

Performance Study of Construction and Demolition Waste as Coarse Aggregate on Strength and Cost-Effectiveness of Concrete

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Abstract - Concrete, the most widely used construction material, is mainly composed of coarse aggregate, fine aggregate, binding material and water. Limited natural resources have been utilized over the years for producing aggregates in the construction industry. The rapidly increasing generation of construction and demolition waste (CDW) threatens the environment, especially for countries like Bangladesh where it has become more difficult to dispose of due to rapid urbanization. As a result, continuous research has been conducted on recycling CDW so that they can be used as partial replacement of conventional aggregates. The objective of this study was to analyze the strength characteristics and cost-effectiveness of concrete with the optimal replacement percentage of coarse aggregate. Compressive strength at 7, 14, and 28 days were determined experimentally by casting concrete cylinders using a mix ratio 1:1.5:3 and water-cement ratio of 0.50 by replacing 25%, 27.5%, 30%, 32.5%, and 35% natural coarse aggregate with construction and demolition waste coarse aggregate (CDWCA). The test results suggested that the compressive strength increased for replacement of up to 30% coarse aggregate. It was also observed that strength and cost comparison was compatible for 27.5%, 30% and 32.5% of CDWCA replacing natural coarse aggregate; however, 30% CDWCA replacement yielded the optimal mix, balancing both cost reduction and compressive strength improvement. Aggregates manufactured from CDW can be utilized as recycled concrete aggregates to replace conventional aggregates for non-structural works with proper guidelines.

Keywords: Construction and demolition waste; Recycled concrete aggregate; Natural coarse aggregate; Compressive strength; Cost analysis.

I. INTRODUCTION

Urbanization is responsible for the increased global demand of concrete, the widely used construction material; with annual consumption rate of approximately 25 giga tons

worldwide [1]. Concrete, a harmonic combination of binding material, coarse aggregate, fine aggregate and water, has supported the towering structures and infrastructure wonders that define the contemporary world. Aggregates play a core role as they account for about 80% to 85% of a typical concrete mixture and are responsible for consumption of local natural resources [2]. Nonetheless, this universal building material is inextricably related to the finite abundance of the planet's natural resources. The increasing urbanization trend and the never-ending cycle of construction and demolition have resulted in a significant ecological issue. This increase in demolition operations, signaled by the removal of buildings that were formerly considered essential to the urban landscapes, has led to the production of enormous amounts of demolition waste. The collection of demolition waste has undergone a thorough and innovative process to become a useful resource. It requires the skillful technique of removing contaminants and painstakingly shredding debris into aggregates with specific dimensions and chemical makeup. On the other hand, utilizing alternatives and replacements of aggregates is an effective way to stop or lessen harm to river and marine ecosystems [3]. Concrete is one of the most common recyclable building materials. It is important for the execution of circular economy strategies in the construction industry [4-6]. Along with the construction process, demolition is also required which generates excessive waste known as construction and demolition waste (CDW). Recycled concrete aggregates have a propensity for greater water absorption, which calls for careful attention. For this property the slump value of concrete gets affected and workability of the concrete may decrease. Here comes the idea of pre-soaked aggregates, a clever scheme created to enhance the qualities of these recycled materials. Pre-soaked aggregates promise to align flawlessly with the matrix of cement using careful preparation and controlled hydration, enhancing the performance and durability of CDW concrete constructions. Their support by utilizing the construction and demolition aggregate for sustainable development is coupled with particular impacts on the functionality of concrete produced [7]. While traversing this landscape, it is found not only the promise of using CDW in concrete but also a tribute

