

# **Influence of coconut shell grades as partial replacement of coarse aggregates on concrete properties**

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## **Abstract**

Globally, the depletion of raw materials for concrete has become prevalent due to the rapid population growth. Coconut shells can be a cheap yet environmentally friendly solution as a partial replacement of coarse aggregate in concrete. In this research, the effect of coconut shell variable particles on concrete is investigated. The coconut shells were crushed in the laboratory using a mini jaw crusher, sieved to 5 to 14 mm and 5 to 20 mm, and used as a partial replacement for coarse aggregate in concrete mixes. To further understand the impact of coconut shell particles at variable grades on concrete, workability, density, compressive and splitting tensile strength, and water absorption properties were assessed. In comparison to the control concrete, five coarse aggregate replacement levels of 5 percent, 10 percent, 15 percent, 20 percent, and 25 percent of coconut shell particles (5-14 mm and 5-20 mm) were tested. The physical and mechanical properties of ordinary Portland cement, sand (fine aggregate), coarse aggregate, and coconut shell particles were all determined. A scanning electron microscope was used to better understand the surface structure of the coconut shell particles, and how these surfaces affect concrete when added. The workability investigation revealed a reduction in slump and compacting factor due to the significant addition of coconut shell particles (5-14 mm and 5-20 mm) into the concrete mixes. Thus, it was concluded that coconut shell particles (5-14 mm) had a significant impact on the density of concrete when compared to 5-20 mm and control concrete. The Slump, compacting factor, compressive, and splitting tensile strength were all lower in the coconut shell particles concrete than in the control concrete. Coconut shell concrete (CSC) absorbed more water after 28 days of curing than control concrete. Although coconut shell particles (5-14 mm) reduced concrete compressive and splitting tensile strength when compared to coconut shell particles (5-20 mm) and control, 5 percent partial coarse aggregate substitution with coconut shell particles was shown to be the optimal percentage after 7, and 28 days of curing. According to the findings captured in this research, the strength of coconut shell concrete is reduced due to the increased surface area because coconut shell particles have a specific gravity that is nearly three times that of coarse aggregate, batching was done by weight making coconut shell particles quantity more and the smoothness of the inner section which causes slip in concrete, while workability is increased due to the presence of micro small pores on the outer surface.

## **Keywords**

Control Concrete, Coconut Shell Particles, Coconut Shell Concrete, Coarse Aggregate, Workability, Density, Compressive strength, Splitting Tensile Strength, Water absorption

## **1. INTRODUCTION**

Concrete is one of the most extensively used building materials, and it is the second most widely utilized substance in the world, behind water [1]. Globally, over 25 billion tons of concrete are produced, and aggregates account for roughly 70–80 percent of the volume of structural concrete, with fine aggregate accounting for 25–30% and coarse aggregate accounting for 40–50% [2]. The world population is projected to reach 9.9 billion by 2050, a rise of 25% from the 2020 population of 7.8 billion [3]. With the rapid growth in the population of the world, the demand for basic needs (infrastructure, shelters, and workplaces) has increased the cost of raw materials that are required to produce concrete in Africa and the world at large.

On the other hand, coconut shell (CS) is one of the most polluting wastes in the world since it is a solid waste in the form of a shell with an annual volume of 3.18 million tons, accounting for almost 60% of the national waste volume in coconut-producing countries [4]. The repurposing of coconut shell has been noticed as a means of discovering alternative waste management solutions. The use of coconut shell components in concrete is gaining popularity as a result of its acceptable mechanical qualities when compared to traditional concrete [5]–[8]. The experimental study of coconut shell concrete (CSC) revealed that it is both cost-effective and strong, with greater impact and abrasion resistance when compared to traditional aggregates [9]. The workability of concrete is improved by the plain and soft surface on one side of the coconut shell. The coconut shell, which is hard and organic in origin, will not percolate or produce any venomous substance once it is bound in a concrete matrix [10], [11].

The coconut shell must be thoroughly cleaned to remove any fiber or husk from the surface. Higher strength may result from a stronger connection between the particles. Large and Reduced particle size of coconut shell, on the other hand, may increase surface area, resulting in greater water demand and binder, and a alter in strength [12]. The majority of research on coconut shells has focused on their usage as materials in concrete. However, the study comparing two types of coconut shell particles at variable particle size and content was undertaken. This has provided us insight into what happens to the physical and mechanical properties of concrete when large or small particles of coconut shell are added to concrete. The overall weight of the concrete is expected to be lowered as a result of the processing of coconut shell to form coconut shell particles and its subsequent use as a partial substitute for coarse aggregate (CA) in concrete. There has been very little research on the use of coconut shell particles (CSP) in concrete at variable particles size gradings. The afore-mentioned research findings demonstrate the importance of understanding the influence of CSP (5-14 and 5-20 mm) on workability, density, and compressive and splitting tensile strength of concrete.

## **2. MATERIALS AND METHODS**

### **2.1 Materials**

#### **2.1.1 Cement**

Ordinary Portland Cement class 42.5 meeting the specifications for the experiments [13] and with acceptable specific gravity and Le Chatelier soundness values respectively was used.

#### **2.1.2 Fine aggregate**

Fine aggregate was sourced from Meru in the eastern part of Kenya. The sand was sieved using a 5.0 mm to 0.15 mm test sieve to determine the particle size distribution and the elimination of bigger particles. Before being used, the specific gravity, water absorption, moisture content, bulk density, fineness modulus, and silt content were all determined conforming to [14].

### 2.1.3 Coarse Aggregate

Graded coarse aggregate of 5 to 20 mm grade conforming to [15] was sourced from Nairobi. The coarse aggregate was dried out before being employed in the experiment to obtain the saturated dried state, such that the water-cement ratio is not affected.

### 2.1.4 Coconut Shell

Coconut shells were sourced from Kaloleni Mombasa. The shells were crushed in a mini jaw crusher at JKUAT Civil Engineering Laboratory and graded into particle sizes ranging from 5 to 14 mm and 5 to 20 mm conforming to the standard [15]. Before the experiment, it was examined for characteristics and used as a partial replacement for coarse aggregate. They were air-dried naturally and soaked in water for 24 hours before being added to the design mix to act as a reservoir and ensure that the workability was not compromised. Figure 2.1 depicts the coconut shell preparation process.

