STRUCTURAL PERFORMANCE OF CONCRETE WITH WASTE GLASS ENHANCED WITH WOOD ASH

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Structural Performance of Concrete with Waste Glass Enhanced with Wood Ash

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

Signature: ……………………….……………Date: ……………………………

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DEDICATION

I dedicate this work to Almighty God, my wife Grace Mbesa, my son Brian Manyara, my daughters Vivian and Adriannah, my parents Mr & Mrs Manyara Ontieri and my brother and sisters.

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LIST OF ACRONYMS

ASR	Acid silicate reaction
ASTM C1260	American Society for Testing Materials
BGA	Blue gum ash
BGAC	Blue gum ash cement
BRE	Building research establishment
BS	British standard
DOE	Department of environment
EN	Eurocode standard
GC	Glass concrete
GCBAC XX-YY	Glass concrete made using cement dosed with blue gum ash
IS	Indian standard
KS	Kenya standard
OPC	Ordinary portland cement
PCA	Portland cement association
PH	Potential hydrogen
XX	Percentage replacement of sand by crushed glass
YY	Percentage dosage of cement by blue gum ash

ABSTRACT

Environmental effects of river sand harvesting and the need to provide cheaper housing has necessitated for researchers to look for alternative materials to concrete ingredients. This can be achieved by partially or fully replacing some of these concrete components. Although several researches on effects of wood ash and waste crushed glass on concrete have been carried out, no research work on effect of blue gum ash on glass concrete has been done hence the necessity to carry out this research. In this research, blue gum ash was dosed in portland cement (power plus 42,5N) in the proportions of 0, 0.5, 0.75, 1.0, 1.25 and 1.5% by cement weight and crushed glass used to partially replace river sand in the proportions of 5,10,15,20 and 25% by river sand weight, in concrete mix of class 25. Physical and mechanical properties of the concrete materials, fresh and hardened properties and cost benefit effects of the blue gum ash glass concrete were studied in this research work. From consistency, setting times and chemical composition tests, it was found that blue gum ash can be dosed in cement up to a maximum of 1%, providing allowable consistency, initial and final setting time and blue gum ash cement with required chemical compositions. Good workability was notable for blue gum ash dosed in cement at 1% and glass used to replace fine aggregates at 10%. For compressive, flexural and tensile split tests, strengths of the various mixes were lower as compared to the control mix. Also, significant increase of up to 1% dosage of cement with blue gum ash at 10% replacement of fine aggregates with crushed glass was noted to achieve strengths of 27.8N/mm^2 and 30.1N/mm^2 at 7 days and 28 days respectively. The tensile split test increased with increase in the concrete curing age, and also increased with increase in blue gum ash content in the mix, up to 1% by cement weight attaining strengths of 2.18N/mm^2 and 3N/mm^2 for 7 and 28 days respectively. The mathematical relationship between the compressive strength (Fcu_{28}) at 28 days and the corresponding split tensile strength (Ft_{28}) at 28 days was quadratic. Also notable was the increase in flexural strength with increase in curing age and blue gum ash dosage in the mix. There was increase in water absorption with increase in blue gum ash content. In terms of cost, there was saving of up to 2.2% for concrete

containing blue gum ash of 1.5% of cement by weight and 30% crushed glass of fine aggregates. All this was based on $1M^3$ concrete. In conclusion, it can be recommended that, cement can be dosed with blue gum ash at 1% and fine aggregates replaced with crushed glass at 10% for good workability and strength. This mix can be used for lightly loaded beams and lintels in buildings provided the engineers design mix for the members is class 25.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The increasing cost of housing and other construction have necessitated researchers to continue to seek ways of reducing the cost of building projects by exploring other alternative eco-friendly materials. Research around the world has shown that industrial and agricultural by products regarded as waste, such as wood ash from factories, fly ash, waste glass could be used as partial replacement of various components of concrete. Ganesan et al. (2007). The utilization of waste agricultural by products (which are dumped in landfills and water bodies) as cement replacement material may impact on the cost of concrete production and other construction materials such as mortar, concrete paving blocks, concrete roof tiles and interlocking blocks.

Concrete is defined as a mixture of cement sand, gravel and water which dries hard and strong and is used as a building material. Admixtures are ingredients in concrete other than Portland cement, water and aggregates that are added to the concrete batch immediately before or during mixing to alter its properties, such as workability, curing temperature range, setting time or color (Portland cement association, 2016).

There are generally two types of admixtures. Firstly, are chemical admixtures which comprise of accelerators, retarders, water-reducing agents, super plasticizers and air entraining agents. Secondly, are mineral admixtures which comprise of fly-ash, blast-furnace slag, silica fume, metakaolin and rice husk ash. (Portland cement association, 2016). Concrete should meet special performance requirement with regard to workability, strength and durability, that is always obtained with techniques and materials adopted for producing conventional cement concrete. Use of admixtures in concrete production has resulted in desirable effects such as reducing the water cement ratio, increasing workability and enhanced strength (Newman & Choo, 2009).

Green building (green construction/sustainable building) refers to both a structure and the using of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition (greenbuildingsolutions.org, 2016)

According to Dave Sharpe (2002) wood fiber and bark are composed of cellulose, which is a carbohydrate containing mainly carbon, hydrogen, and oxygen. Combustion of wet wood has a few distinct phases which are: dehydration or drying of the wood, evaporation of the volatiles which happens as the wood heats from 200 –1100° F (95- 595^0 C) where the volatile components are heated until they come off as gases, pyrolysis (chemical decomposition into volatile gases and other compounds) which then contribute to oxidation and reduction reactions creating heat and light just like in your fireplace.

During the burning of wood, large quantity of gases are formed which include carbon dioxide water vapor and excess air that mainly constitutes of nitrogen and oxygen. Typical exhaust temperatures are around 350 to 450°F (175- 230^0 C). As the wood is burnt, the carbon in the wood combines with oxygen to form carbon dioxide (CO_2) and the hydrogen in the wood and oxygen from the air combines to form water (H_20) vapor. After extracting the heat with the boiler (steam power), exhaust gases at around 400°F (205^0C) are left.

There is substantial amount of energy in the exhaust gases, usually 18% to 34% of the total heat of the wood. The more moisture in the fuel the lower the heating value of the fuel and the lower the efficiency of the boiler where the fuel is wood.

Sand has been predominantly used as fine aggregate in civil engineering construction. River sand harvesting has a lot of impact on the environment. More recently, the cost of sand has been continuously increasing resulting in ever increasing cost of construction. Research in to the utilization of alternative materials such as waste crushed glass as partial replacement for fine aggregate in concrete production for building purposes has been carried out in attempt to use locally available materials which are considered as waste, Olawuyi and Olusola (2010).

Searching, exploration and exploitation of mineral resources in Kenya is regulated by the Mining Act Cap. 306 of the laws of Kenya. The Act was established in 1940 and revised in 1987 and is silent on rehabilitation of mined out areas. The recently enacted Environment Management and Coordination Act, (EMCA 1999) demands rehabilitation of mined areas but enforcement has remained a key challenge. Mining is therefore carried out without adequate control by the mining acts, rules or any other legislation. This has resulted in sand being indiscriminately mined, causing large-scale damage to the natural ecosystems.

1.2 Problem Statement

Glass has been used as fine aggregates in concrete but the resulting concrete is of low compressive strength, as explained by strength relationship established through 7-day and 28-day compressive strength tests, in comparison with normal concrete (Rajabipour et al., 2010). The cause of low compressive strength can be attributed to impaired cement hydration caused by fine glass particles. It has low workability due to glass particle shape, irregular particle size distribution and very low aggregate absorption. However, it has higher resistance against abrasion as compared to sand concrete (Rajabipour et al., 2010). Thus, the aim of this study was to determine the contribution of the use of waste blue gum ash as an admixture alongside crushed glass as fine aggregates in concrete to improve the plastic and hardened mechanical properties. In addition, the research was aimed at promoting environmental preservation and improving the economy of the country by putting waste glass to useful purpose.

1.3 Justification of the study

This research was carried out to ascertain the effects of blue gum ash as an admixture in concrete made with crushed glass as part fine aggregate. According to sustainable agriculture act, July 2010, when blue gum ash admixture is effectively used to enhance the workability and strength of concrete, made with crushed glass as part fine aggregate, it contributes towards lowering costs in construction, promoting green environment and proving beneficial to researchers by contributing to alternatives to concrete ingredients. Clear float glass was used because it is the core base product for most of performance glass products and is commonly used in windows and doors in buildings. From the manufacturer's brochure of Power plus cement (42,5N), this CEM 1 type of cement has low alkali (Na_2O equivalent<0.6%) to guard against alkali aggregate reaction in concrete and that's why it was used in the research.

1.4 Objectives

1.4.1 General objective

To investigate the structural performance of concrete with waste glass enhanced with blue gum ash.

1.4.2 Specific objectives

1) To determine the physical and chemical properties of river sand, crushed waste glass, blue gum ash and cement.
2) To evaluate the effect of blue gum ash on fresh and hardened properties of concrete made with crushed waste glass as part fine aggregate.
3) To cost benefit analysis of using crushed waste glass enhanced with blue gum ash in concrete.

1.5 Research questions

i. Does blue gum ash affect positively or negatively, the performance of cement?
ii. What are the effects of blue gum ash on the rheological properties of glass concrete?
iii. Once the effects of blue gum ash on fresh glass concrete are known, what about the effects on the hardened concrete?

1.6 Hypothesis of study

Blue gum ash is a suitable admixture for concrete made with crushed glass as part fine aggregate. It improves the workability of fresh concrete and enhances the strength of hardened concrete.

1.7 Scope of the study

The study covered physical and chemical properties of river sand, crushed waste glass, blue gum ash and cement. Also, fresh and hardened properties of C25 concrete as an optimum grade made with partial replacement of sand with crushed glass aggregate as part of fine aggregate and blue gum ash as an admixture. The cement used was power plus 42.5N and the ash used was from blue gum, *Eucalyptus saligna*, commonly grown in Kericho and Kisii areas. (Kenya Forest Service, 2009).

1.8 Limitations of the study

Variations in type of cement, glass types and concrete classes could have resulted in different results. However, these variations were not considered as much concentration was based on class (C25) concrete commonly used as structural concrete. The source of blue gum ash was from Toror and Tegat, hence any other source could have resulted to different results.

CHAPTER TWO

LITERATURE REVIEW

Concrete has unlimited opportunities for innovative applications, design and construction techniques. Its great versatility and relative economy in filling wide range of needs has made it is very competitive building material. With the advancement of technology and increased field of applications of concrete and mortars, the strength, workability, durability and other characteristics of the ordinary concrete need modifications to make it more suitable for certain situations (Concrete Portal, 2016). Under such situations the use of admixtures is found to be an important alternative solution.

Glass is a product of the super cooling of a melted liquid mixture consisting primarily of sand (silicon dioxide) and soda ash (sodium carbonate) to a rigid condition, in which the super cooled material, does not crystallize and retains the organization and internal structure of the melted liquid. When waste glass is crushed to sand like particle sizes, similar to those of natural sand, it exhibits properties of an aggregate material.

The traditional market for crushed recycled glass (cullet) is manufacturing new glass products; which primarily use high-quality, color-sorted, and contamination-free cullet (Skumatz & Freeman, 2007). Alternative markets for lower-grade cullet include applications as an abrasive, water filtration media, landscaping material, and as aggregate in construction including in pavement layers, in asphalt and concrete mixtures, and as a fill material.

2.1 Glass

Glass is a unique inert material that could be recycled without changing its chemical properties. According to (Architectural window systems, 2015), there are different types of glasses: -

i. Clear float glass is 4mm, visually colorless and distortion free glass providing high light transmission (daylight) and clarity.
ii. Tinted glass is produced by adding metal oxides to float glass during manufacture. It absorbs and re-radiates solar energy by reducing heat, provides cost efficient climate control, reduces sun glare and is aesthetically appealing.
iii. Reflective glass achieves greater solar control than standard tinted float glass and can be used to create a specific visual appearance in a building.
iv. Toughened glass is a safety glass that has increased strength and will usually shatter in small pieces when broken.
v. Laminated glass is made up of two or more layers of glass permanently bonded together with an interlayer.
vi. Low emissivity glass has a thin metallic coating on the glass that reflects thermal radiation or inhibits its emission reducing heat transfer through the glass.
vii. Double glazing or insulated glass units consist of two panes of glass bonded to both sides of a spacer to create one unit. The space between the panes of glass may be filled with Argon gas to increase the insulating properties of the double-glazing units.

Damaged glass sheets, sheet glass cuttings and post-consumer glass (bottles and window plates) go to waste, usually delivered to landfills for disposal. In Kenya, about 2.3% of total waste is glass (NEMA, 2015). This amounts to approximately 791,292 tonnes annually. Globally, glass forms about 5% of total global waste amounting to approximately 110 million tonnes per year (Muggeridge, 2015). Crushed glass or cullet, if properly sized and processed, can exhibit characteristics relative to that of gravel or sand. Waste glass used in concrete making, improves green environment and economy.

2.2 Wood ash

Wood ash is generated as a by-product of combustion in wood-fired power plants, domestic fireplaces, paper mills, and other wood burning facilities. Despite the world moving towards better sources of energy like solar, wind and nuclear, wood is still used as main source of energy in most middle-class economies and as supplementary source of energy in some 6 processing tea factories in Kericho specifically Tegat and Toror tea factories. In the light of these, it has become essential to develop beneficial uses of wood ashes to solve the problems associated with their disposal.

When waste glasses are reused in making concrete products, it has been noticed that the strength of the concrete goes down hence the addition of wood ash. The wood ash admixture, in line with its pozzolanic nature, will be able to contribute to attaining higher compressive strengths and offer desirable fresh concrete properties. Sources of the wood ash for the study will be obtained from Tegat and Toror tea factories as a primary source from Kericho.

2.3 Waste glass current management options

Over the past decade, efforts to recover postconsumer glass have received support through bottle bill legislation which provides for deposits during purchase and returns of containers at deposits. However, collection of waste glass at material recovery facilities is predominantly being used (Vollmer, 2015).

Traditionally, glass recycling has involved the collection and sorting of glass by color for use in the manufacture of new glass containers. Recycling postconsumer waste glass for use as a raw material in new glass products is limited, however, by the high cost of collection and processing (hand sorting) of waste glass, and specifications that limit impurities (e.g., ceramics, ferrous metal, paper, plastics and mixed-colored cullet) (Vollmer, 2015). In addition, glass breakage (30 to 60 percent) during collection limits the quantity of glass recovered and thus low production levels.

For construction, glass must be crushed and screened to produce an appropriate design gradation. Glass crushing equipment normally used to produce a cullet is similar to rock crushing equipment (e.g., hammer mills, rotating breaker bars, rotating drum and breaker plate, impact crushers). However, the equipment in material recovery facilities is typically smaller and uses less energy than conventional aggregate or rock crushing equipment (Vollmer, 2015). Successful production of glass aggregate using recycled asphalt pavement processing equipment (crushers and screens) has been reported. Magnetic separation and air classification may also be required to remove any residual ferrous materials or paper still mixed in with the cullet.

2.4 Glass material description

2.4.1 Physical properties

Crushed glass (cullet) particles are generally angular in shape and can contain some flat and elongated particles. The degree of angularity depends on the degree of processing (i.e., crushing) (Glasscoasterstore, 2016). Smaller particles, resulting from extra crushing, will exhibit somewhat less angularity and reduced quantities of flat and elongated particles. Proper crushing virtually eliminates sharp edges and the corresponding safety hazards during handling.

2.4.2 Chemical properties

Glass-formers are those elements that can be converted into glass when combined with oxygen. Silicon dioxide (SiO_2), used in the form of sand, is by far the most common glass-former. Common glass contains about 70 percent SiO_2 (Textile Engineering, 2012). Soda ash (anhydrous sodium carbonate, Na_2CO_3) acts as a fluxing agent in the melt as it lowers the melting point and the viscosity of the formed glass, releases carbon dioxide, and helps stir the melt. Other additives are also introduced into glass to achieve specific properties. Alumina, lead, and cadmium are used to increase the strength of the glass and increase resistance to chemical attack (Textile Engineering, 2012).

Most glass bottles and window glass are made from soda-lime glass, which accounts for approximately 90 percent of the glass produced worldwide. Lead-alkali-silicate glasses are used in the manufacture of light bulbs, neon signs, and crystal and optical glassware. The typical chemical compositions of these glasses are shown in the Table 2.1.

Table 2.1: Typical chemical composition of glass types (Zeng & Hing, 2002)

	Typical container glass (%)	**Typical float glass (%)**	**Approximate limits (%)**
SiO_2	74.42	71.86	63-81
Al_2O_3	0.75	0.08	0-2
MgO	0.30	5.64	0-6
CaO	11.27	9.23	7-14
Li_2O	0.00	0.00	0-2
Na_2O	12.9	13.13	9-15
K_2O	0.19	0.02	0-1.5
Fe_2O_3	0.01	0.04	0-0.6
Cr_2O_3	0.00	0.00	0-0.2
MnO_2	0.00	0.00	0-0.2
Co_3O_4	0.00	0.00	0-0.1
TiO_2	0.01	0.01	0-0.8
SO_3	0.16	0.00	0-0.2
Se	0.00	0.00	0-0.1

2.4.3 Mechanical Properties

Glass is non-crystalline and amorphous material that fractures from tensile stress. Gravel-sized particles greater than 4.75 mm size exhibit relatively poor durability, when compared with conventional aggregate materials whereas gravel-sized particles less than 4.75 mm size exhibit relatively improved durability when compared with conventional aggregate materials (Textile Engineering, 2012). The internal friction angle or shear strength and bearing capacity of crushed aggregates is high and its compatibility insensitive to moisture content.

2.5 Glass as part fine aggregate in concrete

For many years, the recycling and waste management industry has struggled with the problem of identifying or developing reliable markets for broken or waste glass. To date, only low value applications are available, which do not utilize the physical and other inherent properties of the glass.

