Civil Engineering Infrastructures Journal xx,xx
DOI: 10.22059/CEIJ.2023.358739.1919

DETERMINATION OF PHYSICAL AND MECHANICAL PROPERTIES OF FIBRE-REINFORCED COCONUT SHELL CONCRETE

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Received: 06/05/2023
Revised: 19/10/2023
Accepted: 23/10/2023

ABSTRACT: This study investigates the potential of using Elephant Grass Straw (EGS) as a reinforcing fibre in Coconut Shell Concrete (CSC) to enhance its mechanical properties. CSC, with a target compressive strength of 20 N/mm², was prepared using coconut shells as coarse aggregate. EGS was incorporated at varying percentages (1-5% by weight of cement). The coconut shell was tested for its properties while the fresh concrete was tested for its workability. The hardened concrete was tested for its density, water absorption capacity, compressive and split tensile strengths. The results indicate that the addition of EGS negatively impacts the workability, compressive and splitting tensile strengths of the concrete specimens. After 28 days of curing, the control sample (without EGS) exhibited the highest compressive strength at 23.1 N/mm² and splitting tensile strength at 1.74 N/mm². Furthermore, a decrease in compressive strength, workability, and density was observed, while water absorption capacity increased with EGS inclusion. Overall, this study demonstrates that the incorporation of EGS does not improve the quality of CSC.

Keywords: Compressive strength, Splitting Tensile Strength, Density, Straw Fibre.

1. INTRODUCTION

Concrete is an essential construction material globally, with its utilization on the rise, driven by increased infrastructure and construction activities (Crow, 2008; Odeyemi, Atoyebi, Kegbeyale, et al., 2022). Comprised of fine aggregate (sand), coarse aggregate (crushed stones), cement, and water (Bamigboye et al., 2015), its production predominantly relies on traditional, heavy aggregates like gravel and granite, raising environmental concerns due to resource depletion (Kakade and Dhawale, 2015).

Surging construction costs are closely linked to escalating material expenses, with concrete a key concern for budget-conscious firms. Its robust properties, mirroring natural limestone, result from a mix of aggregates and cement. This study explores coconut shells, a lightweight aggregate often disregarded as agricultural waste, offering a potentially cost-effective alternative (Nunes et al., 2020).

Concrete fibres fall into two main types: steel and natural/synthetic options such as polypropylene, glass, and basalt. Adding these fibres boosts concrete's mechanical properties, notably increasing compressive, tensile, and flexural strengths. Steel fibres, for example, enhance post-cracking behaviour, making concrete more ductile and less prone to brittle failure. (Modarres and Ghalehnovi, 2023; Wang et al., 2021). Additionally, polypropylene fibres have been shown to improve the properties of concrete structures and Cement-Stabilized Sand, making them more suitable for harsh environmental conditions (Aisheh et al., 2022; Ghanbari and Bayat, 2022). Glass and basalt fibres, being inorganic materials, enhance the compressive strength of concrete, making it more resilient to heavy loads and impacts (Yahiaoui et al., 2022).

While effective, these options come with high costs, energy-intensive production processes, and adverse environmental impacts. As a result, the pursuit of environmentally sustainable alternatives has gained momentum (Odeyemi et al., 2023). A growing body of research explores the feasibility of incorporating annually renewable, cost-effective crops and residues as viable fibre reinforcement in concrete (Adeniyi, Abdulkareem, et al., 2022; Adeniyi, Adeyanju, et al., 2022). Natural fibres, abundant and budget-friendly in many agricultural regions, are emerging as a promising option. Research indicates that the use of natural fibres in concrete can positively affect its tensile and flexural strength (Ayyappa et al., 2020; Chin et al., 2020; Micelli et al., 2020). For instance, when coconut coir fibres are introduced into a concrete mix, they enhance its tensile strength while also providing crack control and durability (Yan et al., 2015).

While prior studies have explored the use of agricultural waste in concrete as cement or aggregate replacements, there is a dearth of research on the impact of fibre reinforcement on coconut shell concrete. This study aims to address this gap by investigating the effects of fibre reinforcement on Coconut Shell Concrete (CSC).

