

STRENGTH EVALUATION OF CONCRETE WITH RECYCLED COARSE AGGREGATE UNDER VARYING MIX PROPORTIONS

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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



Department of Civil Engineering

Sonargaon University

147/I, Green Road, Dhaka-1215, Bangladesh

Section: 25C

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DECLARATION

We hereby declare that this thesis, "Strength Evaluation of Concrete with Recycled Coarse Aggregate Under Varying Mix Proportions ," is the result of our own original research work. All sources of information have been duly acknowledged and referenced. This thesis has not been submitted in whole or in part for any other degree or qualification at Sonargaon University or any other institution.

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Dedicated

to

“----Our Beloved Parents----”

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ABSTRACT

The global construction industry faces a critical sustainability challenge, marked by both the rapid depletion of natural aggregate (NA) resources and the severe environmental impact of accumulating construction and demolition waste in landfills. To address this dual pressure, this experimental research investigated the structural viability of replacing Natural Coarse Aggregate (NCA) with Recycled Coarse Aggregate (RCA) in concrete production. The study centered on two popular mix ratios, 1:1.5:3 and 1:1:2 (Cement: Fine Aggregate: Coarse Aggregate), testing four levels of RCA substitution: 0% (serving as the control), 25%, 50%, and 75%. Comprehensive preliminary testing was conducted to characterize the physical properties of all aggregates, including their Fineness Modulus, specific gravity and unit weight. For compressive strength analysis, standard concrete cylinders were cast for all eight resulting mix variations, subjected to standard water curing, and monitored for strength development at 7, 14, 21, and 28-day. The results consistently demonstrated that an increase in RCA content leads to a progressive, non-linear decrease in compressive strength. From our result for using 25% recycled aggregate, strength gained 89%. For using 50% and 75% recycled used strength gained 81% and 71%.

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CHAPTER 1

INTRODUCTION

1.1 Background and Modification

Concrete is the most-used construction material in the world, forming the backbone of modern infrastructure. Its primary components are cement, water, and aggregates. Coarse aggregates, typically sourced from natural quarries and riverbeds, make up a significant portion of its volume. This immense, global demand for natural aggregates (NCA) has led to significant environmental concerns, including resource depletion, land degradation, and high carbon emissions from extraction and transport.

Simultaneously, the construction industry generates a massive stream of Construction and Demolition (C&D) waste. This waste, primarily composed of old concrete, is most often disposed of in landfills, occupying valuable space and representing a significant loss of potential resources.

This research explores a sustainable solution that addresses both problems: the use of Recycled Coarse Aggregate (RCA). RCA is produced by crushing old, demolished concrete, turning a waste product into a valuable resource. This process promotes a "circular economy" by reducing the demand for virgin aggregates and diverting Construction & Demolition waste from landfills.

1.2 Research Objectives and Overview

The primary **aim** of this research is to investigate and quantify the effect of replacing natural coarse aggregate with recycled coarse aggregate on the compressive strength of concrete.

The specific **objectives** are:

1. To determine the compressive strength of concrete using two different mix ratios with three levels of Recycled Coarse Aggregate. Replacement are 25%, 50%, and 75%.
2. To determine the Compressive strength for the mix ratios are 1:1.5:3 and 1:1:2

1.3 Organization of the thesis

Chapter 1: Introduction and Objective. This chapter provides the background and motivations of the research. The overall objectives and expected outcomes are also described in this chapter.

Chapter 2: Literature Review. This chapter reviews the related works in the field of sustainable construction, with a special focus on Recycled Coarse Aggregate (RCA)

Chapter 3: Methodology. This chapter describes the methodology adopted to carry out the research.

Chapter 4: Results and Discussion. This chapter describes the results of the conducted tests.

Chapter 5: Conclusions and Future Work. This chapter summarizes the conclusions and major contributions of this study and provides recommendations for future studies.

CHAPTER 2

Literature Review

2.1 Introduction

This chapter presents a comprehensive review of existing academic and technical literature related to the use of Recycled Coarse Aggregate (RCA) in concrete. The primary objective of this review is to develop a clear understanding of the current state of knowledge in this research area.

The review discusses the fundamental differences between Natural Coarse Aggregate (NCA) and RCA and examines how these differences influence the properties of fresh concrete, particularly work-ability. More importantly, it analyzes the impact of RCA on the hardened properties of concrete, with a specific focus on compressive strength. Furthermore, this chapter highlights the key challenges and potential opportunities associated with the use of RCA, thereby establishing the background, context, and justification for the present research study.

2.2 The Role of Coarse Aggregate in Concrete

Concrete is a composite construction material composed primarily of a binding agent (cement paste) and inert fillers known as aggregates. Aggregates are generally classified into fine aggregates (sand) and coarse aggregates (gravel or crushed stone). Coarse aggregate forms the main structural skeleton of concrete and typically constitutes about 60% to 75% of the total volume of concrete.

The role of coarse aggregate extends beyond merely filling space within the concrete matrix. Its properties—such as particle shape, surface texture, grading, and inherent strength—significantly influence the work-ability, dimensional stability, load-bearing capacity, and durability of concrete [1]. A strong, clean, and well-graded coarse aggregate is therefore essential for producing durable and high-strength concrete. Consequently, any modification or substitution of this structural skeleton can have a substantial effect on the overall performance of the concrete.

2.3 Recycled Coarse Aggregate (RCA) as a Sustainable Alternative

The global construction industry currently faces two major and opposing environmental challenges:

Rapid depletion of natural resources due to extensive quarrying of stone and sand, and Generation of large volumes of Construction and Demolition waste [2].

Recycled Coarse Aggregate (RCA) offers a practical and sustainable solution to both challenges. RCA is produced by crushing old and demolished concrete obtained from buildings, pavements, and other structures. The reuse of this C&D waste helps reduce landfill pressure while simultaneously decreasing the demand for natural aggregates. This approach aligns with the principles of the circular economy and contributes to sustainable construction practices, often referred to as “green concrete” [3].

However, RCA cannot be considered a direct replacement for NCA. As a secondary and processed material, RCA possesses different physical and mechanical characteristics that arise from its previous service life, which significantly influence its performance in new concrete.

2.4 Key Physical Differences between RCA and NCA

The primary differences between RCA and NCA originate from the presence of adhered mortar. During the crushing of old concrete, the original natural aggregate particles generally remain intact, while a layer of hardened cement mortar remains attached to their surfaces [4]. This adhered mortar is the defining characteristic of RCA and is responsible for most of its distinct properties.

The adhered mortar, which may constitute approximately 25% to 60% of the total weight of RCA, results in several important physical differences:

- 1. Lower Density and Specific Gravity:** The adhered mortar has a lower density than natural aggregate. As a result, RCA exhibits lower bulk density and specific gravity compared to NCA. Research indicates that the specific gravity of RCA may be approximately 10–15% lower than that of NCA [5], which is a critical factor in concrete mix design.
- 2. Higher Water Absorption:** The porous nature of the adhered mortar significantly increases the water absorption capacity of RCA. While NCA typically shows water absorption values ranging from 0.5% to 2.0%, RCA often exhibits much higher absorption, commonly between 4.0% and 9.0% [6]. This characteristic has a direct and immediate impact on the mixing and work-ability of fresh concrete.
- 3. Variable Shape and Gradation:** The crushing process generally produces RCA particles that are more angular and possess a rougher surface texture. Additionally, RCA often exhibits greater variability in grading compared to quarry-controlled NCA.