Recent research has made it possible to use such glass as aggregate in concrete, either in commodity products, with the only objective being to utilize as much glass as possible, or in value-added products that make full use of the physical and aesthetic properties of crushed glass (Concrete Portal, 2016). The potential applications are basically limitless, and it is expected that commercial production of specialty glass concrete products will have a major impact on the economics of glass recycling throughout the world.

Application as concrete aggregates can be particularly rewarding since the high production volume of concrete materials can incorporate large quantities of recycled glass. Specifically, in areas with limited availability of durable natural aggregates, recycled glass can be used as a partial aggregate replacement, thus reducing the cost and environmental impact of importing aggregates from elsewhere (Rajabipour et al, 2010).

According to Mageswari and Vidivelli (2009), the present scenario identifies that the availability of river sand for the preparation of concrete is becoming scarce due to the excessive poor methods of mining from the riverbeds, lowering of water table and sinking of the bridge piers are becoming common treats.

Rajabipour et al. (2010) explains that concrete made through the replacement of river sand with glass aggregates demonstrated poor workability, which resulted in inefficient compaction and low strengths alkali silica reaction (ASR) was noted to be affecting most aggregate particle sizes thus this study will examine the effects of the ASR on different sizes to ascertain the suitable sizes that have lowest ASR effect. It is also expected that the glass aggregate will affect the mechanical properties of the concrete such as strength which is typically controlled by the bond strength between cement matrix and aggregate. If natural aggregate is replaced by crushed glass particles, a drop in strength and in particular a reduction of an already low ductility is expected due to glass's smooth surface. Finally, it was recognized that glass concrete needs further redevelopment and technology since it's a new material.

Aggregates will be chemically inert, clean, hard and durable. Organic impurities can affect the hydration of cement and the bond between the cement and the aggregate. Some aggregates containing silica may react with alkali in the cement causing the concrete to disintegrate. This is the alkali-silica reaction (ASR). The presence of chlorides in aggregates will cause corrosion of the steel reinforcement.

The problem of ASR can occur also in conventional concrete, since the aggregate contains "certain siliceous rocks and minerals, such as opaline chert, strained quartz, and acidic volcanic glass". The build-up of the ASR gel causes volume expansion and may cause the concrete to crack and it's difficult to predict (Understanding Cement, 2016). If ASR in regular concrete is subject to this uncertainty, glass aggregate has the one "advantage" of no uncertainty in this regard due to its chemistry. That makes glass almost an ideal aggregate to study the ASR phenomenon and to search for methods to avoid it or to mitigate its consequences.

Most of the ASR studies with glass concrete utilized the ASTM C1260 test. This is the most popular accelerated test, because it lasts just a little over two weeks while assessing the potential reactivity of an aggregate. It calls for the preparation of 25 by 25 by 280 mm mortar bars containing the aggregate to be investigated, which are immersed in an 80^{o}C sodium-hydroxide solution for two weeks. Their expansions are interpreted as being indicative of the material's potential reactivity. Although a positive test result is not a guarantee that the material is innocuous, the ASTM C1260 test is of great value for comparative purposes.

There are a number of measures to avoid ASR or its damaging effects:- a) Grinding the glass to pass at least 50mm sieve (Ranagaraju & Afshinnia, 2015) b) Adding mineral admixtures like lithium based admixture (Portland cement association, 2015) c) Making the glass alkali-resistant, for example, by coating it with zirconium d) Modifying the glass chemistry, if that is an option, e.g. for special glasses e) Sealing the concrete to protect it from moisture, f) Using low-alkali cement, which is likely to be less effective, unless alkalis from the environment can be kept away (Portland cement association, 2015) and g) Developing special ASR-resistant cements, available commercially (Portland cement association, 2015).

Previous experiments by Ranagaraju and Afshinnia, (2015) showed that the finer the glass is crushed, the more the ability to resist ASR effect particularly when used as an aggregate replacement material, both in the case of crushed glass and natural reactive aggregates

2.6 Aggregate properties of glass for use in concrete products

The properties that make glass an attractive aggregate for a variety of concrete products include: - a) Glass is one of the most durable materials known to man. With the current emphasis on durability of high-performance concrete, it is only natural to rely on extremely durable ingredients (Glasscoastertore, 2016). b) Glass has basically zero water absorption; hence lower water content levels in concrete c) The excellent hardness of glass gives the concrete an abrasion resistance that can be attained only with few natural stone aggregates. d) The aesthetic potential of color-sorted glass offers numerous novel applications. e) Very finely ground glass has pozzolanic properties hence can serve both as partial cement replacement and filler (Portland cement association, 2016).

2.7 Glass concrete products

Glass concrete products can be categorized as commodity products (utilizes waste glass) and value-added products (utilizes aesthetic potential).

For visibility of glass, a certain particle size should be present. Commercial production of commodities requires cleaned, crushed, and graded glass according to specifications. The crushing and grading is done to eliminate any wastage of the glass. The glass powder turns out to be the most valuable product of the crushing operation, both because of its pozzolanic potential and filler effect.

Architects or designers can help coordinate the surface texture and colors of glass aggregate and cement matrix. The economics of concrete production using glass is promising, but depends strongly on a reliable supply of glass. Whereas replacing just the sand by finely ground glass may be of modest economic benefit, replacing also part of the cement by glass powder, which is obtained during crushing, improves the economic outlook.

2.8 Wood ash admixture

Wood fuel for generating heat and power is of interest because wood is a renewable fuel with low ash and sulfur content. Typically, between 0.43 and 1.82 percent of the mass of burned wood; - (dry basis) results in ash as shown in Table 2.2. The conditions of the combustion affect the composition and amount of the residue ash, thus higher temperature will reduce ash yield, (Oriyomi, et al 2014).

Table 2.2: Low temperature ash content of different wood species (Oriyomi et al., 2014**)**

Wood species	Ash, dry basis (%)
Aspen	0.43
Yellow poplar	0.45
White oak	0.87
White oak bark	1.64
Douglas-fir bark	1.82

2.9 Physical and chemical properties of wood ash

Studies of chemical composition of wood ash in the past have primarily been restricted to the elemental composition as the focus was largely on the agricultural use of wood ash. Some of the chemical compositions of wood are shown in Table 2.3.

Table 2.3: General chemical composition of wood ash (Oriyomi et al, 2014)

Constituents	Percentage	Properties class F fly ash
SiO_2	31.8	52
Al_2O_3	28	23
Fe_2O_3	2.34	11
CaO	10.53	5
MgO	9.32	
SO_3	- -	0.8
Na_2O	6.5	1.0
K_2O	10.38	2

Wood ash exhibits a specific gravity of 2.13 and bulk density of 810kg/m^3, (Etiegni & Campbell, 1991). These properties depend on type and source of wood, design, boiler combustion temperature and collection technique.

2.10 Classification of wood ash

Wood ashes are divided into two major classes of fly ash and bottom ashes. For a long time, wood ash has been used in agriculture to recycle soil nutrients though it doesn't contain nitrogen. Its calcium carbonate content makes it act as a liming agent and de-acidifies soil by increasing its potential hydrogen pH value (Etiegni, & Campbell, 1991). One problem with ash is the deposition on heat transfer surfaces in boilers and lack of information on mineral matter behavior in wood. High cost of disposal of wood as in landfills has called for alternative ecological uses to be invented.

2.11 Previous studies on wood ash in cement based construction materials

Investigations have been performed with a view to establish various physical properties of wood ashes and to determine potential uses of wood ashes in cement-based construction materials. Wood ash is an admixture: a pozzolana as it share origin with rice husk ash and fly ash from coal hence could be used as a pozzolana in concrete.

Tarun and Rafat (2014) reported the following elements in wood ash: carbon (5 to 30%), calcium (5 to 30%), carbon (7 to 33%), potassium (3 to 4%), magnesium (1 to 2%), phosphorus (0.3 to 1.4%), sodium (0.2 to 0.5%) and Silica (4 to 59%). Pascale Coatanlem (2011) report aimed at examining the durability of a wood fibre lightweight concrete. Samples stored in humid and dry environments, compressive and flexural strength were measured and the microstructure examined using SEM analysis (Tarun & Rafat, 2014). The material properties are improved when wood chippings are saturated with a sodium silicate solution. This is due to the improved bond between chippings and cement paste, resulting from the formation of calcium silicate hydrate (CSH) gel I and ettringite.

Despite the research in the last decade on admixtures, very little information is available on wood ash concrete. Since wood is a renewable source of energy and an environmentally friendly material, increased use is expected in future hence higher availability.

Research was carried out to utilize wood ash in making self-compacting controlled low-strength materials (Etiegni, & Campbell, 1991). Initial test results indicated that wood ash could be successfully used in making a) Air-entrained structural-grade concrete up to 28-day compressive strength of 50 MPa (PCA, 2016) b) Non-air-entrained structural-grade concrete (up to 60 MPa – 28-day compressive strength) as partial replacement of cement (PCA, 2016) and c) Good quality bricks, blocks and paving stones with wood ash or its blends with coal fly ash (up to 35%) as partial replacement of cement.

Studies conducted by (Tarun & Rafat, 2014) showed that wood ash as partial replacement for cement has been used in various types of concrete: - a) Normal concrete- This is concrete in which common ingredients i.e. aggregate, water, cement are used. It has a setting time of 30 - 90 minutes depending upon moisture in atmosphere and fineness of cement. The development of the strength starts after 7 days the common strength values is 10 MPa to 40 MPa At about 28 days 75 - 80% of the total strength is attained. Almost at 90 days 95% of the strength is achieved. However, it's not durable under severe conditions e.g. freezing and thawing (Types of concrete, 2014). b) High strength concrete- compressive strength of high strength concrete mix is usually greater than 41.37 Mpa. High strength concrete is made by lowering the water cement (w/c) ratio to 0.35 or lower. Low water cement (w/c) ratios and the use of silica fume make concrete mixes significantly less workable. To compensate for the reduced workability in the high strength concrete mix, super plasticizers are commonly added to high-strength mixtures. In this type, aggregate selection is a crucial factor in achieving desired strength (Types of Concrete, 2014) c) Air entrained concrete- It is used where the concrete is vulnerable to freezing and thawing action. It is prepared by adding the air entraining admixture (Types of concrete, 2014). d) Light weight concrete- This concrete has substantially lower mass per unit volume then the concrete made of ordinary ingredients. The aggregates used are lighter in weight. Its density is 240 kg/m³ -1850 kg/m³ Strength of blocks varies from 7 MPa (1000 psi) - 40 MPa). (PCA, 2016). e) Self-compacting concrete - The concrete is compacted due to its own weight. This self-consolidating concrete is characterized by: extreme fluidity as measured by flow, typically between 650-750 mm on a flow table, rather than slump (height). (Types of concrete, 2014). f) Shotcrete – This concrete use compressed air to shoot concrete onto (or into) a frame or structure. It is sometimes used for rock support, especially in tunnelling to counteract seepage or as quick fix for loose soils in construction zones (PCA, 2016). g) Pervious concrete- Pervious concrete contains a network of holes or voids, to allow air or water to move through it. This allows water to drain naturally through it, and can both remove the normal surface water, and allow replenishment of groundwater. It is formed by leaving out some or the entire fine aggregate, and then the remaining large aggregate is bound by a relatively small amount of Portland cement (PCA, 2014). h) Roller compacted concrete- This is a low-cement-content stiff concrete placed on the surface to be covered (like pavement), and is compacted in place using large heavy rollers typically used in earthwork. The concrete mix achieves a high density and cures over time into a strong monolithic block (Types of concrete, 2014).

2.12 Admixtures in concrete

Admixtures are those ingredients in concrete other than portland cement, water, and aggregate that are added to the mixture immediately before or during mixing. To achieve certain desired property.

a. Air-entraining admixtures

These admixtures are used to purposely introduce and stabilize microscopic air bubbles in concrete to improve durability of concrete exposed to cycles of freezing and thawing (Whiting & Dziedzic, 1992).

Entrained air greatly improves concrete's resistance to surface scaling caused by chemical deicers. Furthermore, the workability of fresh concrete is improved significantly, and segregation and bleeding are reduced or eliminated.

Air-entraining cement is a portland cement with an air-entraining addition grinded with the clinker during manufacture

b. Water-reducing admixtures

Water-reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water-cement ratio, reduce cement content, or increase slump. They reduce it by approximately 5% to 10%. They increase slump the rate of slump loss is not reduced. Using a water reducer to reduce the cement and water content of a concrete mixture while maintaining a constant water-cement ratio can result in equal or reduced compressive strength, can increase slump loss by a factor of two or more (Whiting & Dziedzic, 1992). However, they have no effect on bleeding.

c. Retarding admixtures

Retarding admixtures are used to delay the rate of setting of concrete. High temperatures of fresh concrete (30°C) are often the cause of an increased rate of hardening that makes placing and finishing difficult (Concrete portal, 2016). One of the most practical methods of counteracting this effect is to reduce the temperature of the concrete by cooling the mixing water and/or the aggregates. Retarders do not decrease the initial temperature of concrete. The bleeding rate and bleeding capacity of concrete is increased with retarders. They decrease slump loss and extend workability, especially prior to placement at elevated temperatures.

d. Plasticizers

Plasticizers, often called super plasticizers, are essentially high-range water reducers meeting ASTM C 1017; these admixtures are added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete.

e. Accelerating admixtures

An accelerating admixture is used to accelerate the rate of hydration (setting) and strength development of concrete at an early age (Concrete portal, 2016). Calcium chloride ($CaCl_2$) is the chemical most commonly used in accelerating admixtures, especially for non-reinforced concrete. Besides accelerating strength gain, calcium chloride causes an increase in drying shrinkage, potential reinforcement corrosion, discoloration (a darkening of concrete), and an increase in the potential for scaling.

f. Damp proofing Admixtures

Sound, dense concrete made with a water cement ratio of less than 0.50 by mass will be watertight if it is properly placed and cured (Hycrete, 2009). Common damp proofing agents include certain soaps, stearates, and petroleum products. They may, but generally do not reduce the permeability of concretes that have low cement contents, high water cement ratios, or a deficiency of fines in the aggregate. Their use in well-proportioned mixes may increase the mixing water required and actually result in increased rather than reduced permeability. However, they are not useful where concrete is under water pressure.

g. Bonding admixtures and bonding agents

Bonding admixtures are usually water emulsions of organic materials including rubber, polyvinyl chloride, polyvinyl acetate, acrylics, styrene butadiene copolymers, and other polymers (PCA, 2016). They are added to portland cement mixtures to increase the bond strength between old and new concrete. Flexural strength and resistance to chloride-ion ingress are also improved. They are added in proportions equivalent to 5% to 20% by mass of the cementing materials. Some bonding admixtures may increase the air content of mixtures (PCA, 2016). The surface to which they are used must be dry, clean, sound, free of dirt, dust, paint, and grease, and at the proper temperature.

h. Grouting admixtures

Portland cement grouts are used for a variety of purposes: to stabilize foundations, set machine bases, fill cracks and joints in concrete work, cement oil wells, fill cores of masonry walls, grout prestressing tendons and anchor bolts, and fill the voids in preplaced aggregate concrete (Landry et al., 2003). To alter the properties of grout for specific applications, various air-entraining admixtures, accelerators, retarders, and non-shrink admixtures are often used.

i. Gas-forming admixtures

Aluminum powder and other gas-forming materials are sometimes added to concrete and grout in very small quantities to cause a slight expansion of the mixture prior to hardening (Landry et al., 2003). This may be of benefit where the complete grouting of a confined space is essential, such as under machine bases or in post-tensioning ducts of prestressed concrete. The amount of expansion depends on the amount of material used, the temperature of the fresh mixture, the alkali content of the cement, and other variables.

j. Compatibility of admixtures and cementitious materials

Fresh concrete problems of varying severity are encountered due to cement-admixture incompatibility and incompatibility between admixtures. Slump loss, air loss, early stiffening, and other factors affecting fresh concrete properties can result from incompatibilities. These problems affect the long term strength too. Reliable test methods are not available to adequately address incompatibility issues due to variations in materials, mixing equipment, mixing time, and environmental factors (Helmuth, et al, 1995). Tests run in a laboratory do not reflect the conditions experienced by concrete in the field. When incompatibility is discovered in the field, a common solution is to simply change admixtures or cementing materials (Bhattacharja et al., 1997)

2.13 Ordinary portland cement (OPC)

Ordinary portland cement satisfying BS12:1991 and KS-18-1: 2000 of average strength 42,5N/mm^2 will be used for the concrete mix.

OPC is the most common type of cement in general use as a basic ingredient of concrete and mortar originating from limestone. It is a fine powder produced by heating materials in a kiln to form a clinker, and adding small amounts of other materials (Portland cement association, 2016).

Cement testing properties are specified in BS 4550. Performances of cement are subject to its fineness. (BS 4550: Part3). BS 4550: Part 3, gives requirement on setting time as not less than 45 minutes and not more than 10 hours for final setting and strength of hardened cement paste in terms of compressive strength on concrete cubes measured in 28 day of curing after casting of concrete.

2.14 Concrete mix design

In this process the correct proportions of cement, fine and coarse aggregate, glass aggregate, wood ash admixture and water will be determined, to produce the concrete having the desired workability and compressive strength by means of varying the quantity of admixtures added.

2.15 Design principles

Types of aggregates

The characteristics of aggregate particles that affect the properties of concrete are particle shape and surface texture. The particle shape affects the workability of the concrete and the surface texture affects the bond between the cement matrix and the aggregate particles and thus the strength of concrete.

- Aggregate grading

The designs of mixes will be based on specific grading curves of aggregates. The curves of fine aggregates must comply with grading zones of BS882:1992.

