RECYCLING OF WASTE GLASS AS A PARTIAL REPLACEMENT FOR COARSE AGGREGATE IN CONCRETE.

BY

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PLAGIARISM

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DEDICATION

This work is dedicated to different persons dear to me. Firstly, it's dedicated to God Almighty. I thank Him for keeping me alive to see this day and giving me good health to keep going in life despite my shortcomings.

Secondly, it is dedicated to My Family, My Dad and Mum in particular. My Dad, Dr. Rufus Ijeh for always being there for me in any way possible, most especially my academics and life coachings. My Mom, Mrs. Faith Ijeh for her unwavering support towards me all through my life.

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My heartfelt thanks go to my parents and family members for their endless encouragement, prayers, sacrifices and moral support in my entire academic journey. Their constant belief and support has kept me going even through uncertain times.

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ABSTRACT

This research was carried out to investigate the feasibility of using recycled waste glass as a partial replacement for coarse aggregate in concrete. The aim was to evaluate the mechanical, physical and durability characteristics of concrete containing different proportions of crushed waste glass, thereby promoting sustainable construction practices.

The methodology involved collecting, cleaning, crushing and sieving waste glass bottles into particles of 10–20 mm in size. Five concrete mixes were prepared using a 1:2:4 mix ratio, with 0 %, 10 %, 20 %, 30 %, and 40 % waste glass as partial replacements for granite. All specimens were cured in water for 7, 14 and 28 days. Tests conducted included slump (for workability), compressive strength, density, setting time and water absorption capacity.

The results showed that workability increased with higher waste glass content, with slump values ranging from 30mm for the control mix to 60mm at 40% replacement. The compressive strength of 30% replacement after 28 days was 20.30 Mpa, hence it was the optimum replacement level. The density of the concrete decreased slightly from 2.612g/cm3 (0%) to 2.391 g/cm3 (40%), indicating lighter concrete at higher glass content. The setting time test recorded an initial setting time of 65 minutes and a final setting time of 172 minutes, both within standard limits. Water absorption decreased from 1.6% at 0% replacement to 1.2% at 30%, showing improved durability and reduced porosity. From the findings, it was concluded that waste glass could be used effectively as a partial replacement for coarse aggregate in concrete up to 20% without significant loss in strength or durability.

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ACRONYMS

WG- waste glass

SCGC- self-compacting glass concrete

SCC- self-compacting concrete

HPGC- high performance recycled liquid crystal glasses concrete

HSPC- high-strength pervious concrete

UHPC- ultra-high performance concrete

LCDGC- liquid crystal display glass concrete

LCD- liquid crystal display

CRT- cathode ray tube

PVC- polyvinyl chloride

SP- superplasticizer

HRWRA- high-range water-reducing agent

WR- water-reducing

AE- air-entraining

SF- silica fume

F.A.- fly ash

GBFS- granulated blast furnace slag

MK- metakaolin.

SH- sodium hydroxide solution SS- sodium silicate solution

F.A- fine aggregate

C.A- coarse aggregate

Vol.- volume

Wt.- weight

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Concrete is universally recognized as the cornerstone of construction materials, celebrated for its adaptability, resilience and affordability. There literally won’t be anything without it in this world today except tents and tree houses. A fundamental constituent of concrete amongst other constituents is coarse aggregate, traditionally gotten from rocks. However, the escalating demand for granite and its intensive mining activities have led to alarming environmental consequences especially here in Nigeria, including air, water and noise pollution, habitat loss and extensive land degradation.

Against this backdrop, there is a growing quest for sustainable alternatives to coarse aggregate. One promising and underlying candidate is waste glass, an abundant and often improperly managed component of municipal solid waste. In Nigeria, urban areas are increasingly challenged by the rapid increase of waste glass, which, being non-biodegradable, lingers in the environment for centuries, causing pollution and health risks.

Given the chemical similarities between glass and granite particularly their high silica content, processed waste glass emerges as a viable and suitable substitute for coarse aggregates in concrete production. Beyond reducing environmental pollution, recycling waste glass can conserve natural resources, support sustainable and construction practices.

This research is therefore directed at assessing the use of recycled waste glass as a partial replacement for coarse aggregate in concrete in Nigerian, with emphasis on its mechanical performance, economic viability and environmental impact.

1.2 Statement of the Problem

The increasing urbanization across Nigeria has brought about an observation in waste generation, with waste glass constituting a portion of it. Unfortunately, the lack of effective recycling mechanisms results in environmental degradation and public health challenges. Simultaneously, the construction industry’s dependency on granite is causing severe ecological disturbances including air, water and noise pollution, habitat loss and extensive land degradation. Also, these waste glasses when not disposed properly can cause glass cut which may lead to some complications like tetanus and nerve damage.

Although various international studies suggest that waste glass can be used beneficially in concrete, there remains a significant void in localized research within Nigeria. Factors such as different climatic conditions, variations in glass composition and construction practices necessitate indigenous studies to establish suitable standards and practices.

Thus, this study addresses two major issues: the environmental hazards posed by unutilized waste glass and the unsustainable depletion of granite. It seeks to evaluate the potential of recycled glass in producing structurally sound and durable concrete, thus bridging existing research and application gaps in Nigeria.

1.3 Aim and Objectives

The aim of this research is to explore the feasibility of using recycled waste glass as a substitute for coarse aggregates in concrete production in Nigeria.

The objectives are to:

1. collect and appropriately process waste glass for use as coarse aggregate.

2. prepare concrete mixes incorporating various percentages of waste glass as a partial replacement for granite.

3. conduct laboratory tests to evaluate properties such as workability, compressive strength, density, setting time and water absorption capacity.

4. assess the environmental and economical benefits of utilizing recycled glass in construction.

1.4 Scope of Study

The scope of work includes:

1. collection of waste glass and crushing properly to desired diameter.

2. preparation of the different concrete mixes of varying percentages of waste glass.

3. comprehensive laboratory testing to evaluate mechanical behavior such as strength and durability.

4. environmental impact assessment and economic analysis focusing on waste reduction and resource conservation.

1.5 Justification of Study

The indiscriminate disposal of waste materials, especially non-biodegradable substances like glass, poses a threat to environmental health and public safety in Nigeria. With urbanization on the rise and consumption habits rapidly changing, the quantity of waste glass generated from households, hospitality establishments and commercial centers has increased. Unfortunately, much of this waste ends up in open dumps, drainage channels or landfills, where it contributes to soil and water contamination, visual pollution and long-term ecological degradation due to its non-decomposing nature.

This research is therefore driven by the urgent need to develop practical and sustainable strategies for managing the growing volume of waste glass. By exploring its use as a partial replacement for coarse aggregate in concrete, this study aims to transform a major environmental liability into a valuable resource for the construction industry. Such an approach not only offers an alternative means of reducing reliance on granite which is also being depleted at an alarming rate and price increasing but also provides a pathway for integrating waste reduction into mainstream building practices.

Incorporating waste glass into concrete production offers a dual advantage: it supports environmentally responsible waste management while contributing to the development of sustainable construction materials. If proven viable at the end of my research, this solution could reduce landfill accumulation, promote recycling culture, create new economic opportunities within the waste processing sector and align with broader environmental policies focused on circular economy principles. The study, therefore, seeks to provide both scientific evidence and practical recommendations that will support the responsible reuse of glass waste in Nigeria’s built environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background

The early interest in recycling waste glass within construction began in the last century, driven by environmental concerns and resource conservation efforts. However, initial applications were hindered by durability issues, especially those arising from the alkali-silica reaction (ASR) between glass particles and cementitious materials.

Now, let’s go to Nigeria. In urban areas like Akure Metropolis, market centers played a significant role in the production of solid waste in 2017 and glass waste is increasingly becoming a major component. Most of the glass waste generated in markets such as Oja Oba, Isikan and NEPA Market originates from broken bottles, jars, food containers, cosmetic packaging and damaged glassware used for daily trading and consumption activities.

This situation mirrors a growing concern across Nigeria, where the rise in urban population and changing lifestyles have led to a spike in the use of glass products, with little to no proper disposal systems in place. As a result, waste glass is often dumped indiscriminately in open spaces, roadside drains and landfills without segregation or recycling.

