PRODUCTION OF STEEL REINFORCED CONCRETE USING WASTE GLASS POWDER AS PARTIAL REPLACEMENT FOR CEMENT

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BY

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN GLASS TECHNOLOGY

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AUGUST, 2018

DECLARATION

I declare that the work in this dissertation entailed "Production of Steel Reinforced Concrete Using Waste Glass Powder as Partial Replacement for Cement" has been carried out by me in the Department of Glass and Silicate Technology. The information from the literatures 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.

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CERTIFICATION

This dissertation entitled, "PRODUCTION OF STEEL REINFORCED CONCRETE USING WASTE GLASS POWDER AS PARTIAL REPLACEMENT FOR CEMENT", by Hafsah Musa ABDULLAHI meets the standard and regulation governing the award of the Master of Science degree in Glass Technology of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to my parents, Dr. and Mrs. A. M. Abu-Abdissamad.

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ABSTRACT

The reduction in waste is important in our environment. Waste glass tends to be one of the issues because it is considered as non-biodegradable material that pollutes the surrounding. The utilization of waste glass in reinforced concrete as partial replacement due to its pozzolanic property is gaining huge importance these days, principally on account of the development within the future sturdiness of concrete. To achieve such, cement was replaced with powdered glass at 0%, 10%, 20%, 30% and 40% in producing concrete cubes of 100mm by 100mm and beams of 750mm by 150mm. The products were subjected to compressive strength test, flexural strength test, XRD and SEM analyses and results were obtained. Compressive strength test showed that as cement is being replaced with glass powder, the compressive strength decreases. Flexural strength decreased with increase in powder glass replacement upto 20% but increased at 30%. XRD showed no crystalline material present in the powdered glass. SEM showed that the 0% replacement has undergone a complete hydration reaction while that of 10% and 40% have some pores due to incomplete hydration reaction. From the results, it showed that 10% replacement is ideal since it had a compressive strength of 17MPa which conform to the minimum requirement of ASTM standard. The concrete however can be used in reinforced cement concrete structures that are not exposed to severe degrading environments and extreme loads.

LIST OF NOTATIONS AND SYMBOLS

^{o}C = Degree celsius

% = Percentage

ASTM = American Standard for Testing and Materials

cal/g = Calorie/gram

g = Grams

mm = Millimeter

MPa = Mega Pascal

N/mm^2 = Newton per millilmeter square

SEM = Scanning Electron Microscope

XRD = X-ray Diffractometer

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Waste glass constitute environmental problem, because it is considered as non-biodegradable material that pollutes the surrounding environment. The use of waste glass as a component in concrete gives waste glass a sustainable alternative to land filling and therefore makes it economically viable (Shaikh *et al.*, 2013).

Glass is a non-equilibrium, non-crystalline state of matter that appears solid on a short time scale but continuously relaxes towards the liquid state. Or glass is a non-equilibrium, non-crystalline condensed state of matter that exhibits a glass transition. The structure of glasses is similar to that of their parent supercooled liquids and they spontaneously relax toward the supercooled liquid state. Their ultimate fate, in the limit of infinite time, is to crystallize, (Edgar and John, 2017).

In general terms, the word cement refers to any kind of binder that tightly holds other materials together. Concrete, on the other hand, is a mixture of aggregate materials like sand, gravel, and other small rock combined with any type of cement and water. The composition is then allowed to dry and harden. Basically, concrete is a stone-like structure formed after cement and other materials are mixed together, whereas cement is just a part of the recipe (The Constructor, 2007)

Fibre Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Fibre is a small piece of reinforcing material possessing certain characteristic properties. Before any type of fibre reinforced concrete is produced, good selection of raw materials must be put into

consideration. The raw materials should be abundant, cheap, and free from impurities. Physical nature such as grain size is also an important factor to consider. Therefore, the availability of waste glass in our society which can be used in powdered form can make the production cheaper when used as partial replacement for cement in steel fibre reinforced concrete production (The Constructor, 2007).

1.2 Statement of the Problem

The complex nature of society and our increasing demands require that all of us give thought as to how we meet our material needs sensibly (Agwu, 1995). Broken glasses are being thrown away in our environment not knowing that they could be used positively. Broken glasses can either be added as cullet to the batch in furnace to make new bottles (WRAP, 2010); used for decoration (in form of cullet) to make glass mosaic or use cullet as raw material in paint (Adejo, 2016). They are also used in producing tiles by replacing cullet in ceramic molds (Weber, 2006); used in developing glass ceramics (Hauwa, 2016). They are also used in fibre glass insulation products, ceramic sanitary ware production, brick manufacturing and abrasives. Despite all efforts in recycling these waste glasses, they still constitute another problem during sorting into different colors as green, amber and flint and also the need of using chemicals to decolorize before usage (Alemaka, 2006). Therefore, it is imperative to employ waste glass for partial replacement of cement which requires little or no sorting.

1.3 Aim of the Study

The aim of this study is to produce steel reinforced concrete using waste glass powder as partial replacement for cement.

1.4 Objectives of the Study

The objectives of this study are to:

i. Obtain sample of waste glass and steel fibre.

ii. Crush and pulverize the waste glass.

iii. Design mix ratios for the partial replacement of cement with powdered glass.

iv. Produce the designed fibre reinforced concrete and cure the mix ratios for 28 days.

v. Characterise and test the designed steel fibre reinforced concrete.

1.5 Significance of the Study

This research will help in reducing environmental pollution due to disposal of waste glass in our environment. If glass could be incorporated in cement products, it would greatly reduce the disposal of recycled glass and/or its use in lower valued markets such as land fill and road base material. The production cost of concrete will go down and also reduce the stress in mining activities.

1.6 Scope of the Research

This research is delimited to waste glass obtained from container glass, steel fibres and ordinary Portland cement.

CHAPTER TWO

2.0` LITERATURE REVIEW

2.1 Introduction

A concrete containing fibrous materials which increases its structural integrity is referred to as Fibre Reinforced Concrete (FRC). It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres. The properties of fibre reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation and densities (Yang and Li, 2008).

Cement in concrete serves as a binding agent. In most cases, sand is conventionally used as the fine aggregate in concrete whereas the coarse aggregates are mostly gravels which help to increase the durability or strength of the concrete.

2.2 Waste Glass

Wastes are inevitable part of human activity. They are either a bye-product of initial production process, or they arise when objects or materials are discarded after they have been used. Waste glass is generated from broken doors, windows, car windscreens, tablewares, bottles, fluorescent lamps and light bulbs. In general, solid waste is generated from households, offices, shops, markets, restaurants, public institutions, industrial installations, water works and sewage facilities, construction and demolition sites, and agricultural activities (Garkida, 2007).