- Mix parameters

This approach requires the knowledge of expected density of fresh concrete which depends primarily on the relative density of the aggregate and the water content of the mix. This method results in quantification in terms of weight of the different materials required to produce finished concrete

The stages in mix design includes: - a) Selection of target water/cement ratio b) Selection of free-water content c) Determination of cement content d) Determination of total aggregate content e) Determination of percentages of replacement natural fine aggregates with glass aggregates f) Determination of wood ash admixture content as percentage of replacement (5-10% by weight of cement) and g) Mix proportioning

2.16 Batching of the concrete materials

There are two ways of batching aggregates: by weight or by volume. The weight method is however most common since it eliminates errors due to variations contained in a specific volume. Batching of the concrete materials was done by weight, following the mix design process. Inspection and calibration of the weighing equipment must be carried to ensure uniformity in mix.

2.17 Restrictions of blue gum (Eucalyptus species) in civil engineering

There is wide range of products from blue gum (eucalyptus species) such as firewood, charcoal, building materials, fencing posts, transmission poles, pulpwood, timber and plywood. As a result, the government promoted the planting of eucalyptus species, with the increasing demand for timber products, the government has further promoted and supported extensive growing of eucalyptus species which culminated in the introduction of high-yielding, shorter-rotation varieties through biotechnology between 1997 and 2003. Generally, planting of eucalyptus is not recommended in water scarce areas, riparian areas, wetlands and marshy areas. It should also not be planted near buildings, road reserves and on boundaries. (Kenya Forest Service, December 2009). In Toror and Tegat tea factories, they have adopted the use of blue gum, *Eucalyptus saligna*, for supplementing their energy. This type of eucalyptus species is commonly grown in Kericho and Kisii areas. (Kenya Forest Service, December 2009)

2.18 Research gap

Literature reviewed on concrete made with crushed glass and effects of concrete mixes made using ash, it was found that no research on contribution of waste blue gum ash as an admixture alongside crushed glass as fine aggregate in concrete. Also, the cost implications of the use of waste blue gum ash and crushed waste glass on concrete are unknown, hence this research project was aimed at bridging such knowledge gaps. The ash used was from blue gum, *Eucalyptus saligna*, commonly grown in Kericho and Kisii areas. (Kenya Forest Service, 2009).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Conceptual framework

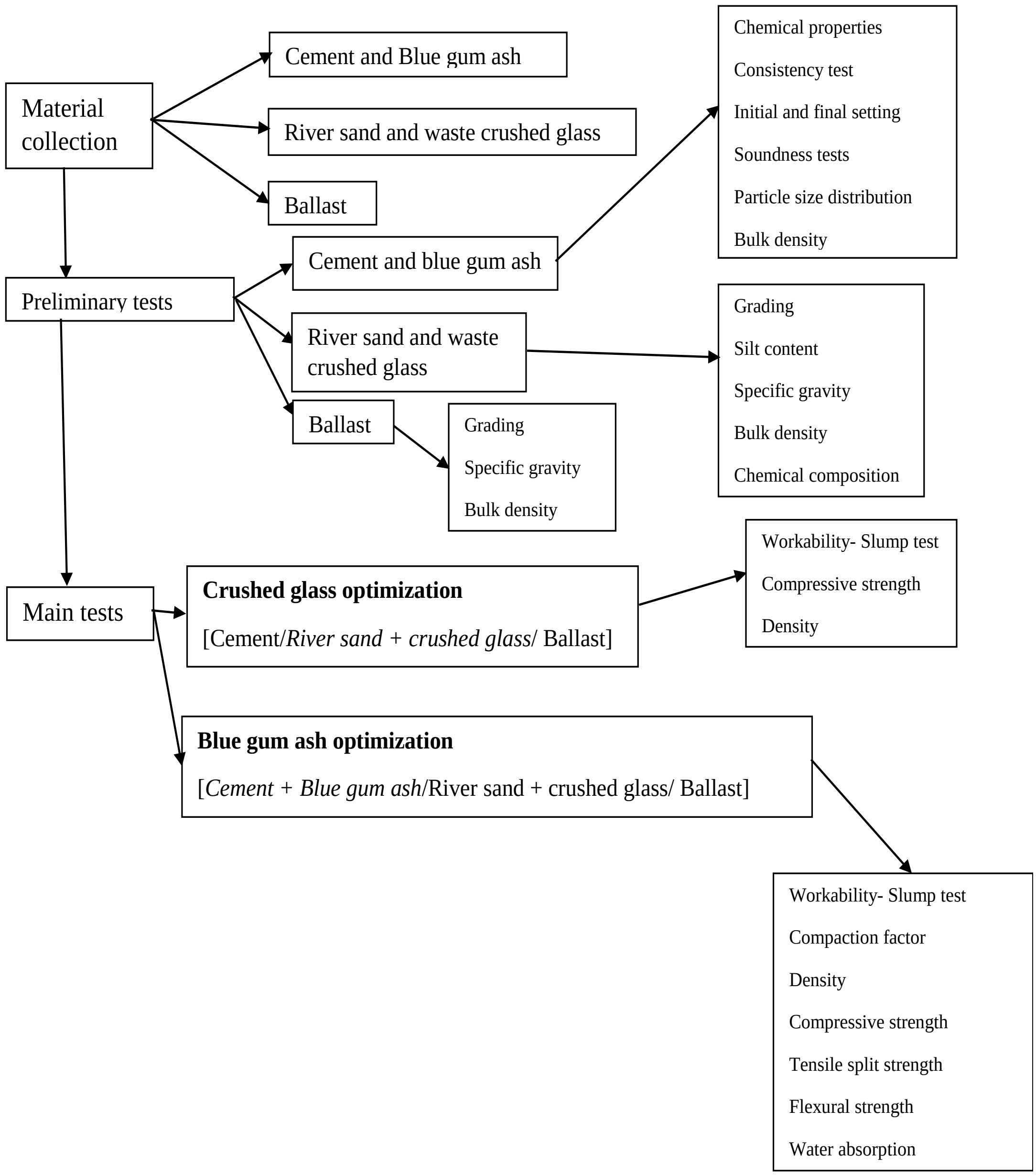

Figure 3.1: Conceptual framework

3.2 Materials, sampling and preparation

The study was carried out through experimental research approach, where laboratory experiments were conducted before coming up with feasible recommendations and conclusions, involving comparison between BS standards, control specimens of nominal concrete class 25 with only crushed waste glass as part fine aggregates and other specimens with wood ash as an admixture.

The materials that were used in the research included: - cement (power plus, 42,5N) - (binder), sand (fine aggregates), ballast (coarse aggregates), crushed waste glass (part of fine aggregates) and blue gum wood ash (admixture).

3.2.1 Cement and blue gum ash

Portland cement (Power Plus 42,5N) satisfying BS12:1991 and KS-18-1: 2000 of 28 days' strength; 42.5N/mm^2 was used. Wood ash from blue gum was obtained from Tegat and Toror tea factories in Kericho. Blue gum ash is a waste from boiler chimney, got from burning blue gum to produce steam in electricity generation process.

3.2.2 River sand and crushed waste glass

River sand and crushed waste glass were used as fine aggregate in the study. River sand was obtained from Machakos, while waste glass was sourced from a shop in Juja, crushed manually and reduced to 5mm grains and below as per BS882:1992. The type of glass which was used was clear float glass of 4mm thick which is visually colorless and distortion free glass, providing high light transmission (daylight) and clarity. The crushed glass was used as partial replacement material for river sand.

3.2.3 Coarse Aggregate (ballast)

The coarse aggregates were obtained from Aristocrats concrete limited quarry in Mlolongo which controls its ballast source due to consistency quality of its products. The ballast consisted of crushed stone mixed in a ratio of 1:2 for 10mm: 20mm single aggregate size in accordance with building research establishment (BRE) (1988).

3.3 Physical properties of river sand, crushed glass, ballast and blue gum ash

3.3.1 Particle size distribution

Particle size distributions for river sand, ballast and crushed waste glass aggregates were carried out by dividing up and separating by means of a series of test sieves. This helped in determining the particle size distribution of specified aggregates and enabled the plotting of the grading curves for the various aggregates specified.

Grading limits for each size of coarse and fine aggregate are set out in BS882:1983, (Specification for aggregates from natural sources for concrete).

3.3.2 Silt content of river sand and crushed glass

The objective of this test was to determine the cleanliness of the river sand and crushed glass. The silt content test was done in accordance with the BS 812 (1990). A solution of sodium of chloride was prepared, about two tea spoonsful of salt was added to 1 litre of water (1% solution). 50 ml of this solution was poured into 250 ml measuring cylinder and the river sand or crushed glass was added gradually until the volume was 100ml, then the volume was made up to 150ml by addition of more salt solution. The mixture was shaken vigorously until adherent silt particle had been dispersed, and then cylinder was placed on a level bench and it was gently tapped until the surface of aggregate was level.

3.3.3 Specific gravity of ballast, river sand and crushed glass

The test was carried out according to BS 812-2 (1990) to determine the specific gravity of ballast, river sand and crushed glass. For each material, the sample was washed and transferred to the tray and the water was added to ensure that the sample was completely immersed. After immersion, bubbles were removed of entrapped air by gentle agitation with a rod. The sample was kept immersed in water for 24 hours. After that the water from the sample was drained by decantation through a 0.075mm test sieve. Then the saturated and surface dry sample was weighed. The sample was placed in the pycnometer and it was filled with water. The cone into place was screwed and any trapped air was eliminated by rotating on its sides. The bottle on the outside was dried and it was weighed. The sample into the tray had been empty; the pycnometer was refilled with water to the same level as before. It was dried on the outside and weighed. The water from the sample was drained by decantation. The sample was dried at a temperature of 105° C for 24 hours, during which period it was stirred occasionally to facilitate drying. The sample was cooled by air and weighed.

3.3.4 Bulk density of ballast, river sand, crushed glass

The bulk density test was carried out according to BS 812-2 (1990). The volume of the cylindrical metal was measured by pouring water into the metal measure and recording the volume in m^3. The cylindrical measure was filled to overflowing by means of a scoop with the aggregate being discharged from a height not exceeding 5 cm above the top of the measure. Levelling the top surface of the aggregate was done in the metal measure, with a straightedge or tamping bar. The weight of the aggregate in the measure was determined and recorded in kilograms.

3.4 Physical and chemical properties of blue gum ash cement

3.5.1 Chemical properties of blue gum ash cement

This was done to determine the chemical composition of the different samples of blue gum ash cement based on BS 812: 1992. The blue gum ash cement was prepared by dosing cement (Power plus 42,5N) with blue gum ash by 0, 0.5, 0.75, 1.0, 1.25 and 1.5% by weight of cement. The exercise was conducted using XRF technology (X-Ray florescence spectral analysis) in the ministry of mining, Mines and geological department, Nairobi.

3.5.2Consistency of blue gum ash cement

The standard consistency of a cement paste is defined as that consistency which permits the vicat plunger to penetrate to a point 5 to 7mm from the bottom of the vicat mould. The standard procedure as stipulated in IS:4031 (Part 4) 1988 was followed. The apparatus required were; Vicat apparatus conforming to IS: 5513:1976, weighing balance and a trowel. 1200g of cement and 300g of blue gum ash was also required to enable four runs of the experiment. The blue gum ash cement was prepared by dosing cement (Power plus 42,5N) with blue gum ash by 0, 0.5, 0.75, 1.0, 1.25 and 1.5% by weight of cement. A total of five samples were prepared and four runs per sample were done to get the amount of water which made the paste per mix to resist the 10mm needle of the vicat apparatus to penetrate to the bottom of the mould base as shown in Figure 3.1. The consistency cement paste was expressed as a percentage by weight of dry cement and is usually this percentage varies from 26 to 33%.

Figure 3.1: Experimental set up for consistency and setting time for blue gum ash cement

3.5.2 Initial and final setting time for blue gum ash cement

Once the consistency tests of the various replacements are obtained, the results were used to determine the initial and final setting times of the blue gum ash cement as per the standard procedure as stipulated in IS: 4031 (Part 5) 1988 where by the initial setting time was that time period between the time water was added to cement and time at which 1 mm square section needle failed to penetrate the cement paste, placed in the vicat's mould 5 to 7 mm from the bottom of the mould. Final setting time was that time period between the time water was added to cement and the time at which 1 mm needle made an impression on the paste in the mould but 5 mm attachment did not make any impression. The required apparatus were weighing balance, vicat apparatus, stop watch and measuring cylinder.

3.5.3 Soundness test for blue gum ash cement

Soundness of cement refers to the ability of a hardened cement paste to retain its volume after setting without delayed expansion. This expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). The test was carried according to IS: 4031-3-1988 whereby a cylinder (which is open on both ends) was placed on a glass plate filled with cement paste of normal consistency (pre-determined earlier in consistency test), and covered with another glass plate.

The whole assembly, as shown in Figure 3.2, was then immersed in water at 20 ± 1^{o} C for 24 hours. At the end of that period the distance between the indicator points was measured. The mould was then immersed in water again and brought to a boil. After boiling for one hour the mould was removed from the water. After cooling, the distance between the indicator points was measured again and the soundness calculated using Equation 3.1: -

Soundness (expansion of cement) = L_1-L_2 ……………Equation 3.1

L_1=Measurement taken after 24 hours of immersion in water at a temperature of 27 $\pm 2^{o}$ C

L_2=Measurement taken after 3 hours of immersion in water at boiling temperature.

Calculate the mean of two values to the nearest 0.5 mm.

The increase represented the expansion of the cement paste dosed with blue gum ash at 1% proportion by weight as achieved from the consistency test results. The expansion according to the IS: 8112-1989 standard is limited to 10mm for OPC 42,5N.

Figure 3.2: Experimental set up for soundness of blue gum ash cement

3.6 Evaluating the effect of blue gum ash on properties of concrete with crushed waste glass as partial fine aggregate

3.6.1 Design mix for blue gum ash glass concrete

The design mix was done according to BS Department of Environment (DOE) method and the results are as shown in Table 13 in the appendix. The individual ingredients of concrete were mixed in the ratio of 1:1.5:3 for binder: fine aggregate: coarse aggregate. The summary of the percentages of the materials used in the concrete are as shown in Table 3.1: -

Table 3.1: Percentage of binder, fine aggregates and coarse aggregates

	Binder		Fine aggregate		Coarse aggregate
Mix type	Cement	Blue gum ash (%)	Sand (%)	Glass (%)	Ballast (%)
GCBGA 25-0.0	100	0	100	0	100
GCBGA 25-0.5	100	0.5	90	10	100
GCBGA 25-0.75	100	0.75	90	10	100
GCBGA 25-1	100	1	90	10	100
GCBGA 25-1.25	100	1.25	90	10	100
GCBGA 25-1.5	100	1.5	90	10	100

3.6.2 Workability test for blue gum ash glass concrete

A slump test was done according to BS EN 12350-2:2009, whereby the mould used for the slump test was frustum of a cone, 300 mm of height. The base was 200 mm in diameter and it had a smaller opening at the top of 100 mm. The base was placed on a smooth surface and the container was filled with concrete in three layers, whose workability was being tested. Each layer was temped 25 times with a standard 16 mm diameter steel rod, rounded at the end. When the mould was completely filled with concrete, the top surface was struck off (levelled with mould top opening) by means of screening and rolling motion of the temping rod. During the whole process of concrete filling, the mould was firmly held against its base so that it could not move due to the pouring of concrete. Immediately after filling was completed and the concrete was leveled, the cone was slowly and carefully lifted vertically for the slump to form as shown in Figure 3.3.

Figure 3.3: Slump test

The compaction factor test was carried out according to BS 1881: Part 103 to measure the degree of workability of fresh concrete with regard to the internal energy required for compacting the concrete thoroughly as shown in Figure 3.4 (a) and (b). The upper hopper was filled by pouring the concrete sample in it. The hinged door at the lower end of the upper hopper was opened allowing the concrete to fall into the lower hopper. Immediately the gate at the bottom of the lower hopper was opened to allow the concrete to fall into the cylindrical mould. The excess concrete above the top level of the mould was removed by using a trowel. The weight of the cylindrical mould with concrete (partially compacted concrete) was taken and the weight of the concrete measured (W_1). Each layer of the concrete was fully compacted using mechanical vibrator. The weight of the cylinder with concrete (fully compacted concrete) was taken and the weight of the concrete measured (W_2). The compaction factor was calculated by dividing the weight of partially compacted concrete (W_1) by the weight of fully compacted concrete (W_2).

Figure 3.4: (a) Compaction factor test (b) Weighing of the sample

3.6.3 Compressive strength

The main objective of this experiment was to determine the strength of the hardened glass concrete containing blue gum ash. It was done in accordance to BS EN: 12390: 2000, whereby samples containing different proportions of crushed glass and blue gum ash cement were prepared and casted in moulds of internal dimensions of 150x150x150mm. Then the compressive strengths at 7, 14, 21, 28, 60 and 90 days were determined by crushing the samples in a universal testing machine as shown in Figure 3.5. For each proportion, three cubes were casted and the average taken.

Figure 3.5: Compressive strength test

3.6.4 Tensile split test

Tensile split test was carried out to determine the tensile strength of concrete in an indirect way as shown in Figure 3.6. A standard test cylinder of concrete specimen of 200 mm X 100mm was prepared for the various percentages of replacements of cement with blue gum ash in crushed glass concrete at 0.5, 0.75, 1, 1.25, and 1.5%. For each replacement, three cylinders were casted, cured and tested according to BS EN: 12390: 2009. The average tensile split strength was taken for 7 and 28 days. Concrete cylinders split into two halves along vertical plane due to indirect tensile stress generated by Poisson's effect.

Figure 3.6: Cylinder split test

3.6.5 Flexural test

This test carried out to determine the flexural strength of concrete according to BS EN: 12390: 2009. The samples were prepared for the various percentages of replacement of blue gum ash with cement in crushed glass concrete and conducting three runs per replacement, then testing at 7 and 28 days after curing. Beams of dimensions 150x150x450mm were prepared and tested as shown in Figure 3.7 using three point flexural test method whereby the beam specimen was placed between two supports and load applied at the centre until failure using a universal testing machine.

