A STUDY ON THE STRENGTH PROPERTIES OF CONCRETE USING COCONUT SHELL AS PARTIAL REPLACEMENT OF COARSE AGGREGATE

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ABSTRACT

This study investigates the strength properties of concrete that uses coconut shell as a partial replacement of coarse aggregate. Coconut shells are agricultural waste products that are readily available in tropical regions. By burning coconut shells, toxic gases such as methane and carbon-di-oxide are released into the atmosphere. The utilization of coconut shells as coarse aggregate may reduce construction materials cost and save the dumping spaces and reduce carbon emission. In this study, different percentages of coconut shell aggregates (CSA) of 2%,5%,8%,10%,12%,15%, and 20% of the weight were used to partially replace coarse aggregates in concrete. A total number of 144 cubes of concrete specimens with size (100 mm × 100 mm × 100 mm) were made with concrete mix proportion of 1:2:4 and the water-cement ratio of 0.50. The mechanical properties of the samples, including compressive strength and tensile strength were evaluated at 7, 28 and 56 days. The results show that using coconut shell aggregates in concrete can result in a slight decrease in compressive strength. From the test results, it is also seen that around 75% strength of conventional concrete can be achieved up to 8% replacement of level of coarse aggregate with coconut shell chips. The findings of this study suggest that coconut shell aggregates can be used as a partial replacement for coarse aggregates in concrete production, which can lead to a more sustainable and eco-friendly construction industry.

Keywords: *Concrete; Coconut shell; Compressive Strength; Splitting Tensile Strength; Sustainable Materials*

1. INTRODUCTION

Due to the expanding population and contemporary lifestyle choices, there has been a rapid escalation in the generation of waste materials, posing a significant challenge for their proper disposal. Bangladesh has about 2800 hectare (ha) of coconut land, and the average annual coconut production is about 431,596 ton (T) in 2019. Coconut shell, a principal bi-product of coconut oil industry produces a significant amount of waste every year. To minimize the waste, waste materials can be utilized for some construction purposes. Concrete is widely utilized in construction and requires an annual output of 10 billion tons, making it one of the most frequently employed materials. Aggregate comprises of about 70-80% of the volume of concrete , where 40-50% is naturally available coarse aggregate. Conventional aggregate sources are rapidly depleting as a consequence of the construction industry's exponential expansion, leading to a scarcity of resources. Waste coconut shell has the potential to be used as a partial replacement of coarse aggregate in concrete.

Natural materials such as mud, jute straw, wood, and bamboo have long been used to build low-cost structures. These products may also be used to construct low-cost infrastructure. However, the main disadvantage of these materials is that they are all biodegradable, which means that their strength can deteriorate over time, resulting in a non-durable structure. As a result, constant supervision is required to ensure the structure's longevity, which is also one of these materials' drawbacks. However, if coconut shell is used as a coarse aggregate instead of these materials, most of the adverse effects would be reduced. Apart from that, using coconut shells in concrete keeps the cost down, making it more accessible to people from the middle and lower classes.

Replacement of the conventional coarse aggregates with CSA also has several environmental advantages. Coconut shells, which are leftovers from the coconut oil factory, can pollute the atmosphere and clog drainage systems, resulting in a water clogging problem. As a result, processing these coconut shells in various ways can also benefit the ecosystem. Using coconut shells with concrete, for example, helps the environment while still keeping costs down, allowing for low-cost housing and construction. It can accommodate people from the middle to lower economic classes to a large degree if sufficient research is done.