The pretest results of this study (fineness modulus of 7.5 for RCA and 7.1 for NCA) are consistent with findings reported in previous studies [7].

2.5 Effect of RCA on Fresh Concrete (Work-ability)

One of the most noticeable effects of incorporating RCA into concrete is the reduction in work ability, which is commonly evaluated using the slump test.

Due to its high water absorption capacity, RCA tends to absorb free water from the cement paste during mixing. When dry RCA is used, it rapidly draws water from the mix, resulting in a stiffer and less workable concrete [8]. Kou, Poon, and Chan (2007) reported that, for a constant water-to-cement ratio, the slump value of concrete decreased significantly as the RCA replacement level increased [9].

To mitigate this issue, two common approaches are adopted in practice:

1. Pre-soaking the RCA to achieve a saturated surface-dry (SSD) condition before mixing, or
2. Adding additional mixing water to compensate for the absorption of RCA.

Each method has limitations. For example, increasing the water content raises the effective water-to-cement ratio, which is known to adversely affect the strength and durability of concrete [1].

2.6 Effect of RCA on Hardened Concrete (Compressive Strength)

The influence of RCA on compressive strength is the most critical concern for structural applications. The majority of published research consistently indicates that an increase in RCA replacement level generally leads to a reduction in compressive strength [10], a trend that is also observed in the experimental results of this study.

This reduction in strength is primarily attributed to the presence of adhered mortar and its effect on the Inter-facial Transition Zone (ITZ). In conventional concrete, a single ITZ exists between the natural aggregate and the cement paste. This zone is typically the weakest region in the concrete matrix. In RCA concrete, two distinct weak zones are present:

1. **The Old ITZ:** The interface between the original natural aggregate and the adhered mortar.
2. **The New ITZ:** The interface between the adhered mortar and the newly formed cement paste [4,11].

Under applied load, micro cracks initiate and propagate more easily through these weak ITZ regions, leading to premature failure and reduced compressive strength.

The extent of strength reduction depends on the percentage of RCA replacement:

- **Low Replacement Levels (10–30%):**

Many studies report that replacement levels up to 30% result in relatively minor strength reductions, often less than 10% [12].

- **Medium Replacement Levels (Around 50%):**

This range has attracted considerable research interest. Strength reductions at 50% replacement are typically moderate and predictable, usually within 10–25% [13]. Such reductions are often considered acceptable when balanced against the significant environmental benefits.

- **High Replacement Levels (100%):**

Studies involving full replacement with RCA generally report substantial strength losses, commonly between 20% and 40% compared to control mixes [5,10]. Consequently, 100% RCA replacement is generally unsuitable for high-strength structural applications.

2.7 Summary and Research Gap

The reviewed literature leads to the following conclusions:

- RCA is a sustainable and environmentally beneficial construction material, although it exhibits inferior physical properties compared to NCA due to the presence of adhered mortar.
- These inferior properties include higher water absorption, lower density, and reduced work ability in fresh concrete.
- In hardened concrete, RCA results in weaker ITZs, leading to a predictable reduction in compressive strength as the replacement level increases.

Despite extensive research, a significant gap remains. The degree of strength reduction associated with RCA is not constant and depends on several factors, including the quality of the source concrete, aggregate processing methods, and mix proportions.

While many studies focus on advanced or optimized mix designs, limited data are available for commonly used nominal mixes in practical construction, such as 1:1.5:3 and 1:1:2. The performance of these mixes incorporating locally sourced RCA has not been sufficiently investigated.

Therefore, the present research aims to address this gap by experimentally evaluating the compressive strength of concrete produced using locally available RCA with two widely used nominal mix proportions.

CHAPTER 3

Methodology

3.1 Introduction

This study employs a quantitative, experimental research design. The methodology is based on established laboratory testing procedures and standards (primarily ASTM) to ensure the accuracy and repeatability of the results. The independent variables are the RCA replacement percentage (0%, 25%, 50%, 75%) and the concrete mix ratio (1:1.5:3 and 1:1:2). The primary dependent variable is the compressive strength of the concrete at 7, 14, 21, and 28 days.

3.2 Materials and Sourcing

3.2.1 Cement

Portland Composite Cement (PCC) was used as the sole binder for all mixes. The cement conformed to ASTM C595 Type IP standards and was sourced from a single batch to eliminate variations in chemical composition.



Figure 3.1: PCC Cement

3.2.2 Fine Aggregate (FA)

Sylhet sand was used as the fine aggregate. It was ensured to be clean, free from organic impurities and poorly graded.



Figure 3.2: Sylhet sand

3.2.3 Natural Coarse Aggregate (NCA)

Natural khoa was used as a Natural Coarse Aggregate. It was collected from local shop of Rajabajar. The natural coarse aggregate was 20mm nominal size, crushed bricks, sourced from a local supplier. It was washed dust and impurities before use.



Figure 3.3: Natural Coarse Aggregate

3.2.4 Recycled Coarse Aggregate (RCA)

The recycled coarse aggregate was sourced from a local construction building. It was derived and processed to have a similar gradation to the NCA. It was also washed and screened to remove fine particles and contaminants.



Figure 3.4: Recycled Coarse Aggregate

3.2.5 Water

Clean, potable tap water from the university laboratory, free from oils, acids, and organic matter, was used for both mixing and curing of the concrete specimens.

3.2.6 Use of Admixture

Recycled Coarse Aggregate (RCA) is typically coated with a layer of old, porous cement mortar, which behaves like a sponge and absorbs significantly more water than Natural Coarse Aggregate (NCA). The water absorption capacity of RCA generally ranges from 4.0% to 9.0%, whereas that of NCA is much lower, typically between 0.5% and 2.0%. This high water absorption of RCA can adversely affect the work ability and consistency of fresh concrete.

To control this issue without negatively influencing the overall mix properties, a chemical admixture was used in this study. The admixture helped maintain the desired work ability by compensating for the additional water demand caused by RCA, without increasing the effective water-to-cement ratio. The dosage of admixture was

kept constant at 4 ml per kilogram of cement for all concrete mixes to ensure uniformity and reliable comparison of results.



Figure 3.5: Cement Admixer

3.3 Experimental Program

The experimental program was divided into three phases:

Phase 1: Testing the physical properties of all constituent materials

Phase 2: Batching, mixing, and casting of concrete cylinders, including fresh property tests.

Phase 3: Curing and testing of hardened concrete cylinders for compressive strength.

3.4 Material Property Testing (Pre-Casting)

Before mix design, a series of standard tests were conducted on the aggregates, as per data sheet, determining their essential properties.

3.4.1 Fineness Modulus (FM)

Sieve analysis (ASTM C136) was performed to determine the particle size distribution of the aggregates. The Fineness Modulus (FM) was then calculated. This test is crucial for fine aggregate (sand) as it determines its work ability and paste requirements. For coarse aggregate, it provides an understanding of the gradation.



Figure 3.6: Fineness Modulus Test

3.4.2 Specific Gravity (Bulk and Apparent)

Specific gravity tests were conducted as per ASTM C127 (for coarse aggregates) and ASTM C128 (for fine aggregates). These values are essential for mix design calculations, as they are used to convert the required mass of aggregates into absolute volumes. Both Specific Gravity (Bulk and Apparent) were done for all the materials . Ex. Fine Aggregates, Coarse Aggregates and Recycle Coarse Aggregate.



