A COMPARATIVE STUDY ON THE COMPRESSIVE STRENGTH OF CONCRETE USING WASTE GLASS AS PARTIAL REPLACEMENT OF FINE AGGREGATE AND COARSE AGGREGATE

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A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering



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Section: 25B

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We the undersigned hereby declare that the work and all resources presented in this thesis titled **"A Comparative Study on the Compressive Strength of Concrete Using Waste Glass as Partial Replacement of Fine Aggregate and Coarse Aggregate"** are the result of our original efforts and have not been submitted either in whole or in part for academic credit at any university, college or institution.

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Dedicated

to

“Our Beloved Parents’’

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ABSTRACT

This thesis presents a comparative study on the compressive strength of concrete using waste glass as a partial replacement of fine aggregate and coarse aggregate. The main objective of the study is to evaluate the effectiveness of incorporating waste glass in concrete mixes, particularly its influence on compressive strength, and to examine its potential as an eco-friendly and sustainable construction material. In this research, Indian Pakur stone was used as the coarse aggregate and Sylhet sand as the fine aggregate. Crushed waste glass was used as a partial replacement for both aggregates at four different replacement levels: 5%, 10%, 15%, and 20% by weight. The concrete was designed with an M20 mix ratio (1:1.5:3) and a constant water-cement ratio of 0.45. Cylindrical concrete specimens were cast and tested for compressive strength after 7 and 28 days of curing using a Universal Testing Machine (UTM) with a maximum capacity of 1000 kN, following ASTM standards. The results showed that the 7-day compressive strength did not exhibit a significant increase compared to the control mix. However, the 28-day compressive strength showed notable improvements. The best performance is seen at 10% and 15 % fine aggregate replacement and 5% and 20% coarse aggregate replacement at 28 days. This study demonstrates that waste glass can be effectively used in concrete as a partial replacement for both fine and coarse aggregates, contributing to the production of lightweight, strong and sustainable concrete. The findings support the potential for large-scale application of waste glass in the construction industry, aligning with global sustainability trends and reducing the environmental impact of glass waste.

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CHAPTER 1
INTRODUCTION

1.1 General

Concrete is the most widely used construction material in the world due to its excellent durability, strength and versatility. However, the large-scale use of natural aggregates in concrete production has resulted in the depletion of natural resources and environmental degradation. In recent years, the concept of sustainable construction has gained significant attention, emphasizing the use of alternative materials to reduce the environmental footprint of construction activities.

One of the major contributors to environmental pollution is glass waste. Millions of tons of glass waste are generated globally each year, much of which ends up in landfills or the environment due to the limited options for recycling. Glass has a long decomposition time and poses a serious threat to the environment if not managed properly.

Recent research has explored the use of waste materials in concrete to improve sustainability and reduce production costs. Among these materials, waste glass has emerged as a potential replacement for both fine and coarse aggregates in concrete. Glass possesses a high silica content and hardness, making it suitable for use in concrete with minimal processing.

1.2 Significance of the Study

The significance of this study on the use of waste glass in concrete is outlined as follows:

1. **Environmental Impact:** Since waste glass is non-biodegradable, its disposal poses a significant challenge. Using it partially in concrete allows for recycling, reducing environmental pollution.
2. **Socio-Economic Benefits:** Reducing the demand for natural aggregates and utilizing waste glass can lower material costs and conserve natural resources, benefiting both local and global construction sectors.
3. **Sustainable Construction:** Incorporating waste glass into concrete promotes sustainable construction practices, providing long-term environmental and economic advantages.
4. **Research Contribution:** The study provides precise data on the effect of waste glass on the compressive strength of concrete, forming a foundation for future mix designs and project implementation.

5. **Alternative to Conventional Aggregates:** With limited availability of natural sand and stone, evaluating the feasibility of waste glass as a partial replacement is crucial for sustainable resource management.

Overall, this research supports environmentally friendly, sustainable, and cost-effective practices in the concrete industry.



Figure 1.1: Waste Glass Sheet

1.2 Objectives of the Study

The objectives of the study are following -

1. To evaluate the compressive strength of concrete using waste glass as partial replacement of fine aggregate.
2. To evaluate the compressive strength of concrete using waste glass as partial replacement of coarse aggregate.
3. To assess the compressive strength concrete using waste glass as partial replacement for both fine and coarse aggregate.

1.4 Scope of the Study

This study focuses on the experimental investigation of the compressive strength of concrete using waste glass as a partial replacement of both fine aggregate (Sylhet sand) and coarse aggregate (Indian Pakur stone). The scope of the study is outlined as follows:

- Waste glass will be used to replace fine and coarse aggregates at 5%, 10%, 15%, and 20% by weight.
- Standard cylindrical concrete specimens will be prepared, cast, and cured under laboratory conditions.
- Compressive strength will be tested at 7 and 28 days of curing to evaluate the performance at different stages of strength development.
- The results will be compared with fine aggregate and coarse aggregate replacement to determine the effects of waste glass on compressive strength.
- The study is limited to compressive strength only.

This scope ensures a controlled and systematic assessment of the feasibility of incorporating waste glass into concrete as a sustainable alternative to conventional aggregates.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and versatility. However, the increasing demand for natural aggregates such as sand and stone has led to depletion of natural resources and environmental concerns. In response, researchers have explored alternative materials, including waste glass, as partial replacements for fine and coarse aggregates. Glass, being non-biodegradable, poses serious disposal challenges. Incorporating waste glass into concrete not only reduces environmental impact but also contributes to sustainable construction practices.

2.1.1 Concrete and Compressive Strength

The primary property of concrete is its compressive strength, which determines its ability to withstand loads without failure. Various studies have demonstrated that compressive strength is influenced by factors such as the type and grading of aggregates, water–cement ratio, curing period, and replacement materials.

2.1.2 Use of Waste Glass in Concrete

Several researchers have studied the potential of using waste glass in concrete to enhance sustainability. Waste glass is considered a non-biodegradable material, and its accumulation presents environmental challenges. Incorporating it into concrete can reduce landfill pressure and promote recycling.

- Shao et al. (2000) investigated the pozzolanic reactivity of finely ground glass powder in concrete. Results showed that glass powder can enhance strength due to its pozzolanic behavior, especially when particle size is below 75 μm.
- Ismail and Al-Hashmi (2009) replaced natural sand with crushed waste glass at 10%, 15%, and 20% replacement levels. They observed a decrease in workability but an increase in compressive strength at 10% replacement.
- Park et al. (2004) found that using finely crushed glass as fine aggregate improved the compressive strength due to better particle packing and angular shape.
- Taha and Nounu (2008) studied the mechanical properties of concrete containing waste glass as coarse aggregate. They concluded that up to 20% replacement showed promising results in terms of compressive strength.

- Du and Tan (2014) analyzed the behavior of concrete with crushed glass as coarse aggregate and found satisfactory strength development, though bond strength between glass and cement paste was relatively lower than conventional aggregates.
- Ali and Al-Tersawy (2012) demonstrated that using recycled glass as coarse aggregate up to 15% did not significantly affect the compressive strength of concrete.
- Patel et al. (2013) carried out a study replacing both fine and coarse aggregates with waste glass in various proportions. They reported that at 10% replacement levels, the compressive strength was comparable to that of conventional concrete.
- Shaikh et al. (2016) observed that increasing replacement beyond 20% often led to strength reduction due to weak interfacial bonding and potential alkali-silica reaction (ASR).

2.2 Raw Materials

2.2.1 Cement

Cement is one of the most important and widely used construction materials in the world. It is a fine, gray powder that, when mixed with water, forms a paste that hardens over time through a process known as hydration. It acts as the primary binding agent in concrete ensuring the cohesion and strength of the composite material. This hardened paste binds with aggregates to form concrete, which is the backbone of modern construction.



Figure 2.1: Cement

- **Types of Cement**

  There are the different types of cement commonly used in construction:

  1. Ordinary Portland Cement (OPC)
  2. Portland Composite Cement (PCC)
  3. Sulphate Resisting Cement
  4. Blast Furnace Slag Cement
  5. Rapid Hardening Cement
  6. Quick Setting Cement
  7. Hydrophobic Cement
  8. Low Heat Cement
  9. Colored Cement
  10. White Cement

- **Ingredients of Cement**

Ingredient	**Content (%)**	**Role in Cement**
Lime (CaO)	60–65%	Strength, soundness
Silica (SiO_2)	17–25%	Strength
Alumina (Al_2O_3)	3–8%	Reduces clinkering temp
Iron Oxide (Fe_2O_3)	0.5–6%	Color, clinker formation
Magnesia (MgO)	0.1–4%	Hardness, unsound if excess
Sulphur Trioxide (SO_3)	1–3%	Controls setting time
Alkalies (Na_2O, K_2O)	1%	Harmful if excess

- **Chemical Composition of Cement**

  The chemical composition of cement determines its properties such as strength, setting time, durability and resistance to chemical attack. When raw materials are heated in a kiln, they form a product called clinker, which is then ground to produce cement. The major chemical Composition present in the clinker and their functions are shown in Pie chart below:

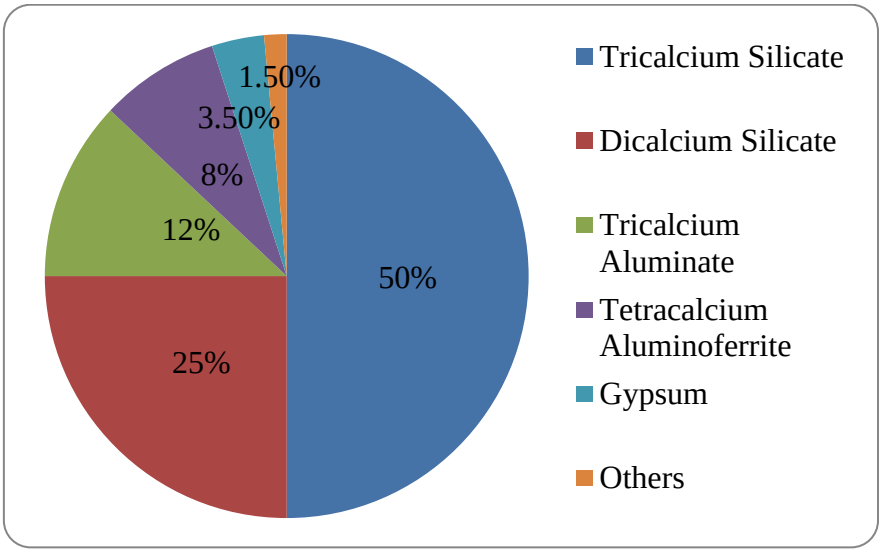


Figure 2.2: Chemical Composition of Cement

- **Role of Cement in Concrete**

  Cement is the most critical component of concrete as it reacts with water and binds the other materials (fine aggregates and coarse aggregates) together. During the hydration process, calcium silicate hydrates (C-S-H) are formed which give concrete its strength and durability.

