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Original Article

Influence of Coconut Shell Particles Grades as Partial Replacement of Coarse Aggregate on Concrete Properties

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Abstract - *The increasing population has led to a global shortage of raw materials for concrete production. As a cheap and eco-friendly alternative to coarse aggregate in concrete, coconut shells can be used as a partial replacement. Although coconut shell aggregate has been studied in concrete, the study integrating coconut shells of varying grades in concrete is still unclear. In this research, the effect of coconut shell variable particles in concrete is investigated. The coconut shells were crushed and sieved (5 to 14 mm and 5 to 20 mm) and used in concrete as a partial replacement of coarse aggregate. The properties of concrete were all investigated. Five coarse aggregate replacement levels of 5%, 10%, 15%, 20%, and 25% were studied in contrast to control concrete. The material properties were also determined. The inclusion of coconut shell particles (CSP) 5-14 mm reduced workability compared to CSP 5-20 mm and control concrete. The CSP (5-14 mm) had a substantial impact on density, water absorption, compressive strength, and split tensile strength of the concrete after 28 and 56 days of curing. Thus, CSP 5-20 mm has a less negative effect on concrete properties. CSP 5-14 mm and 5-20 mm can partially replace coarse aggregate up to 10% and 15% in concrete, respectively.*

Keywords - *Control concrete, coconut shell particles, density, workability, water absorption, strength.*

I. 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]. It is becoming increasingly difficult to find new aggregate sources, which results in a rise in aggregate prices due to a lack of availability and scarcity in the local market [2]. Globally, over 25 billion tons of concrete are produced, and aggregates account for roughly 70–80 percent of the volume for concrete, with fine aggregate accounting for 25–30% and coarse aggregate accounting for 40–50% [3]. The world population is projected to reach 9.9 billion by 2050, a rise of 25% from the 2020 population of 7.8 billion [4]. 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. Using treated and untreated industrial by-products and residential wastes as an alternative source for cement and aggregate in concrete production is becoming increasingly popular around the world as a means of reducing depletion of raw materials and promoting a cleaner, greener environment [5].

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 [6] The repurposing of coconut shell has been noticed as a means of discovering alternative waste management solutions. The use of coconut shell (CS) components in concrete are gaining popularity as a result of its acceptable mechanical qualities when compared to traditional concrete [7]–[10]. 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 [11]. The global production of coconut is captured in Figure 1, which shows a rise in coconut production.

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 [12], [13]. Before using the coconut shell as aggregate in concrete, it must be properly cleaned to eliminate any fiber or husk from the surface. A stronger connection between the particles could lead to increased strength. 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 [14]. It has been reported byArifin et al. [15] that the compressive strength of concrete decreased beyond 2.5% with an increase in coconut shell aggregate substitution. The compressive strength of coconut shell concrete is determined by the strength of the coconut shells used [16]. Ramesh et al. [17] have published a similar result that the compressive strength and spite tensile strength are reduced with increased coconut shell aggregate content in concrete due to increased surface area.

The impact of coconut shell variable particles on the properties of concrete is investigated in greater depth in this study. The research adds to the body of civil engineering knowledge about what happens to the properties of concrete when coconut shell particles are added at different grades. When comparing the grades, to what percent replacement level can coconut shell particle no longer be suitable in concrete for structural application? The research looked at these concerns