Figure 3.7: Specific Gravity Test



Figure 3.8: Specific Gravity Test

3.4.3 Unit Weight

The unit weight, or bulk density, of the aggregates was determined as per ASTM C29. This measures the weight of aggregate that can fit into a known volume and is important for batching by volume. Two methods were used for unit weight test. Shoveling procedure and Rodding procedure.

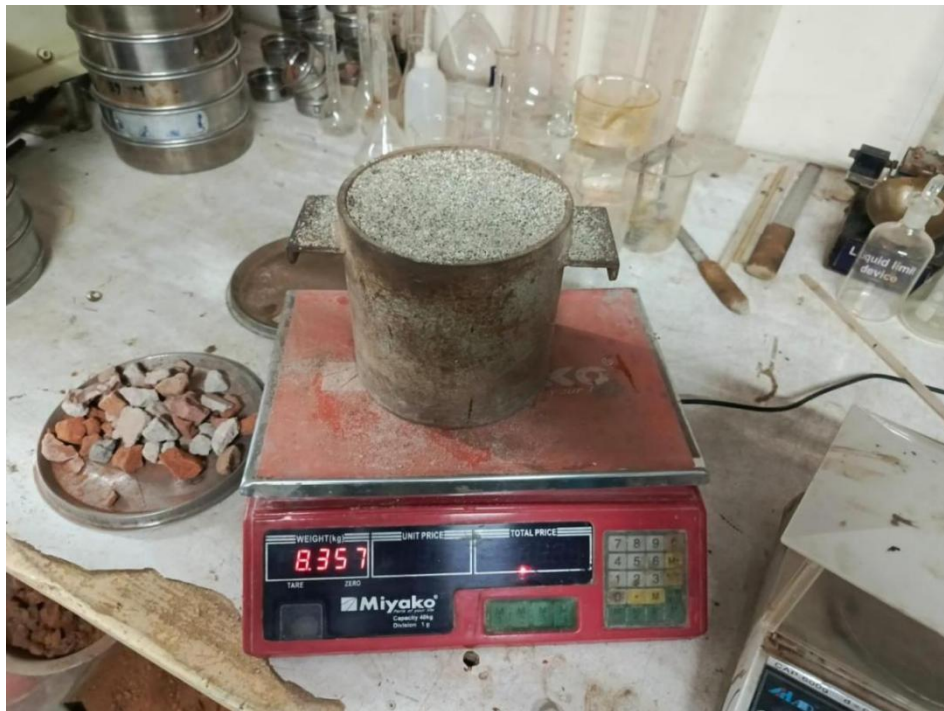


Figure 3.9: Unit Weight Test

3.5 Mix Design and Proportions

3.5.1 Mix Ratios

Two common nominal mix ratios (by volume) were selected for this study:

- **Mix 1 (M1):** 1:1.5:3 (Cement : Fine Aggregate : Coarse Aggregate) - A standard, versatile mix.
- **Mix 2 (M2):** 1:1:2 (Cement : Fine Aggregate : Coarse Aggregate) - A richer, higher-strength mix.

3.5.2 Replacement Levels

For each mix ratio, the coarse aggregate component was varied by partially replacing the NCA with RCA by volume:

- **Case 1:** 0% RCA (100% NCA) - Control Mix
- **Case 2:** 25% RCA (75% NCA)
- **Case 3:** 50% RCA (50% NCA)
- **Case 4:** 75% RCA (25% NCA)

3.5.3 Mix Designation

This design resulted in a total of 8 unique concrete mixes, as designated in Table 3.1.

Table 3.1: Mix Designations for Experimental Program

Case	RCA	Ratio	NCA
1	0%	1:1.5:3	100%
2	25%	1:1.5:3	75%
3	50%	1:1.5:3	50%
4	75%	1:1.5:3	25%
5	0%	1:1:2	100%
6	25%	1:1:2	75%
7	50%	1:1:2	50%
8	75%	1:1:2	25%

3.6 Preparation of Cylinder

The Compressive strength of the concrete cylinder is one of the most common performance measures performed by the engineers in the structural design. The compressive strength of concrete cylinders is determined by applying continuous load over the cylinder until failure occurs. The test is conducted using a compression

testing machine. The cylinder specimens are cast in steel, cast iron or any mold made of non-absorbent material. Even under severe conditions, the molds used must retain its original shape and dimensions. Cylinder specimens for testing should be 4 inch * 8 inch.



Figure 3.10: Cylinder Mold

3.7 Concrete mixing

A Concrete mixing is a device that homogeneously combines cement, such as sand or coarse aggregate , and water to form concrete. A typical concrete mixer use a revolving drum to mix the components. This process is so crucial that if the concrete making ingredients are not mixed properly. It can lead to concrete failure under compression load. A M20 concrete mixture ratio of 1:1.5:3 will produce a strength of 2900 psi, and A M25 concrete mixture ratio of 1:1:2 will produce a strength of 3600 psi average. Mixing with the cement, sand and coarse aggregate will form a paste that will bind the materials together until the mix hardens. Admixture will be added when water will be applied. The primary goal of concrete mixing is to make the concrete mass homogeneous and uniform in color while maintaining the required consistency. Production of good quality and bad quality of concrete includes the same material, but the proportion and mixing method can be differentiating. As a result, sufficient

precautions should be followed while mixing concrete. After mixing mortar needs to be casted immediately otherwise mortar will not be usable.



Figure 3.11: Concrete Mixing

3.8 Casting of Cylinder

Concrete cylinder casting is a controlled laboratory process in which freshly mixed concrete is placed into cylindrical molds to prepare test specimens for strength evaluation. Casting is a manufacturing process in which a liquid or plastic material is poured into a mold containing a hollow cavity of the desired shape and then allowed to solidify. The hardened specimen, known as a casting, is removed from the mold after initial setting to complete the process. This method allows the production of uniform and standardized specimens, ensuring accuracy, repeatability, and cost effectiveness in material testing.

The freshly mixed concrete was placed into the cylindrical molds in layers not exceeding 50 mm in depth. Each layer was compacted by applying an adequate number of strokes using a tamping rod. The strokes were applied in such a way that

they penetrated into the underlying layer to ensure proper bonding between layers and to allow the entrapped air to escape, thereby minimizing air voids.

After casting, the top surface of each specimen was leveled and finished smoothly. The molds were then kept undisturbed for an initial period to allow the concrete to set properly



Figure 3.12: Concrete Mixing

3.9 Curing of Specimens

The cast concrete cylinders were kept in their molds and covered in the laboratory for an initial period of 24 hours. After this period, the specimens were carefully demolded and properly marked for identification. The cylinders were then immediately submerged in a large water tank for curing in accordance with ASTM C31. Water curing was maintained throughout the curing period to ensure that the concrete specimens remained fully saturated. This curing method promotes continuous cement hydration, which is essential for strength development and overall durability of the concrete. The specimens were cured until the designated testing age was reached.

3.10 Compressive Strength Test

At the end of each curing period (7, 14, 21, and 28 days), cylinders were removed from the curing bucket for each mix variation.

1. The cylinders were surface-dried to remove excess water.
2. The specimens were placed in a Universal Testing Machine (UTM).
3. A compressive axial load was applied at a constant, controlled rate until the cylinder failed.
4. The maximum load (in Newtons) at failure was recorded.