Figure 3.7: Flexural test

3.6.6 Water absorption test of blue gum ash glass concrete

Cracking of concrete, which may be induced by several mechanisms, such as shrinkage, thermal effect, and loading, plays an important role in the deterioration of reinforced concrete structures because they provide additional pathways for water and aggressive agents, for example, chlorides, to penetrate into concrete. To well understand the transport properties of cracked/damaged concrete is essential for predicting its long-term durability. In general, water acts as the medium for agents to move into concrete, and water penetration by capillary absorption is more common for the real concrete structures since concrete is rarely saturated. As a result, absorption of water is regarded as the dominant factor for the ingress of aggressive substances (Shi, Xie, Fortune, & Gong, 2012).

The coefficient of permeability is the material characteristic describing the permeation of gases or liquids through a porous material due to a pressure head (Hilsdorf & Kropp, 1995). Several studies have shown that there is no universally accepted standard method for measuring permeability properties of concrete, the ASTM C 1202-97 is used, which is based on chloride ion diffusion.

To determine the water absorption of blue gum ash glass concrete as per BS 1881: Part 122: 1983, standard cubes of 150mm X 150mm X 150mm were casted and after demoulding, they were weighed and immersed in water. Their weights were taken after 7, 14, 28, 60 and 90 days. The measured absorption of each specimen was calculated as the increase in mass resulting from immersion expressed as a percentage of the mass of the dry specimen.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Physical and chemical properties of river sand and crushed glass

4.1.1 Physical properties of river sand and crushed glass

The grading curve for the river sand is as shown in Figure 4.1 and the grading results for river sand are as shown in Table 1 in the Appendix. The results show that, river sand grading curve was lying between the upper and lower limit implying that it was within the required limits as given in BS812:103-1. (1985), hence they were recommended for use in the study.

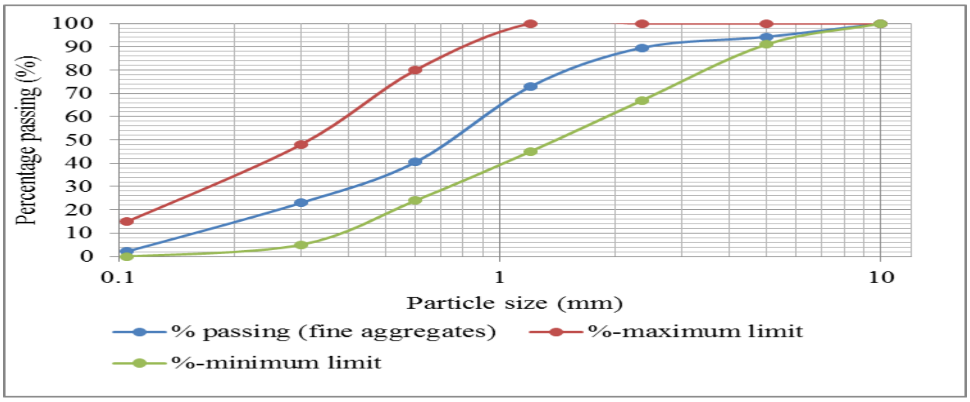

Figure 4.1: Fine aggregates grading

Figure 4.2 shows the grading curve for crushed glass and the results are shown in Table 4.2 in the Appendix.

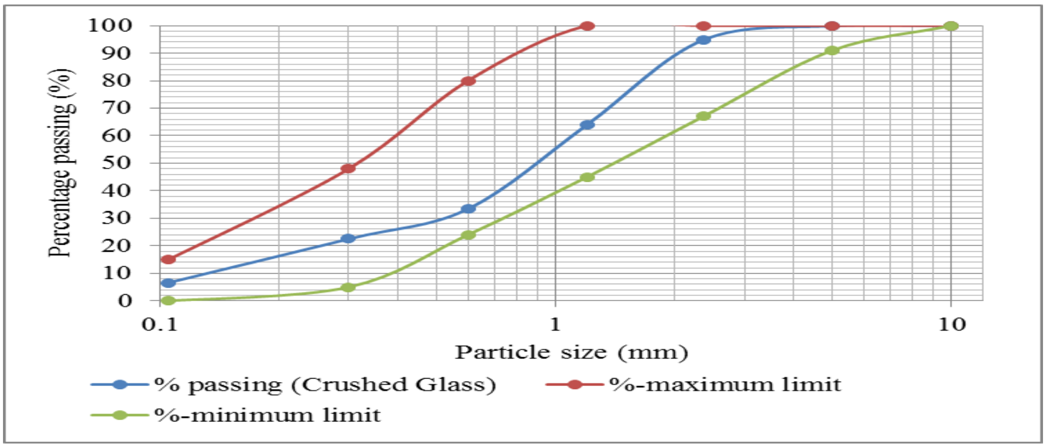

Figure 4.2: Crushed glass grading

These results show that the crushed glass grading curve was lying between the upper and lower limit implying that it was within the required limits as given in BS812:103-1. (1985), hence they were recommended for use in the research work. It was also observed from the grading curves that glass had uneven particle size distribution.

For comparison between grading for river sand and crushed glass, Figure 4.3 was used to show the similarities between the two materials for the study. From the results, crushed glass and river sand grading curves behaved in a similar manner for their individual particle size distribution. River sand was found to have more particles passing through 600µm than crushed glass. Also, the material passing sieve 150µm was more in glass at 12% compared to sand at 8%. This explained the difference in curve formation between the two materials for fine aggregates but generally the materials were suitable for use in the study.

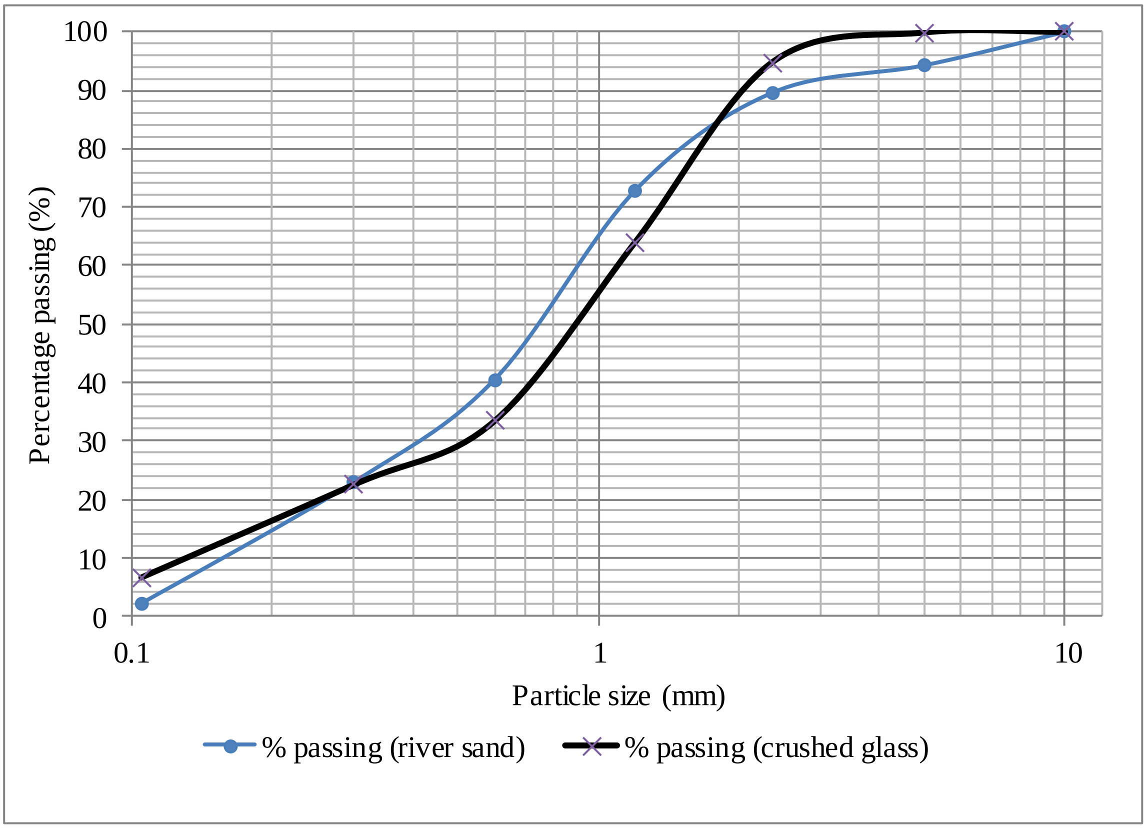

Figure 4.3: Fine aggregates grading

The grading curve for the coarse aggregates is as shown in Figure 4.4 and the results are as shown in Table 4.3 in the Appendix. From the aggregate curves in Figure 4.4 for coarse aggregates, most of the aggregates were found to lie within zone 2 and were within the required limits as given in BS812:103-1. (1985), hence they were recommended for use in the study.

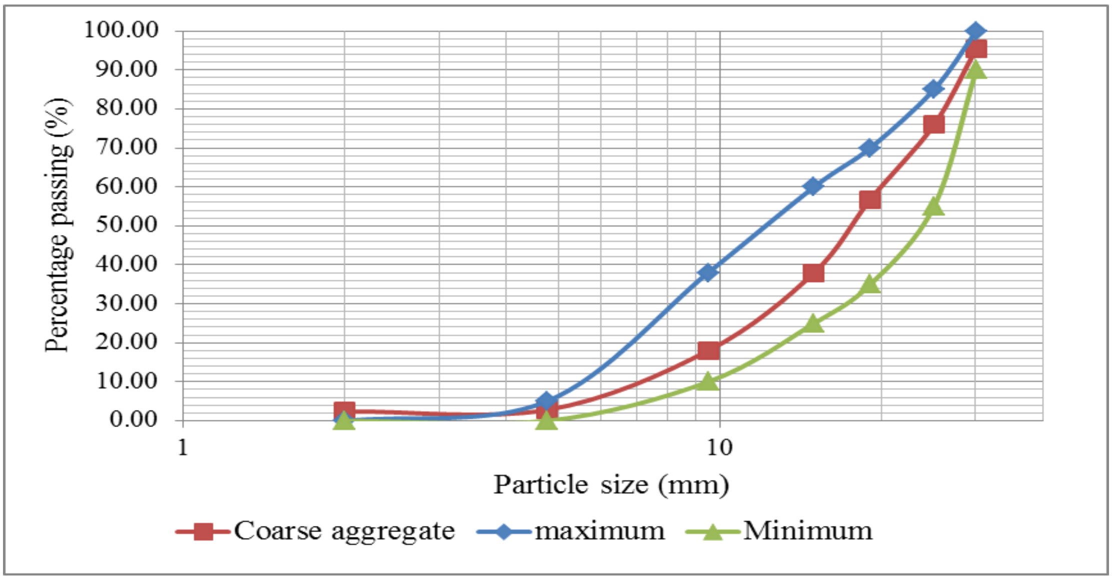

Figure 4.4: Coarse aggregates grading

The results for the specific gravity of river sand and crushed glass were found to be 2.5 and 2.4, respectively. The specific gravity of sand was found to be not within the range of 2.63 and 2.70 as per BS1097-6. (2013); but also, the specific gravity of sand provided by Firm.net (2017) are a minimum of 2.4 and a maximum of 2.8 thus the test result was found to be credible for use in this research.

The bulk density results for ballast, river sand and crushed glass were 1405, 1563 and 1414kg/m^3 respectively. According to BS 812-2 (1990), the approximate bulk density of aggregates commonly used in normal-weight concrete ranges from about 1200 to 1750 kg/m^3.

The silt content results of river sand and crushed glass were found to be 2.2 and 5.6% respectively. It is recommended to wash the sand or reject if the silt content exceeds a value of 6% (BS 812: Part 1: 1975), hence the results were satisfactory within the limit required.

4.1.2 Chemical composition of river sand, crushed glass, blue gum ash and cement

From the chemical composition test results in Table 4.1, important elements were found in the samples. From the results, it was found that chemicals that formed the highest percentages in blue gum ash were CaO (67.5%), K_2O (15.5%), MgO (9.0%) and P_2O_5 (3.8%). According to (M. S. Shetty, 2015), Class C fly ash contains more than 20% CaO (Lime). This supports the blue gum ash used in this research which has a higher CaO of 67.5%. From (Mamlouk & Zaniewski, 1999) K_2O forms between 0.4 to 1.3% by weight in ordinary portland cement used for concrete works thus the percentage achieved from the test here shows that the ash had enough K_2O (15.5%) as shown in Table 4.2.

Table 4.1: Main chemical composition of blue gum ash, cement and crushed glass

S/No.	Sample name	Magnesium Oxide – MgO	Aluminium Oxide (Alumina)-Al_2O_3	Silicon Dioxide (Silica)-SiO_2	Phosphorus Oxide-P_2O_5	Potassium Oxide-K_2O	Calcium Oxide - CaO
1	Crushed glass	2.3	1	83.2	0.1	0.5	12
2	Blue gum ash	9	0.1	0	3.8	15.5	67.5
3	Power plus cement (42,5) N	0.6	4.7	18	0	0.51	60

Table 4.2: Proportion of elements in the blue gum ash versus class F fly ash

Constituents	% Composition of typical pozzolanic class F fly ash	% Composition in the blue gum ash	Remarks
CaO	7.8-9.0	67.50	Sufficient
MgO	10.38-18.4	8.96	Slightly below but adequate for research
P_2O_5	0.43-7.64	3.79	Sufficient
K_2O	12.3-28.1	15.50	Sufficient
SiO_2	55-57	0.00	Inadequate
Fe	0.85-2.03	1.91	Adequate

The glass chemical test results revealed that; glass had CaO (12.0%) and SiO_2 (83.2%). The proportion of SiO_2 in glass and power plus cement in the experiment supplements the absence of SiO_2 in blue gum ash. These values are suitable for the required strength of concrete to be achieved at 28 days when curing is done appropriately in the laboratory as shown in Table 4.3. These contents from the laboratory test were sufficient for improving concrete workability and reducing bleeding and segregation (M. S. Shetty, 2015)

Table 4.3: Percentages of elements present in the soda-lime glass versus crushed glass

Constituents	% Composition in soda-lime glass	% Composition in the crushed glass	Remarks
CaO	9.1-9.8	12.043	Sufficient
MgO	1.1-1.7	2.278	Adequate for research
K_2O	0.55-0.68	0.456	Slightly low but can be used for the research
SiO_2	70-73	83.157	Sufficient
Fe_2O_3	0.60-2.40	0.990	Adequate

From Table 4.3, the chemical composition of crushed glass was within the acceptable limits of soda lime glass, hence making it a suitable material for use in the study.

4.2 Physical properties of blue gum ash and cement

4.2.1 Particle size distribution and bulk density of blue gum ash and cement

The particle size distribution of cement is shown in Table 4 and blue gum ashes from Tegat and Toror tea factories are as shown in Table 5 in the Appendix. From the hydrometer test results for both cement and blue gum ashes, it was found that the results were clayey silt; implying that the contents contained mostly silt contents. It was observed that clayey silt contents were evident from particle size distributions of cement (power plus, 42,5N) as shown in Figure 4.5.

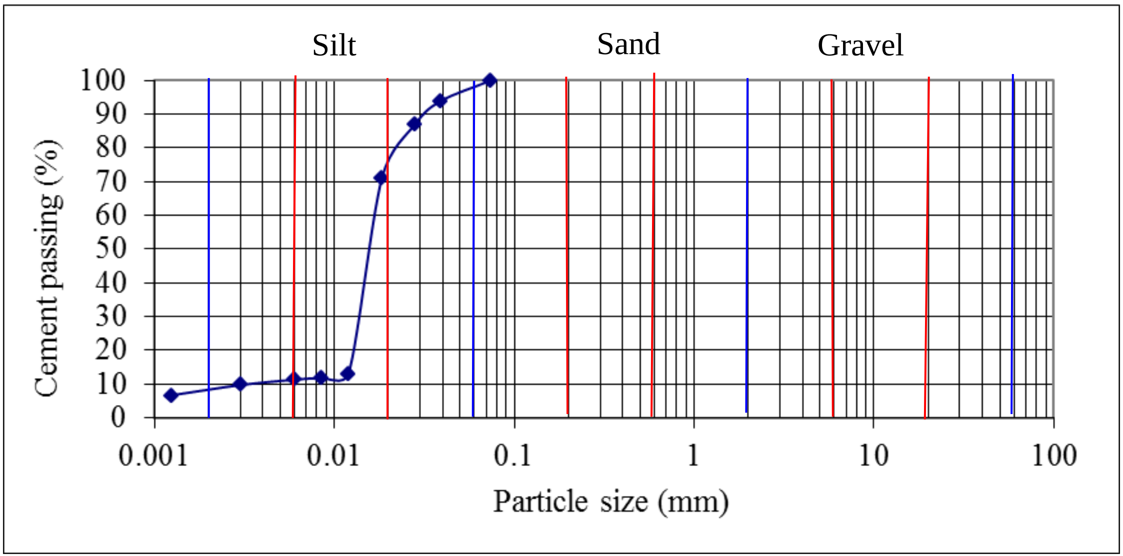

Figure 4.5: Particle size distribution for cement (Power plus 42,5N)

It was also observed that clayey silt contents were evident from particle size distributions of blue gum ashes from Tegat and Toror tea factories as shown in Figure 4.6.