2.3 Glass Powder

Glass powder is obtained from cullet. Cullet refers to scrap of broken or waste glass gathered for remelting, especially with new material. Glass powder is an extremely fine powder made from ground glass. It can be used in a number of industrial and craft applications. Glass powders

consist of various glass compositions ground into fine particles. Glass powder is used for large array of different technical applications. The various powders are either used directly in the end applications or further processed into paste, granulate or sintered preforms (Schott, 2015).

2.4 Cement

Cement has been used as a binding material for over 5000 years. No one knows for sure who first came up with the idea to use a cement substance to bind materials together to make concrete, bricks, and other building materials. The process can be traced back to Ancient Macedonia, but was more widely popularized during the Roman Empire. Early forms of cement used things like lime and pozzolana, a type of volcanic ash. The Romans were able to produce massive structures like the Pantheon and the Roman aqueducts using this formula (Sismondo, 2009). The most common type of modern cement is ordinary Portland cement.

2.4.1 Forms of cement

Currently, cement comes in two forms: hydraulic and non-hydraulic. Hydraulic cement refers to any cement that uses water to begin a chemical reaction that hardens the mixture, and when fully formed, creates a water resistant product. This reaction is independent of the water content of the mixture, so allows for the material to harden even underwater. This makes it a very versatile construction material. Mostly, all the cement used today are hydraulic cements. Non-hydraulic cements use materials that do not harden when exposed to water. While this type is much cheaper than hydraulic cement, the problems of long drying times combined with the inability to use it in wet environment makes it a poor choice in most applications (Sismondo, 2009).

2.4.2 Portland cement manufacturing

Although several variations of commercially manufactured Portland cement exist, Portland cement is usually made from the same raw materials and chemical components. The basic raw materials used for the manufacture of Portland cement depends upon their availability at the quarry near the cement plant location, and are commonly limestone, shale, marl, chalk, clays and sand; other materials include industrial by-products such as mill scale and blast furnace slag.

The process of manufacture of Portland cement consists essentially of grinding the raw materials into a very fine powder, mixing them intimately in predetermined proportions and burning in a large rotary kiln at a temperature of about 1400^{o}C (2550^{o}F) where the material sinters and partially fuses into clinker. The clinker is cooled and ground to a fine powder, with some gypsum added, and the resulting product is the commercial Portland cement used throughout the world. The mixing may be in a dry or wet state depending on the hardness of the available rock (Neville, 2002).

The wet process is used in general for the softer materials such as chalk or clay. Water is added to the proportioned mixture of crushed chalk and clay to produce slurry which is eventually led off to a kiln. This is a steel cylinder with a refractory lining, which is slightly inclined to the horizontal and rotates continuously about its own axis. It is usually fired by pulverised coal, although gas or oil may be used. It may be as large as 3.5 m in diameter and 150 m long and handles up to 700tons of cement in a day. The slurry is fed in at the upper end of the kiln and clinker is discharged at the lower end where fuel is injected with its temperature increasing progressively. The slurry undergoes a number of changes as it travels down the kiln. At 100^{o}C, the water is driven off; at about 850^{o}C carbon dioxide is given off and at about 1400^{o}C incipient fusion takes place at the firing zone where calcium silicates and calcium aluminates are formed

in the resulting clinker. The clinker is allowed to cool and then ground, with 1 to 5 per cent gypsum added, to the required fineness. Different types of Portland cement are obtained by varying the proportions of the raw materials, the temperature of burning and the fineness of grinding and in some cases by inter-grinding the clinker with other recognized materials such as pulverized-fuel ash (pfa), or granulated blast furnace slag (gbfs). Gypsum is added to control the setting of the cement which would otherwise set much too quickly for general use. Certain chloride is added in the manufacture of extra rapid hardening cement (Neville, 2002).

The dry or semi-dry process is used for harder rocks such as limestone and shale. The constituent materials are crushed into powder form and with a minimum amount of water, passed into an inclined rotating nodulising pan where nodules are formed. These are known as raw meal. This is fed into a kiln and thereafter the manufacturing process is similar to the wet process although a much shorter length of kiln is used. The dry and semi-dry are more energy efficient than the wet process. The grinding of the clinker produces cement which is still hot and this hot cement is usually allowed to cool before it leaves the cement works (Neville, 2002).

2.4.3 Hydration in Portland cement

Portland cement is a hydraulic cement; hence it derives its strength from chemical reactions between the cement and water, through a process known as hydration. According to Nicholas (2014), cement consists of the following major phases: Tricalcium silicate, C_3S or Ca_3SiO_5 or $3CaO{\cdot}SiO_2$ (alite), dicalcium silicate, C_2S or Ca_2SiO_4 or $2CaO{\cdot}SiO_2$ (belite), tricalcium aluminate, C_3A or $Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$ (celite), tetracalcium aluminoferrite, C_4AF or $Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$, (braunnmillerite / ferrite).

2.4.4 Chemical reactions during hydration

When water is added to cement, the following series of reactions occur: The tricalcium aluminate reacts with the gypsum in the presence of water to produce ettringite and heat:

Tricalcium aluminate + gypsum + water → ettringite + heat

$C_3A + 3C\underline{S}H_2 + 26H \rightarrow C_6A\underline{S}_3H_{32}$, D H = 207 cal/g (2.1)

or

$3CaOAl_2O_3+3CaSO_4\cdot 2H_2O+26H_2O \rightarrow 6\,(CaO)\,3(Al_2O_3)3(SO_4)$ or $Ca_6Al_2\,S_3H_{12}O_{24}$

Ettringite consists of long crystals that are only stable in a solution with gypsum. The compound does not contribute to the strength of the cement glue. The tricalcium silicate (alite) is hydrated to produce calcium silicate hydrates, lime and heat:

Tricalcium silicate + water → calcium silicate hydrate + lime + heat

$2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH$, D H = 120 cal/g (2.2)

or

$3CaO\cdot 2SiO_2+4H_2O \rightarrow 2Ca_3OSiO_5 + 7H_2O + 3Ca\,(OH)_2 + 173.6KJ$

The CSH has a short-networked fiber structure which contributes greatly to the initial strength of the cement glue. Once all the gypsum is used up as per reaction (2.1), the ettringite becomes unstable and reacts with any remaining tricalcium aluminate to form monosulfate aluminate hydrate crystals:

Tricalcium aluminate + ettringite + water → monosulfate aluminate hydrate

$2C_3A + 3\,C_6AS_3H_{32} + 22H \rightarrow 3C_4ASH_{18}$ (2.3)

The monosulfate crystals are only stable in a sulfate deficient solution. In the presence of sulfates, the crystals resort back into ettringite, whose crystals are two-and-a-half times the size of the monosulfate. It is this increase in size that causes cracking when cement is subjected to sulfate attack.