to the never-ending human effort devoted to protecting the limited resources of the natural world and preserving the environment. Research on the recycling of CDW materials for use as partial replacements in concrete production has been significantly influenced by the pursuit of sustainable construction methods. Natural aggregates are used extensively in the traditional manufacture of concrete, with riverbeds being the primary source of fine particles. Rapid expansion of the construction industry has resulted in an abundance of CDW, particularly concrete debris. Such garbage disposal is extremely difficult and might be hazardous to the environment [8]. Researchers and business experts have looked at recycling CDW materials to lessen environmental effect and solve the scarcity of natural resources. According to research, concrete mixes including various amounts of coarse demolition waste particles can preserve or even increase compressive strength, preserving the concrete's structural integrity [9]. Halahla *et. al.* (2019) showed that the evolution of compressive strength of concrete using recycled coarse aggregate was similar in behavior to the concrete with natural aggregate, except that it was about 10% lower in values [10]. The replacement of natural coarse aggregate by construction and demolition waste coarse aggregate (CDWCA) does not have any effect on the compressive strength of concrete up to a degree of substitution of 30% by weight [11]. After this percentage of replacement, the compressive strength decreases with greater replacement percentage of coarse aggregate [12]. The main objective of the research is to identify the possibility of replacing natural coarse aggregate with CDWCA for lightweight concrete with specified compressive strength and cost minimization. This study develops as an expedition to understand the possibilities of recycled concrete in the furnace of innovation and sustainability. The aim is to highlight the approaches for enhancing building sustainability, with a strong focus on resource conservation and environmental care at its core.

II. MATERIALS AND METHODS

2.1 Cement

The CEM II-Portland Composite Cement (PCC) was used as the binding material for concrete in this study. The PCC used in this investigation complied with the exacting requirements outlined in BDS EN 197-1:2003 Part-1 [14], guaranteeing its adherence to recognized quality standards. This particular PCC had a specific gravity of 2.90.

2.2 Coarse Aggregate

Coarse aggregates come in a variety of sizes and forms; however, well-graded mixtures can improve packing and interlocking properties of concrete. Brick chips with a fineness modulus of 6.80, saturated surface dry (SSD) density of 1675

kg/m³ and under dense condition density of 1632 kg/m³ were used in this investigation.

2.3 Fine Aggregate

Fine aggregate employed in this study was sourced from local Sylhet sand, characterized by particle sizes below 4.75 mm. The choice of Sylhet sand as the fine aggregate was driven by its availability in locality for concrete production. The sand utilized in this study had a fineness modulus of 2.53. Its density was 1583 kg/m³ for air dry condition and 1632 kg/m³ for SSD condition.

2.4 Construction and Demolition Waste Coarse Aggregate (CDWCA)

Coarse aggregate used in this study was made from CDW of a building foundation. It is made up of bigger crushed concrete pieces that are generally larger than 3/8 inches (9.5 mm). When using CDWCA, quality control and adherence to standards are critical to ensuring safety and performance in construction projects. The air dry and SSD densities at dense condition for CDW coarse aggregate were found as 1394 kg/m³ and 1479 kg/m³, respectively, with a fineness modulus of 6.83.

2.5 Water

Water used in concrete mixing must meet specific quality criteria to ensure the integrity of the concrete. In this research, tap water supplied by Dhaka Water Supply and Sewerage Authority (WASA) was chosen as the primary water source for all aspects, including cylinder casting and curing. The water exhibited a pH level within the range of 6.5 to 9.5, indicating its suitability for concrete applications. Furthermore, it conformed to the stringent standards outlined in BDS ISO 12439:2011 [15], aligning with the requirements for mixing water in concrete as stipulated in BNBC-2020 regulations [16].



(a) Brick chips



(b) Sylhet sand



Figure 1: Testing Materials

2.6 Mix Design

The American Concrete Institute's (ACI, 211.1-91) [17] recommendations were followed in the mix design for this study. Prior to mixing, it was important to make sure that all aggregates were kept with SSD condition. Suitable slump value was chosen. The maximum size of coarse aggregate used was 20 mm. The mix design requirements were predicted to reach a water-cement ratio of 0.5 with 1:1.5:3 mixing proportion, which is essential for defining the strength and longevity of concrete.

2.7 Concrete Casting

Cylindrical molds were prepared to facilitate the casting of concrete cylinders. These molds were specifically designed with dimensions of 4 inches in diameter and 8 inches in height, ensuring precision and consistency in preparing the cylinders. The predetermined quantities of natural coarse aggregates with varying percentage of CDWCA, maintained in their SSD condition, were evenly spread across the mixture's surface. These aggregates were meticulously mixed by hand to ensure a thorough and uniform distribution within the concrete mixture. Freshly mixed concrete was carefully poured into the molds with proper compaction. This removed any trapped air gaps and guaranteed a constant density all the way around the cylinder. A total of 33 cylinders was cast, each designed to assess the compressive strength under different replacement scenarios, yielding valuable insights into the characteristics of concrete. After casting, the concrete cylinder's upper surface was skillfully smoothed using a trowel or a straight edge to provide a smooth and uniform finish.