2. MATERIALS AND METHODS

The materials for this research are cement, fine aggregate (sand), coconut shell (coarse aggregate) and natural fibre (Elephant Grass straw).

Dangote brand of Limestone Portland Cement (LPC), Grade 42.5R, with a specific gravity of 3.13 was used for the concrete. Natural sand passing through sieve 4.75 mm having a fine modulus of 2.27, specific gravity 2.63, and water absorption capacity of 2.54 % meeting the standard specified in BS EN 12390-2 (2019) was used as fine aggregate. Potable water with a pH of 7 as recommended by Odeyemi (2022) was used in mixing the concrete.

Coconut shells, sourced from Oja Oba in Ilorin, Kwara State, Nigeria, were manually crushed, water-rinsed, and air-dried for days to eliminate impurities potentially harmful to concrete. Figure 1 illustrates particle size distribution, and Table 1 details other properties, determined following BS EN 12620:2002+A1:2008 standards (2008).

The elephant grass straw fibre used for this study was obtained from Malete, Kwara State, Nigeria. The fibre was chopped into small, homogeneous strips and dried for 7 days.

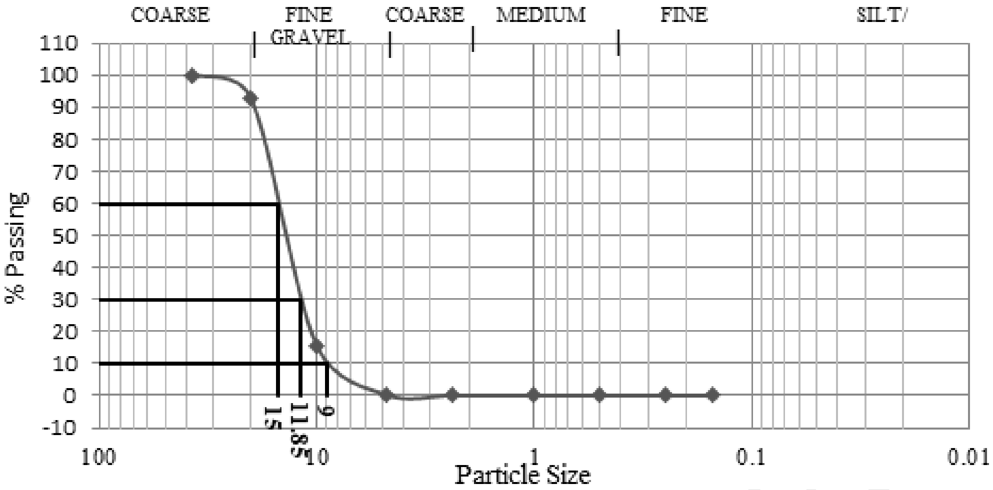


Fig. 1. Particle size distribution curve for coconut shell aggregate.

Table 1. Physical properties of coconut shell

S/N	Description	Test value
1	Specific Gravity	1.04
2	Water Absorption	12 %
3	Fineness modulus	6.9
4	Moisture Content	15.2 %
5	Aggregate Impact Value	2.56 %
6	Abrasion	7.9 %
7	Bulk density	717.6 kg/m^3
8	Surface Texture	Smooth in inner surface and rough outer surface

Coconut shells served as coarse aggregate, while fibre was added at 1%, 2%, 3%, 4%, and 5% of cement weight. Fresh concrete workability was assessed using the slump method. Cube moulds (100 x 100 x 100 mm) and cylindrical moulds (100 x 200 mm) were cleaned, oiled, and filled with well-compacted concrete. Labels indicated fibre content percentages (0%, 1%, 2%, 3%, 4%, and 5%). The mix ratio was 1:0.5:0.5 for cement, sand, and aggregate with a water-binder ratio (w/b) of 0.5 for CSC, targeting a compressive strength of 20 N/mm² (Grade 20).

