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# EXPERIMENTAL PERFORMANCE OF RECYCLED AGGREGATE CONCRETE IN BANGLADESH CONTEXT

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**Graphical abstract**

**Abstract**

Due to the deterioration of existing structures and the replacement of numerous low-rise buildings with comparatively high-rise ones, the amount of demolished concrete in Bangladesh is increasing. One of the major challenges of our present society is to construct environmental friendly sustainable structures with low-cost technology. Reusing concrete in the form of aggregate would lead to environmental and economical benefits. The research covers experimental work on Particle size distribution by sieve analysis, Fineness modulus, Specific Gravity, Water absorption, Bulk density, and percent void of recycled coarse aggregate. The goal of this study is to measure the compressive strength of recycled aggregates as a substitute for coarse aggregate. For this reason, several important experiments like a) slump test of concrete, b) compressive strength of cylinder concrete specimen are performed. Here, brick aggregates are used as coarse aggregate, the water-cement ratio (0.4) is kept the same, and 30%, 50%, and 70% natural aggregate are replaced by the same percentage of recycled aggregate without any admixture. The result shows that the compressive strength of recycled aggregate concrete (RAC) with 30% replacement of natural aggregate by recycled aggregate is near to the compressive strength of natural aggregate concrete (NAC). It is found that the specific gravity and bulk density of Recycled Concrete Aggregate (RCA) are 2.07 and 1163-1245 kg/m$^3$ respectively which is significantly smaller than Natural Aggregate (NA). Recycled concrete aggregate (RCA) is discovered to have a larger percentage of pore volume and water absorption capacity than natural aggregate (NA), measuring around 13% and 36% respectively. The aggregate properties used in this research are in an acceptable range compared to other researchers.

*Keywords:* Recycled Aggregate Concrete (RAC), Compressive Strength, Natural Aggregate Concrete (NAC), sieve analysis, Specific Gravity.



## 1.0 INTRODUCTION

Bangladesh is a country that is on the rise. Dhaka is Bangladesh's capital and largest city, with a population of 21.74 million people as of 2021 (Bangladesh Bureau of statistics). It is the world's sixth most densely inhabited city, with roughly 29,029 people per square kilometer according to 2020 (Tabassum and Beard, 2021). Dhaka is Bangladesh's most important economic, political, and cultural center. According to 2016, the city's population has been growing at a rate of roughly 4.2 percent each year (Bangladesh Bureau of statistics). In order to compete with the increasing population, high-height building development is on the rise nowadays. To create new high-level buildings, older structures must be demolished (Abbasi, 2022). The amount of destroyed concrete is increasing as a result of the deterioration of concrete structures, as well as the replacement of numerous low-rise structures with relatively high-rise structures and the construction of new structures. This demolition building generates a significant amount of construction waste. The current annual rate of construction waste generation is 145 million tons worldwide, requiring vast amounts of land to land-fill this waste (Nowrin et al., 2018). As a result, Construction waste recycling is critical for two reasons: reducing the quantity of open area necessary for

landfilling and conserving resources. Recycling has long been known to reduce energy consumption, pollution, global warming, greenhouse gas emissions, and costs (Erfan Najaf M. O., 2022). The annual global production of demolished concrete is predicted to be between 2 and 3 billion tons. In the next ten years, the amount of destroyed concrete produced worldwide will rise to 7.5-12.5 billion tons (Nowrin et al., 2018). The usage of natural aggregate, which is the most common concrete component, is quickly expanding in tandem with the rise in concrete production (Erfan Najaf, 2022). Cutting mountains, breaking river gravels or boulders, and breaking clay bricks are the most typical ways to obtain aggregates (Uddin et al, 2013). This situation raises concerns regarding the sustainability of natural aggregate sources. Recycling the concrete from old buildings might conserve natural resources. One typical method for producing more ecologically friendly concrete is to crush concrete to provide coarse aggregate for the construction of new concrete. Using recycled concrete aggregate (RCA) in the manufacturing of concrete is one option to alleviate this problem.
The main objectives of this study is

- To determine the physical properties of recycled coarse aggregate & also to compare these properties with natural aggregates.
- To investigate the influence of Recycled Aggregates at various proportions on concrete.
- To investigate the percentage of Recycled Aggregate use in concrete without affecting the properties of concrete.

## 2.0 METHODOLOGY

The whole research work was done by maintaining the following steps that are given in the flow chart 1 and also describe below with appropriate figures.

### 2.1 Decide a research topic

After careful consideration, it has been chosen to focus our study on recycled concrete aggregate in Bangladesh because of the country's growing urbanization.

### 2.2 Collection and Gathering of Recycled Aggregates

For this research recycled Aggregates are collected from the demolitions of an old building which was made around 25 years later. Figure 1 illustrated the collection procedure of recycled concrete aggregates.

RA Collection Site          Manual Collection of RA

Collected Recycled Concrete Blocks

**Figure 1:** Collection of Recycled Aggregates.

### 2.3 Materials used for Preparing Test Specimen

In this study, cement, sand, natural coarse aggregate, recycled coarse aggregate and water are used to prepare test specimens. Materials used for preparing test specimens are shown in figure 2.