2.8 Curing and Testing

After being demolded, the concrete cylinders were carefully put inside a water tank to aid in the ongoing curing process. These specimens were kept immersed in water during the whole curing process for appropriate curing. The concrete

cylinders were withdrawn from the curing tank at precise intervals of 7 days, 14 days, and 28 days. Their compressive strength was carefully evaluated. Detailed records were kept for each tested cylinder. The compressive strength was thoroughly examined using a variety of mixing ratios, including replacement percentages of 25%, 27.5%, 30%, 32.5%, and 35% of natural coarse aggregate with CDWCA.



Figure 2: Concrete Casting, Curing, and Testing

III. RESULTS AND DISCUSSION

3.1 Slump Test

The workability and consistency of the concrete mixes utilized in this study were evaluated using the slump test, which was carried out in line with ASTM C143 criteria [18]. This frequently used test includes adding newly mixed concrete in three equal layers; each compacted with a rod, to a conventional slump cone with a bottom diameter of 4 inches and a height of 8 inches. After removing the cone, the vertical distance between the top of the cone and the highest point of the settled concrete is used to calculate the concrete slump. The slump test results offer important insights into the characteristics of the concrete by helping in determining its cohesion, general consistency, and ease of placing. The slump value varied depending on the replacement percentage and was often lower than the natural aggregate value. Only 25% and 27.5% replacement of CDWCA provided higher and equal slump value respectively [19].

Table 1: Slump value for different replacement percentage of CDWCA

| Experiment Condition | Slump Value (mm) |
|------------------------|------------------|
| 100% Natural aggregate | 30 |
| 25% CDWCA | 32 |
| 27.5% CDWCA | 30 |
| 30% CDWCA | 29 |
| 32.5% CDWCA | 27 |
| 35% CDWCA | 25 |

3.2 Compressive Strength Test

The compressive strength of concrete with natural coarse aggregate and various percentages of replacement were evaluated on cylindrical specimens. Values of compressive strength are provided below as a tabular representation. The compressive strength of cylinders was increased up to 30% of natural coarse aggregate replacement with CDWCA. The strength of natural concrete is less than any of the replacement percentage of CDWCA.

Table 2: Compressive strength of concrete for different replacement percentage of CDWCA [19]

| Replacement percentage | Compressive strength (psi) | | |
|-------------------------------|----------------------------|---------|---------|
| | 7 Days | 14 Days | 28 Days |
| 100% Natural coarse aggregate | 1108 | 1459 | 2400 |

| | | | |
|-------------|------|------|------|
| 25% CDWCA | 1477 | 1846 | 2714 |
| 27.5% CDWCA | 1569 | 2031 | 2862 |
| 30% CDWCA | 1754 | 2308 | 2954 |
| 32.5% CDWCA | 1533 | 1957 | 2899 |
| 35% CDWCA | 1200 | 1514 | 2456 |