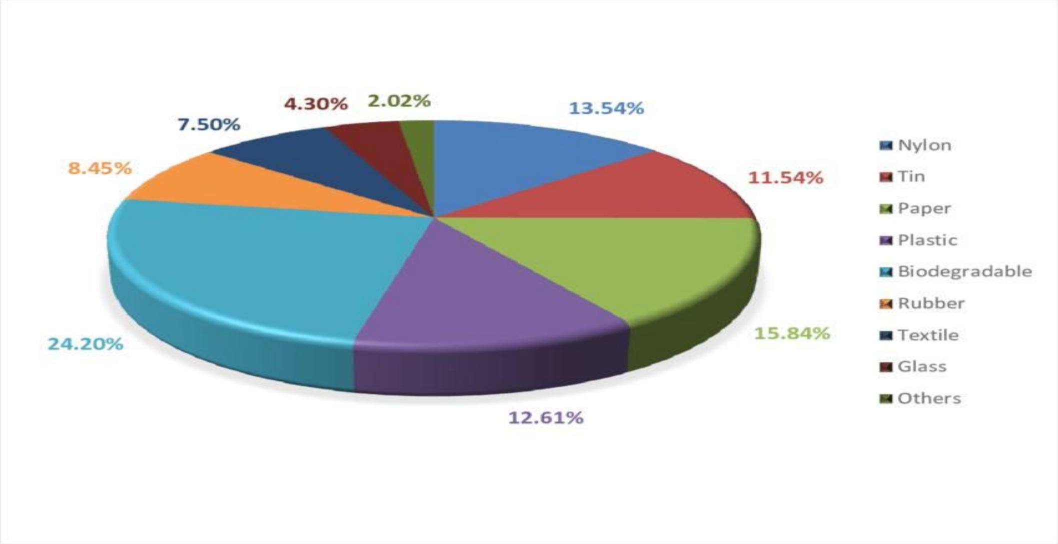


Figure 2.1: The overall percentage of solid wastes generated in Market Areas of Akure Metropolis (Adewumi et al., 2017)

2.2 Hazards Associated with Waste Glass in Market Areas:

Improper disposal of waste glass in market environments poses serious health, environmental and economic concerns. Marketplaces in many Nigerian cities often experience high volumes of commercial activity, which naturally leads to the generation of considerable glass waste, particularly from beverage bottles, cosmetics and food containers. When this waste is not properly collected, sorted or recycled, it creates multiple hazards that affect both the people and the surrounding environment.

2.2.1. Injury Risk

Broken glass scattered around stalls, walkways and refuse heaps poses a threat to traders, customers and sanitation workers. Sharp glass fragments can easily cause cuts, puncture wounds or even serious lacerations, especially in crowded areas where people often walk barefoot or with minimal protection. Children playing around the market are particularly vulnerable. In some cases, untreated injuries caused by broken glass may lead to infections or long-term health complications.

2.2.2. Environmental Damage

Glass is non-biodegradable, meaning it does not decompose naturally in the environment. When left in open spaces, it contributes to land pollution and can disrupt natural habitats, especially when swept into nearby water bodies or green spaces. Over time, accumulated glass waste degrades the aesthetic quality of the environment and undermines efforts to keep public spaces clean and safe.

2.2.3. Blocked Drainage Systems

Waste glass, especially when mixed with other refuse, often finds its way into drainage channels in and around markets. These materials can obstruct the free flow of stormwater, leading to blocked drains and localized flooding during the rainy season. Stagnant water caused by poor drainage becomes a breeding ground for mosquitoes and other disease vectors, further endangering public health.

2.2.4. Fire Risks

Under certain conditions, waste glass particularly clear or magnifying-shaped fragments can focus sunlight to a point that ignites nearby dry waste or flammable material, increasing the risk of fire outbreaks. In congested market areas with makeshift wooden structures and flammable packaging materials, such fires can spread rapidly and cause significant property damage, injuries, or even fatalities.

2.2.5. Lost Economic Potential

When glass waste is discarded rather than recycled or reused, its potential as a raw material is wasted. Recycled glass can be transformed into construction materials, decorative items, or new glass products, thereby generating income and employment opportunities. Markets that fail to collect and channel glass waste into recycling streams miss out on these economic benefits, contributing instead to environmental degradation and increased public cleaning costs.

2.3 Properties and Characteristics of Waste Glass

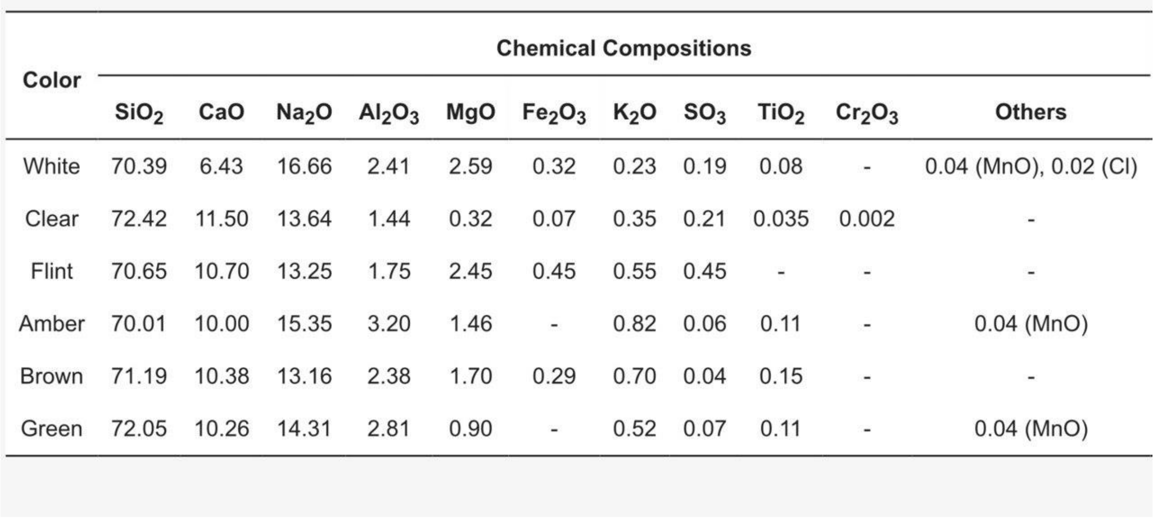
Glass primarily consists of silica (SiO_2), a material also predominant in granite and sand. Crushed glass particles exhibit a generally angular shape with smooth surfaces, influencing the mechanical interlock and bond strength in concrete mixtures. Glass is also chemically inert and impermeable, these are characteristics that can enhance concrete’s resistance to chemical attack when used appropriately.

Others include;

2.3.1. Chemical Properties of Glass

There exists various colors and types of glass, with various chemical components. Table 2.1 and Table 2.2 show the chemical compositions of different colors and types of typical glass, respectively.

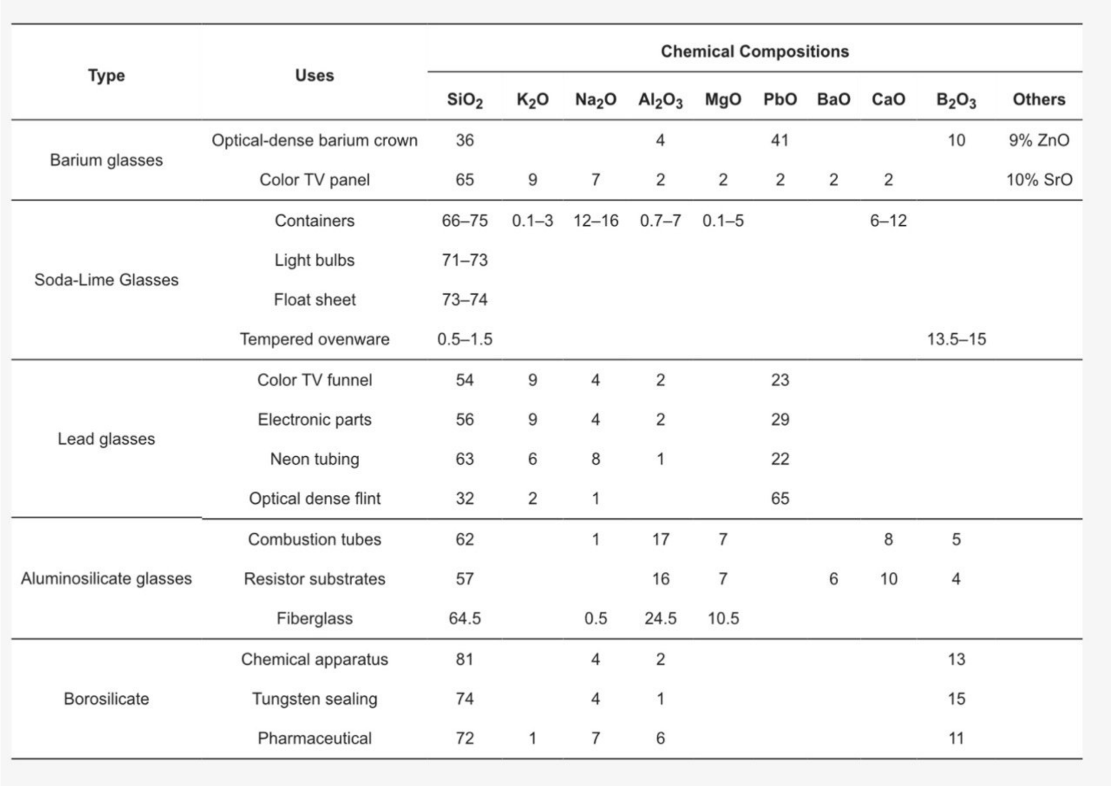
Table 2.1. Chemical components of glass for various colors.



Color	Chemical Compositions										
	SiO_2	CaO	Na_2O	Al_2O_3	MgO	Fe_2O_3	K_2O	SO_3	TiO_2	Cr_2O_3	Others
White	70.39	6.43	16.66	2.41	2.59	0.32	0.23	0.19	0.08	-	0.04 (MnO), 0.02 (Cl)
Clear	72.42	11.50	13.64	1.44	0.32	0.07	0.35	0.21	0.035	0.002	-
Flint	70.65	10.70	13.25	1.75	2.45	0.45	0.55	0.45	-	-	-
Amber	70.01	10.00	15.35	3.20	1.46	-	0.82	0.06	0.11	-	0.04 (MnO)
Brown	71.19	10.38	13.16	2.38	1.70	0.29	0.70	0.04	0.15	-	-
Green	72.05	10.26	14.31	2.81	0.90	-	0.52	0.07	0.11	-	0.04 (MnO)

Source: Qaidi et al, 2022.