Cement: For the preparation of test specimens, Portland Pozzolana Cement complying was utilized.
Water: The concrete specimens were mixed and cured with portable water from the laboratory.
Fine Aggregate: Natural river sand was used as the fine aggregate in this experiment.
Natural Coarse Aggregate: Natural aggregates were crushed granite aggregates that passed through a 25.4 mm sieve and were retained on a 4.75 mm ASTM sieve.
Recycled Coarse Aggregate: Recycled Coarse aggregates were crushed concrete aggregates that passed through a 25.4 mm sieve and were retained on a 4.75 mm ASTM sieve.
Water: The concrete specimens were mixed and cured with portable water from the laboratory.

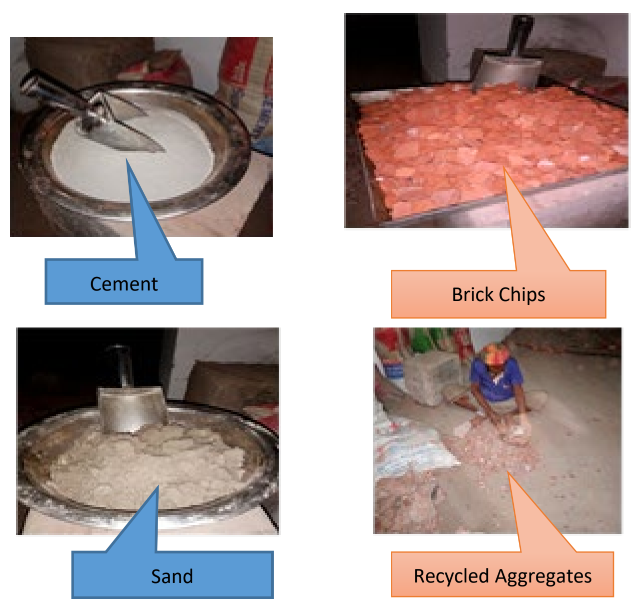
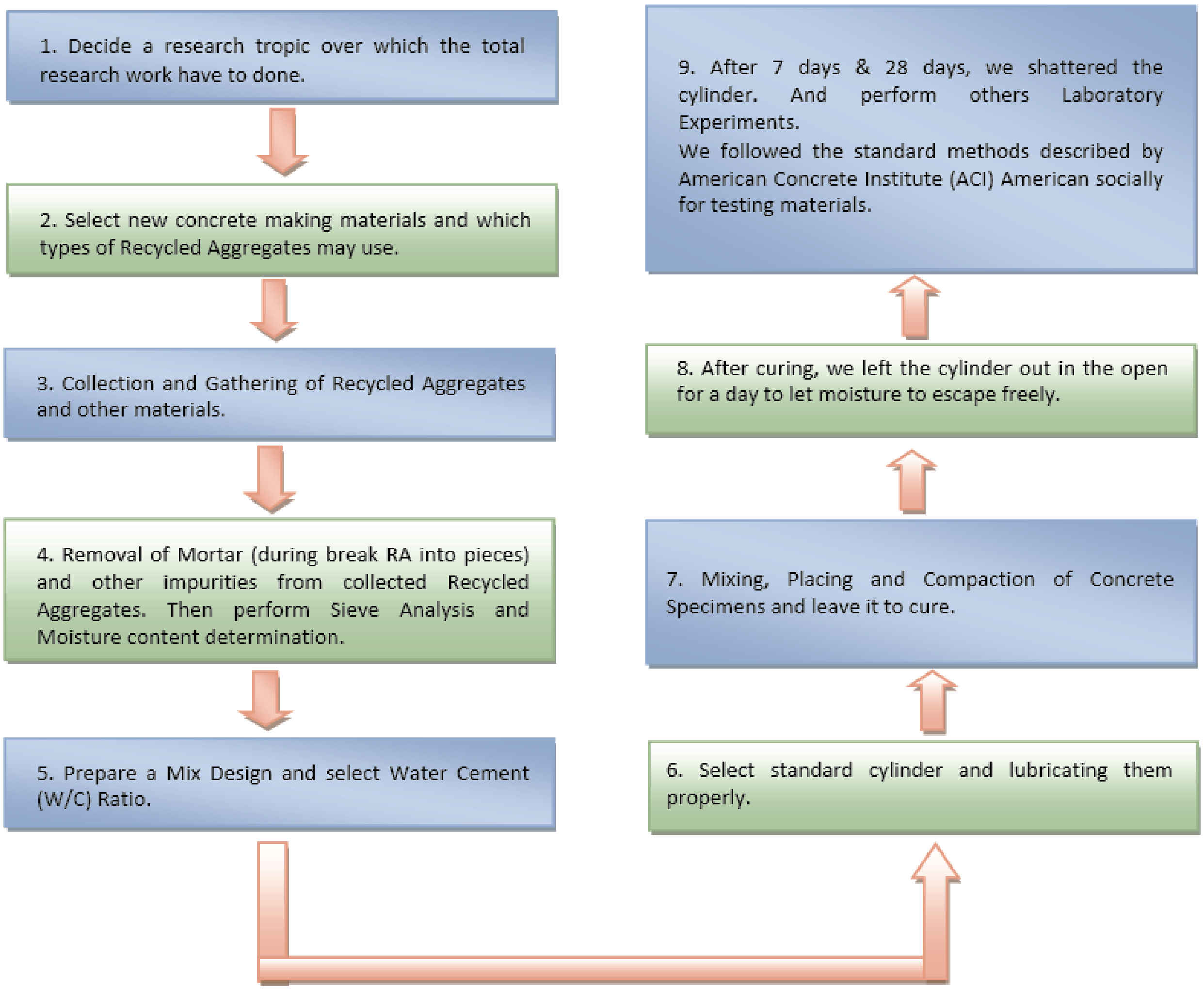