The compressive strength (in Mega pascals, MPa) was calculated by dividing the maximum load by the cross-sectional area of the cylinder.

$$\text{Stress} = \text{Load} / \text{Area}$$

The average strength of the three specimens was taken as the representative compressive strength for that mix and age.



Figure 3.13: Universal Testing Machine

3.11 Faillure Pattern

After crushing the concrete cylinder specimens using the Universal Testing Machine (UTM), different failure patterns were observed. Some specimens exhibited cracks initiating from the corners and propagating diagonally, while others showed cracking predominantly at the middle portion of the cylinder. These variations in crack patterns indicate differences in stress distribution, internal micro structure, and material homogeneity within the specimens.



Figure 3.14: Demolished Cylinders

CHAPTER 4

Results and Discussion

4.1 Sample Test Results

4.1.1 Fineness Modulus of Sylhet sand

Sylhet sand was used as Fine aggregate. Sylhet sand was collected from a construction building of Mohammadpur. After bringing sand to the laboratory we tested its fineness modulus test, and the data is given below:

Table 4.1 Fineness Modulus of Sylhet Sand

Sieve Opening	Wt. Remain (gm)	% Retain	Cumulative % Retain	FM	% Finer
4.76	0	0	0	2.378	100
2.36	9	1.8	1.8		98.2
1.18	60	12	13.8		86.2
0.6	133	26.6	40.4		59.6
0.3	224	44.8	85.2		14.8
0.15	57	11.4	96.6		3.4
PAN	17	3.4	100		0
Total	500	100	237.8		

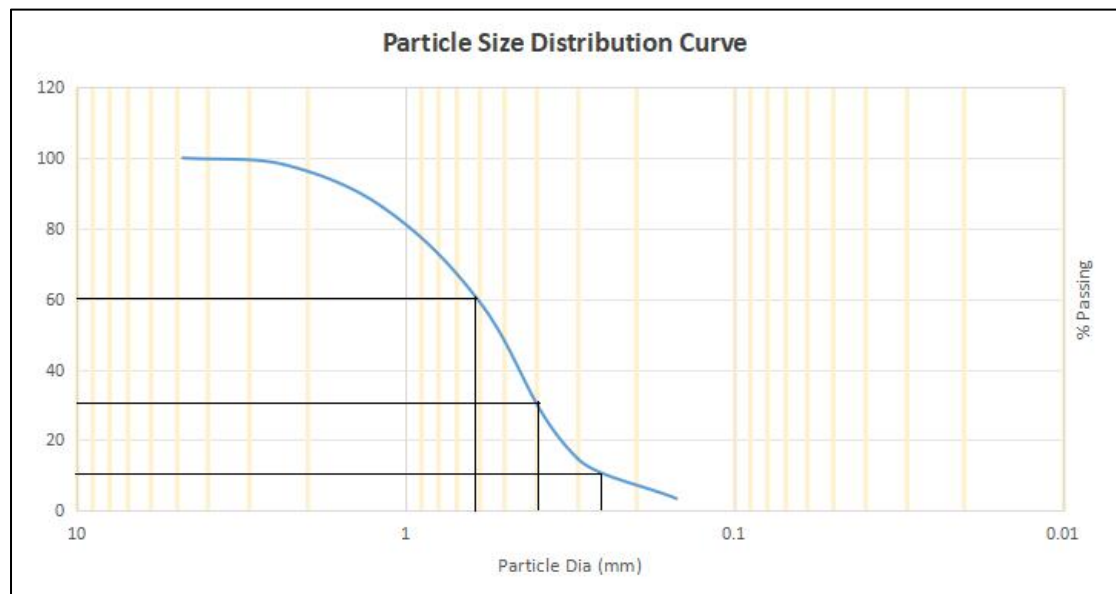


Figure 4.1: Partile Size Distribution Curve for FA

Table 4.2 Gradation and Shape Parameters of Fine Aggregate

D	Values	Cu	Cc
D10	0.22	2.72	1.09
D30	0.38		
D60	0.6		

4.1.2 Fineness Modulus of Natural Coarse Aggregate

Fineness Modulus test of Natural Coarse Aggregate (Khoa) are given below.

Table 4.3 Fineness Modulus of Natural Coarse Aggregate

Sieve Opening	Wt. Remain (gm)	% Retain	Cumulative % Retain	FM	% Finer
40	0	0	0	7.108	100
20	213	21.3	21.3		78.7
10	692	69.2	90.5		9.5
4.76	85	8.5	99		1
2.36	10	1	100		0
1.18	0	0	100		0
0.6	0	0	100		0
0.3	0	0	100		0
0.15	0	0	100		0
Pan	0	0	-		
Total	1000	100	710.8		

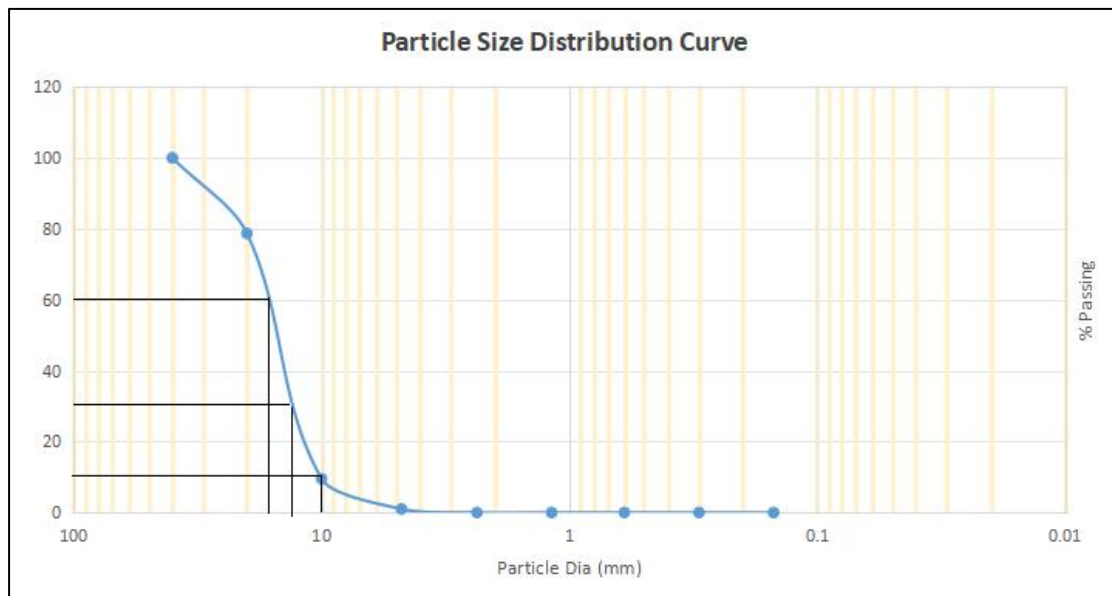


Figure 4.2: Partile Size Distribution Curve for NCA

Table 4.4 Gradation and Shape Parameters of NCA

D	Values	Cu	Cc
D10	10.99	1.28	0.968
D30	12.25		
D60	14.1		

4.1.3 Fineness Modulus of Recycled Coarse Aggregate

The recycled coarse aggregate (RCA) was prepared by breaking down larger pieces of demolished concrete into smaller, manageable sizes.