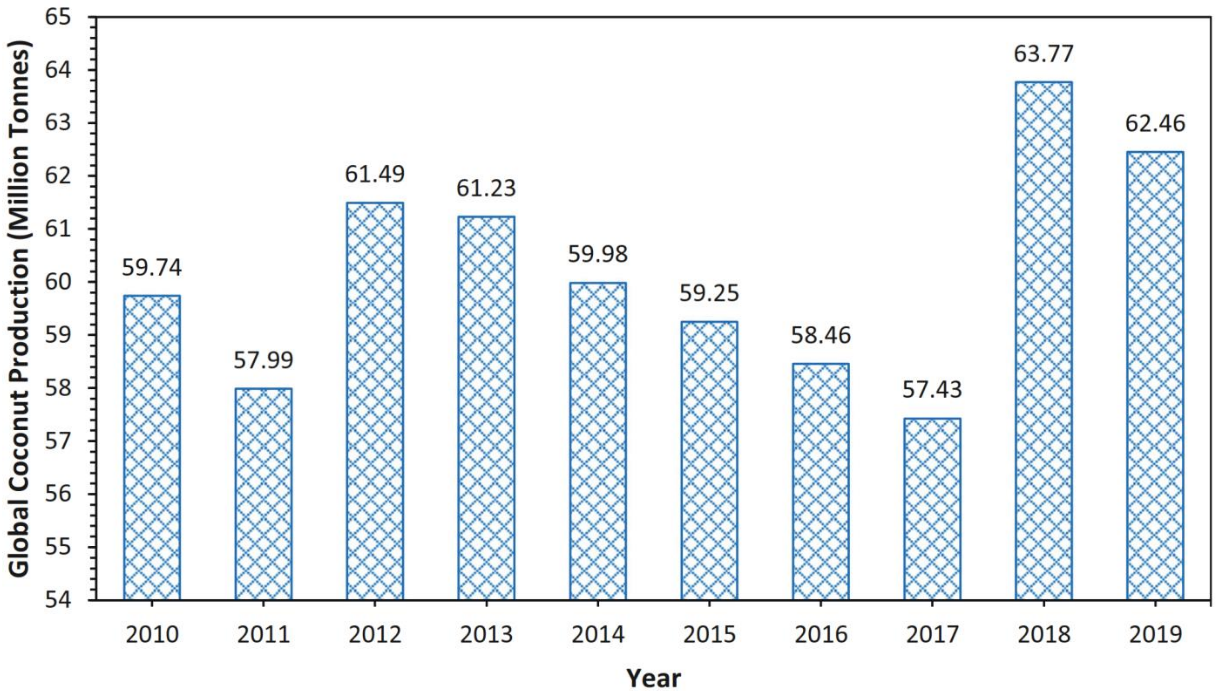

Fig. 1Global production of coconut [18]

II. MATERIALS AND METHODS

A. Materials

a) Cement

Ordinary Portland Cement class 42.5 meeting the specifications for the experiments BS EN 197-1, (2000) and with acceptable specific gravity and *Le Chatelier soundness* values respectively was used.

b) 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, bulk density and void, fineness modulus, and silt content were all determined conforming to [20].

c) Coarse aggregate

Graded coarse aggregate of 5 to 20 mm grade conforming to [21] 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.

d) Coconut shell

Coconut shells were sourced from Kaloleni Mombasa. The shells were crushed in a mini jaw crusher atJomo Kenyatta University of Agriculture and Technology(JKUAT) Civil

Engineering Laboratory, named as coconut shell particles (CSP), and graded into particle sizes ranging from 5 to 14 mm and 5 to 20 mm conforming to the standard [21]. 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. Figure 2 depicts the coconut shell preparation process.

(c) Crushing (b) Sieving (a) CSP graded

Fig.2Preparing of coconut shell particles (5-14 & 5-20 mm)

B. Methods

a) Properties of cement, fine, and coarse aggregate, and coconut shell particles

The Le-Chatelier Flask method was used to determine the specific gravity of OPC per [22] guidelines. The initial and final setting times of OPC were determined using [23]. One (1) mm^2 needle was used, along with a Vicat device and an annular needle. The soundness and normal consistency tests were also completed according to [23].

The distribution of the particle size was achieved by the sieve analysis method in conformity with the standard [24]. 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 [25]. The tests for water absorption, specific gravity, bulk density, aggregate crushing, and impact values were also performed conforming to [26], [27].

b) Mix Proportions

According to the reference[28] and [29], 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 partially replacing coarse aggregate with discarded coconut shell (CS) graded to CSP at 5-14 and 5-20 mm, using the same mix design. Table I shows the mixed proportion used. The matrix is made up of cubes and cylinders that have been cured for 7, 28, and 56 days. The effects on concrete workability, density, water absorption, compressive, and splitting tensile strength were studied.

c) Slump and compaction factor

Slump and compaction factor tests were carried out in conformity with the code [30] and[31]. 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.

d) 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 BS EN[32], 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 [33] 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).