**Figure 2:** Materials used for preparing test specimens




Flow Chart 1: Methodology

**2.4 Removal of Mortar**

The glued mortar layer is the primary drawback of recycled concrete aggregate. Concrete's characteristics would be substantially enhanced if it could be eliminated as much as feasible. During break Recycled Concrete blocks into desired pieces in laboratory, figure 3 is captured.

**Figure 3:** Removal of Mortars (during break Recycled Concrete blocks into desired pieces in laboratory)

**2.5 Mix Design and selection of Water Cement (W/C) Ratio**

Here, the Water cement ratio was kept at 0.4 and the Mix ratio was maintained 1:2:4.

**2.6 Select standard cylinder and lubrication**

Cylinder mold dimension – 4” × 8”
Here, Diameter of Cylinder = 4”
Height of Cylinder = 8”
Proper lubrication is necessary because if lubrication is not done properly then it is difficult to separate concrete specimens from cylinder molds. Figure 4 illustrated the lubrication procedure of the cylinder

**Figure 4:** Lubrication of Cylinder (In Laboratory)

### 2.7 Mixing, Placing, and Compaction of Concrete Specimens

For this research, concrete mixing was done with a Mixer Machine. Mixture machine produces high quality concrete mix. Figure 5 shows that the concrete are mixing in a mixer machine

**Figure 5:** Machine Mixing of Concrete (Mixing concrete with a mixer machine in Laboratory)

Concrete compaction is necessary to preserve the slab's structural integrity and to help it reach its maximum strength. Compaction of concrete properly has a number of advantages. Here, Figure 6 illustrated the procedure of compaction and leveling of concrete.

**Figure 6:** Compaction & Leveling of Concrete (In Laboratory)

### 2.8 Curing

In this research, curing was done by using the ponding method. Curing by ponding method is shown in figure 7

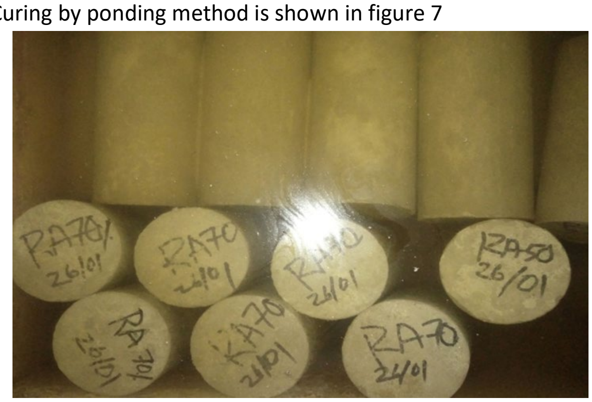


**Figure 7:** Curing by Ponding (In Laboratory)

### 2.9 Test Plan

Table 1 shows the test plan of this experimental work. According to this test plan, total 24 cylindrical specimens were made for performing compressive strength tests at 7 days and 24 days.

**Table 1:** Test plan

| Criteria | % Of Fresh Coarse Aggregate | % Of Recycled Coarse Aggregate | Diameter of Cylinder (in) | Height of Cylinder (in) | No. of Cylinder | Total Volume of Cylinder (in$^3$) |
|---|---|---|---|---|---|---|
| Fresh | 100 | 0 | 4 | 8 | 6 | 603.18 |
| Recycled | 30 | 70 | 4 | 8 | 6 | 603.18 |
| Recycled | 50 | 50 | 4 | 8 | 6 | 603.18 |
| Recycled | 70 | 30 | 4 | 8 | 6 | 603.18 |

## 3.0 RESULTS AND DISCUSSION

### 3.1 Sieve analysis and Fineness Modulus

The purpose of this experiment is to utilize sieving to figure out how coarse aggregate particle sizes are distributed. The fineness modulus test and sieve analysis of RCA were performed according to ASTM method C 136 (ASTM, 2017), and the results of the sieve analysis are shown in Table 2 below.

**Table 2:** Sieve Analysis for RCA

| Sieve No. | Sieve Size(mm) | Aggregates Retained(gm) | % Aggregate Retained | %Cumulative Retained | %Finer |
|---|---|---|---|---|---|
| 1.5" | 37.5 | 257.5 | 12.88 | 12.88 | 87.13 |
| 3/4" | 19 | 1200 | 60.00 | 72.88 | 27.13 |
| 3/8" | 9.5 | 58 | 2.90 | 75.78 | 24.23 |
| #4 | 4.75 | 3 | 0.15 | 75.93 | 24.08 |
| #8 | 2.36 | 0 | 0.00 | 75.93 | 24.08 |
| #16 | 1.18 | 459.5 | 22.98 | 98.90 | 1.10 |
| #30 | 0.6 | 13 | 0.65 | 99.55 | 0.45 |
| #50 | 0.3 | 3 | 0.15 | 99.70 | 0.30 |
| #100 | 0.15 | 2 | 0.10 | 99.80 | 0.20 |
| Pan | | 4 | 0.20 | 100.00 | 0.00 |
| | | Total Aggregate Retained =2000 | Sum of % Aggregate Retained =100.00 | Sum of % Cumulative Retained =811.33 | |

Fineness Modulus = 811.33/100 = 8.11

The grading curve below depicts the findings of the sieve analysis according to table 2. Figure 8 depicts the RCA gradation curve.

