EFFECT OF WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

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PLAGIARISM

This work, **EFFECT OF WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE** by **AJOKUTA, Adeoluwa Adesina**

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DEDICATION

I give thanks to God Almighty, my wonderful parents for their unwavering efforts to secure my academic success, and my teachers and lecturers for sharing their knowledge with me.

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ABSTRACT

This research explores the effect of using Waste Glass Powder (WGP) as a partial substitute for cement in concrete production. The study focused on identifying optimal WGP replacement levels that achieve comparable or improved strength, maintain workability, and ensure structural integrity. A comprehensive experimental program was conducted to evaluate key concrete properties, including compressive strength, water absorption, sieve analysis and workability.

Waste Glass Powder (WGP) was sourced, crushed, and ground into a fine powder .A control concrete mix was prepared using Portland Limestone Cement (PLC), fine and coarse aggregates, and water. Cement was replaced with WGP at 5%, 10%, 15%, and 20% by weight, and the concrete was mixed thoroughly. Concrete samples were casted in standard molds and cured for 7, 14, and 28 days. The samples were then tested for compressive strength, water absorption, and workability using the slump test.

Deleted[ADEGBEMILEKE]: For the aim and objectives of this study to be achieved, the following laboratory experiment was carried out:

After 7,14 and 28 days of curing, the results of the study indicate that incorporating Waste Glass Powder (WGP) at low replacement levels (5% and 10%) resulted (19.06 and 15.64) at 28 days, having a minimal impact on the mechanical performance of the concrete, with compressive strengths at these levels being comparable to, or only slightly lower than, the control mix. However, higher replacement levels (15% and 20%) resulted (15.14 and 10.88) at 28 days, in significant reductions in both compressive and flexural strengths were observed, as well as an increase in water absorption, due to the increased porosity and altered microstructure caused by the finer nature of WGP, which has a lower specific gravity than ordinary Portland cement. Slump test results also showed improved workability with higher WGP content, but excessive replacement could compromise the concrete's structural integrity. Overall, the study concludes that WGP can be a viable partial cement replacement, with optimal performance at 5–10% replacement levels, and suggests further research on optimizing mix designs using chemical admixtures and conducting long-term durability studies in various environmental conditions..

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The global construction industry is under increasing pressure to adopt more sustainable practices, particularly in response to environmental concerns associated with traditional concrete production. The cement industry, a major contributor to greenhouse gas emissions, is actively seeking ways to reduce its carbon footprint. One major solution to this challenge is replacing a percentage of cement with a cheap and readily available waste product which exhibits pozzolanic properties. This study aims to explore the effects of WGP on the mechanical properties and durability of concrete, highlighting its potential as a sustainable construction material.

Glass Powder is a finely milled form of glass that is created by crushing and grinding waste glass or glass materials into a powder-like consistency. This powder can vary in particle size, but it is typically very fine to maximize its surface area and reactivity.

Around the world, massive amounts of waste glass powder (WGP) are produced, there was about 200 million tons of solid waste and about 7% of it was glass waste (Aljabri et al., 2020; World Bank, 2021). In the United States, a total of 11.5 million tons of WG has been produced, with a recycling rate of 27% as of 2010. In contrast, it was anticipated that the overall WG produced in European countries would reach 4.1 million tons by 2008, with a recycling rate of approximately 60%.(EPA, 2010; European Container Glass Federation, 2008).

It is uncertain to say when, where, or how the human population was taught to produce glass. Around 4000 years ago, hand-made glass was discovered in Iraq and Egypt. In recent years, due to an ever-increasing use of glass items, the amount of waste glass produced has significantly increased. The majority of waste glass is dumped into landfills. The process of dumping glass waste is undesirable because it has serious environmental problems, and may cause harm to humans and animals. In addition, glass waste is leading to significant global environmental concerns, which can be traced back to the fact that glass is not biodegradable (Wang et al., 2020; Sharma et al., 2019).

1.2 Statement of the problem

The rising costs of cement, a crucial material in construction, have become a significant challenge for the industry, particularly in developing countries. Also, improper disposal of waste glass is of growing environmental concern due to their role in environmental degradation.

This research seeks to investigate the effect of waste glass powder as partial replacement for cement in concrete while maintaining structural integrity and meeting industry standards. It examines the potential use of waste glass powder to reduce dependency on Portland Limestone Cement, addressing the need for more sustainable alternatives within the construction industry. It seeks to add to the expanding knowledge of research on sustainable building materials by providing insightful information about the benefits, difficulties, and long-term viability of using these materials in concrete. In the end, the study hopes to pave the way for greener building methods and stimulate greater investigation into sustainable material substitutes.

1.3 Aim and objective of the study

The aim of this study is to partially replace cement with waste glass powder in the production of concrete. The objectives of this study are to:

i. Determine the particle size distribution of aggregate used.

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ii. Determine Specific gravity of waste glass powder.

iii. Determine the slump value of the concrete at 0%, 5%, 10%, 15%, and 20% replacement with Waste glass powder.

iv. Determine the compressive strength of the concrete at 0%, 5%, 10%, 15%, and 20% replacement with Waste glass powder.

v. Investigate the durability property of the sample via water absorption tests.

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Determine the slump value of the concrete at 5%, 10%, 15%, and 20% replacement with Waste glass powder.

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1.4 Scope of the study

This research project focuses on the partial replacement of cement with Waste glass powder in the production of concrete, examining the impact of WPG at six different replacement levels: 5%, 10%, 15%, and 20% The scope of the study encompasses carrying out compressive strength tests, flexural strength tests, water absorption tests, bleeding, segregation of this percentage replacement.

1.5 Justification of the study

The comparative analysis of using waste glass powder (WGP) as a partial replacement for cement in concrete holds significant implications across several key areas:

This research addresses the growing concern regarding the rising costs of Portland Limestone Cement (PLC) and proposes solutions to reduce these expenses while adhering to sustainable construction standards. By investigating WGP as a cost-effective alternative to cement, construction costs—particularly those related to cement procurement—can be substantially lowered.

Additionally, this study contributes to global efforts aimed at reducing the carbon footprint of the construction industry. Its relevance is particularly pronounced in an era where environmental responsibility and sustainability are central to both societal and industrial discussions. Incorporating WGP in concrete production has the potential to significantly decrease carbon emissions associated with cement manufacturing. As the challenges posed by climate change and environmental degradation escalate, the pursuit of eco-friendly construction solutions becomes increasingly critical.

These findings highlight the importance of utilizing local materials in sustainable development, promoting the use of readily accessible resources, and supporting local economies. This research provides valuable insights for policymakers and industry stakeholders, laying the groundwork for the creation of policies and guidelines that encourage the use of WGP as a substitute material in concrete production.

Furthermore, the construction industry can benefit from the knowledge gained regarding the adoption of more sustainable, efficient, and cost-effective practices. This study enhances the existing body of knowledge in civil engineering and materials science, particularly in the realm of sustainable construction. It paves the way for future research on alternative construction materials and their effects, thereby fostering academic and scientific advancement.

CHAPTER TWO

LITERATURE REVIEW

2.1 Glass powder as partial replacement of cement in concrete

Concrete is considered one of the most important, versatile, economical, and extensively used building materials due to its unique attributes and the strength and serviceability it exhibits. To produce concrete at any construction site, it involves a huge number of materials, which include cement, fine aggregate, coarse aggregate, water, and sometimes the use of admixtures. The major component in concrete is cement, and the demand for cement itself is increasing day by day, which in turn results in immense exploitation of natural resources and the formation of large amounts of industrial by-products worldwide, including ultra-fine industrial by-products that pose many hazards to nature. These by-products, which are being disposed of in nature, cause a serious threat to our environment. Additionally, mining such natural resources causes problems in the form of land degradation, deforestation, and destruction of natural land. Concrete stands as one of the most widely utilized construction material globally, due to its superior properties such as strength, durability, co-effectiveness and its emphasis on sustainable construction. The construction community is becoming more interested in employing waste materials in concrete. Concrete production is the most significant among all man-made materials with a global production of 8.8 billion tons per year. Concrete, the prime constituent in solid, request huge creation prompting the emanation of carbon dioxide and consequently a worldwide temperature alteration. The construction sector, being a significant user of natural resources, accounts for the extraction of approximately 60% of these resources.