The belite (dicalcium silicate) also hydrates to form calcium silicate hydrates and heat:

Dicalcium silicates + water → calcium silicate hydrate + lime

$2C_2S + 4H \rightarrow C_3S_2H_3 + CH, D\ H$ (2.4)

Or

$2Ca_2SiO_2 + 5H_2O \rightarrow 3CaO{\cdot}SiO_2{\cdot}4H_2O + Ca(OH) + 58.6KJ$

Like in reaction (ii), the calcium silicate hydrates contribute to the strength of the cement paste. This reaction generates less heat and proceeds at a slower rate, meaning that the contribution of C_2S to the strength of the cement paste will be slow initially. This compound is however responsible for the long-term strength of portland cement concrete. The ferrite undergoes two progressive reactions with the gypsum:

In the first of the reactions, the ferrite reacts with the gypsum and water to form ettringite, lime and alumina hydroxides, i.e.

Ferrite + gypsum + water → ettringite + ferric aluminum hydroxide + lime

$C_4AF + 3CSH_2 + 3H \rightarrow C_6(A,F)S_3H_{32} + (A,F)H_3 + CH$ (2.5)

or

$4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3+3CaSO_4{\cdot}5H_2O \rightarrow Ca_6(Al_2O_3{\cdot}Fe_2O_3)SO_3{\cdot}3H_2O+(Al_2O_3{\cdot}Fe_2O_3)$

$3H_2O+Ca(OH_2)$

The ferrite further reacts with the ettringite formed above to produce garnets, i.e.

Ferrite + ettringite + lime + water → garnets

$C_4AF + C_6(A,F)S_3H_{32} + 2CH + 23H \rightarrow 3C_4(A,F)SH_{18} + (A,F)H_3$ (2.6)

or

$4CaO\ Al_2O_3\ Fe_2O_3 + Ca_6(Al_2O_3\ Fe_2O_3)\ SO_3 3H_2O + 2CaOH + 23H_2O \rightarrow 7CaO(Al_2O_3\ Fe_2O_3)SiO$

The garnets only take up space and do not in any way contribute to the strength of the cement paste. According to Nicholas, 2014, hardened paste consists of the following:

Table 2.1: Composition of hardened cement paste

Materials	Percentage Composition
Ettringite	15 to 20%
Calcium silicate hydrates, CSH	50 to 60%
Calcium hydroxide (lime)	20 to 25%
Voids (in the form of capillary voids and entrapped and entrained air)	5 to 6%

(Nicholas, 2014)

2.5 Pozzolanic Material

A "pozzolan" is defined as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form - and in the presence of moisture - chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Malhotra and Mehta, 1996).

Cement gives off lime as it hardens and the lime will inevitably react with silica (silicates or alumino-silicates). The aggregate in the concrete is basically silica, but unfortunately it reacts too slowly, due to its reduced total surface area. In a concrete without pozzolans, the lime produced in the hardening of the cement will slowly react with the aggregate, producing gels. These gels are expansive, and that is welcome as long as they just fill the voids with a slight pressure thus avoiding water penetration and leaching (Brunges, 2016).

The problem starts when too large a volume of gel is produced after the concrete has hardened. That is the case if the lime only has aggregate or large pozzolanic particles to react with. Given the relatively small total surface area of the aggregate or big pozzolanic particles, as well as the slow reaction between lime and silica, most of the gels will be produced after the hardening of the cement, resulting in possible disastrous pressure build-up and a slow destruction of the concrete. This makes it clear that the pozzolan has to be very fine to ensure that most of the gels are formed before the hardening (Brunges, 2016).

Pozzolans are being extensively used as a partial cement replacement in the production of Portland cement concrete. The advantages of using pozzolans are lower costs and better

durability, however it requires longer setting time and the strength development at the initial age is slower. Different methods have been developed to overcome these disadvantages and to enhance the reactivity of natural pozzolans (Abdullahi *et al.*, 2012).

According to Shetty (2008), suitable pozzolans used in appropriate amount, modify certain properties of fresh and hardened mortars and concretes, such as:

a) Lower the heat of hydration.

b) Reduce the alkali-aggregate reaction.

c) Improve resistance from sulphate attack in soils and sea water.

d) Improve extensibility.

e) Lower susceptibility to dissolution and leaching.

f) Improve workability.

g) Lower cost.

The use of pozzolan materials as partial cement replacement in blended cements and concrete has become more attractive due to energy saving concerns and other environmental considerations, such as CO_2 emission related to the production of Portland cement clinker (Ashraf *et al.*, 2009).

According to Velosa and Cachim (2009), pozzolanic materials should have a high degree of specific surface area and contain high content of amorphous silica in order to generate a pozzolanic reaction.

Various reactive pozzolanas have been used as supplementary cementing materials in order to produce highly durable and high performance concrete. Examples of such are silica fume (SF),

metakaolin (MK), fly ash (FA), ground granulated blast furnace slag (GGBS) and rice husk ash (RHA) being used as blended mineral admixtures in cement (Shi and Day, 2001).

According to Pujari and Ponnala (2016), fly ash when used as partial replacement in concrete save thermal trade disposal costs, improves the physical and mechanical properties and it manufacture a greener concrete for construction. In the case of rice husk, the compressive strength tends to increase with increase in rice husk ash replacement of 5%, 10%, 15% and 20%,and reduces at 25% replacement (Seyed *et al*, 2017).

2.5.1 Pozzolanic reaction

If a concrete contains a pozzolan, less cement is required to obtain a specified strength. The amount of cement reduction will vary depending upon the reactivity of the pozzolan. A highly reactive pozzolan has more cementitious strength value than a lower reactive pozzolan. The amount of cement reduction will be greater with a more reactive pozzolan. By the above definition, to form a compound that has cementitious value, a pozzolan must react with lime which in concrete comes from the cement. Two factors are important here; (i) The quantity of lime that is available, (ii) The chemical reaction of pozzolan with lime (Malhotra and Mehta, 1996).