Several experimental studies have been conducted by researchers based on variable constitutive materials and blend proportions. (Olanipekun, 2006) carried out an expense investigation, and strength attributes of cement delivered using crushed, granular coconut and palm kernel shell alternative for ordinary coarse aggregate. (Tukiman et al., 2009) replaced the coarse aggregate with coconut shell and grained palm kernel in their study. (Ries et al., 2010) observed that lightweight aggregate assuming a significant part in the present move towards economic concrete. The physical and mechanical properties of coconut shell and squashed stone with an addition to a sum of 72 solid 3D squares of size 150 mm x 150 mm x 150 mm with various blend proportions was studied by (Abubakar A. and Abubakar M.S., 2011). Yerramala and Ramachandrudu (2012) found the coarse aggregate to be a part of the way to supplant by coconut shell and fly ash. (Kukarni et al., 2013) studied that aggregates give volume effortlessly, including 66 to 78 percent of the solid. (Ganiron Jr, 2013) used coconut shells and fiber as an alternative for aggregates in creating a solid empty square. (Sai et al., 2018) conducted a test to examine the consequences for concrete by the expansion of characteristic coconut fiber and substitution of concrete (by weight) with various rates of fly ash on flexural strength, parting rigidity, compressive strength, and modulus of versatility.

Based on the tests conducted by the researchers, it is definitive that coconut shell can be an effective replacement of the conventional coarse aggregate. Though the strength may vary compared to the stone or brick aggregates, the global target to omit carbon production can be enhanced by the use of CSA. The values are taken in this study to reduce the proportion of conventional coarse aggregates with a view to obtain the most acceptable compressive strength.

2. EXPERIMENTAL INVESTIGATION:

This study investigates the optimum coconut shell content in concrete with partial replacement of coarse aggregate. Coconut shell aggregate was added by partial replacement of coarse aggregate at varying concentrations of 2%, 5%, 8%, 10%, 12%, 15% and 20% by weight. The specimens were named according to their varying concentration of coconut shell aggregate (CSA) with their shorthand CSA used at first of the names. The names of the specimens are 2% (CSA-2), 5% (CSA-5), 8% (CSA-8), 10% (CSA-10), 12% (CSA-12), 15% (CSA-15) and 20% (CSA-20).

2.1 Materials properties

In this study, Ordinary Portland Cement (OPC) was used as the binding material of concrete. Various Tests such as standard consistency, initial setting time, final setting time, fineness and specific gravity test were performed as per BDS EN 197-1:2003. Table 1 shows the properties of cement used.

Table 1: Test Properties of Cement

Properties	Values obtained	Standard value
Standard consistency	26.5%	-
Initial setting time	140 min	>45 min
Final setting time	185 min	< 600 min
Fineness	3800 cm^2/gm	3500-4000 cm^2/gm
Specific gravity	2.98	3.15

The aggregate test results are depicted in Table 2. CA obtained from crushed stone having a maximum size of 20 mm was used in the present work. The fine aggregates were well-graded as per the gradation curve. The gradation curve of coarse aggregate is exhibited in Figure 1. The coarse aggregate is also well-graded which can be inferred from the S-shaped gradation curve. The nominal maximum size of the coarse aggregate was 19 mm. Potable water was used for each of the mixes. The mix design of the concrete was done according to ACI 211.R-93 specifications. The water-to-cement (w/c) ratio was fixed at 0.50 as it is one of the most common w/c ratios used in the field to produce concrete. To measure the workability of the fresh concrete, a slump test was conducted for each batch.

Table 2: Test Properties of Aggregates

Properties	Fine Aggregate	Coarse Aggregate	Coconut Shell Aggregate
FM	2.91	7.3	-
Sp. gravity	2.55	2.6	1.12
Unit wt (loose)	-	1345 Kg/m^3	694.45 kg/m^3
Unit wt (dry rodded)	1550 kg/m^3	1425 kg/m^3	-
Absorption capacity	1.05%	0.85%	14.89%
Moisture content	-	0.40%	-
Shape	Round	Angular	Flaky
Surface Texture	-	Rough	Smooth inner surface & rough outer surface

