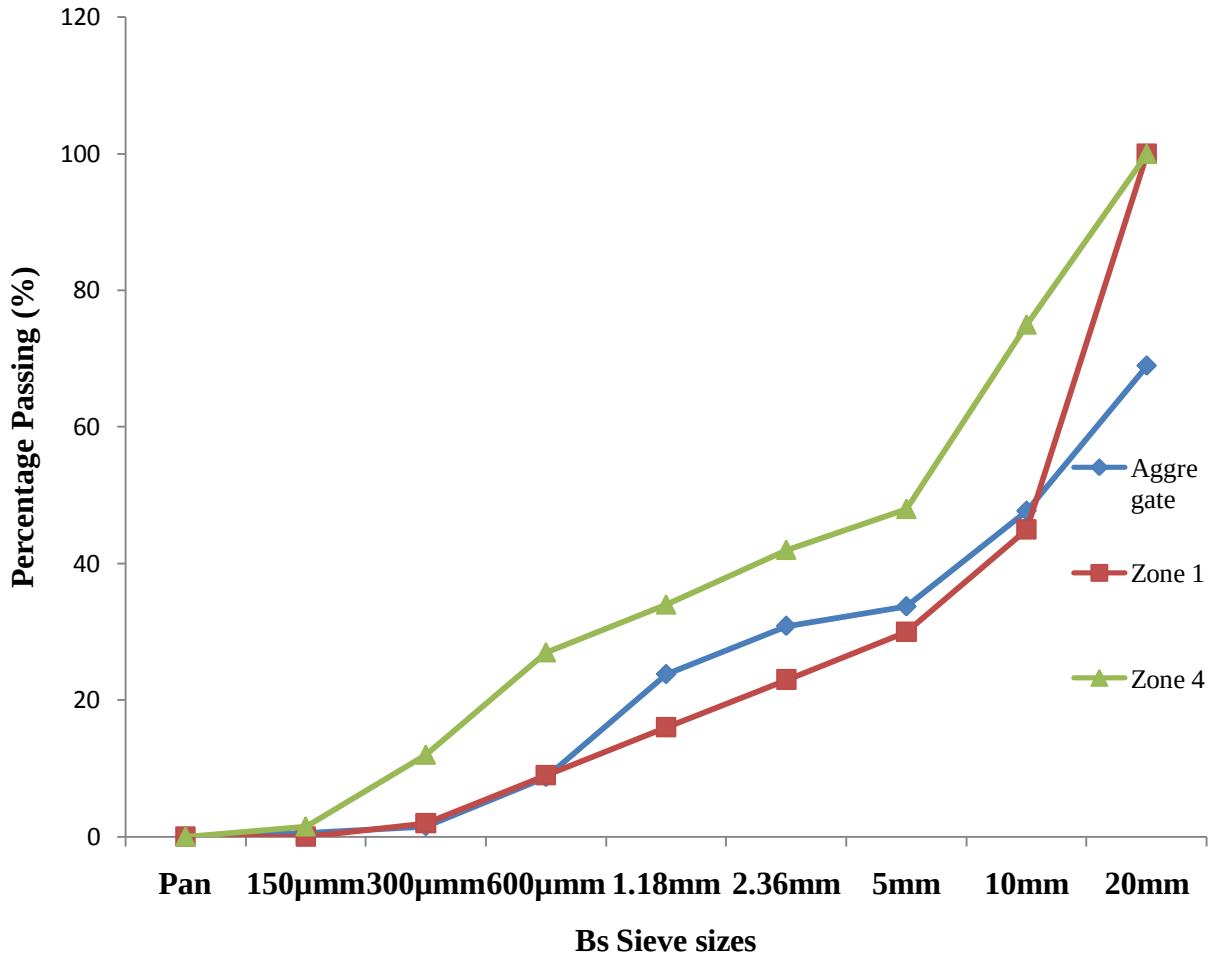

Figure 4.1: Sieve analysis curve of combined aggregate

4.2.2 Aggregate moisture content, absorption capacity and bulk density

Table 4.2 present the results for aggregate moisture content, absorption capacity and bulk density of cement, SLG and BSG, 0.89% and 0.43 were obtained as moisture content of coarse aggregate and fine aggregate, the absorption capacity of 1.02% and 1.68% were obtained for the fine aggregate and coarse aggregate respectively.

Table 4.2: Summary ofthe preliminary tests conducted on materials

	Materials				
Tests	**Cement**	**F.Aggregate**	**C.Aggregate**	**BSG**	**SLG**
Specific Gravity (Kg/m^3)	3.20	2.51	2.86	2.10	2.22
Compacted Bulk Density (Kg/m^3)	1440	1767	1498.3	1200	1275
Uncompacted Bulk Density (Kg/m^3)	1353	1233.4	1359.24	1009	1196
Moisture Content (%)	0	0.89	0.43	0	0
Water Absorption(%)	0	1.68	1.02	0	0

Source: Laboratory Research Work (2017)

4.2.3 Chemical properties of cement, soda-lime silicate and borosilicate waste glass

Table 4.3: The preliminary determination of chemical composition of cement, soda-lime silicate glass and borosilicate glass (XRF)

	Percentage Composition (%)		
Oxides	**Cement**	**Borosilicate Glass**	**Soda-lime silicate Glass**
Silicon Oxide (SiO_2)	**20.211**	**72.998**	**73.202**
Aluminum (Al_2O_3)	**4.698**	**0.201**	**0.411**
Iron Oxide (Fe_2O_3)	**3.022**	**0.112**	**0.223**
Sodium Oxide (Na_2O)	**0.189**	**5.722**	**6.843**
Calcium Oxide (CaO)	**61.889**	**3.766**	**6.433**
Magnesium Oxide (MgO)	**2.619**	**0.723**	**1.269**
Potassium Oxide (K_2O)	**0.820**	**0.588**	**0.168**
Sulfur Oxide (SO_3)	**3.889**	**0.135**	**0.158**
Boron Oxide (B_2O_3)	------	**5.251**	------
Loss on Ignition (LOI)	**2.660**	**10.502**	**11.287**

Source: Experimental Work (2017)

4.3 Presentation of Results for Tests on Fresh Concrete Specimens

4.3.1 Setting time of cement pastes

Table 4.4: Setting time testpresents the result of setting time test of different cement pastes samples. Dangote Portland cement was used for the experimental work.

Effects of SLG and BSG in Cement Mortar

Sample	%Replacement	IST(min)	FST(min)	Water (g)
A	0	113	168	126
B	2.5	126	180	130
C	5	132	196	133
D	7.5	138	202	138
E	10	146	220	145
F	12.5	156	226	155
G	15	168	238	125
H	17.5	180	269	130
I	20	188	284	142

Source: Laboratory Research Work (2017)

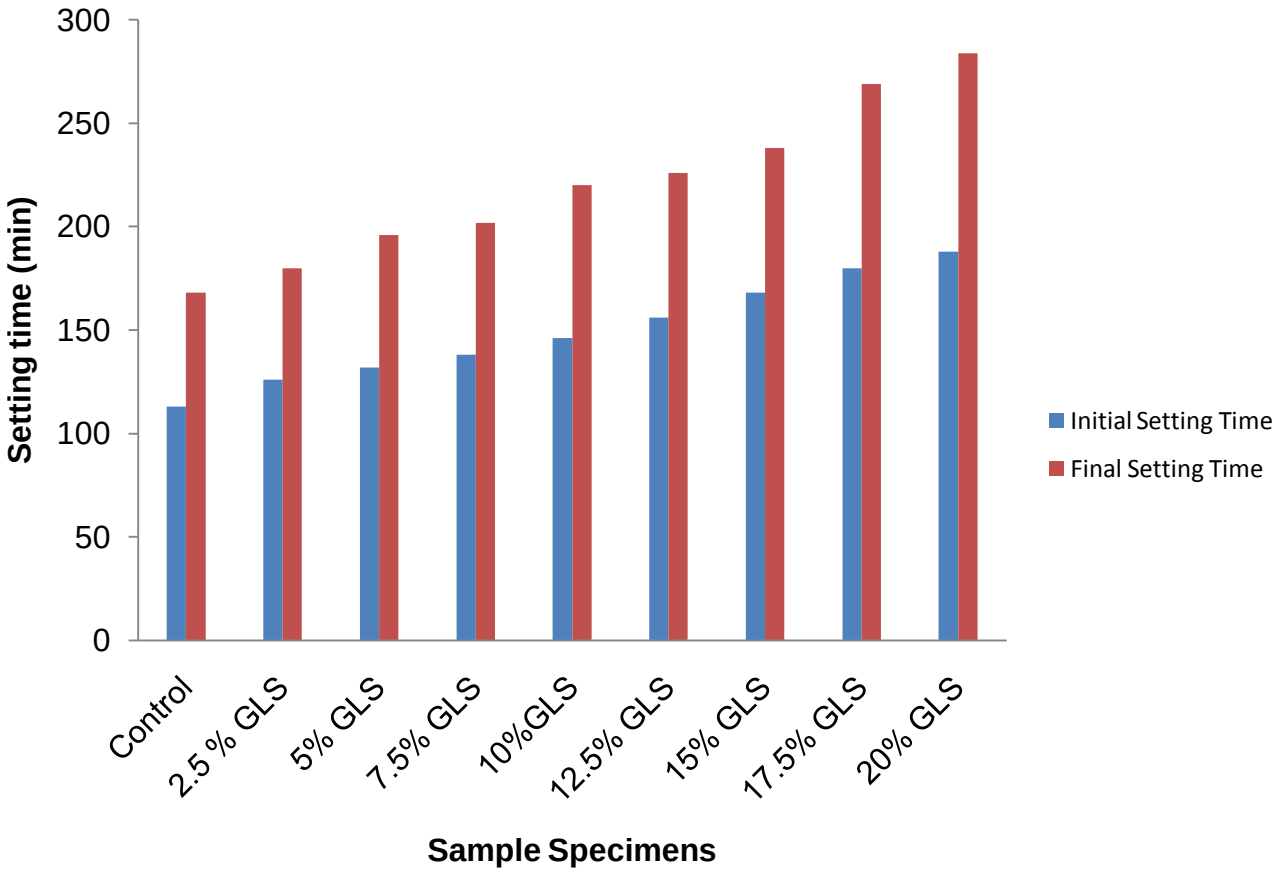

Figure 4.2: Initial and final setting time of the sample specimens

4.3.2 Slump test

Figure 4.3 shows the result of workability determined by slump test method.