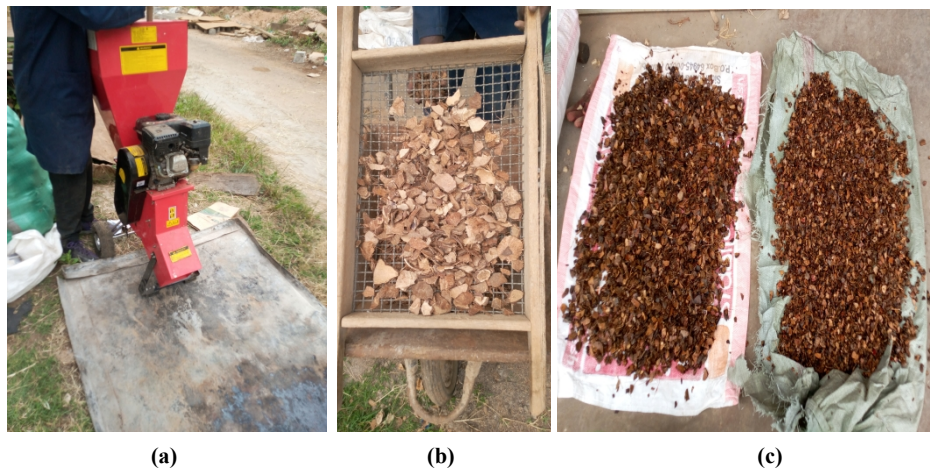


Figure 2.1: (a) Crushing CSP, (b) Sieving CSP & (c) Graded CSP at 5-20 mm & 5-14 mm

## 2.2 Methods

### 2.2.1 Scanning Electron Microscopy of Coconut Shell Particles

At the food fortification laboratory of Jomo Kenyatta University of Agriculture and Technology (JKUAT), the microstructure of coconut shell particles was investigated utilizing a high-resolution Scanning Electron Microscope (SEM) at a 15kV high voltage system. The JEOL Neo Scope JCM-7000 SEM machine was used to scan the specimens. The specimens were cleaned and dried before the experiment to improve surface exposure. The specimen was properly positioned in the equipment by first placing it on the inner side for scanning and later on the outside side. After an accelerated electron beam penetrating through apertures and electromagnetic lenses scanned the surfaces of the objects using scan coils, the images were collected.

### 2.2.2 Properties of Portland cement, Fine Aggregate, Coarse aggregate, and Coconut shell particles

The Le-Chatelier Flask method was used to determine the specific gravity of OPC per [16] guidelines. The initial and final setting times of OPC were determined using [17]. One (1) mm<sup>2</sup> needle was used, along with a Vicat device and an annular needle. The soundness and normal consistency tests were also completed according to [17].

The distribution of the particle size was achieved by the sieve analysis method in conformity with the standard [18]. Sieving was performed on three samples of sand (fine aggregate), coarse aggregate (5-20 mm), and coconut shell particles (5-14 and 5-20 mm). The process of hand sieving was used. Before manually shaking the column of sieves, the sample was put into the top sieve. This yielded the quantity of retained particles on the sieve. Hand manipulation was done without putting any pressure on the materials. Following that, each sieve was brushed to ensure that no particles clung to the sieves. The weight of items retained on each sieve was calculated cumulatively and reported as a percentage of the total mass. The fineness modulus of fine aggregate was computed by dividing the cumulative percentage retained. The test for evaluating the moisture content of FA, CA, and CSP were explored according to British Standard [19]. The test for water absorption, specific gravity, bulk density, aggregate crushing, and impact value was also performed conforming to [20], [21].

### 2.2.3 Mix Proportions

According to the standard [22] and [23], the M30 mix design was carried out for the control concrete mix (i.e., without coconut shell particles). The concrete mix was designed for a slump of 30-60 mm at the ratio of 1:1.9:2.7. Coconut shell concrete was made by replacing coarse aggregate with discarded coconut shell (CS) graded into CSP at 5-14 and 5-20 mm, using the same mix design. Table 2.1 shows how coconut shell particles replaced conventional aggregate by 5 percent, 10 percent, 15 percent, 20 percent, and 25 percent (by weight). The matrix is made up of cubes and cylinders that have been cured for 7 and 28 days. The influence on concrete workability, compressive and splitting tensile strength, density, and water absorption were studied.

Table 2.1: Mix design for 1 m<sup>3</sup>

Material	Control	Modified Concrete containing CSP 5-14 mm and CSP 5-20 mm in individual mixes				
	CSP 0 %	5%	10%	15%	20%	25%
Portland Cement 42.5 R (kg)	381.82	381.82	381.82	381.82	381.82	381.82
Water (kg)	210.00	210.00	210.00	210.00	210.00	210.00
W/C ratio	0.55	0.55	0.55	0.55	0.55	0.55
River sand (kg)	759.44	759.44	759.44	759.44	759.44	759.44
Coarse aggregate (kg)	1048.75	996.31	943.87	891.43	839.00	786.56
Coconut shell Particles (kg)	0	52.44	104.87	157.31	209.75	262.19

### 2.2.4 Slump and Compacting Factor Test

Slump and compacting factor tests were carried out in conformity with the code [24] and [25]. A slump cone with dimensions of 30 cm height, 10 cm top diameter, 20 cm bottom diameter, and metal thickness of 1.60 mm was used. The purpose of these tests was to evaluate the physical performance of CSP as a partial replacement in conventional concrete on the workability.

### 2.2.5 Density

The density of concrete was determined after 28 days of curing for control and coconut shell particles (5-14 mm and 5-20 mm) concrete cubes. According to [26] the concrete density was calculated by dividing the mass of each cube by its volume. Specimens were cured in water for more than 3 days in conformity with [27] and were thus deemed to be saturated to a constant mass for the test. The specimens were weighed on a balancing scale and their masses were recorded in kilograms (kg). Each specimen's volume was measured in cubic meters ( $m^3$ ), and its density was determined in kilograms per cubic meter ( $kg/m^3$ ).

### 2.2.6 Compressive Strength

To assess the compressive strength, sixty-six (66) cubes with the size of 100 mm x 100 mm x 100 mm containing control and coconut shell particles concrete (CSP 5-14 mm and 5-20 mm) were cured for 7 and 28 days. The Universal Testing Machine (UTM) complying with the [28] standard was utilized for the test. Figure 2.2 shows the specimen undergoing testing and recording of results.



Figure 2.2: (a) Cube under compressive strength test, (b) reading and recording of results

### 2.2.7 Splitting Tensile Strength

This test was performed on all sixty-six (66) cylinder specimens, with control, CSP 5-14 and 5-20 mm having a diameter of 100 mm and a length of 200 mm that had been cured for 7 and 28 days before testing conforming to [29]. The test was carried out on the UTM machine, and Figure 2.3 depicts the test equipment as well as the specimen.

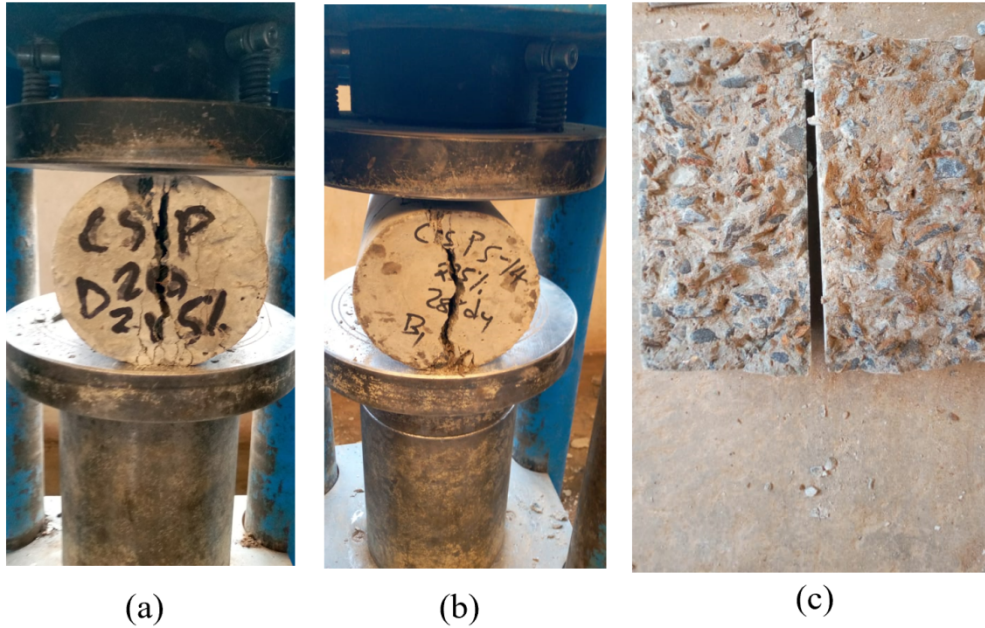


Figure 2.3: (a) & (b) Splitting tensile test on specimen and (c) crushed specimen