Table 4.5 Fineness Modulus of Recycle Coarse Aggregate

Sieve Opening	Wt. Remain (gm)	% Retain	Cumulative % Retain	FM	% Finer
40	0	0	0	7.506	100
20	608	60.8	60.8		39.2
10	300	30	90.8		9.2
4.76	82	8.2	99		1
2.36	10	1	100		0
1.18	0	0	100		0
0.6	0	0	100		0
0.3	0	0	100		0
0.15	0	0	100		0
Pan	0	0	-		
Total	1000	100	710.8		

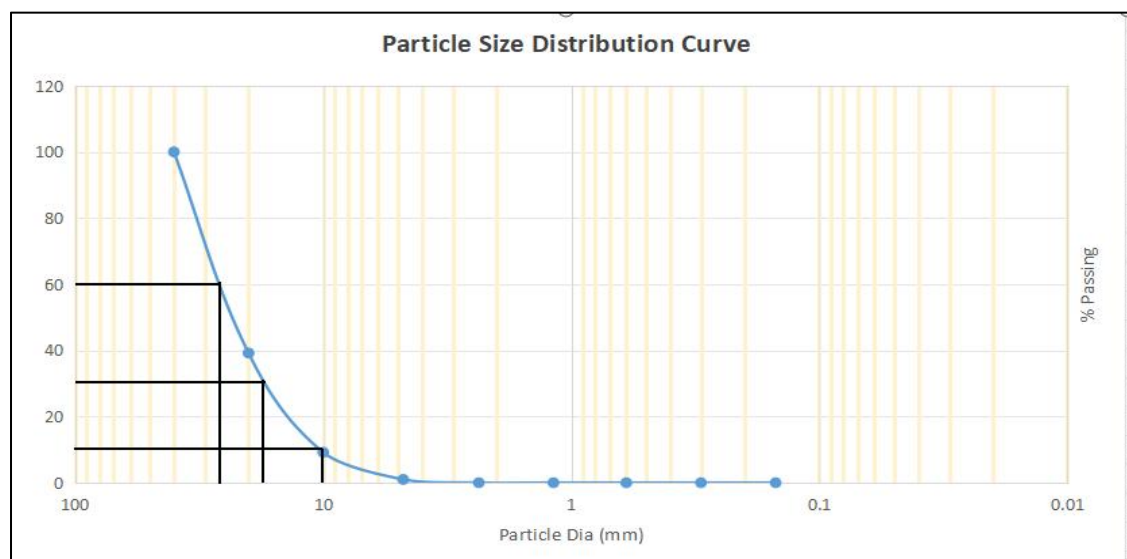


Figure 4.3: Partile Size Distribution Curve for RCA

Table 4.6 Gradation and Shape Parameters of RCA

D	Values	Cu	Cc
D10	10.2	2.2	1.02
D30	14.9		
D60	22		

4.1.4 Specific Gravity Test

Bulk Specific gravity and Apparent Specific Gravity was determined for Fine aggregates and Coarse aggregates.

Table 4.7 Specific Gravity Test

Materials	Bulk Specific Gravity	Apparent Specific Gravity
Sylhet Sand	2.43	2.52
NCA	2.71	2.96
RCA	2.23	2.53

4.1.5 Unit Weight Test

The unit weight test is conducted to determine the weight of aggregate per unit volume, which is an important parameter in concrete mix design and quality control. This test provides information about the bulk density of aggregates in different conditions and helps in evaluating the void content between aggregate particles. The unit weight of aggregate influences concrete yield, work ability, and overall mix proportions.

Table 4.8 Unit Weight Test

Materials	Rodding (kg/m ³)	Shoveling(kg/m ³)	Average (kg/m ³)
Sylhet Sand	1522	1567	1544.5
NCA	1492	1521	1506.5
RCA	1305	1289	1297

4.2 Compressive strength test

It determines the ability of concrete to resist compressive loads and is a key parameter for assessing the suitability of concrete for structural applications. Compressive strength is influenced by several factors, including mix proportions, water-to-cement ratio, curing conditions, and the properties of aggregates used in the mix.

4.2.1 Result of 7 days Compressive Strength test

The experimental results for 16 concrete samples across 8 cases show that while Case 2 and Case 6 achieve strengths near the standard benchmarks, there is a clear downward trend in performance as recycled aggregate volume increases.

Table 4.9 7 days Compressive Strength test

After 7 days concrete stress										
Case	Serial	Weight	Height	Dia	Area	Load	Stress (PSI)	Avg. Stress	Stress (Mpa)	Avg. Stress
1	1	3.34	204	101.3	8059.51	120000	2159.51	2057.31	14.89	14.18
	2	3.27	205	101	8011.85	108000	1955.12		13.48	
2	3	3.56	205	102.6	8267.70	95000	1666.56	1747.48	11.49	12.05
	4	3.39	208	101	8011.85	101000	1828.40		12.61	
3	5	3.43	209	102.6	8267.70	88000	1543.76	1577.28	10.64	10.87
	6	3.45	207	102.7	8283.82	92000	1610.79		11.11	
4	7	3.36	208	99.8	7822.60	76000	1409.11	1406.80	9.72	9.70
	8	3.39	208	103.2	8364.68	81000	1404.49		9.68	
5	9	3.48	205	103	8332.29	137000	2384.72	2382.95	16.44	16.43
	10	3.48	206	102.7	8283.82	136000	2381.17		16.42	
6	11	3.36	205	101.5	8091.37	115000	2061.38	1966.21	14.21	13.56
	12	3.37	206	101.8	8139.27	105000	1871.05		12.90	
7	13	3.49	206	102.9	8316.12	95000	1656.86	1712.44	11.42	11.81
	14	3.37	205	102.2	8203.36	100000	1768.03		12.19	
8	15	3.45	207	101.3	8059.51	85000	1529.65	1524.35	10.55	10.51
	16	3.37	206	104.6	8593.17	90000	1519.05		10.47	