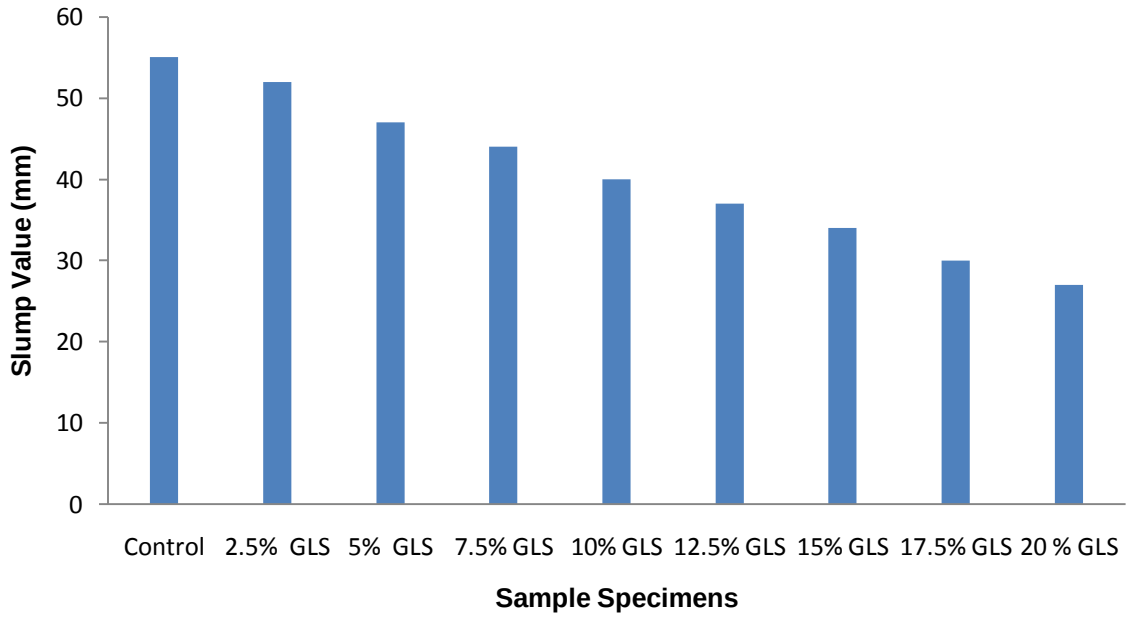

Figure 4.3: Slump mixes of the sample specimens

4.3.3 Compacting factor test

Figure 4.4 shows the result of workability determined by compacting factor test method.

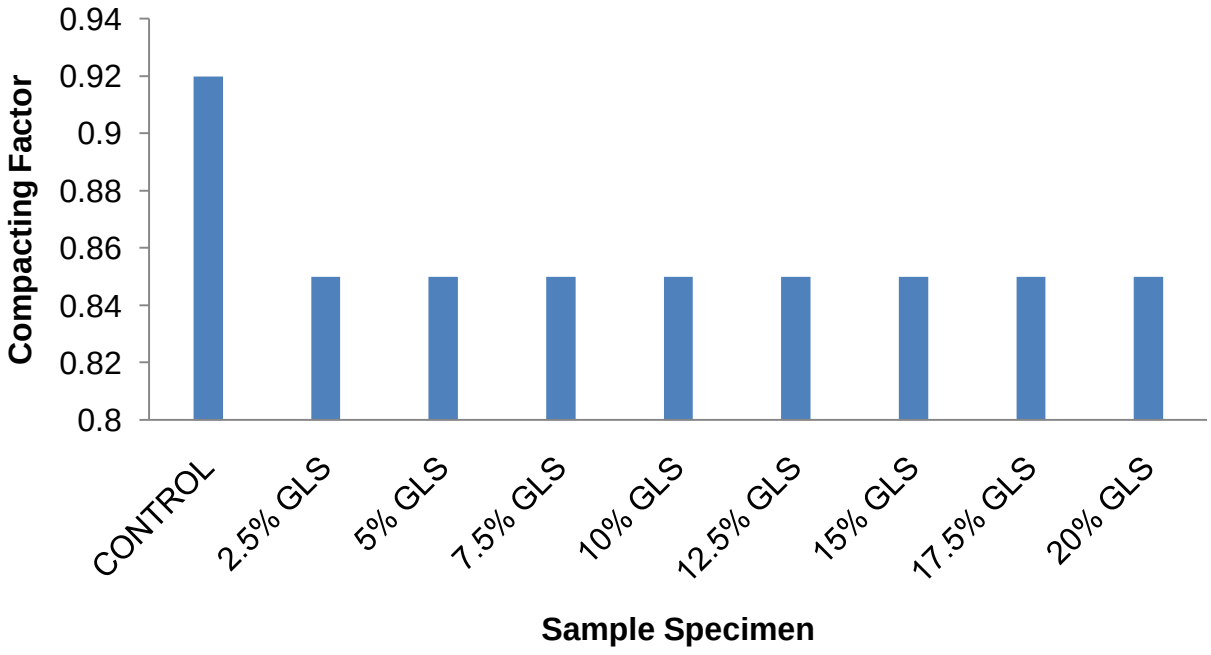

Figure 4.4: Compacting factor test of the sample specimens

4.4 Presentation of Results of Tests Conducted on Hardened Concrete

4.4.1 Compressive strength of samples

Figure 4.6 shows the compressive strength of all the sample specimens at 7, 14 and 28 days respectively.

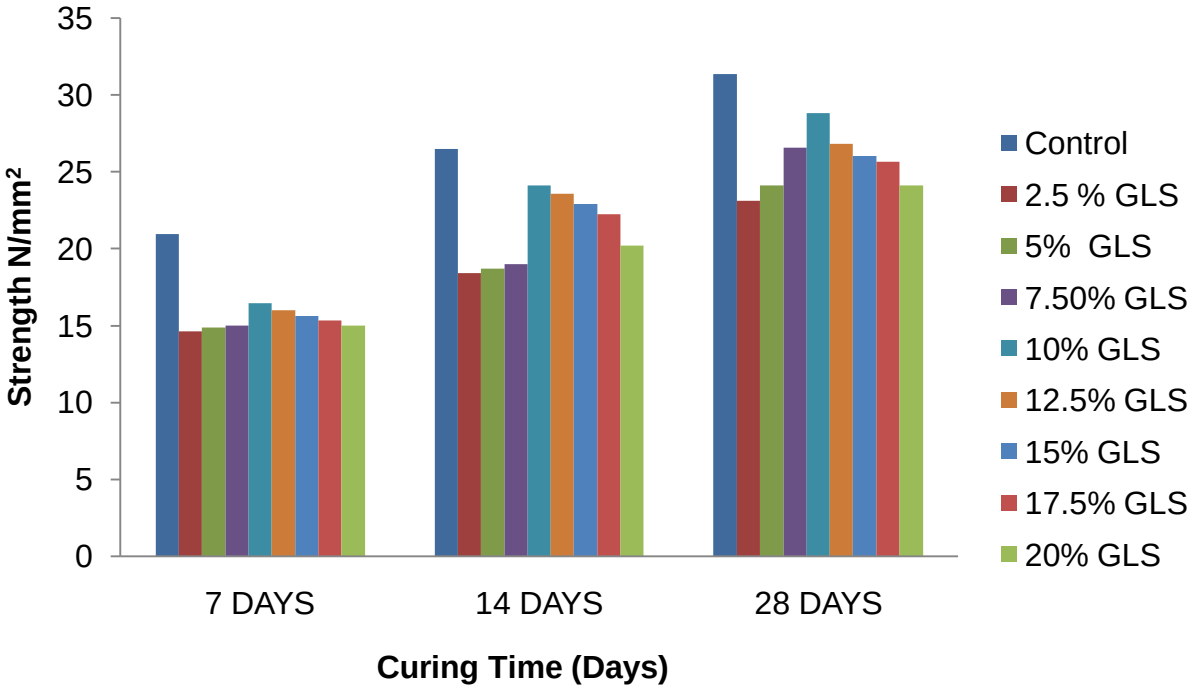

Figure 4.5: Compressive strength of samples cured in water

4.4.2 Tensile strength test of samples

Figure 4.6 shows the tensile strength of all the sample specimens at 7, 14 and 28 days respectively.

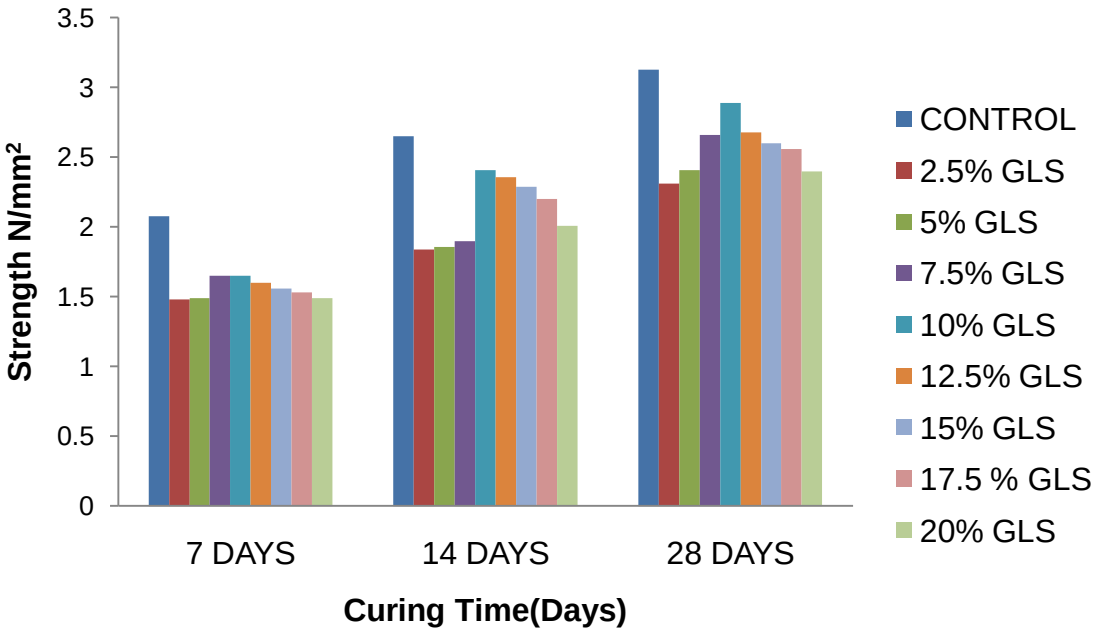

Figure 4.6: Tensile strength of samples cured in water

4.4.3 Flexural strength test of samples

Figure 4.7 shows the flexural strength of all the sample specimens at 7, 14 and 28 days respectively.

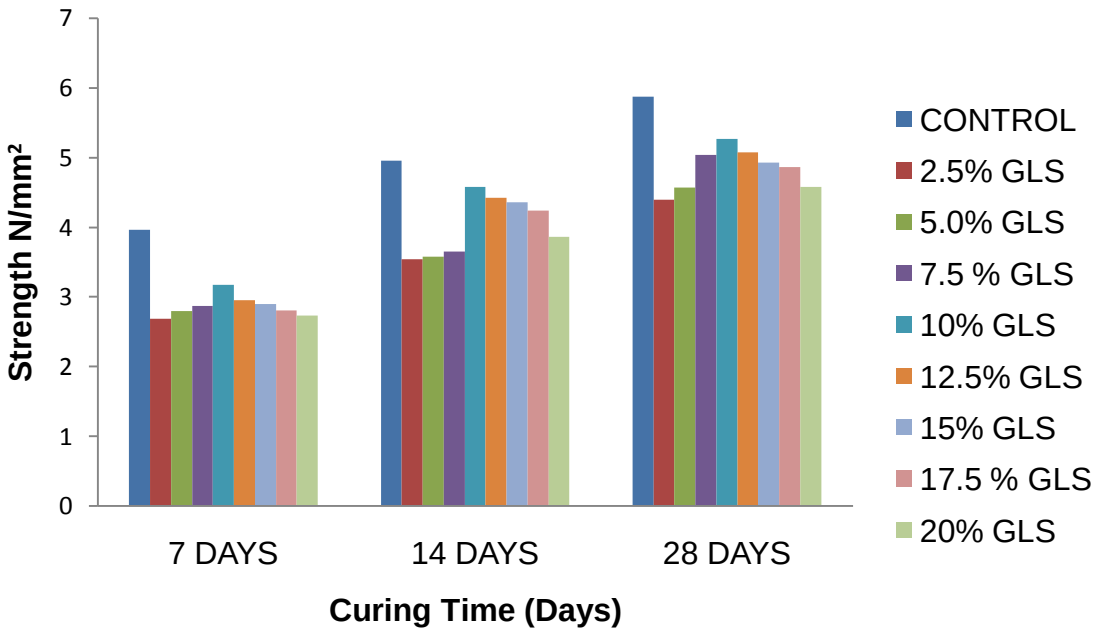

Figure 4.7: Flexural strength of samplescured in water

4.4.4 Water absorption capacity test

Figure 4.8 shows water absorption capacity of all the specimens, at 7 days, 14 days and 28 days and the control samples absorbed water equivalent of 5.14%, 4.6% and 4.02% respectively.