2.1.1 Properties of concrete

The properties of concrete include:

a. Compressive Strength

i. Definition: The ability of concrete to withstand axial loads without failure.

ii. Importance: Determines the load-bearing capacity of structures.

b. Tensile Strength

i. Definition: The resistance of concrete to tension or pulling forces.

ii. Importance: Generally, much lower than compressive strength, leading to the need for reinforcement (like steel).

c. Durability

i. Definition: The ability to withstand weathering action, chemical attack, and abrasion.

ii. Importance: Affects the lifespan and maintenance needs of concrete structures.

d. Workability

i. Definition: The ease with which concrete can be mixed, placed, and finished.

ii. Importance: Affects the quality of the finished product and the efficiency of construction.

e. Setting Time

i. Definition: The time it takes for concrete to start hardening after mixing.

ii. Importance: Affects placement and finishing operations.

f. Shrinkage and Expansion

i. Definition: Change in volume due to moisture loss (shrinkage) or temperature changes (expansion).

ii. Importance: Can lead to cracking if not properly managed.

g. Permeability

i. Definition: The ability of concrete to allow fluids to pass through.

ii. Importance: High permeability can lead to corrosion of reinforcement and reduced durability.

h. Thermal Properties

i. Definition: Behavior of concrete under temperature variations.

ii. Importance: Affects energy efficiency and structural integrity.

i. Density

i. Definition: Mass per unit volume of concrete.

ii. Importance: Influences the weight and structural load of concrete elements.

j. Elasticity

i. Definition: The ability of concrete to deform under stress and return to its original shape once the stress is removed.

ii. Importance: Affects how concrete responds to loads.

2.2 Cement

Cement is a binding agent and a key component used for making concrete. There is no substitute for cement in making concrete. It is known that producing cement contributes to emissions of carbon dioxide and leads to an increase in climate change. To solve this problem, the partial replacement of cement with various easily available industrial by-product materials, without affecting the mechanical properties of concrete, is under the limelight. Cement production is one of the main sources of CO2, accounting for a significant portion of global anthropogenic CO2 production, and it is the third-largest industrial source of CO_2, with a large percentage coming from the decomposition of raw materials and a portion coming from the combustion of fuel in the cement kilns. A typical small wet cement plant produces a substantial amount of CO_2 while manufacturing one ton of cement with an energy consumption of a considerable amount. Since the weight percentage of cement in concrete is huge, the partial replacement of cement with various mineral additives has the effect of producing concrete with a much-reduced environmental impact.

2.2.1 Properties of cement

The properties of cement include:

a. Chemical Composition

Cement is primarily composed of compounds like tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF) (Neville, 2012). These compounds influence the strength and setting properties of cement.

b. Hydration

The hydration process is critical as it determines the development of strength in cement. When mixed with water, cement undergoes a series of chemical reactions that lead to the formation of a hardened matrix (Mehta & Monteiro, 2014).

c. Specific Gravity

The specific gravity of cement typically ranges from 3.1 to 3.3. This property helps in calculating the mix design and understanding the density of concrete (BSI, 2011).

d. Heat of Hydration

The heat generated during the hydration of cement can lead to temperature variations in large structures, affecting their integrity. This property is particularly important in mass concrete applications (Chisholm, 2015)

2.3 Glass

Glass is a solid material that is typically hard, brittle, and transparent or translucent. It is primarily made from silica (silicon dioxide), often mixed with other compounds to modify its properties. Glass has been made into practical and decorative objects since ancient times, and it is still very important in applications as building constructions, housewares, and telecommunications. It is made by cooling molten ingredients such as silica sand with sufficient rapidity to prevent the formation of visible crystals.

2.3.1 Properties of glass

i. Chemical Composition: Glass is primarily made up of silica (SiO2), with other components like soda (Na_2O) and lime (CaO). This composition contributes to its pozzolanic properties when finely ground.

i. Physical Characteristics: Glass being non-porous and has a smooth surface, making it an excellent material for improving the aesthetics of concrete surfaces.

ii. Transparency: Glass is often transparent, allowing light to pass through, which makes it useful for windows and lenses.

iii. Chemical Resistance: Glass is generally resistant to many chemicals, making it suitable for laboratory and industrial applications.

iv. Thermal Stability: While glass can withstand heat, it is sensitive to sudden temperature changes, which can cause it to crack or shatter.

v. Brittleness: Glass is strong under compression but weak under tension, making it prone to breaking if subjected to impact or stress.

2.3.2 Types of glass

i. Soda-Lime Glass: This is used in windows and containers.

ii. Borosilicate Glass: it is known due to its thermal resistance.

iii. Lead Glass (Crystal): it contains lead oxide, known for its brilliance and clarity, often used in fine glassware and decorative items.

iv. Tempered Glass: These are Heat-treated for strength and safety, which is commonly used in buildings and vehicles.

v. Fused Quartz Glass: This is made from pure silica and used in high-temperature applications.

2.3.3 Uses

i. Construction: Windows, doors, facades, and interior partitions.

ii. Containers: Bottles, jars, and packaging materials.

iii. Optics: Lenses, prisms, and other optical components.

iv. Decorative Arts: Stained glass, glass sculptures, and jewelry.

v. Technology: Screens for devices, fiber optics, and semiconductor applications.

2.3.4 Application areas

i. Structural Concrete: Can be used in slabs, beams, and columns.

ii. Architectural Features: Suitable for facades, pavements, and decorative elements.

iii. Precast Products: Used in the manufacturing of blocks, tiles, and other precast elements.

Concrete, which is a prime construction material around the world, is growing day by day. This high demand of concrete results in using high amounts of river sand as a fine aggregate. This process leads to the exploitation of this natural resource and lowering of the water table of rivers. Attempts have been made to use glass waste as replacement of natural river sand. Apart from material and energy conservation, reuse of some solid wastes could lead to improved concrete performance in a variety of areas. For example, using glass waste as fine aggregates increases the resistance of concrete to chloride penetration. Glass powders can improve the mechanical properties of concrete by the means of pozzolanic activity. It's noteworthy to mention that waste glass powder, with particle size of 100 micrometers or less, exhibits a reactive property similar to pozzolanic reaction in concrete.

Furthermore, in contrast to other industrial byproducts like slag which is obtained from large steel mills and fly ash that obtained from power stations, recycled glass powder offers several advantages as it is more readily available in nearly all urban areas since it is obtained from smaller, localized facilities. Waste glass powder was used successfully as well in producing geopolymer concrete as sand replacement. Taher et al.

On the other hand, Portland cement is generally recognized to be an energy-intensive industry and accounts for around 5–8% of global anthropogenic CO_2 emissions Depending on the type of fuels used, an estimated 0.9–1.0 ton of CO_2 is generated in producing 1 ton of cement clinker.

Using glass waste powder as a cement replacement can have a possessive effect on the reduction of CO_2 emission and saving energy, which can be considered as a significant step in producing sustainable eco-friendly concrete.

2.3.5 Benefits of using glass in concrete

i. Sustainability: Utilizing waste glass helps divert it from landfills and reduces the environmental impact of concrete production.

ii. Resource Conservation: Reduces the need for natural aggregates and cement, leading to lower carbon emissions associated with their extraction and production.

iii. Aesthetic Qualities: Glass can enhance the visual appeal of concrete, especially in decorative applications where color and finish are important.

iv. Improved Strength: As previously mentioned, WGP can improve compressive and tensile strength due to its pozzolanic properties.

v. Reduced Shrinkage: The use of glass may reduce shrinkage in concrete mixes, which can improve crack resistance.

vi. Better Durability: Concrete with waste glass can exhibit enhanced resistance to freeze-thaw cycles, chemical attacks, and other environmental stresses.

2.4 Review of previous related works

Değirmenci and Yilmaz (2011), investigated the utilization of waste glass as sand replacement in cement mortar.

The researchers analyse the alkali silica reaction (ASR) expansion and strength characteristics of mortar containing waste glasses. The mixtures showed non-deleterious expansion, but continued to expand beyond 14 days. The strength of the mortar depends on the level of waste glass replacement and age. The researchers reported that up to 30% waste glass replacement, glass containing mortar can achieve improved strength performance compared to 100% limestone mortar.

Al-jburi Najad *et al* 2019 investigated waste glass as partial replacement in cement. The researcher evaluated Chemical properties of clear and colored glass and tests showed that adding glass to mortar and concrete increased flow and compressive strength. The result showed that a 20% replacement of cement with waste glass was found to be convincing in terms of cost and environmental impact.

Bindhu and_Mafalda Matos (2022) investigated eco-friendly powder with glass powder. The researcher investigates the use of finely ground waste glass (GP) as a cement replacement in concrete. The researchers incorporated two GPs from consumer scrap in equal proportions to M30 and M40 concrete grades. The researcher reported that the results showed improved compressive strength and durability indicators.

Bheel and Adesina (2020), investigated the influence of binary blend of Glass Powder as partial replacement of cement in concrete. The researchers found out that glass powder could be used as Binary Cementitious Material (BCM) to replace Portland Cement up to 20% in concrete production The researchers stated that the incorporation of BCM will result to decrease in slump of concrete mixtures and in terms of mechanical properties, 10% BCM was deemed the optimum replacement level due to the enhancement of the compressive and split tensile strength.