After casting, the concrete samples were left to set for 24 hours, then demoulded and immersed in water at 21°C as prescribed by BS EN 12390-2 (2019) for thorough hydration. Before density and water adsorption testing at 28 days, excess moisture was removed by airing the samples for 30 minutes. Compressive and split tensile strengths were evaluated at 7, 28, and 56 days in the University of Ilorin Concrete Laboratory.

2.1 WORKABILITY

A slump test of the freshly prepared CSC was carried out to determine the effect of straw fibre on the workability of concrete at the University of Ilorin Concrete Laboratory. The test was conducted following BS EN 12350:2 (2009) specifications.

2.2 DENSITY

A set of three concrete specimen cylinders were removed from storage after 28 days of curing to undergo an ASTM C 642 density test. By wiping the surfaces dry, these specimens were brought into Saturated Surface Dry (SSD) condition. The SSD specimen's weight in air (C) was then determined. The samples were then heated to between 100 ^{O}C and 110 ^{O}C for 24 hours in the oven. The specimen's weight was then determined. This is the samples' air-filled oven dry weight (A). The specimens were then submerged in water in a bucket to determine their weight underwater (D). Water density (ρ) for that temperature was determined using the water's test day temperature (T), which was also recorded. Concrete density was then determined using Equation 1.

$$\text{Dry density} = \frac{A \times \rho}{(C - D)} \tag{1}$$

where,
A = mass of oven-dried sample in the air (gram), C = mass of saturated surface-dry sample in the air (gram), D= mass of sample in water after immersion (gram), ρ = density of water at T ^{o}C (kg/m^3)

2.3 WATER ABSORPTION

The fine aggregate, CSC, and concrete specimens were weighed and given the designation (A) to calculate the aggregates' water absorption. These samples were placed in an oven for 24 hours to dry before being removed and allowed to cool at room temperature. To achieve saturation, the aggregate samples were removed from the oven, placed in pans, and left submerged in water for 24 hours. When the samples were completely soaked, they were surface-dried by rolling them in a towel until all observable water films were gone. Surface-dry saturated sample weight was calculated and given the letter (B) designation. Equation 2 was used to determine the aggregates' water absorption capacity in percentage.

$$\text{Water absorption} = \frac{(A-B)}{B} \times 100\% \tag{2}$$

2.4 COMPRESSIVE AND SPLIT TENSILE STRENGTH

Similar to the density test, a set of three concrete specimens each was prepared for the compressive strength and split tensile test after 7, 28, and 56 days of curing following the procedure in BS EN 12390-3 (2019) and BS EN 12390-6 (BS EN 12390-6:2000, 2000). According to Standards, the cube's length and cylinder's diameters were measured, and their cross-sectional areas were calculated. Compressive load was applied to specimens using a Universal Testing Machine (UTM) at the desired loading rate. The specimens' axis was correctly aligned, the specimens were positioned inside the bearing blocks, and compression was then applied. By dividing the greatest force attained during the test by the specimen's cross-sectional area, the compressive strength and split tensile of the specimen were determined by the UTM.

3. RESULTS AND DISCUSSION

3.1 WORKABILITY

The results of the slump test in this study, presented in Figure 2, show that as the quantity of straw increases, the workability of the concrete decreases which is evident with the reduction in the slump height. This result follows the same trend as the one reported by Olanipekun et al. (2006).

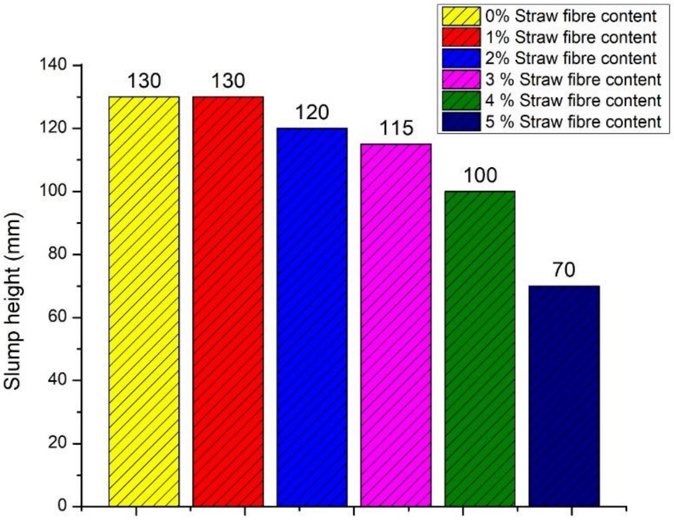


Fig. 2. Slump for CSC with different percentages of Straw Fibre.