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Table I: Mix proportion for concrete Specimens (kg/m^3)

Material	Percent replacement					
	0 %	5%	10%	15%	20%	25%
Portland Cement 42.5 R	381.82	381.82	381.82	381.82	381.82	381.82
Water	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	759.44	759.44	759.44	759.44	759.44	759.44
Coarse aggregate	1048.75	996.31	943.87	891.43	839.00	786.56
Coconut shell Particles	0	52.44	104.87	157.31	209.75	262.19

e) Water absorption

For all combinations, the water absorption test was performed on hardened concrete cubes. 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 an oven at 100°C for 72 hours, following [34] 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.

f) Compressive strength

To assess the compressive strength, ninety-nine (99) 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, 28, and 56 days. The Universal Testing Machine (UTM) complying with the [35] standard was utilized for the test.

g) Split 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 [36]. The test was carried out on the UTM machine.

III. RESULTS AND DISCUSSIONS

A. Material Properties

a) Properties of ordinary portland cement 42.5R

The amounts of each property in cement are listed in Table II. As shown, the lack of MgO in cement has been proven to result in acceptable soundness properties of less than 10 mm [32]. 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 [19] requirement.

b) Particles size distribution (PDS) of aggregate

With particles ranging in size from 0.15mm to 5mm, the fine aggregate was well graded. Figure 3 shows that the fine aggregate grading met the [21] 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 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. Hence, the coarse aggregate and coconut shell particles employed in the study complied with [36] grading. Also, from Figure 3, 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 utilized in this study was finer than CSP 5-20 mm and CA, thus resulting in a higher demand for cement paste for appropriate bonding.

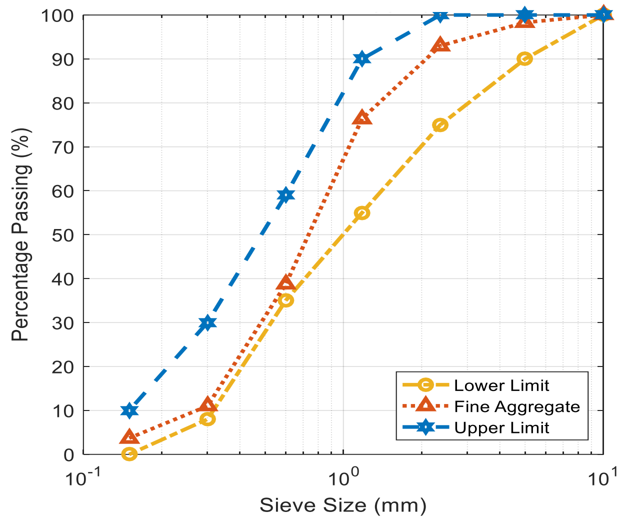

Fig.3 Particle size distribution of fine aggregate

Table II: Physical properties of cement

Description	Unit	OPC
Specific Gravity	--	3.11
Soundness	mm	5.9
Normal Consistency	%	34
Initial setting time	minutes	169
Final setting time	minutes	278
Bulk density compact	kg/m^3	1398.71
Bulk density Loose	kg/m^3	1190.43