Deb, P., et al. (2021), The researcher investigated the use of waste glass powder in concrete. This research highlighted that WGP not only reduced the environmental impact of concrete production but also maintained mechanical performance similar to traditional concrete mixes. It suggested optimal replacement levels for balanced performance.

Khan, M. I., et al. (2021), investigated the effect of glass powder on the mechanical and durability properties of concrete. The study reported that the addition of WGP improved the compressive strength and durability of concrete, particularly with 15% replacement. A decrease in water absorption and an increase in resistance to aggressive environments was noted.

Gamal, A. M., et al. (2021), investigated "Utilization of waste glass powder in concrete as a sustainable alternative to Portland limestone cement. The research indicated that concrete mixes with 15% WGP exhibited optimal compressive strength and workability. The study highlighted the potential for waste glass to reduce the environmental footprint of concrete.

2.5 Research gap Identified

Numerous studies have highlighted the potential for improving the sustainability and cost-effectiveness of concrete through the incorporation of waste glass powder. While significant research has been conducted on the partial replacement of cement with various materials, including waste glass powder, there is a lack of information regarding its combined use with other supplementary materials. Most existing studies have focused on the effects of waste glass powder alone, with few investigating how it interacts with other materials in concrete mixes.

This research aims to fill this gap by providing empirical data on the performance and optimal replacement levels of waste glass powder as a cement alternative, particularly in combination with other supplementary materials. Given that waste glass powder has unique chemical and physical properties, understanding its collective impact on workability, compressive strength, setting time, and long-term durability of concrete is essential for optimizing its use in construction.

CHAPTER THREE

METHODOLOGY

A sample set of fourty-five (45) concrete cubes was used in the study. The University of Benin's Civil Engineering Laboratory in Benin City, Edo State, Nigeria, is where these samples were created. After the samples were cured in water for 7, 14, and 28 days, respectively, testing of their compressive and fresh state properties were performed.

The concrete mix design will include various formulations to assess the impact of waste glass powder (WGP) as both a partial cement replacement and as a filler material. The following mixes will be prepared:

i. Control Mix: Standard concrete mix without any replacements.
ii. Replacement Mixes: Concrete mixes with WGP replacing cement at different percentages (e.g., 5%, 10%, 15%, and 20%).

3.2 Materials

The resources employed for this research include the following:

i. Cement**:** Portland limestone Cement (PLC).

ii. Waste Glass Powder: Processed waste glass, ground to a fine powder.

iii. Fine Aggregate: Sand conforming to relevant standards.

iv. Coarse Aggregate**:** Gravel or crushed stone as per standard specifications.

v. Water: Clean potable water.

3.2.1 Material sourcing

Material Sourcing is a crucial phase in any project study, focusing on the strategic procurement of raw materials and components. The materials used during the course of this study were procured to ensure quality, cost-effectiveness, and sustainability in the supply chain.

3.2.2 Cement

Portland Limestone Cement, grade 42.5N, specifically Dangote Portland cement, was used in this study. It was purchased from a local vendor from a depot at Isihor, Ugbowo, Benin city. Tests were conducted to ascertain its properties in compliance with EN 197-1 and the results showed that it met the standard.

3.2.3 Fine aggregate (Sharp sand)

In essence, fine aggregates are any naturally occurring sand particles that have been eroded away from the ground during mining. Fine aggregate includes materials like sand, silt, and clay and is described as being 4.75 mm or smaller. Fine aggregate particles are typically smaller than 6.4 mm (.25 in), while coarse aggregate particles are bigger than that size (Microsoft Encarta, 2009). This was taken in a cement depot in Isihor, Benin City. The standard sieve set (i.e., 2.36mm, 2.00mm, 1.18mm, 600μm, 425μm, 300μm, 212μm, 150μm, 75μm) was used to analyze the sand in order to determine its grade and the amount of fines present. The fine aggregate used complied with B.S. 882: 1992.

3.2.4 Coarse aggregate (Granite)

Coarse aggregate, which are used to make concrete, are naturally occurring, irregularly shaped stones or round gravels. Coarse aggregate for structural concrete contains broken fragments of hard rock, such as granite, limestone, or river gravel. Crushed volcanic rock with distinct and identifiable crystal formation and texture is known as granite chippings. Feldspar and quartz make up the majority of its composition, with trace amounts of mica and other minor accessory minerals. Granite has a specific gravity between 2.63 and 2.75. 1050 to 14,000 kilograms per square centimetre (15,000 to 20,000 lb per square inch) is its crushing strength. Granite is harder to quarry since it is stronger than other stone kinds like marble, limestone, and sandstone. Although coarse aggregate with a maximum size of 10 mm that has been sieved through 19 mm, 13.26 mm, 10 mm, 8 mm, and 5 mm was employed for this investigation, the typical maximum size of coarse aggregate designed was 10 mm. This was obtained from the same depot as the fine aggregate and cement.

3.2.4 **Waste glass powder**

Waste glass powder was sourced from New Benin market, Benin City Edo State and crushed to fine ness before taken to the laboratory for further sieving,

3.2.5 Water

Concrete was mixed using impurity-free water from the University of Benin's (UNIBEN) Civil Engineering Structural Laboratory in order to complete this project. Overall, the water met BS 3148:1980 requirements.

3.3 Particle size distribution

3.3.1 Sieve analysis

This test uses the evaluation value of the coefficient uniformity (Cu) derived from the particle size distribution curve derived from the sieve analysis test result to show the range of particle sizes of an aggregate in order to determine the normal size of the particle and its suitability as aggregate. Dry sieving technique was used in the test in accordance with BS 1377-2: 1990 instructions.

The following equipment was used to determine the particle size distribution for the fine and coarse aggregates:

i. A sieve shaker

ii. Different-sized sieves

iii. A 0.1g sensitivity weighing balance

3.3.1.2 Apparatus

The apparatus used include:

i. After cleaning and weighing each sieve to 0.1g(W), they were ready for usage.

ii. The sieve's aperture sizes were placed in decreasing order.

iii. A representative sample of the aggregate to be examined was removed, and fingers were used to break it up into individual particles.

iv. After weighing, 500g of the dried aggregate was added to the top filter.

v. The aggregate was then shaken by hand in a horizontal circular motion for approximately half an hour in order to sieve it through the stack of sieves.

vi. A weight of 0.1g (W_2) was assigned to each sieve and its contents.

vii. The initial soil weight was compared to the weight of the aggregate retained on each filter (W_2-Wi) by calculating Σ (W_2-W_1).

3.4 Concrete mix design method

3.4.1 Procedure for mix design

Based on a technique created by Okamura and Ouchi (2003), an example of a process for effectively designing SCC mixtures will be carried out.

1. According to Okamura and Ouchi (2003), the sequence is as follows:
2. Specifying the required air content, typically around 2%.
3. Calculating the volume of coarse aggregate.
4. Estimating the quantity of sand.

5. Formulating the composition of the paste.
6. Identifying the ideal water-to-powder ratio and the amount of superplasticizer needed in the mortar.
7. Lastly, evaluating the properties of the concrete through standard testing procedures.

3.4.1.1 Calculating the volume of coarse aggregate

The bulk density of coarse aggregate determines its volume. Coarse aggregate (defined as aggregate with a diameter larger than 4 mm) often makes about 50–60% of the total. The coarser aggregate there is in the concrete, the more likely it is that the coarse aggregate particles may collide or interact, increasing the chance of obstruction as the concrete travels through spaces between steel bars. The ideal quantity of coarse aggregate is contingent upon the following factors:

3.4.1.2 Estimating the quantity of sand

Sand is defined as any particle greater than 0.125 mm and smaller than 4 mm in this mixing process. Sand's bulk density determines how much of it there is. The optimal amount of sand in the mortar ranges from 40 to 50%, depending on the properties of the paste.

3.5 Material tests

3.5.1 Sampling of materials

When working with bulk samples, the sampling techniques are guided by applicable British Standards. To make sure that the samples are representative of the bulk materials, a portion of the obtained samples is usually carefully removed. Both fine and coarse aggregates are first spread out on a dry surface and allowed to air dry for at least three days at room temperature. This procedure seeks to guarantee that there is no unexplained moisture present in the samples and to attain sample homogeneity for accurate test findings. In accordance with the applicable British Standard, samples should, if required, be accompanied by a sampling certificate.

If not, the elements are used in the amounts that are provided or specified for the mixture. The cements were kept in separate, airtight containers of an appropriate size in a dry place when they arrived at the laboratory. They were fully combined with each individual component before use, either by hand or with the aid of a suitable mixer, before water was added. While taking care to avoid the loss of materials or the introduction of extraneous matter, this procedure was executed to guarantee maximum uniformity (BS 1881-125:1986).