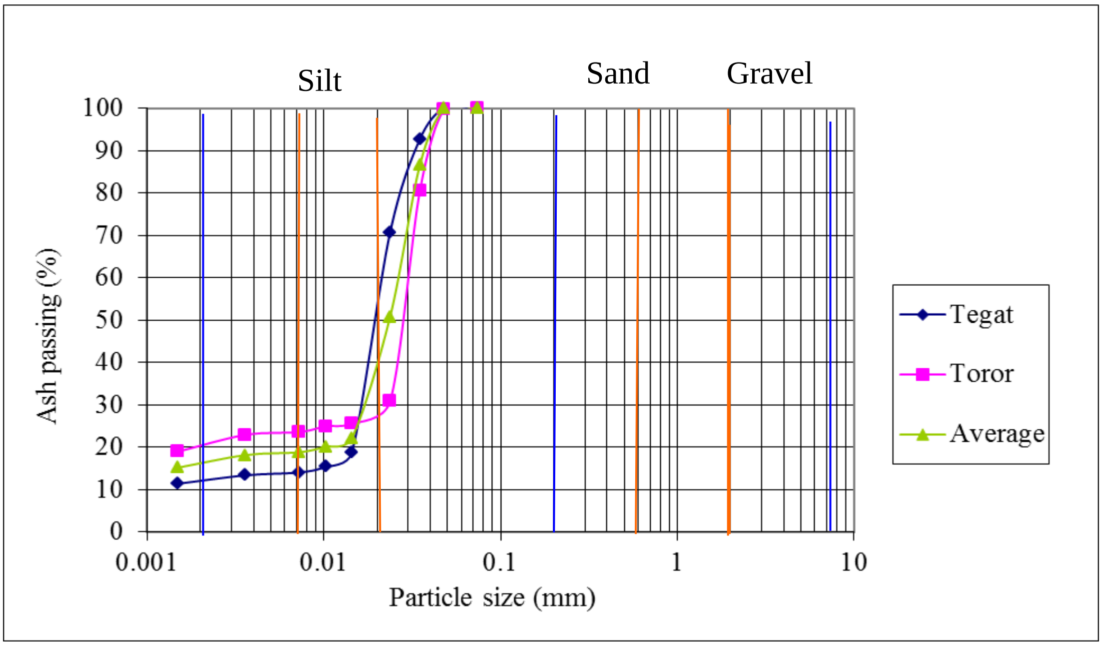

Figure 4.6: Particle size distribution for blue gum ashes

The results in Figures 4.5 and 4.6 show that the curves for both cement and blue gum ashes seem to have the same trend. The same is depicted in the combined grading curves of cement and average of Toror and Tegat blue gum ashes in Figure 4.7.

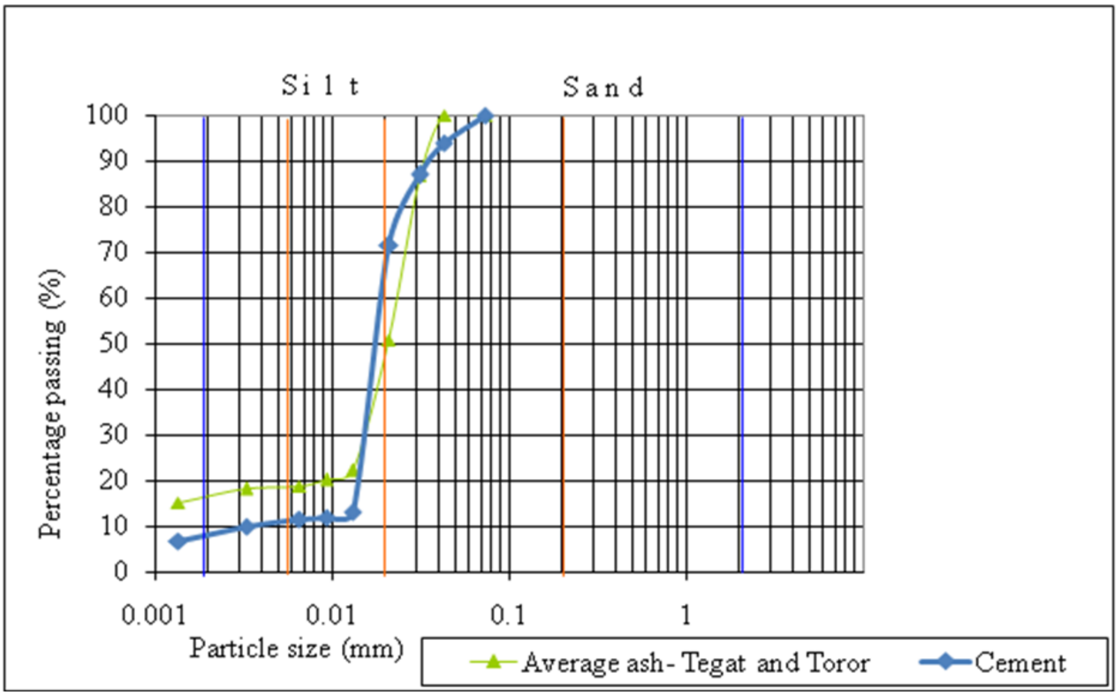

Figure 4.7: Particle size distribution curves for cement and average blue gum ashes from Toror and Tegat

The dense particle size distribution of cement was lying within 15 to 70% of the grading range for particle sizes ranging from 12 to 18.4µm, respectively. The implication of this range shows that the finer the size of the particle, the faster it undergoes hydration and the faster it will set. However, since there are more particle-to-particle bridges that need to be built to form a percolated pathway in finer cement particles, the more hydration it requires hence higher water cement ratio. Cement with finer particles has faster strength development than the one with coarser particles, (Bentz et al 1990). Most of the particle size distributions of the ashes were within 30 to 80%, of the grading range for particle sizes ranging from 14.4 to 34.9µm, respectively. The implication was that, the smaller the size of the ash particle, the more water content is required and also, the strength gain is faster, (BS 1377 part 120). This means that the highest particle size distribution of blue gum ash was within the range of the particle size distribution of cement used (Power plus 42,5N) hence; the ashes were suitable material to use with cement because of the similarity in particle size distribution.

The result for the bulk density of blue gum ash was found to be 798kg/m^3, while the bulk density of power plus 42,5N cement has been found to range between 800 – 1000kg/m^3 so it was approximately within the range hence suitable admixture material.

4.2.2 Consistency of blue gum ash and cement

Table 4.4 shows the consistency of blue gum ash cement. The consistency was calculated as a percentage of the dry weight of the blue gum ash cement.

Table 4.4: Consistency of blue gum ash cement

S/No.	% of blue gum ash in cement	Water content (ml)	Plunger resistance(mm)	Consistency (mm)
1	0	153	6	38.25
2	0.5	155	6	38.75
3	0.75	158	5	39.5
4	1.0	160.8	6	40.2
5	1.25	160	6	40
6	1.5	152	5	38

From results, the consistency increased as the amount of blue gum ash content increased in the mix sample up to 1% blue gum ash composition in cement as shown in Figure 4.8. Even though, the required consistency varies from 26 to 33% (IS 1489-1: 1991), the samples never fell within the range.

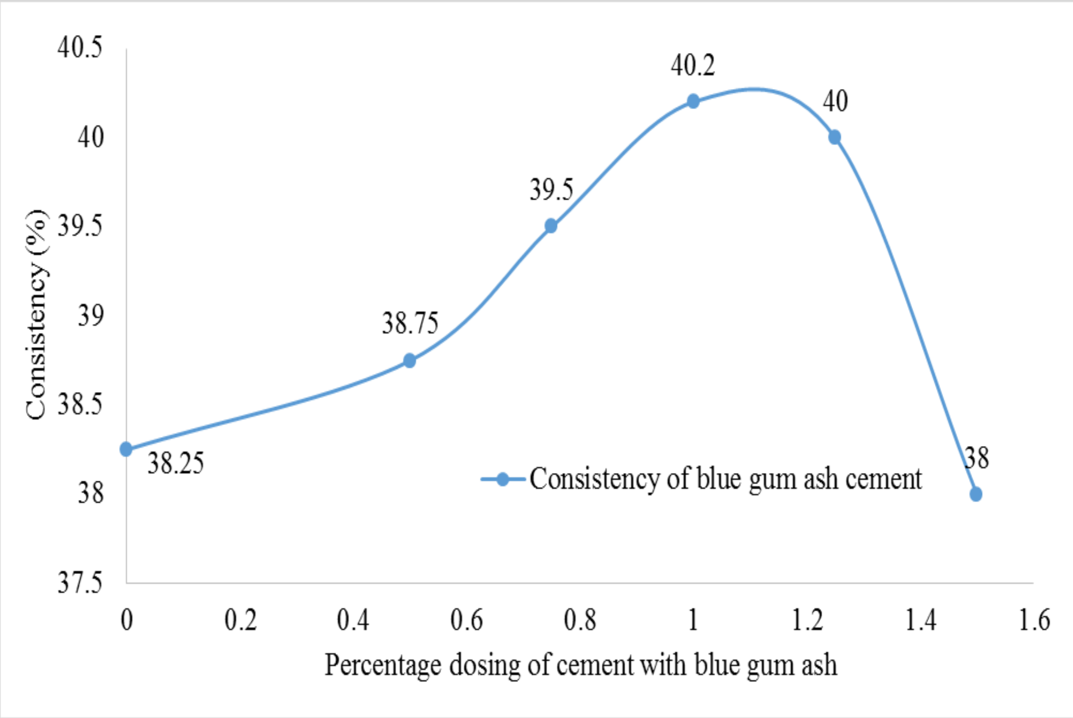

Figure 4.8: Consistency of blue gum ash cement

This is explained by the fact that, by adding blue gum ash to Power plus cement 42,5N, has the effect of increasing the amount of water required to achieve the required consistency. Hence the more the amount of blue gum ash in cement, the higher the amount of water required to achieve a certain consistency. This explains the phenomenon that, the strength of the final concrete is reduced due to the possibility of delayed setting time and delayed strength gain. In this study, the consistency of the blue gum ash cement was found to be 40.2 for up to 1.0% blue gum ash dosage in cement (Power plus cement 42,5N).

4.2.3 Initial and final setting times of blue gum ash and cement

Table 10 in Appendix shows the average initial and final setting times for blue gum ash cement. This was done after the consistency test had been done to determine the amount of water to give the required consistency per mix.

For the initial setting time, four runs in two separate sets of vicat apparatus of the experiment were carried out to determine the initial setting time of each mix of blue gum ash cement. The observed initial setting time for the four runs per vicat apparatus was recorded and the mean initial setting time for the two vicat apparatus was calculated and tabulated in Table 10 in the Appendix.

From the results, the initial setting time increased as the amount of blue gum ash proportion increased in cement. Also, the final setting time decreased as the blue gum ash content in the cement increased. Both, the initial and final setting times, as shown in Figure 4.9, complied with British and European Standard (BS EN 196–3) which requires that the initial setting time shall be not less than 2 hours, and the final setting time not more than 8 hours.

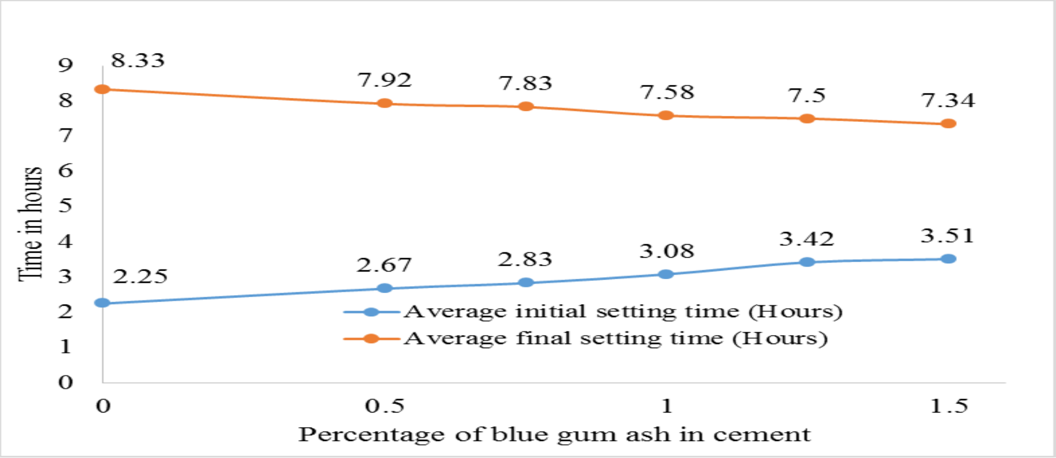

Figure 4.9: Setting time of blue gum ash cement

This result shows that if the amount of blue gum ash in cement is increased, then there is a probability that there might be some convergence of both the average initial and final setting times. However, this research did not explore further increase in the percentage of blue gum ash in cement up to the convergence point. Hence, blue gum ash behaves as an accelerator, as the more the content in cement, the less the time it takes before it finally sets. This can be explained by the fact that most of the water had been used in the initial strength development stages; hence finally, the setting was reduced by less water available.

The presence of calcium oxide (CaO) reacts with free silicon dioxide (SiO_2) in power plus cement (42.5N); which is absent in blue gum ash; to form calcium silicate compounds (C_3S- Tri-calcium silicate and C_2S- Di-calcium silicate) which are responsible for early strength developments, hence, fastening the reaction time at initial stages. This reduces the initial setting time at initial stages. As more of cement is replaced with blue gum ash, calcium oxide starts depleting available silicon dioxide. This results in slowed reaction hence increases final setting time. From the specifications of power plus (42.5N), this type of cement is characterised by early strength development as given in its manufacturer's brochures. Hence, the addition of the blue gum ash does not interfere with the properties of the original cement, power plus (42.5N).

4.2.4 Soundness test of blue gum ash cement

The soundness test results for; power plus (42,5N) cement dosed with 1% blue gum ash, (based on the optimum blue gum dosage as per the consistency test results) and pure power plus cement 42,5N which is the control experiment; are as shown in Tables 11 and 12 in the Appendix.

From the results, it can be seen that the average soundness for power plus, 42,5N cement dosed with 1% blue gum ash was 0.4mm and for the control experiment (power plus cement, 42,5N without blue gum ash) was 0.07mm. From IS 8112-1989, the maximum allowed soundness is 10mm. Hence, from the results, the mixture which gave good consistency; blue gum ash cement with 1% blue gum ash dosage- had far much low soundness than the maximum allowed. This means the mixture had less free calcium oxide (CaO) and magnesium oxide (MgO) which if in excess, they can slowly hydrate and cause expansion of the hardened cement paste.

4.3 Effect of crushed glass as a partial replacement of fine aggregate in concrete

In the glass optimization, GC XX-YY axis means: GC glass concrete, XX class of concrete (25 N/mm^2) and YY percentage of glass in fine aggregate. Also 25GCBGA XX-YY means: 25 is the class of concrete 25N/mm^2, GCBGA is glass concrete containing blue gum ash, XX means percentage of glass in fine aggregate and YY means percentage dosage of blue gum ash.

4.3.1 Compressive strength of glass concrete

The results of glass optimization whereby glass was used as partial replacement of fine aggregates are shown in Table 13 in the Appendix.

The control mixes (GC 25-00) without glass had higher compressive strength for 7, 14, 21 and 28 days as shown in Figure 4.10.

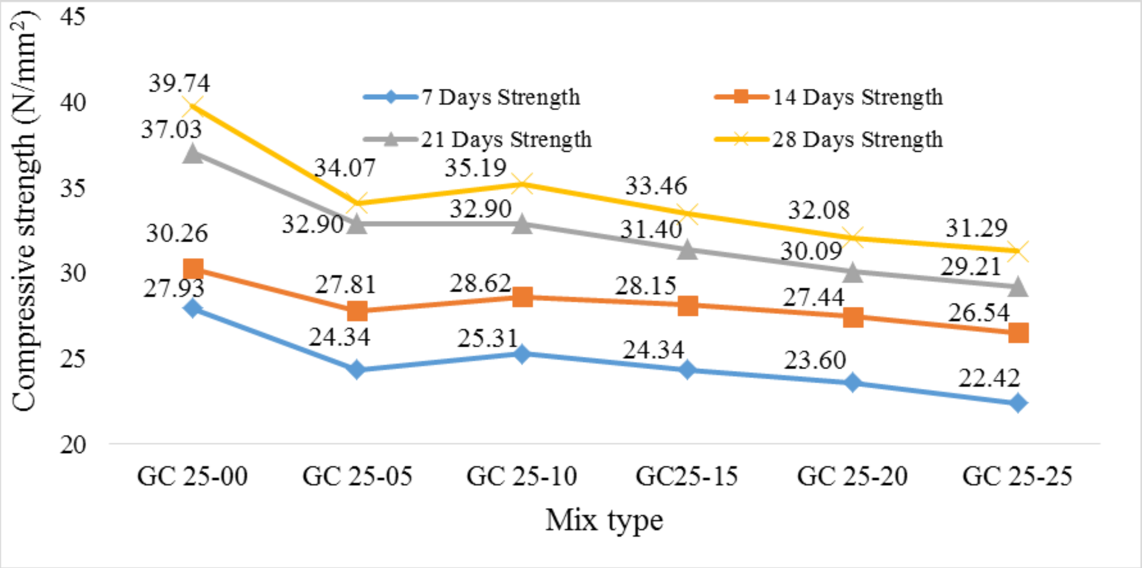

Figure 4.10: Compressive strength variations of glass concrete

From the results, the addition of crushed glass can be seen to be reducing the strength of concrete by comparing the results of mix type GC 25-00 (Control experiment without crushed glass) and other mixes containing up to 25% of crushed glass by weight. However, it can be seen that the best percentage of glass replacement in fine aggregate is 10% giving us strengths of up to 35.19 N/mm^2 in 28 days which is far higher than the design strength of 25 N/mm$^{2.}$ Addition of glass up to 10% is seen to positively influence the strength development of the concrete past which, the excess crushed glass starts absorbing the essential water required for the hydration process of the concrete because of the excess fines present in crushed glass as seen in the grading curve in Figure 4.3. Thereafter, 10% glass proportion of fine aggregate; the strength is seen to start reducing as this excess crushed glass starts behaving as a deleterious material to the concrete as its saturation point in the concrete has been surpassed. Also, the non-crystalline and amorphous nature of glass also plays part as past the 10% composition in fine aggregates, the concrete cannot sustain extra load as it will be subject to crushing because of the presence of the excess crushed glass.