Table 2.2. Chemical components of glass for various types.

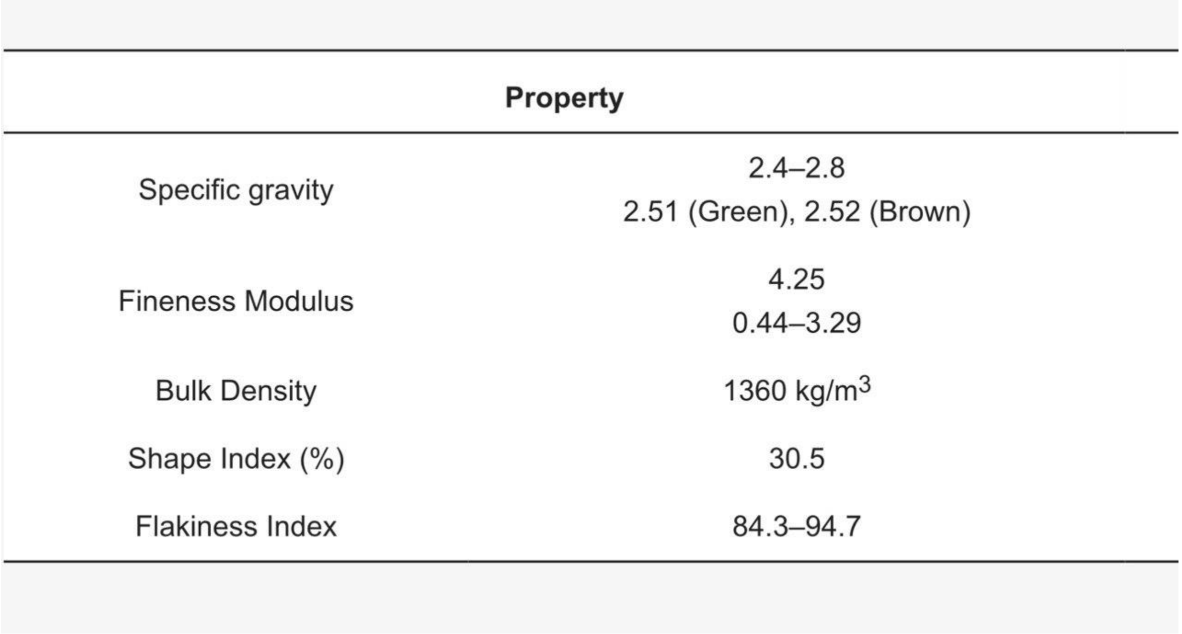


Type	Uses	Chemical Compositions									
		SiO_2	K_2O	Na_2O	Al_2O_3	MgO	PbO	BaO	CaO	B_2O_3	Others
Barium glasses	Optical-dense barium crown	36			4		41			10	9% ZnO
	Color TV panel	65	9	7	2	2	2	2	2		10% SrO
Soda-Lime Glasses	Containers	66–75	0.1–3	12–16	0.7–7	0.1–5			6–12		
	Light bulbs	71–73									
	Float sheet	73–74									
	Tempered ovenware	0.5–1.5								13.5–15	
Lead glasses	Color TV funnel	54	9	4	2		23				
	Electronic parts	56	9	4	2		29				
	Neon tubing	63	6	8	1		22				
	Optical dense flint	32	2	1			65				
Aluminosilicate glasses	Combustion tubes	62		1	17	7			8	5	
	Resistor substrates	57			16	7		6	10	4	
	Fiberglass	64.5		0.5	24.5	10.5					
Borosilicate	Chemical apparatus	81		4	2					13	
	Tungsten sealing	74		4	1					15	
	Pharmaceutical	72	1	7	6					11	

2.3.2 Physical properties

The physical properties of waste glass are shown in the table below.

Table 2.3. Physical properties of glass



Property	
Specific gravity	2.4–2.8 2.51 (Green), 2.52 (Brown)
Fineness Modulus	4.25 0.44–3.29
Bulk Density	1360 kg/m^3
Shape Index (%)	30.5
Flakiness Index	84.3–94.7

Source: Qaidi et al, 2022.

2.3.3 Workability of concrete with WG

The slump test is one of the oldest and most commonly used methods for determining the workability of freshly mixed concrete. The procedure follows the ASTM C143 standard.

According to the findings of Topcu and Canbaz (Topcu and Canbaz, 2004), incorporating waste glass into a concrete mix resulted in a decrease in slump value of approximately 0.2%. They attributed this reduction to the irregular shape and surface texture of the glass particles.

Similarly, Andrić et al. (2017) conducted experiments using a water–cement ratio of 0.45, where waste glass was introduced as part of the aggregate. Their results also indicated a decline in workability of around 1.5%.

The effect of waste glass (WG) on the workability of concrete has been interpreted in two main ways by researchers. A number of studies, summarized suggest that replacing traditional aggregates with WG can actually enhance workability. This is often attributed to the smooth texture and low water absorption rate of glass, which weaken the bond between the cement paste and aggregate, allowing for easier flow. In a similar line of research, Liu, Wei, Zou, Zhou, and Jian (Liu et al., 2020) explored the use of recycled liquid crystal display (CRT) glass in ultra-high-performance concrete (UHPC), with WG replacement rates from 25% up to 100%. With a fixed water–cement ratio and controlled superplasticizer dosages, they observed a noticeable improvement in flowability, when compared to the control samples. These findings point to the potential of WG to serve as a workable and sustainable alternative in mixes where high fluidity is critical, such as in high-performance concrete (HPC). Using WG in this way could reduce reliance on chemical admixtures like HRWR or high doses of superplasticizers (Rashad,2014; Emad et al., 2022,Almeshal et al.,2022; Al-Tayeb, 2022) .

On the other hand, some research has shown that introducing WG into concrete can have a negative effect on workability. This drop in workability is often associated with the angular shape and high aspect ratio of glass particles, which disrupt the flow of the cement paste and aggregate mix (Taha and Nounu, 2008; Tan and Du, 2013; Yildizel et al., 2020; Al saffar et al., 2020; Akeed et al., 2022; Akeed et al., 2022; Akeed et al., 2022). Similarly, Arabi, Meftah, Amara, Kebaïli, and Berredjem (Arabi et al., 2019) examined SCC mixes using recycled windshield glass to replace coarse aggregates at levels between 25% and 100%. Their tests, which also varied the water–cement ratio (0.60–0.69) and superplasticizer dosage, showed slump flow losses of 3% to 11% depending on the amount of WG used. According to Rashad (Rashad, 2014), using around 20% WG appears to offer the best balance between workability and material performance.

2.3.4 Compressive Strength.

Compressive strength refers to the maximum load that concrete can withstand under axial compression. It is typically expressed in pounds per square inch (psi) or in megapascals (MPa).

Among the various mechanical tests used to assess concrete performance, the compressive strength test is regarded as one of the most significant. It provides insight into how different constituent materials affect the overall quality of concrete and clearly demonstrates the influence of additives incorporated to enhance its properties. In the case of waste glass, the compressive strength test has been widely used to evaluate its impact, with most studies reporting a decline in strength as the proportion of glass increases (de Castro & de Brito, 2013).

Topcu and Canbaz (2004) investigated the use of waste glass as a partial replacement for coarse aggregate at varying percentages. Concrete specimens were cured for 28 days and the results showed that mixes without glass achieved compressive strengths ranging from 2.04 to 23.50 MPa. However, as the glass content increased, the compressive strength decreased by about 8% at 15% replacement, 15% at 30% and up to 31% at 45%. The reduction was attributed to poor bonding between the smooth glass surface and the cement paste.

Similarly, Serniabat et al. (2014) examined nine concrete mixtures containing crushed waste glass sized between 5 mm and 20 mm. Their results recorded a maximum compressive strength of 268.14 MPa.

Ganiron Jr. (2014) reported that concrete containing 10% glass replacement exhibited a 28.7% increase in compressive strength after seven days, although no further improvement was observed at 28 days. The testing was performed in accordance with ASTM C39-86.

In another study, Al-Zubaid, Shabeeb, and Ali (Al-Zubaid et al., 2017) evaluated concrete incorporating 11%, 13% and 15% waste glass. They found that the 13% replacement yielded the highest compressive strength at 7, 14, and 28 days of curing.

Several researchers have also noted that the particle size of the waste glass significantly affects compressive strength, likely due to the pozzolanic behavior of finely ground glass. Ildir, Cyr, and Tagnit-Hamou (Ildir et al., 2010) observed that when glass particles were reduced to around 80 µm, the compressive strength of the concrete increased from 30 MPa to 35 MPa.

Numerous previous studies have explored the effect of incorporating waste glass (WG) into concrete, particularly focusing on its compressive strength. As summarized in Table 2.5, most findings indicate that replacing traditional aggregates with WG tends to reduce compressive strength. Researchers have attributed this decline to several factors: first, the sharp and smooth surfaces of glass particles which weaken the bond between the cement paste and the aggregate at the interfacial transition zone (ITZ); second, the higher water absorption capacity of glass, which affects the water-to-cement ratio; and third, internal stresses caused by alkali-silica reaction (ASR), which can lead to micro-cracking.