Mix design for C20 grade concrete

Descriptions of the mix:

1. Characteristic compressive strength of 20 N/mm^2 after 28 days
2. 5 % Defective
3. Cement: class 42.5
4. Slump required, 10-30 mm
5. Maximum free-water/Cement ratio 0.64
6. Minimum cement content 290 kg/m
7. Coarse aggregate: uncrushed single sized 20mm
8. Fine aggregate: Uncrushed with 90% passing 600 µm sieve
9. Relative density of aggregate: 2.6 (assumed)
10. Volume of trial mix: 0.001 m3

Step 01: Calculations for the target mean strength

Target mean strength = $\mathbf{f_m}$

Specified characteristic strength = $\mathbf{f_c}$, Margin = $\boldsymbol{k}.\ \boldsymbol{s}$

The standard deviation is 4 N/mm^2 (figure 1) Specified characteristic strength is 20N/mm^2

k for 5% defectives = 1.64

$\boldsymbol{fm} = \boldsymbol{fc} + \boldsymbol{k}.\ \boldsymbol{s}$

$\boldsymbol{fm}$ = 20 + 1.64 × 4 = 25.56 N/mm^2

Step 02: Calculation of water/cement ratio

the compressive strength for w/c =0.50 is 42 N/mm^2.

Step 03: Calculation of free water content

From Table 3.2, for 10-30 mm level of workability, crushed aggregates and maximum aggregate size of 10mm the water content is 205 kg/m^3 concrete

Step 04: Calculation of cement content

Water/cement Ratio = 0.64

Cement content = 205 ÷ 0.64

= 320.3 Kg/m^3 of cement

Step 05: Weight of total tggregates

From Figure 3.2 for free water content of 205 kg/m3, Specific gravity of uncrushed aggregates =2.6 (assumed), the wet density of concrete = 2400 Kg/m^3. Therefore, the total aggregate content is

Total aggregate content = Wet density of 1m^3 concrete – water content – cement content

= 2400 – 205 – 320.3 = 2515.3 Kg/m^3

Step 06: Weight of fine aggregate

The workability level =10-30mm, FM=2.6, w/c=0.64, MSA=10 mm

The percentage of fine aggregates = 35%.

Fine aggregate content = 2515.3×0.35 = 880.3 Kg/m^3

Coarse aggregate content = 2515.3 – 880.3 = 1635Kg/m^3

3.5.2 Batching and mixing of concrete

3.5.3 Casting of concrete

The still usable material was then put into cube molds with 100mm sides (EN-12390-2) after the concrete had been successfully blended using a mechanical concrete mixer and rheological testing. The cube molds were placed on a level horizontal surface and firmly secured on all sides to produce the ideal concrete example. To avoid the mortar and aggregate from separating, the concrete was carefully poured into each mold using a trowel. In order to prevent the creation of any shear planes within the hardened concrete, the pouring procedure was carried out as much from bottom to top as feasible.

3.5.4 Compressive strength test

The compressive strength test was based on British Standard for Testing Hardened Concrete (ASTM C39, BS EN 12390-3:20). All cubes underwent the concrete's compressive strength test. On each crushing day, the average compressive strength was measured after three cubes were crushed.

3.5.4.1 Apparatus

i. A compression testing machine conforming to BS EN 12390-3:2019

ii. Test specimens (concrete cubes)

iii. Steel plates for the testing machine

iv. A device for centering and aligning the specimen within the testing machine

v. A spherically seated block.

3.5.4.2 Procedure

Three concrete cubes was prepared for each mix to test their compressive strength, and the specimens were cured for 7, 14, and 28 days to track the concrete's strength development.

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After curing, the cubes were crushed in a compressive testing machine to determine their maximum load at failure.

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3.5.4.3 Calculations and expression of results

The compressive strength of the crushed cubes was calculated the expression:

$$\text{Compressive Strength } (\text{N/mm}^2) = \frac{\textit{Failure load}}{\textit{Cross section Area of cube}} \qquad (3.1)$$

3.6 Slump test

The Slump Test is used to assess the consistency or workability of concrete mixes made in labs or on construction sites while the project is underway (BS 1881 part 2:1983). To ensure that the concrete is of consistent quality during construction, concrete slump tests are conducted from batch to batch. The most straightforward concrete workability test, the slump test is inexpensive and yields findings right away. Since 1922, it has been extensively utilized for workability tests as a result. The slump is performed in accordance with the guidelines outlined in Eurocode (EN12350-2).

The workability, which indicates the water-to-cement ratio, is often determined by the concrete slump value; however, the concrete slump value is influenced by a number of factors, including material qualities, mixing techniques, dosage, admixtures, etc. This test is done to check the consistency of the concrete, to determine if the concrete flow smoothly into the shape of the formwork, it is a quick check to see if the concrete is suitable for use.

3.6.1 Apparatus

Slump test mold, non-porous base plate, tamping rod, and measurement scale. The test mold is a cone's frustum, measuring (300 mm) in height, (200 mm) in bottom diameter, and (100 mm) in top diameter. The tamping rod has a rounded end and is (600mm) long and 16mm in diameter.

3.6.2 Procedure for slump test

I applied oil to prevent the concrete from sticking to the mold, ensuring that it could be easily removed without damaging the specimen. Made sure to place the mold on a stable and smooth base plate, preventing any interaction between the base and the concrete that might have interfered with the specimen's consistency or the test. I carefully poured the concrete in four roughly equal layers to ensure that the mold was evenly filled, applied 25 strokes evenly across the mold's cross-section to each layer using the rounded end of the tamping rod. The tamping reached the underlying layer for the successive layers after tamping, I used a trowel to smooth the surface and carefully removed any excess concrete. This step gave the specimen a neat and even finish, ensuring the top of the mold was flush and prepared for the next steps. I gently lifted the mold vertically to avoid disturbing the specimen, after removing the mold, I measured the difference in height between the mold and the highest point of the specimen. This gave me the slump value, which helped assess the workability and consistency of the concrete.

3.6.3 Slump value observation

When the slump test is carried out, following are the shape of the concrete slump that can be observed.

1. True Slump: The test can only measure this type of slump. Following the removal of the cone, as indicated above, the distance between the top of the cone and the top of the concrete is measured.

2. Zero Slump: This indicates an extremely low water-to-cement ratio, leading to dry mixtures. Typically, this kind of concrete is utilized for building roads.
3. Collapsed Slump: A slump test is inappropriate for concrete mixes that have an excessively high water-to-cement ratio, meaning they are either too wet or have a high workability.
4. Shear Slump: This means that more testing is necessary for the concrete because the result is not complete.

3.7 Curing of cubes

To help the cement paste hydrate and provide the concrete strength, fresh concrete is kept damp or moist for a few days. This process is known as curing. As long as the environment is conducive to ongoing hydration, concrete's qualities have been found to improve with age. Lack of proper curing has a substantial impact on the rate and degree of cement paste hydration and, in turn, its strength because it causes the strength to build slowly. This rise in strength creates hydrates that must be properly cured in order to sustain concrete. Curing is a crucial practical step in concrete technology that ensures the concrete reaches the necessary strength. Following 14 and 28 days of curing, the specimens will be taken out of the water and a test of compressive strength will be performed.

3.8 Water absorption test

The water absorption test was carried out in accordance to the ASTM C1585 guidelines. Concrete cubes of dimensions 100mm x 100mm x 100mm were cured for 28days, these specimens were then oven dried for 24 hours at 100^0C. Their weight was measured and recorded (W1), the specimen is now placed in water for 24hours and their weight is taken as (W2). The percentage absorption was calculated from

Absorption (%) = $W_2 - W_1$ x 100

3.8.1 Procedure

I measured the weight of the dry specimens. This initial weight served as my baseline or reference point. I understood that the dry weight was essential because the change in mass after submerging the specimen in water would directly show how much water it had absorbed. After 24 hours of immersion in water, I carefully removed the specimens. I made sure to wipe off any excess water from their surfaces, as to measure the water that had been absorbed into the specimen itself. Once I had wiped them down, I weighed the specimens again to determine how much water they had absorbed. The difference in mass between the dry weight and the weight after immersion allowed me to calculate the amount of water absorbed.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the findings from every test that was conducted during the course of this investigation. Where required, graphs and charts are also provided to illustrate the performance of each % replacement aggregate in comparison to the others.

The tests carried out include:

(i) Particle size distribution

(ii) Specific Gravity Test

(iii) Slump Test

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(iv) Water absorption test

(v) Compressive strength

4.1 Sieve analysis

4.1.1: Particle size distribution of natural fine aggregates

Sieve analysis is a critical test used to assess the particle size distribution of a substance. In this work, sieve analysis was performed on the fine aggregate and coarse aggregate to evaluate their particle size distribution and to determine their viability as a constituent for concrete production. The experiment was conducted in compliance with the specifications stated in the BS 812 part 03(1) – 1985. The findings of the sieve analysis are shown in the table below.