2.2.2 Fine Aggregate

Fine aggregate is one of the essential components of concrete and mortar. It consists of naturally occurring or manufactured granular materials that pass through a 4.75 mm (No. 4) sieve and are retained on a 75-micron (No. 200) sieve. Fine aggregate works as a filler material that contributes to the strength, workability and durability of concrete by filling the voids between coarse aggregates and reducing the volume of cement paste required.



Figure 2.3: Fine Aggregate

- **Sources of Fine Aggregate**

Fine aggregates are generally obtained from the following sources:

1. River Sand
2. Pit Sand
3. Sea Sand
4. Desert Sand
5. Crushed Stone Sand
6. Recycled Sand

- **Characteristics of Fine Aggregate**

To ensure the quality of concrete, fine aggregate must meet certain physical requirements:

1. Grain Size and Fineness Modulus (FM): FM typically ranges from 2.3 to 3.1. It indicates the coarseness or fineness of the sand.
2. Cleanliness: Fine aggregate should be free from clay, silt, organic matter, salts and other impurities.
3. Shape and Texture: Rounded particles improve workability while angular particles may provide better bonding with cement paste.
4. Specific Gravity: Generally ranges from 2.6 to 2.7.
5. Moisture Content: Affects the water-cement ratio and should be accounted for in mix design.

- **Functions of Fine Aggregate in Concrete**

  Fine aggregates serve several important roles in concrete:

  1. Filling Voids: They help fill the gaps between coarse aggregates to form a dense and compact mix.
  2. Reducing Cement Content: Proper grading of fine aggregates helps reduce the amount of cement and water required, making the mix economical.
  3. Improving Workability: Fine aggregate influences the mix's ease of handling, placing, and finishing.
  4. Enhancing Strength and Durability: A well-graded fine aggregate helps develop high-strength concrete with good resistance to environmental degradation.

2.2.3 Coarse Aggregate

Coarse aggregate is a key ingredient in concrete, making up a significant portion of its total volume. It consists of naturally occurring or crushed stones that are retained on a 4.75 mm sieve. Coarse aggregates provide bulk, strength and durability to concrete and are essential for the overall stability of a structure.



Figure 2.4: Coarse Aggregate

- **Sources of Coarse Aggregate**

  Coarse aggregates are generally obtained from the following sources:

  1. Natural Gravel
  2. Crushed Stone
  3. Quarry Stones
  4. Blast Furnace Slag
  5. Recycled Aggregate

- **Characteristics of Coarse Aggregate**

  Coarse aggregates serve several important roles in concrete:

  1. Size and Grading: Commonly used sizes are 10 mm, 20 mm, and 40 mm. Well-graded aggregates reduce voids and improve the strength and durability of concrete.
  2. Shape and Texture: Angular, rough-textured aggregates provide better mechanical bond and strength than rounded ones.
  3. Specific Gravity: Typically ranges from 2.5 to 2.9.
  4. Water Absorption: Should be low (usually below 2%) to maintain the desired water-cement ratio.
  5. Cleanliness: Should be free from dust, clay, organic materials, or other contaminants.

- **Functions of Coarse Aggregate in Concrete**

  1. Strength and Stability: Coarse aggregates form the skeleton of the concrete, providing compressive strength and load-bearing capacity.
  2. Economy: They reduce the amount of cement and water required in the mix, making concrete more economical.
  3. Durability: Good quality coarse aggregates enhance resistance against abrasion, freeze-thaw cycles, and chemical attacks.
  4. Shrinkage Reduction: They help control volume changes and reduce shrinkage cracks in concrete.

2.2.4 Water-Cement Ratio

The water-cement ratio (w/c ratio) is one of the most critical factors in determining the strength, durability and overall performance of concrete. It is defined as the ratio of the weight of water to the weight of cement used in a concrete mix.

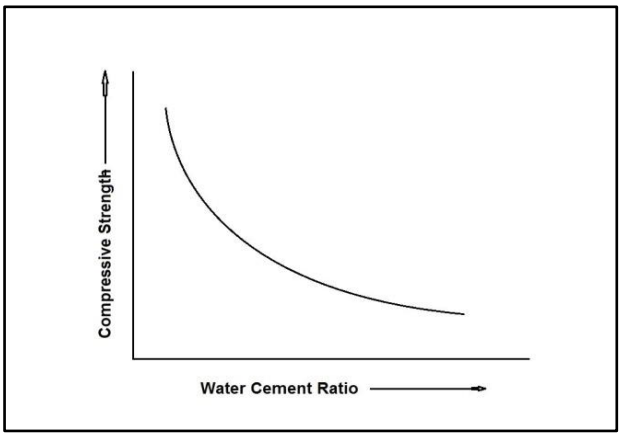


Figure 2.5: Water-Cement Ratio Diagram

- **Importance of Water-Cement Ratio**

  Water is essential for the hydration of cement, which is the chemical reaction that allows concrete to harden and gain strength. However, the amount of water must be carefully controlled:

  - Too much water leads to a weak and porous concrete with reduced strength and durability.
  - Too little water makes the mix unworkable and can prevent full hydration of cement, also reducing strength.

- **Effect on Strength and Durability of Water-Cement Ratio**

  - A lower water-cement ratio (e.g., 0.40 to 0.50) generally results in higher strength and better durability.
  - A higher water-cement ratio (above 0.60) increases workability but significantly reduces the strength and long-term durability of the concrete.

According to Abram's Law, the compressive strength of concrete is inversely proportional to the water-cement ratio, provided the mix is workable and properly compacted.

- **Typical Water-Cement Ratios**

Application	W/C Ratio
High-strength concrete	0.35 – 0.45
Normal reinforced concrete	0.45 – 0.55
Mass concrete or unreinforced	0.50 – 0.65

- **Factors Affecting Water-Cement Ratio**
    - Type of Cement: Fineness and composition affect water demand.
    - Type and Gradation of Aggregates: Well-graded aggregates require less water.
    - Environmental Conditions: Hot and dry weather may require more water for workability but must be carefully balanced.

- **Water Quality**
    - Cleanliness: The water used for concrete must be clean and clear, free from dirt or suspended particles.
    - Absence of Harmful Substances: Water should not contain oils, acids, alkalis, or organic materials, as these can adversely affect cement hydration.
    - Impact on Concrete Quality: Impurities in water can weaken the bond between cement and aggregates, reducing the overall strength and durability of concrete.
    - Standards Compliance: Potable or drinkable water is generally considered suitable for mixing concrete unless otherwise specified by standards.

2.3 Summary

The literature indicates that waste glass can be used as a partial replacement for fine and coarse aggregates in concrete. Compressive strength, influenced by aggregate type, water–cement ratio, curing, and replacement level, may improve at optimal glass content. Studies also highlight environmental and economic benefits, such as reduced landfill waste and conservation of natural resources, supporting sustainable construction practices.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This chapter outlines the methodology adopted to evaluate the compressive strength of concrete incorporating waste glass as partial replacement for both fine and coarse aggregates. The objective of this experimental study is to investigate the effects of varying replacement levels (5%, 10%, 15%, and 20%) of crushed waste glass on the strength performance of concrete, compared to a control mix with conventional aggregates. Standard procedures and specifications from relevant codes such as ASTM, BDS, and ACI were strictly followed to ensure accuracy, consistency, and reliability of the results.

Natural materials such as Indian Pakur stone (coarse aggregate) and Sylhet sand (fine aggregate) were used as the base reference. The waste glass, mainly of the soda-lime type, was processed and graded to match the required particle size ranges for coarse (10–20 mm) and fine aggregates (<4.75 mm). Concrete cylinders were prepared in accordance with standard dimensions and cured under controlled conditions.

This chapter also describes the rationale for selecting the water-cement ratio, the mixing procedures, the casting of specimens, and the timeline for compressive strength testing at specific curing ages 7 and 28 days. The experimental design aims to ensure repeatability and allow for comparative analysis of performance across all mixes.

By systematically describing the research process, this chapter ensures transparency, reproducibility, and provides a foundation for interpreting the results presented in subsequent chapters.

3.2 Methodology Overview

The initial phase of our work involved the collection of all necessary materials. Subsequently, these materials were transported to a laboratory setting for comprehensive testing. For the purpose of this study, the concrete formulation included cement, sand, stone chips, waste glass (used as partial replacement for both fine and coarse aggregates) and water.



Figure 3.1: Flowchart of Methodology

3.3 Selection of Materials

3.3.1 Sieve Analysis of Aggregate

Sieve analysis is a laboratory procedure used to determine the particle size distribution of fine and coarse aggregates. It helps classify the aggregate and assess its suitability for use in concrete. This analysis helps determine the Fineness Modulus (FM) which indicates the average size of particles in the sample. Well-graded aggregates (a mix of different sizes) improve the workability and strength of concrete while poorly graded (uniformly sized) aggregates may lead to voids and lower strength. Sieve analysis is essential for quality control in construction and mix design optimization.