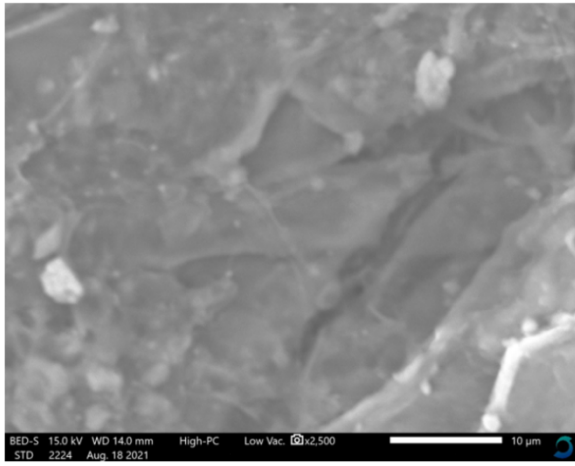
### 2.2.8 Water Absorption

For all combinations, the water absorption test was performed on hardened concrete. Before testing, three cube specimens of each concrete mix were cured for 28 days. Following the 28-day curing period, the specimens were placed in a drying oven at 100°C for 72 hours, following [30] specifications. The specimens were allowed to cool for 24 hours after being removed from the oven. After cooling, the specimens were weighed and then placed in a tank of water for 30 minutes. Specimens were retrieved from the tank and weighed after being dried using a cloth to remove the majority of the water from the surface. Water absorption was then determined as the increase in mass caused by immersion and expressed as a percentage of the dry specimen's mass.

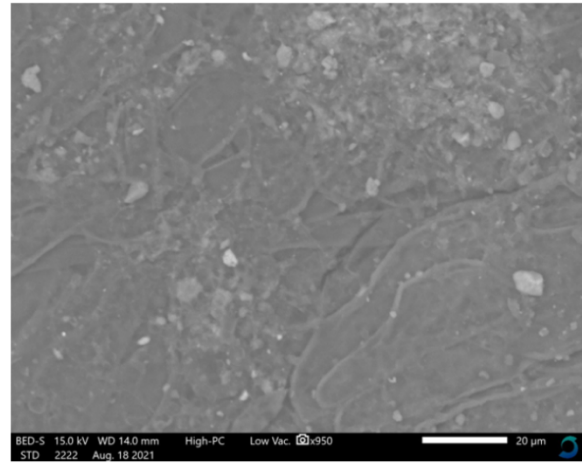
## 3. RESULTS AND DISCUSSION

### 3.1 Scanning Electron Microscope

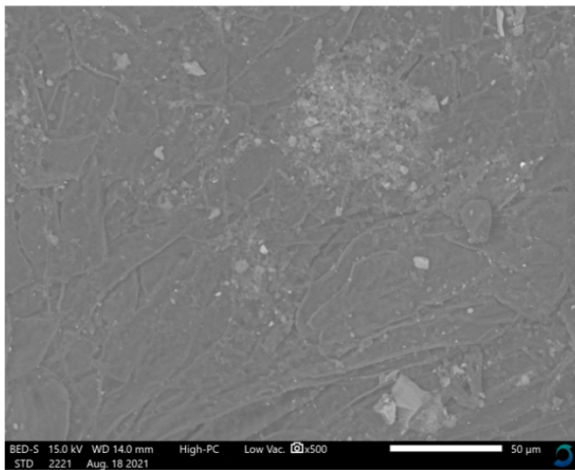
Figures 3.1 and 3.2 show images of the inner and exterior surfaces of coconut shell particles obtained using the SEM technique. The inner surface of coconut shell particles in this study is identified to be smooth, whereas the exterior surface is found to be rough, which portrayed similar SEM observations from other literature [31]–[33]. However, the workability of concrete may not be impacted due to the surface orientation of the inner section of CSP but may produce slip in concrete, thus resulting in a loss of bond between the coconut shell particles and the cement matrix. The out surface of CSP, on the other hand, is found to be rough and contains capillaries that allow liquid circulation, increasing the water demand in freshly mixed concrete. To reduce this effect, CSP was saturated surface dry (SSD) after 24 hours in water before being added to the mix.