The results of the sieve analysis are summarized in Table 4.1. The results of testing the aggregates physical characteristics are crucial for comprehending how each aggregate property affects the overall functionality of concrete samples. Figure 4.1 shows the particle size distribution (PSD) for the river sand material, while Table 4.1 contains the mass retained, percentage retained and percentage passed for the fine aggregate used in the production of concrete.

Fineness Modulus = $\frac{\sum F}{\text{Total Mass tested}} = \frac{486.68}{100}$ =4.8668

% Retained = $\frac{\text{Mass retained}}{\text{Total Mass tested}} \times 100$

Cumulative % Retained = % retained + the succeeding % retained

% passing = 100−Cumulative % Retained

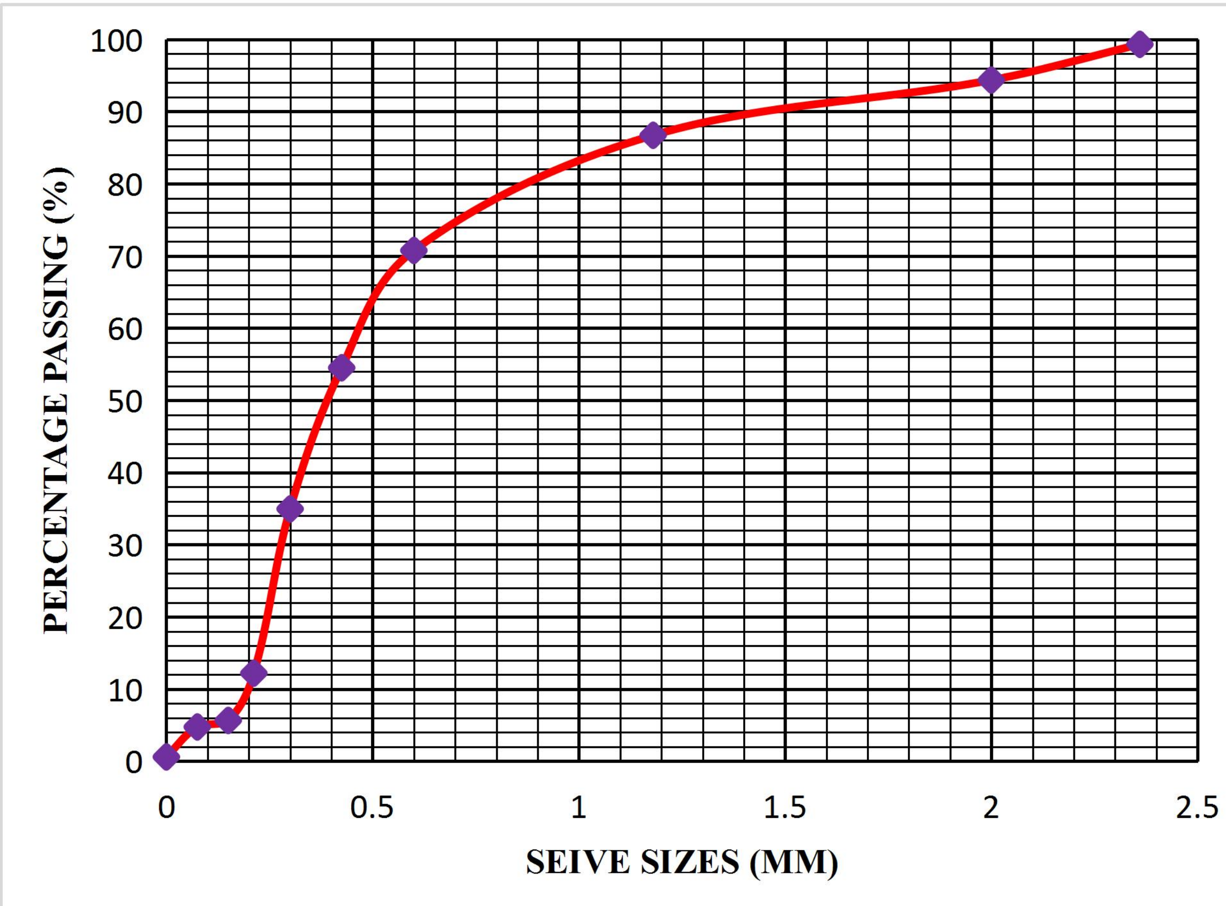

Fig 4.1: Graph showing the variation of % passing of the natural fine aggregate

Fig 4.1 illustrates the particle size distribution of the fine aggregate (sand). The distribution shows a continuous gradation with a significant portion of material retained between 600 µm and 212 µm such a gradation is typically considered good for concrete, as it offers a balance between workability and strength. Well-graded aggregates contribute to a dense packing, reducing voids and improving the concrete's mechanical properties. The relatively low content of extreme fines (less than 75 µm) is beneficial, as an excessive number of fines can increase the water demand and adversely affect the bond between the cement paste and aggregates. In summary, the sieve analysis results indicate that the fine aggregate is well-graded and suitable for use in concrete production.

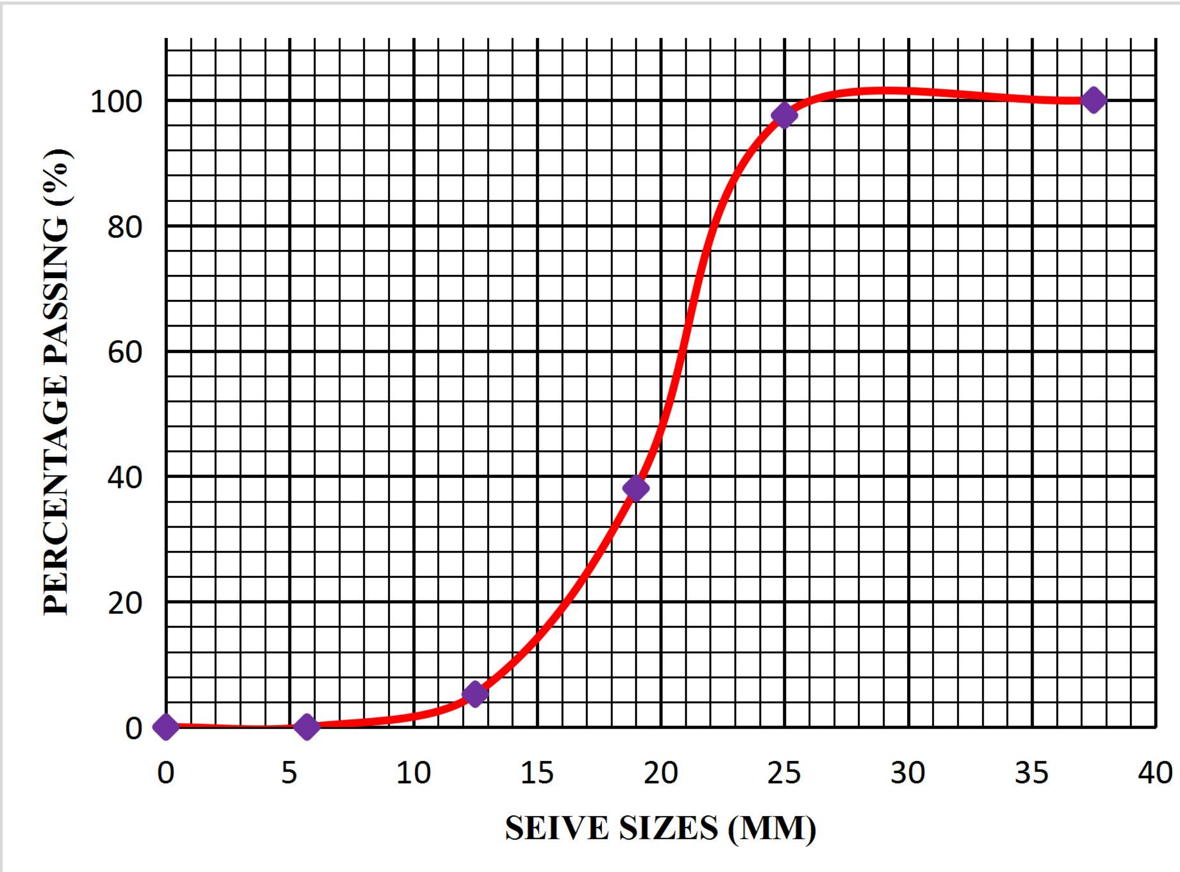

Fig 4.2: Graph showing the variation of % passing of the Coarse aggregate

The sieve analysis in Fig 4.2 indicates that the aggregate is predominantly coarse, with very little fine material. In summary, the aggregate grading shows a well-distributed particle size, with most of the mass concentrated between 25 mm and 12.5 mm, and very few fines below 5.7 mm. This gradation is favorable for concrete applications as it typically contributes to good workability and adequate packing density.