In our laboratory, the sieve analysis of aggregate was conducted to determine the particle size distribution and gradation of fine and coarse aggregates. The following steps were carried out during the experiment:

- ✓ A representative dry sample of aggregate was taken ensuring it was free from moisture and impurities.
- ✓ The total weight of the sample was recorded before starting the sieving process.
- ✓ A set of standard sieves was arranged in descending order with the largest size sieve (No. 4) on top and the smallest (No. 200) at the bottom followed by the receiving pan.
- ✓ The dry aggregate sample was poured into the top sieve and the stack was securely closed with a lid.
- ✓ The stack was held firmly and shaken horizontally, vertically and with a circular motion for about 5–10 minutes to ensure proper separation of particles according to their sizes.
- ✓ After sieving the material retained on each sieve and the pan was carefully collected and weighed separately.
- ✓ The percentage retained and cumulative passing percentage were calculated for each sieve size from which we determined the fineness modulus (FM).

The results were used to assess the gradation and suitability of the aggregate for use in concrete mix design.



Figure 3.2: Sieve Analysis of Aggregate (Fine & Coarse)

3.3.2 Specific Gravity and Water Absorption of Aggregates

The specific gravity and water absorption of the aggregates used in this study including coarse aggregate and fine aggregate were determined in accordance with the standard procedure outlined in AASHTO T84 for fine aggregates and AASHTO T85 for coarse aggregates.

These tests were conducted to evaluate the physical characteristics of the aggregates, which are essential for accurate concrete mix design. Specific gravity provides an indication of the material's density and overall quality, while water absorption reflects the porosity of the aggregate and its ability to retain moisture.

The results from these tests were used in mix proportion calculations to ensure consistency in concrete quality and performance across all experimental mixes.

- **Specific Gravity and Water Absorption of Coarse Aggregate**



Oven Dry Sample



SSD Sample (Air)



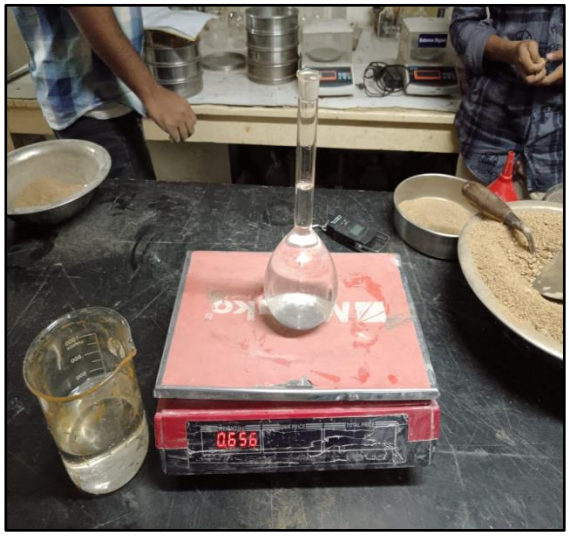
SSD Sample (Water)

Figure 3.3: Specific Gravity and Water Absorption of Coarse Aggregate

- **Specific Gravity and Water Absorption of Fine Aggregate**



Oven Dry Sample



Pycnometer Filled with Water



Pycnometer Filled with Specimen and Water



SSD Sample (Air)

Figure 3.4: Specific Gravity and Water Absorption of Fine Aggregate

3.3.3 Unit Weight Test of Aggregates

The unit weight (bulk density) of the aggregates including natural fine aggregate, partially replaced recycled fine aggregate and natural coarse aggregate was determined following the standard procedure described in AASHTO T19**.** This test was conducted to evaluate the mass of aggregate required to fill a unit volume, which is critical for concrete mix design and batching.

The Unit Weight of aggregate is determined to assess the compaction and void content of aggregate. There are two types of measured:

1. Loose Unit Weight

The clean, dry bucket is filled with aggregate without compaction. After leveling the surface, the bucket is weighed. The aggregate weight is divided by the bucket volume to get the loose unit weight.

2. Compacted Unit Weight

The bucket is filled in three layers, each compacted with 25 tamping blows. After striking off and weighing, the unit weight is calculated similarly.

- **Unit Weight of Fine Aggregate – Sylhet Sand**



Shoveling Condition (Weight)



Working Process



Rodding Condition (Weight)



Jiggling Condition (Weight)

Figure 3.5: Unit Weight of Fine Aggregate-Sylhet Sand

- **Unit Weight of Fine Aggregate – Glass Powder**



Shoveling Condition (Weight)



Working Process



Rodding Condition (Weight)



Jiggling Condition (Weight)

Figure 3.6: Unit Weight of Fine Aggregate – Glass Powder

- **Unit Weight of Coarse Aggregate – Indian Pakur Stone**



Shoveling Condition (Weight)



Working Process



Rodding Condition (Weight)



Jiggling Condition (Weight)

Figure 3.7: Unit Weight of Coarse Aggregate – Indian Pakur Stone

- **Unit Weight of Coarse Aggregate – Waste Glass**



Shoveling Condition (Weight)



Working Process



Rodding Condition (Weight)



Jiggling Condition (Weight)

Figure 3.8: Unit Weight of Coarse Aggregate – Waste Glass

3.4 Used of Materials

3.4.1 Cement

Shah Special Portland Composite Cement (PCC) is a premium-quality cement product manufactured by Shah Cement Industries Ltd., one of the leading cement producers in Bangladesh. This type of cement is designed to meet the diverse construction needs of modern infrastructure, offering enhanced durability, workability and sustainability.

- **Specifications of Cement**

Name of Cement	: Shah Cement (Portland Composite Cement)
BDS EN 197-1	: 2010 CEM II/A-M (S-V-L), 42.5 N
Clinker	: 80%–94%
Limestone	: 3% – 15%
Gypsum	: 3% – 5%
Standard Fineness	: 280 m^2/kg
Standard Soundness	: 10 mm
Standard Consistency	: 29%
Initial Setting Time	: 30 Minutes
Final Setting Time	: 10 Hours
Specific Gravity	: 3.15
Weight	: 50 Kg.
Compressive Strength (28 days):	: Minimum 42.5 MPa



Figure 3.9: Shah Cement

3.4.2 Fine Aggregate

Sylhet Sand

Sylhet Sand is a naturally occurring fine aggregate sourced from the riverbeds and quarries of the Sylhet region in northeastern Bangladesh. It is one of the most widely used construction materials in the country due to its superior physical and chemical properties.

- **Physical Properties of Sylhet Sand**

Type	: Natural River Sand
Color	: Light grey to off-white
Grain Shape	: Sub-angular to rounded
Specific Gravity	: 2.46 - 2.66
Fineness Modulus (FM)	: 2.6
Unit Weight	: 1570 kg/m³
Water Absorption Capacity	: 3.06%



Figure 3.10: Sylhet Sand

- **Advantages of Sylhet Sand**
  i. Clean and Well-Graded.
  ii. Fine Particle Size.
  iii. High Silica Content.
  iv. Locally Available.
  v. Improves Strength.

Glass Powder as Fine Aggregate

Glass powder is a finely ground material produced from waste glass, such as discarded bottles, windows and other glass products. In recent years, it has gained significant attention in the construction industry as a sustainable and eco-friendly alternative to traditional materials in concrete.

- **Physical Properties of Glass Powder**

Type	: Recycled Sand
Color	: White, light green or bluish etc
Shape of Particles	: Angular to sub-angular
Surface Texture	: Smooth and glassy
Standard Specific Gravity	: 2.4 – 2.6
Fineness Modulus (FM)	: 2.9
Unit Weight	: 1332 kg/m³
Water Absorption Capacity	: Very low, usually less than 0.5%, due to its non-porous and glassy texture.



Figure 3.11: Glass Powder

- **Advantages of Glass Powder**
  - i. Pozzolanic Properties.
  - ii. Waste Utilization.
  - iii. Improves Workability.
  - iv. Reduces Cement Consumption
  - v. Increases Durability.

3.4.3 Coarse Aggregate

Indian Pakur Stone

Indian Pakur Stone is a high-quality black stone commonly used as coarse aggregate in concrete construction across Bangladesh and eastern India. It is quarried mainly from the Pakur district in Jharkhand, India and is highly valued for its superior strength, durability and hardness**.**

- **Physical Properties of Indian Pakur Stone**

Type	: Trap rock / Basalt
Color	: Dark gray to black
Shape of Particles	: Angular
Specific Gravity	: 2.57-2.63
Fineness Modulus (FM)	: 6.9
Unit Weight	: 1502 kg/m³
Water Absorption Capacity	: 0.89%



Figure 3.12: Indian Pakur Stone

- **Advantages of Indian Pakur Stone**
  i. High Compressive Strength.
  ii. Hard and Dense Texture.
  iii. Long-Term Durability.
  iv. Good Bonding with Cement.
  v. Uniform Size and Shape

Waste Glass as Coarse Aggregate

Waste glass can be used as a partial replacement for natural coarse aggregate in concrete. After being collected, cleaned, and crushed into suitable sizes, waste glass exhibits physical characteristics similar to natural stone. It is hard, angular, and non-porous with low water absorption and moderate specific gravity.

- **Physical Properties of Waste Glass**

Type	: Recycled Stone
Color	: White, light green or bluish etc
Shape of Particles	: Angular and sharp edges
Particle Size	: 4.75 mm to 20 mm
Standard Specific Gravity	: 2.5
Fineness Modulus (FM)	: 6.7
Unit Weight	: 1432 kg/m^3
Water Absorption Capacity	: Very low, usually less than 0.5%, due to its non-porous and glassy texture.



Figure 3.13: Waste Glass

- **Advantages of Waste Glass**
  i. Conserves Natural Resources.
  ii. High Hardness and Strength.
  iii. Low Water Absorption.
  iv. Cost-Effective.
  v. Improves Aesthetics.

3.4.4 Water-Cement Ratio

The water-cement ratio (w/c ratio) is one of the most critical parameters in concrete mix design, as it directly influences the strength, durability, workability and long-term performance of concrete. It is defined as the ratio of the mass of water to the mass of cement used in a concrete mix. In this study, the water-cement ratio was carefully selected based on the desired compressive strength, workability and durability requirements of the concrete. For this experimental study, the w/c ratio was maintained within a controlled range 0.45 to ensure consistent testing and allow meaningful comparison between conventional concrete and concrete mixes incorporating waste glass as fine and coarse aggregate.