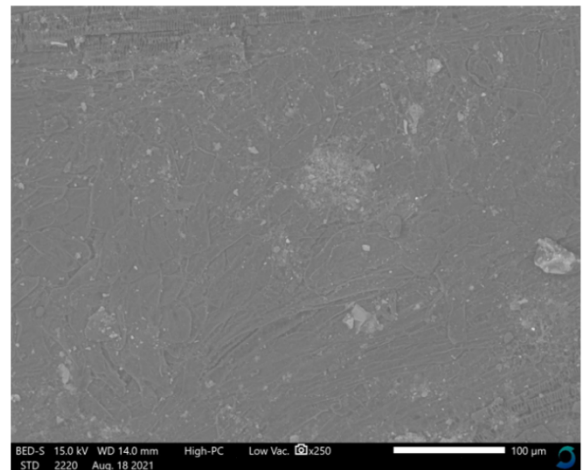
(a) Scale bar: 10 µm



(b) Scale bar: 20 µm



(c) Scale bar: 50 µm



(d) Scale bar: 100 µm

Figure 3.1: SEM images of CSP inner surface

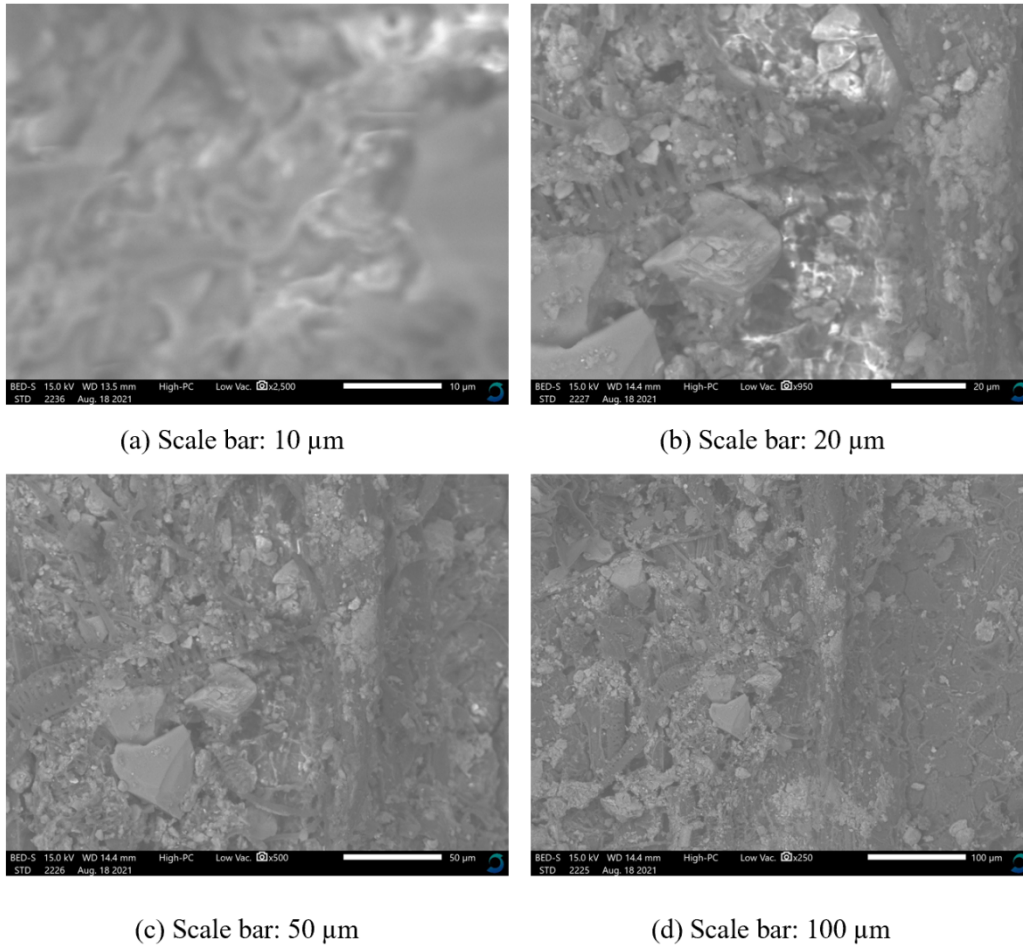


Figure 3.2: The SEM images of CSP exterior surface

### 3.2 Material Properties

#### 3.2.1 Properties Portland Cement

The amounts of each property in cement utilized are listed in Table 3.1. As shown, the lack of MgO in cement has been proven to result in acceptable soundness properties less than 10 mm [31]. The minimal water to cement ratio of the required cement for this study was 0.34, based on the normal consistency result. As a result, the water-to-cement ratio used in the mix design was 0.55 at a slump of 30-60 mm, which was adequate for cement hydration. The specific gravity, initial and final setting time of cement used conform to [13] requirement.

**Table 3.1: Physical Properties of Portland Cement 42.5R**

Description	Unit	OPC
Specific Gravity	--	3.15
Soundness	mm	5.9
Normal Consistency	%	34
Initial setting time	minutes	169
Final setting time	minutes	278
Bulk density compact	kg/m <sup>3</sup>	1398.71



Description	Unit	OPC
Bulk density Loose	kg/m <sup>3</sup>	1190.43

### 3.2.2 Particles Size Distribution of Aggregates

With particles ranging in size from 0.15mm to 5mm, the fine aggregate was well graded. Figure 3.3 shows that the fine aggregate grading met the [15] standards, indicating uniformity in the concrete. the fineness modulus was 2.79, indicating that the material was neither too fine nor too coarse, making it ideal for the manufacture of concrete with good workability.

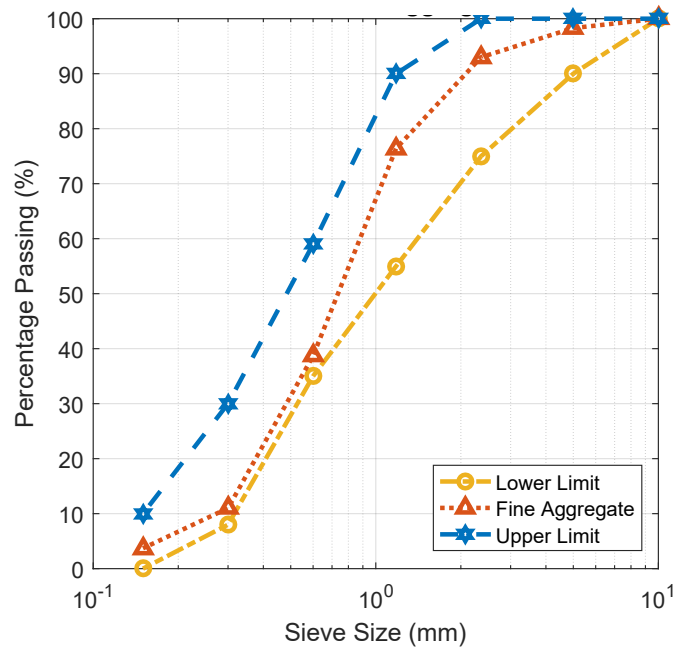


Figure 3.3: Particle Size Distribution of Fine Aggregate

Figure 3.4 shows the particle size distribution of coarse aggregate and coconut shell particles. Coarse aggregate had a maximum and minimum aggregate size of 20 mm and 5 mm, while CSP had maximum and minimum aggregate sizes of 14 and 5 mm, and 20 and 5 mm respectively. CA and CSP particle sizes are also compared.