For instance, Park, Lee, and Kim (Park et al., 2004) observed a compressive strength reduction of 3%, 13%, and 18% when 30%, 50%, and 70% of fine aggregates were substituted with recycled green WG, respectively. Interestingly, Terro (Terro, 2006) reported that incorporating up to 25% WG led to higher strength than the control mix, while levels above 25% showed a notable decline.

To better understand the behavior of waste glass in concrete, Omoding, Cunningham, and Lane-Serff (Omoding et al., 2021) carried out microstructural analysis using SEM by replacing 12.5–100% of coarse aggregates with green WG (10–20 mm in size). Their study revealed two key points: a weak bond exists between the smooth surface of WG and the cement paste and increasing WG content leads to more voids and cracks in the concrete matrix, thereby affecting strength.

However, note that not all studies report a reduction in strength. Some have shown that WG can actually improve mechanical strength. This is often linked to the angular nature and hardness of WG, which can enhance interlocking, and the pozzolanic reaction that occurs due to its silica content. For example, in a study by Jiao, Zhang, Guo, Zhang, Ning, and Liu (Jiao et al., 2020), ultra-high-performance concrete (UHPC) with 25% to 100% WG replacement showed strength increases of 2%, 17%, 34%, and 20%, respectively.

Lastly, the color of the waste glass has also been considered. While some researchers found no significant difference in strength due to glass color (Park et al., 2004; Degirmencia et al., 2011), Tan and Du (Tan and Du, 2013) noted that clear glass tends to result in lower strength values.

2.3.5 Flexural Strength.

Flexural strength is an indicator of the tensile capacity of concrete. It reflects the ability of a concrete beam or slab to resist bending failure under applied loads. This property is commonly represented by the modulus of rupture (MR) (Jamal, 2018). The standard test methods for determining flexural strength are outlined in ASTM C78 (third-point loading) and ASTM C293 (center-point loading).

Findings from numerous studies indicate that the flexural strength of concrete generally decreases as the proportion of waste glass increases (Jani & Hogland, 2014). This reduction is often attributed to the weak interfacial bonding between the smooth surface of glass particles and the surrounding cement paste (Khmiri et al., 2013).

In the experimental investigation by Topcu and Canbaz (2004), flexural strength values ranged between 3.00 and 5.27 MPa. Their results showed a decline of up to 2% in flexural strength with increasing waste glass content.

Conversely, Al-Zubaid et al. (2017) observed an improvement in flexural strength when waste glass was incorporated into concrete. Their study reported that a 13% partial replacement produced the highest flexural strength at 7, 14 and 28 days of curing, which was attributed to an increased presence of calcium carbonate ($CaCO_3$) in the mix.

Similarly, Batayneh, Marie and Asi (Batayneh et al., 2007) found an increase of about 20% in flexural strength when waste glass was used as a fine aggregate. Mageswari and Vidivelli (2010) also achieved comparable results by introducing sheet glass powder into concrete, reporting an improvement of approximately 20% in flexural strength.

The flexural strength behavior of concrete containing waste glass (WG) tends to follow similar trends as its compressive and tensile strengths. In many studies, the inclusion of WG as aggregate has been found to reduce flexural strength. However, there are also studies that observed an improvement in flexural strength when WG was added (Qaidi, 2022; Qaidi, 2022; Qaidi, 2022).

Overall, the conflicting outcomes across different studies can likely be explained by variations in the type, size and source of waste glass used in each mix. Since different types of glass have different mineral compositions, they interact with cement binders in unique ways, which ultimately influences the concrete's properties.

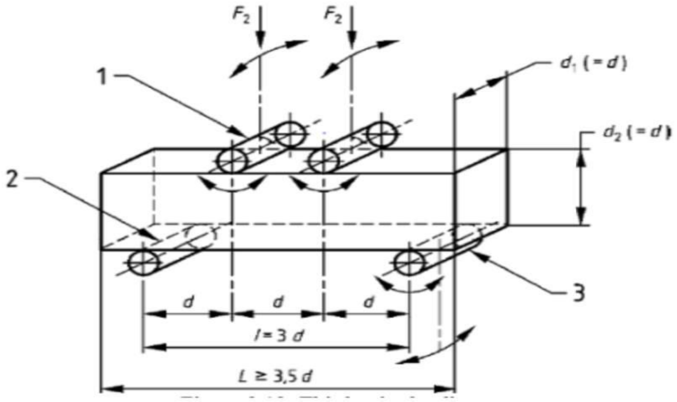


Figure 2.2: Flexural Strength Test for Concrete

Source: (Jamal, 2018)

2.3.6 Splitting Tensile Strength.

The split tensile strength test is used to determine the tensile capacity of concrete. Because concrete is inherently brittle, it tends to crack when subjected to tensile stresses. This test measures the amount of load required to initiate such cracking in a cylindrical concrete specimen.

When waste glass is incorporated as part of the aggregate, studies have reported varying effects on the tensile strength of concrete. Some researchers observed a reduction in tensile strength, while others recorded an improvement depending on the mix proportions and particle characteristics.

Topcu and Canbaz (2004) reported a decrease of about 10% in tensile strength, with a more pronounced reduction of up to 37% at 60% waste glass replacement. This behavior was attributed to the amorphous structure and smooth surface of the glass particles, which hinder effective bonding with the cement matrix. Similar findings were reported by Park et al. (2004), who also noted a reduction in tensile strength as the waste glass content increased.

In contrast, Mageswari and Vidivelli (Mageswari and Vidivelli, 2010) observed a 20% increase in tensile strength when waste glass was added to the concrete mix. Tan and Du (Tan and Du, 2013) also found an improvement of approximately 25%, concluding that higher proportions of finely ground waste glass could enhance tensile strength.

(Al-Zubaid et al., 2017) reported that concrete containing waste glass exhibited higher splitting tensile strength compared to the control mix. However, they noted that while strength increased at 11% and 13% partial replacements, it began to decline when the replacement level reached 15%.

A number of studies have assessed the influence of incorporating waste glass (WG) into concrete on its splitting tensile strength. Most findings indicate that the addition of WG generally leads to a reduction in tensile strength. This trend has often been explained by the weak bond between the smooth glass particles and the cement paste at the interfacial transition zone (ITZ), similar to what is observed in compressive strength reductions.

On the other hand, a different outcome was reported by Jiao, Zhang, Guo, Zhang, Ning, and Liu (Jiao et al., 2020), who studied ultra-high-performance concrete (UHPC) incorporating recycled WG as fine aggregate from 25% to 100% by weight. Unlike the previous studies, their findings showed improvements in tensile strength—by 1%, 3%, 11%, and 7% for 25%, 50%, 75%, and 100% WG, respectively. The increase was attributed to the inclusion of steel fibers in the mix, which likely enhanced crack resistance and overall tensile performance.

2.3.7 Water absorption capacity

Water absorption capacity is a key property used to evaluate the durability of concrete. It provides insight into other related characteristics such as permeability and resistance to sulfate attack (Zhang & Zong, 2014). According to ASTM C642-13, water absorption is defined as the increase in the weight of oven-dried concrete after being immersed in water for a specified period.

Incorporating waste glass as an aggregate in concrete is expected to influence its absorption characteristics. Due to the non-porous and impermeable nature of glass, its inclusion tends to reduce the permeability of concrete and consequently, its water absorption capacity.

Taha and Nounu (Taha and Nounu., 2008) reported that replacing natural aggregates with waste glass led to a reduction in the water absorption capacity of concrete. They attributed this improvement to the ability of glass particles to limit the propagation of micro-cracks and restrict the migration of moisture within the concrete matrix.

2.3.8 Alkali–Silica Reaction

Alkali–Silica Reaction (ASR) is a detrimental chemical process that occurs in concrete when reactive silica present in certain aggregates reacts with alkalis found in cement. This reaction leads to the formation of an expansive silica gel, which absorbs moisture and causes internal cracking and volumetric expansion within the concrete matrix (Abdelrahman et al., 2015).

The phenomenon was first identified by Stanton in 1940, who discovered that silica and alkalis react to produce a gel that swells in the presence of moisture. Although ASR typically weakens concrete and compromises its durability, in some cases it may slightly increase strength due to secondary cementitious reactions that fill voids in the interfacial transition zone. This process is somewhat similar to the pozzolanic reaction that occurs in cement-based materials (Hadlington, 2002).

ASR testing is commonly carried out in accordance with established standards to ensure consistency and reliability of results. One of the major organizations responsible for developing such standards is the American Section of the International Association for

Testing Materials, founded in 1898, which later became ASTM International. (Abdelrahman et al., 2015) evaluated ASR behavior using ASTM C1293 and the data obtained were consistent and within acceptable limits.

In the past, aggregates used in concrete were selected mainly based on their physical properties under the assumption that they were chemically inert. However, it was later discovered that certain aggregates can react with cement components under alkaline conditions. Glass, in particular, is considered unstable in such environments (Hadlington, 2002).

Although both sand and glass are primarily composed of silica, their behavior in concrete differs significantly. The silica in sand exists in a crystalline form, which is chemically stable and resistant to alkali attack. In contrast, glass contains silica in an amorphous form, making it more reactive and susceptible to ASR. This difference has prompted extensive research into the use of glass in concrete and methods to mitigate its reactivity.