4.3.2 Density variations of glass concrete

The density variation of the control mixes and the various mixes of blue gum ash glass concrete are as shown in Table 14 in the appendix and the graphical presentation is as shown in Figure 4.11.

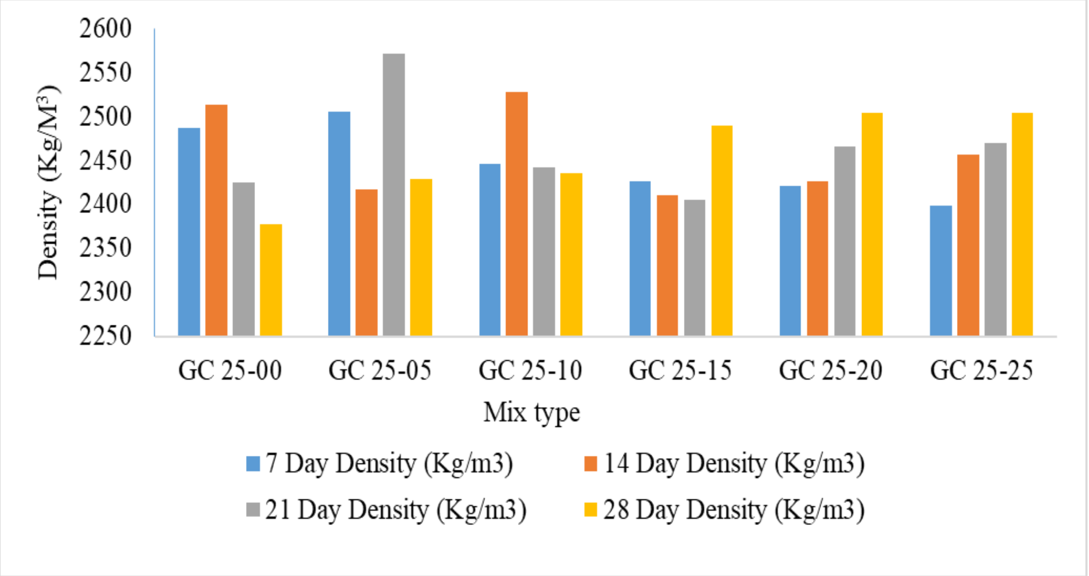

Figure 4.11: Density variations of glass concrete

From the density variations results, glass has lower bulk density (1414kg/m^3) than river sand (1563kg/m^3). For 7, 14 and 21 days, the density of concrete is seen to reduce on average with addition of crushed glass. This is from the test results of bulk density, that, glass is lighter than river sand. Also, the manual mixing employed could have brought unequal glass distribution and compaction rates in the mix which could also have contributed to the irregular density variations.

4.3.3 Workability tests of glass concrete

The variations in the water content to get the targeted slump of between 30-60mm for the various mixes was done in accordance to BS 12350(2009). Concrete mix of 1:1.5:3 representing; binder: fine aggregate: coarse aggregate respectively was used. In this mix, crushed glass was used to replace the fine aggregates in the proportions of 0 (control), 5, 10, 15, 20and 25% by weight of river sand. The binder and the coarse aggregates were not replaced. Table 15 in the Appendix shows the resulting slump obtained.

From Figure 4.12, it is observed that the slump increased with increase in the crushed glass content in concrete. For the selected mix type (GC 25-10), the approximate slump was found to be 45mm which was within the range of 30-60mm for vibrated concrete, hence the one used for the experiment.

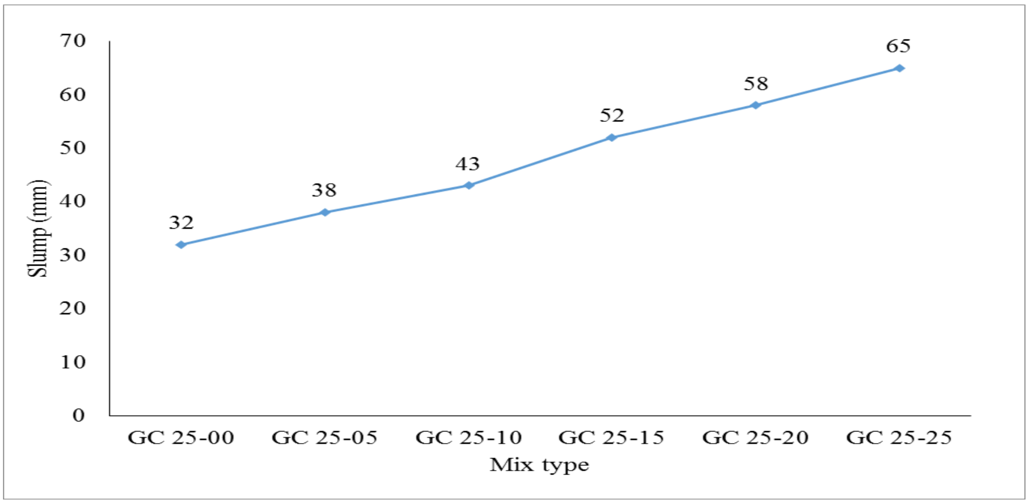

Figure 4.12: Slump variations of glass concrete

From the results, the higher the crushed glass content in the concrete, the higher the slump due to the angular flaky shape of the glass and the poor bonding between cement and the glass particles as opposed to cement and normal aggregates bonding.

4.4 Effects of blue gum ash on properties of concrete with crushed waste glass concrete

4.4.1 Workability tests of blue gum ash glass concrete

The variations in the water content to get the targeted slump of between 30-60mm for the various mixes was done in accordance to BS 12350(2009). Concrete mix of 1:1.5:3 representing; binder: fine aggregate: coarse aggregate, respectively, was used. In this mix, 10% of the fine aggregate was crushed glass and the rest was river sand. This was arrived at after optimizing the glass content in concrete according to Figure 4.10. Blue gum ash was dosed at 0 (control), 0.5, 0.75, 1.0, 1.25 and 1.5%. Table 16 in the appendix shows the resulting water cement content, slump obtained and the compaction factor. From Table 16 in the appendix, it is observed that the water cement ratio decreased with increase in blue gum ash content in concrete as in Figure 4.13.

The slump level increased with increase in blue gum ash content but according to the consistency test, the best working value was maintained at 1% blue gum dosage. According to concrete specifications, vibrated concrete slump should be between 30mm- 60mm and most of the values were within the acceptable range.

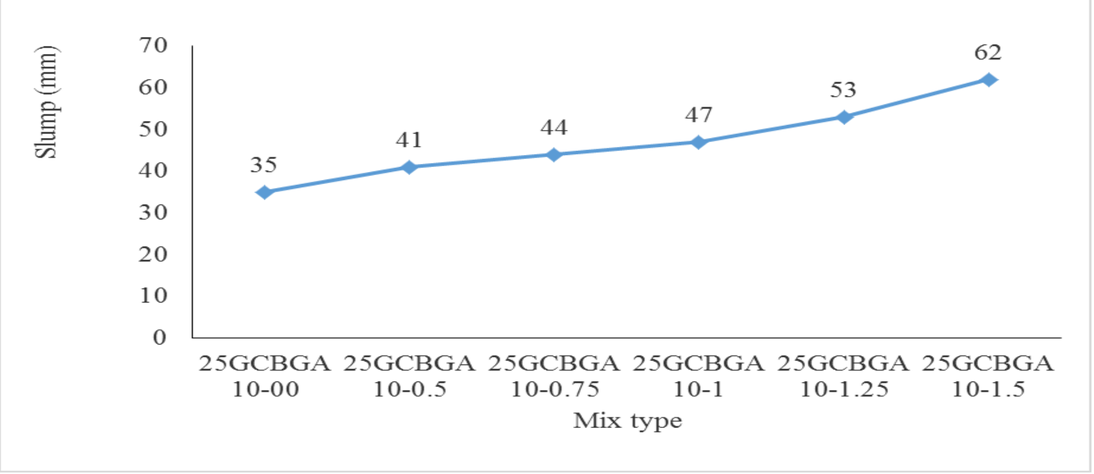

Figure 4.13: Slump variations of blue gum ash glass concrete

The compaction factor was seen to behave the same way as the slump, i.e. increased with increase in blue gum ash proportion up to 0.93 for 1.0% blue gum ash proportion then started decreasing. For medium workability of concrete, the allowed slump is between 50-100 mm (https://www.aboutcivil.org/concrete-slump-test.html); hence blue gum ash proportions of between, 1.0 to 1.5% satisfied the requirements. For the compaction factor, all mixes were within 0.9 ranges hence the addition of blue gum ash improved the compaction factor of class 25 concrete. The graphical representation for the compaction factor is as shown by Figure 4.14.

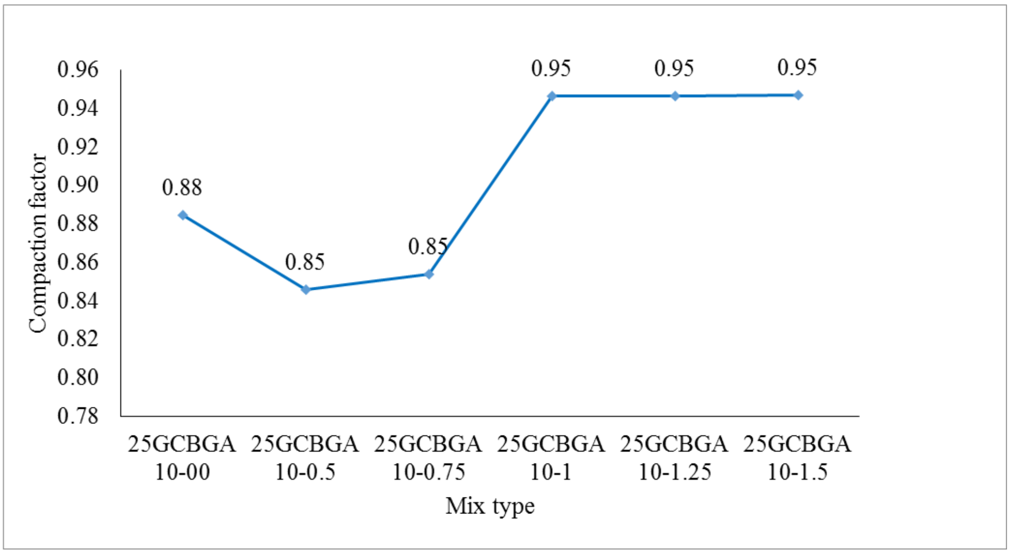

Figure 4.14: Compaction factor variations of blue gum ash glass concrete

According to M. T. Atoom (2002), the normal range of concrete the compaction factor lies between (0.8 – 0.92). From the results, blue gum ash replacement of up to 1% dosage of cement by weight, containing crushed glass content of 10% by weight of fine aggregate satisfies the normal range of concrete compaction factor of (0.8-0.92).

4.4.2 Density variations of blue gum ash glass concrete

The density variation of the control mixes and the various mixes containing glass are as shown in Table 17 in the Appendix.

From the density variation results as shown in Figure 4.15, the variable which had effect on density was rushed waste glass. The effect of blue gum ash on concrete density was insignificant (dozed in very small quantities).

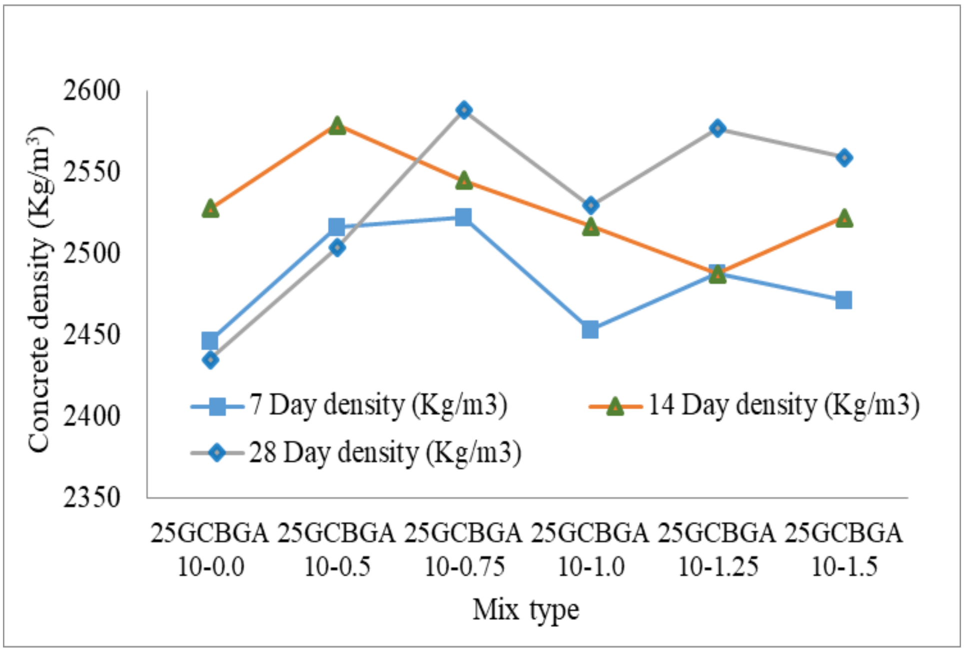

Figure 4.15: Density variations of glass concrete with blue gum ash cement

4.4.3 Compressive strength variations of blue gum ash glass concrete

Table 4.5 shows the various mix proportions of the different ingredients used in the glass concrete containing blue gum ash whereby, for each mix, class 25 concrete was designed. Crushed glass proportion was maintained at 10% of fine aggregates and blue gum ash was dosed at 0 (control), 0.5, 0.75, 1.0, 1.25 and 1.5%. Cement and coarse aggregates proportions were maintained constant.

Table 4.5: Mix proportions of glass concrete with blue gum ash

Mix type	Binder		F. A		C.A
	Cement	Blue gum ash (%)	Sand (%)	Glass (%)	Ballast (%)
25GCBGA 10-00	100	0	100	0	100
25GCBGA 10-0.5	100	0.5	90	10	100
25GCBGA 10-0.75	100	0.75	90	10	100
25GCBGA 10-1	100	1	90	10	100
25GCBGA 10-1.25	100	1.25	90	10	100
25GCBGA 10-1.5	100	1.5	90	10	100

Table 18 in the Appendix shows the compressive strengths of each mix proportion and each value is the mean of triplicate results per test.

Graphically, the results are shown in Figure 4.16.

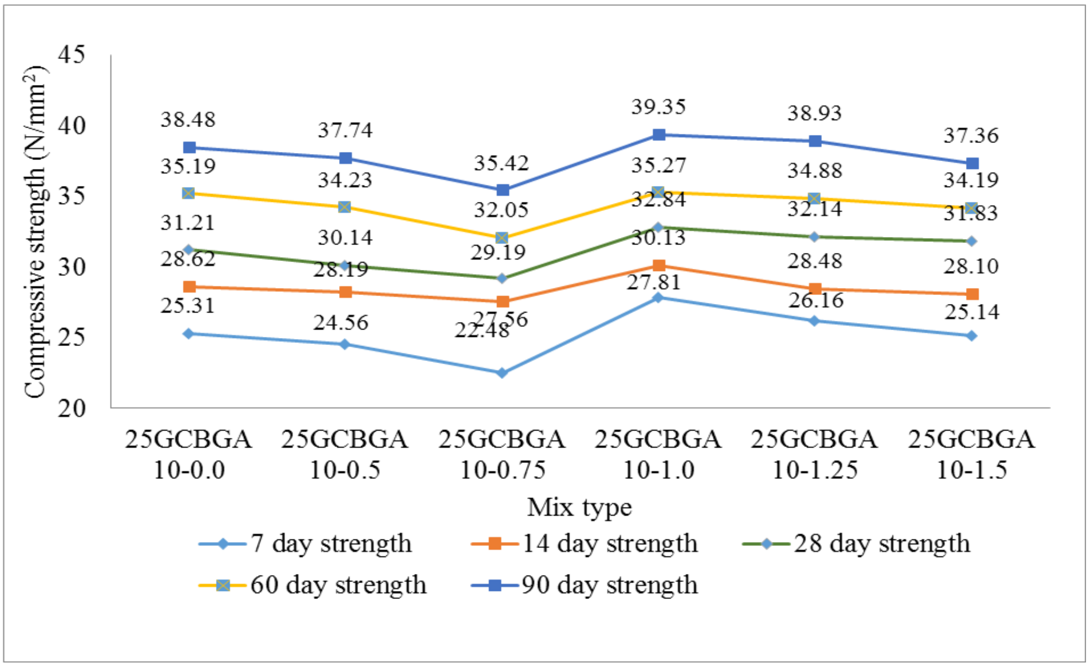

Figure 4.16: Compressive strength of glass concrete with blue gum ash

Comparatively, the strength of the glass concrete made using blue gum ash at 1.0% was found to have the highest strength than the control. Also, the strengths were found to decrease from 0.5 to 0.75%, increase from 0.75 to 1.0% then continuously decrease up to 1.5% blue gum ash proportion. This explains that, up to 10% crushed glass replacement in fine aggregates with 1.0% blue gum ash proportion in concrete attained the highest strength. From the different mixes containing blue gum ash, 1% dosage of cement by blue gum ash gave the highest strength and 0.75% gave the lowest strength at all ages of concrete as shown in Figure 4.17.