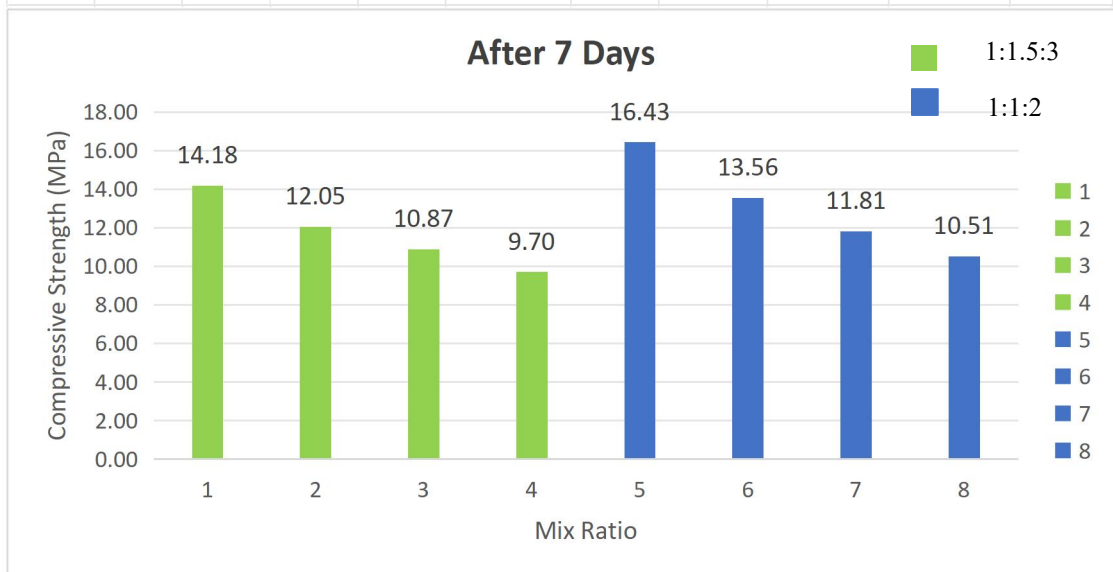


Figure 4.4: Results of 7 days Compressive Strength Test

4.2.2 Result of 14 days Compressive strength test

Table 4.10 14 days Compressive Strength Test

After 14 days concrete stress										
Case	Serial	Weight	Height	Dia	Area	Load	Stress (PSI)	Avg. Stress	Stress (Mpa)	Avg. Stress
1	1	3.38	204	101.1	8027.72	118000	2131.92	2247.60	14.70	15.50
	2	3.37	204	100.4	7916.94	129000	2363.27		16.29	
2	3	3.56	206	103.2	8364.68	110000	1907.33	1892.56	13.15	13.05
	4	3.4	206	102.1	8187.31	106000	1877.79		12.95	
3	5	3.42	207	101.3	8059.51	90000	1619.63	1702.37	11.17	11.74
	6	3.29	205	101.2	8043.61	99000	1785.11		12.31	
4	7	3.47	206	102.9	8316.12	91000	1587.09	1543.49	10.94	10.64
	8	3.5	207	102.3	8219.42	85000	1499.89		10.34	
5	9	3.47	207	100.6	7948.51	145000	2645.84	2578.59	18.24	17.78
	10	3.41	206	101.1	8027.72	139000	2511.33		17.32	
6	11	3.35	207	99.8	7822.60	119000	2206.37	2314.82	15.21	15.96
	12	3.47	205	97.6	7481.51	125000	2423.27		16.71	
7	13	3.29	207	100.2	7885.43	100000	1839.32	1954.33	12.68	13.47
	14	3.40	206	96.8	7359.37	105000	2069.33		14.27	
8	15	3.32	208	95.8	7208.10	95000	1911.54	1756.55	13.18	12.11
	16	3.46	208	99.0	7697.69	85000	1601.55		11.04	

Here are the image of comparative bar chart

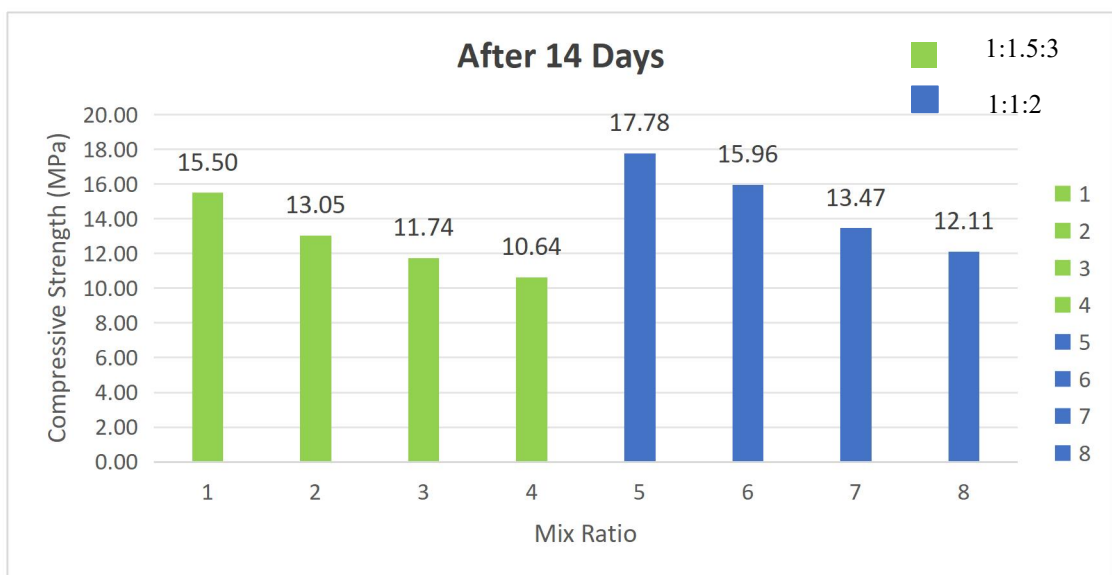


Figure 4.5: Results of 14 days Compressive Strength Test

4.2.3 Result of 21 days Compressive strength test

Table 4.11 21 days Compressive Strength test

After 21 days concrete stress										
Case	Serial	Weight	Height	Dia	Area	Load	Stress (PSI)	Avg. Stress	Stress (Mpa)	Avg. Stress
1	1	3.46	203	103.3	8380.90	132000	2284.36	2439.19	15.75	16.82
	2	3.33	205	101.6	8107.32	145000	2594.02		17.89	
2	3	3.41	206	102.8	8299.96	122000	2131.89	2088.97	14.70	14.40
	4	3.47	211	103.2	8364.68	118000	2046.04		14.11	
3	5	3.37	209	101	8011.85	108000	1955.12	1889.94	13.48	13.03
	6	3.30	203	101.6	8107.32	102000	1824.76		12.58	
4	7	3.54	210	103	8332.29	110000	1914.74	1843.12	13.20	12.71
	8	3.49	205	102.1	8187.31	100000	1771.50		12.21	
5	9	3.41	209	101.5	8091.37	155000	2778.38	2840.30	19.16	19.58
	10	3.32	208	100.9	7995.99	160000	2902.21		20.01	
6	11	3.52	210	103.4	8397.13	137000	2366.31	2449.36	16.32	16.89
	12	3.31	205	101.4	8075.43	141000	2532.42		17.46	
7	13	3.39	205	102.6	8267.70	128000	2245.47	2267.47	15.48	15.63
	14	3.47	209	102.4	8235.50	130000	2289.47		15.79	
8	15	3.40	207	102.2	8203.36	115000	2033.24	1971.36	14.02	13.59
	16	3.31	207	102.2	8203.36	108000	1909.47		13.17	