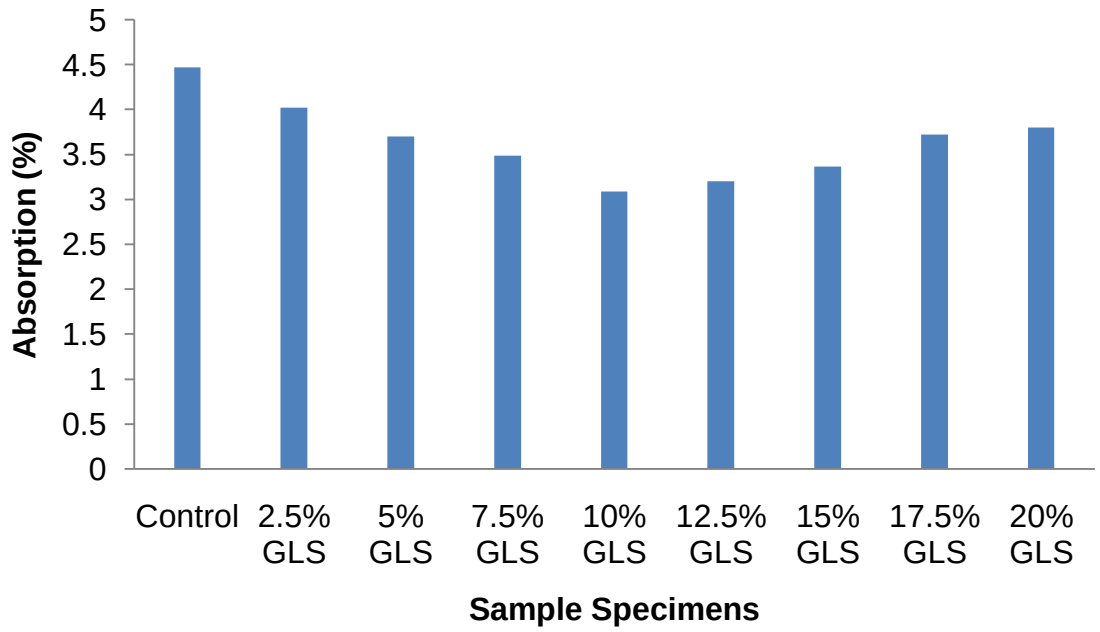

Figure 4.8: Water absorption capacity of the sample specimens after 28 days of curing

4.4.5 Scanning electron microscopy (SEM) analysis

Plate 4.1: shows the micrograph of the control 0% waste glass powder (100% Pure Portland cement) cured at room temperature for 28 days.

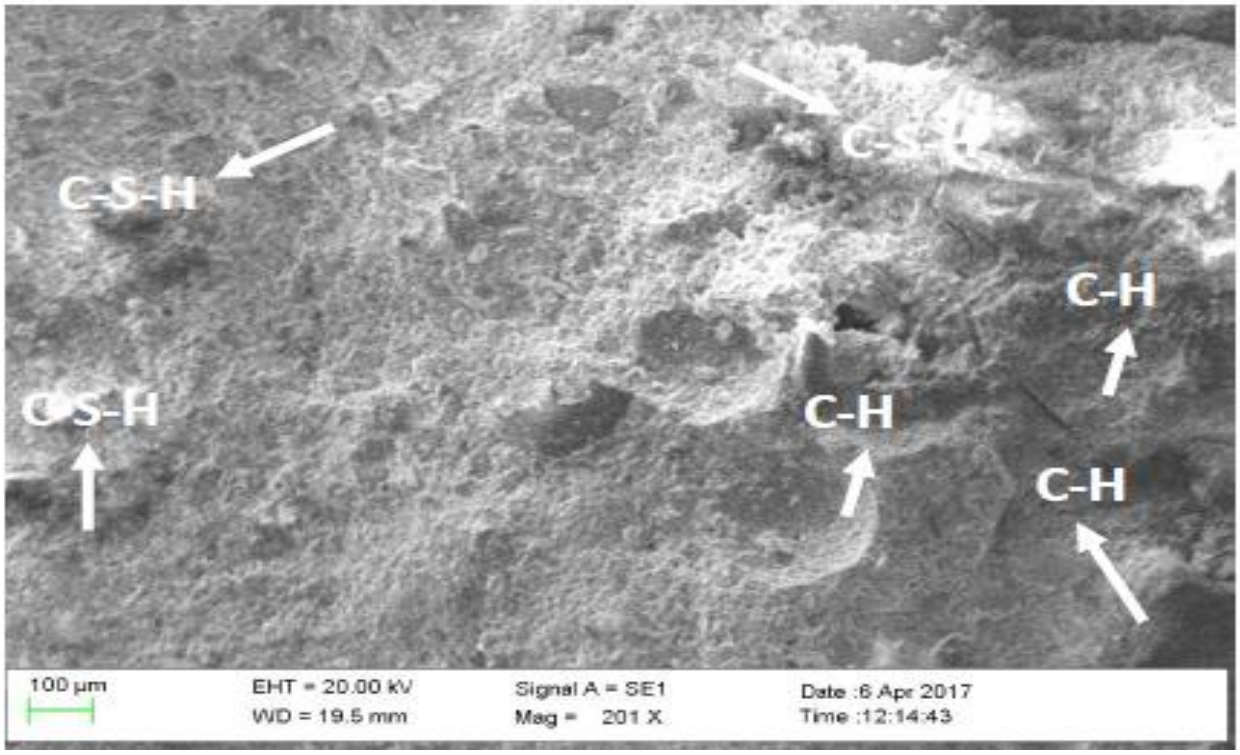

Plate4.1: A SEM micrograph of control 0% waste glass powder. CH = $Ca(OH)_2$ C-S-H = Calcium Silicate Hydrate gel

Plate 4.2: shows the micrograph of the 10% waste glass powder (90% Pure Portland cement) cured at room temperature for 28 days.

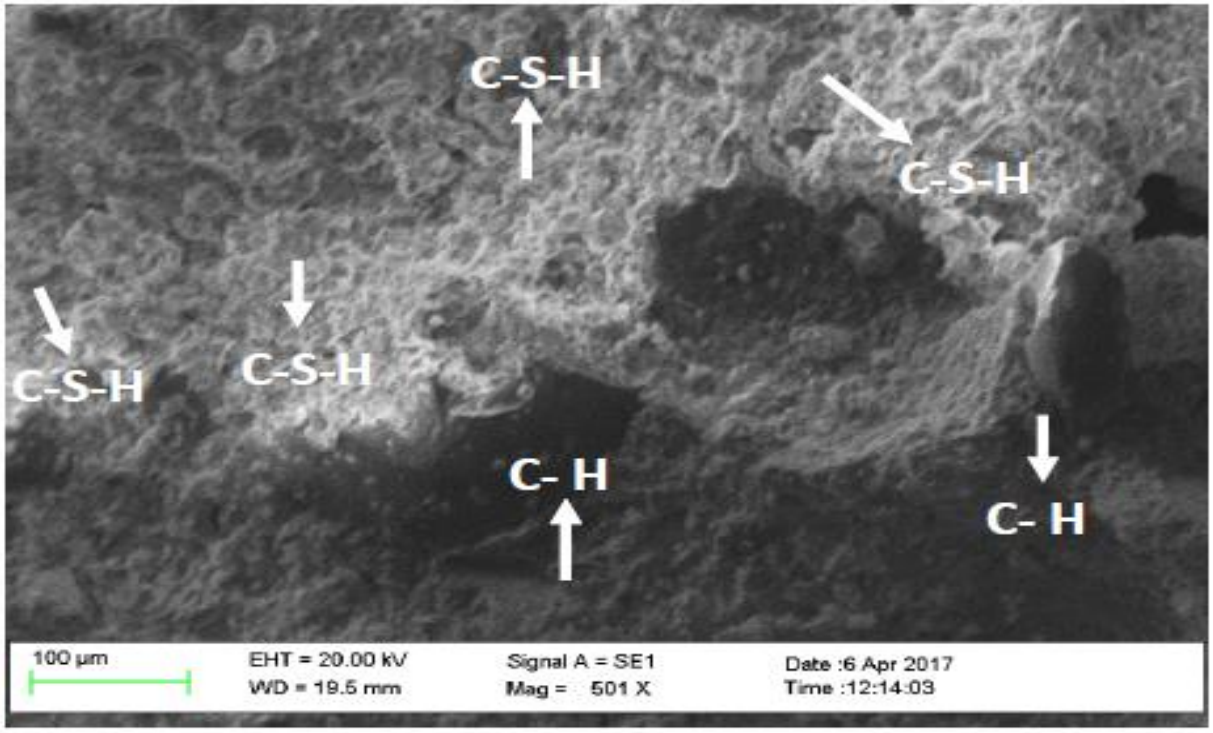

Plate 4.2: A SEM micrograph of 10% waste glass powder. CH = $Ca(OH)_2$
C-S-H = Calcium Silicate Hydrate gel

Plate 4.3: shows the micrograph of the 15% waste glass powder (85% Pure Portland cement) cured at room temperature for 28 days.

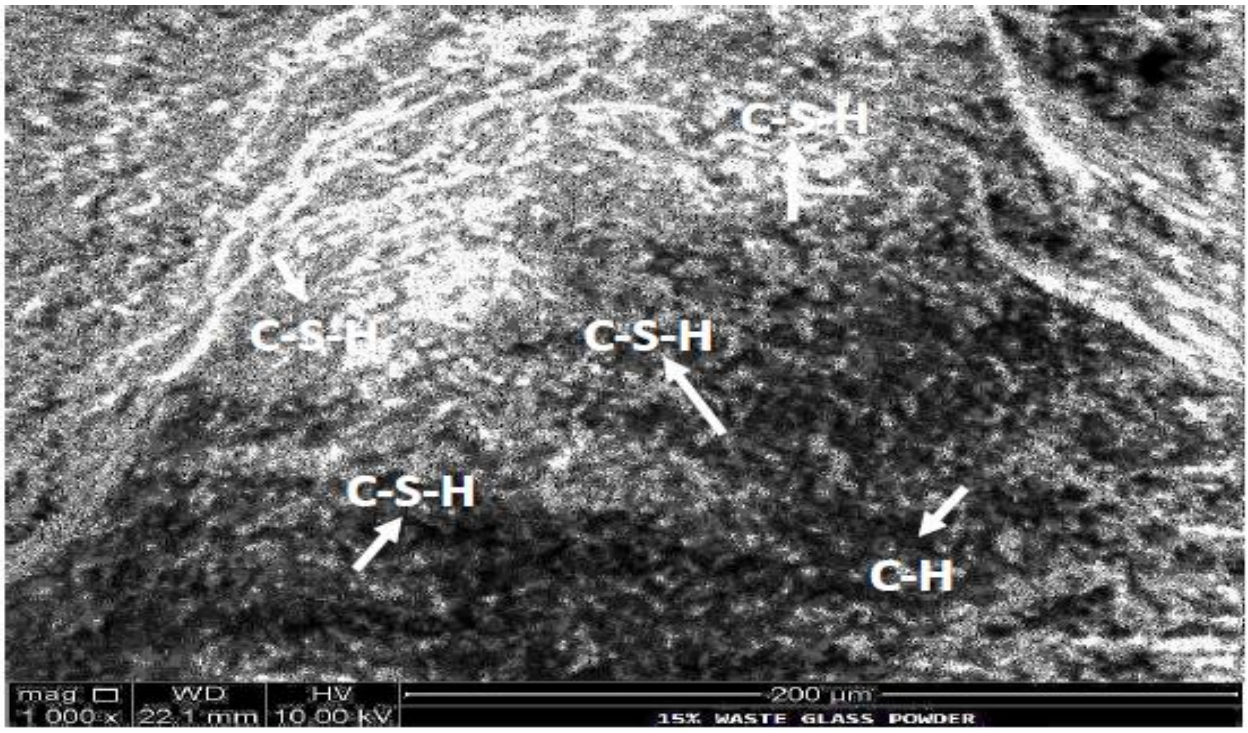

Plate 4.3: A SEM micrograph of 15% waste glass powder. CH = $Ca(OH)_2$ C-S-H = Calcium Silicate Hydrate gel

Plate 4.4: shows the micrograph of the 20% waste glass powder (80% Pure Portland cement) cured at room temperature for 28 days.