4.2 Specific gravity for waste glass powder (WGP)

The method used to carry out this experiment was in compliance with the BS 82: 1951 standard. For traditional cement, figuring out the specific gravity is crucial since it aids in figuring out how much cement is used in the concrete mix. It is also employed to relate the material's fineness. The water needs and setting time are impacted by the decreased specific gravity of finer cement. The outcome of this experiment is utilized to make comparisons with the standard value for regular Portland cement. The results are shown in Table 4.4 displays the results of the specific gravity test that was performed on the waste glass powder replacement. In high-quality cement, the specific gravity typically ranges between 3.12 and 3.15. However, the waste glass powder exhibits an average specific gravity of 2.695, which is considerably lower. This lower specific gravity indicates that the waste glass powder is extremely fine, a characteristic that may lead to increased water demand and altered setting times in the concrete mix. Moreover, the reduced specific gravity suggests that the quality of the waste glass powder may be below permissible levels for optimal performance, potentially compromising the concrete's strength and long-term durability.

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4.3 Slump test

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The slump test is used to evaluate the workability or consistency of the concrete mixes. The results of the slump tests conducted on each mix, including the control and waste glass powder mixes, are presented in Table 4.5.

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The slump test results indicate that as the replacement percentage increases, the workability of the concrete mix also increases. Overall, while increasing the replacement improves workability, caution must be exercised at higher percentages to ensure that the mix maintains its stability and structural integrity.

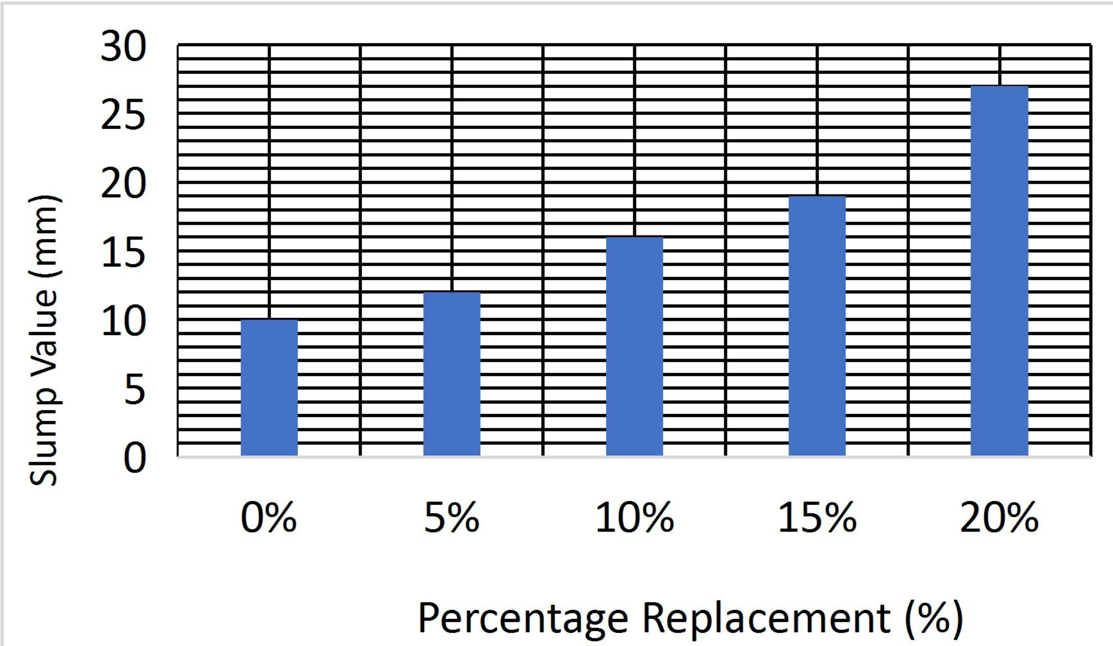

Fig 4.2: Graph of Slump test of waste glass powder concrete at various % replacement

4.4 Water absorption test

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The results of the water absorption tests conducted on each mix, including the control and waste glass powder mixes, are presented in Table 4.6.

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$$W_A = \frac{W_T - W_D}{W_D} \times 100 = \text{WATER ABSORPTION}$$

From the results presented in Table 4.6, the table shows that the water absorption of concrete cubes, measured after 24 hours of immersion at 28 days of curing, increases with higher waste glass powder replacement levels. For the control mix (0% replacement), the average water absorption is approximately 0.800%, while at 5% replacement it rises to about 0.922%. At 10% replacement, the average absorption increases to roughly 1.020% (as indicated by the sample values of 1.007% and 1.032%), and further increases to around 1.102% at 15% replacement. Finally, at 20% replacement, the water absorption averages approximately 1.225%. This progressive increase in water absorption suggests that the inclusion of waste glass powder, while potentially enhancing sustainability, tends to increase the porosity or disrupt the microstructure of the concrete, thereby leading to a higher absorption of water.

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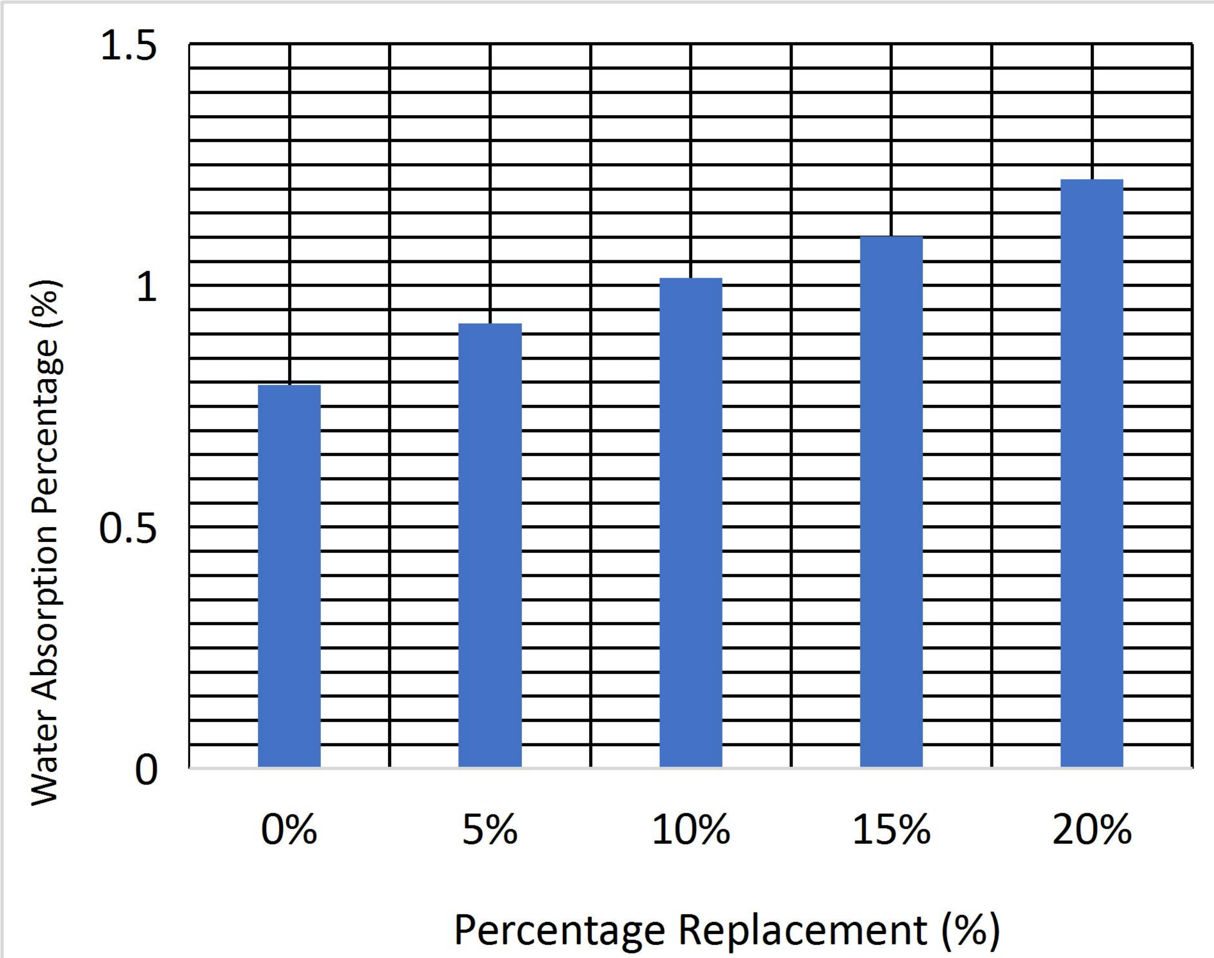

Fig 4.4: Graph of water absorption percentage obtained with waste glass powder concrete at various % replacement

4.5 Compressive strength test

The compressive strength of concrete cubes was measured using a universal compression testing machine that could measure up to 2000 KN. Finding out what kind of failure happens is a crucial part of the compressive strength test. Crushing is usually the expected result of concrete failures. Sometimes, nevertheless, the test may uncover unanticipated failure modes like splitting or shearing. Important information about how concrete behaves under stress can be obtained by documenting and examining the failure mode. Following the test, the concrete specimen's compressive strength is determined using the recorded data. The computation is carried out by dividing the cross-sectional area of the specimen by the highest applied load.