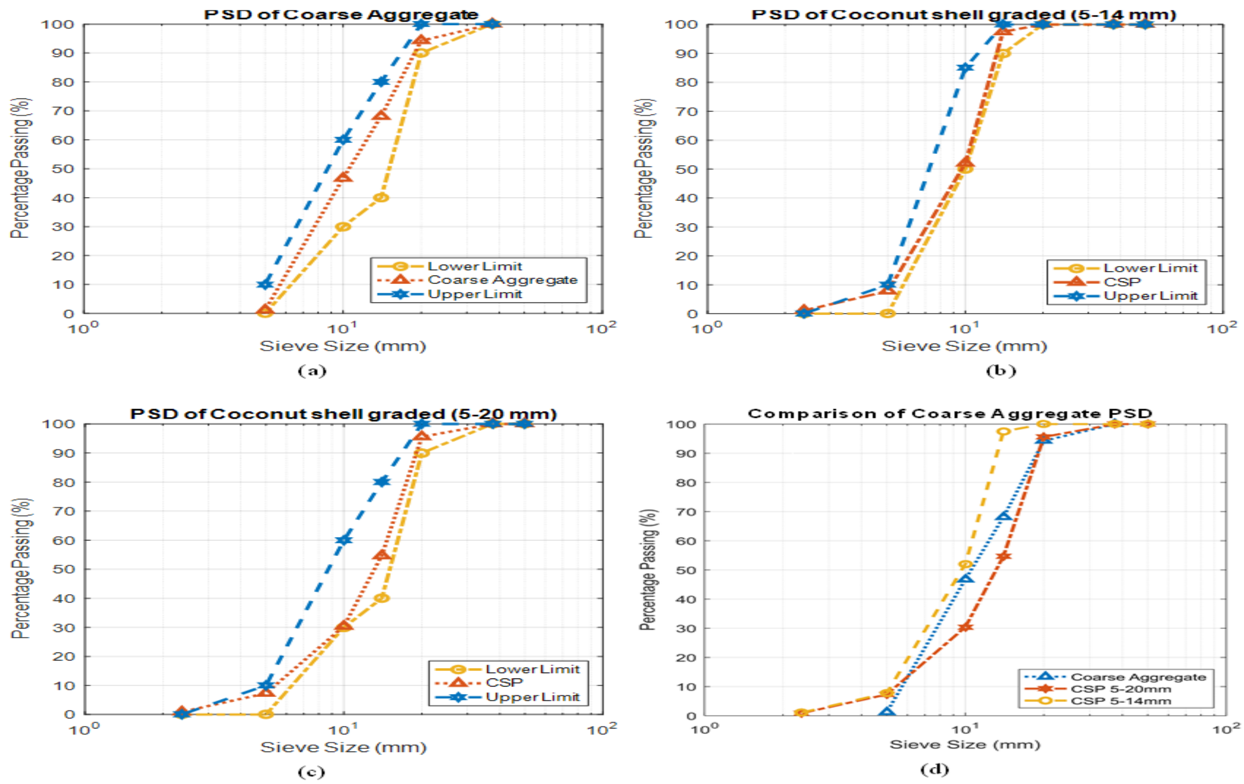

Fig.4 Particle size distribution of: (a) CA, (b) CSP 5-14 mm, (c) CSP 5-20mm and (d) comparison

c) Properties of aggregates

Fine aggregate, coarse aggregate, and coconut shell particles had specific gravity values of 2.57, 2.53, and 1.28, respectively. CSP was classified as a lightweight aggregate (LWA) since its specific gravity was less than 2.4 [37]. Concrete becomes heavier when the specific gravity of the aggregates is high [38]. With such, the specific gravity of aggregates must be determined to identify concrete qualities at the fresh and hardened stages. The coconut shell particles findings revealed that concrete containing such waste material is likely to have a low density.

Fine aggregate, coarse aggregate, and coconut shell particles absorbed 2.14%, 3.01%, and 29.67% of the water during the water absorption test, respectively. Among the three aggregates, the coconut shell particle aggregates had the highest percentage of water absorption. CSP was also soaked in water for 24 hours before being placed under saturated surface dry (SSD) conditions and blended into concrete due to its absorptive nature. The compacted bulk density and percentage of voids of fine aggregates, coarse aggregates, and coconut shell particles were calculated as follows: 1609.11 kg/m3 and 39.61 percent, 1457.05 kg/m3, and 39.97 percent, and 514.8 kg/m3 and 50 percent, respectively. The compacted bulk density is critical in the manufacture of concrete. Increased compacted bulk density and reduced void spaces between aggregates overcome the need for a larger quantity of cement paste to occupy the full surface area during concrete mixing [39]. Fine aggregates have a 10% higher compacted bulk density than coarse aggregates [40]. In this study, the compacted bulk density of fine aggregates was found to be 9.33 percent higher than that of coarse aggregates. This indicates that the aggregates in this investigation would have an acceptable amount of voids. The void content of fine aggregates ranges from 40% to 50%, while coarse aggregates have a void percentage ranging from 30% to 45 % [41]. It was noted that the value of void content for coarse aggregates is within the range, whereas the value for fine aggregates is near to the lower value of the range and coconut shell particles are out of range. A drop in the value of void content leads to a decrease in the workability of concrete [42]. In contrast, an increase in void content increases the need for more cement paste [42].