2.5.2 Types of composite cements

Composite cement system consists of Ordinary Portland Cement blended with one or more cementitious materials depending on the desired properties and synergistic effect of the constituent. The commonly used design systems are binary and tertiary cement systems. Binary cement system is a two cementitious constituent system in which one constituent is ordinary

Portland cement and the other is one of the cementitious pozzolan, such as fly ash, silica fume, and rice husk ash. These environment friendly cements have been successfully used in the construction of important projects, meeting demanding design criteria in some of the most hostile environments. With 50% replacement of Ordinary Portland Cement with fly ash that has fine particles, mostly less than 45microns, water requirement is reduced by about 30% as compared to the reduction in the range of 20-30% obtained with an expensive super-plasticiser (Bhatia, 2008).

Ternary cement system is a three cementitious constituent system. The rationale behind developing ternary and even quaternary cement is to produce composite in which the various mineral additives combine to provide tailor-made properties by compensating for their mutual short comings. The composite cements of OPC-SF-GBFS or FA have shown desired balance of mechanical and durability properties in marine and offshore environment (Ghambir, 2008).

2.6 Steel Fibre Reinforced Concrete (SFRC)

Steel fibre reinforced concrete is a composite material having bars as the additional ingredients, dispersed uniformly at random in small percentages, i.e. between 0.3% and 2.5% by volume in plain concrete. SFRC products are manufactured by adding steel bars to the ingredients of concrete in the mixer and by transferring the green concrete into moulds. The product is then compacted and cured by the conventional methods (The Constructor, 2017).

Steel fibres are added to concrete to improve the structural properties, particularly tensile and flexural strength. The extent of improvement in the mechanical properties achieved with SFRC over those of plain concrete depends on several factors, such as shape, size, volume, percentage and distribution of bars (The Constructor, 2017).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

This chapter contains the methodology which describes the procedures for the collection and beneficiation of the waste glass, convertion of the waste glass into powdered` form, mix design, production, characterization and testing the steel reinforced concrete. The experimental method was used for this research.

3.2 Materials and Equipment

The materials used in this research include: waste glass locally sourced from available scraps of container glasses within Zaria metropolis, Kaduna State, cement (OPC), gravel, sand, engine oil and water.

The equipment used included, dual purpose crushing machine, mortar and pestle, plastic containers, wooden and metal moulds, a rotating pan mixer, platform weighing balance, wheel barrow, shovel, trowel, 200 mesh sieve, pinches, steel reinforced bars (rebars), compression testing machine, SEM and XRD machines.

Table 3.1 Chemical Constituent of OPC

Oxides	Percentage Composition
Lime (CaO)	60-67%
Silica (Sio_2)	17 to 25%

Alumina (Al_2O_3)	3 to 8%
Iron oxide(Fe_2O_3)	0.5 to 6%
Magnesia (MgO)	0.1 to 4%
Sulphur trioxide (SO_3)	1 to 3%
Soda and/or Potash ($Na_2O + K_2O$)	0.5 to 1.3%

(Source: The Constructor, 2018)

Table 3.2 Typical Chemical Composition of Container Glass

Oxide	Weight Percentage Range	+/-
Silica (SiO_2)	66 to 88%	1.00
Alumina (Al_2O_3)	0 to 7%	0.50
Lime (CaO)	0 to 15%	0.50
Magnesia (MgO)	0 to 5%	0.50
Soda (Na_2O)	8 to 18%’’’’’	0.50
Potash (K_2O)	0 to 4%	0.50
Iron oxide (Fe_2O_3)	< 0.5	0.50

Chromium oxide (Cr_2O_3)	< 0.1	0.20
Sulphur trioxide (SO_3)	< 0.20	0.20
All other oxides	< 0.10	0.20
Carbon (C)	< 0.10	0.20

(Source: Chicago Board of Trade (CBOT) Recyclables Exchange, 2016)

3.3 Sample Collection and Preparation

Waste container glasses were sourced within Zaria metropolis. The glasses were then soaked and washed. After drying, they were broken into smaller sizes and then fed into a dual purpose glass crushing machine at the Department of Glass and Silicate Technology. The glasses were crushed and sieved to 2mm particle sizes for easy pounding. A mortar and pestle were then used to get powdered form. The 200 mesh sieve was used to sieve into 0.75mm particle size.

3.4 Conversion of Waste Glass to Powder

The glass powder was sieved through a 0.75mm sieve which resulted in fine particles. From the result of crushing waste glass, the powder obtained from 5000g of waste glass was 400g on the average.

3.5 Concrete Mix Design and Preparation of Concrete Specimen

Different compositions of the powdered glass sample and other raw materials were formulated by percentage weight. From formulation, the required amounts of powdered glass and cement were calculated as shown in Table 3.3.

Table 3.3: Composition of Concrete Mix

Percentage (%)	0%	10%	20%	30%	40%
Cement (kg)	6.50	5.85	5.20	4.55	3.90
Powdered Glass (kg)	0.00	0.65	1.30	1.95	2.60

A total of 15 rectangular specimens of 750mm by 150mm dimensions and 15 cubical specimens of 100mm dimensions were prepared for this study with water-binder ratio of 0.55. A trial mix design was conducted based on M20 concrete design using the ratio 1:2:4 for cement, sand and gravel respectively to obtain the target strength of 20MPa at 28 days (HAPPHO, 2016) and calculations were done. The water curing method was adapted. The replacement of proportion of cement with powdered glass was varied between 0% (no powdered glass), 10%, 20%, 30% and 40%. Casting was then done with all the materials mixed together.

A rotating pan mixer was used to mix the constituent materials. Fresh concrete mix was cast into 750mm by 150mm rectangular moulds where it is poured into the mould to $1/3^{rd}$ depth, then the steel reinforcing bar (rebar) that was design 700mm by 100mm was embedded passively and then filled finally with fresh concrete mix. The procedure is repeated for all rectangular specimens. For the 100mm cubical moulds, the fresh concrete was cast into the moulds directly. The specimens were demoulded after 2 days and allowed for curing. Specimens were immersed in water in a curing tank for 28 days. The flexural strength and compressive strength of beams and cubes were measured after 28 days respectively.

3.6 Characterization and Property Tests

The compressive and flexural strength tests were carried out. The analytical technique that was employed to know the microstructural morphology of the reinforced concrete was scanning electron microscopy. The x-ray diffraction technique was employed to know whether there are crystalline materials in the powdered glass.