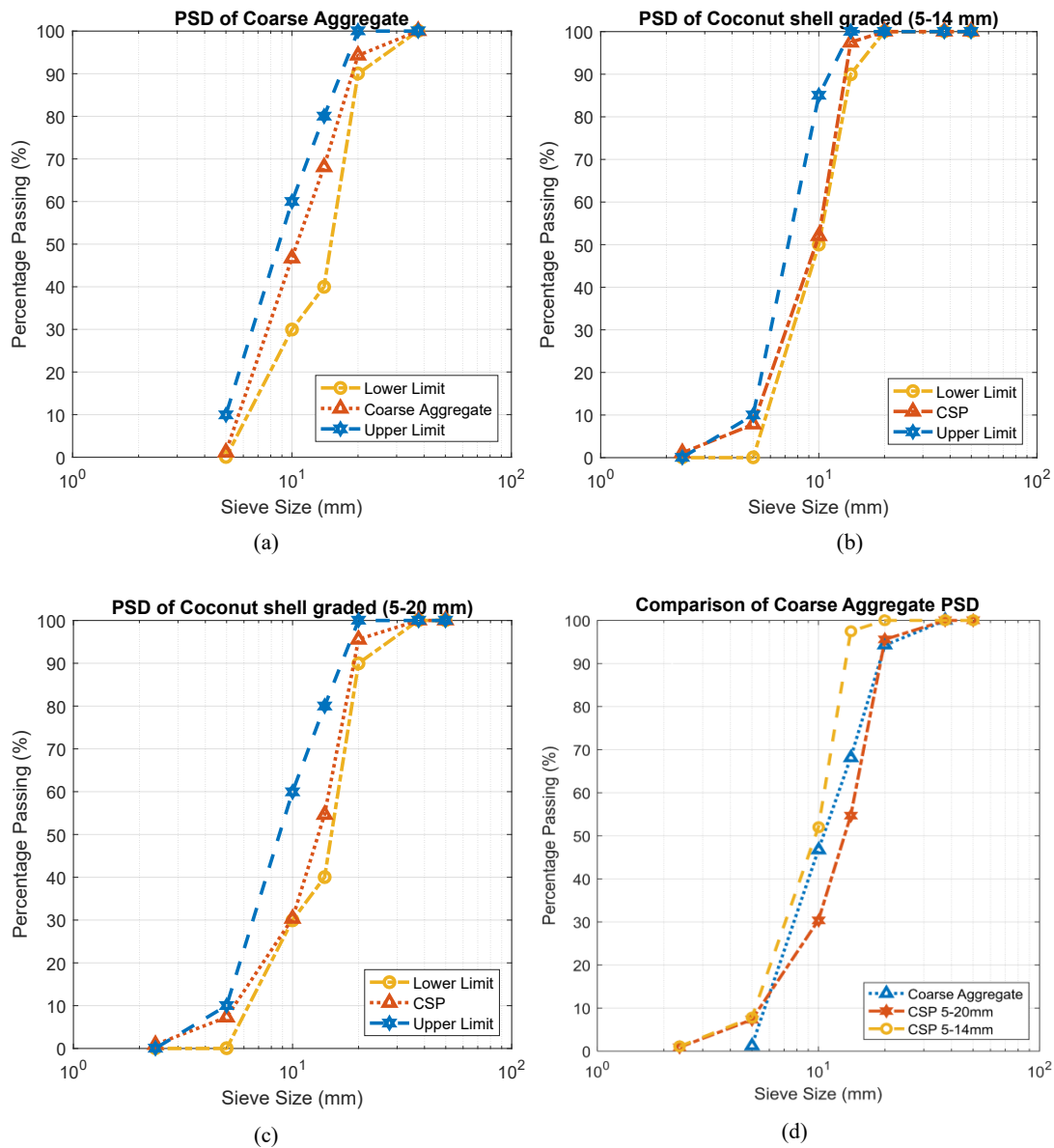


Figure 3.4: Particle Size Distribution of: (a) CA, (b) CSP 5-14 mm, (c) CSP 5-20mm and (d) comparison

Hence, the coarse aggregate and coconut shell particles employed in the study comply with [34] grading. Also from Figure 3.4, it can be seen that CA and CSP used were classified as graded aggregates. With the use of CSP as a percentage replacement for CA as the aggregate size decreased, it was discovered that the CSP 5-14 mm employed in this study was finer than CSP 5-20 mm and CA, thus resulting in a higher demand for cement paste for appropriate bonding.

### 3.2.3 Properties of Aggregate

Table 3.2: Properties of Aggregate

Properties	FA	CA	CSP
Specific Gravity on SSD	2.57	2.53	1.28

Properties	FA	CA	CSP
24 hr Water Absorption (%)	2.14	3.33	29.67
Bulk Density Compact (Kg/m <sup>3</sup> )	1,609.11	1457.05	514.8
Bulk Density Loose (Kg/m <sup>3</sup> )	1,579.91	1389.35	501.2
Aggregate Crushing Value, ACV (%)	--	16.74	2.62
Fineness Modulus	2.78	--	--
Silt Content (%)	2	--	--
Aggregate Impact Value, AIV (%)	---	12.69	8.14

### 3.3 Workability of CSP 5-14 mm and 5-20 mm Concrete

Figures 3.5 show the results of the slump and compacting factor tests for varying percentages of CSP 5-14 and CSP 5-20 mm substitution for coarse aggregate. To assess the effect on workability, the slump and compacting factor tests were performed. The concrete slump with zero percent of CSP 5-14 and CSP 5-20 was 55mm at a constant w/c ratio. As the fraction of CSP substitution grew, slump and compacting factor decreased. When compared to control concrete, it was discovered that CSP 5-20 mm had a better slump and compacting factor value than CSP 5-14 mm. Although the water absorption of CSP 5-14 mm and 5-20 mm was taken into consideration by applying the saturated surface dry (SSD) method, but there was still a decrease in the slump and compacting factor as CSP content increased, notably CSP 5-14 mm. Similarly, Subbramani et al and Kumbar et al [35] and [36] found that increasing CSP content reduced workability. This could be due to the finer particle sizes of CSP 5-14 mm and 5-20 mm when compared to coarse aggregate, resulting in a lower slump value for CSP 5-14 mm compared to CSP 5-20 mm and control. This brings to mind that as the size of coconut shell particles decreases, the surface area increases, requiring more water, negatively affecting the workability of concrete.

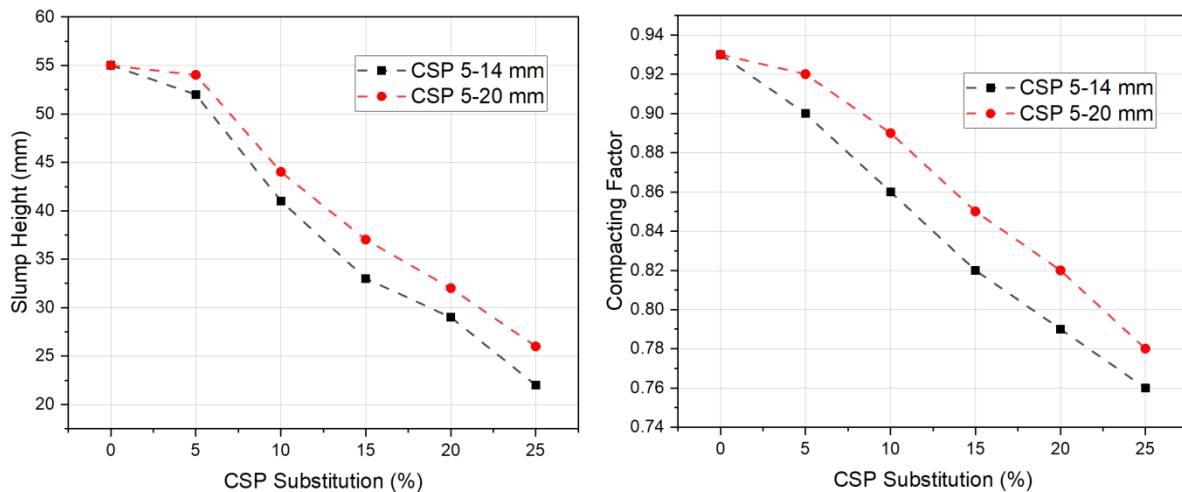


Figure 3.5: Slump and Compacting Factor of CSP Concrete

Hence, as CSP increases, workability decreases, which may necessitate greater compacting efforts, resulting in poor compaction. As a result of poor compaction, voids can form in the concrete, reducing the strength, density, and durability of the material. Furthermore, poorly compacted concrete can increase water absorption, reducing the longevity of the concrete.

### 3.4 Density of CSP 5-14 mm and 5-20 mm Concrete

Figure 3.6 shows how different coconut shell particles percentages of 5-14 mm and 5-20 mm affect concrete density. The densities of CSP 5-14 mm percent replacements were lower than those of CSP 5-20 and control concrete after 28 days of curing. The figure also shows how the density of the concrete reduces as the amount of CSP in the concrete increases. This is because CSP has a lower specific gravity (Table 3.2) than the coarse aggregate. CSP concrete density was found to follow a similar trend by [37], [38]. Additionally, because of the decrease in the slump, there must have been insufficient compaction, resulting in voids in the concrete and hence a reduction in density. Despite a 25% substitution of CSP 5-14 and 5-20, the concrete density was still higher than the [39] requirement of 2000kg/m<sup>3</sup> for normal weight concrete (NWC). This is because the coarse aggregate used was more than coconut shell particles in the concrete mix. The density of CSP 5-14 mm was found to be lower than that of CSP 5-20 mm and control. Because batching was done by weight, CSP could potentially replace twice as much coarse aggregate for the same mass. A similar amount of coarse aggregate might have been replaced with CSP if batching by volume had been used.