Coarse aggregate and coconut shell particles both had aggregate crushing values (ACV) values of 16.74% and 2.26%, respectively. The maximum recommended ACV for aggregates for concrete production was set at 30% by [27]. Findings from the experiment reviled that CSP has a lower ACV value than coarse aggregate and is hence projected to function better when crushed under progressive compressive stress. With CSP having an ACV value lower than CA, this means it is more ductile and can withstand stress without failing abruptly. The aggregate impact value of coarse aggregate was 12.69% and 8.14% for coconut shell particles, respectively. The aggregate impact value (AIV) limit for aggregates that are acceptable for concrete with good impact resistance, as specified by [26], is 25%. This means that aggregates with a greater AIV have weak impact resistance, while those with a lower AIV have superior impact resistance. Thus, CSP is tougher than coarse aggregate and, when stockpiled, fed through, and compacted with rollers, may prevent crushing, deterioration, and disintegration without generating construction and performance issues. The characteristics of fine, coarse aggregate, and coconut shell particles employed in the study are summarized in Table III.

Table III: Properties of aggregate

Properties	FA	CA	CSP
Specific Gravity on SSD	2.57	2.53	1.28
24 hr Water Absorption (%)	2.14	3.01	29.67
Bulk Density Compact (Kg/m^3)	1,609.11	1457.05	514.8
Percent of Void (%)	39.61	39.97	50
Bulk Density Loose (Kg/m^3)	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

B. Workability Control and CSP Concrete

Figures 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 compaction 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. The result of the study is in good agreement with other literature[43] and [44]. This could be due to the finer particle sizes of CSP 5-14 mm when compared to CSP 5-20 mm and coarse aggregate.

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

C. The density of Control and CSP Concrete

Figure 6 shows how different coconut shell particles percentages affect concrete density. The densities of CSP 5-Shows how the density of the concrete reduces as the amount of CSP in the concrete increases. This is because CSP has lower specific gravity and bulk density (Table III) than the coarse aggregate. CSP concrete density was found to follow a similar trend by [45], [46] 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 [47] requirement of 2000kg/m3 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 CSP partially replaced CA by
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14 mm percent replacements were lower than those of CSP 5-20 and control concrete after 28 days of curing. The figure also

weight substitution, CSP could potentially replace twice as much as coarse aggregate for the same mass.

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.