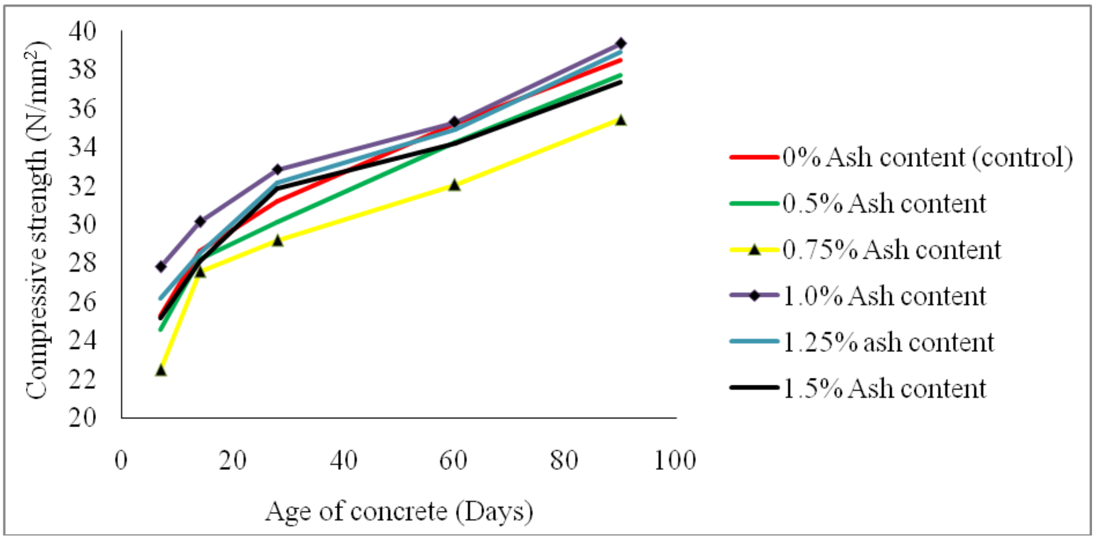

Figure 4.17: Compressive strength of glass concrete with blue gum ash

As the level of blue gum dosage increases, the early-age strength decreases. However, long-term strength development is improved when blue gum ash is used and at some age, the strength of the ash concrete becomes equal to that of the pozzolanic cement. The age at which strength parity with the control (pozzolanic cement) concrete is achieved is greater at higher levels of blue gum ash. The ultimate strength achieved by the concrete increases with increasing blue gum ash content, at least with dosage levels up to 1%. Generally, the differences in the early-age strength of pozzolanic cement and blue gum ash concrete are less for blue gum ash with higher levels of calcium. Notably also was the increase in strength with increase in concrete age up to 90 days. This is because concrete containing pozzolanic cement gains strength with age for the rest of its life.

4.4.4 Tensile split strength test of blue gum ash glass concrete

Table 19 in the appendix shows the results of the 7 and 28 days tensile split strength of glass concrete made using blue gum ash glass concrete, each value being a mean of three-cylinder test results.

The results in Table 19 in Appendix showed that the tensile split test increased with increase in the concrete curing age, and also increased with increase in blue gum ash content in the mix up to 1% by cement weight attaining strengths of 2.18 N/mm^2 and 3 N/mm^2 for 7 and 28 days, respectively, then the strengths decreased. Also notable is that these strengths were higher than the control (glass concrete only) as shown in Figure 4.18. Concrete is poor in tension and good in compression, hence the low tensile split strength values. Pozzolanic materials gain strength with age, hence as the curing age increases, the strength increases. The increase in blue gum ash, increased bonding between the concrete matrix, hence as the level increases, the strength increases up to the optimum level where by, increase in the blue gum ash content does not have the bonding effect, hence the decline in strength.

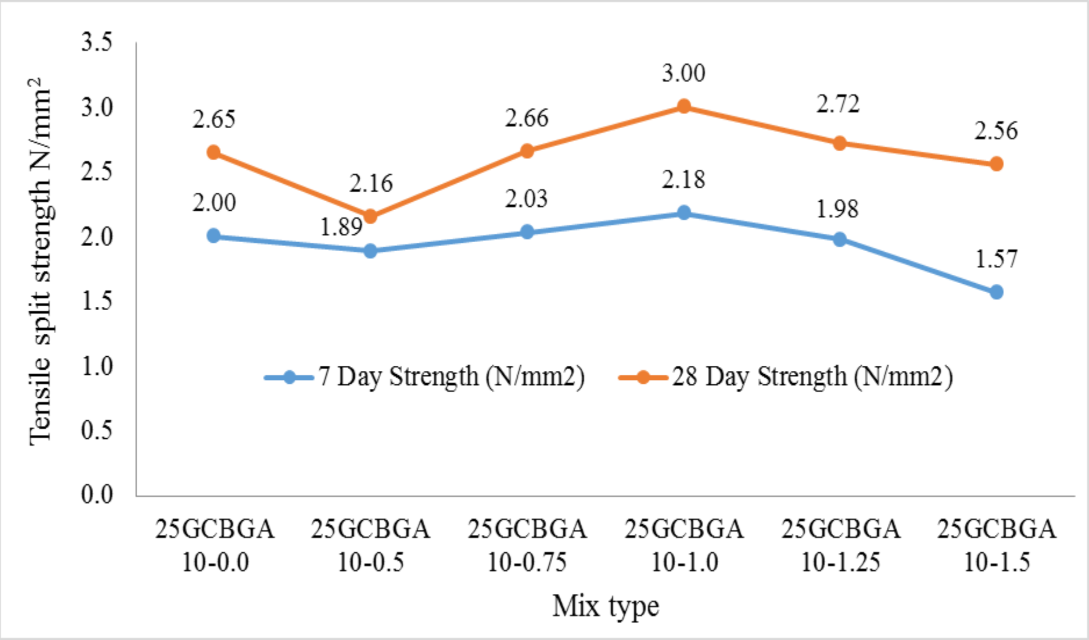

Figure 4.18: Tensile split strength of glass concrete with blue gum ash

The concrete containing 1% dosage of blue gum ash by cement weight achieved higher strength than the control mix at both 7 and 28 days reaching at 109 and 113% respectively then, the strength ratio started to decrease after 1% blue gum ash by cement weight as shown in Figure 4.19: -

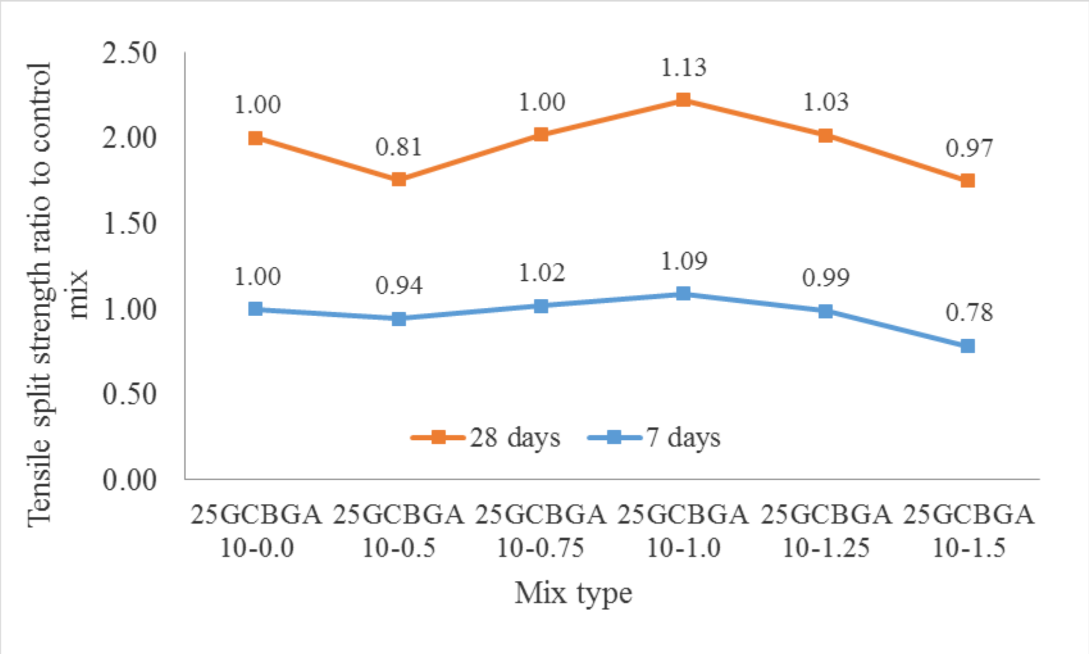

Figure 4.19: Ratio of tensile split strength to control mix

This is all attributed to the effect of the blue gum ash content in the concrete as discussed in the tensile split strength results.

The relationship between compressive strength and tensile split strength of blue gum ash glass concrete at 28 days is as shown in Table 20 in the Appendix. Figure 4.20 explained the relationship based on the strengths at 28 days. The mathematical relationship between the compressive strength (Fcu28) at 28 days and the corresponding split tensile strength (Ft28) at 28 days is represented in the quadratic Equation 1.

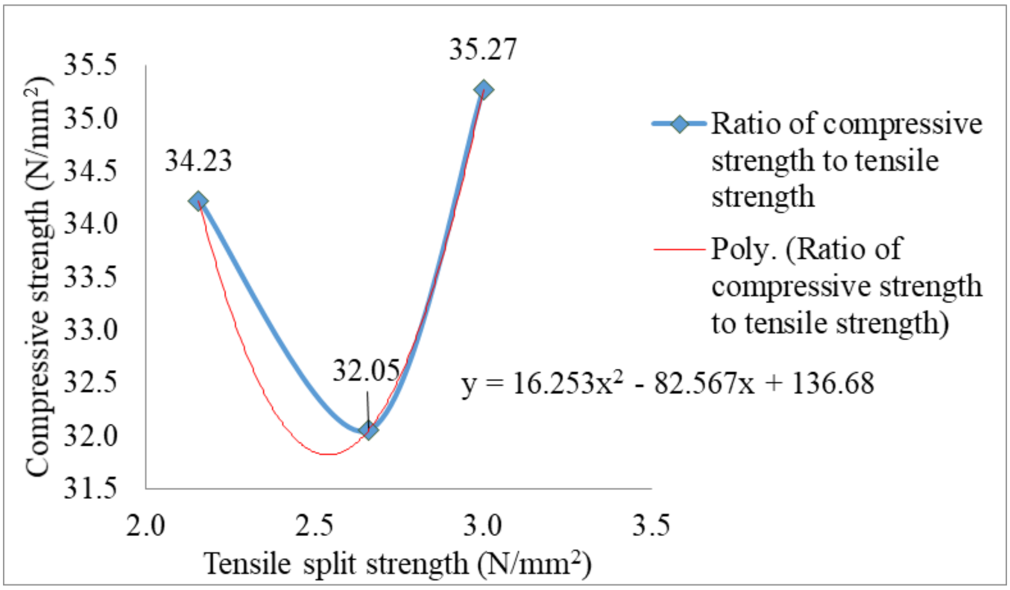

Figure 4.20: Compressive strength against tensile split strength of glass concrete with blue gum ash cement

$Fcu28 = 16.253Ft28^2 - 82.567Ft28 + 136.68$ ------------- (Equation 4.1)

The values of tensile strength of concrete are usually 10-15% of compressive strength but not more than 20%. From the equation, the estimated values were within the range of 10-15% and from the mathematical relationship; the tensile split strength can be predicted from the compressive strength.

4.4.5 Flexural strength variations of blue gum ash glass concrete

Flexural strength test was done using a universal testing machine and the results are shown in Table 21 in the Appendix. Each value of the flexural strength represents the mean of triplicate results and tests were done at 7, 14 and 28 days. From the results, the flexural strength was higher than the control mix.

Generally, from Figure 4.21, it can be observed that the more the replacement of blue gum ash in the mix, the higher the flexural strength. Also notable was that there was increase in flexural strength with increase in curing age due to the improved bonding between the concrete ingredients due to the dosage of the blue gum ash.

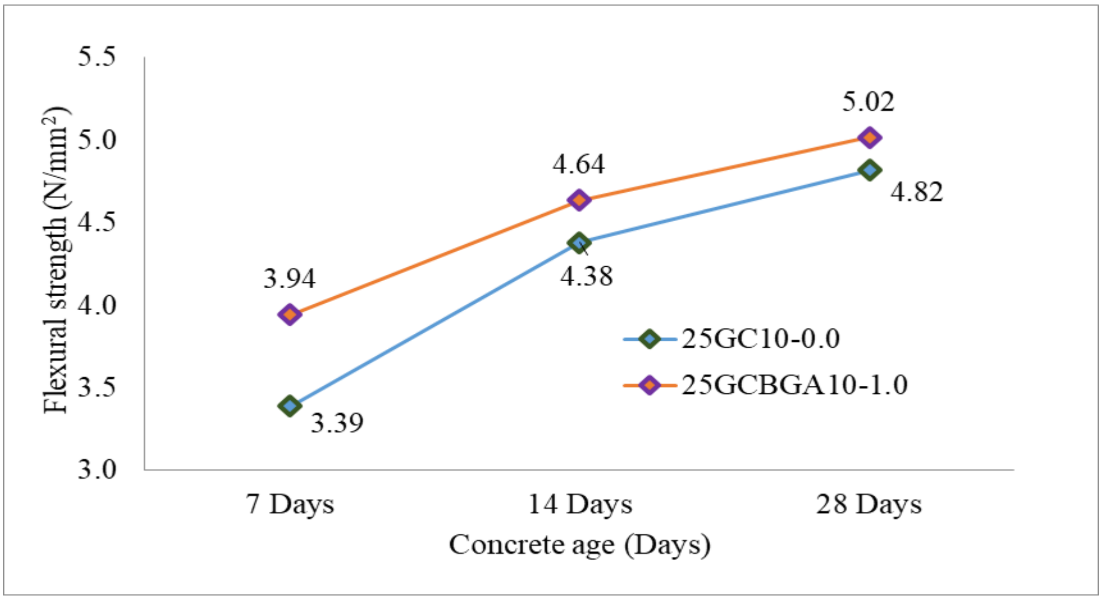

Figure 4.21: Flexural strength of glass concrete with blue gum ash cement

4.4.6 Water absorption test results of blue gum ash glass concrete

Water absorption of concrete is very important to a structural engineer as steel reinforcement embedded in concrete need to be protected in order to prevent it from corroding. On this note, a comparative of blue gum ash glass concrete was carried out and the results are as tabulated in Table 22 in the appendix.

From the results, as the amount of blue gum ash in glass concrete increases, the water absorption also increases. Also, as the curing age of the concrete increases, the water absorption also increases as shown in Figure 4.22.

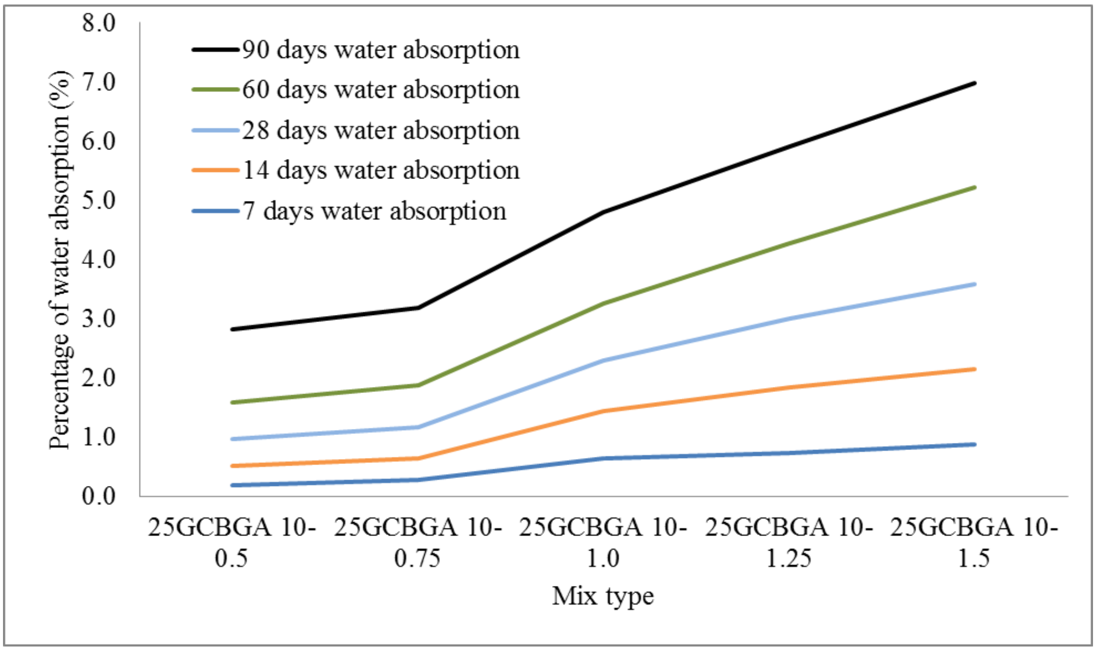

Figure 4.22: Water absorption of blue gum ash glass concrete

From Figure 4.22, increase in water absorption with increase in blue gum ash content is attributed to the fineness of the ash, hence the more the surface area of the ash, the more the water absorption. Also, as the curing age of the concrete increases more water is required for curing hence the increase in water absorption with age of concrete. Also, as the content of blue gum ash increases, extra water is required as generally ashes have high affinity of water.

4.5 Cost benefit analysis of using crushed waste glass enhanced with blue gum ash in concrete

Concrete made using crushed waste glass enhanced with blue gum ash has several cost benefits including. Based on the materials used, a brief on cost analysis was carried out to bring out the cost benefits of using blue gum ash and crushed waste glass in concrete over the normal concrete without these materials. The basis of the analysis was market buying price hence, both blue gum ash and crushed waste glass were considered to be zero shillings while water was obtained from the laboratory for free hence its cost was not considered. The mixture to produce one cubic metre of concrete using the ratio 1:1.5:3 containing these waste materials at different proportions was used. The cement quantity did not change as blue gum ash was dozed thus not replacing cement. Also, crushed waste glass replaced sand by 10%. The cost of the materials were Kshs. 2000, 1700 and 1200 for 1000 Kg of sand, 1000kg of ballast and 50 kg of power plus 42.5N cement respectively. The density of concrete was taken as 2400 Kg/m^3. Table 4.5 shows the cost components of all the constituents used in the mix and the savings made excluding the cost of mixing.