3.6.1 Flexural strength test

Flexural test was carried out at the Concrete Laboratory of the Department of Building, A. B. U Zaria according to ASTM C1550-12 using the Mini Flexural and Transverse Testing Machine. Flexural strength is a mechanical test measuring the ability of beam or slab to resist failure in bending. The bed of the testing machine is provided with two steel rollers on which the specimen was supported. The load was applied through two similar rollers mounted at the third points of the supporting span that was spaced at 150mm from both sides. The load was divided equally between the two loading rollers. Force was then applied with testing apparatus until the sample failed. Upon failure, the failure force in N/mm^2 was recorded. The flexural strength (Fs) was calculated using the formula

Fs = Fa/bd^2, where F is failure load, a is distance between bottom support, b is breadth and d is depth. The unit is in N/mm^2 or MPa.

3.6.2 Compressive strength test

The compressive test was carried out at the Concrete Laboratory of the Department of Building, A. B. U Zaria according to ASTM C39/C39M-17a using the STYE-2000 Compression Testing Machine, Okhard Machine Tools Ltd. Compressive (crushing) strength is a mechanical test measuring the maximum amount of compressive load the concrete cube can bear before fracturing. The sample concrete cube of 100mm by 100mm was placed on a solid surface and a force was applied with the testing apparatus until the sample failed. Upon failure, the failure force in N/mm^2 was recorded.

The cross-sectional area, or A of the specimen was calculated. The specimen is four-sided, so the formula

A = LW, where L is the length and W is the width was used. The area is in units of m^2. The compressive strength was calculated using the formula

$S = {}^{P}/_{A}$, where S is the compressive strength, P is the maximum load applied to the specimen and A is the area. The final compressive strength value was in units of N/mm^2 .

3.6.3 Scanning electron microscopy

According to ASTM E986-04, the microstructural morphology of selected spots on each hardened concrete sample is analysed. The experiment was carryout using SEM (model Quarum with Serial number Q150RES) in the Department of Chemical Engineering Ahmadu Bello University, Zaria. The sample being insulating in nature does not conduct electrons therefore it was grounded with gold (to conduct electricity which will improve the resolution of the image) and was placed on the aluminium holder stub using a double sticky carbon tape and was allowed to dry on oven at $60^{o}C$ for 4 hours. The valves of the two nitrogen gas tanks were opened and the "Vent" button located at the display panel of the microscope table was pressed, after a clicked sound it takes about 1 minute to fill up the chamber with Nitrogen gas and lever on the bottom of the door was gently pulled up to open the chamber door.

The sample mounting stage was brought down by pressing the keyboard of the microscope control table, the sample holder stubs were placed into the mounting holes. With the aid of long screwdriver, the set screws for the mounting holes were well tight. Precautionary measures were taken in ensuring nothing gets into the door before it was closed, EVAC button was pressed to start the rotary pump and after 2 minutes the green light was displayed. After about 30-45 minutes the vacuum reaches proper level and the filament light of the SEM and the monitor were all turned ON. Dialled positions status were in order, the acceleration voltage was adjust to 10 kV. The filament was turned ON and the red light indicates that the filament has burned out and the high voltage was turned ON as well. Precaution is being taken to ensure that the filament

emission, beam alignment, aperture alignment, and astigmatism were all in order. The lowest magnification (10x) was used to choose the TV scan mode and the track ball was used to find or locate the sample. The coarse focus switch was turned ON and it was used to change the working distance to 14 mm, the sample stage was slowly brought up by means on command key from the key board and the sample position (z-position) where the image focuses was located the record was noted and the coarse focus was turned OFF while the medium light was turned ON.

Slow scan mode was activated, spot size was switch to medium and the magnification was further increased 500x respectively. Variable button was pressed to open up a small variable window on the screen, the size of the screen was adjusted and it's been overlaid in the region of interest. The image focus was within the small screen, the outer and inner focus ring was used to fine tone the focus. The scanning speed was adjusted to S1 to allow electronic imaging acquisition; the spirit icon was double clicked on the computer, file menu was clicked and folder name and mapping option were selected to normal resolution of 1024. The image acquire icon was selected to record the image and software takes the control over the SEM and monitor was freeze, no parameter was changed during the image recording and the image was finally saved on the image folder.

3.6.4 X-ray crystallography (diffraction)

The test was carried out using EMPYREAN Diffractometer. The glass powder sample was finely ground, homogenized and mounted on a goniometer and gradually rotated while being bombarded with X-rays. When the x-ray has sufficient energy to dislodge inner shell electrons of the target material, characteristic x-ray spectra were produced. The x-rays are then collimated and directed onto the sample. As the sample and detector are rotated, the intensity of the

reflected x-rays is recorded. This was carried out at the Nigerian Survey Agency; National Geosciences Research Laboratory (NGRL), Kaduna.

CHAPTER FOUR

4.0 RESULTS

4.1 Concrete Production

The following are the results of the concrete after production.



Plate 4.1: Fibre Reinforced Concrete



Plate 4.2: Concrete Cubes

Plates 4.1 and 4.2 shows the resultant reinforced concrete and concrete cubes after production respectively.

4.2 Mechanical Tests

4.2.1 Flexural strength

Figure 4.1 shows the result of the flexural strength test of the steel reinforced concrete

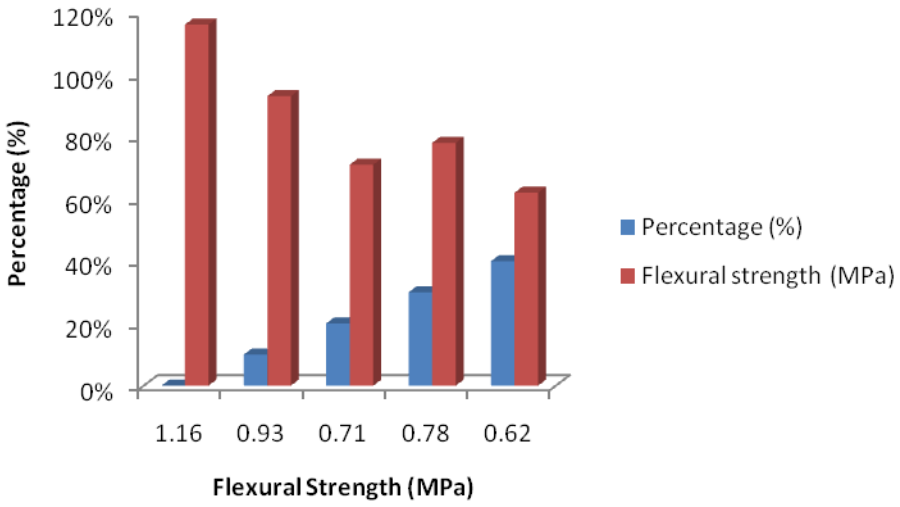


Fig 4.1 Flexural Strength of Steel Reinforced Concrete

The results of the flexural strength test from Table 4.2 showed that the samples with 0%, 10%, 20%, 30% and 40% have their compressive strengths of 1.16MPa, 0.93MPa, 0.71MPa, 0.78MPa and 0.62MPa respectively.