Studies have shown that finely ground glass powder can help reduce ASR expansion in concrete. Afshinnia and Rangaraju (Afshinnia and Rangaraju., 2015) reported that replacing 20–30% of aggregate with glass powder effectively mitigated ASR. Similarly, Zheng (Zheng., 2016) found that using fine glass particles reduced ASR activity in concrete. Ammash, Muhammed, and Nahhab (Ammash et al., 2017) also demonstrated that incorporating waste glass as a partial replacement for fine and coarse aggregates at 10%, 20%, 30% and 40% replacement levels led to a noticeable reduction in ASR expansion.

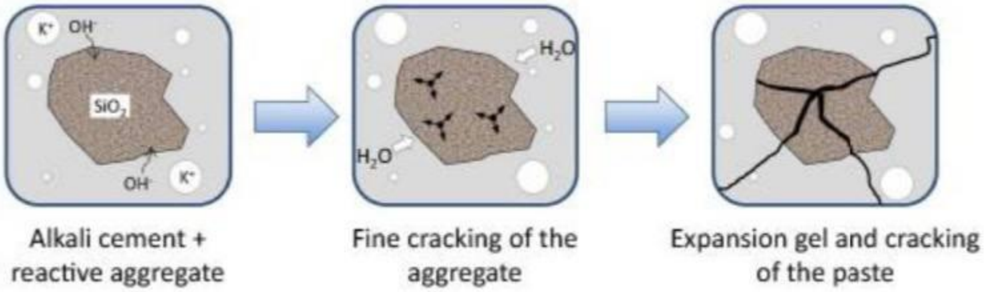


Figure 2.3 Alkali- Silica Reaction in Concrete

Source: (Abdelrahman et al., 2015)

2.4 Processing Techniques

The recycling process involves several steps, including collection, cleaning to remove impurities, crushing into specific particle size. Proper processing is essential to ensure consistent performance and minimize potential adverse effects on concrete quality.

2.5 Challenges and Mitigation Strategies

One of the primary challenges in using glass aggregate is the risk of ASR, leading to expansion and cracking. It can be mitigated by adding supplementary cementitious materials such as fly ash, metakaolin, or silica fume, which reduce the alkali content and limit the reactivity of the glass.

2.6 Environmental and Economic Implications

The recycling of waste glass as a partial coarse aggregate replacement can reduce landfill volume and conserve virgin aggregate. Economically, using local waste materials can cut material costs. It will be nice to know that there are diverse means possible to achieve sound and durable concrete, instead of relying on granite alone.

2.7 Previous works done.

According to Reindl (2003), waste glass has been utilized in various construction-related applications, including asphalt paving, road construction, building materials (such as glass tiles, wallpapers and bricks), glass fibers, abrasives, insulation materials, landscaping, decorative art, hydraulic cement and as aggregates in concrete. However, for any application to be effective, it is essential to understand the physical and chemical characteristics of waste glass.

Research into this application dates back to the 1960s, 1970s, and 1980s (Johnston, 1974; Phillips, 1972; Schmidt & Santucci, 1966). Many of these early investigations, however, lacked precision and consistency in experimental methods. Renewed interest in the use of waste glass has emerged in recent decades, largely driven by the environmental challenges associated with glass disposal and the implementation of global sustainability policies such as the European Union Directive 2008/98/EC which promote waste reduction and recycling.

Studies have shown that incorporating crushed glass in concrete can improve abrasion resistance and reduce drying shrinkage compared to conventional concrete. Additionally, concrete containing glass aggregates generally exhibits lower water absorption (Anna, 2013).

Jin, Meyer and Baxter (Jin et al., 2000) examined the use of colored glass as both fine and coarse aggregate replacements in concrete mixes. Their results revealed that non-colored waste glass produced greater expansion due to alkali–silica reaction (ASR) compared to concrete containing colored glass. Similarly, Meyer et al. (2001) observed that the inclusion of glass aggregates influenced the mechanical behavior of concrete. They explained that the relatively smooth surface of glass particles reduces the interfacial bonding strength with cement paste, thereby altering the mechanical properties.

Topcu and Canbaz (Topcu and Canbaz., 2004) also reported that incorporating glass waste as coarse aggregate replacement led to a general reduction in the mechanical strength of concrete. Their findings were supported by Park, Lee and Kim (Park et al., 2004), who concluded that replacing fine aggregate with waste glass reduced slump values and that increasing the replacement percentage further decreased mechanical strength.

In contrast, Shehata et al. (1996) found that using waste glass as a partial replacement for fine aggregate improved the mechanical performance of concrete. Their results indicated higher modulus of rupture values across all mixtures and showed that glass particles enhanced interfacial bonding and acted as crack arrestors, preventing the propagation of microcracks.

Shayan (Shayan, 2002) reported that up to 50% by weight of natural aggregate could be replaced with glass both coarse and fine for structural and non-structural applications. However, he cautioned that adequate measures should be taken to minimize ASR, such as incorporating suitable pozzolanic materials in appropriate proportions.

Serniabat, Khan and Zain (Serniabat et al., 2014) conducted experiments using crushed waste glass sized between 5 mm and 20 mm as coarse aggregate, replacing natural aggregate in proportions ranging from 0% to 80%. Using ordinary Portland cement (Type I) and fine sand smaller than 0.5 mm, they achieved a maximum compressive strength of 3,889 psi (26.81 MPa) at an optimal blend of glass particles.

Ganiron Jr. (2014) investigated the use of waste glass bottles as a substitute for coarse aggregate in mass housing concrete projects. The study employed ASTM testing standards and used Portland pozzolanic cement (Type IP). Specimens were tested after 7 and 28 days of curing at replacement levels of 0% and 10%, showing comparable mechanical behavior suitable for structural applications.

Otunyo and Tornwini (2016) evaluated concrete in which coarse aggregate was partially replaced with waste glass at 5%, 10%, 15%, 20%, and 25%. The mixes were prepared at a ratio of 1:2:4 with a water–cement ratio of 0.4 and tested after 7, 14, and 28 days of curing.

Their results indicated that moderate replacement levels provided acceptable strength characteristics.

Gerges et al. (2018) used recycled green glass bottles as coarse aggregate replacements at 33%, 50%, 66%, and 100%. They concluded that 33% replacement was optimal for maintaining the desired mechanical and workability properties, noting that waste glass significantly influences both fresh and hardened concrete performance.

Similarly, Kereyou and Ibrahim (2014) utilized window glass waste as a coarse aggregate substitute at replacement levels of 0%, 20%, 25%, and 30%. After 28 days of curing, they observed favorable fresh and hardened concrete properties, with the most economical and performance-efficient results achieved at 25% replacement.

Al-Bawi, Kadhim, and Al-Kerttani (2017) examined self-compacting concrete (SCC) in which recycled waste glass replaced aggregates at 0%, 20%, 40%, 60%, 80%, and 100% by weight. The concrete was produced with a water-to-binder ratio of 0.35, a total binder content of 570 kg/m^3, and a constant slump flow of 700 ± 30 mm. Testing at 28 days revealed that waste glass reduced the brittleness of SCC compared to the reference mix, demonstrating its potential to improve deformation characteristics and energy absorption capacity.

2.8 Research Gap

While numerous studies have explored the mechanical properties and strength development of concrete incorporating waste glass as coarse aggregate, there remains limited understanding of how this substitution specifically affects the setting time of concrete under varying environmental and mix conditions. Most existing research focuses on compressive strength, durability and workability but the implications on initial and final setting times which are critical for construction scheduling and placement have not been addressed. This creates a knowledge gap, particularly in the context of tropical climates like Nigeria's, where temperature and humidity can further influence setting behavior.

CHAPTER THREE

METHODOLOGY

3.1 Materials

The following materials were used for this project and their sources as well were of standard. Ordinary Portland Cement (OPC) conforming to Nigerian Industrial Standard (NIS) [444-1:2003] specifications was used. The cement was obtained from a local distributor and stored properly to prevent contamination or moisture entry. Also fine aggregate (sand), clean and free from materials such as clay, silt and organic matter sourced from a local riverbed was sieved to meet standard grading requirements according to [BS EN 12620]. Then, crushed granite of maximum size 20 mm was used as the coarse aggregate. It was washed, air-dried and tested to ensure compliance with the specifications. Afterwards, glass bottles were collected from Coca-Cola Bottling Company. They weren't of different types but different colours of the same compositions. The glass bottles were washed thoroughly to remove labels and dirt before being crushed manually into particles of sizes 10-20mm. Water free from impurities was used for mixing and curing the concrete specimens.

3.2 Sample preparation.

3.2.1. Preparation of waste glass

This preparation of waste glass for use as a partial replacement for coarse aggregate in concrete involved several critical steps designed to ensure the cleanliness, appropriate particle size and usability of the glass in concrete mixtures. This process began with the cleaning of the waste glass materials because the glass often contains impurities such as paper labels, adhesives, organic residues and general dirt. These contaminants were removed through comprehensive washing using clean water. It was necessary to prevent the introduction of unwanted materials that could compromise the strength or durability of the final concrete product.

After washing, the glass was dried by exposing the washed material to open sunlight for a sufficient period. This air-drying step was important to eliminate residual moisture that could affect both the grinding process and the water-cement ratio during concrete mixing.

The next stage was crushing the dried glass into smaller pieces of size 10 to 20mm. It was done using a hammer to reduce the material into smaller particles. Once the glass had been crushed, it was passed through the sieving process which was to isolate particles within the desired size range. Particles exceeding this size limit were either re-crushed or excluded, depending on the requirements of the concrete mix.