Figure 3.14 : Water-Cement Ratio

3.5 Preparation of Molds

Standard steel cylinder molds of size 100 mm (4 Inch) diameter × 200 mm (8 Inch) height were used in this study as per ASTM C39 specifications.

- The inside surfaces of the molds were cleaned and lightly oiled to facilitate easy de-molding.
- Each mold was placed on a smooth, level surface and secured against movement during casting.



Figure 3.15: Preparation of Molds

3.6 Mix Design of Concrete

Concrete mix design is the process of selecting suitable ingredients (cement, fine aggregate, coarse aggregate and water) and determining their relative proportions to produce concrete with the required strength, durability and workability.

- **Specifications of Mix Design**
  - ✓ Concrete Mix Ratio = 1:1.5:3
  - ✓ Shrinkage Factor = 1.5
  - ✓ Wastage = 10% Added
  - ✓ Water Cement Ratio = 0.45

- **Materials Estimation for Cylinder Casting**

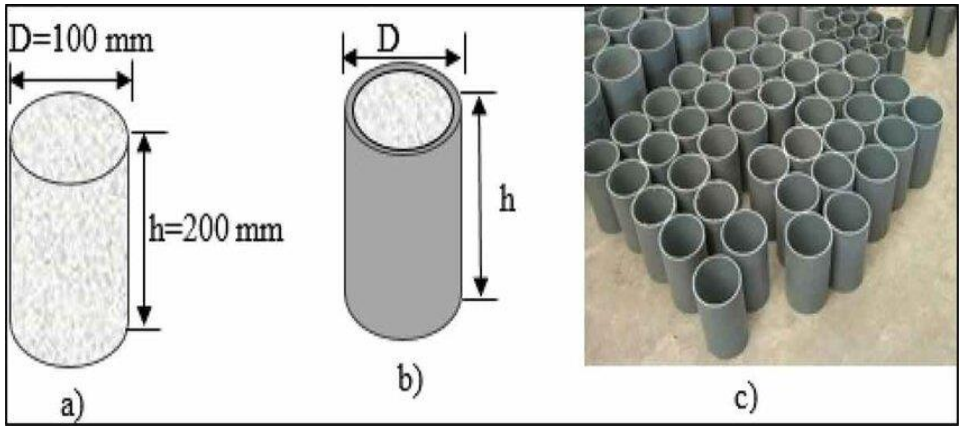


Figure 3.16: Cylinder Shape & Size

The following estimate is done based on the shape and size of the cylinder.

Here,

d = 100 mm = 4 in = 0.33 ft

h = 200 mm = 8 in = 0.67 ft

Volume =$(\pi d^2 h)/4$ = 3.1416 x $(0.33)^2$ x 0.67= 0.057 x 1.5 = 0.0855 cft + 10

= 0.09405 cft

Sum of Ratio = 1+1.5+3 = 5.5

Cement = (0.09405 x 1)/5.5 = 0.0171 cft = 697 gm

Sand = (0.09405 x 1.5)/5.5 = 0.02565 cft = 1166 gm

Stone = (0.09405 x 3)/5.5 = 0.0513 cft = 2410 gm

Water = 697 x 0.45 = 313.65 gm

Table 3.1: Mix Proportion for Concrete (Weight Basis)

SL No.	Case	Cylinder Nos	Cement (gm)	Sylhet Sand + Fine Glass (gm)	Indian Pakur + Coarse Glass (gm)	Water (gm)
01	SS-FG 5	6	4182	6646+350	14460+0	1880
02	SS-FG 10	6	4182	6296+700	14460+0	1880
03	SS-FG 15	6	4182	5947+1049	14460+0	1880
04	SS-FG 20	6	4182	5597+1399	14460+0	1880
05	IP-CG 5	6	4182	6996+0	13737+723	1880
06	IP-CG 10	6	4182	6996+0	13014+1446	1880
07	IP-CG 15	6	4182	6996+0	12291+2169	1880
08	IP-CG 20	6	4182	6996+0	11568+2892	1880
Total		Cylinder = 48 Nos	Cement = 33.456 Kg	SS = 52.47 Kg & FG = 3.498 Kg	IP = 93.99 Kg & CG = 7.23 Kg	Water = 15.04 Kg

[Case Notation:*SS-FG = Sylhet Sand+ Fine Glass, *IP-CG = Indian Pakur + Coarse Glass, All Case number are in percentage (%)]

3.7 Mixing of Concrete

The mixing of concrete was carried out in accordance with standard laboratory procedures to ensure a homogeneous mix suitable for strength testing. The concrete mix ratio was maintained at 1 : 1.5 : 3 (Cement : Fine Aggregate : Coarse Aggregate) with a constant water-cement ratio of 0.45 and Portland Composite Cement (PCC) was used as the binder. Waste glass was used as a partial replacement for both fine aggregate (Sylhet Sand) and coarse aggregate (Indian Pakur Stone) at 5%, 10%, 15% and 20% by weight.

The following steps were followed for the mixing process:

- **Batching of Materials**

  Batching is the process of measuring and combining the concrete ingredients—cement, fine aggregate, coarse aggregate and water in accurate proportions to ensure a consistent and high-quality concrete mix. It is a critical step in concrete production, directly affecting the strength, workability and durability of the final product.

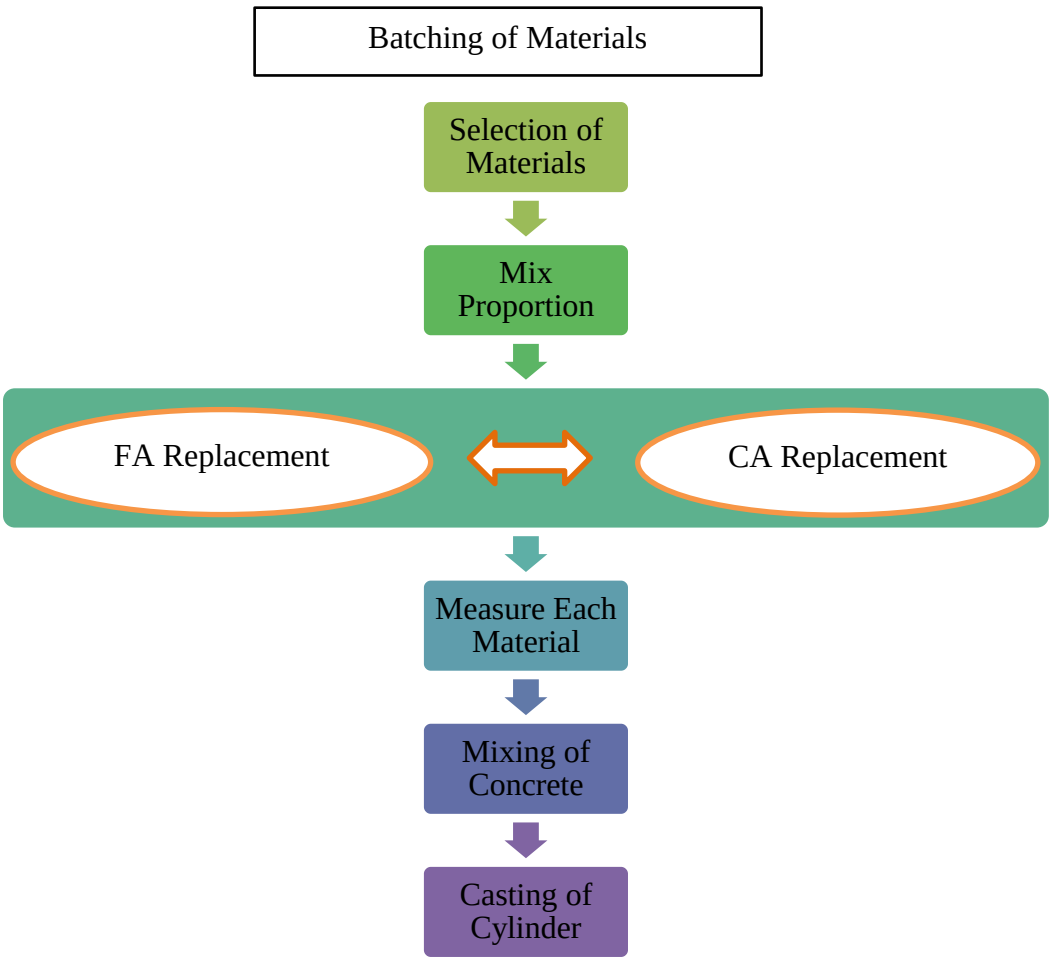


Figure 3.17: Flowchart of Batching of Materials

Condition – 1: Fine Aggregate (FA) Replacements

The required quantities of cement, Sylhet sand with replacement percentage of glass powder and Indian Pakur Stone were measured accurately by weight using a digital balance.



Cement



Indian Pakur Stone



Sylhet Sand



Glass Powder

Figure 3.18: Fine Aggregate Replacements

Condition – 2: Coarse Aggregate (CA) Replacements

The required quantities of cement, Sylhet sand and Indian Pakur Stone with replacement percentage of waste glass were measured accurately by weight using a digital balance.



Cement



Sylhet Sand



Indian Pakur Stone



Waste Glass

Figure 3.19: Coarse Aggregate Replacements

- **Dry Mixing**

  The dry materials—cement, fine aggregate, coarse aggregate and the waste glass—were first mixed in a clean, dry mixing tray. This dry mixing was continued for approximately 2–3 minutes to achieve a uniform and consistent color, ensuring even distribution of glass particles.



Figure 3.20: Dry Mixing

- **Addition of Water**

  The pre-measured water was gradually added to the dry mix while continuously turning the mixture using hand mixer. The addition of water was done slowly to prevent any localized wet or dry zones in the mix.