4.2.2 Compressive strength

Figure 4.2 shows the result of the compressive strength test of concrete cubes

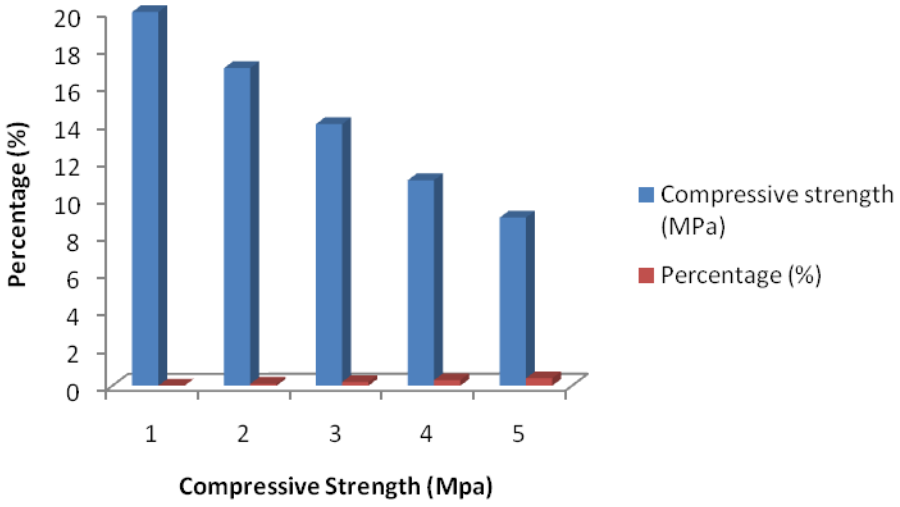


Fig 4.2 Compressive Strength of Concrete Cubes

The results of the compressive strength test from Table 4.3 showed that the samples with 0%, 10%, 20%, 30% and 40% have their compressive strengths of 20MPa, 17MPa, 14MPa, 11MPa and 9MPa respectively.

4.3 Characterization

The following characterization were carried out; X-Ray Diffraction Analysis (XRD) for powdered glass and Scanning Electron Microscopic Analysis (SEM) for three different samples of the resultant concrete with the most optimal properties.

4.3.1 X-ray crystallography (diffraction)

No crystalline material found and so no diffraction pattern produced. This is because amorphous materials like glass do not have a periodic array with long range order, so they do not produce a diffraction pattern but only broad scattering peaks.

4.3.2 Scanning electron microscopy of hardened concrete (ASTM C1723-16, 2016)

Plates 4.3, 4.4 and 4.5 show the morphology of concrete with 0%, 10% and 40% respectively.