This test is crucial because it determines how well the concrete can tolerate compressive loads. The concrete's compliance with the structural design's goal strength is verified by the test. A compressive testing machine was used for this experiment, and the findings are displayed in Table 4.7-4.9 below.

From the results presented in Table 4.7-4.9, the table shows that the average compressive strength of concrete cubes after 7 ,14 and 28 days of curing decreases as the replacement level of waste glass powder increases. At 5% replacement, the strength drops slightly, At 10% replacement, the strength further decreases. The average strength at 15% replacement shows a small reduction compared to the 10% level. Finally, at 20% replacement, the compressive strength represents the most significant decrease. This progressive decline in strength indicates that while small amounts of waste glass powder (up to 5%) have minimal impact, higher replacement levels significantly weaken the concrete, likely due to reduced bonding and the overall effectiveness of the waste glass powder in the mix.

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Deleted[User-PC]: Since it indicates the mix's strength, the compressive strength result is the most crucial factor for every concrete mix. Although the strength could only be assessed after 7, 14, and 28 days due to time constraints, concrete should have reached between 50 and 65 percent of its ultimate strength after 7 days of curing.

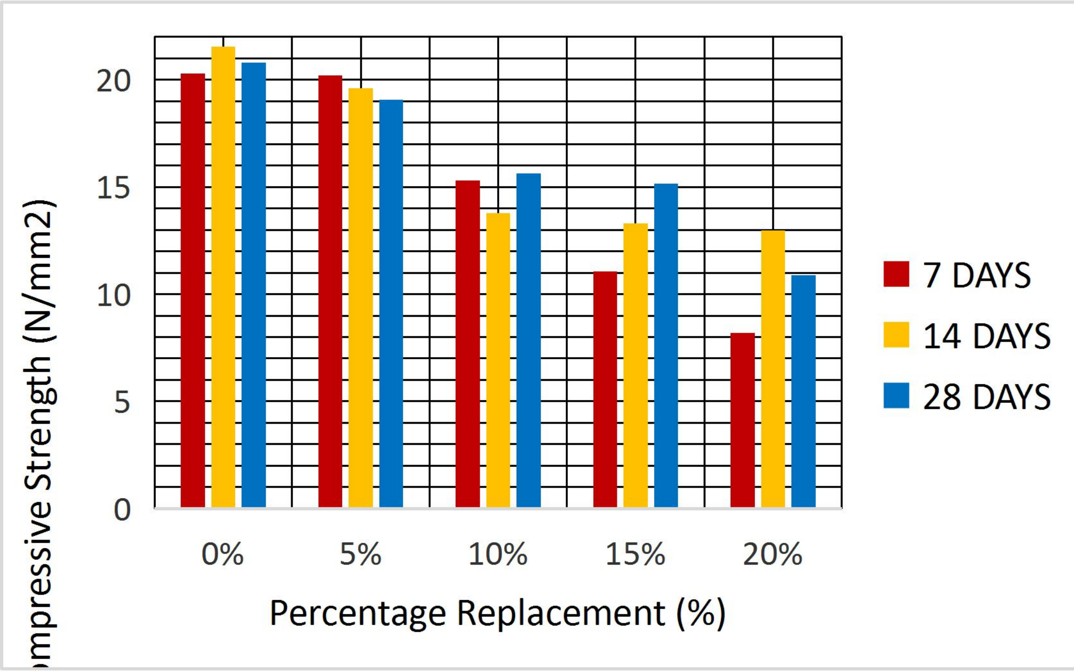

Fig 4.5:

Graph showing average compressive strength obtained at various curing period for each percentage replacement

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4.6 Specific gravity for waste glass powder (WGP)

The method used to carry out this experiment was in compliance with the BS 82: 1951 standard. For traditional cement, figuring out the specific gravity is crucial since it aids in figuring out how much cement is used in the concrete mix. It is also employed to relate the material's fineness. The water needs and setting time are impacted by the decreased specific gravity of finer cement. The outcome of this experiment is utilized to make comparisons with the standard value for regular Portland cement. The results are shown in Table 4.8 Table 4.8 displays the results of the specific gravity test that was performed on the waste glass powder replacement. In high-quality cement, the specific gravity typically ranges between 3.12 and 3.15. However, the waste glass powder exhibits an average specific gravity of 2.695, which is considerably lower. This lower specific gravity indicates that the waste glass powder is extremely fine, a characteristic that may lead to increased water demand and altered setting times in the concrete mix. Moreover, the reduced specific gravity suggests that the quality of the waste glass powder may be below permissible levels for optimal performance, potentially compromising the concrete's strength and long-term durability.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 Conclusion

This study investigated the effect of using waste glass powder (WGP) as a partial replacement for cement in concrete. The research evaluated several key performance indicators including compressive strength (at 7, 14, and 28 days), slump test, water absorption, and specific gravity to determine the impact of various replacement levels (0%, 5%, 10%, 15%, and 20%) on the quality and durability of concrete.

1. The compressive strength tests revealed that the control mix (0% replacement) exhibited robust performance with average strengths of approximately 20.20 N/mm² at 7 days, 21.54 N/mm² at 14 days, and 20.79 N/mm² at 28 days. At a 5% replacement level, the compressive strengths were comparable to the control indicating that a low level of WGP does not significantly compromise strength. However, a notable reduction in compressive strength was observed at 10% replacement, with averages dropping to around 15.30 N/mm² (7 days), 13.78 N/mm² (14 days), and 15.64 N/mm² (28 days). This trend worsened at higher replacement levels (15% and 20%), where the concrete exhibited considerable loss in strength, which can be attributed to the lower cementitious binding capacity and increased porosity introduced by higher WGP content. Concrete samples from all mixes demonstrated substantial strength gain over time, particularly between the 7-day and 28-day curing periods. The compressive strength continued to increase with curing age, highlighting the importance of adequate curing time to achieve optimal concrete performance.

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2. The specific gravity tests performed on the waste glass powder revealed an average value of 2.695, which is significantly lower than that of high-quality ordinary Portland cement (typically between 3.12 and 3.15). The reduced specific gravity of WGP implies that it is considerably finer, thereby increasing water demand and potentially altering the setting time. This finer nature may also contribute to the lower strength observed in mixes with high replacement levels.

3. Water absorption tests demonstrated that the concrete's porosity increases with higher WGP content. The control mix recorded an average water absorption of approximately 0.800%, while mixes with 5%, 10%, 15%, and 20% replacements showed progressive increases to averages of about 0.922%, 1.016%, 1.102%, and 1.220%, respectively. This trend indicates that the incorporation of WGP, particularly at higher levels, leads to a more porous microstructure, which could compromise long-term durability and resistance to environmental attacks.

4. The experimental results indicate that waste glass powder can be utilized as a sustainable partial replacement for cement without markedly affecting concrete properties provided that the replacement level is kept low (ideally between 5% and 10%). Beyond this range, the negative impacts on compressive and flexural strength, as well as increased water absorption, suggest that the concrete's performance and durability could be compromised. Therefore, the optimum balance between environmental benefits and mechanical performance appears to be achieved at lower replacement percentages.

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5.1 Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. For structural applications, limit the replacement of cement with waste glass powder to between 5% and 10% by weight. This range provides sustainability benefits while maintaining acceptable compressive strength.

2. For non-load-bearing applications, higher replacement levels may be considered; however, their long-term durability should be carefully evaluated.

3. Incorporate chemical admixtures, such as superplasticizers or water-reducing agents, to counteract the increased water demand resulting from the finer waste glass powder.

4. Explore the combined use of waste glass powder with other supplementary cementitious materials (e.g., fly ash, silica fume) to improve the pozzolanic activity and enhance strength development.

REFERENCES

Abdollahzadeh, S., & Heidari, A. (2021). The influence of waste glass powder on the properties of high-strength concrete**.** *Journal of Materials in Civil Engineerin*g, 33(2), 04020213.

Adebisi, K. E., & Adeyemi, O. (2020). Utilization of waste glass powder in concrete: A review. Materials Today: Proceedings, 27, 1234-1241.

ASTM C192/C192M: Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.

ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

Babaei, M., & Shafigh, P. (2021). Utilization of waste glass powder as cement replacement: A comparative study. Cement and Concrete Composites, 119, 104024.

Ganesan, K., & Rajagopal, K. (2021). Utilization of waste glass powder as a supplementary cementitious material in concrete. Journal of Cleaner Production, 280, 124675.