Figure 3.21: Addition of Water

- **Wet Mixing**

  After adding water, the mixing process was continued for another 2–3 minutes until a uniform and workable concrete mix was obtained. The workability was visually checked and adjustments were not required as the water-cement ratio remained constant.



Figure 3.22: Wet Mixing

3.8 Casting of Cylinders

After proper mixing, the fresh concrete was used to cast cylindrical specimens for compressive strength testing. The following procedure was followed for casting:

- **Filling the Molds**
  - The concrete was poured into the molds in three equal layers**.**
  - Each layer was compacted using a standard tamping rod (16 mm diameter, 600 mm length)**.**
  - 25 strokes were applied per layer, distributed evenly over the cross-section to eliminate voids and ensure proper compaction.
  - For additional compaction and surface finishing, the molds were lightly tapped on the sides with a tamping rod after the final layer.



Figure 3.23: Filling Molds & Tamping

- **Leveling and Identification**
  - After the final layer was compacted, the surface of the concrete was leveled using a trowel to ensure a smooth finish.
  - Each specimen was marked with a unique identification code indicating its mix type and replacement percentage (e.g., Coarse-5%,Coarse 10%, Coarse-15,Coarse-20%,Fine-5%,Fine-10%,Fine-15%,Fine-20% etc.).



Figure 3.24: Leveling and Identification

3.9 Curing Process

Curing is a critical stage in the concrete production process that ensures the development of the desired strength and durability. It involves maintaining adequate moisture, temperature, and time to allow the cementitious materials in the concrete to hydrate properly. In this study, water curing was adopted for all cylindrical concrete specimens.

- **De-molding**

  After casting, the concrete cylinders were allowed to set undisturbed for 24 hours at room temperature (approximately 25–27°C). The top surface was covered with a damp cloth to prevent moisture loss during initial setting.

  - Once the initial setting was complete, the specimens were carefully de-molded to prevent any surface damage or deformation.
  - Each specimen was identified with a unique label indicating its mix type and replacement percentage (e.g., Coarse-5%,Coarse 10%, Coarse-15,Coarse-20%,Fine-5%,Fine-10%,Fine-15%,Fine-20% etc.).



Figure 3.25: After De-molding of Specimens

- **Water Curing**

  All specimens were fully submerged in a curing tank filled with clean potable water maintained at a temperature of 27 ± 2°C.

  - The curing tank was kept in a shaded area to avoid direct sunlight and temperature fluctuations.
  - Water was changed periodically to ensure cleanliness and avoid contamination.



Figure 3.26: Curing in Water Tank of SU

- **Curing Periods**

  The specimens were cured for two standard durations in accordance with ASTM and ACI testing practices:

  - 7 Days Curing**:** To assess early strength development.
  - 28 Days Curing**:** To determine the standard compressive strength of the concrete.

3.10 Preparation to Crush the Concrete Cylinders

Prior to conducting the compressive strength test, proper preparation of the concrete cylinders was essential to ensure accurate and consistent results. The following steps were followed to prepare the specimens for testing:

- **Selection of Specimens**
  - Concrete cylinders cured for 7 days and 28 days were selected according to the testing schedule.
  - Each specimen was identified based on its mix designation (e.g., Coarse-5%,Coarse 10%, Coarse-15,Coarse-20%,Fine-5%,Fine 10%, Fine-15%,Fine-20% etc.).
  - Care was taken to ensure that no damaged or cracked specimens were selected for the test.



Figure 3.27: Preparation to Crush the Concrete Cylinder

- **Surface Cleaning**
  - The cylinders were removed from the curing tank before 24 hours for crush.
  - Surface water was wiped off using a damp cloth to remove any excess moisture.
  - Loose particles, algae, or dirt were also cleaned from the surface to avoid any influence on the load distribution during testing.

3.11 UTM Machine

The Universal Testing Machine (UTM) was used to determine the compressive strength of the concrete cylinders. This machine applies a controlled and uniform compressive load to the specimen until failure, and records the maximum load at which the specimen fails. The testing was conducted in accordance with ASTM C39 and AASHTO T22 standards.

- **Machine Description**

  The Universal Testing Machine (UTM) used in this study was a compression testing machine equipped with an analog dial gauge and a maximum load capacity of 1000 kN**.**

Although it featured an analog display for load and stress readings, the machine was also equipped with:

- An automatic load rate control system for consistent application of force.
- A digital display unit for secondary readout and calibration purposes.
- A load cell to ensure precise measurement and monitoring of applied loads.

The machine was capable of applying compressive load at a constant rate of 0.25 ± 0.05 MPa/sec**,** in accordance with standard testing guidelines (e.g., ASTM C39/C39M or equivalent)**,** ensuring the reliability and repeatability of the test results.

- **Features of the UTM**
  - Load Capacity**:** Up to 1000 kN
  - Loading Type**:** Hydraulic
  - Display Unit**:** Analog Dial Gauge (Load in kN and stress in MPa)
  - Accuracy**:** ±1% of the indicated load
  - Control System**:** Manual with precise loading rate adjustment.

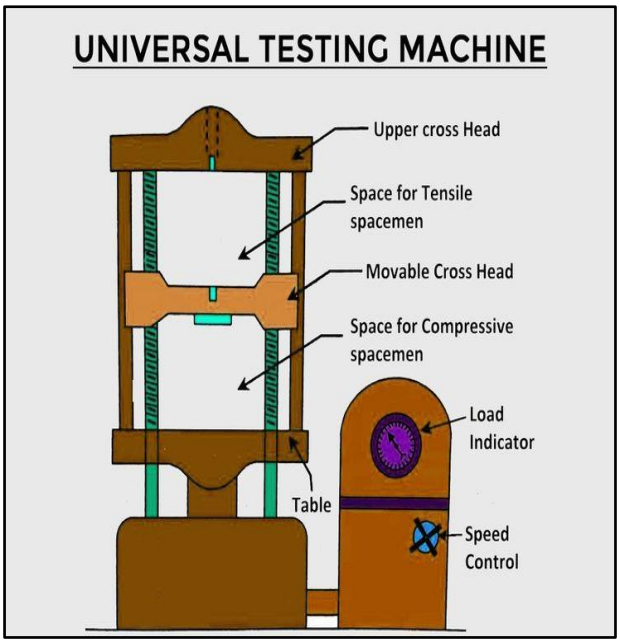


Figure 3.28: Features of the UTM

3.12 Compressive Strength Test

The compressive strength test is one of the most important tests for evaluating the mechanical properties of concrete. It determines the ability of a concrete specimen to resist axial loads and is used as a key indicator of overall concrete quality and structural performance. In this study, the test was performed on cylindrical specimens to assess the strength variation with different percentages of waste glass as partial replacements for fine and coarse aggregates.

To determine the compressive strength of concrete cylinders cast with varying percentages of waste glass (5%, 10%, 15%, and 20%) replacing both Sylhet sand (fine aggregate) and Indian Pakur stone (coarse aggregate).

- **Equipment Used**

✓ Universal Testing Machine (UTM) with a capacity of 1000 kN.



Figure 3.29: UTM Machine

✓ Calibrated Vernier Caliper: For measuring diameter of cylinder**.**



Figure 3.30: Measuring Diameter of Cylinder

✓ Steel Ruler: For measuring height of cylinder**.**



Figure 3.31: Measuring Height of Cylinder

✓ Digital Balance: For recording weight of cylinder.



Figure 3.32: Recording Weight of Cylinder

- **Testing Procedure**
    - **Machine Setup**
        - The UTM was calibrated and the loading rate was set to 2.5 kN/sec (approx. 0.25 MPa/sec).
        - The cylinder was placed vertically and centered between the platens.
    - **Load Application**
        - A compressive load was applied gradually without shock until the specimen failed.
        - The maximum load at failure was recorded in kilonewtons (kN).



Figure 3.33: UTM Load Application

3.13 Fracture of Cylinders

Compressive fracture of a concrete cylinder refers to the breaking or failure of the cylinder specimen when it is subjected to compressive force in a Universal Testing Machine (UTM). This test helps determine the compressive strength of the concrete.

- **Procedure Overview**
    - Cured concrete cylinder is placed vertically between two steel platens of the UTM.
    - Load is applied gradually and uniformly until failure occurs.
    - The maximum load at failure is recorded.

- **Fracture Patterns**

  The mode of failure usually depends on concrete strength, mix type, and loading condition. Common fracture types include:

  - Shear Failure (Cone and Split)**:** Sudden diagonal crack with a conical top.
  - Columnar Failure (Splitting)**:** Vertical cracks running along the cylinder height.
  - Explosive Failure**:** High-strength concrete may explode or break suddenly.
  - Cone Failure**:** The top or bottom shears off in a cone shape due to platen friction.



Figure 3.34: Compressive Fracture of Cylinder after 7 Days



Figure 3.35: Compressive Fracture of Cylinder after 28 Days

3.14 Compressive Strength Calculation

The compressive strength (MPa) was calculated using the following formula:

Compressive Strength (MPa) = Ultimate Load (N)/ Cross-sectional Area (mm^2)

Where:

- ✓ Ultimate Load (N) is the maximum load the concrete specimen can withstand before failure, as recorded by the Universal Testing Machine (UTM).
- ✓ Cross-sectional Area (mm^2) is the surface area of the cylinder's circular face, calculated as:

Area= $\pi (d^2)/4$

Where d is the diameter of the cylinder.

- **Result Documentation**
  - The results were tabulated for each mix and curing age.
  - Average strength for each group was calculated and compared across the different replacement levels.

3.15 Compressive Strength Importance

Compressive strength is considered the most crucial mechanical property of concrete. It represents the material's ability to resist axial loading and is a primary indicator of structural performance, durability, and quality control in construction projects. In this study, assessing compressive strength was fundamental to understanding how waste glass, used as a partial replacement for both fine and coarse aggregates, influences the performance of concrete.

❖ **Structural Reliability**

- Compressive strength directly reflects the load-bearing capacity of structural elements such as columns, beams, and slabs.
- Concrete's ability to withstand axial loads ensures stability and safety in both residential and industrial constructions.