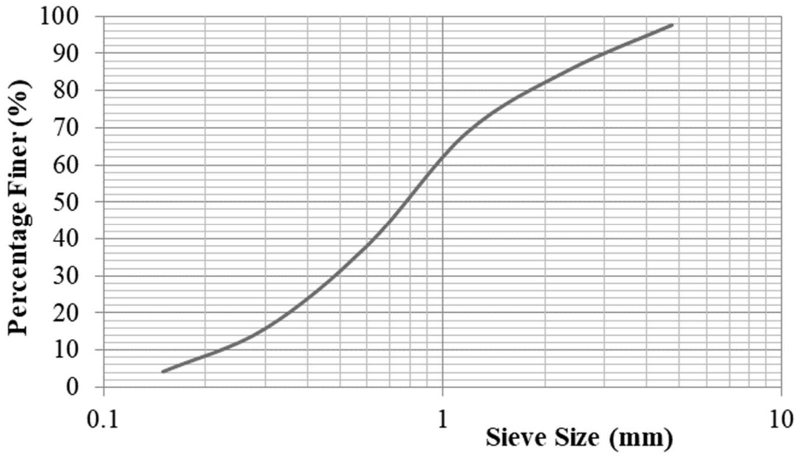

Figure 1: Gradation Curve for fine aggregate

2.1.1 Properties of Coconut Shell

A crushed Coconut shell having a maximum size of 20 mm was used in the study. As coconut shell was used as the replacement of coarse aggregate, similar coarse aggregate tests were conducted for CSA.

2.1.1.1 Preparation of Coconut Shell Aggregate

The separation of fibers from the coconut shell constitutes the initial step in the extraction procedure. Following this, the removed waste material is systematically subjected to a rigorous cleansing process. In order to reduce the moisture content of the coconut shells, a specific period of time is thereafter spent to the drying procedure. Following a fifteen-day drying period, the substance becomes considerably more brittle. The coconut shells are subjected to a crushing operation using a crushing machine, as depicted in Figure 2, once they have attained the necessary level of dryness in order to acquire unique shapes.

(a) (b)

Figure 2: Coconut Shell Aggregate (a) collection of raw coconut shell; (b) grinding of coconut shell

In the phase of coconut shell processing, the shells undergo sieving using a coarse aggregate sieve, with particular attention given to the retention of particles with a size of 4.75mm, designated as coarse aggregate. A sieve analysis is conducted to ascertain the gradation of the coconut shells, revealing a gap-graded aggregate. Subsequent to sieving, various tests are conducted, and the coconut shells are meticulously prepared for incorporation into cement and fine aggregate. The determination of the unit weight of coconut shells involves measuring the volume of a cylindrical metal container, filling it incrementally with aggregate, and employing a tamping bar to compact the material. The weight of the aggregate is recorded to establish its unit weight.

(a) (b)

Figure 3: Tests of Coconut Shell Aggregate (a) Sieve Analysis; (b) Unit Weight of CSA

Additionally, a specific gravity test is performed to assess the strength and quality of the coconut shells. This involves immersing an aggregate sample in water, removing entrapped air, and measuring the weight both in water and after drying. The aggregate is subsequently heated, cooled, and weighed to complete the specific gravity determination. These comprehensive procedures contribute to a thorough characterization of the coconut shells for their potential application in construction materials.

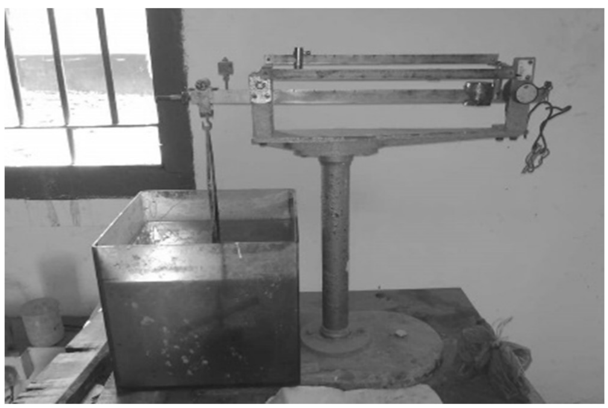

Figure 4: Specific Gravity Test of Coconut Shell Aggregate

2.2 Test Matrix

The following test matrix had been followed during this study. Here the concrete mix design was done according to ACI 211.R-93 specifications. All the required constituents of concrete cement, water, fine aggregate , coarse aggregate and coconut shell aggregate are tabulated in Table 3.