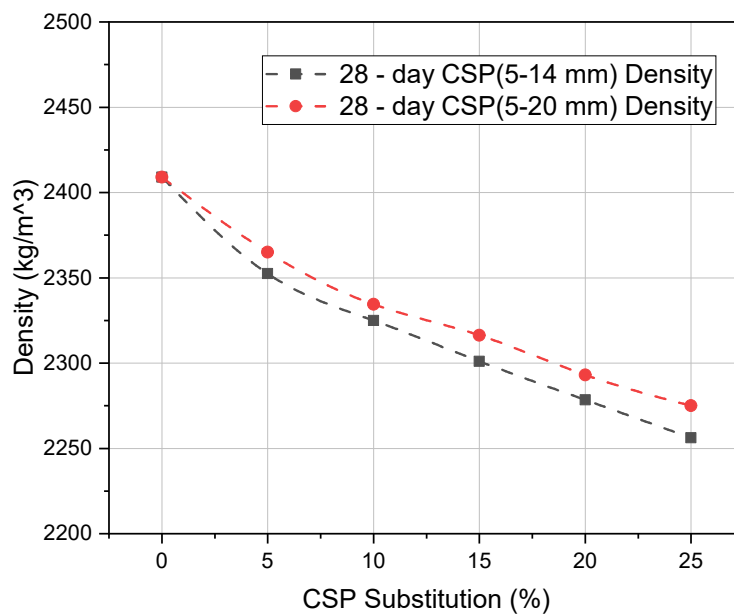


Figure 3.6: Density of CSP Concrete cubes after 28 days curing period

Based on the findings, it can be inferred that coconut shell particles affect concrete density, as all percent substitutions produced different densities in decreasing order, with CSP 5-14 mm producing the least. As a result, because CSP 5-14 mm has a lower density than CSP 5-20 mm and control, CSP 5-14 mm may have lower compressive strength whereas CSP 5-20 mm and control have higher compressive strength. Also, because the concrete density of CSP 5-14 mm is lower than that of the other, smaller sections for supporting members can be chosen instead of bigger ones, resulting in significant savings in construction costs.

### 3.5 Compressive Strength of CSP 5-14 mm and 5-20 mm Concrete

Figure 3.7 shows that the greatest compressive strength values achieved for the control at 7 and 28 days of curing were 25.6 MPa and 35.7 MPa, respectively. CSP 5-20 mm had lower compressive strength than control but was higher than CSP 5-14 mm. The compressive strength of concrete improves with days of curing but decreases as the amount of CSP in the concrete increases. Following Kambi et al, Azuma et al, and Gunasekaran et al [40]–[42], have published similar results which were restricted to a specific particles size of coconut shell but now this current research introduced the variability of the sizes and content of coconut shell particles (5-14 and 5-20 mm) in concrete, additional information on the microstructure check which now explain why there was a reduction in strength and increment in workability. The poor workability of CSP concrete, as evidenced by the

slump and compacting test in Figure 3.5, is to be blamed for the reduction in concrete compressive strength. Reduced workability could have resulted in poor compaction, putting the concrete's compressive strength at risk.

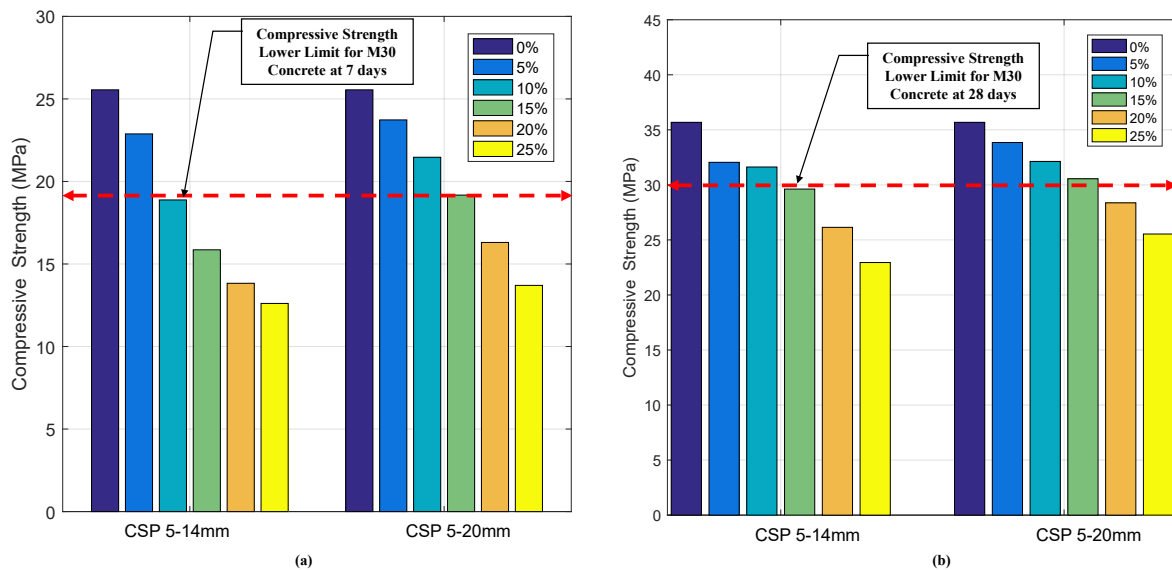


Figure 3.7: Compressive strength of concrete after (a) 7 & (b) 28 days curing period

In addition, when compared to coarse aggregate, the increased surface area of CSP 5-14 mm and CSP 5-20 concrete may have resulted in a reduction in compressive strength, necessitating the use of more cement paste for adequate bonding. Again, the reduction in concrete density caused by the addition of CSP could have contributed to the loss of compressive strength also. The compressive strength obtained for all of the percent substitutions, however, was greater than the [43] minimum criterion of 17MPa for structural concrete. This is because coconut shell particles have an aggregate crushing value (ACV) which conforms to standard [15]. Coconut shell particles 5-20 mm concrete has also been found to be more suitable for structural concrete, with up to 15% by weight replacement substitution when compared to CSP 5-14mm concrete. This is because CSP 5-20 mm has larger particles and occupies less surface area. CSP 5-14 mm concrete can thus be used for the low-cost construction of residential buildings for functional purposes.

### 3.6 Splitting Strength of CSP 5-14 mm and 5-20 mm Concrete

Figure 3.8 shows the results for the splitting tensile strength after 7 and 28 days of curing. The splitting tensile strength curve follows a similar pattern as compressive strength. Hence, it is clear that the behavior of CSP is identical to that of the result obtained by [44] for palm kernel shell concrete.