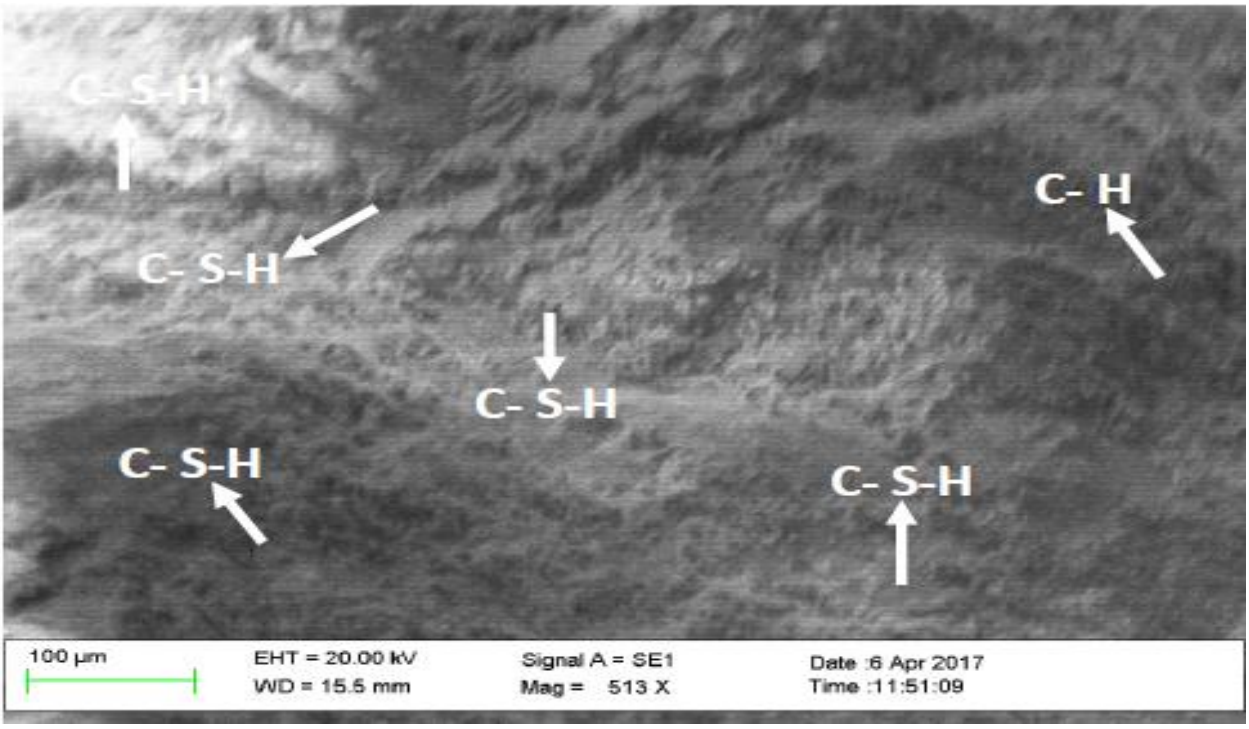

Plate 4.4: A SEM micrograph of 20% waste glass powder. CH = $Ca(OH)_2$ C-S-H = Calcium Silicate Hydrate gel

4.4.6 X-ray diffractomatory (XRD) analysis

Figure 4.9shows the X-ray diffractogramspattern of the control0% waste glass powder of concrete sample material cured at room temperature for 28 days, whose in the concrete mixture, several minerals present in the concrete mixture used as a precursor are identified, such as microline, quartz, biotitecalcite and portlandite(37%, 20%, 27%, 6% and 10% respectively).

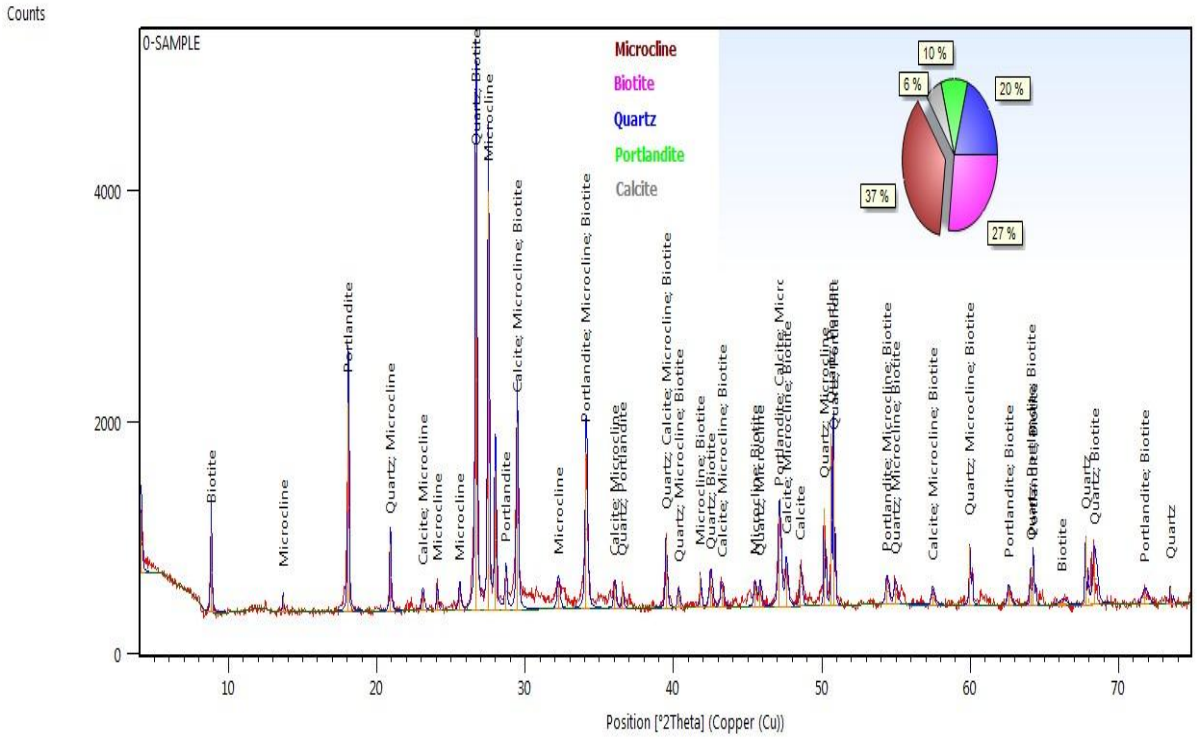

Figure 4.9: X-ray diffractograms pattern of the control 0% waste glass powder. It shows 10% of portlandite ($Ca(OH)_2$)

Figure 4.10shows the X-ray diffractogramspattern of the 10% waste glass powder of concrete sample material cured at room temperature for 28 days, whose in the concrete mixture, several minerals present in the concrete mixture used as a precursor are identified, such as microline, quartz, biotitecalcite and portlandite(67%, 14%, 13%, 4% and 2% respectively).

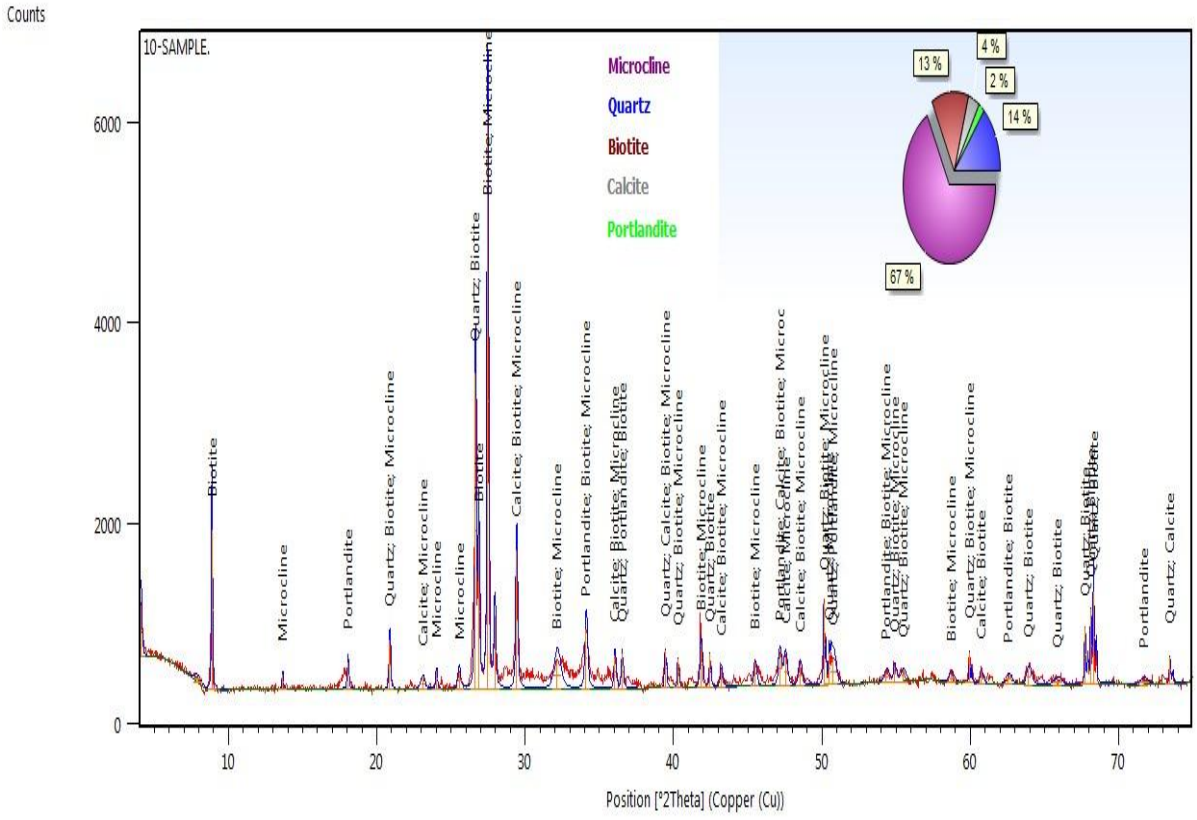

Figure 4.10: X-ray diffractograms pattern of the 10% waste glass powder. It shows 2% of portlandite($Ca(OH)_2$)

Figure 4.11shows the X-ray diffractogramspattern of the 15% waste glass powder of concrete sample material cured at room temperature for 28 days, whose in the concrete mixture, several minerals present in the concrete mixture used as a precursor are identified, such as microline, quartz, annitecalcite and portlandite(44%, 35%, 13%, 4% and 4% respectively).