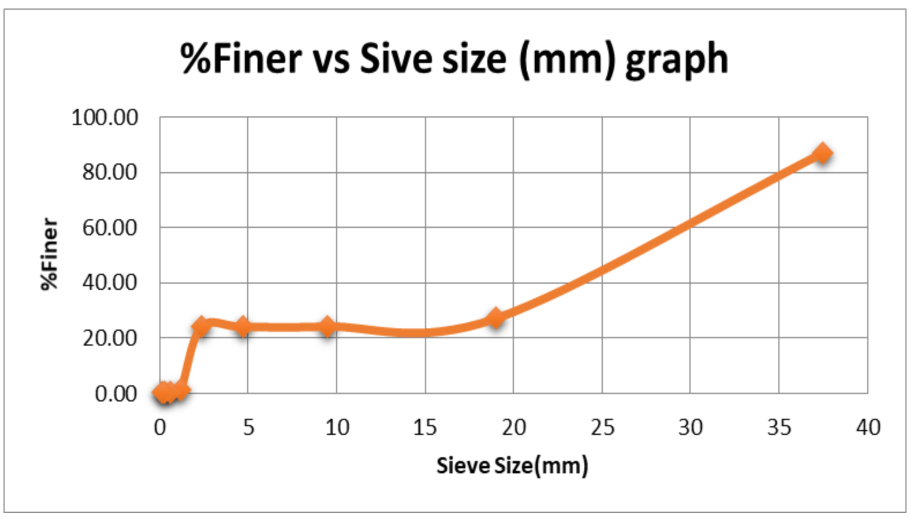



**Figure 8:** Gradation curve of RCA

- From the obtained result in Table 2, most of the recycled aggregate passed through 37.5 mm sieve size, but less than 1% of aggregate passed through 0.6 mm sieve size. Through a 37.5 mm sieve, almost 90% of recycled aggregates are passed.
- The FM for fine aggregate used in concrete is typically between 2.3 and 3.1. However, fine sands with an FM less than 2.0 and coarser fine aggregates with an FM of more than 3.1 are employed in some circumstances. FM was found 8.11 which is higher than 3.1. So, it satisfies the satisfactory criteria.
- Types of gradation curves-

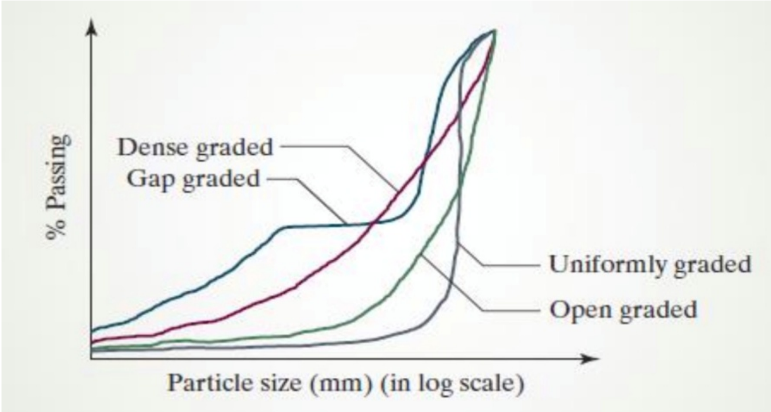



**Figure 9:** Typical Gradation curve (Different Types of gradation curves) (Uddin et al, 2013).

According to the Figures 8 and 9 comparisons, it may say that figure 8 is a gap-graded curve. Gap grading is characterized by the absence of one or more intermediate-size fractions. It displays a horizontal line across the range of sizes that aren't present on a grading curve.

### 3.2 Slump of Concrete

The ASTM technique C 143/C143M was used to test the Slump of RCA's Hydraulic-Cement Concrete.

Proportion of concrete mix = 1:2:4; W/C = 0.4

**Figure 10:** Slump Test (In Laboratory)

**Table 3:** Slump of Hydraulic-Cement Concrete

| Sample | Height of concrete before slump subsidence | Height of concrete after slump subsidence | Height of the slump |
|---|---|---|---|
| 01. | 12” | 11.4” | 0.6” or 15.24mm |

According to table 3 and figure 10, the slump value of the given concrete mix was found to be 0.6” or 15.24mm. All of the slumps are true slumps.

This Concrete Slump Chart from table 4 illustrates several slump ranges and their applications.

**Table 4:** Concrete Slump Chart (ASTM, 2017).

| Slump, in (mm) | Degree of Workability | Application |
|---|---|---|
| 0-1 (0-25) | Very low | Very dry mixes used in paving machines with high-powered vibration |
| 1-2 (25-50) | Low | Low-workability mixes used for foundations with light reinforcement; Pavements consolidated by hand-operated vibrators |
| 2-4 (50-100) | Medium | Medium workability mixes; manually consolidated flat slabs. Normal reinforced concrete manually placed; heavily reinforced sections with mechanical vibration |
| 4-7 (100-175) | High | High workability concrete for sections with congested reinforcement; May not respond well to vibration |

- ✓ According to table 4, the Degree of Workability is very low. It may influence the various strength properties of concrete.