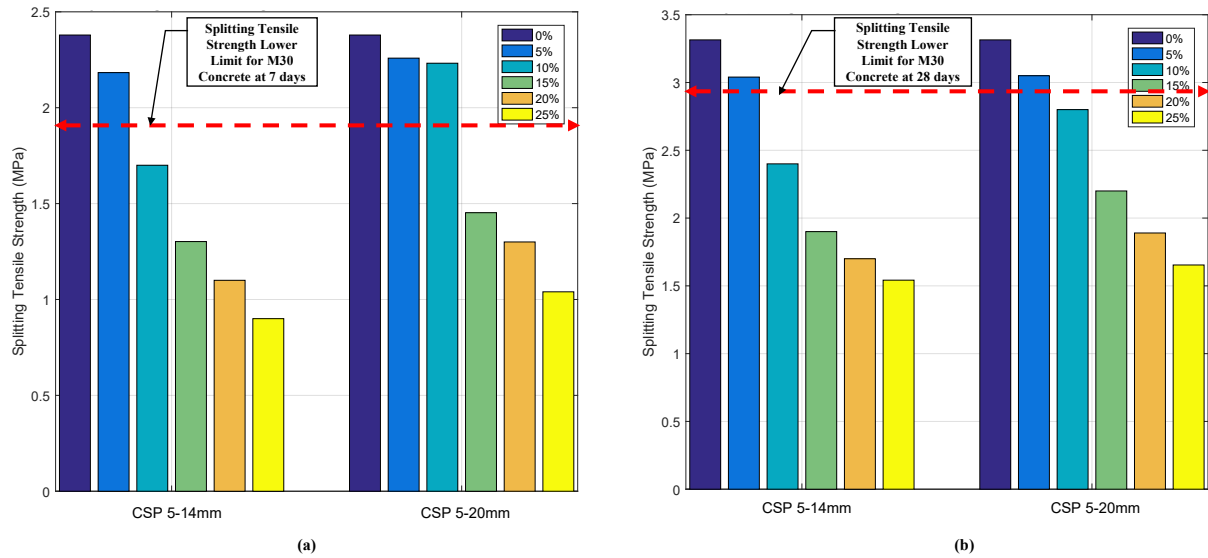


Figure 3.8: (a) and (b) Splitting tensile strength of concrete after 7 and 28 days curing period

The splitting tensile strength, like the compressive strength, decreases with an increase in coconut shell particles percentage substitution but increases with curing age. Poor compaction, higher CSP surface area, and decreased concrete density with increasing CSP content are all factors that contribute to a loss in splitting tensile strength. As a result, bond failure between the aggregate and the cement paste was the primary cause of failure. Furthermore, as shown in Figure 3.8, the splitting tensile strength at 28 days for CSP 5-14 and 5-20 mm at 5% replacement of CA yields the greatest value, however, the result differs with 10% replacement. Because batching was done by weight, this could have also contributed to the increased surface area covered by CSP 5-14 mm because the particles are smaller.

### 3.7 Water Absorption

Figure 3.9 shows that CSP absorbs more water after 28 days than control concrete. The water absorption of CSP increases as the CSP content in the concrete increases, in contrast to density. [45] found similar findings. The high-water absorption of CSP, as shown in Table 4, accounts for the increase in water absorption with increasing CSP content. Because CSP is so absorbent, adding more of it to the mix will increase the concrete's water absorption. Increased water absorption is also linked to decreased concrete workability as CSP content rises. Poor workability can lead to poor compaction, which can leave gaps in the concrete, thus increasing water absorption. More so, Figure 3.9 also demonstrates that CSP 5-20 mm has a little lower water absorption than CSP 5-14 mm. This is because the particle sizes of CSP 5-14 mm are smaller and batching was done by weight conforming to the DoE concrete mix design method [23], this can also be ascribed to CSP 5-14 mm having reduced workability and higher surface area.

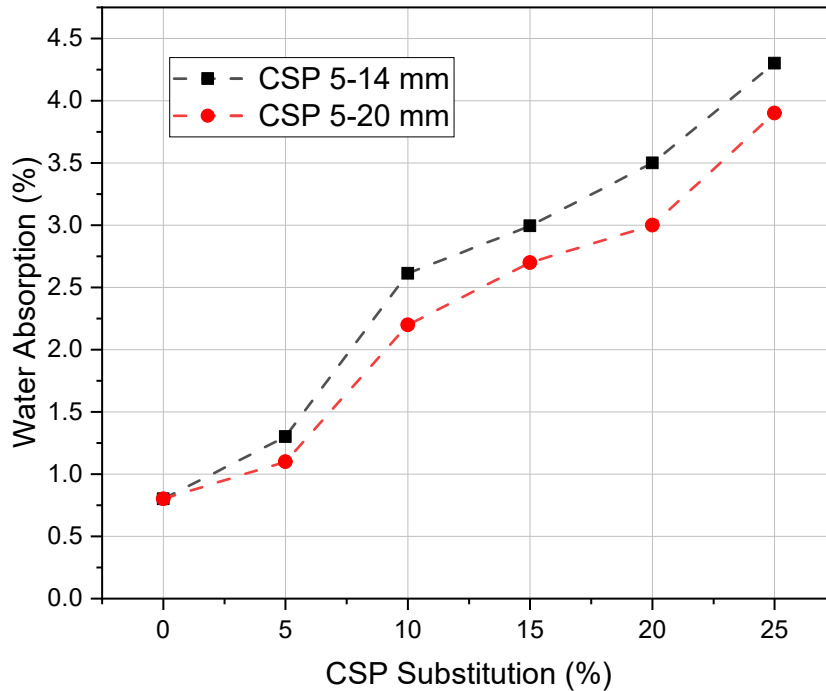


Figure 3.9: Water Absorption of CSP concrete after 28 days curing period

## CONCLUSIONS

The following conclusions are derived from the findings reported in this paper.

- This study revealed that CSP (5-20 and 5-14 mm) derived from discarded coconut shell can be used as a partial substitute for coarse aggregate in structural concrete production, with up to 15% of CSP 5-20 mm and 10% of CSP 5-14 mm being employed.
- The workability of fresh concrete decreases as the CSP concentration rises. However, by introducing superplasticizers to provide the desired workability, the problem can be solved. Batching by volume can also lessen the effect of CSP 5-14 mm to CSP 5-20 mm on workability, density, compressive strength, splitting tensile strength, and water absorption.
- At 7 and 28 days, the compressive strength of concrete containing CSP 5-14 and 5-20 mm attained its maximum value at 5% partial coarse aggregate replacement.
- Concrete with CSP has a lower strength than control. The strength of low percentages is greater than that of high percentages. In comparison to the other percentages of CSP substitution, 5% of CSP 5-14 and 5-20 mm content in the mix creates more workable concrete, higher strength and density, and less water absorption.

A similar investigation with the addition of superplasticizer is needed to further understand the impact of CSP 5-20 mm and 5-14 mm on the mechanical and physical properties of normal weight concrete (NWC). To analyze the influence of CSP 5-14 and 5-20 mm on other mechanical properties of normal weight concrete in an aggressive environment, additional flexural strength and Young's modulus tests are proposed. Furthermore, a similar study using batching by volume is required to see whether there would be an improvement in the mechanical and physical properties of concrete.