❖ **Quality Control Indicator**

- In practice, compressive strength is used to verify mix design accuracy, monitor consistency in batching, and determine the suitability of raw materials.
- Strength values at 7 and 28 days provide a benchmark for early and long-term performance.

❖ **Impact on Durability and Service Life**

- Higher compressive strength often correlates with better resistance to environmental factors**,** including weathering, chemical attack, and abrasion.
- It contributes to longer lifespan and lower maintenance costs of concrete structures.

❖ **Role in Mix Design Optimization**

- In this study, compressive strength results guide the evaluation of waste glass as a sustainable material in concrete.
- By analyzing strength variations with different replacement levels (5%, 10%, 15%, 20%), we assess the feasibility of waste glass in practical construction applications.

❖ **Compliance with Standards**

- Compressive strength is a standardized measure used to ensure compliance with building codes and engineering specifications (e.g., ASTM C39, ACI 318).
- It helps in classifying concrete grades (e.g., M20, M25) used for different structural requirements.

3.16 Summary

This chapter provided a detailed overview of the methodology followed in conducting a comparative study on the compressive strength of concrete using waste glass as partial replacement for both fine and coarse aggregates. The key steps involved in the research were carefully designed to ensure accurate, reliable, and reproducible results.

Concrete was mixed in a standard 1:1.5:3 ratio with a water-cement ratio of 0.45, using Portland Composite Cement. Cylindrical specimens of size 100 mm × 200 mm were cast for compressive strength testing.Waste glass was used to replace fine aggregate (Sylhet sand) and coarse aggregate (Indian Pakur stone) at replacement levels of 5%, 10%, 15%, and 20%.

The mixing, casting, curing, and testing procedures were executed as per standard practices. The compressive strength test was conducted using a Universal Testing Machine (UTM) at 7 and 28 days of curing. Each cylinder's failure pattern and fracture behavior were documented, highlighting the mechanical response of glass-infused concrete.

The compressive strength values obtained from each mix helped evaluate the influence of waste glass content on the strength and durability of the concrete. The findings from these tests are essential for determining the feasibility of using waste glass as a sustainable and environmentally friendly alternative in concrete production.

CHAPTER 4

RESULTS AND ANALYSIS OF LAB TEST

This chapter provides a comprehensive analysis of the experimental results derived from a series of laboratory tests aimed at assessing the compressive strength performance of concrete. In this study, waste glass was utilized as a partial replacement for both fine and coarse aggregates at varying proportions. The objective was to investigate how different replacement levels influenced the mechanical behavior of concrete, particularly its compressive strength at 7 and 28 days. The findings presented here are based on standardized testing procedures and contribute valuable insight into the feasibility of incorporating waste glass in sustainable concrete production.

4.1 Sieve Analysis of Aggregates

Table 4.1: Sieve Analysis of Fine Aggregate – Sylhet Sand

Sieve No	Materials Retained (gm)	% Materials Retained (gm)	Cumulative % Materials Retained (gm)	% Finer	FM
#4	13	1.3	1.3	98.7	2.6
#8	65	6.5	7.8	92.2	
#16	190	19	26.8	73.2	
#30	200	20	46.8	53.2	
#50	370	37	83.8	16.2	
#100	153	15.3	99.1	0.9	
Pan	9				
Total	1000		265.6		

Table 4.2: Sieve Analysis of Fine Aggregate – Glass Powder

Sieve No	Materials Retained (gm)	% Materials Retained (gm)	Cumulative % Materials Retained (gm)	% Finer	FM
#4	0	0	0	0	2.9
#8	20	2	2	98	
#16	392	39.2	41.2	58.8	
#30	235	23.5	64.7	35.3	
#50	209	20.9	85.6	14.4	
#100	137	13.4	99.3	0.7	
Pan	25				
Total	1000		292.8		

Table 4.3: Sieve Analysis of Coarse Aggregate – Indian Pakur Stone

Sieve No	Materials Retained (gm)	% Materials Retained (gm)	Cumulative % Materials Retained (gm)	% Finer	FM
#3/4''	135	13.5	13.5	86.5	6.9
#3/8''	750	75	85.5	14.5	
#4	115	11.5	100	0	
#8	0	0	100	0	
#16	0	0	100	0	
#30	0	0	100	0	
#50	0	0	100	0	
#100	0	0	100	0	
Pan	0				
Total	1000		699		

Table 4.4: Sieve Analysis of Coarse Aggregate – Waste Glass

Sieve No	Materials Retained (gm)	% Materials Retained (gm)	Cumulative % Materials Retained (gm)	% Finer	FM
#3/4''	47	4.7	4.7	95.3	6.7
#3/8''	606	60.6	65.3	34.7	
#4	347	34.7	100	0	
#8	0	0	100	0	
#16	0	0	100	0	
#30	0	0	100	0	
#50	0	0	100	0	
#100	0	0	100	0	
Pan	0				
Total	1000		670		

4.2 Unit Weight of Aggregates

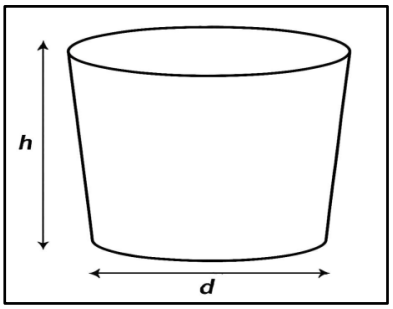


Figure 4.1: Empty Bucket

Here,

Bucket Height, h = 6'' = 0.1524 m

Bucket Diameter, d = 6'' = 0.1524 m

∴ Bucket Radius, r = d/2 = 0.1524/2 = 0.0762 m

Weight of Empty Bucket = 4000 gm

We Know,

Volume of Bucket = $\pi r^2 h$ = 3.1416 x $(0.0762)^2$ x 0.1524 = 0.00278m^3

Table 4.5: Unit Weight of Fine Aggregate – Sylhet Sand

Condition	Weight of Bucket, (gm)	Weight of Bucket + Material (gm)	Weight of Material (gm)	Volume of Bucket,(m^3)	Unit Weight, (kg/m^3)	Average Unit Weight, (kg/m^3)
Shoveling	4000	8071	4071	0.00278	1464	1570
Rodding	4000	8411	4411	0.00278	1587	
Jiggling	4000	8613	4613	0.00278	1659	

Table 4.6: Unit Weight of Fine Aggregate – Glass Powder

Condition	Weight of Bucket, (gm)	Weight of Bucket + Material (gm)	Weight of Material (gm)	Volume of Bucket,(m^3)	Unit Weight, (kg/m^3)	Average Unit Weight, (kg/m^3)
Shoveling	4000	7322	3322	0.00278	1195	1332
Rodding	4000	7829	3829	0.00278	1377	
Jiggling	4000	7961	3961	0.00278	1425	

Table 4.7: Unit Weight of Coarse Aggregate – Stone Chips (Indian Pakur)

Condition	Weight of Bucket, (gm)	Weight of Bucket + Material (gm)	Weight of Material (gm)	Volume of Bucket,(m^3)	Unit Weight, (kg/m^3)	Average Unit Weight, (kg/m^3)
Shoveling	4000	7781	3781	0.00278	1360	1502
Rodding	4000	8328	4328	0.00278	1557	
Jiggling	4000	8420	4420	0.00278	1590	

Table 4.8: Unit Weight of Coarse Aggregate – Waste Glass

Condition	Weight of Bucket, (gm)	Weight of Bucket + Material (gm)	Weight of Material (gm)	Volume of Bucket,(m^3)	Unit Weight, (kg/m^3)	Average Unit Weight, (kg/m^3)
Shoveling	4000	7641	3641	0.00278	1310	1432
Rodding	4000	8086	4086	0.00278	1470	
Jiggling	4000	8214	4214	0.00278	1516	

4.3 Specific Gravity of Aggregates

Table 4.9: Specific Gravity of Fine Aggregate – Sylhet Sand

Oven Dry Weight of Sample in Air, A (gm)	Weight of Pycnometer Filled with Water to Calibration Mark, B (gm)	Weight of Pycnometer with Specimen and Water to Calibration Mark, C (gm)	Weight of SSD Sample in Air, S (gm)
295	656	840	304

Tests	Formula	Calculation	Results
Apparent Specific Gravity	A/(B+A-C)	295/(656+295-840)	2.66
Bulk Specific Gravity (Oven Dry Basis)	A/(B+S-C)	295/(656+304-840)	2.46
Bulk Specific Gravity (SSD Basis)	S/(B+S-C)	304/(656+304-840)	2.54
Absorption Capacity, D %	(S-A)/A x 100	(304-295)/295 x 100	3.06

Table 4.10: Specific Gravity of Coarse Aggregate –Indian Pakur Stone

Oven Dry Weight of Sample in Air, A (gm)	Weight of SSD Sample in Air, B (gm)	Weight of SSD Sample in Water, C (gm)
1680	1695	1040

Tests	Formula	Calculation	Results
Apparent Specific Gravity	A/(A-C)	1680/(1680-1040)	2.63
Bulk Specific Gravity (Oven Dry Basis)	A/(B-C)	1680/(1695-1040)	2.57
Bulk Specific Gravity (SSD Basis)	B/(B-C)	1695/(1695-1040)	2.59
Absorption Capacity, D%	(B-A)/A x 100	(1695-1680)/1680 x 100	0.89