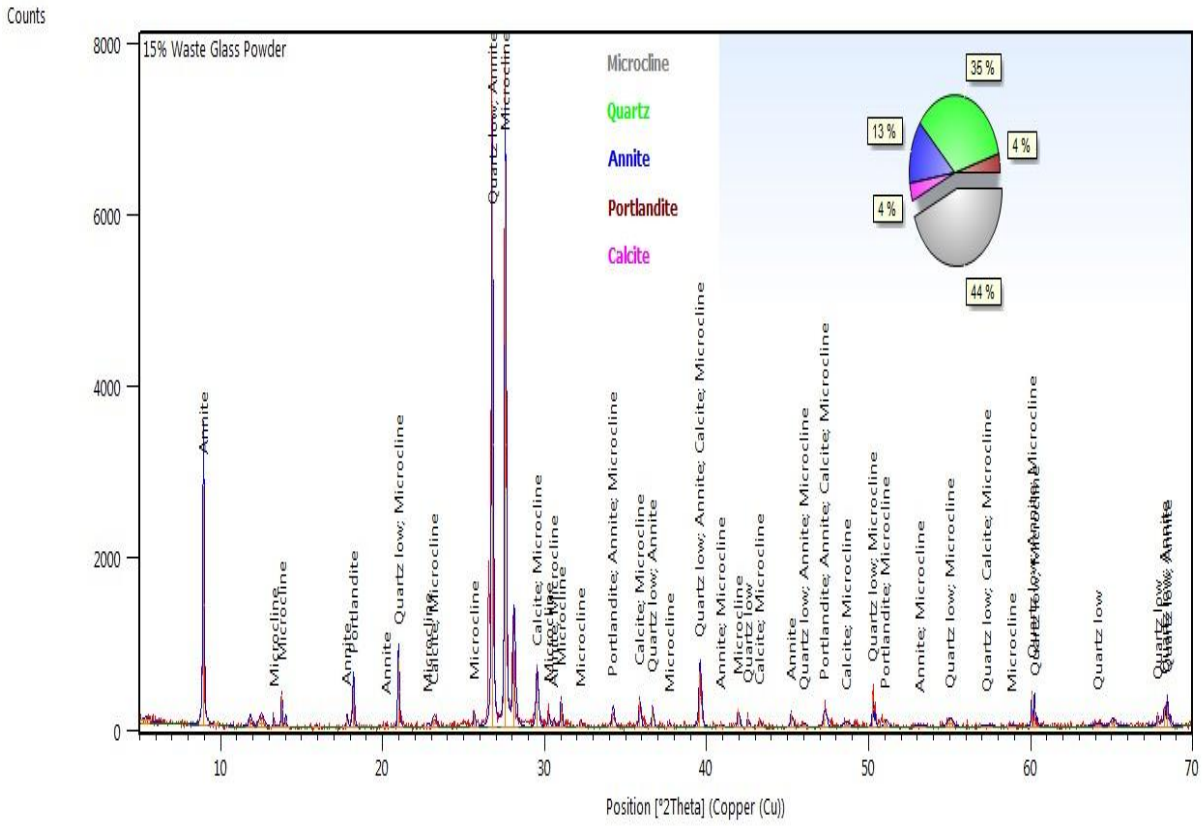

Figure 4.11: X-ray diffractograms pattern of the 15% waste glass powder. It shows 4% of portlandite ($Ca(OH)_2$)

Figure 4.12shows the X-ray diffractogramspattern of the 20% waste glass powder of concrete sample material cured at room temperature for 28 days, whose in the concrete mixture, several minerals present in the concrete mixture used as a precursor are identified, such as microline, quartz, biotitecalcite and portlandite(57%, 22%, 3%, 13% and 5% respectively).

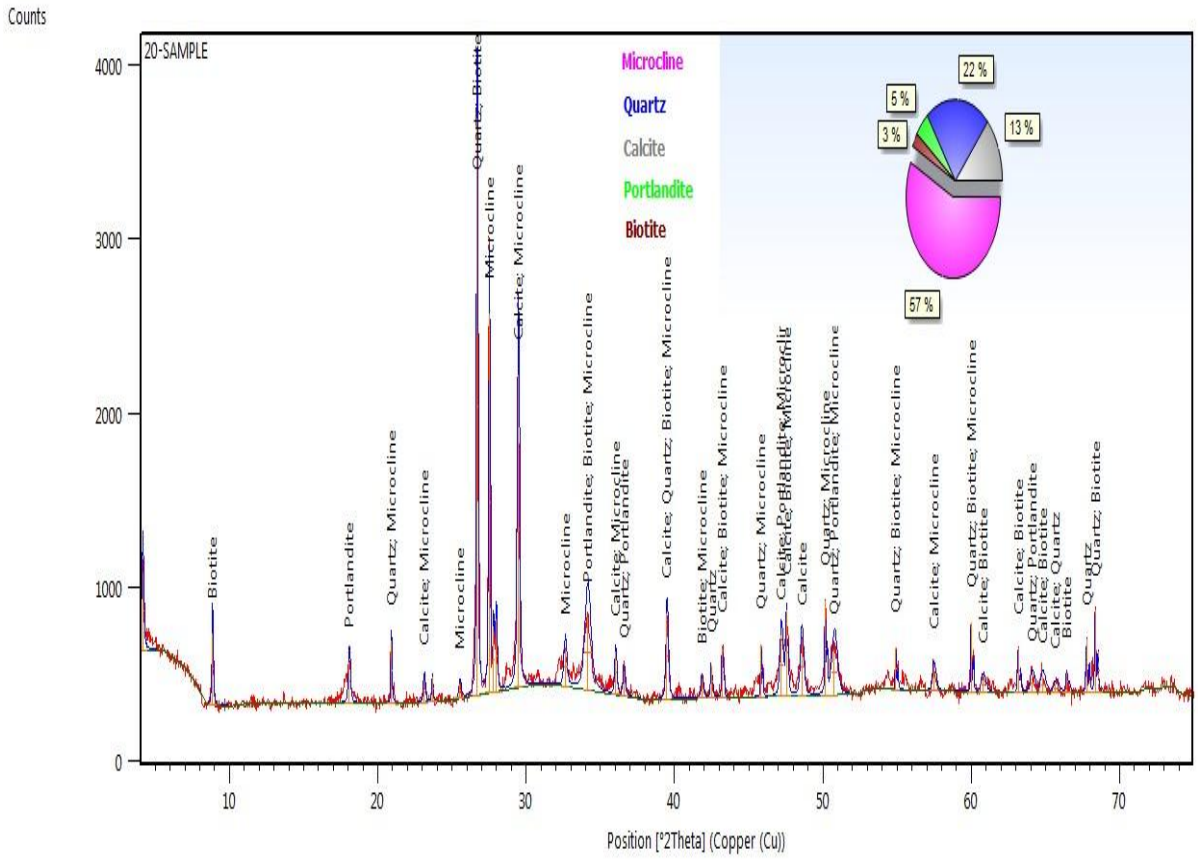

Figure 4.12: X-ray diffractograms pattern of the 20% waste glass powder. It shows 5% of portlandite($Ca(OH)_2$)

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Hydration Reaction of $SiO_2$and $Ca(OH)_2$

The dominant product of these reactions is C–S–H gel, which is principally responsible for the mechanical properties of the hydrated cement. C–S–H gel is generated by the interaction of the replacement materials with portlandite, CH, liberated during the hydration of the alite and belite present in the cement (Taylor, 1997).

- $2(3CaO.SiO_2) + 7H_2O \longrightarrow 3CaO.2SiO_2.4H_2O + 3Ca(OH)_2$ 5.1
- $2(2CaO.SiO_2) + 5H_2O \longrightarrow 3CaO.2SiO_2.4H_2O + Ca(OH)_2$ 5.2
- $2SiO_2 + 3Ca(OH)_2 + H_2O \longrightarrow 3CaO.2SiO_2.4H_2O$ 5.3

5.2 Discussions on the Physical properties of the Materials

Table 4.1 depicts the result of sieve analysis of fine aggregate, 500g of fine aggregate was measured and adopted. The sieves were arranged in ascending order of aperture (20mm, 10mm, 5mm, 2.36mm, 1.18mm, 600um, 300um, 150um and pan; weight retained was determine for each sieve size. No weight was retained on 20mm, 10mm and 5mm sieve sizes, thus the definition of Zongji (2011) was fulfilled. 600um retained the highest weight of 226g, 2.36mm

sieve size has the highest weight passing of 463g, and followed by 1.18mm sieve size of the percentage passing through 600um was 26.2g which fall in grade zone 1 and is applicable for structural works (Duggal, 2008). Cumulative retained weight on the pan was 500g and fineness modulus was 3.37 this is slightly above the range established by Neville and Brooks, 2010 which specifies 2.3 – 3 and any value above 3 means coarser grading, Jayesh and Umrigar (2013) got 3.35 as fineness modulus of fine aggregate.

From table 4.2, the bulk density of coarse aggregate was 1498.4kg/m^3 and the bulk density of fine aggregate was 1767kg/m^3, this shows that an equal volume of fine aggregate is heavier than an equal volume of coarse aggregate, though they both satisfy the requirements of BS 812: part 2 (1995) that states that the range for normal weight aggregate to be between 1280 and 1920 Kg/m^3.

The bulk density of cement was 1440 Kg/m^3, the bulk density of SLG was 1275 Kg/$m^3$and the bulk density of BSG was 1200Kg/m^3; this shows that an equal volume of cement is heavier than an equal volume of SLG, they both satisfy the requirement that bulk density of cement varies between 830 Kg/m^3 -1638 Kg/m^3 (Kimberley, 2004). The values of specific gravity for the aggregates (coarse and fine), cement, SLG and BSG. The specific gravity of coarse aggregate was found to be 2.86 and fine aggregate was 2.51. This shows that the result of specific gravities of aggregates fall within the range of 2.3 to 2.9 respectively as specified by ACI 201 (2010) and the coarse aggregate can be classified as heavy weight aggregate because according to Duggal(2008) aggregate with specific gravity of 2.8 to 2.9 are classified as heavy weight aggregate. The specific gravity of cement was 3.20 which is slightly above the value specified by

IS:8112-1989; the specific gravity of SLG was 2.22, this value is slightly below the value specified by KIM, 2014 that specific gravity of SLG is 2.8, and the specific gravity of BSG was found to be 2.10.

5.3 Discussions on the Chemical Properties of Cement, Soda-lime silicate Glass and Borosilicate Glass

From table 4.3 it can be seen that, the major oxides detected were combined proportion of silicon oxide (SiO_2) Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3) with percentage value of 73.202%,72.998%,0.411%, 0.201%,and 0.223%, 0.112%respectively this result is similar to that of Novais, *et al.*,(2016)except slight difference in the percentage composition of SiO_2 and Al_2O_3. This means that soda-lime silicate and borosilicate glass satisfy the requirement of ASTM C 618-05.