Here are the image of comparative bar chart

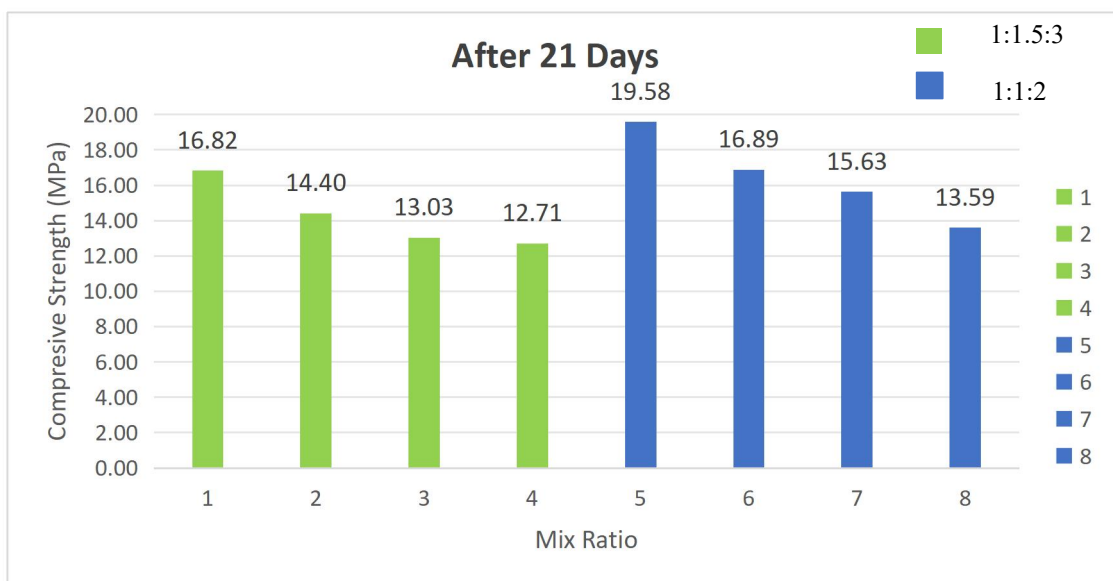


Figure 4.6: Results of 21 days Compressive Strength Test

4.2.4 Result of 28 days Compressive strength test

The results confirm that even at full maturity, specific mix designs involving recycled aggregates can perform closely to natural aggregate standards:

- Case 6 Correlation: This group achieved an average strength of 18.90 MPa, effectively matching and slightly exceeding the Case 1 standard.
- Case 2 Correlation: Reached 16.41 MPa, maintaining a strong performance profile that is approximately 89.3% of the Case 1 Standard.
- Case 3 Correlation: Reached 14.87 MPa, maintaining a good performance profile that is approximately 81% of the case 1 Standard
- Case 7 Correlation: Reached 16.66 MPa, maintaining a medium performance profile that is approximately 79% of the Case 5 Standard.

Table 4.12 28 days Compressive Strength test

After 28 days concrete stress										
Case	Serial	Weight	Height	Dia	Area	Load	Stress (PSI)	Avg. Stress	Stress (Mpa)	Avg. Stress
1	1	3.49	209	102.9	8316.12	148000	2581.21	2665.53	17.80	18.38
	2	3.41	203	100.7	7964.32	151000	2749.86		18.96	
2	3	3.32	210	103.2	8364.68	134000	2323.47	2379.98	16.02	16.41
	4	3.52	205	101.9	8155.27	137000	2436.49		16.80	
3	5	3.31	209	102.7	8283.82	121000	2118.54	2157.33	14.61	14.87
	6	3.39	208	101.7	8123.29	123000	2196.12		15.14	
4	7	3.47	210	103.1	8348.48	110000	1911.03	1910.25	13.18	13.17
	8	3.40	205	102.2	8203.36	108000	1909.47		13.17	
5	9	3.31	206	101	8011.85	174000	3149.91	3113.14	21.72	21.46
	10	3.46	205	102.2	8203.36	174000	3076.38		21.21	
6	11	3.33	207	101.3	8059.51	155000	2789.36	2741.02	19.23	18.90
	12	3.41	203	102.1	8187.31	152000	2692.68		18.57	
7	13	3.47	205	103.1	8348.48	141000	2449.59	2415.89	16.89	16.66
	14	3.37	206	102.3	8219.42	135000	2382.18		16.42	
8	15	3.30	211	101.9	8155.27	120000	2134.15	2114.31	14.71	14.58
	16	3.54	208	102.0	8171.28	118000	2094.47		14.44	

Here are the images of comparative bar charts.

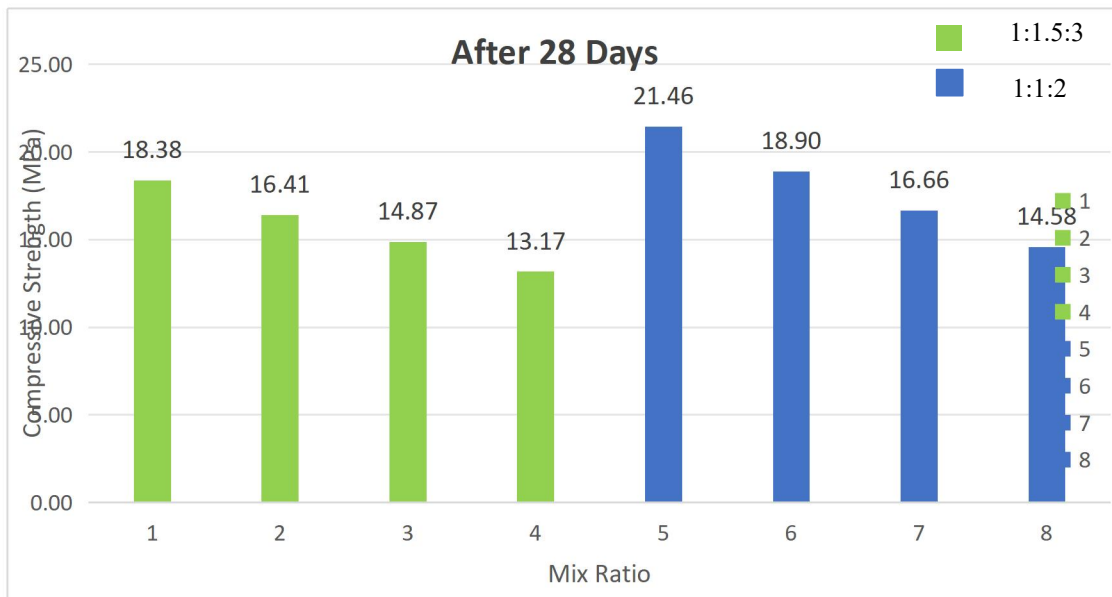


Figure 4.7: Results of 28 days Compressive Strength Test

4.2.5 Strength Achieve

Table 4.13 Strength Achieve Chart

Strength Achieved				
Cases	7 Days	14 Days	21 Days	28 Days
Case 1	100.00	100.00	100.00	100.00
Case 2	84.94	84.20	85.64	89.29
Case 3	76.67	75.74	77.48	80.93
Case 4	68.38	68.67	75.56	71.66
Case 5	100.00	100.00	100.00	100.00
Case 6	82.51	89.77	86.24	88.05
Case 7	71.86	75.79	79.83	77.60
Case 8	63.97	68.12	69.41	67.92

4.3 Economic Analysis

4.3.1 Unit Material Costs

The following market rates were utilized for the estimation:

1. Cement (PCC): 520 Taka per 50 kg bag (Approx. 416 Taka/cft)
2. Fine Aggregate (Sylhet Sand): 150 Taka/cft
3. Natural Coarse Aggregate (NCA/Khoa): 40 Taka/cft
4. Recycled Coarse Aggregate (RCA): 0 Taka/cft (Sourced as construction waste)

4.8.2 Cost Breakdown per Cylinder

The volumes for each specimen were calculated based on the two nominal mix ratios utilized in the study: **1:1.5:3 (M1)** and **1:1:2 (M2)**. A dry volume factor of 1.54 was applied to account for shrinkage and compaction.