Table 4.6: Cost analysis of glass concrete beams made using sugar cane bagasse ash cement

Mix type	**Cement**	**Blue gum ash**	**Sand**	**Crushed waste glass**	**Ballast**	**Total cost (Kshs.)**	**Saving (%)**
	Cost (Kshs.)	Cost (Kshs.)	Cost (Kshs.)	Cost (Kshs.)	Cost (Kshs.)		
25GCBGA 00-00	10473	0	982	0	2225	13680	0.0
25GCBGA 05-00	10473	0	933	0	2225	13631	0.4
25GCBGA 10-0.5	10473	0	884	0	2225	13582	0.7
25GCBGA 15-0.75	10473	0	835	0	2225	13533	1.1
25GCBGA 20-1	10473	0	785	0	2225	13484	1.4
25GCBGA 25-1.25	10473	0	736	0	2225	13435	1.8
25GCBGA 30-1.5	10473	0	687	0	2225	13385	2.2

From Table 4.6, as the mix proportions increased, the saving increased up to 2.2% for concrete containing blue gum ash of 1.5% of cement by weight and 30% crushed glass of fine aggregates. All this was based on 1M^3 concrete.

In addition to the above cost benefits achieved, the following additional advantages of recycling the waste materials (crushed waste glass and blue gum ash) in construction are (a) Reduction in environmental risks posed by poor disposal of waste glass. Being non-biodegradable, it can be harmful to living things. (b) Reduced sand harvesting by using crushed waste glass reduces effects of environmental effects like lowering water table, sinking of bridge piers among others. (c) Blue gum ash waste from tea factories, that use this type of trees for energy supplement, being not disposed well, poses health hazard effects on surrounding communities and also environmental degradation.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND AREAS OF FURTHER RESEARCH

5.1 Conclusions

The structural performance of concrete containing 10% of fine aggregates as crushed waste glass and cement dosed with blue gum ash of 0 to 1.5% was studied. From this study, the following conclusions may be drawn;

i. The best water cement ratio was maintained at 0.47 because all the slump values were within (30-60mm) as required for vibrated concrete but at 1% dosage (which gave 0.47 water cement ratio), it had the standard consistency.
ii. The increased slump with increase in the crushed glass content is due to the poor bonding (adhesion forces) between the crushed glass and cement as opposed to good bondage between cement and normal aggregate.
iii. Best working combination of waste glass, blue gum ash in addition to other concrete ingredients was 25GCBGA 10-1 because standard consistency was gotten at 1% dosage of blue gum ash to cement and at 10% replacement of glass to sand gave the best compressive strength.
iv. Glass has lower density (1414kg/m^3) as compared to river sand (1563kg/m^3) hence for glass concrete, compressive strength for control experiment was higher than the one with addition of glass.
v. In general, for GCBGA, blue gum ash had positive impact on the strength of concrete made from glass (with river sand replacement by crushed glass at 10%).
vi. In all aspects of compressive strength, addition of glass and blue gum ash increased the strength with increase in the curing age of concrete.

5.2 Recommendations

From the experimental results and analysis, the following recommendations were made: -

a) In order to recycle and make our wastes useful especially in civil engineering, there is need to encourage researchers to take up research courses on these wastes to determine their engineering properties and where they can be used best. E.g. Recycled waste use in civil engineering.
b) Once cement is dosed with blue gum ash at 1% and fine aggregates replaced with crushed glass at 10%, good workability is achieved and early strength developments of concrete of mix ratio of 1:1.5:3 are achieved of up to $35.27 N/mm^2$ in 28 days. This is possible at maximum water cement ratio of 0.6. This mix can be used for lightly loaded beams like lintels and slabs in buildings.
c) There is also need to develop codes or guiding standards on the use of various wastes like blue gum ash and glass in concrete. Once developed, there will be reduced cost of construction due to use of readily available wastes and solve the problem of environmental degradation.

5.3 Further research areas

The following research areas are recommended for further research pertaining the use of blue gum ash and crushed glass on concrete;

a) Combined effects of blue gum ash and crushed glass on concrete permeability and cracking effects.
b) Effect of blue gum ash and crushed glass concrete on other cement types and mix ratios of concrete apart from 1:1.5:3.
c) Effects of plasticizers on glass concrete made using cement dosed with blue gum ash.
d) Investigation of columns and slabs behaviour using glass concrete made using cement dosed with blue gum ash.
e) Investigation of cracking and excessive expansion of glass concrete made using cement dosed with blue gum ash.

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APPENDICES

Appendix I: Grading Tables

Table 1: River sand grading

Test sieve (mm)	Weight retained (g)	Weight passing (g)	% passing	% maximum limit	% minimum limit
0	22.8	0	0	0	0
0.105	219	22.8	2	15	0
0.3	184.5	241.8	23	48	5
0.6	340.5	426.3	41	80	24
1.2	176	766.8	73	100	45
2.36	49.5	942.8	90	100	67
5	60	992.3	94	100	91
10	0	1052.3	100	100	100
Total sample		1052.5(g)			

Table 2: Crushed waste glass grading

Test sieve size (mm)	Weight retained (g)	Weight passing (g)	% passing	% maximum limit	% minimum limit
0	65	0	0.00	0	0
0.105	157.5	65	6.60	15	0
0.3	107	222.5	22.50	48	5
0.6	302.5	329.5	33.40	80	24
1.2	304	632	64.00	100	45
2.36	50.5	936	94.80	100	67
5	0.5	986.5	99.90	100	91
10	0	987	100.00	100	100
Total sample		987 (g)			

Table 3: Coarse aggregate grading

Sieve size (mm)	weight retained (g)	weight passing (g)	% retained	% passing	maximum	minimum
2	22.1	91	0.37	2.42	0	0
4.76	909.5	990	15.21	2.79	5	0
9.52	1438	3426.5	22.05	18.00	38	10
15	1958	4298.5	30.75	38.00	60	25
19.1	1144.5	5258.5	10.41	56.80	70	35
25.1	1167.5	5862.5	16.75	75.94	85	55
30.1	271	5979.5	4.53	95.47	100	90
Totals	5979.5 (g)		100.00			

Table 4: Particle size distribution of cement

			Hydrometer data for cement							
Clock Time	Test Time	Hydrometer Reading		Hydrometer	Temperature	Viscosity-density	Particle	Temperatur	Percent	Corrected
		Actual	Corrected	Length, L	of Solution	Constant	Diameter	Correction	Cmt Passing	Cmt Passing
(h:m)	t (min)	r	r' = r+Cm	(mm)	(°C)		(mm)	(F)	(%)	(%)
0.402778	0									
	1	0.03	0.0308	118.0492	24	0.003581586	0.03891	0.0015	93.897409	93.8974095
	2	0.0276	0.0284	122.3536	24	0.003581586	0.02801	0.0015	86.920512	86.9205122
	5	0.0222	0.023	132.0385	24	0.003581586	0.01841	0.0015	71.222493	71.2224933
	15	0.0022	0.003	167.9085	24	0.003581586	0.01198	0.0015	13.081682	13.0816824
	30	0.0018	0.0026	168.6259	24	0.003581586	0.00849	0.0015	11.918866	11.9188662
	60	0.0016	0.0024	168.9846	24	0.003581586	0.00601	0.0015	11.337458	11.3374581
0.569444	240	0.0008	0.0016	170.4194	24.5	0.003560763	0.003	0.00175	9.7364486	9.7364486
	1440	0	0.0008	171.8542	24	0.003581586	0.00124	0.0015	6.6861932	6.68619324

Table 5 Particle size distribution for blue gum ash

		Hydrometer data-TEGAT blue gum ash								
Clock Time	Test Time	Hydrometer Readings		Hydrometer	Suspension	Viscosity-density	Particle	Temperature	Percent	Corrected
		Actual	Corrected	Length, L	Temperature	Constant	Diameter	Correction	Ash Passing	Ash Passing
(hm)	t (min)	r	r' = r+Cm	(mm)	(°C)		(mm)	(F)	(%)	(%)
0.388889	0	0								
	1	0.0278	0.0285	122.27025	23.5	0.004361817	0.04823	0.0015	100.09956	100.099557
	2	0.0256	0.0263	126.21595	23.5	0.004361817	0.03465	0.0015	92.758923	92.7589232
	5	0.019	0.0197	138.05305	23.5	0.004361817	0.02292	0.0015	70.737021	70.7370206
	15	0.0034	0.0041	166.03165	23.5	0.004361817	0.01451	0.0015	18.685251	18.6852507
	30	0.0024	0.0031	167.82515	23.5	0.004361817	0.01032	0.0015	15.348599	15.3485988
	60	0.002	0.0027	168.54255	23.5	0.004361817	0.00731	0.0015	14.013938	14.013938
0.555556	240	0.0018	0.0025	168.90125	24	0.004335574	0.00364	0.0015	13.344369	13.3443691
	1440	0.0012	0.0019	169.97735	23.5	0.004361817	0.0015	0.0015	11.344617	11.3446165
			Hydrometer data-TOROR blue gum ash							
Clock Time	Test Time	Hydrometer Readings		Hydrometer	Suspension	Viscosity-density	Particle	Temperature	Percent	Corrected
		Actual	Corrected	Length, L	Temperature	Constant	Diameter	Correction	Ash Passing	Ash Passing
(hm)	t (min)	r	r' = r+Cm	(mm)	(°C)		(mm)	(F)	(%)	(%)
0.394444	0	0								
	1	0.0278	0.0286	121.9809	23.5	0.004331671	0.04784	0.0015	99.856713	99.8567129
	2	0.022	0.0228	132.3832	23.5	0.004331671	0.03524	0.0015	80.61522	80.61522
	5	0.007	0.0078	159.2857	23.5	0.004331671	0.02445	0.0015	30.852739	30.8527385
	15	0.0054	0.0062	162.1553	23.5	0.004331671	0.01424	0.0015	25.544741	25.5447405
	30	0.0052	0.006	162.514	23.5	0.004331671	0.01008	0.0015	24.881241	24.8812408
	60	0.0048	0.0056	163.2314	23.5	0.004331671	0.00714	0.0015	23.554241	23.5542412
0.561111	240	0.0046	0.0054	163.5901	24	0.00430561	0.00355	0.0015	22.886923	22.8869234
	1440	0.0034	0.0042	165.7423	23.5	0.004331671	0.00147	0.0015	18.909743	18.909743

Table 6: Specific gravity of river sand

Sample weight (g)	500
Sample +pater +pycnometre (g)	1709.5
Pycnometre + water (g)	1409
Weight of oven dried sample (g)	473.5
Specific gravity SSD	2.5

Table 7: Specific gravity of crushed glass

Sample weight (g)	500
Sample +water +pycnometre (g)	1698
Pycnometre + water (g)	1409
Weight of oven dried sample (g)	472.3
Specific gravity SSD	2.4

Table 8a: Bulk density of ballast and river sand

	Ballast	River sand
Container volume (m^3)	0.00995	0.00205
Cont. weight (Kg)	4.52	1.557
Cont.+ sample Weight (Kg)	18.5	4.761
Sample weight (Kg)	13.98	3.204
Bulk density (Kg/m^3)	1405.0	1562.9

Table 8b: Bulk density of crushed glass and blue gum ash

	Crushed glass	Blue gum ash
Container volume (m^3)	0.00205	0.00205
Cont. weight (Kg)	1.557	1.557
Cont.+ sample Weight (Kg)	4.455	3.194
Sample weight (Kg)	2.898	1.637
Bulk density (Kg/m^3)	1413.7	798.5

Table 9a: Silt content of river sand

Silt content calculation (river sand)	
Weight of dry trays without sand (g)	2471
Weight of trays with sand before washing (g)	3405.5
Weight of trays with sand after drying (g)	3385
Silt content calculation (%)	2.24

Table 9b: Silt content of crushed glass

Silt content calculation (crushed glass)	
Weight of dry trays without glass(g)	2489
Weight of trays with glass before washing (g)	3303
Weight of trays with glass after drying (g)	3260
Silt content calculation (%)	5.58

Table 10: Initial and final setting times of blue gum ash cement

Percentage of blue gum ash in cement (%)	Average initial setting time (Hours)	Average final setting time (Hours)
0	2.25	8.33
0.5	2.67	7.92
0.75	2.83	7.83
1	3.08	7.58
1.25	3.42	7.5
1.5	3.51	7.34

Table 11: Soundness test for blue gum ash cement (1% blue gum ash composition)

Soundness test for blue gum ash cement (Power plus -42,5N dosed with 1% blue gum ash)			
Test number	Initial measurement L_1 (mm)	Final measurement L_2 (mm)	Soundness = L_2-L_1 (mm)
1	11.8	12.0	0.2
2	23.5	24.0	0.5
3	10.5	11.0	0.5
Average soundness (mm)			0.4

Table 12: Soundness test for power plus, 42,5N cement (0% blue gum ash composition)

Soundness test for Power plus -42,5N (control- 0% blue gum ash composition)			
Test number	Initial measurement L_1 (mm)	Final measurement L_2 (mm)	Soundness = L_2-L_1 (mm)
1	17.0	17.0	0.0
2	30.0	30.1	0.1
3	5.0	5.1	0.1
Average soundness (mm)			0.07

Table 13: Average compressive strength of glass concrete

Mix type	7 day strength (N/mm^2)	14 day strength (N/mm^2)	21 day strength (N/mm^2)	28 day strength (N/mm^2)
GC 25-00	27.933	30.257	37.031	39.737
GC 25-05	24.337	27.811	32.901	34.069
GC 25-10	25.305	28.617	32.900	35.195
GC25-15	24.341	28.149	31.401	33.461
GC 25-20	23.597	27.441	30.085	32.080
GC 25-25	22.416	26.536	29.208	31.295

Table 14: Density variations of glass concrete

Mix type	7 day density (Kg/m^3)	14 day density (Kg/m^3)	21 day density (Kg/m^3)
GC 25-00	2486	2513	2425
GC 25-05	2506	2417	2571
GC 25-10	2447	2528	2442
GC 25-15	2426	2410	2405
GC 25-20	2421	2426	2466
GC 25-25	2399	2456	2470

Table 15: Slump variations of glass concrete

Mix type	Slump (mm)
GC 25-00	32
GC 25-05	38
GC 25-10	43
GC 25-15	52
GC 25-20	58
GC 25-25	65

Table 16: Water cement ratio, slump and compaction factor

Mix type	Slump (mm)	Water- cement ratio	Compaction factor
25GCBGA 10-00	35	0.555	0.88
25GCBGA 10-0.5	41	0.552	0.85
25GCBGA 10-0.75	44	0.550	0.85
25GCBGA 10-1	47	0.549	0.95
25GCBGA 10-1.25	53	0.548	0.95
25GCBGA 10-1.5	62	0.546	0.95

Table 17: Density variations of glass concrete with blue gum ash cement

Mix type	7 day density (Kg/m^3)	14 day density (Kg/m^3)	28 day density (Kg/m^3)
25GCBGA 10-0.0	2447	2528	2435
25GCBGA 10-0.5	2516	2579	2504
25GCBGA 10-0.75	2522	2545	2588
25GCBGA 10-1.0	2453	2517	2529
25GCBGA 10-1.25	2488	2488	2577
25GCBGA 10-1.5	2472	2522	2559

Table 18: Compressive strength of glass concrete with blue gum ash cement

Mix type	7 day strength (N/mm^2)	14 day strength (N/mm^2)	28 day strength (N/mm^2)	60 day strength (N/mm^2)	90 day strength (N/mm^2)
25GCBGA 10-0.0	25.31	28.62	31.21	35.19	38.48
25GCBGA 10-0.5	24.56	28.19	30.14	34.23	37.74
25GCBGA 10-0.75	22.48	27.56	29.19	32.05	35.42
25GCBGA 10-1.0	27.81	30.13	32.84	35.27	39.35
25GCBGA 10-1.25	26.16	28.48	32.14	34.88	38.93
25GCBGA 10-1.5	25.14	28.10	31.83	34.19	37.36

Table 19: Tensile split strength of glass concrete with blue gum ash cement

Mix type	7 day strength (N/mm^2)	28 day strength (N/mm^2)
25GCBGA 10-0.0	2.00	2.65
25GCBGA 10-0.5	1.89	2.16
25GCBGA 10-0.75	2.03	2.66
25GCBGA 10-1.0	2.18	3.00
25GCBGA 10-1.25	1.98	2.72
25GCBGA 10-1.5	1.57	2.56

Table 20: Compressive strength against tensile split strength of glass concrete with blue gum ash cement

Mix type	28 day compressive strength (N/mm^2)	28 day tensile split strength (N/mm^2)
25GCBGA 10-0.0	35.19	2.65
25GCBGA 10-0.5	34.23	2.16
25GCBGA 10-0.75	32.05	2.66
25GCBGA 10-1.0	35.27	3.00
25GCBGA 10-1.25	34.88	2.72
25GCBGA 10-1.5	34.19	2.56

Table 21: Flexural strength of glass concrete with blue gum ash cement

Mix type	7 days	14 days	28 days
25G 10-0.0	3.39	4.38	4.82
25GCBGA 10-1.0	3.94	4.64	5.02

Table 22: Water absorption for blue gum ash glass concrete

	Percentage of water absorption for				
Mix type	7 days	14 days	28 days	60 days	90 days
25GCBGA 10-0.5	0.19	0.33	0.45	0.62	1.23
25GCBGA 10-0.75	0.27	0.38	0.52	0.71	1.31
25GCBGA 10-1.0	0.65	0.78	0.87	0.96	1.54
25GCBGA 10-1.25	0.73	1.12	1.16	1.26	1.64
25GCBGA 10-1.5	0.88	1.27	1.44	1.63	1.77