Finally, the glass particles were put in a clean and dry storage facility where they were kept until they were needed for concrete production. Storage was done under controlled conditions to prevent moisture absorption and contamination from dust or foreign materials. Maintaining a dry storage environment helped preserve the quality of the prepared glass particles and guaranteed that their properties remain stable up to the point of mixing.

3.2.2. Preparation of concrete mix.

The concrete mix was prepared targeting a characteristic compressive strength of 20 KN/M^2 at 28 days. A conventional ratio of 1:2:4 was adopted across all mixes to maintain consistency. Five different mix proportions were prepared in table 3.1.

Table 3.1 Different proportion mixes.

Mix	Mass of fine aggregate (kg)	Mass of coarse aggregate (kg)	Mass of glass (kg)	Mass of cement (kg)	Mass of water (kg)
Mix 1 (0%)	6.2	12.4	0	3.1	1.55
Mix 2 (10%)		11.16	1.24		
Mix 3 (20%)		9.92	2.48		
Mix 4 (30%)		8.68	3.72		
Mix 5 (40%)		7.44	4.96		

3.2.3. Concrete Production and Casting

The dry constituents (fine aggregate, coarse aggregate, waste glass and cement were thoroughly mixed until a uniform colour and texture were obtained. Water was then gradually added while mixing continued until a homogeneous and workable mix was achieved in the mixer. Cube molds of internal dimensions 100 mm × 100 mm × 100 mm were cleaned and lightly oiled to prevent the concrete from sticking to the mold surfaces. The cubes were placed on the vibrator so they could be compacted properly. The filled molds were allowed to set for 24 hours at room temperature. After this period, the hardened concrete cubes were carefully demolded to avoid edge damage. The demolded cubes were immersed in clean water in a curing tank maintained for specified curing periods of 7, 14, and 28 days. The curing process ensured proper hydration and development of concrete strength.

3.3 Laboratory Testing Procedures

Different tests were carried out to ensure the aftermath concrete mix is up to standard and also suitable for use in the society.

3.3.1 Slump Test (Workability Test)

The workability of concrete was assessed using the slump test method, in accordance with BS EN 12350-2:2009. This test provided a quick and practical measure of the consistency and flowability of fresh concrete, which were key indicators of its workability. It helped determine how easily the concrete could be mixed, placed and compacted without segregation. The slump test was conducted for all replacement levels which helped evaluate the influence of WG on the fresh properties of the concrete.

Apparatus used to carry out this slump test were; Slump cone (100 mm diameter at the top, 200 mm diameter at the bottom and 300 mm high), tamping rod (600 mm long, 16 mm diameter), flat base plate, weighing balance, trowel and scoop

Then to begin with, internal surface of the slump cone was moistened and placed on a smooth, horizontal, non-absorbent base. Freshly mixed concrete was filled into the cone in three layers, each approximately one-third of the cone’s height. Each layer was tamped 25 times using the rounded end of the tamping rod to ensure compaction. The top surface was leveled and the cone was carefully lifted vertically. The concrete slumped and the vertical difference between the top of the cone and the displaced concrete was measured in millimeters

3.3.2 Compressive Strength Test

The compressive strength test was conducted to determine the load-bearing capacity at various replacement levels. This test was essential for assessing the structural performance of concrete, as compressive strength is a critical property in most structural applications. The test was carried out in accordance with BS EN 12390-3:2002. Concrete cubes of standard dimensions 100 mm × 100 mm × 100 mm were casted and cured in distilled water. The compressive strength was measured at curing ages of 7, 14, and 28 days, to evaluate both early and long-term strength development.

The test apparatus used were compression testing machine, steel molds, weighing balance, trowel, tamping rod and compacting tools, curing tank or water bath, metallic sheet, vibrator.

Fresh concrete was placed into lubricated cube molds in three layers, each layer compacted using a vibrating table. The surface was leveled and the specimens were left to set for 24 hours at room temperature. After demolding, the cubes were cured by immersion in clean water until the designated testing ages. At the end of each curing period (7, 14, and 28 days), the cubes were removed from the curing tank, surface-dried and tested using a compression testing machine. Each cube was placed centrally between the plates of the machine and loaded until failure.

The compressive strengths were calculated using the formula:

$$\text{Fcu} = \frac{P}{A} \qquad \text{equ 3.1}$$

Where: Fcu= compressive strength (N/mm^2)

P= maximum load applied at failure (N)

A= cross-sectional area of the cube (mm^2)

The average strengths of three cubes per mix per age were recorded and compared across the different replacement levels to assess the influence of WG on the compressive performance of the concrete.

3.3.3 Density Test

The density of concrete specimens were calculated by dividing the mass by the volume after 7, 14 and 28 days of curing.

3.3.4 Setting Time

The apparatus employed included the Vicat apparatus fitted with a 1 mm needle for setting time determination and a 10 mm plunger for consistency checks, a Vicat mould (40 mm height, 70 mm top diameter, and 80 mm base diameter), a non-porous mixing bowl (1 L capacity), a spatula or trowel for mixing, an analytical balance (±0.01 g), a graduated cylinder (accuracy ±1 mL), a stopwatch or timer, a glass plate for covering the mould, and a temperature-controlled water bath or chamber maintained at 20 ± 2 °C.

For the determination of standard consistency, 400 g of the cementitious material (OPC + waste glass at the specified replacement level) was weighed. Approximately 26 % water by weight (~130 mL) was added and thorough mixing was carried out for 4 minutes (2 minutes slow and 2 minutes fast). The prepared paste was then filled into the Vicat mould placed on a glass plate. The 10 mm plunger of the Vicat apparatus was brought into contact with the paste surface and released. The depth of penetration after 30 seconds was noted. The procedure was repeated with incremental adjustments in water content (±5–10 mL) until a penetration of 6 ± 2 mm was achieved. The corresponding water content was recorded and taken as the standard consistency.

For the paste preparation for setting time determination, a fresh paste was prepared using the same cementitious material (400 g) and the water content obtained from the consistency test. Mixing was carried out for 4 minutes (2 minutes at low speed followed by 2 minutes of vigorous mixing). The paste was immediately filled into the Vicat mould within 5 minutes of water addition, ensuring that no air voids were present and the surface was levelled. The mould was then covered with a glass plate to minimize moisture loss.

For the measurement of initial setting time, the plunger was replaced with the 1 mm Vicat needle. The needle was carefully lowered to touch the surface of the paste and released to penetrate vertically. The depth of penetration was measured at 15-minute intervals from the time of water addition, and the needle was cleaned after each reading to maintain accuracy. The initial setting time was defined as the time elapsed from water addition until the needle penetrated to a point 25 mm from the top or 5 mm from the bottom of the mould. It was carried out on three samples and the average initial setting time was calculated by dividing the data gotten from the samples by 3 as seen in equation 3.2.

$$\text{Average initial setting time (mins)} = \frac{\text{Ti1} + \text{Ti2} + \text{Ti3}}{3} \qquad 3.2$$

Where;

(i.) Ti1= initial setting time for sample 1.

(ii.) Ti2= initial setting time for sample 2.

(iii.) Ti3= initial setting time for sample 3.

For the measurement of final setting time, testing was continued every 30 minutes after the initial setting time had been reached. The final setting time was recorded at the point when the needle failed to make a visible impression on the surface of the paste, indicating that sufficient rigidity had been attained. It was carried out on three samples and the average final setting time was calculated by dividing the data gotten from the samples by 3 as seen in equation 3.3.

$$\text{Average final setting time (mins)} = \frac{\text{Tf1} + \text{Tf2} + \text{Tf3}}{3} \qquad 3.3$$

Where;

(i.) Tf1= initial setting time for sample 1.
(ii.) Tf2= initial setting time for sample 2.
(iii.) Tf3= initial setting time for sample 3.

3.3.5 Water Absorption Test

The water absorption test was conducted to evaluate the permeability and durability characteristics of the concrete specimens at 28 days of curing. After the concrete cubes were removed from the molds, they were allowed to dry and their average dry weights were determined using a digital weighing balance.

Subsequently, the specimens were completely immersed in water for curing at varying partial replacement levels of 0%, 10%, 20%, 30%, and 40% with waste glass as coarse aggregate. After the designated curing period, the average saturated weights of the cubes were recorded.

The percentage of water absorption for each sample was then calculated based on the difference between the saturated and dry weights, relative to the dry weight of the specimen. This ratio provided an indirect measure of the concrete's durability and porosity, as lower water absorption generally indicates denser and more durable concrete.

3.4 Data Analysis

Experimental findings/results were analyzed through descriptive statistical methods. Comparative analysis between the control mix and glass-modified mixes were carried out to assess performance variations. Results were presented in tables and charts for better interpretation and visualization.

3.5 Health, Safety, and Environmental Considerations.

All necessary safety measures were observed throughout the research. Personal protective equipment (PPE) such as gloves and nose masks were worn during glass crushing and concrete mixing activities. Efforts were also made to reduce dust generation and properly dispose of waste materials to reduce environmental impact that this project is about.

CHAPTER FOUR

RESULTS AND DISCUSSION

The main goal of this chapter is to show the experimental outcomes and results of the different concrete mixtures to determine the usefulness and effects of waste glass on the performance and properties of concrete. For every test, the samples modified using waste glass were compared to those made using the control mixes. The following tests, including: slump test, compressive strength, density and water absorption test were performed for each of the samples. The results are illustrated using different tables and graphs for better understanding.