## LIST OF ABBREVIATIONS

JKUAT	=	Jomo Kenyatta University of Agriculture and Technology
NWC	=	Normal Weight Concrete
SEM	=	Scanning Electron Microscopy
SSD	=	Saturated Surface Dry

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## REFERENCES

- [1] C. Meyer, "The greening of the concrete industry," *Cement and Concrete Composites*, vol. 31, no. 8, Sep. 2009.
- [2] M. S. Shetty and A. K. Jain, *Concrete Technology (Theory and Practice)*, 8e. S. Chand Publishing, 2019.
- [3] AMOAH YEBOAH DERRICK, "ANALYSIS OF EMISSIONS AND ENERGY CONTENT OF COCONUT HUSK," 2016.
- [4] Bamgboye A. Isaac and Jekayinfa .S, "Energy Consumption Pattern in Coconut Processing Operations.," *the CIGR Journal Manuscript EE 05 013.* , vol. VIII., pp. 1–11, 2006.
- [5] K. Gunasekaran, R. Annadurai, and P. S. Kumar, "Long term study on compressive and bond strength of coconut shell aggregate concrete," *Construction and Building Materials*, vol. 28, no. 1, Mar. 2012.
- [6] K. Gunasekaran, G. Pennarasi, S. Soumya, and L. Shruti, "All-in-one about a momentous review study on coconut shell as coarse aggregate in concrete," *International Journal of Civil Engineering and Technology*, vol. 8, pp. 1049–1060, Apr. 2017.
- [7] P. Vasanthi, S. S. Selvan, P. Murthi, I. R. Reddy, and K. Poongodi, "Impact of Partial Replacement of Cement by Coconut Shell Ash and Coarse Aggregate by Coconut Shell on Mechanical Properties of



- Concrete,” in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 981, no. 3, p. 032080.
- [8] M. Palanisamy *et al.*, “Permeability properties of lightweight self-consolidating concrete made with coconut shell aggregate,” *Journal of Materials Research and Technology*, vol. 9, no. 3, May 2020.
- [9] E. A. Olanipekun, K. O. Olusola, and O. Ata, “A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates,” *Building and Environment*, vol. 41, no. 3, Mar. 2006.
- [10] H. B. Basri, M. A. Mannan, and M. F. M. Zain, “Concrete using waste oil palm shells as aggregate,” *Cement and Concrete Research*, vol. 29, no. 4, Apr. 1999.
- [11] K. Gunasekaran, R. Annadurai, and P. S. Kumar, “Long term study on compressive and bond strength of coconut shell aggregate concrete,” *Construction and Building Materials*, vol. 28, no. 1, Mar. 2012.
- [12] A. Yerramala and C. Ramachandrudu, “Properties of concrete with coconut shells as aggregate replacement,” *International journal of engineering inventions*, vol. 1, no. 6, pp. 21–31, 2012.
- [13] BS EN 197-1, *Cement - Part 1: Composition, specifications and conformity criteria for common cements*. London, UK: BSI, 2000.
- [14] BS EN 1097, *Test for Mechanical and Physical Properties of Aggregates*, BSI Standards Limited, 2013.
- [15] BS 882, *SPECIFICATION FOR AGGREGATES FROM NATURAL SOURCES FOR CONCRETE*. London: British Standards Institution, 1992.
- [16] American Association State Highway and Transportation Officials Standard, *C188 – 17: Standard Test Method for Density of Hydraulic Cement*, vol. 04.01. ASTM International, 2017.
- [17] BS EN 196-3, *Methods of testing cement Part 3: Determination of setting times and soundness*, 2016th ed. British Standards Institution (BSI), 2016.
- [18] BS EN 933-1, “Tests for Geometrical Properties of Aggregates Part 1: Determination of Particle Size Distribution—Sieving Method,” *Farmington Hills, MI, USA: Concrete Society.*, 2012.
- [19] BS 812-109, “Testing aggregates: Methods for determination of moisture content,” *London, UK: BSI.*, 1990.
- [20] BS 812-112, “Testing aggregates: Methods for determination of aggregate impact value (AIV),” *London, UK: BSI.*, 1990.
- [21] BS 812-110, “Testing aggregates: Methods for determination of aggregate crushing value,” *London, UK: BSI.*, 1990.
- [22] C. T. Tam, D. S. Babu, and W. Li, “EN 206 Conformity Testing for Concrete Strength in Compression,” *Procedia Engineering*, vol. 171, 2017.
- [23] Department of the Environment, *Design of Normal Concrete Mixes (Building Research Establishment)*. Walford, UK, 1988.
- [24] ASTM C143, *Standard Test Method for Slump of Hydraulic-Cement Concrete*. West Conshohocken, PA: ASTM International, 2018.
- [25] BS 1881-102, “Testing concrete. Method for determination of slump,” *London, UK: BSI.*, 1983.
- [26] BS EN 12390-7, *Testing hardened concrete Part 7: Density of hardened concrete*. 2009.
- [27] BS 1881-111, *Testing concrete. Method of normal curing of test specimens*. London, UK, 1983.

- [28] BS 1881-116, "Testing concrete. Method for determination of compressive strength of cubes," *London, UK: BSI*, 1983.
- [29] BS 1881-117, "Testing concrete. Method for determination of tensile splitting strength," *London, UK: BSI*, 1983.
- [30] BS 1881-122, *Testing concrete. Method for determination of water absorption*. London, UK, 1983.
- [31] K. Gunasekaran, P. S. Kumar, and M. Lakshmi pathy, "Mechanical and bond properties of coconut shell concrete," *Construction and Building Materials*, vol. 25, no. 1, Jan. 2011.
- [32] K. Gunasekaran, R. Annadurai, and P. S. Kumar, "Long term study on compressive and bond strength of coconut shell aggregate concrete," *Construction and Building Materials*, vol. 28, no. 1, Mar. 2012.
- [33] K. Gunasekaran, R. Annadurai, and P. S. Kumar, "Study on reinforced lightweight coconut shell concrete beam behavior under flexure," *Materials & Design*, vol. 46, Apr. 2013.
- [34] BS 812-103, *Testing aggregates. Methods for determination of particle size distribution*. London, UK, 1990.
- [35] T. Subramani and A. Anbuve, "The Behavior Of Reinforced Concrete Beams With Coconut Shell As Coarse Aggregate," *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*, vol. 5, no. 5, pp. 2319–4847, May 2016.
- [36] V. R. P. Kumar, K. Gunasekaran, and T. Shyamala, "Characterization study on coconut shell concrete with partial replacement of cement by GGBS," *Journal of Building Engineering*, vol. 26, Nov. 2019.
- [37] A. Kanojia and S. K. Jain, "Performance of coconut shell as coarse aggregate in concrete," *Construction and Building Materials*, vol. 140, Jun. 2017.
- [38] K. Gunasekaran, P. S. Kumar, and M. Lakshmi pathy, "Mechanical and bond properties of coconut shell concrete," *Construction and Building Materials*, vol. 25, no. 1, Jan. 2011.
- [39] BS 5328-1, *Guide to specifying concrete*. London, 1997.
- [40] P. S. Kambli and S. R. Mathapati, "Compressive strength of concrete by using coconut shell," *IOSR Journal of Engineering*, vol. 4, no. 4, pp. 1–7, 2014.
- [41] S. Azunna, F. A. Aziz, N. A. Bakar, and N. M. Nasir, "Mechanical properties of concrete with coconut shell as partial replacement of aggregates," *Materials Science and Engineering*, vol. 431, pp. 1–8, 2018.
- [42] K. P. Gunasekaran K and Lakshmi pathy M, "Mechanical and bond properties of coconut shell concret," *Const Build Mate*, vol. 26, no. 1, pp. 92–8, 2011.
- [43] American Concrete Institute, *ACI Committee 116 (ACI 116R-2000)- 00) - Cement and Concrete Terminology*. Armington Hills, 2000.
- [44] E. S. Philips, R. Mutuku, and J. Mwero, "Palm Kernel Shell as Partial Replacement for Normal Weight Aggregate in Concrete," *Civil and environmental research*, vol. 9, pp. 40–47, 2017.
- [45] E. A. Olanipekun, K. O. Olusola, and O. Ata, "A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates," *Building and Environment*, vol. 41, no. 3, Mar. 2006.