4.4 Compressive Strength Test Result of 7 Days

Table 4.11: Result of 7 Days Compressive Strength Test

SL No	Percentage of Replacement	Mix Ratio	Cylinder Mold			Compressive Strength (PSI)	Average Compressive Strength (PSI)	Average Compressive Strength (MPa)
			Dia (mm)	Height (mm)	Weight (gm)			
Condition -1 Fine Aggregate (Glass Powder) Replacements								
1	5 %	1:1.5:3	103.98	204	4133	1964	1737	11.98
			100.30	205	3923	1652		
			102.08	205	3960	1595		
2	10 %	1:1.5:3	102.97	206	4172	1654	1727	11.91
			102.50	206	3988	1845		
			102.10	206	4060	1682		
3	15 %	1:1.5:3	102.05	205	4027	1684	1826	12.60
			102.27	206	4032	1853		
			102.29	206	4145	1941		
4	20 %	1:1.5:3	101.67	206	4045	2322	2313	15.95
			101.40	206	3982	2370		
			102.13	206	4005	2248		
Condition -2 Coarse Aggregate (Waste Glass) Replacements								
5	5 %	1:1.5:3	103.00	204	4013	1827	1864	12.86
			101.62	206	4020	1788		
			101.35	204	3982	1977		
6	10 %	1:1.5:3	103.31	206	4114	1816	1844	12.72
			101.94	205	3998	1777		
			102.35	206	4090	1939		
7	15 %	1:1.5:3	103.50	207	4130	1655	1588	10.96
			103.02	206	4038	1566		
			103.80	207	4080	1542		
8	20 %	1:1.5:3	101.40	206	4007	1347	1444	9.96
			101.93	206	3997	1599		
			103.28	206	4027	1385		

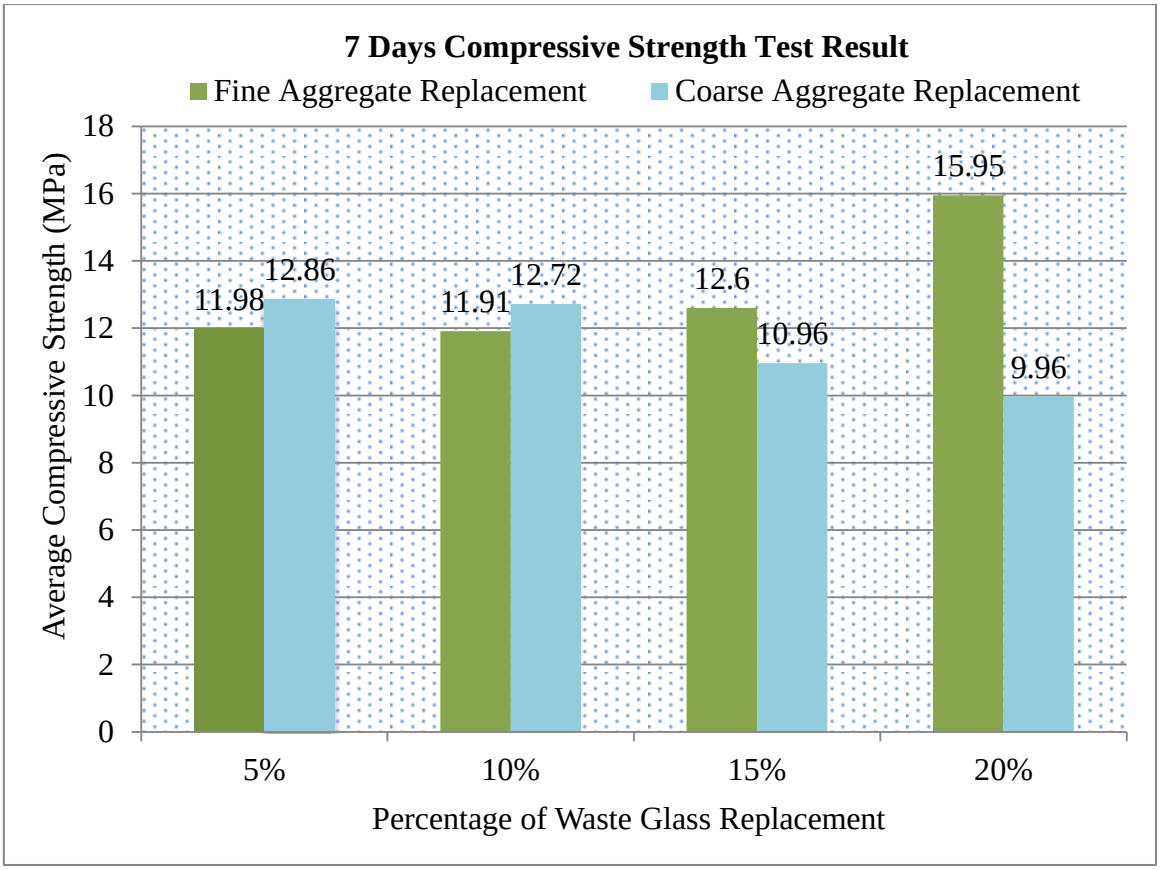


Figure 4.2: Result of 7 Days Compressive Strength Test

Key Observations:

- For 20% fine aggregate replacement shows the highest strength due to better packing and pozzolanic effect over early age. Strength remains nearly same at 5%, 10%, and 15%.
- For coarse aggregate replacement shows the strength is lower overall, especially at 20% replacement levels due to poor bonding.

The best performance overall is seen at 20% fine aggregate replacement at 7 days.

4.5 Compressive Strength Test Result of 28 Days

Table 4.12: Result of 28 Days Compressive Strength Test

SL No	Percentage of Replacement	Mix Ratio	Cylinder Mold			Compressive Strength (PSI)	Average Compressive Strength (PSI)	Average Compressive Strength (MPa)
			Dia (mm)	Height (mm)	Weight (gm)			
Condition-1: Fine Aggregate (Glass Powder) Replacement								
1	5 %	1:1.5:3	102.24	206	4062	3444	3383	23.34
			103.35	206	4236	3042		
			101.63	206	4074	3664		
2	10 %	1:1.5:3	101.82	207	4060	3473	3966	27.36
			102.81	206	4139	4157		
			104.00	206	4256	4267		
3	15 %	1:1.5:3	102.57	207	4184	3896	3784	26.1
			102.50	203	4130	3427		
			101.75	205	3998	4030		
4	20 %	1:1.5:3	102.22	204	4041	3445	3582	24.70
			103.92	205	4130	3385		
			101.84	206	4093	3916		
Condition-2: Coarse Aggregate (Waste Glass) Replacement								
5	5 %	1:1.5:3	101.91	206	4192	3555	3565	24.59
			101.87	205	4150	3416		
			103.26	204	3969	3723		
6	10 %	1:1.5:3	103.06	205	4163	3129	2991	20.63
			102.50	204	4121	3040		
			101.65	205	4074	2805		
7	15 %	1:1.5:3	102.77	206	4186	3059	3070	21.18
			101.72	205	4005	3123		
			101.83	205	4070	3027		
8	20 %	1:1.5:3	100.00	206	3920	3415	3400	23.45
			102.25	206	4135	3532		
			101.65	206	4045	3252		

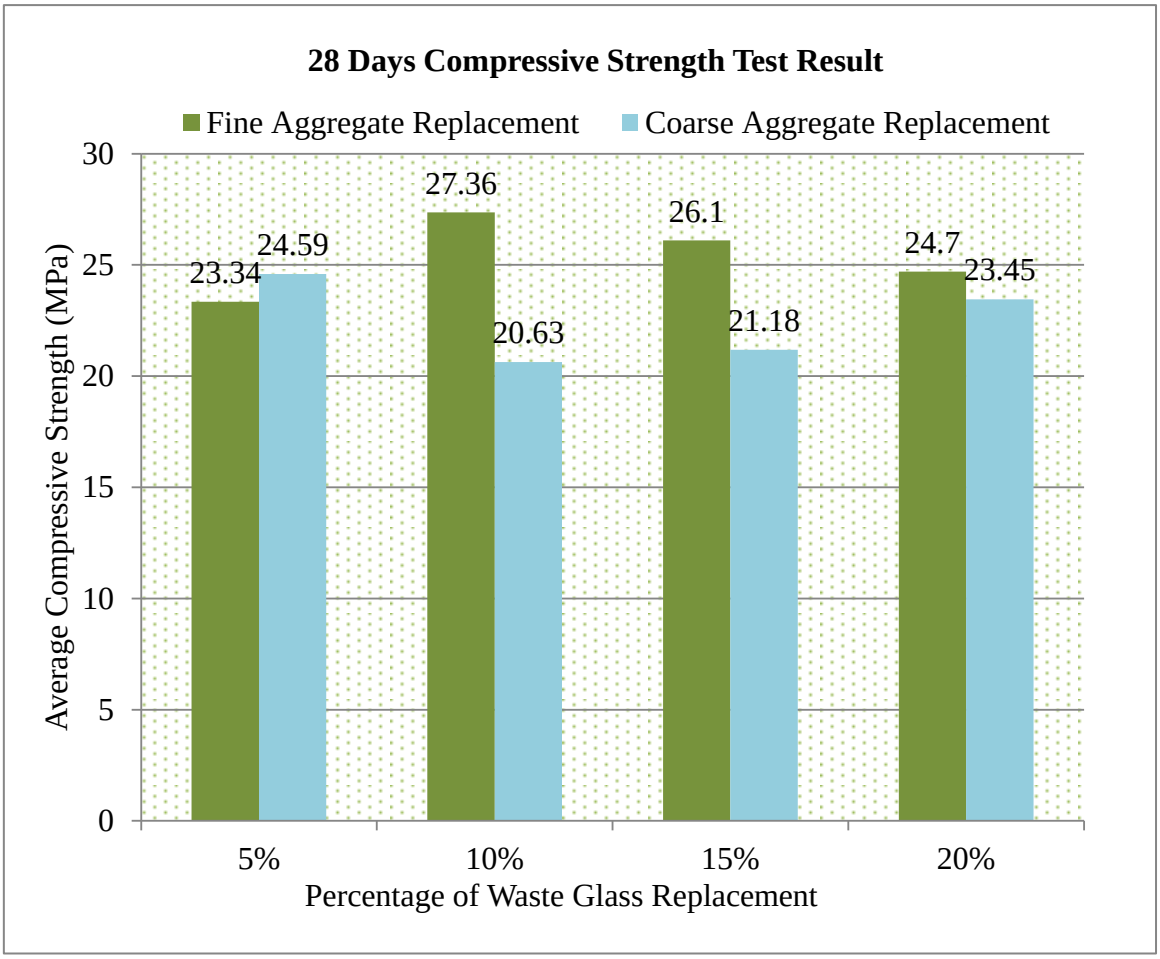


Figure 4.3: Result of 28 Days Compressive Strength Test

Key Observations:

- For 10% fine aggregate replacement shows the highest strength due to improved packing and pozzolanic action. At 15% and 20%, the strength becomes a little lower but still gives good results.
- For 5% coarse aggregate replacement shows the highest strength. After that, the strength goes down but improves a bit later.