3.2 DENSITY

Figure 3 shows the density of the concrete samples with varying percentages of straws. The density of the concrete specimen was found to range from 1989.7 to 2103.54 kg/m^3 with different straw fibre content. The maximum density of 2103.54 kg/m^3 was obtained at 0% replacement. The minimum density of 1989.7 kg/m^3 was obtained at 5% replacement. It was observed that as the straw content increased, the density of the concrete reduced.

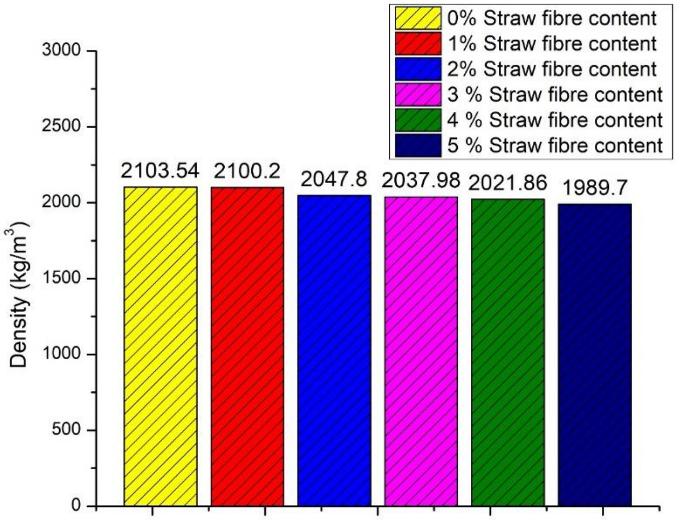


Fig. 3. *Density of CSC with Straw Fibre content (%) at 28 days of curing*

3.3 WATER ABSORPTION TEST

At 28 days after curing, the samples were tested for water absorption capacity. Figure 4 shows how different percentages of straw fibre content affected water absorption.

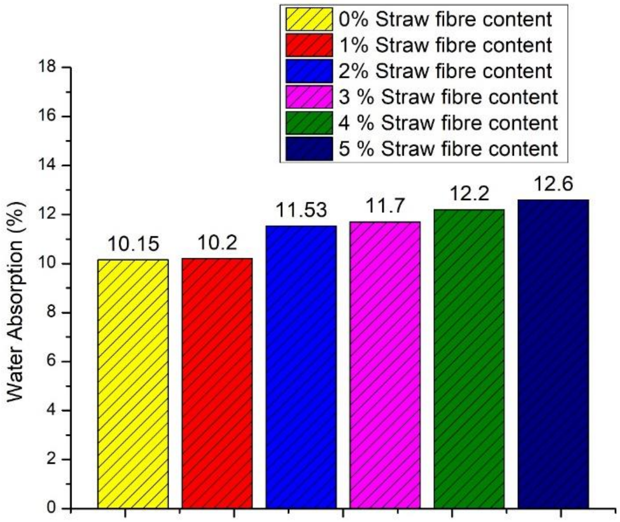
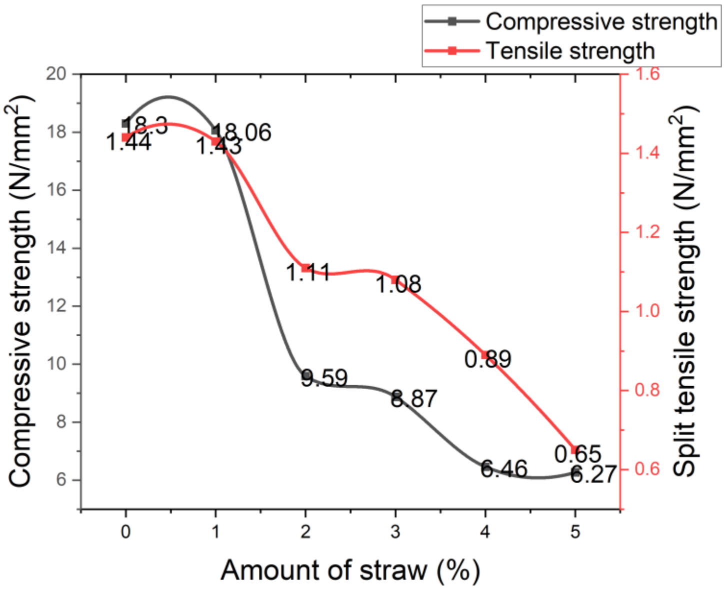