**3.3 Physical Properties**

The Physical properties of RCA impact the blend extent and properties of concrete. Because of the existence of remaining cement paste/mortar and impurities, the fundamental properties of RCA, such as specific gravity, bulk density, percent pore volume, and water absorption, are worse than those of NCA.

**Table 5:** For comparison, the physical characteristics of NCA and RCA are shown below.

| Physical property | Natural Concrete Aggregate(NAC) (Jamal and Haseeb, 2019) | Recycled Concrete Aggregate(RCA) (For stone) (Jamal and Haseeb, 2019) | Recycled Concrete Aggregate(RCA) (For Brick) |
|---|---|---|---|
| Specific gravity (saturated surface-dry based) | 2.4-2.9 | 2.1-2.5 | 2.07 |
| Bulk Density(Kg/m$^3$) | 1450-1750 | 1200-1425 | 1163-1245 |
| Absorption (wt. %) | 0.5-4 | 3-12 | 13 |
| Pore Volume (vol. %) | 0.5-2 | 5-16.5 | 36 |

***3.3.1 Specific Gravity***

The specific gravity of RCA is smaller than that of NCA, as noticed in Table 5. According to our study, the specific gravity of RCA (for brick) is around 2.07, which is unsatisfactory when compared to Natural Aggregates. The adhesion of leftover old cement paste on recycled aggregate is the cause of the lower specific gravity of RCA.

***3.3.2 Bulk Density***

The bulk density of RCA is noticeably lower than that of NCA, as noticed in Table 5. According to our study, the Bulk Density of RCA (for brick) is between 1163 (Kg/m$^3$) to 1245 (Kg/m$^3$), which is unsatisfactory when compared to Natural Aggregates. This is attributable to the RCA's higher porosity when sufficient mortar is present.

***3.3.3 Absorption of Coarse Aggregate***

Table 5 shows that RCA has a significantly higher water absorption capacity than NCA. According to our study, the water absorption of coarse aggregate (for brick) was found 13, which is higher compared to Natural Aggregates due to the higher porosity of RCA.

***3.3.4 % Voids or Pore Volume***

RCA has a slightly larger pore capacity than NCA, as seen in Table 5. For Recycled Concrete Aggregates (for brick), pore volume was found 36%, which is so much higher compared to NAC due to the adhered mortar.

**3.4 Compressive Strength**

Compressive Strength is the most important parameter to identify the quality of concrete. Figures 12, 13, 14 and 15 represents the variation of compressive strength with the age of concrete and also a variation with the % replacement of Natural Aggregates using Recycled aggregates. The whole machine and machine setup during testing are shown in figure 11.


**Figure 11:** Compression Testing Machine (In Laboratory)

For all Specimens

- W/C = 0.4
- Mix Proportion = 1:2:4
- Using Brick Chips.

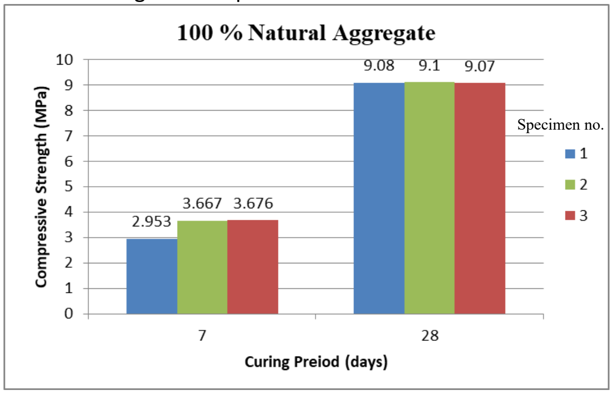



**Figure 12:** 100% natural aggregate compression test result

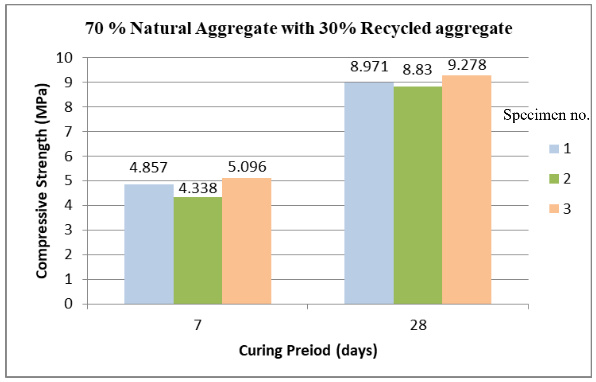



**Figure 13:** 70% natural aggregate with 30% recycled aggregate compression test result

It may conclude from figure 12 the average compressive strength is 3.432 MPa for 7 days and 9.083 MPa for 28 days in case of using 100% natural aggregate with 0% Recycled Aggregate. As noticed in figure 13, the average compressive strength is 4.764 MPa for 7 days and 9.026 MPa for 28 days in case of using 70% natural aggregate with 30% recycled aggregate