The best performance overall is seen at 10% fine aggregate replacement at 28 days.

4.6 Compressive Strength Comparison to 7 Days and 28 Days

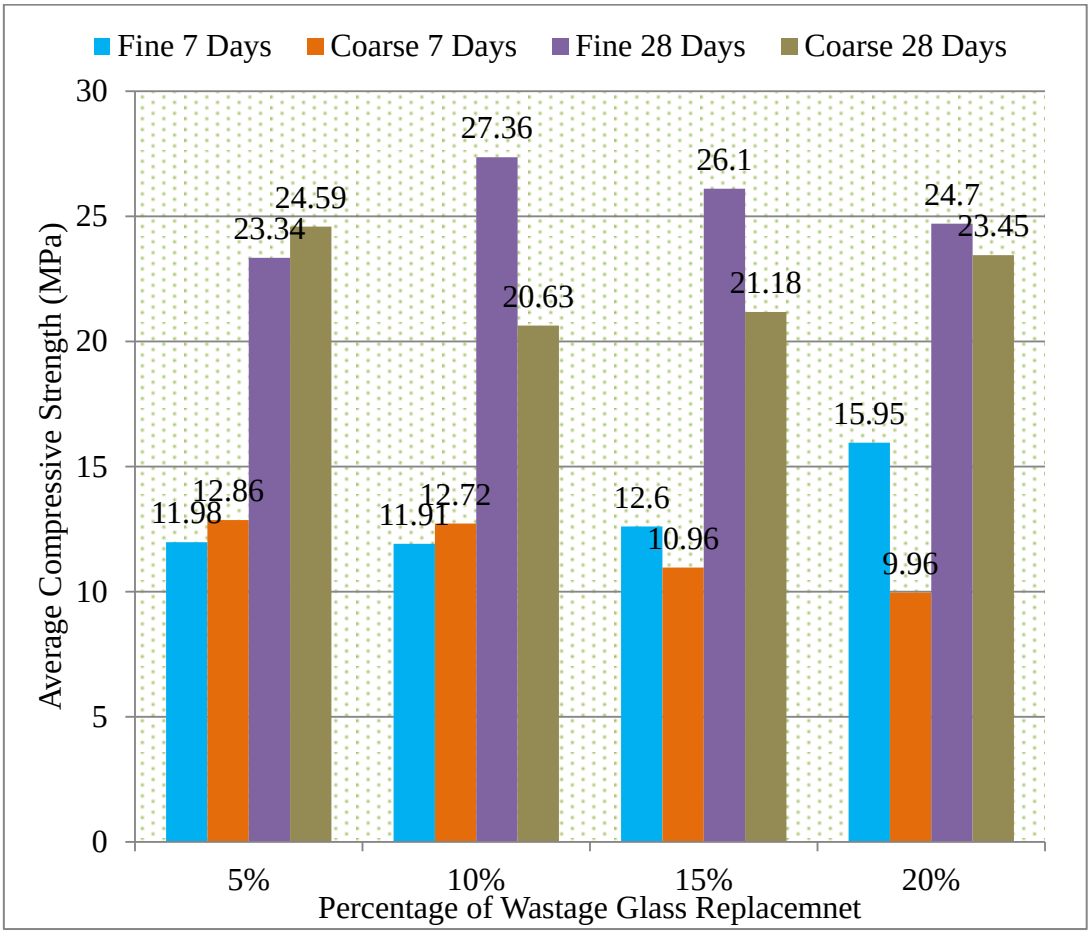


Figure 4.4: Compressive Strength Comparison Bar Chart

Key Insights:

- For 7 Days**:**
  - Fine Aggregate: Strength increases gradually, peaking at 20%.
  - Coarse Aggregate: Strength decreases steadily beyond 5%.
- For 28 Days**:**
  - Fine Aggregate**:** Peaks at 10%, then slightly drops.
  - Coarse Aggregate**:** Peaks at 5%, drops at 10%, but slightly recovers at 20%.

The best performance overall is seen at 10% fine aggregate replacement at 28 days**.** Also shown in line graph below:

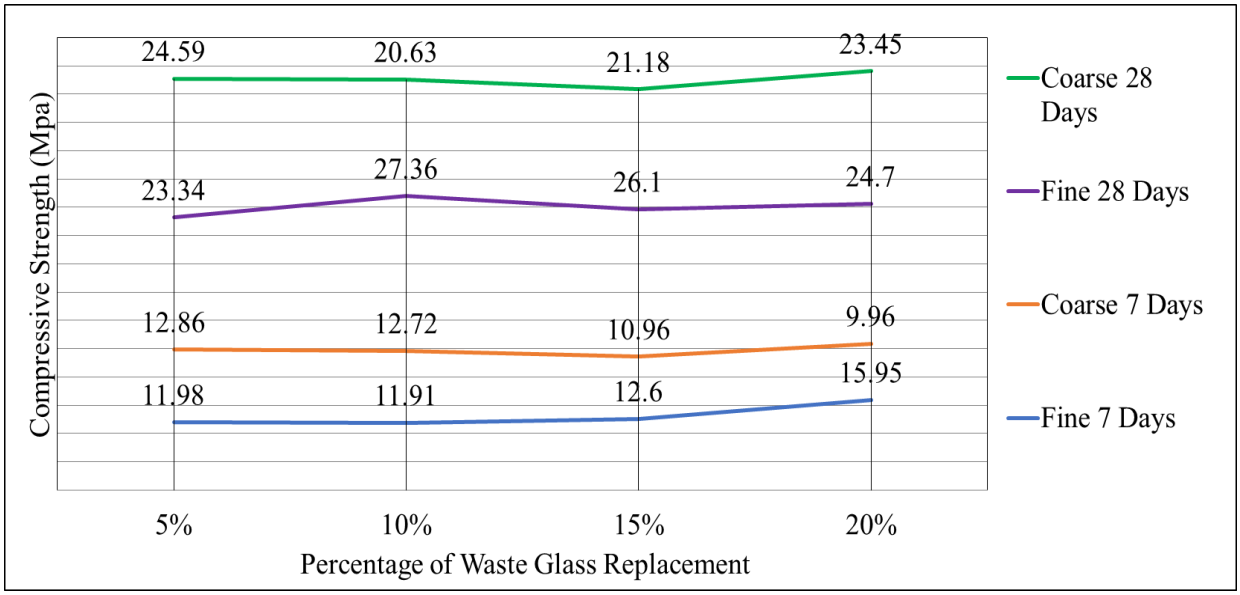


Figure 4.5: Compressive Strength Line Graph

4.7 Summary

This chapter presented and analyzed the results of a comprehensive experimental study investigating the effects of partially replacing natural fine and coarse aggregates with waste glass in concrete. The evaluation was based on laboratory tests, including sieve analysis, unit weight measurement, specific gravity determination and compressive strength testing at 7 and 28 days. The best compressive strength result (27.36 MPa) was achieved with 10% fine aggregate replacement at 28 days.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was conducted to investigate the effects of using waste glass as a partial replacement for both fine and coarse aggregates in concrete, at replacement levels of 5%, 10%, 15%, and 20%**,** and to compare their performance based on compressive strength at 7 days and 28 days**.**

The main findings of the study are mentioned below.

- For 7 days, the compressive strength of fine aggregate replacement by waste glass gradually increased. The maximum compressive strength is 15.95 MPa for 20% replacement. On the other hand, the maximum compressive strength is 11.98 MPa for 5% replacement of coarse aggregate by waste glass.
- For 28 days, 10% fine aggregate replacement achieved the highest strength of 27.36 MPa, followed by a slight decline at higher percentages. 5% coarse aggregate replacement achieved the highest strength of 24.59 MPa. For 5–10% replacement by waste glass improves concrete strength through pozzolanic action and better packing.
- For 28 days, 15-20% fine aggregate replacement the compressive strength of concrete is gradually decreasing due to weak bonding, brittleness, and alkali silica reaction risk but for coarse aggregate the results are vice-versa fine aggregate.
- Partial replacement of fine aggregate by using waste glass gave maximum compressive strength rather than using waste glass as partial replacement of coarse aggregate.

5.2 Limitations

Despite its contributions, this study has the following limitations:

- The investigation is limited to the compressive strength of concrete. Other mechanical and durability properties such as tensile strength, flexural strength, water absorption, and resistance to chemical attack are not addressed.
- The study is carried out at a laboratory scale under controlled conditions, which may not fully represent field performance or large-scale applications.
- Only one type of waste glass and specific sources of natural aggregates (Sylhet sand and Indian Pakur stone) are used. Variations in material properties from different sources are not considered.

The research does not include a life cycle assessment (LCA) or a cost analysis**,** which are important for a complete evaluation of environmental and economic feasibility.

5.3 Recommendations

- Early strength is important for precast elements, fast construction, repair work, and cold weather concreting, and replacing 20% of fine aggregate with waste glass gives the best results.
- Long-term strength is important for high-rise buildings, bridges, dams, and heavy-load structures, and replacing 10% of fine aggregate with waste glass gives the best results.
- Avoid using more than 10% coarse glass aggregate because too much coarse glass can weaken the bond between cement and other aggregates, which may reduce the strength of the concrete.

5.4 Future Works

- Test concrete by partially replacing fine and coarse aggregates with glass in various proportions.
- Higher percentages can be investigated by using waste glass as partial replacement of fine aggregate and coarse aggregate.
- Assess concrete strength and performance after longer curing periods, like 56 or 90 days.

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