Table 3: Test Matrix

Mix Proportions Kg/m^3	Control Mix	CSA-2	CSA-5	CSA-8	CSA-10	CSA-12	CSA-15	CSA-20
Cement	421	421	421	421	421	421	421	421
Sand	711	711	711	711	711	711	711	711
Coarse Aggregate	1006	985.88	955.7	925.52	905.4	885.28	855.1	804.8
Coconut Shell Aggregate	0.00	20.12	50.3	80.48	100.6	120.72	150.9	201.2
Ratio water/cement	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

2.3 EXPERIMENTAL SETUP

For the assessment of compressive strengths, cube specimens with dimensions of 100 mm × 100 mm × 100 mm were cast. These specimens were subjected to a curing period of 7, 28, and 56 days at room temperature while submerged in water. After the curing period, compressive strength tests and tensile strength test were conducted to evaluate the mechanical properties of the concrete samples. Additionally, the density of the concrete was also investigated. The test arrangement and the equipment utilized in this study are depicted in Figure 5.

Figure 5: Compressive Strength Test

Following the designated curing period, the specimen underwent a compression test, aiming to assess its crucial property—compressive strength. This property, integral to concrete evaluation, gauges the material's crush resistance. Compressive strength is determined by dividing the applied force by the cross-sectional area, usually at a loading rate between 0.2 N/mm²-s and 0.4 N/mm²-s.

Figure 6: Tensile Strength Test Setup

The tensile strength of a concrete specimen is determined through a split tension test, which constitutes an indirect method for evaluating tensile properties. In this procedure, a true line load is simultaneously applied to both the top and bottom faces of the specimen. To mitigate high compressive local stresses, a soft material may be inserted as a narrow strip between the plate and the specimen. While this results in elevated horizontal compressive stresses at the top and bottom, the presence of a comparable vertical compressive stress establishes a state of biaxial compression, preventing failure at three distinct positions. Instead, failure is initiated by uniform horizontal tensile stresses acting across the remaining cross-section of the specimen. The test involves the application of a load at a constant rate, incrementing the tensile stress between 0.02 to 0.04 MPa/sec.

3. RESULTS AND DISCUSSION

The graphs mainly compare results to a control section (0%) in the study, shown in figures 7 to 11. The compressive and tensile strength tests for replacement percentages of 0%, 2%, 5%, 8%, 10%, 12%, 15%, and 20% are then summarized. The compressive test results for 7 days, 28 days, and 56 days indicate that replacing normal aggregates with coconut shells decreases compressive strength. Up to an 8% replacement, strength is good compared to regular aggregates, but it declines at 20% replacement.