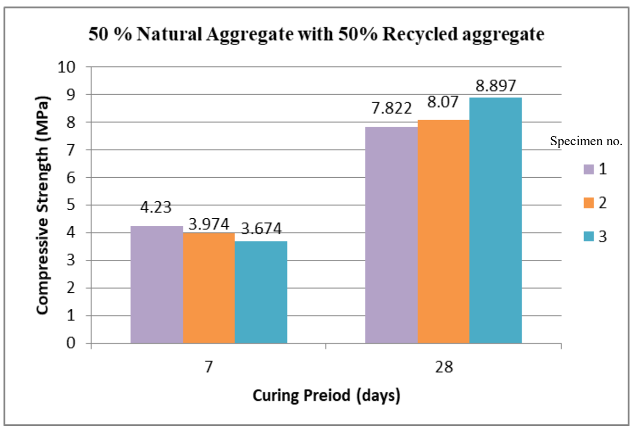



**Figure 14:** 50% natural aggregate with 50% recycled aggregate compression test result

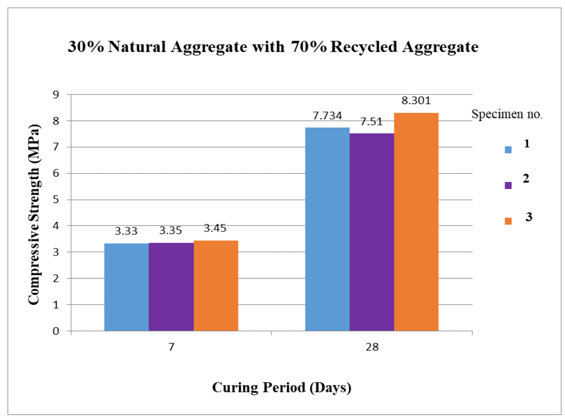



**Figure 15:** 30% natural aggregate with 70% recycled aggregate compression test result

It may conclude from figure 14 the average compressive strength is 3.959 MPa for 7 days and 8.263 MPa for 28 days in case of using 50% natural aggregate with 50% recycled aggregate. As noticed in figure 15, the average compressive strength is 3.377 MPa for 7 days and 7.848 MPa for 28 days in case of using 30% natural aggregate with 70% recycled aggregate.

**Table 6:** Variation of average compressive strength

| Percentage of aggregate | 7 Days | | 28 Days | |
|---|---|---|---|---|
| | Avg. Compressive Strength (MPa) | Variation | Avg. Compressive Strength (MPa) | Variation |
| 100% natural aggregate with 0% Recycled Aggregate | 3.432 | 0% | 9.083 | 0% |
| 70% natural aggregate with 30% Recycled Aggregate | 4.764 | +38.90% | 9.026 | -0.63% |
| 50% natural aggregate with 50% Recycled Aggregate | 3.959 | +15.36% | 8.263 | -9.03% |
| 30% natural aggregate with 70% Recycled Aggregate | 3.377 | -1.60% | 7.848 | -13.60% |

Table 6 (-) indicates reductions of strength and (+) indicates an increment of strength. Usually, the compressive strength of recycled aggregate concrete is lower when it is compared with Natural aggregate concrete.

- From Table 6 & Figure 16, in the case of 7 Days, it is seen that compressive strength increases with the increase in the percentage of Recycled Aggregate. This may happen due to the adhered mortar layer with the recycled aggregates. Adhered mortar layer contains some Cementitious materials. That's why compressive strength increases due to a certain amount of adhered Cementitious materials.
- From Table 6 & Figure 16, in the case of 28 Days, it is seen that compressive strength reduces with the increase in the percentage of Recycled Aggregate.

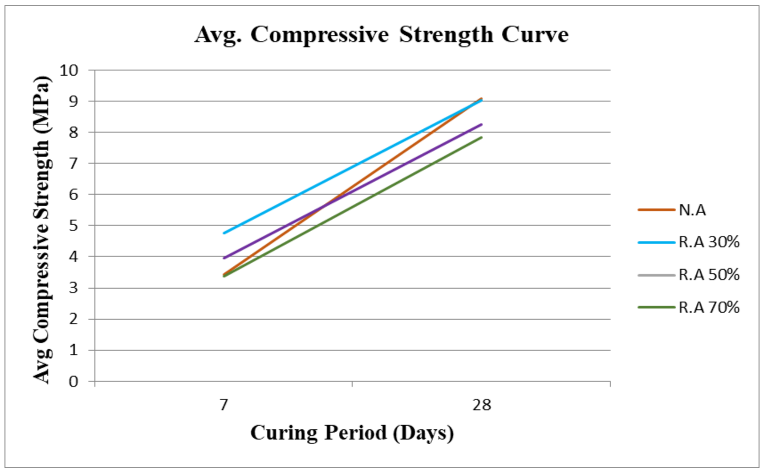



**Figure 16:** Avg. Compressive Strength Curve

**3.5 Crack Pattern determination**

It is wanted to compare all the cracks that take place after the compressive strength test with a typical Sketches of Type of Fracture in Concrete Cylinder (figure 17). Different types crack patterns that take place after compressive strength test are shown in figure 18.