4.1 Slump Test Result

The results of the slump test represented in Table 4.1 showed a clear variation in the workability of concrete with the addition of waste glass as a partial replacement for coarse aggregate.

Table 4.1 Influence of waste glass on Workability.

% of glass (%)	**Slump (mm)**	**Standard value (mm)** **50**
0	30	Ok
10	40	Ok
20	30	Ok
30	50	Ok
40	60	Ok

The control mix, which contained no waste glass, recorded a slump value of 30 mm, indicating a relatively low workability typical of conventional concrete with natural coarse aggregates. When 10 % of the coarse aggregate was replaced with waste glass, the slump increased slightly to 40 mm, suggesting an improvement in the ease of placement and compaction. At 20 % replacement, the slump value dropped back to 30 mm, before rising again to 50 mm and 60 mm at 30 % and 40 % replacement levels, respectively.

This trend indicates that workability was generally enhanced with higher percentages of waste glass, especially beyond 20% replacement. The increase in slump values may be attributed to the smooth and impervious surface texture of glass particles, which tend to reduce internal friction between aggregates and improve the flow of the mix. As a result, the concrete becomes more workable and easier to handle. Additionally, the angular shape and uniform size distribution of the glass particles may have contributed to better particle arrangement, reducing interlocking and allowing the mix to move more freely during compaction.

However, the slight fluctuations observed between 10 % and 20 % replacement levels could be due to variations in water demand and mix consistency, as waste glass can alter the internal moisture distribution of the concrete. Despite these minor changes, the overall increase in slump with higher glass content suggests that waste glass, when used as a coarse aggregate, tends to act as a workability enhancer due to its smooth texture and non-absorbent nature.

It was therefore concluded that the incorporation of waste glass in concrete led to an improvement in workability as the replacement level increased.

4.2 Compressive Strength Test

The compressive strength results at 7 days of curing as shown in Table 4.2 were observed to vary with the percentage replacement of coarse aggregate by waste glass.

Table 4.2 Compressive Strength Test Results (MPa) at 7 days.

% of WG (%)	Compressive strength (Mpa)
0	12.85
10	13.59
20	13.78
30	13.37
40	12.96

The control mix, which contained no waste glass, recorded a strength of 12.85 MPa. An increase in strength was observed at 10 % replacement, reaching 13.59 MPa and the maximum value of 13.78 MPa was obtained at 20 % replacement. Beyond this level, the strength was found to decrease gradually to 13.37 MPa at 30 % and 12.96 MPa at 40 %.

The improvement in strength up to 20 % replacement was attributed to better particle packing and the filler effect of the crushed glass, which were believed to reduce voids and enhance the density of the concrete matrix. Limited pozzolanic activity may also have been developed as the amorphous silica in the glass reacted with calcium hydroxide from cement hydration, forming additional calcium silicate hydrate (C–S–H) gel that strengthened the matrix.

At higher replacement levels, the reduction in compressive strength was attributed to the smooth and non-porous surface texture of the glass, which resulted in weaker bonding between the cement paste and aggregate. The decrease lead to micro-cracking within the concrete.

Overall, it was concluded that the use of waste glass as a partial replacement for coarse aggregate at 7 days improved compressive strength up to an optimum level of about 20 %, beyond which a gradual decline was observed.

The compressive strength results at 14 days of curing as shown in Table 4.3 were found to decrease progressively with an increase in the percentage of waste glass used as a partial replacement for coarse aggregate.

Table 4.3 Compressive Strength Test Results (MPa) at 14 days.

% of WG (%)	Compressive strength (Mpa)
0	21.92
10	21.42
20	20.95
30	19.28
40	17.00

The control mix, containing no waste glass, recorded the highest compressive strength of 21.92 MPa. When 10 % of the coarse aggregate was replaced with waste glass, the strength slightly decreased to 21.42 MPa, followed by a further reduction to 20.95 MPa at 20 % replacement. A more pronounced decline was observed at higher levels, where the compressive strength dropped to 19.28 MPa and 17.00 MPa for 30 % and 40 % replacements, respectively.

The gradual decrease in strength with increasing waste glass content was attributed to poor interfacial bonding between the glass particles and the cement paste, as the smooth and impervious surface of glass limited adhesion and mechanical interlock. The reduction in strength may also have been caused by the inert nature of glass, which contributed little to the hydration process, as well as by the increased brittleness. Inadequate compaction and the possible formation of micro-voids could also have contributed to the observed reduction in compressive strength.

Overall, it was concluded that the inclusion of waste glass as a coarse aggregate replacement resulted in a decrease in compressive strength beyond the control mix. The results indicated that higher percentages of waste glass negatively affected the mechanical performance of the concrete, suggesting that such replacement levels may not be suitable where high compressive strength is required.

The compressive strength results at 28 days of curing as shown in Table 4.4 were observed to decrease consistently with an increase in the percentage of waste glass used as a partial replacement for coarse aggregate.

Table 4.4 Compressive Strength Test Results (MPa) at 28 days.

% of WG (%)	**Compressive strength (Mpa)**	**Standard value (Mpa)** **20**
0	23.02	Ok
10	22.40	Ok
20	21.71	Ok
30	20.30	Ok

The control mix, containing no waste glass, achieved the highest compressive strength of 23.02 MPa. When 10 % of the coarse aggregate was replaced with waste glass, the strength decreased slightly to 22.40 MPa, followed by further reductions to 21.71 MPa at 20 % and 20.30 MPa at 30 %.

The continuous decline in strength with increasing glass content was attributed to the smooth and non-porous surface of glass particles, which provided limited mechanical interlocking and weak adhesion with the cement paste. This weak interfacial bond likely resulted in poor stress transfer within the concrete matrix. In addition, the inert nature of glass meant that it did not participate significantly in the hydration process, thereby reducing the formation of strength-contributing compounds such as calcium silicate hydrate (C–S–H). At higher replacement levels, possible segregation may also have contributed to the formation of micro-voids, leading to lower compressive strength values.

Overall, it was concluded that increasing the percentage of waste glass as a coarse aggregate replacement led to a gradual reduction in compressive strength. The best performance was obtained in the control mix, with all glass-containing mixes showing lower strength values. This pattern agreed with findings from previous studies, which reported that excessive use of waste glass in concrete tends to weaken the matrix due to poor bonding characteristics and the brittle nature of glass aggregates.

4.3 Density Test

The results of the density test conducted after 28 days of curing as shown in Table 4.5 were observed to show a gradual decrease in the density of concrete with increasing percentages of waste glass used as a partial replacement for coarse aggregate.

Table 4.5 Influence of waste glass on Density.

% of WG (%)	Density (g/cm^3)	Standard value (g/cm^3) 2.400
0	2.6120	Ok
10	2.5442	Ok
20	2.5239	Ok
30	2.4109	Ok
40	2.3911	Not ok

The measured densities were 2.6120 g/cm^3, 2.5442 g/cm^3, 2.5239 g/cm^3, 2.4109 g/cm^3, and 2.3911 g/cm^3 for 0 %, 10 %, 20 %, 30 %, and 40 % replacement levels, respectively.

The reduction in density with higher glass content was attributed to the lower bulk density of waste glass compared to that of natural coarse aggregate. It was also believed that the smooth and angular nature of crushed glass particles resulted in less effective packing and bonding within the concrete matrix, leading to an increase in internal voids and a corresponding decrease in overall mass per unit volume. As the glass content increased, the cumulative effect of this reduced compactness became more pronounced, resulting in lower density values.

The observed decrease in density suggested that the replacement of natural aggregate with glass particles led to a lighter concrete mix. This behaviour has been reported by several researchers, who explained that the substitution of dense natural aggregates with relatively lighter glass aggregates reduces concrete's specific gravity and, consequently, its density.

Although this reduction may slightly affect compressive strength, it can be beneficial where lightweight concrete is desirable, such as in non-structural applications or components requiring reduced dead load.

In summary, it was concluded that the inclusion of waste glass as a partial replacement for coarse aggregate caused a progressive reduction in concrete density. This reduction was primarily due to the lower specific gravity and smooth texture of glass particles, which affected the compactness of the mix. Nevertheless, the resulting densities remained within acceptable limits for structural concrete, indicating that waste glass can be effectively utilized in concrete production without significant loss of quality.

4.4 Setting Time.

The results of the setting time test as shown in Table 4.6 revealed that the initial setting time of the cement paste was recorded as 65 minutes, while the final setting time was obtained as 172 minutes.

Table 4.6 Setting Time Test Values

Initial Setting Time (mins)	Avg. Initial Time (mins)	Final Setting Time (mins)	Avg. Final Time (mins)	**Standard value (mins)**
61	65	170	172	Initial – 60 (ok)
70		172		Final – 180 (ok)
64		174		

These values indicated that the cement used exhibited a normal rate of setting and hardening, remaining well within the standard limits prescribed by BS EN 196-3 (2016) and ASTM C191, which require the initial setting time to be not less than 30 minutes and the final setting time to be not more than 600 minutes.

The initial setting time of 65 minutes suggested that the cement began to stiffen and lose plasticity at a moderate rate, allowing sufficient time for proper mixing, placing, and compaction before hardening commenced. This behaviour was considered typical of ordinary Portland cement of sound quality. The final setting time of 172 minutes indicated that the cement had achieved complete rigidity and could no longer be reworked, which is also within the expected range for good-quality cement.