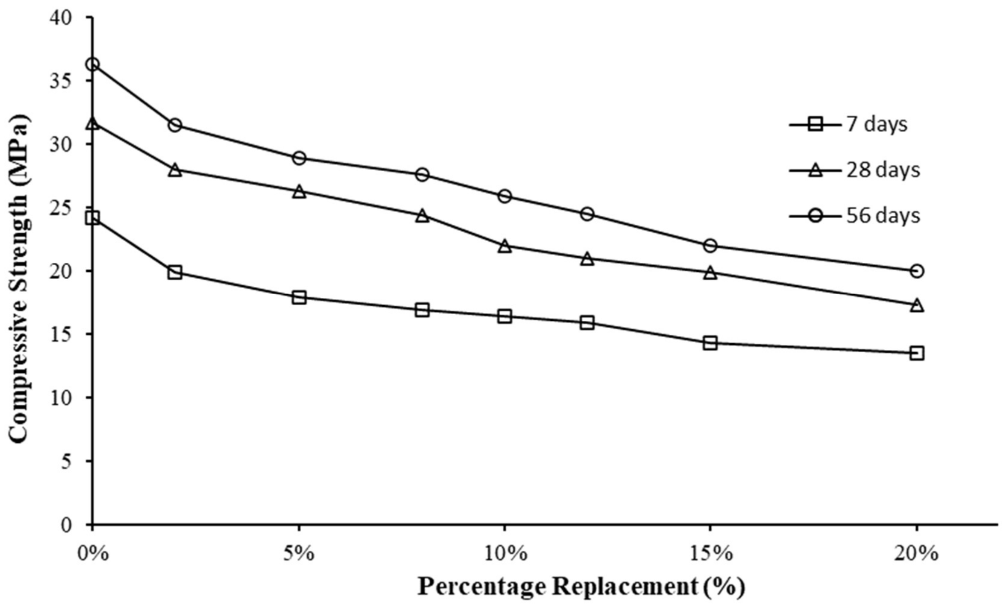

Figure 7: Compressive Strength for Varying Coconut Shell Aggregate Content

The findings indicate that up to an 8% replacement, compressive strengths fall within 75% of the conventional concrete control mix (0%) values for 7, 28, and 56 days. However, at 20% replacement, the compressive strength decreases to 55% of the conventional concrete strength. Considering both cost and strength, the optimum value for compressive strength is achieved at 8% replacement. These results are graphically presented in figures 7 and 8. Specifically, at 56 days, the control mix concrete's compressive strength is 36.55 MPa, whereas at 8% replacement with coconut shell aggregates, it is found to be 27.6 MPa. In contrast, a 20% replacement yields a compressive strength of 20.01 MPa

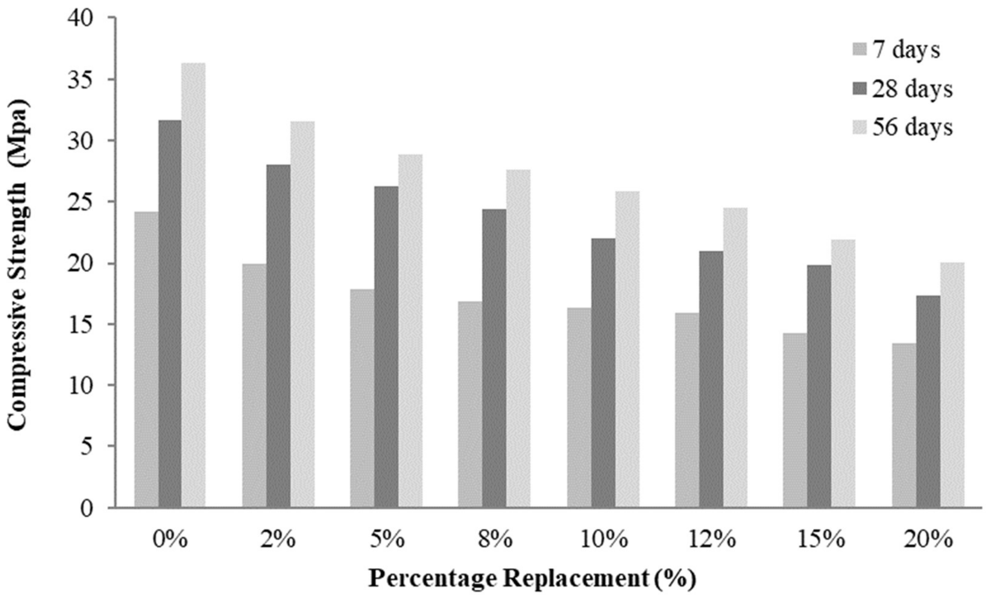

Figure 8: Bar Chart of Compressive Strength for Varying CSA Content

The results of the splitting tensile strength of 7 days, 28 days, and 56 days were both represented in bar chart and graphical form in figure 9 and 10. The figures show the variation of tensile strength from conventional concrete. There is a tendency of strength reduction as the percentage of coconut shell increased. The coconut shell percentage is inversely proportional to the split tensile strength. From the results, we observe that up to 8% of replacement tensile strengths are within a range of 75% tensile strength of conventional concrete control mix (0%) for 7 days, 28 days and 56 days.