Fig. 4. *Water Absorption Capacity of CSC with varying Straw Fibre content (%)*

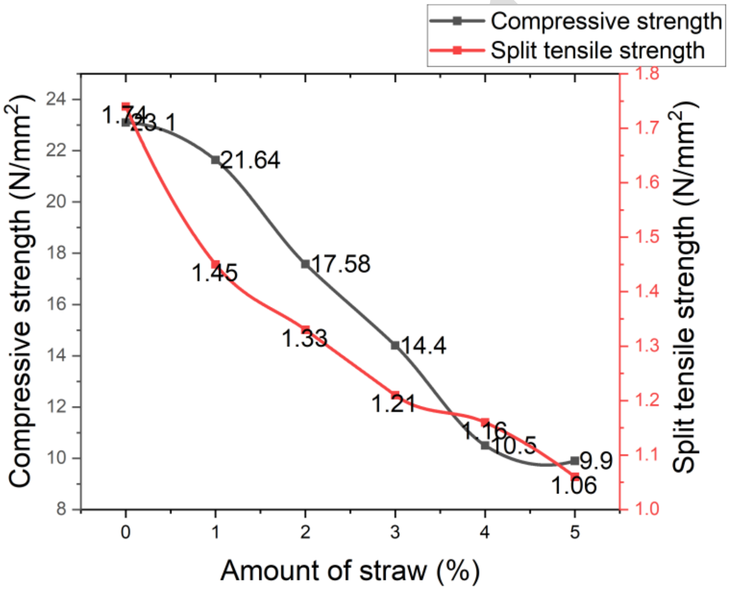
The percentage of water absorption increased as the percentage of straw fibre increased with CSC. The highest water absorption was found in CSC with a straw fibre content of 5%, followed by 4%, 3%, 2%, 1% and 0%. The maximum absorption required for lightweight aggregate concrete is 45% (Domagała, 2015), indicating that the specimens meet the requirements.

3.4 HARDENED PROPERTIES (COMPRESSIVE STRENGTH AND SPLIT TENSILE STRENGTH)

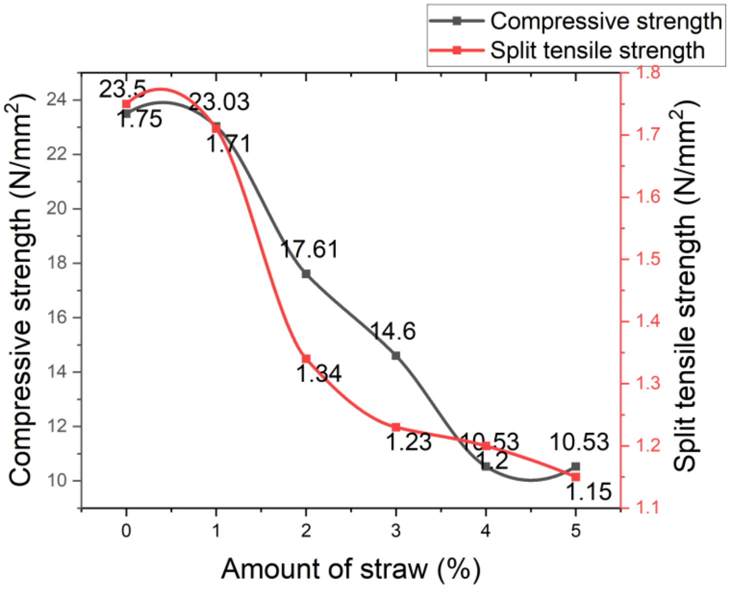
Figure 5 shows the compressive strength and split tensile strength of the CSC specimens at 7, 28, and 56 days of curing.