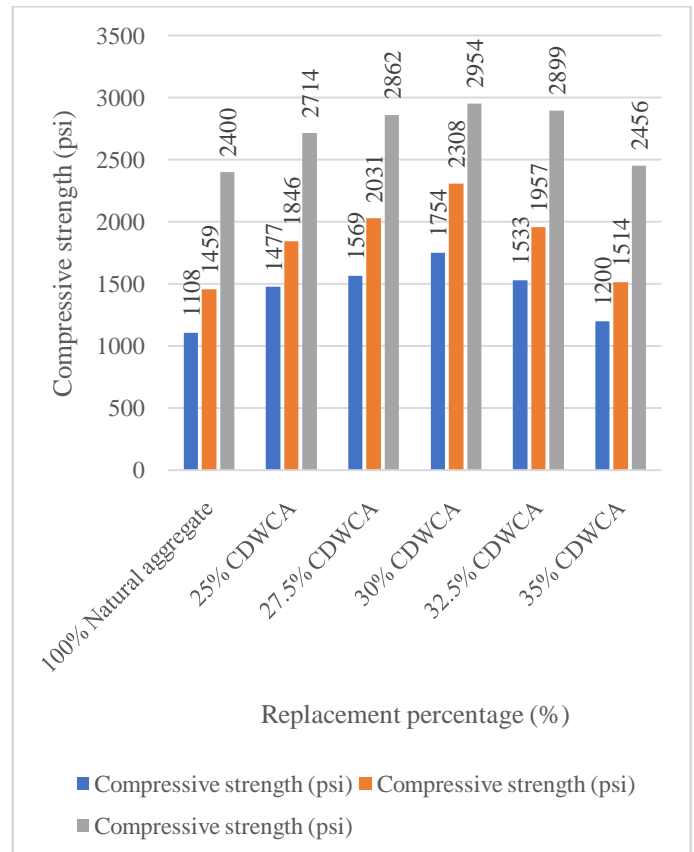


Figure 3: Compressive strength for different replacement percentage of CDWCA

3.3 Cost Analysis

As the quantities of all materials, except the coarse aggregate, are consistent across the concrete mixes, a cost analysis was performed to compare natural coarse aggregate with CDWCA, aiming to identify the more cost-effective alternative. Significant gains in compressive strength and cost reduction were shown when CDWCA was used. The fineness value is reported in accordance with the Schedule of Rates (SoR) 2022 for Civil Works, published by the Public Works Department of the Government of the People's Republic of Bangladesh [20]. The combination made entirely of natural materials cost BDT 6544.8, but the cost gradually decreased as CDWCA was added. The cost dropped by 12.5% to BDT 5726.7 for 25% CDWCA, and more reductions were seen as the CDWCA percentage increased, reaching a 17.5% cost minimization to BDT 5399.46 for 35% CDWCA.

After 28 days, the mix made entirely of natural ingredients had a compressive strength of 2400 psi. Up to 30% CDWCA, when the strength reached 2954 psi, or a 23.08% increase, the addition of CDWCA produced a steady gain in strength. Nevertheless, a decrease resulted from CDWCA rates rising beyond 30%. However, further increases in CDWCA percentages beyond 30% led to a decline in compressive strength, with the strength dropping to 2456 psi

at 35% CDWCA, which is only a 2.33% improvement compared to the natural mix. The 25% CDWCA, 30% CDWCA and 32.5% CDWCA replacement is compatible regarding strength and cost comparison while 30% CDWCA replacement yields the most efficient results.

Thus, 30% CDWCA emerged as the optimal mix, balancing both cost-effectiveness and compressive strength improvement without compromising structural requirements.

Table 3: Comparative study on Compressive strength of concrete and cost for replacement of CDWCA

| Materials | Cost (BDT) | % Cost decrease | Compressive strength of cylinder after 28 days (psi) | % Strength increase |
|--------------|------------|-----------------|--|---------------------|
| 100% Natural | 6544.8 | 0 | 2400 | 0.000 |
| 25% CDWCA | 5726.7 | 12.5 | 2714 | 13.083 |
| 27.5% CDWCA | 5644.89 | 13.75 | 2862 | 19.250 |
| 30% CDWCA | 5563.08 | 15 | 2954 | 23.083 |
| 32.5% CDWCA | 5481.27 | 16.25 | 2899 | 20.792 |
| 35% CDWCA | 5399.46 | 17.5 | 2456 | 2.333 |