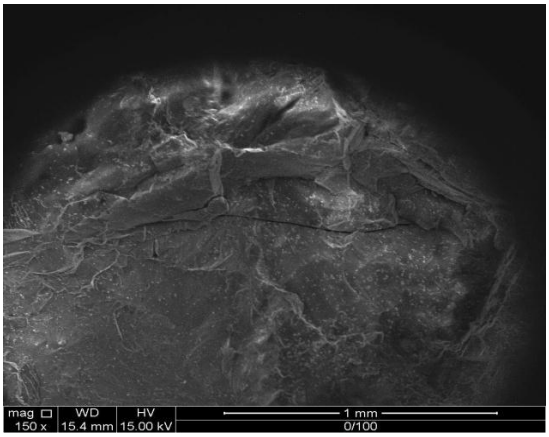


Plate 4.3: SEM of Concrete with 0% Replacement. Magnified at 150×

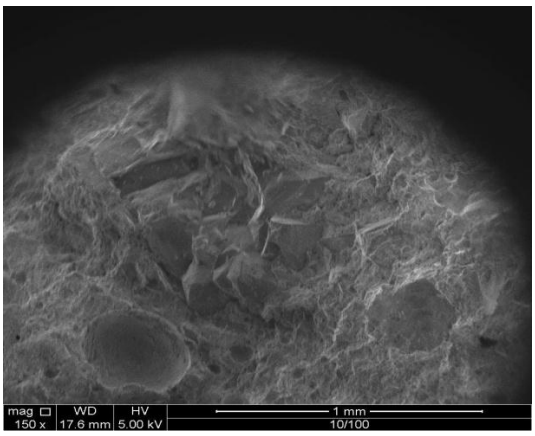


Plate 4.4: SEM of Concrete with 10% Replacement. Magnified at 150×

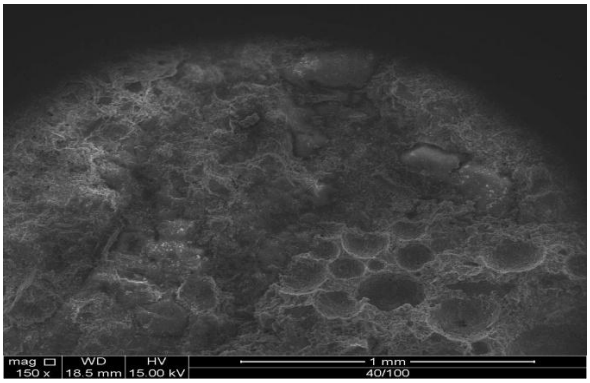


Plate 4.5: SEM of Concrete with 40% Replacement. Magnified at 150×

CHAPTER FIVE

5.0 DISCUSSION

5.1 Flexural Strength

Figure 5.1 shows the result of the flexural strength test of concrete beams

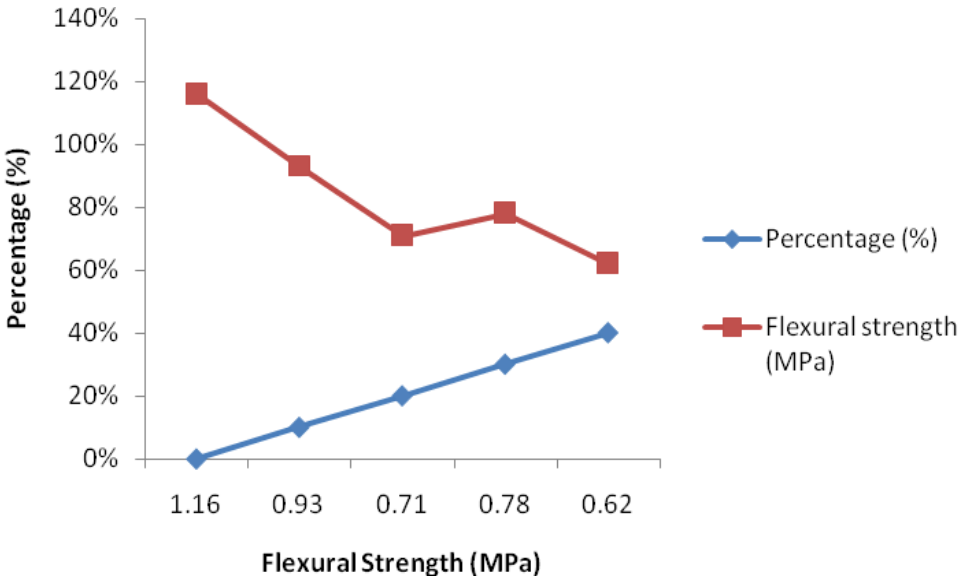


Fig 5.1 Flexural Strength of Steel Reinforced Concrete

From figure 5.1, it shows that as the percentage of replacement increases, the flexural decreases but increases when the replacement was at 30% it tends to increase and this could be due to machine error. The decrease in flexural strength could also be due to specimen preparation, handling and curing procedure or drying of beam specimen before testing.

5.2 Compressive Strength

Figure 5.2 shows the result of the compressive strength test of concrete cubes

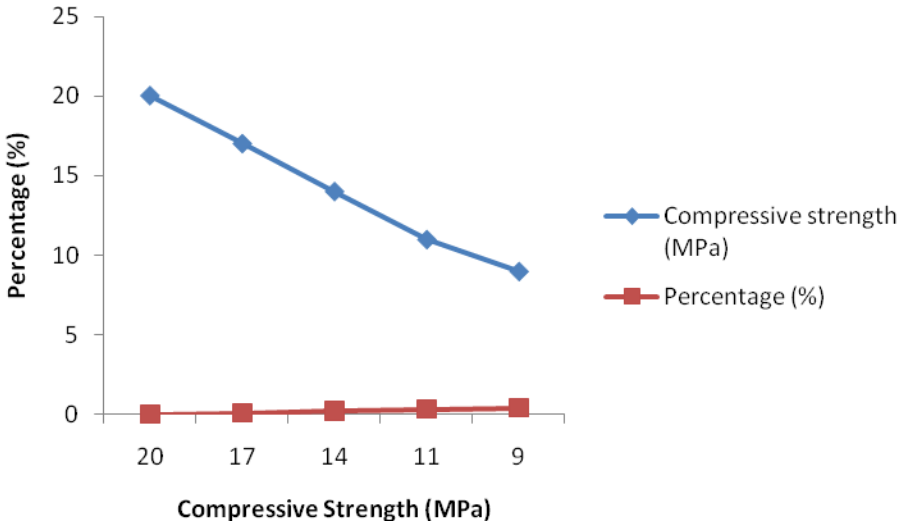


Fig 5.2 Compressive Strength of Concrete Cubes

From figure 5.2, it can be seen that as the percentage of powdered glass is been increased, the compressive strength decreases because lower mean compressive strengths compared to the control sample were obtained at 7, 14, 28 and 56 days age. This indicate that the super-plasticising effect on ground glass is lower compared to that of Portland cement as cement starts diluting and reacting as soon as water is added to the mix but glass requires longer period to start pozzolanic reaction (Islam *et al,* 2011). The compressive strength of 10% achieves the highest strength of 17MPa which conform to the standard of compressive strength of concrete (ASTM C39/C39M-17a, 2017).

5.3 Scanning Electron Microscopy

From Plate 4.3, hydration reaction was complete, while Plate 4.4 and Plate 4.5 shows some pores which could be as a result of the presence of powdered glass resulting to breaking down of the bonds in the network structure of glass and hence, accelerating the rate of hydration of the pozzolan; also, the hydration of cements precede that of the powdered glass. This is because, calcium silicate hydrate (CSH) is the product of hydration of cement, but that hydration reaction produces calcium hydroxide (CH) as by product (up to 25% of the hydrated Portland cement) which do not contribute to strength and density, but actively work against it. By reacting it with powdered glass, reactions occur with the CH there by converting it into additional CSH. This reduces the hydration heat during hardening.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The first stage of this study was directed towards sourcing of waste glass within Zaria metropolis. The waste glass were soaked, washed and dried. It was then ground to particles sizes of about 2mm with a dual purpose grinding machine to reduce the particle size, further ground with mortar and pestle to achieve fine particles. The 0.75mm sieve was used to achieve the desired particle size. The M20 mix design was adopted for the concrete production using ratio 1:2:4. Calculations were done for the percentage replacement in each case from 0%, 10%, 20%, 30% and 40% respectively. The water/cement ratio used was 0.55. Concrete cubes and beams were then produced.

The resultant concretes were characterized by scanning electron microscope (SEM) to ascertain their microstructural morphology. The physical properties of the concrete were tested to determine their conformity to standards set for concrete. Flexural and compressive strength tests were determined for the samples and some of their values conformed to ASTM C1550-12 (2012) and ASTM C39/C39M-17a (2017) standards respectively.

5.3 Conclusion

From the results and discussions of this study, the following conclusions were drawn:

i. The glass powder shows no any crystalline material according to the XRD test.

ii. The result of the compressive test showed that the concrete obtained from replacement by 10% is 17MPa which was the highest among the replaced samples.

iii. From SEM result, it shows that the 10% and 40% replaced concrete has pores which could either be due to incomplete hydration since hydration of cement happens before that of glass powder or air was entrapped during production process.

5.4 Recommendations

i. This concrete can be used in RCC (reinforced cement concrete) structures that are not exposed to severe degrading environments and extreme loads.

ii. For further researches, smaller particle size should be used since the finer the pozzolan particles, the more reactive they seem to be.

iii. The curing time of the concrete should be increased to 90 days since the pozzolanic reaction requires several weeks for hydration reaction.

REFERENCE

Abdullah, A., Jaafar, M. S., Taufiq-Yap, Y. H., Alhozaimy, A. and Al-Negheimish, A. and Noorzaei, J. (2012). A Review on the Effect of Various Chemical Activators on ozzolanic Reactivity. Academic Journal of Scientific Research and Essays Vol. 7(7), pp. 719-729. Retrieved 23 February, 2015 from http://www.academicjournals.org/SRE

Adejo, A. O. (2016). Utilization of Glass Cullet for the Production of Paint for Buildings. An Unpublished Post Graduate Dissertation Submitted to Department of Industrial Design, Ahmadu Bello University, Zaria, Nigeria.