Since waste glass was used as a partial replacement for coarse aggregate, it was understood that the glass particles did not directly interact with the cement paste during hydration. Consequently, any variation in setting time observed among the mixes was not attributed to the waste glass itself but rather to normal differences in environmental conditions, water–cement ratio, or experimental handling during testing.

4.5 Water Absorption Test.

The water absorption behavior at 28 days of curing was observed to decrease with increasing proportions of waste glass up to 30 %, with a minor increase recorded at 40 % replacement as shown in Table 4.6.

Table 4.7 Water absorption test values.

% of WG (%)	Avg. Dry Weight of Cube (g)	Avg. Wet Weight of Cube (g)	% of Water Absorbed (%)	Standard % of water absorbed (%) 3
0	2.6120	2.6528	1.64	Ok
10	2.5442	2.5756	1.40	Ok
20	2.5239	2.5528	1.30	Ok
30	2.4109	2.4392	1.21	Ok
40	2.3911	2.4211	1.30	Ok

The control mix (0 %) exhibited an absorption of 1.6 %, while the mixes with 10 %, 20 % and 30 % replacements showed absorptions of 1.4 %, 1.3 % and 1.2 %, respectively; the 40 % replacement mix displayed an absorption of 1.3 %. This trend was considered to reflect the non-porous character and low water uptake of glass, which were believed to reduce overall mix porosity when natural aggregates were partially replaced. The slight rise in absorption at 40 % was attributed to the possible deterioration of the interfacial transition zone caused by excessive glass content, leading to micro-void formation and a marginal increase in water ingress. Overall, the water absorption values remained low, indicating that the mixes retained satisfactory densification and durability characteristics for the studied replacement range.

Below is a project-ready cost–benefit section for inclusion in your report. It uses your actual materials and transport figures and a small set of transparent assumptions so the reader can follow the calculation. The outcome is realistic and shows whether a cost saving was actually achieved for the 30% replacement case.

4.6 Cost Benefit Analysis

The cost benefit analysis was carried out for one laboratory batch at 30% waste glass replacement, which was identified as the optimum replacement level. All costs were computed for a fixed total coarse aggregate mass of 12.40 kg, so that the 30% replacement mix and control mix differ only in the proportion of granite and waste glass used. This allowed direct cost comparison by summing individual cost components for each mix.

4.6.1 Material Quantities Used

The quantities presented below were taken directly from the mix design. The mass of granite and waste glass was determined by multiplying the total coarse aggregate mass (12.40 kg) by their respective percentage proportions (70% granite and 30% glass).

i. Granite used = 0.70 x 12.40 = 8.68 kg.

ii. Waste glass used = 0.30 x 12.40 = 3.72 kg.

iii. Total coarse aggregate mass = 8.68 + 3.72 = 12.40 kg.

iv. Fine aggregate mass = 6.2 kg.

v. Cement mass = 3.1 kg.

vi. Water mass = 1.55 kg.

4.6.2 Unit Cost of Granite and Glass

Total costs of the control mix and 30% replacement mix were calculated by summing material cost, transportation cost and labour cost. Granite was priced per cubic metre in the local market. To obtain a unit cost compatible with laboratory batching, the market price was divided by the bulk density of granite to convert the cost from ₦/m^3 to ₦/kg. As for glass, it was not costed because it is waste.

i. Market price of crushed granite = ₦9,000/m^3

Bulk density of granite = 1,600 kg/m^3

Granite unit cost = $\frac{₦9,000}{1,600}$ = ₦5.625/kg.

ii. Glass cost = ₦0.00/kg.

A. 30% Replacement Mix.

i. Granite cost = Granite used x unit cost for granite

$= 8.68\ x\ 5.625 =$ ₦48.82.

Granite transportation = ₦3,000.

ii. Glass cost = Glass used x Glass unit cost

= $3.72\ x\ 0.00 =$ ₦0.00.

Glass transportation = ₦200.

Glass crushing and washing = ₦1,000.

Total cost = 48.82 + 3,000 + 200 + 1000 = ₦4,248.82

B. Control mix (100% Granite)

i. Granite cost = 12.40 x 5.625 = ₦69.75.

Granite transport = $\frac{3000 \text{ x } 12.40}{8.68}$ = ₦4,285.71.

Total cost = 69.75 + 4,285.71 = ₦4,355.46.

4.6.3 Net Cost Difference

Net cost difference is the final financial gap between two options, calculated by comparing their respective total costs after subtracting all relevant discounts as shown in equation 4.1.

$$\text{Net Cost Difference} = \text{CMC} - \text{RMC} \tag{4.1}$$

Where: CMC = Control mix cost.

RMC = 30% Replacement mix cost.

Net cost difference = ₦4,355.46 - ₦4,248.82 = ₦106.64.

4.6.4 Percentage Cost Savings

The percentage cost savings was calculated by dividing the net cost difference by the total cost of the control mix and multiplying by 100 as shown in equation 4.2.

$$\text{Percentage cost savings} = \frac{\text{NCD x 100}}{\text{CMC}} \tag{4.2}$$

Where: NCD = Net Cost Difference.

CMC = Control mix cost.

$$\text{Percentage cost savings} = \frac{106.64 \text{ x } 100}{4{,}355.46} = 2.5\%.$$

At 30% replacement level, the use of waste glass as a partial replacement for coarse aggregate resulted in a cost saving of approximately 2.5% compared to conventional concrete, indicating favorable economic viability.

The cost reduction observed in the 30% replacement was primarily due to the reduced quantity of natural granite required, coupled with the assumption that waste glass was freely available and incurred minimal transportation. This demonstrated that, under favorable sourcing and processing conditions, waste glass can serve as a cost-effective partial replacement for coarse aggregate. While the cost savings observed were significant at laboratory scale, the economic feasibility of waste glass incorporation in real construction projects will depend on factors such as availability of waste glass, transportation distance, processing method and scale of production. Nevertheless, the results suggested strong potential for economic benefits when waste glass is sourced locally and processed efficiently.

CHAPTER FIVE

5.1 Conclusion

From the results obtained, it was concluded that the incorporation of waste glass as a partial replacement for coarse aggregate influenced the properties of concrete both in the fresh and hardened states. The slump test revealed that workability increased progressively with higher percentages of waste glass, particularly beyond 20% replacement. This improvement was attributed to the smooth and impermeable surface of glass particles, which reduced internal friction between aggregates and enhanced the flow of the mix.

From the 28-day compressive strength results, it was concluded that the replacement of coarse aggregate with waste glass led to a gradual decrease in strength, with the control mix achieving 23.02 MPa and the mixes containing 10 %, 20 %, and 30 % waste glass recording 22.40 MPa, 21.71 MPa, and 20.30 MPa, respectively. Although each increment in replacement resulted in a reduction in strength, the mix with 30 % waste glass was found to retain a compressive strength above 20 MPa, indicating that it remained structurally acceptable for various non-structural and moderate-load applications. Consequently, 30 % was identified as the optimum replacement level, as it provided the best compromise between acceptable strength performance and the sustainability advantage of reducing natural aggregate usage, making it a practical and environmentally beneficial choice for concrete production.

The density test indicated a gradual reduction in concrete density as the waste glass content increased. This reduction was attributed to the lower bulk density and compactness of glass aggregates compared to natural stones. Nevertheless, all recorded density values remained within acceptable limits for structural-grade concrete, indicating that waste glass can be safely utilized without significantly compromising concrete quality.

It was concluded that the cement used exhibited normal setting behaviour, with an initial setting time of 65 minutes and a final setting time of 172 minutes, both within the limits specified by standard codes. The results indicated that the incorporation of waste glass as a partial replacement for coarse aggregate had no significant effect on the setting characteristics of the cement, as the glass did not chemically interact with the paste during hydration. Minor variations observed were attributed to normal testing and environmental conditions.

The water absorption test showed a decrease in absorption values with increasing glass content up to 30%, followed by a slight rise at 40%. The low absorption values recorded across all mixes confirmed that the inclusion of waste glass reduced porosity and improved the impermeability of the concrete, which is beneficial for durability. The minor increase at 40% was believed to have resulted from the weakening of the interfacial transition zone at higher replacement levels.

In summary, it was concluded that the use of waste glass as a partial replacement for coarse aggregate improved workability and durability while maintaining acceptable strength and density properties up to 20–30% replacement levels. Beyond this range, performance declined slightly due to poor bonding characteristics and reduced interlocking between the cement paste and the smooth glass surface.

5.2 Recommendations

Based on the findings of this research, the following recommendations were made:

1. Waste glass can be safely used as a partial replacement for coarse aggregate in concrete production up to 20–30%, as this range provides an optimal balance between strength, workability, and durability.

2. Individuals, contractors, and ready-mix producers are encouraged to incorporate recycled glass aggregates in non-structural or medium-strength concrete works, such as paving blocks, kerbs, and floor screeds, to promote sustainable waste management.

3. Government agencies and environmental bodies should support and regulate the collection, sorting, and processing of waste glass for use in the construction industry, as this can reduce environmental pollution and the demand for natural aggregates.

4. Awareness campaigns and training programs should be established to educate builders and engineers on the benefits and safe use of recycled materials in concrete.

5. Quality control measures should be enforced to ensure that glass used in concrete is properly crushed, cleaned, and free of impurities that may negatively affect performance.

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