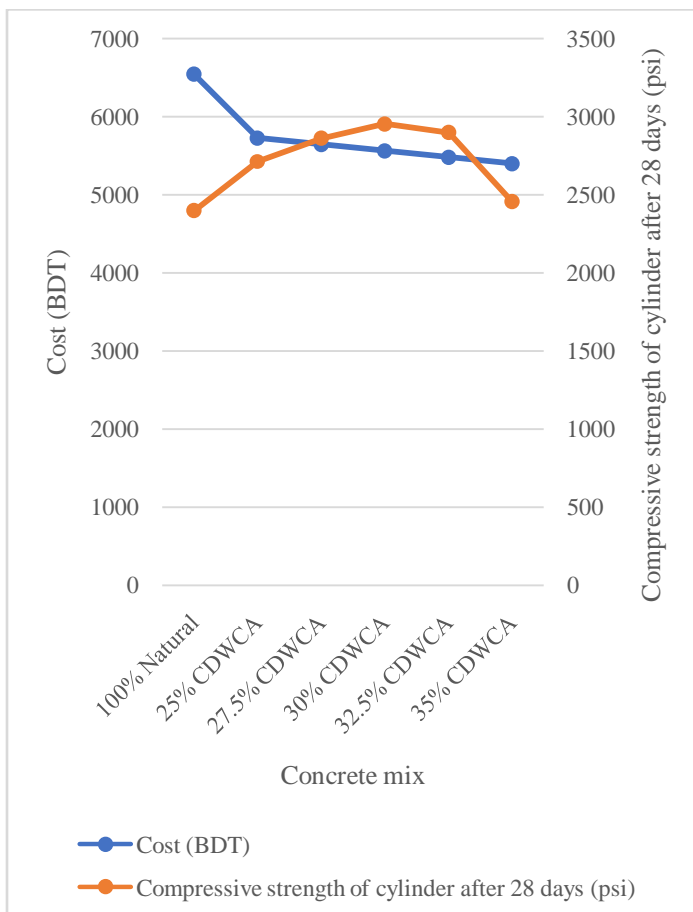


Figure 4: Comparison of compressive strength and cost for different replacement percentage of CDWCA

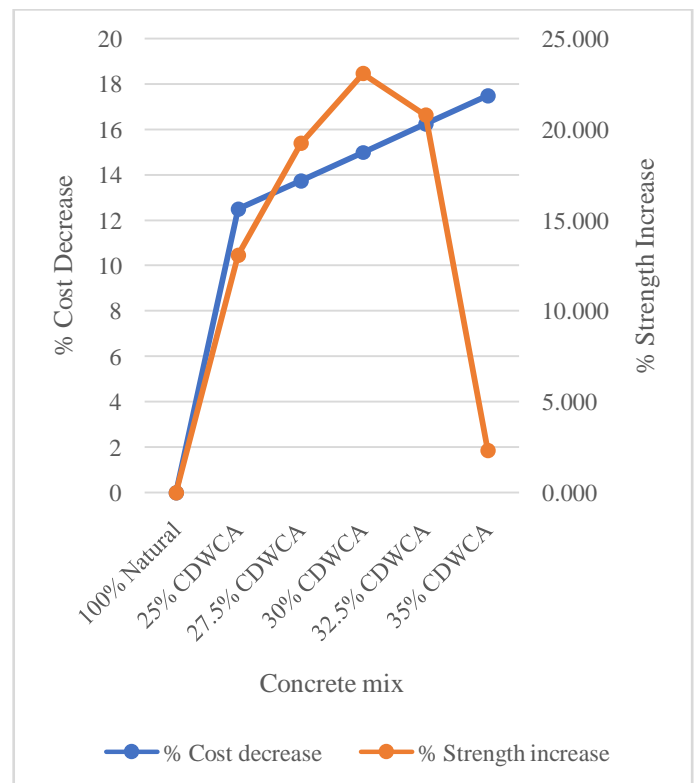


Figure 5: Comparison of % cost decrease and % strength increase for different replacement percentage of CDWCA

IV. CONCLUSION

An investigation into the effects of using CDW as a partial replacement in concrete mixes was the main goal of this study. Concrete cylinders were used for the compressive strength testing, which provided important information on the extent to which these mixes worked. At first, the highest

compressive strength attained was 2400 psi without the usage of any recycled aggregate. However, it was observed that a noticeable improvement in compressive strength, reaching a maximum of 2954 psi, when CDWCA was included as replacement for brick chips at 30% level. This result highlighted that the possibility of CDWCA as a workable substitute for natural coarse aggregate, further boosting the performance and strength of concrete.

The study demonstrated that adding CDW aggregate to concrete mixes in a strategic way may increase compressive strength, making sustainable building practices feasible both economically and environmentally. These findings highlight the benefit of CDW aggregate as a resource in the construction sector because it may improve structural performance while also conserving resources.

ACKNOWLEDGEMENT

The authors would like to take this opportunity to express sincere appreciation to the relevant persons who worked very hard to gather experimental data in this study.

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Citation of this Article:

Most. Sonia Aktar, Md. Sultanul Islam, & Syria Mostak. (2024). Performance Study of Construction and Demolition Waste as Coarse Aggregate on Strength and Cost-Effectiveness of Concrete. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 8(12), 53-59. Article DOI <https://doi.org/10.47001/IRJIET/2024.812009>