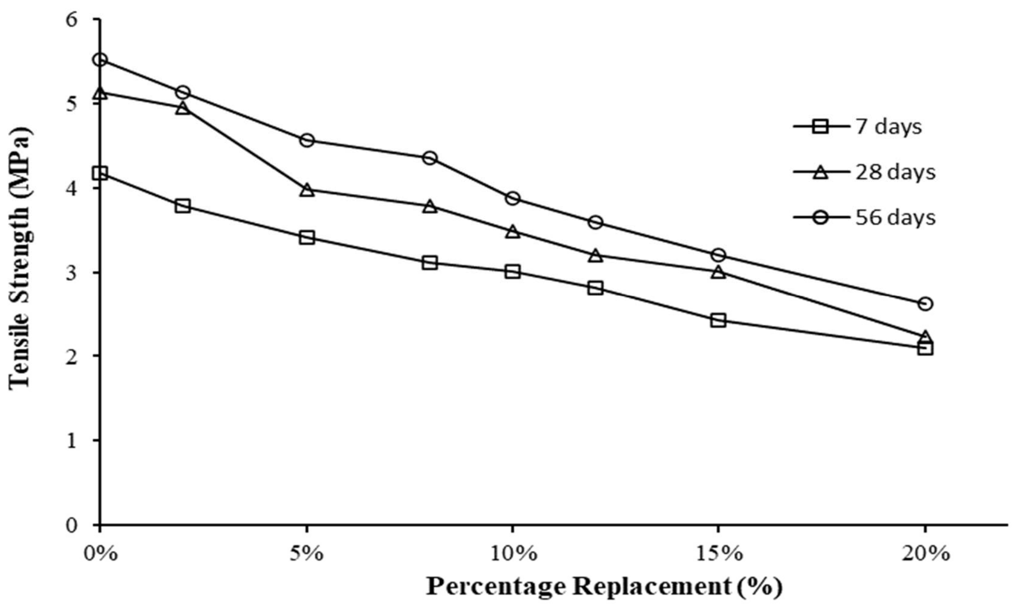

Figure 9: Tensile Strength for Varying Coconut Shell Aggregate Content

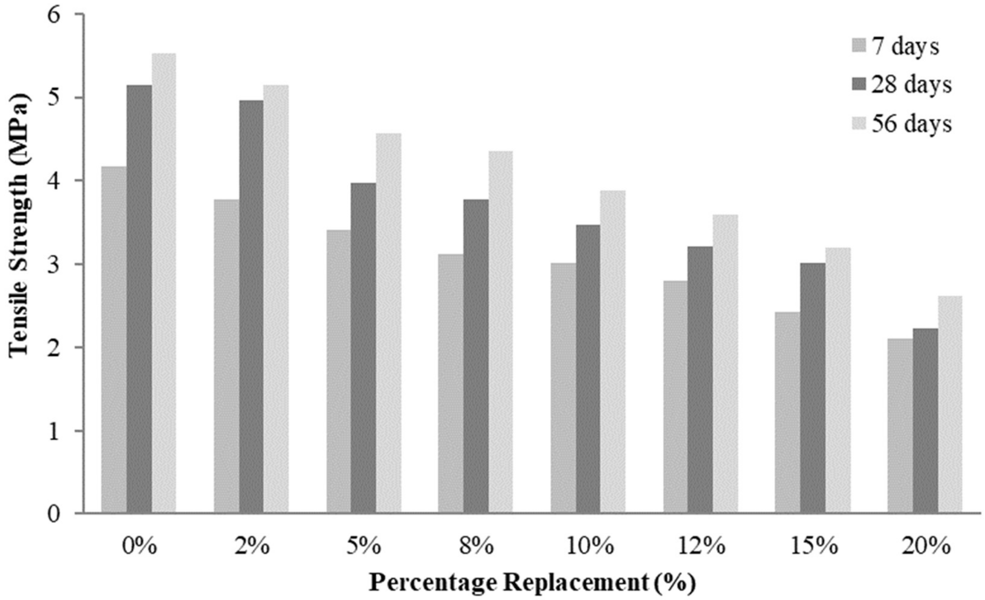

Figure 10: Bar Chart of Compressive Strength for Varying CSA Content

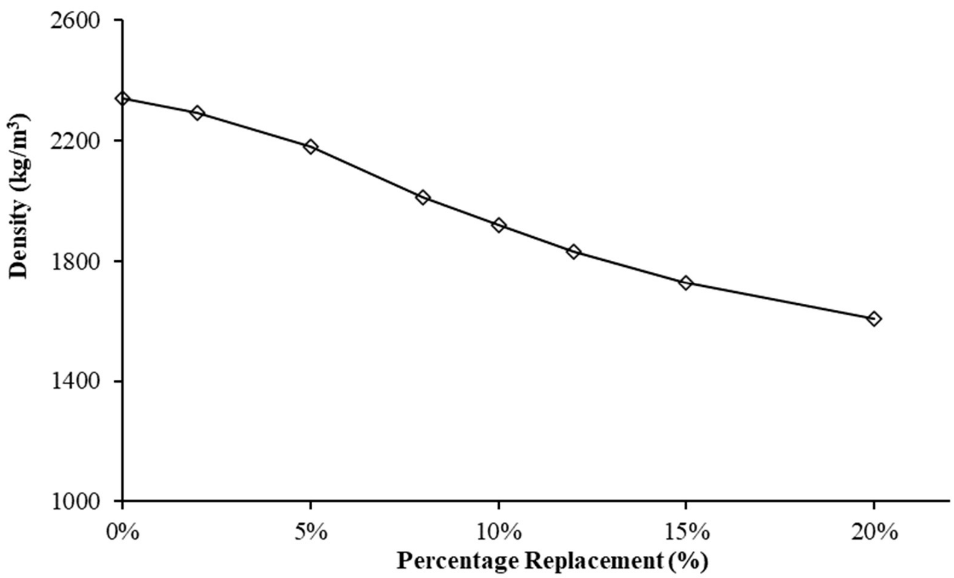

Figure 11: Density of Concrete in Varying Coconut Shell Aggregate Content

As the quantity of substitution of CSA content increased, the density of the concrete exhibited a notable decrease. The control mix displayed a density of 2340 kg/m³. In contrast, the concrete mix with an 8% CSA replacement manifested a reduced density of 2010 kg/m³, while further reduction to 1605 kg/m³ was observed with a 20% CSA replacement. Figure 11 visually captures this trend, offering a graphical representation of the diminishing density associated with increasing CSA replacement levels.

4. CONCLUSIONS

The objective of this study was to investigate the optimum content of coconut shell in concrete with the partial replacement of coarse aggregate. Coconut shell aggregate was added by partial replacement of coarse aggregate at varying concentrations of 2%, 5%, 8%, 10%, 12%, 15%, and 20% by weight. Compressive strength and split tensile strength were conducted on a total of 144 cube specimens consisting of different concentrations of CSA. Based on the experimental study, the following conclusions can be inferred:

- Although the strength of concrete is reduced by partially substituting coarse aggregate with coconut shell, it remains a viable option for cost-effective construction endeavours.
- Due to the coconut shells being smaller in size and having smooth round surface on one side, concrete containing coconut shell exhibits better workability.
- The specific gravity and density of the concrete decreases with an increase in the replacement of coarse aggregate.
- An approximate of 75% improvement in the compressive and split tensile strengths of conventional concrete can be obtained by substituting 8% of the coarse aggregate in the concrete with coconut shell.
- The observed strengths are still well in terms of cost and strength perspective.

ACKNOWLEDGEMENTS

The present study was conducted within the Civil Engineering department of Chittagong University of Engineering and Technology (CUET), Chittagong. The authors express their sincere appreciation for the assistance and resources rendered by CUET. Additionally, the authors express their heartfelt gratitude to Md. Taohidul Islam for his assistance with this study.

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