5.4 Discussions on the Fresh Concrete Properties of the Specimens

From table 4.4 it can be seen that, the control has least initial setting time and final setting time of 113 minutes and 168minutes respectively. The initial setting time and final setting time increases as the percentage replacement of cements with waste glass powder(Pozzolana) increases.This is as a result of absorption by the waste glass powder and delayed hydration, asUtsevu and Taku (2013) reportedthat waste glass powder delays initial and final setting time. Therefore higher strength will be developed after prolonged curing, also the mixing water

increases as the percentage replacement of cement with waste glass powder increases.It is as a result of absorption by the powder glass since it is specific surface area is smaller than that of cement;Abalaka, (2012) reported that an increase in mixing water as percentage replacement of cement with waste glass powder increases.

The permeability reducing admixture do not have adverse effect on the initial setting time and final setting time of the mix but resulted in mild retardation of the mix, this can be as a result of formation of crystals which cause mild deceleration, therefore higher strength will be developed after prolonged curing. NPCT, (2014) and Kim, (2014) also reported that permeability reducing admixture do not have adverse effect on setting time.

The specimens that contains SLG and BSG (modified blended cement) delayed initial and final setting time, and the effect increases as the percentage replacement of cement with GLSincreases. This could be attributed to the combined effects of absorption by the pozzolana, delayed hydration by pozzolana and crystalline formation by SLG and BSG. It is expected that higher strength will be developed after prolonged curing. Robert *et al.* (2010) reported that waste glass powder modified blended cement concrete delays setting time, the mixing water also increases as the percentage replacement of pozzolana soars higher.

It can be recommended that all the mixes can be used for structural work since the expansion due to soundness do not exceed 10mm.

From figure 4.3 it shows that, the control had slump of 55 mm the samples that contains 2.5% of waste glass powder had 46mm slump 12.72% less than the control thereby reduces the slump value, which is in agreement with Kim, (2014) who reported that waste glass powder reduces concrete slump value. This can be attributed to formation of crystals by the waste glass powder,

this will make the concrete dense and more cohesive, therefore waste glass modified concrete will need to be compacted and vibrated.

The specimens that contain soda-lime silicate and borosilicate waste glass as partial replacement of cement reduces the slump of the fresh concrete and the slump reduces further as percentage replacement increases, which agrees with Osei and Jackson (2012).

The waste glass powder modified pozzolana blended cement reduces the slump of fresh concrete and the reduction increase as the percentage replacement of cement increases. This can be attributed to the combined effects of delayed in hydration, absorption by pozzolana, and formation of crystals by waste glass powder (complex chemical reaction). This is in accordance to the findings of Robert *et al.* (2010) that modified pozzolana blended cement reduces slump of concrete, and therefore requires more mixing water in order to achieve the same level of workability with conventional concrete. It is therefore recommended that all the concrete specimen can be used for structural work depending on the strength development required.

The slump test correlates with the compacting factor, since the value of control mixes higher. It means that it is more workable than other mixes, however none of the mixes fall below the acceptable value for structural work. Usually, the compacting factor of all the mixes rangebetween 0.92 to 0.85, this is in agreement with the findings of Zongji (2011) who reported that the range of compaction factor is from 0.78 to 0.95. For the normal range of concretes the compacting factor lies between 0.8 and 0.92. The test is particularly useful for drier mixes for which the slump test is not satisfactory, and is appropriate for concrete with a maximum size of aggregate up to 40mm (Rahim, 2010). Therefore, all the concrete mixes can be used for

structural works and the mixes with lower compacting factor will require additional mixing water and or compaction and vibration.

5.5 Discussions on the Mechanical Properties of the Hardened Concrete

From figure 4.5 at 7 and 14 days the control samples have the highest compressive strengths of 20.96 N/mm^2 and 26.52 N/mm^2 respectively. This may be attributed to the fact that strength increased at the early stage due to higher temperature during placement and setting but undesirably affected the strength at later ages while samples are continuously cured in water. This can be as a result of rapid hydration process in the paste therefore the conventional concrete develops high early strength at early age which agrees with the findings of Utsevu and Taku (2013).

Vignesh*et al.,* (2014) reported that waste glass powder blended cement concrete have lower strength than the control, at 14 days and 28 days the rate of strength development of the conventional concrete decrease significantly, the strength were 35.69 and 37.73N/mm^2.

Early age (curing time) strength is lower as a result of slower and delay hydration process leading to low early strength and high strength after prolonged curing, which agrees with NPCT (2014) reported that samples contain waste glass powder should not develop strength that is less than 90% the strength of control while later age strength is higher than control samples. This results collaborates with the views of Jiri and Eva (2016). The strength gain reduces as the pozzolan content increases, this can be attributed to the slower consumption of $Ca(OH)_2$. The reason for low early strength delay hydration. The result agreed with the findings of Vigneshi*et al.,*(2014) and Utsevu and Taku (2013).

It was reported that the higher the waste glass powder content the lower the strength development, and the reason for lower early strength can be attributed to slower hydration processes at the onset of curing. Therefore, pozzolana blended cement concrete requires prolonged curing in order to maximize its full potentials.

This chemical reaction affects the strength development, which is in line with the views of Robert *et al.*,(2010) that waste glass modified pozzolana blended cement concrete develops higher strength than the conventional concrete. It can be concluded that all samples can be used for structural purposes, this is because all the samples (except for 2.5% replacement which had 23.12 N/mm^2) which had less than the maximum strength specified by ASTM 24.2 N/mm^2 at 28 days.

Figure 4.6 shows the tensile strength of all the sample specimens at 7, 14 and 28 days respectively, at 7 and 14 days the control samples had highest tensile strengths of 2.08 N/mm^2 and 2.65 N/mm^2 respectively. This can be attributed to the fact that strength increased at the early stage due to higher temperature during placement and setting but undesirably affected the strength at later ages while samples are continuously cured in water.This can be as a result of rapid hydration process in the paste therefore the conventional concrete develops high early strength at early age which agrees with the findings of (Vijayakumar*et al.,* (2013) : Madhangopal*et al.,* (2014) reported that waste glass powder blended cement concrete have lower strength than the control, at 14 days and 28 days.

From figure 4.7 at 7, 14 days the control samples had highest flexural strength of 3.96 N/mm^2 and 4.95 N/mm^2 respectively. This can be attributed to the fact that strength increased at the early stage due to higher temperature during placement and setting but undesirably affected the strength at later ages while samples are continuously cured in water.This can be as a result of rapid hydration process in the paste therefore the conventional concrete develops high early strength at early age which agrees with the findings of (Vijayakumar*et al.,* (2013): Madhangopal*et al.,* (2014) reported that waste glass powder blended cement concrete have lower strength than the control, at 14 days and 28 days.

5.6 Discussions on the Durability Properties of the Hardened Concrete

The water absorbed decreases as the curing age increases, which can be attributed to the influence of rich mix, and improved microstructure therefore making it less susceptible to water ingression. The result also agreed with the requirement of Neville and Brooks (2011) that water absorption of concrete sample fired at temperature of 105^0C and immersed in water for 24 hours should not exceed 7.4% the weight of concrete.

The samples that contain waste glass powder absorbed 2.05%, 2.03% and 1.43 % of its own weight at 7 days, 14 days and 28 days respectively. Thus 60%, 62% and 64.4 % reduction when compared with control, which is as a result of crystalline formation in the concrete pores and throughout the entire depth of concrete. Therefore making the concrete less susceptible to moisture ingression which is in line with the findings of Annu and Jeena (2016).

Therefore concrete modified with waste glass powder is less prone to attack by dissolved substances in water. It can be observed that water absorption increases with increase in pozzolanic content, this may be attributed to insufficient $Ca(OH)_2$ that will trigger pozzolanic reaction. Water absorption decreases as curing age decreases, this may be attributed to improved micro structure from curing thereby making the concrete less permeable, which is in agreement with the investigation of Jayesh and Umrigar (2013). Therefore,pozzolana blended cement concrete reduces water absorption into concrete.

The reduction in quantity of water absorption as curing ages progress can be attributed to improved internal microstructure, pore refinement and crystalline, throughout the entire depth of the concrete (synergistic effect of pozzolana and waste glass powder). Therefore making the concrete less impermeable and less susceptible to harmful substances dissolved in water. This agrees with the findings of ACI 21 3R (2010) that waste glass modified blended pozzolana cement has lesser absorption than pozzolana cement concrete, and therefore it is less susceptible to moisture absorption and dissolved injurious substance.

5.7Discussions on the Microstructural Characterization of the Concrete Samples

Plate 4.1: shows the micrograph of the control 0% waste glass powder (Pure Portland cement cured at room temperature for 28 days. the grey level of the phases present can be observed. In descending order of brightness, the anhydrous phases, calcium hydroxide, C–S–H gel and porosity (which appears black) can bedistinguished, as indicated in plate 4.1.

The first connected the composition of C–S–H to that of portlandite, marked CH in plate 4.1 and corresponding to the cement hydration of alite and belite respectively.

These analyses are believed to correspond to a fine intimate mixture of C–S–H and CH formed in spaceoriginally occupied by water. X-ray diffraction indicated the presence of both phases and since no AFt crystals were noted in the microstructures it is concluded that it must be finely intermixed with the C–S–H and excess of porttlanditeCa(OH)$_2$ of about 10% as indicated in fig. 4.8.

This results imply that the use of pozolannic materials SiO_2 reacted with excess Ca(OH)$_2$promoted the formation of C–S–H, which was consistent with a high compressive strengths. The glass particles showed rims of reaction products, inner products formed via a solid state mechanism, which could be an effect of use SiO_2 in the various compositions of 10%, 15% and 20% respectively. In general, the microstructure of 10%, 15% and 20% waste glass replacement were denser than that of the control which was attributed to the presence of abundant and reactive particles of SiO_2 homogeneously dispersed. This result is similar to that of Escalante-Garcia and Sharp (2014).

The microstructure of control appeared less dense than the others, which was consistent with the excess of portlanditeCa(OH)$_2$. There were abundant unreacted particles of portlanditeCa(OH)$_2$ homogeneously dispersed, identified by their bright gray tone. On the other hand, it was noteworthy that unreacted waste glass powderparticles were scarce, and that the smallest ones appeared completely reacted while the larger ones showed thick rims of reaction products (inner products).

This indicates that theSiO_2strongly promoted the utilization of excess of portlandite$Ca(OH)_2$, but not necessarily the reaction of SiO_2 with portlandite$Ca(OH)_2$. The chemical composition of the rims of thewaste glass powder particles had a composition similar to that of (Avila-López*et al.*, 2015)which indicates the presence of silica gel and C–S–H gel.

From figure 4.10, the X-ray diffractogramspattern of the 10% waste glass powder of concrete sample material cured at room temperature for 28 days, whose in the concrete mixture, several minerals present in the concrete mixture used as a precursor are identified, such as microline, quartz, biotitecalcite and portlandite(67%, 14%, 13%, 4% and 2% respectively) type; their crystalline nature is indicative of reduced participation in the geopolymerisation process. It is observed that the intensity of the peaks, in particular of portlandite, is significantly reduced in the 10% waste glass sample than the control (10% of porlandite in OPC and 2% of portlandite in 10% of waste glass replacement).