Alemaka, E. M. (2006). Chemical Decolorization of Amber Glass for Mixed Cullet Recycling. A Post Graduate Dissertation Submitted to Department of Industrial Design, Ahmadu Bello University, Zaria, Nigeria.

Agwu, I. C. (1995). Environmental Sciences-A planners view. Lagos, Nigeria. Mish bet (Nigeria) Limited. 3rd Edition,pp 3-5.

Ashraf, M., Khan, A. N., Ali, Q., Mirza, J., Goyal, A. and Anwar, A. M. (2009). Physico-chemical, Morphological and Thermal Analysis for the Combined Pozzolanic Activities of Minerals Additives. Construction Building Materials 23: 2207-2213.

ASTM E986-04 (2010). Standard Guide for Examination of Hardened Concrete Using Scanning Electron Microscopy. ASTM International, West Conshohocken, PA. Retrieved from http://www.astm.org.

ASTM C39/C39M-17a (2017). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA. Retrieved from http://www.astm.org.

ASTM C1550-12 (2012). Standard Test Method for Flexural Toughness of Fibre Reinforced Concrete (Using Centrally Loaded Round Panel), ASTM International, West Conshohocken, PA. Retrieved November 22, 2017 from http://www.astm.org.

Bhatia, S. C. (2008). Engineering Chemistry. CBS Publishers, 4596/1-a, Darya Gary, New Delhi. Pp 26, 29 and 67.

Bradshaw, A., Southwood, R., and Warner, F. (1992). Municipal Solid Waste Management in an Economic Perspective. Published by Turner R.K and Hall London, pp 94-95

Brunges, U. (2016). Pozzolans: Trash to Treasure. Retrieved February 24, 2016, from http://ferrocement.net/ferror/files/pozzolans_uwe.html.

CBOT (2016). Chemical Composition of Container Glass. Retrieved July 30, 2018, from http//www.pharosproject.net.

Edgar, D. Z. and John C. M. (2017). The Glassy State of Matter: Its Definition and Ultimate Fate**.** Journal of Non-Crystalline Solids. Pp 490-494.

Garkida, A. D. (2007). Glass Recycling in Waste Management. A Published PhD Dissertation Submitted to Department of Industrial Design, Ahmadu Bello University, Zaria.

Ghambir, M. L. (2008). Concrete technology, Third Edition. Published by Tata M. C. Publishing Company, Niagara, New Delhi.

HAPPHO (2016). "Quantities of Cement, Sand and Aggregate for Nominal Concrete Mix" Retrieved November 29, 2017, from http://www.happho.com/calculate-quantities-cement-sand-aggregate-nominal-concrete-mix-124

Hauwa, I. (2016). Development of Glass Ceramics Using Kaolin Processing Waste, Sodalime and Borosilicate Glass Wastes. An Unpublished PhD Dissertation Submitted to Department of Industrial Design, Ahmadu Bello University, Zaria.

Malhotra, V. M. and Mehta, P. K. (1996). Pozzolanic and Cementitious Materials. Published by Gordon and Breach Publishers, pp 94-154.

Neville, A. M. (2002). "Properties of Concrete": Fourth and Final Edition. Printed by Pearson Education Limited, Essex.

Nicholas, B. W. (2014). Understanding Cement. Retrieved December 30, 2014, from http://www.understanding-cement.com/hydration.html.

Pujari, S. and Ponnala, R. (2016). Partial Replacement of cement with Fly Ash and Its Compressive Strength. International Journal of Research in Advanced Engineering Technologies Vol.5, pp 223-227.

Schott, A. G (2015). Technical glass Powder. Retrieved August 15, 2014, from http//www.schott.com/epackaging/english/glass/technical_powder/index.html.

Seyed A. Z., Farshad A., Farzan D. and Mojtaba A. (2017). Rice Husk Ash as Partial Replacement in High Strength Concrete Containing Micro Silica: Evaluating Durability and Mechanical Properties. Case Studies in Construction Materials Vol.7, pp 73-81.

Shaikh, N. A., Khot, M. A., Gujar, M. S., Khan, M. A. and Khan, F.A. (2013). Suitability of waste glass powder as a partial replacement of cement in fibre reinforced concrete:

A.I.A.R Kalsekar polytechnic, New Panvel 410 206, Navi Mumbai. Retrieved August 17, 2015, from http://works.bepress.com/nawaz_shaikh/2

Shetty, M. S. (2008). Concrete technology: Theory and practice. Published by S. Chand and Company Ltd. New Delhi, India, pp 456-501.

Shi, C. and Day, R. L. (2001). Comparison of different methods for enhancing reactivity of pozzolans. Journal of Cement and Concrete. Res., 31: 813-818.

Sismondo, S. (2009). An Introduction to Science and Technology Studies. John Wiley and Sons, 2nd edition, p. 142. ISBN 978-1-4051-8765-7.

The Constructor (2007). "Steel Fibre Reinforced Concrete" Retrieved August 18, 2015 from http://theconstructor.org/concrete/steel-fibre-reinforced-concrete/4771

The Constructor (2018). "Composition of Portland Cement" Retrieved July 30, 2018 from http://theconstructor.org/building/composition-of-portland-cement/5725

Velosa A. L and Cachim P. B (2009). Construction and Building Materials, Published by Elsevier Publishers, Vol. 23, pp 2107-2111. ISSN 0950-0618

Weber, W. (2006). Recycled Glass Tiles. Retrieved May 14, 2015 from http//www.LoveToKnowCorp.Database.

WRAP (2010). Can you Recycle your Flat Glass Waste? The Potential for Recycling Flat Glass Waste in the Domestic Replacement Window Sector, Banbury, WRAP, Retrieved August 3, 2016, from http://www.wrap.org.uk/downloads/FlatGlassWaste1.c48b676f.55.pdf.

Yang, E. and Li, M. (2008). Field Demonstration of Durable Link Slabs for Jointless Bridge Decks Based on Strain-Hardening Cementitious Composites – Phase 3: Shrinkage Control. Michigan Department of Transportation.

APPENDICES

Appendix I: Flexural Strength of the Steel Reinforced Concrete

Percentage (%)	0%	10%	20%	30%	40%
Flexural strength (MPa)	1.16	0.93	0.71	0.78	0.62

Appendix II: Compressive Strength of the Concrete Cubes

Percentage (%)	0%	10%	20%	30%	40%

Compressive strength (MPa)	20	17	14	11	9