Table 4.14 Cost Breakdown per Cylinder

Case	Mix Ratio	RCA %	Cement (cft)	Sand (cft)	NCA (cft)	RCA (cft)	Total Cost (Taka)
1	1:1.5:3	0%	0.016	0.024	0.048	0	12.18
2	1:1.5:3	25%	0.016	0.024	0.036	0.012	11.70
3	1:1.5:3	50%	0.016	0.024	0.024	0.024	11.22
4	1:1.5:3	75%	0.016	0.024	0.012	0.036	10.74
5	1:01:02	0%	0.022	0.022	0.045	0	14.26
6	1:01:02	25%	0.022	0.022	0.034	0.011	13.82
7	1:01:02	50%	0.022	0.022	0.022	0.022	13.34
8	1:01:02	75%	0.022	0.022	0.011	0.034	12.90

4.8.3 Analysis and Discussion

The cost analysis reveals several key financial trends:

- 1. Economic Viability of 25% Replacement:** At the identified "structural sweet spot" of 25% RCA replacement, the cost per cylinder is reduced to 11.70 Taka (M1) and 13.82 Taka (M2), providing a balanced solution of structural adequacy and financial savings.
- 2. Waste-to-Wealth:** Since RCA is treated as free, the cost reduction is entirely proportional to the substitution level, reinforcing the case for a circular economy in the Dhaka construction sector.

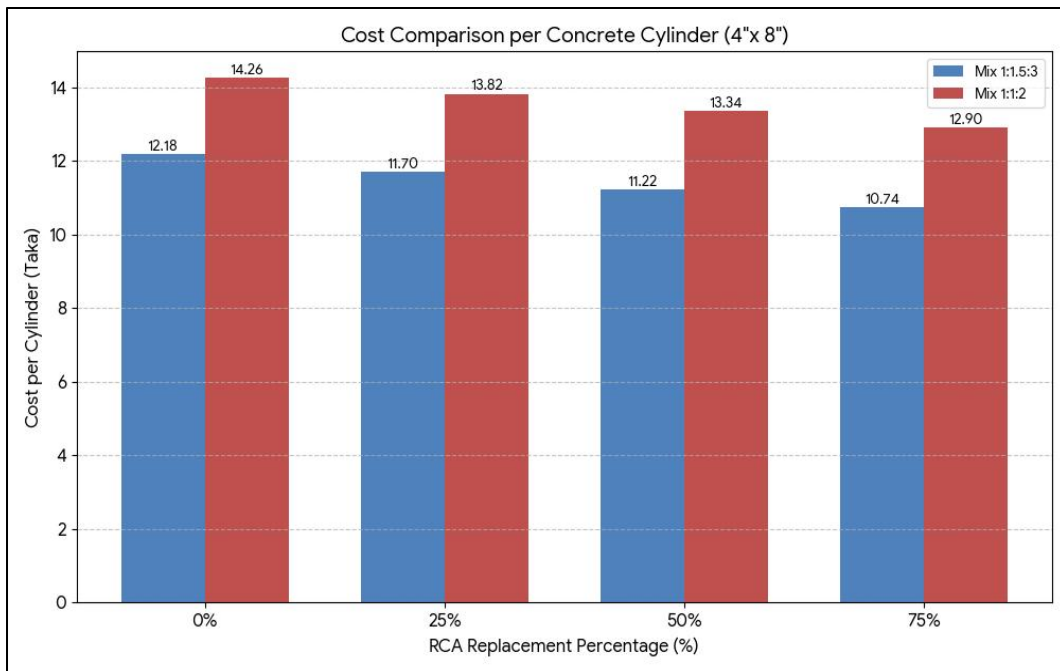


Figure 4.8: Cost Comparison per Cylinder

CHAPTER 5

Conclusions and Future Works

5.1 Conclusions

This research investigated the structural viability of using Recycled Coarse Aggregate (RCA) as a sustainable alternative to Natural Coarse Aggregate (NCA) in concrete production. The study evaluated two common mix ratios (1:1.5:3 and 1:1:2) with varying RCA replacement levels (0%, 25%, 50%, and 75%) over a 28-day curing period. Based on the experimental results, the following conclusions are drawn:

1. Physical Property Variations: Preliminary testing confirmed that RCA possesses inherently different physical properties compared to NCA, specifically a higher porosity and lower density due to the presence of a residual layer of adhered mortar. The Fineness Modulus (FM) of RCA was found to be slightly higher (7.5) than NCA (7.1).

2. Impact on Compressive Strength: The results consistently demonstrated that increasing the RCA content leads to a progressive, non-linear decrease in compressive strength across all tested intervals (7, 14, 21, and 28 days). This reduction is primarily attributed to the weakening of the Inter-facial Transition Zone (ITZ) caused by the porous adhered mortar.

3. Optimal Replacement Level: While high substitution levels (75%) significantly downgrade structural capacity, a 50% RCA replacement was found to be the "sweet spot". At 50% replacement, the concrete retained approximately 80% of the strength achieved by the control mix (0% RCA).

4. Practical Viability: The findings confirm that concrete with up to 25% RCA is a robust and substantial structural alternative for specific applications such as residential footings, concrete slabs, and non-structural elements. This supports the implementation of a circular economy model within the local building sector.

5.2 Limitations and Recommendations for Future Works

5.2.1 Limitations :

Despite the valuable findings obtained from this research, certain limitations should be acknowledged:

1. Limited Range of Mix Ratios:

The study considered only two nominal mix ratios (1:1.5:3 and 1:1:2). While these mixes represent commonly used proportions in practical construction, the results may not be directly applicable to other mix designs, particularly high-strength or performance-based concrete.

2. Single Source of RCA:

The Recycled Coarse Aggregate used in this study was obtained from a single local source. Since the properties of RCA depend heavily on the quality and origin of the parent concrete, the findings may vary when RCA is sourced from different demolition wastes.

3. Focus on Compressive Strength Only:

This research primarily evaluated compressive strength as the indicator of structural performance. Other important mechanical and durability properties such as tensile strength, flexural strength, shrinkage, permeability, and long-term durability were not investigated.

4. Limited Curing Duration:

The performance of concrete was assessed up to a curing age of 28 days. Long-term behavior beyond 28 days, including strength gain at later ages and durability under environmental exposure, was not considered.

5. Controlled Laboratory Conditions:

All experiments were conducted under controlled laboratory conditions. Therefore, variations that typically occur in field conditions—such as improper curing, temperature fluctuations, and workmanship—were not accounted for in this study.

5.2.2 Recommendations for Future Works

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

1. Investigation of Additional Mechanical Properties:

Future studies should evaluate tensile strength, flexural strength, modulus of elasticity, and durability-related properties to develop a more comprehensive understanding of RCA concrete performance.

2. Use of Different RCA Sources:

Research using RCA collected from multiple demolition sources is recommended to assess variability and establish more generalized conclusions suitable for wider application.

3. Long-Term Performance Evaluation:

Extended curing periods (56, 90, and 180 days) should be considered to study long-term strength development, shrinkage, creep, and durability characteristics.

4. Optimization through Admixtures and Treatment Methods:

Further research may explore advanced admixtures, surface treatments, or pre-treatment techniques for RCA to reduce water absorption and improve the Interfacial Transition Zone (ITZ).

5. Field-Level Implementation Studies:

Pilot-scale field studies are recommended to evaluate the practical performance of RCA concrete under real construction conditions.

6. Development of Local Guidelines:

Based on accumulated experimental data, local standards and guidelines for the safe use of RCA in structural and non-structural concrete applications should be developed to support sustainable construction practices.

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30% RCA replacement produced compressive strength comparable to natural aggregate concrete.