The reduction of diffraction lines intensity of portlandite is mainly due to the addition of replacement materials to Portland cement which brings additional complexity to the chemical reactions developed during the hydration of the composite cements. The dominant product of these reactions is C–S–H gel, which is principally responsible for the mechanical properties of the hydrated cement. C–S–H gel is generated by the interaction of the replacement materials with portlandite, CH, liberated during the hydration of the alite and belite present in the cement (Taylor, 1997).However, it can be seen that this reduction is also present in the 5%, of waste glass sample 15% and the 20% respectively. This allows to deduce that, in addition to hydration reactions of alite and belite, a partial dissolution of certain crystalline phases occurs; this is

consistent with results reported by other authors for several types of precursors (Ahmari*et al.*, 2012). However, this decrease in intensity has also been attributed to the increase in the SiO_2/Na_2O ratio due to the presence of sodium silicate in the mixture (Komnitsas*et al.*, 2015). The small traces of portlandite ($Ca(OH)_2$) are attributed to the hydrated cement contained in the undissolved concrete mixture particles.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary and Conclusion

The use of Soda-lime silicate and Borosilicate Waste glass for Partial Replacement of cement in Concretewas carried out. This study evaluated the possibility of using Soda-lime Silicate mixedBorosilicate glass waste as an effective additives for improvingthe properties of cement-based cementitious materials with obvious advantages both from environmental and economic viewpoints geopolymerization, but the ultimate strength (after 28 days of curing).

Results show that the incorporation of various compositions (wt)of waste glass powder (2.5%, 5.0%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20%) increases the compressive strength by nearly 46%, while higher amounts have the opposite results.

The chemical analysis of waste glass powder and cement sample were determined using X-Ray fluorescence (XRF) technique and found minor differences in composition between Soda-lime silicate and Borosilicate Waste glass. The major oxides detected were combined proportion of silicon oxide (SiO_2) Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3) with percentage value of 73.202%,72.998%,0.411%, 0.201%,and 0.223%, 0.112%respectively.

Scanning Electron Microscope (SEM) was utilized to characterize the morphology of the concrete samples. It was found that the morphology of concrete samples modified with waste glass powder was denser than the control sample. The microstructure of control appeared less dense than the others, which was consistent with the excess of portlanditeCa$(OH)_2$. There were abundant unreacted particles of portlanditeCa$(OH)_2$ homogeneously dispersed, identified by their bright gray tone. On the other hand, it was noteworthy that unreacted waste glass powderparticles were scarce, and that the smallest ones appeared completely reacted while the larger ones showed thick rims of reaction products (inner products).This indicates that theSiO_2strongly promoted the utilization of excess of portlanditeCa$(OH)_2$, but not necessarily the reaction of SiO_2 with portlanditeCa$(OH)_2$.

Also, XRD results indicated that the CH peaks were less in the samples containing waste glass powder compared with the control sample.It is observed that the intensity of the peaks, in particular of portlandite, is significantly reduced in the 10% waste glass sample than the control (10% of porlandite in OPC and 2% of portlandite in 10% of waste glass replacement).
It also can be seen that this reduction is also present in the 5%, of waste glass sample 15% and the 20% respectively.

Various compositions of the samples (Control 0%, 2.5%, 5.0%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20%) of concrete cube, cylinder and beam samples were prepared and tested for strength at 7, 14 and 28 days of curing.

The compressive strength, tensile strength and flexuraltest results indicated that the 10% replacement of cement with waste glass powder was found convincing considering cost and the environment at the 28 days of curing.

This work demonstrates the feasibility of producing lightweight, waste based-concrete with potential as construction materials, using a simple and eco-friendly approach. Furthermore, the incorporation of local and unexplored residue (fluorescent lamp and bottle waste glass) is a positive contribute toward sustainable construction.

6.2 Recommendation

It is recommended that further studies should be carried out on the microstructural arrangement of the aggregates and also the curing time of the compressive strength, tensile strength and flexural strength test should be extended to one year to better reactivity.

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APPENDICES

Appendix A1.

Combined Particle Size Distribution Result for Fine aggregate and Natural Coarse Aggregate(20mm and below)

Appendix A1.1: Sieve analysis of coarse aggregate

Sieve Sizes	Weight Retained (g)	Weight Passing (g)	Percentage Passing (g)	Cummulative Retained Passing (g)	Fineness Modulus
20mm	465	1035	69	465	58.86
10mm	325	710	47.73	790	79.47
5mm	204	506	33.73	994	95.85
2.36mm	43	463	30.87	1037	90.73
1.18mm	106	357	23.8	1143	83.49
600	226	131	8.73	1369	92.68
300	108	23	1.53	1477	99.1
150	14	9	0.6	1491	99.4
Pan	9	0	0	1500	699.2 6.99

Source: Laboratory Research Work (2017)

Appendix A1.2

Particle Size Distribution Result for Natural Coarse Aggregate (20mm and below)

Table A1.2: Sieve analysis of coarse aggregate

Sieve size	**Weight Retained (g)**	**Weight Passing (g)**	**Percentage Passing (%)**	**Cumulative retained Passing (%)**
20mm	465	535	53.5	465
10mm	325	210	21.0	790
5mm	204	6	0.60	994
Pan	6	0	0.00	1000

Source: Laboratory Research Work (2017)

Appendix A1.3

Appendix A1.3: Sieve analysis of natural fine aggregate

BS Sieve Size	Weight Retained (g)	Weight Passing (g)	Percentage passing (%)	Cumulative retained Passing (%)	Fineness Modulus
20mm	0	500	100	0	0
10mm	0	500	100	0	0
5mm	0	500	100	0	0
2.36mm	37	463	92.6	37	25.87
1.18mm	106	357	71.4	143	38.75
600 µm	226	131	26.2	369	77.35
300 µm	108	23	4.6	477	97.1
150 µm	14	9	1.8	491	98.2
Pan	9	0	0	500	337.2
					3.37

Source: Laboratory Research Work (2017)

Appendix A2

Appendix A2.1: Specific Gravity Test Table of Coarse Aggregate

Sample	1	2	3
W_1 = Weight of Cylinder	244	244	244
W_2 =Weight of cylinder + Water	1190	1190	1190
W_3 Weight of cylinder + Sample	559	548	534
W_4 = Weight of cylinder + Sample + Water	1399	1386	1387
Specific Gravity =	2.97	2.81	2.81
Average		2.86	

Source: Laboratory Research Work (2017)

Appendix A2.2:Workability, Slump and Compacting factor of concrete with 19mmor 38mmsize of aggregate

Degree of workability	Slump		Compacting factor	Use for which concrete is suitable
	mm	in.		
Very low	0–25	0–1	0.78	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	25–50	1–2	0.85	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	25–100	2–4	0.92	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	100–175	4–7	0.95	For sections with congested reinforcement. Not normally suitable for vibration.

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Appendix A3 Mix design for grade 30 concrete

Appendix A3.1: Slump mixes of the sample specimens

Mixes	0%	2.5%	5%	7.5%	10%	12.5%	15%	17.5%	20%
Slump	55	52	47	44	40	37	34	30	27

Source: Laboratory Research Work (2017)

Appendix A3.2: Compacting factor test

Mixes	0%	2.5%	5%	7.5%	10%	12.5%	15%	17.5%	20%
C. F.	0.92	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85

Source: Laboratory Research Work (2017)

Appendix A3.3: Specific gravity of materials

Material	Cement	C. Aggregate	F. Aggregate	BSG	SLG
S. Gravity	3.15	2.72	2.76	2.22	2.36

Source: Laboratory Research Work (2017)

Appendix A3.4: Bulk density test

Material	Cement	C. Aggregate	F. Aggregate	BSG	SLG
B. Density	1440	1500	1600	1200	1275

Source: Laboratory Research Work (2017)

Appendix A3.5: Setting time of cement pastes

Mixes	Initial Setting Time	Final Setting Time
Control	113	168
2.5% GLASS	126	180
5 % GLASS	132	196
7.5 % GLASS	138	202
10 % GLASS	146	220
12.5 % GLASS	156	226
15% GLASS	168	238
17.5% GLASS	180	269
20% GLASS	188	284

Source: Laboratory Research Work (2017)

Appendix A4.1: 7days compressive strength test

7days Compressive Strength Test				
Sample	Weight	Failure	Compressive Strength	Average Compressive Strength
Control	W_1=2350	209.6	20.96	
	W_2 =2310	205.6	20.56	20.95
	W_3 =2346	213.4	21.34	
	W_1=2250	145.6	14.56	
2.5%	W_2 =2248	141.2	14.12	14.64
	W_3 =2346	152.6	15.26	
	W_1=2240	150.0	15.00	
5%	W_2 =2240	148.6	14.86	14.87
	W_3 =2238	147.6	14.76	
	W_1=2238	150.0	15.00	
7.5%	W_2 =2230	148.6	14.86	15.00
	W_3 =2236	151.4	15.14	
	W_1=2230	166.6	16.66	
10%	W_2 =2226	173.2	17.32	16.44
	W_3 =2226	153.4	15.34	
	W_1=2222	160.0	16.00	
12.5%	W_2 =2220	152.0	15.20	16.00
	W_3 =2224	168.0	16.80	
	W_1=2218	154.6	15.46	
15%	W_2 =2216	146.0	14.60	15.64
	W_3 =2212	168.6	16.86	
	W_1=2208	153.0	15.30	
17.5%	W_2 =2208	145.4	14.54	15.33
	W_3 =2206	161.6	16.16	
	W_1=2200	149.8	14.98	
20 %	W_2 =2218	153.6	15.36	14.98
	W_3 =2218	146.0	14.60	

Source: Laboratory Research Work (2017)

Appendix A4.2: 14days compressive strength test

14days Compressive Strength Test				
Sample	Weight	Failure	Compressive Strength	Average Compressive Strength
Control	W_1=2360	268.0	26.80	
	W_2 =2320	256.0	25.60	26.52
	W_3 =2356	271.6	27.16	
	W_1=2350	185.6	18.56	
2.5%	W_2 =2348	193.6	19.36	18.42
	W_3 =2346	173.4	17.34	
	W_1=2340	190.0	19.00	
5%	W_2 =2340	194.2	19.42	18.69
	W_3 =2338	176.6	17.66	
	W_1=2338	198.0	19.80	
7.5%	W_2 =2330	182.6	18.26	19.02
	W_3 =2336	190.0	19.00	
	W_1=2330	231.6	23.16	
10%	W_2 =2326	247.4	24.74	24.14
	W_3 =2326	245.4	24.54	
	W_1=2322	233.6	23.36	
12.5%	W_2 =2320	231.6	23.16	23.59
	W_3 =2324	242.7	24.27	
	W_1=2318	225.8	22.58	
15%	W_2 =2316	231.0	23.10	22.93
	W_3 =2312	231.2	23.12	
	W_1=2308	222.6	22.26	
17.5%	W_2 =2308	228.8	22.88	22.23
	W_3 =2306	215.6	21.56	
	W_1=2300	202.6	20.26	
20 %	W_2 =2298	204.6	20.46	20.21
	W_3 =2298	199.0	19.90	

Source: Laboratory Research Work (2017)