Compressive strength
Tensile strength
Compressive strength (N/mm^2)
Split tensile strength (N/mm^2)
Amount of straw (%)
20
18
16
14
12
10
8
6
1.6
1.4
1.2
1.0
0.8
0.6
0
1
2
3
4
5
18.3
1.44
18.06
1.43
1.11
1.08
9.59
8.87
0.89
6.46
0.65
6.27

(a)


Compressive strength
Split tensile strength
Compressive strength (N/mm^2)
Split tensile strength (N/mm^2)
Amount of straw (%)
24
22
20
18
16
14
12
10
8
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
1
2
3
4
5
1.74
23.1
21.64
1.45
17.58
1.33
14.4
1.21
1.16
10.5
9.9
1.06

(b)



(c)

Fig. 5. Relationship between Compressive strength and Split Tensile of CSC with Straw Fibre content (%) at (a) 7 days, (b) 28 days, (c) 56 days of curing.

In Figure 5(a), the correlation between compressive strength and split tensile of CSC with straw fibre content at 7 days shows a consistent decline in strengths as straw content increases. The highest compressive strength (18.3 N/mm²) occurs at 0% straw, dropping to 6.27 N/mm² at 5% straw. Similar trends are observed in split tensile strength. Figure 5(b) at 28 days depicts a decline in compressive and split tensile strengths with increasing straw content, reaching 23.1 N/mm² and 1.74 N/mm², respectively, at 0% straw. Figure 5(c) at 56 days shows the highest compressive strength (23.03 N/mm²) and splitting tensile strength (1.71 N/mm²) at 1% straw, decreasing to 10.53 N/mm² and 1.01 N/mm² at 5% straw. Results indicate that exceeding 1% straw adversely affects compressive strength, while the water absorption capacity and straw fibre addition contribute to a sudden decrease in strength at 56 days. This study suggests that maintaining straw fibre below 1% in the mix ratio can yield Grade 20 lightweight concretes, with compressive strength increasing with age.

4. CONCLUSIONS

From the findings of the study, the following conclusions were derived:

1. The workability of Coconut Shell Concrete (CSC) displays a noticeable decline as the proportion of straw content increases. This inversely proportional relationship suggests that the incorporation of straw fibres comes at the expense of concrete workability, a crucial factor in construction.
2. An obvious reduction in density was observed in CSC as the percentage of straw content increased. This trend underlines the impact of straw fibres on the structural characteristics of the concrete, potentially influencing its load-bearing capacity and overall performance.
3. The study reveals a clear association between the percentage of straw fibre content in CSC and increased water absorption. Notably, the highest water absorption was recorded in CSC samples with a 5% straw fibre content. This insight underscores the necessity for careful consideration of water resistance in concrete mixtures containing straw fibres.

4. Analysis of the hardened concrete properties demonstrates a consistent reduction in both compressive and split tensile strengths with a rising percentage of straw fibre in the CSC mixture. Although it is important to note that strength improves with age, it becomes evident that the inclusion of 1% straw content in CSC yields concrete of Grade 20, implying a potential balance between sustainability and structural performance in specific applications.

These findings provide valuable insights into the effects of straw fibre reinforcement on the properties of Coconut Shell Concrete, offering practical guidance for engineering applications and sustainable construction practices. Further research may explore optimization techniques to harness the benefits of straw fibres in CSC while mitigating their adverse impacts on workability and strength.

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