Jamal, M., & Zubair, M. (2021). Experimental study on waste glass powder as partial replacement of cement in concrete. Materials Today: Proceedings, 47, 1605-1611.

Javadi, A., & Mohammadi, N. (2022). Sustainability of concrete using waste glass powder: A review. Environmental Science and Pollution Research, 29, 34567-34580

Khan, M. I., & Al-Jabri, K. S. (2020). The effect of waste glass powder on the mechanical properties of concrete. *Construction and Building Materials*, 255, 119288.

Khan, M. S., & Malik, A. (2020). Performance of concrete using waste glass powder as partial replacement of cement. Materials Science Forum, 986, 45-50.

Kumar, V., & Singh, B. (2020**).** Influence of waste glass powder on the properties of concrete: A review. International Journal of Civil Engineering and Technology, 11(3), 151-162.

Mehta, P.K. & Monteiro, P.J.M. (2014). *Concrete: Microstructure, Properties, and Materials*. McGraw-Hill Education.

Oluokun, E. J., & Adebisi, K. (2020). Properties of concrete with waste glass powder: A review. Journal of Environmental Management, 260, 110139.

Patel, V., & Thakkar, P. (2021). Study on the effects of glass powder on concrete properties. International Journal of Engineering Research and Applications, 11(4), 29-35.

Ranjbar, N., & Sadeghi, A. (2021). Mechanical and durability properties of concrete containing waste glass powder. Materials Science and Engineering, 101, 123456.

Raza, A., & Rahman, A. (2020). Properties of concrete containing waste glass powder: An experimental study. Construction Materials, 173, 123456.

Saha, P., & Pal, S. (2021). Effect of waste glass powder on the mechanical properties of concrete. Advances in Civil Engineering, 2021, Article ID 987654.

Sajid, M., & Naz, A. (2021). Experimental analysis of concrete using waste glass powder. Construction and Building Materials, 287, 123456.

Sinha, R., & Kumar, S. (2022). Effect of glass powder on strength and durability of concrete. Materials Today: Proceedings, 55, 452-459.

Tian, Y., & Zhang, Y. (2020). The effects of glass powder on concrete properties: A review. Advances in Civil Engineering, 2020, Article ID 123456.

Torgal, F. P., & Jalali, S. (2019). Waste glass in concrete: A review of the research. Journal of Cleaner Production, 212, 1241-1252.

APPENDIX

Table 4.1: Design mix ratio for grade 20 concrete

Cement	Fine aggregate	Coarse aggregate
0.3203	**0.8803**	**1.635**

Table 4.2: Result from Sieve analysis for fine aggregate (200g)

Sieve Size (mm)	Mass Retained (g)	Percentage Retained (%)	Cumulative percentage Retained (%)	Percentage Passing (%)
2.36	9.1	9.1	0.7	99.3
2.00	2.1	2.1	5.65	94.35
1.18	13. 5	13. 5	13.3	86.7
600	46.4	46.4	29.25	70.75
425	40. 3	40. 3	45.5	54.5
300	31.7	31.7	65.05	34.95
212	30.2	30.2	87.8	12.2
150	16.2	16.2	94.35	5.65
75	9.2	9.2	95.25	4.75
Pan	0.6	0.6	99.40	0.6

Table 4.3: Result from sieve analysis for coarse aggregate (3000g)

Sieve Size (mm)	Mass Retained (g)	Mass passing (g)	Percentage Passing (%)
37.5	0	3000	100
25	73.5	2926.5	97.55
19	1783.8	1142.7	38.09
12.5	985.5	157.2	5.24
5.7	156.9	0.3	0.01
Pan	1.2	0.1	0.00

Table 4.4: Specific gravity for waste glass powder replacements

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Bottle No	Test A	Test B
Weight of pycnometer(g) (W1)	21.42	22.33
Weight of pycnometer + WGP (W2)	73.83	74.89
Weight of pycnometer + water + WGP (W3)	78.96	79.18
Weight of pycnometer + water (W4)	31.04	30.07
Specific gravity	2.689	2.750
Specific gravity	2.695	

Table 4.5: Results from slump test

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Sample No	Slump (mm)
0%	10
5%	12
10%	16
15%	19
20%	27

Table: 4.6: Result of water absorption percentage obtained after 24hrs of immersion of concrete cubes with waste glass powder replacement of 0%, 5%, 10%, 15%, and 20% cured for 28 days

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S/N	PERCENTAGE REPLACEMENT	DRY WIEGHT (Kg)	SATURATED WEIGHT AFTER 24HRS (Kg)	PERCENTAGE OF WATER ABSORBED (%)	AVERAGE OF WATER ABSORBED (%)
1	0%	2.500	2.700	0.800	0.794
2		2.503	2.703	0.799	
3	5%	2.500	2.730	0.920	0.922
4		2.502	2.733	0.924	
5	10%	2.510	2.750	1.007	1.016
6		2.507	2.758	1.032	

7	15%	2.511	2.770	1.083	1.102
8		2.495	2.780	1.122	
9	20%	2.517	2.802	1.202	1.220
10		2.505	2.810	1.248	

Table 4.7: Average compressive strength obtained after 7 days of curing with waste glass powder replacement of 0%, 5%, 10%, 15%, and 20%

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Replacement %	**Sample No**	**Weight (Kg)**	**Density (Kg/m³)**	**Failure load (KN)**	**Compressive Strength (N/mm²)**	**Average strength (N/mm²)**
0%	1	2.452	2452	188.75	18.88	20.20
	2	2.476	2476	212.07	21.21	
	3	2.497	2497	205.15	20.52	
5%	1	2.507	2507	182.42	18.24	20.30
	2	2.43	2430	228.39	22.84	
	3	2.497	2497	198.04	19.80	

10%	1	2.373	2373	134.82	13.48	15.30
	2	2.493	2493	159.19	15.92	
	3	2.509	2509	165.03	16.50	
15%	1	2.536	2536	148.27	14.83	11.07
	2	2.572	2572	85.01	8.50	
	3	2.499	2499	98.85	9.89	
20%	1	2.469	2469	77.22	7.72	8.20
	2	2.577	2577	88.81	8.88	
	3	2.564	2564	79.89	7.99	

Table 4.8: Average compressive strength obtained after 14 days of curing with waste glass powder replacement of 0%, 5%, 10%, 15%, and 20%

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Replacement %	Sample No	Weight (Kg)	Density (Kg/m³)	Failure load (KN)	Compressive Strength (N/mm²)	Average strength (N/mm²)
0%	1	2.45	2450	215.35	21.54	
	2	2.45	2450	203.14	20.31	21.54
	3	2.40	2400	227.75	22.78	
5%	1	2.40	2400	219.26	21.93	
	2	2.40	2400	226.25	22.63	19.60
	3	2.60	2600	142.57	14.26	
10%	1	2.55	2550	126.94	12.69	
	2	2.70	2700	146.6	14.66	13.78
	3	2.50	2500	139.71	13.97	
15%	1	2.45	2450	126.3	12.63	
	2	2.50	2500	133.73	13.37	13.31
	3	2.45	2450	139.34	13.93	
20%	1	2.40	2400	120.55	12.06	
	2	2.50	2500	152.34	15.23	
	3	2.45	2450	115.96	11.60	12.96

Table 4.9: Average compressive strength obtained after 28 days of curing with waste glass powder replacement of 0%, 5%, 10%, 15%, and 20%

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Replacement %	**Sample No**	**Weight (Kg)**	**Density (Kg/m³)**	**Failure load (KN)**	**Compressive Strength (N/mm²)**	**Average strength (N/mm²)**
0%	1	2.40	2400	168.53	16.85	20.79
	2	2.45	2450	201.73	20.17	
	3	2.40	2400	253.48	25.35	
5%	1	2.35	2350	207.13	20.71	19.06
	2	2.30	2300	162.69	16.27	
	3	2.55	2550	202.02	20.20	
10%	1	2.45	2450	159.23	15.92	15.64
	2	2.50	2500	156.98	15.70	
	3	2.55	2550	153.12	15.31	
15%	1	2.55	2550	156.85	15.69	15.14
	2	2.55	2550	171.45	17.15	
	3	2.45	2450	126.03	12.60	
20%	1	2.50	2500	143.75	14.38	10.88
	2	2.45	2450	85.49	8.55	
	3	2.45	2450	97.12	9.71	

Plate 1: Preparation of waste glass powder

Deleted[User-PC]: **Table 4.9: Specific gravity for waste glass powder replacements**

Bottle No

Test A

Test B

Weight of pycnometer(g) (W1)

21.42

22.33

Weight of pycnometer + WGP (W2)

73.83

74.89

Weight of pycnometer + water + WGP (W3)

78.96

79.18

Weight of pycnometer + water (W4)

31.04

30.07

Specific gravity

2.689

2.750

Specific gravity

2.695

Plate 2: Casting process of concrete

Plate 3: Casting process of concrete