Appendix A4.3: 28days compressive strength test

28days Compressive Strength Test				
Sample	Weight	Failure	Compressive Strength	Average Compressive Strength
Control	W_1=2380	321.2	32.12	
	W_2 =2360	314.8	31.48	31.38
	W_3 =2366	305.6	30.56	
	W_1=2360	234.8	23.48	
2.5%	W_2 =2358	228.8	22.88	23.12
	W_3 =2356	23.00	23.00	
	W_1=2350	244.8	24.48	
5%	W_2 =2350	238.8	23.88	24.12
	W_3 =2348	240.0	24.00	
	W_1=2348	262.6	26.26	
7.5%	W_2 =2340	263.4	26.34	26.60
	W_3 =2346	272.0	27.20	
	W_1=2340	286.8	28.68	
10%	W_2 =2336	284.6	28.46	28.82
	W_3 =2336	293.4	29.34	
	W_1=2332	272.2	27.22	
12.5%	W_2 =2330	267.2	26.72	26.83
	W_3 =2334	265.5	26.56	
	W_1=2328	260.0	26.00	
15%	W_2 =2326	270.0	27.00	26.06
	W_3 =2322	252.0	25.20	
	W_1=2318	260.0	26.00	
17.5%	W_2 =2318	256.2	25.62	25.68
	W_3 =2316	254.2	25.42	
	W_1=2310	245.6	24.56	
20 %	W_2 =2300	237.8	23.78	24.11
	W_3 =2298	240.0	24.00	

Source: Laboratory Research Work (2017)

Appendix A4.4: 7days tensile strength test

7days Tensile Strength Test				
Sample	Weight	Failure load KN/mm^2	Tensile Strength N/mm^2	Average Tensile Strength N/mm^2
Control	W_1= 4216	32.48	2.05	
	W_2 = 4200	32.10	2.05	2.08
	W_3 = 4196	33.50	2.14	
	W_1= 4188	22.57	1.45	
2.5%	W_2 = 4182	22.03	1.41	1.48
	W_3 = 4180	23.96	1.58	
	W_1= 4178	23.25	1.48	
5%	W_2 = 4176	23.18	1.48	1.49
	W_3 = 4172	23.80	1.52	
	W_1= 4168	25.82	1.66	
7.5%	W_2 = 4166	27.02	1.73	1.65
	W_3 = 4162	24.10	1.55	
	W_1= 4158	25.82	1.65	
10%	W_2 = 4156	27.33	1.75	1.65
	W_3 = 4150	24.10	1.55	
	W_1= 4146	24.80	1.59	
12.5%	W_2 = 4142	23.71	1.52	1.60
	W_3 = 4142	26.38	1.69	
	W_1= 4122	23.96	1.53	
15%	W_2 = 4120	22.78	1.46	1.56
	W_3 = 4126	26.47	1.69	
	W_1= 4112	23.72	1.52	
17.5%	W_2 = 4110	22.68	1.45	1.53
	W_3 = 4110	25.37	1.63	
	W_1= 4108	23.22	1.49	
20 %	W_2 = 4106	23.96	1.53	1.49
	W_3 = 4100	22.92	1.47	

Source: Laboratory Research Work (2017)

Appendix A4.5: 14days tensile strength test

14days Tensile Strength Test				
Sample	Weight	Failure load KN/mm^2	Tensile Strength N/mm^2	Average Tensile Strength N/mm^2
Control	W_1= 4226	41.63	2.66	
	W_2 = 4200	39.94	2.56	2.65
	W_3 = 4222	42.65	2.73	
	W_1= 4200	28.77	1.85	
2.5%	W_2 = 4194	30.20	1.93	1.84
	W_3 = 4196	27.22	1.74	
	W_1= 4194	29.45	1.88	
5%	W_2 = 4194	30.29	1.94	1.86
	W_3 = 4190	27.73	1.77	
	W_1= 4188	30.69	1.96	
7.5%	W_2 = 4186	28.49	1.83	1.90
	W_3 = 4190	29.83	1.91	
	W_1= 4184	35.90	2.30	
10%	W_2 = 4182	38.59	2.47	2.41
	W_3 = 4184	38.53	2.47	
	W_1= 4174	36.21	2.32	
12.5%	W_2 = 4176	36.13	2.31	2.36
	W_3 = 4178	38.10	2.44	
	W_1= 4170	34.99	2.24	
15%	W_2 = 4170	36.04	2.31	2.29
	W_3 = 4172	36.30	2.32	
	W_1= 4168	34.50	2.21	
17.5%	W_2 = 4166	35.69	2.28	2.22
	W_3 = 4166	33.85	2.17	
	W_1= 4160	31.40	2.00	
20 %	W_2 = 4160	31.92	2.04	2.01
	W_3 = 4164	31.24	1.99	

Source: Laboratory Research Work (2017)

Appendix A4.6: 28days tensile strength test

28days Tensile Strength Test				
Sample	Weight	Failure load KN/mm^2	Tensile Strength N/mm^2	Average Tensile Strength N/mm^2
Control	W_1= 4236	49.79	3.19	
	W_2 = 4230	49.11	3.14	3.13
	W_3 = 4222	47.98	3.07	
	W_1= 4210	36.39	2.33	
2.5%	W_2 = 4206	35.69	2.28	2.31
	W_3 = 4206	36.11	2.32	
	W_1= 4206	37.94	2.43	
5%	W_2 = 4204	37.25	2.38	2.41
	W_3 = 4202	37.68	2.41	
	W_1= 4200	40.70	2.61	
7.5%	W_2 = 4196	41.09	2.63	2.66
	W_3 = 4194	42.70	2.73	
	W_1= 4190	44.45	2.85	
10%	W_2 = 4190	44.39	2.84	2.89
	W_3 = 4192	46.10	2.99	
	W_1= 4188	42.19	2.70	
12.5%	W_2 = 4186	41.66	2.67	2.68
	W_3 = 4188	41.69	2.66	
	W_1= 4180	40.30	2.57	
15%	W_2 = 4180	42.12	2.70	2.6
	W_3 = 4182	39.56	2.53	
	W_1= 4178	40.30	2.58	
17.5%	W_2 = 4176	39.96	2.56	2.56
	W_3 = 4172	39.90	2.55	
	W_1= 4166	38.07	2.44	
20 %	W_2 = 4162	36.86	2.36	2.40
	W_3 = 4164	37.68	2.41	

Source: Laboratory Research Work (2017)

Appendix A4.7: 7days flexural strength test

7days Flexural Strength Test				
Sample	Weight	Failure load	Flexural Strength	Average Flexural Strength
Control	W_1=2350	21.66	3.95	
	W_2 =2310	21.76	3.96	3.96
	W_3 =2346	21.84	3.98	
	W_1=2250	14.76	2.68	
2.5%	W_2 =2248	14.72	2.68	2.69
	W_3 =2346	14.8	2.71	
	W_1=2240	15.5	2.83	
5%	W_2 =2240	15.0	2.74	2.80
	W_3 =2238	15.5	2.83	
	W_1=2238	15.5	2.83	
7.5%	W_2 =2230	15.8	2.88	2.87
	W_3 =2236	15.9	2.89	
	W_1=2230	16.66	3.03	
10%	W_2 =2226	17.32	3.15	3.17
	W_3 =2226	18.34	3.34	
	W_1=2222	16.45	2.99	
12.5%	W_2 =2220	15.36	2.79	2.95
	W_3 =2224	16.82	3.06	
	W_1=2218	15.66	2.85	
15%	W_2 =2216	14.78	2.69	2.9
	W_3 =2212	16.47	3.00	
	W_1=2208	15.45	2.82	
17.5%	W_2 =2208	14.67	2.67	2.81
	W_3 =2206	16.2	2.95	
	W_1=2200	14.98	2.73	
20 %	W_2 =2218	15.38	2.80	2.73
	W_3 =2218	14.56	2.65	

Source: Laboratory Research Work (2017)

Appendix A4.8: 14days flexural strength test

14days Flexural Strength Test				
Sample	Weight	Failure	Flexural Strength	Average Flexural Strength
Control	W_1=2360	27.8	5.07	
	W_2 =2320	26.0	4.74	4.95
	W_3 =2356	27.62	5.03	
	W_1=2350	19.5	3.55	
2.5%	W_2 =2348	20.38	3.71	3.54
	W_3 =2346	18.34	3.35	
	W_1=2340	20.00	3.65	
5%	W_2 =2340	20.42	3.72	3.58
	W_3 =2338	18 .62	3.39	
	W_1=2338	20.80	3.79	
7.5%	W_2 =2330	19.26	3.51	3.65
	W_3 =2336	20.10	3.66	
	W_1=2330	24.16	4.40	
10%	W_2 =2326	25.74	4.69	4.58
	W_3 =2326	25.46	4.64	
	W_1=2322	24.36	4.43	
12.5%	W_2 =2320	23.16	4.22	4.42
	W_3 =2324	25.27	4.60	
	W_1=2318	23.58	4.29	
15%	W_2 =2316	24.10	4.39	4.36
	W_3 =2312	24.26	4.41	
	W_1=2308	23.34	4.25	
17.5%	W_2 =2308	23.82	4.34	4.24
	W_3 =2306	22.66	4.13	
	W_1=2300	21.62	3.94	
20 %	W_2 =2298	21.78	3.96	3.86
	W_3 =2298	20.26	3.69	

Source: Laboratory Research Work (2017)

Appendix A4.9: 28days flexural strength test

28days Flexural Strength Test				
Sample	Weight	Failure Load	Flexural Strength	Average Flexural Strength
Control	W_1=2380	33.12	6.03	
	W_2 =2360	32.00	5.83	5.87
	W_3 =2366	31.56	5.75	
	W_1=2360	24.48	4.46	
2.5%	W_2 =2358	23.86	4.35	4.39
	W_3 =2356	24.00	4.37	
	W_1=2350	25.48	4.64	
5%	W_2 =2350	24.88	4.53	4.57
	W_3 =2348	25.00	4.56	
	W_1=2348	27.26	4.96	
7.5%	W_2 =2340	27.44	5.00	5.04
	W_3 =2346	28.24	5.15	
	W_1=2340	29.68	5.41	
10%	W_2 =2336	29.64	4.85	5.27
	W_3 =2336	30.48	5.55	
	W_1=2332	28.26	5.15	
12.5%	W_2 =2330	27.72	5.05	5.07
	W_3 =2334	27.55	5.02	
	W_1=2328	27.00	4.92	
15%	W_2 =2326	28.00	5.10	4.93
	W_3 =2322	26.20	4.77	
	W_1=2318	27.00	4.92	
17.5%	W_2 =2318	26.62	4.85	4.86
	W_3 =2316	26.38	4.81	
	W_1=2310	25.64	4.67	
20 %	W_2 =2300	24.78	4.52	4.58
	W_3 =2298	25.08	4.56	

Source: Laboratory Research Work (2017)

Appendix A5.

Appendix A5.1 28 days water absorption capacity test

28 days Water Absorption Capacity Test				
Sample	Oven Dried Weight (W_1)	Saturated Surface Dried Weight (W_2)	Difference	Average Difference
	2288	2394	4.63	
Control	2280	2382	4.47	4.47
	2268	2366	4.32	
	2266	2356	3.97	
2.5%	2256	2349	4.12	4.02
	2246	2335	3.96	
	2256	2342	3.81	
5%	2248	2331	3.69	3.7
	2248	2329	3.60	
	2236	2316	3.58	
7.5%	2232	2310	3.49	3.49
	2228	2304	3.41	
	2222	2292	3.15	
10%	2220	2287	3.00	3.09
	2218	2287	3.11	
	2210	2280	3.16	
12.5%	2206	2276	3.17	3.20
	2202	2274	3.26	
	2198	2276	3.45	
15%	2190	2264	3.38	3.37
	2188	2260	3.29	
	2180	2259	3.62	
17.5%	2176	2257	3.72	3.72
	2166	2249	3.83	
	2168	2248	3.69	
20 %	2166	2249	3.83	3.80
	2156	2240	3.89	

Source: Laboratory Research Work (2017)