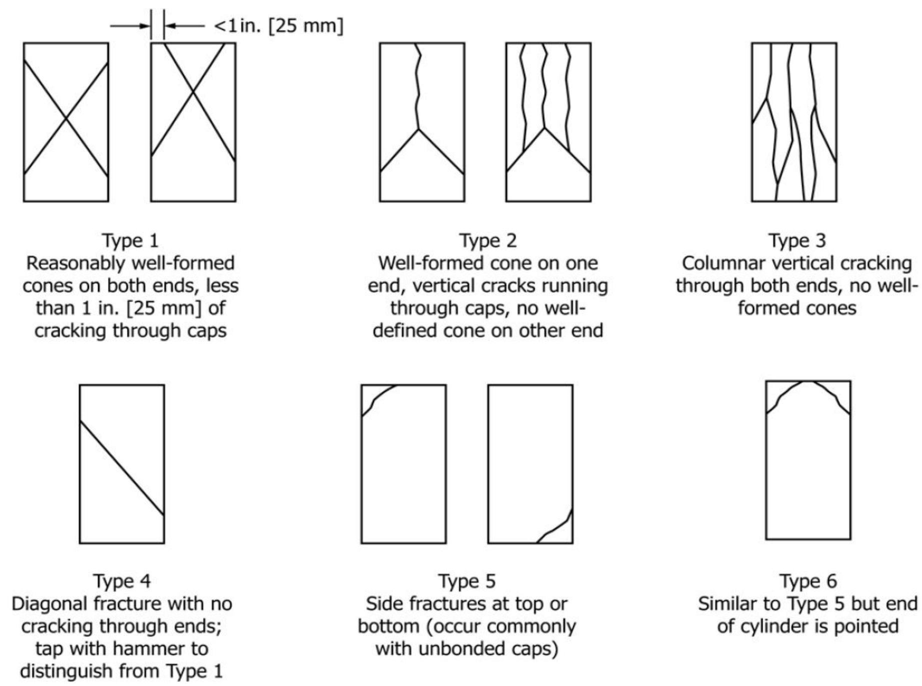



**Figure 17:** Typical Sketches of Type of Fracture in Concrete Cylinder (Backus, 2022)

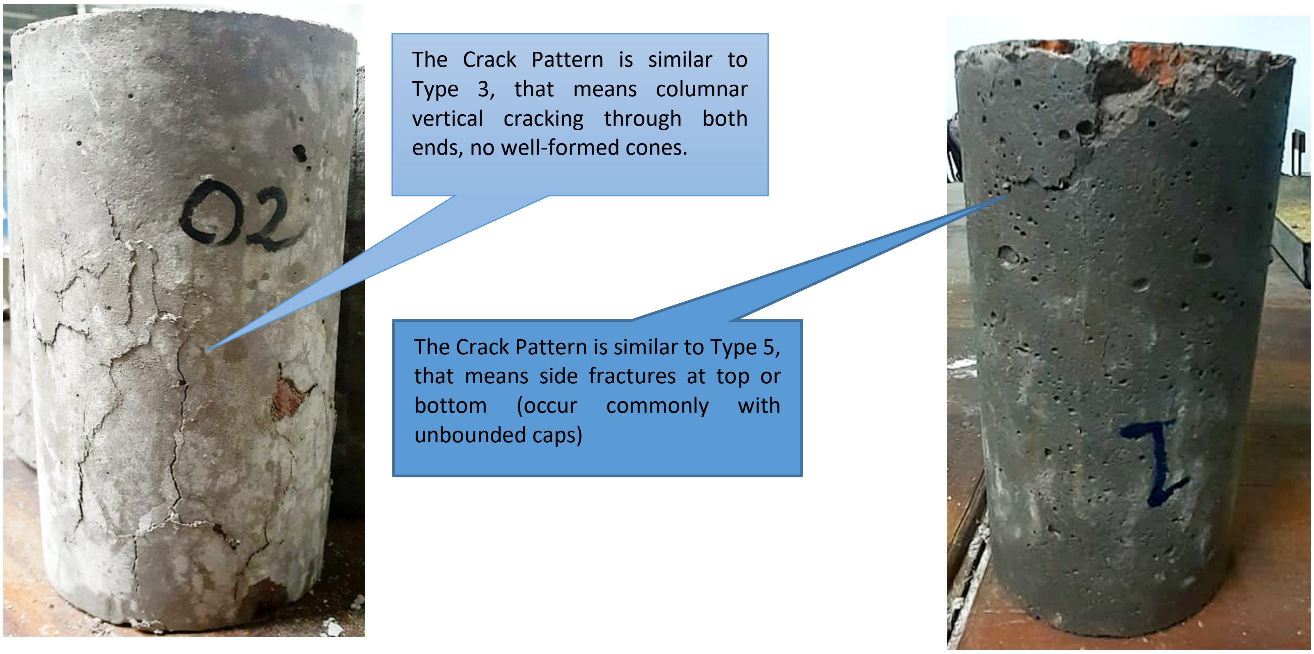



**Figure 18:** Different types crack patterns that take place after compressive strength test

## 4.0 CONCLUSIONS

The following conclusions are made based on the experimental studies:

- In this study, it is found that the specific gravity and bulk density of Recycled Concrete Aggregate (RCA) are around 2.07 and 1163-1245 kg/m$^3$ which is appreciably smaller than Natural Aggregate (NA). The strength of concrete may be slightly reduced as a result of its decreased specific gravity and bulk density value.
- Compared to Natural Aggregate (NA), Recycled Concrete Aggregate (RCA) has a higher value of % pore volume and water absorption capacity of around 13% and 36%. The higher water absorption capacity of recycled aggregates may reduce the concrete strength for the pre-utilization of the water which is required for the hydration reaction of cement.
- The compressive strength of the specimen which contains 100% natural aggregates as coarse aggregates at 7 days is comparatively lower than all other specimens. Due to the presence of adhered mortar (Cementitious materials) in recycled aggregates, the compressive strength at 7 days for recycled aggregates specimen's increases rapidly compared to natural aggregates specimens. But in the case of 28 days, compressive strength of natural aggregates as well as 30% replacement of natural aggregates specimens shows better results than other specimens.
- It is found from this study that RAC with replacing 25% to 30% of recycled coarse aggregate can be made without adversely altering the properties of natural aggregate concrete.
- The main drawback of recycled concrete aggregate is the adhered mortar layer. Adhered mortar increases water absorption capacity which leads to reduced workability of RAC. It was attempted to remove the mortar layer from recycled aggregates for research purposes, but it was never feasible to entirely remove it.
- In this research, RCA is utilized without any form of treatment, such as washing, acetic acid treatment, one-layer cement treatment, etc. If one can utilize recycled aggregates by providing proper treatment then the water absorption capacity, bulk density and specific gravity will additionally boost.

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## References

[1] B.B.o.S.-D.i.a. statistics, 2022. "https://worldpopulationreview.com/world-cities/dhaka-population," [Online], April 12, 2022.

[2] T.H./.B.BEARD, 2021. "Exploration of Dhaka, Bangladesh," https://storymaps.arcgis.com/stories/cd249054ae7842fbac01 9c496f8fa479, June 7, 2021.

[3] A. R. T. T. B. Nowrin Akhter Keya, 2018. "To Investigate the Effect of Using Recycled Concrete as Partial Replacement of Coarse Aggregate in Concrete Strength," research gate, Dhaka.

[4] A. Z. K. A. H. M. Mohammed Tarek Uddin1, August 2013, "Recycling of Demolished Brick Aggregate Concrete as Coarse and Fine Aggregate," Third International Conference on Sustainable Construction Materials and Technologies, http://www.claisse.info/Proceedings.htm, Research gate, at: https://www.researchgate.net/publication/259863669.

[5] A. International, 2017, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates" https://www.astm.org/c0136-01.html," [Online]. Aug 16, 2017.

[6] H. Jamal, 2019. "Gradation Of Aggregates | Types of Aggregate Grading," AboutCivil.com, https://www.aboutcivil.org/gradation-of-aggregates, Oct 05, 2019.

[7] U. J. A. M. R. A. S. Z. J. Md. Safiuddin, 2013, "Use of Recycled Concrete Aggregate In Concrete: A Review," Journal Of Civil Engineering And Management, 19(6): 796–810, https://doi.org/10.3846/13923730.2013.799093.

[8] D. A. Advisor: Kuchma, 2015. "Investigation of fiber and cracking behavior for conventional and ultra-high performance concretes using x-ray computed tomography,"https://www.researchgate.net/publication/303863201_Investigation_of_fiber_and_cracking_behavior_for_conventional_and_ultra-high_performance_concretes_using_x-ray_computed_tomography .

[9] N.a.B.S.Choo, 2003. Advanced Concrete Technology, https://www.sciencedirect.com/book/9780750656863/advanced-concrete-technology.

[10] G. c. Benjamin E. Backus, 2022, Workability of Concrete " https://www.globalgilson.com/blog/what-is-workability-of-concrete ," [Online]. 1st February, 2022.

[11] H. A. S. M. Z. Erfan Najaf, 2022, "Effect of waste glass powder, microsilica and polypropylene fibers on ductility, flexural and impact strengths of lightweight concrete," International Journal of Structural Integrity, 13: 511-533, https://doi.org/10.1108/IJSI-03-2022-0039.

[12] E. N. a. H. Abbasi, 2022, "Using Recycled Concrete Powder, Waste Glass Powder, and Plastic Powder to Improve the Mechanical Properties of Compacted Concrete: Cement Elimination Approach,"Hindawi, 2022, Volume 2022, Article ID 9481466, 12 pages, https://doi.org/10.1155/2022/9481466.

[13] M. O. a. S. M. Z. Erfan Najaf, 2022, "Improving nonlinear behavior and tensile and compressive strengths of sustainable lightweight concrete using waste glass powder, nanosilica, and recycled polypropylene fiber," Nonlinear Engineering 2022; 11: 58–70, https://doi.org/10.1515/nleng-2022-0008, Available: https://www.degruyter.com/document/doi/10.1515/nleng-2022-0008/html.

[14] S. M. Z. &. E. N. Maedeh Orouji, 2021, "Effect of glass powder & polypropylene fibers on compressive and flexural strengths, toughness and ductility of concrete: An environmental approach," ScienceDirect, 33: 4616-4628, https://doi.org/10.1016/j.istruc.2021.07.048, Available: https://www.sciencedirect.com/science/article/abs/pii/S2352012421006640?via%3Dihub.