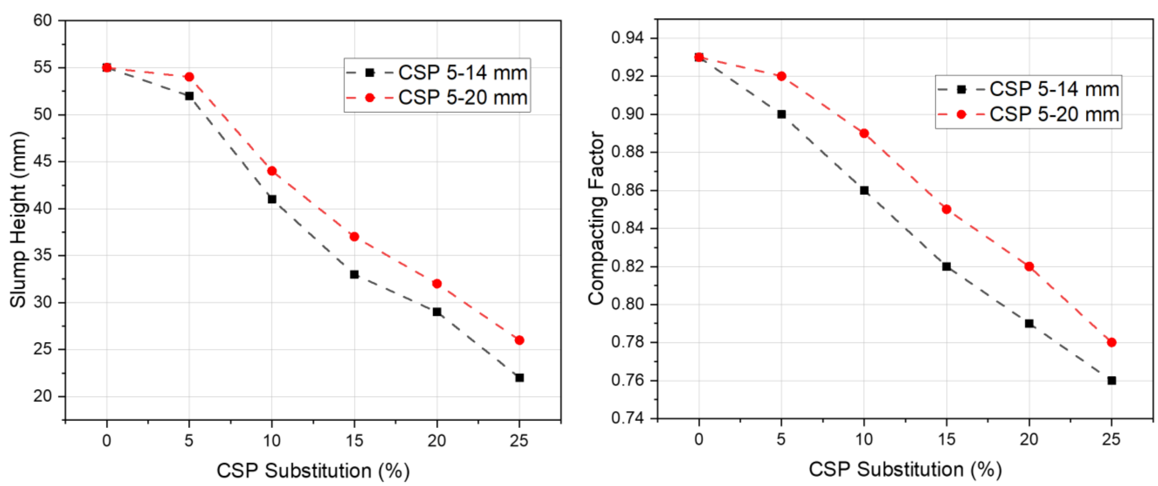


Fig.5 Slump and compaction factor of control and CSP concrete

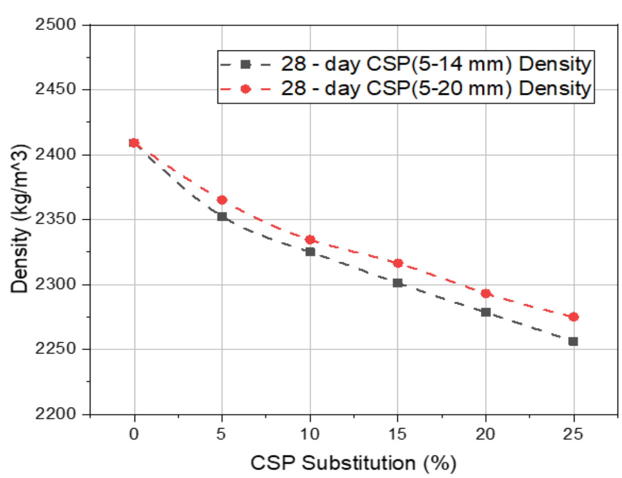


Fig.6 Density of control CSP concrete cubes after 28 days

D. Water Absorption of Control CSP Concrete

Figure 7 shows that CSP 5-14 mm absorbs more water after 28 days than CSP 5-20 mm and control concrete. The water absorption increases as the CSP content in the concrete increases, in contrast to density. Olanipekun et al. [48] found similar findings. The high-water absorption of CSP, as shown in Table III, 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 7 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, they occupy more spaces, and they partially replace coarse aggregate by weight substitution, thus resulting in increased surface area.

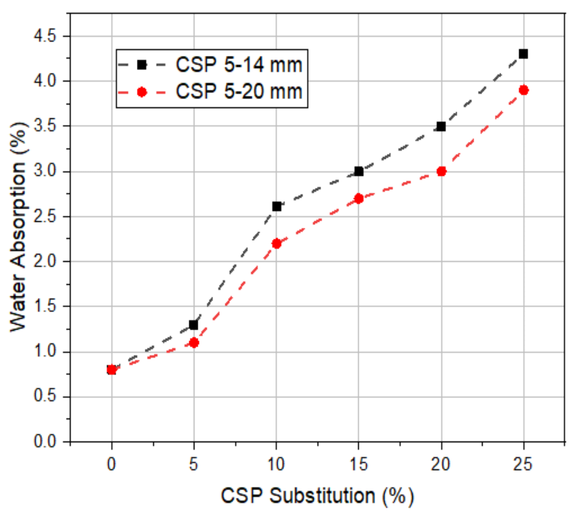


Fig. 7 Water absorption of CSP concrete after 28 days

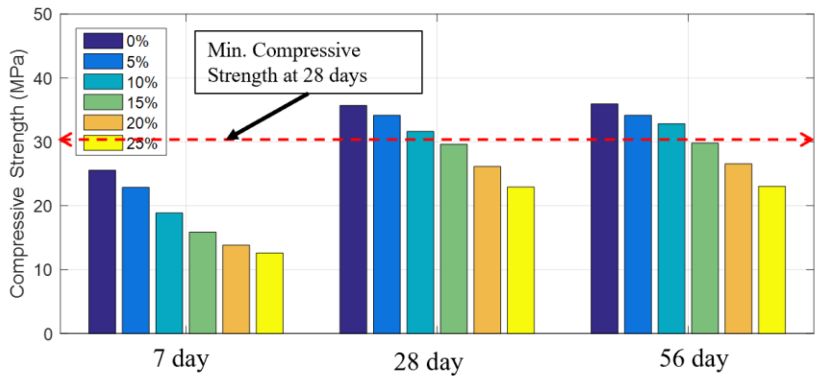
E. Compressive strength of Control and CSP Concrete

Figure 8 shows that the greatest compressive strength values achieved for the control at 7, 28, and 56 days of curing were 25.6 MPa, 35.7 MPa, and 35.9 MPa, respectively. CSP 5-20 mm had lower compressive strength than control but was higher than CSP 5-14 mm. After 56 days of curing, CSP 5-20 mm at 5% replacement of coarse aggregate yields a good compressive strength (35.6 MPa) than 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 [49]–[51], have published similar results which were restricted to a specific particles size grading 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. The poor workability of CSP concrete, as evidenced by the slump and compacting test in Figure 8, 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. The result also shows that coconut shell particle concrete can increase strength beyond 28 days. This is because coconut shell particle absorbs water during soaking and store it in their pore structures, which act as a reservoir for the long-term growth of concrete strength [7].

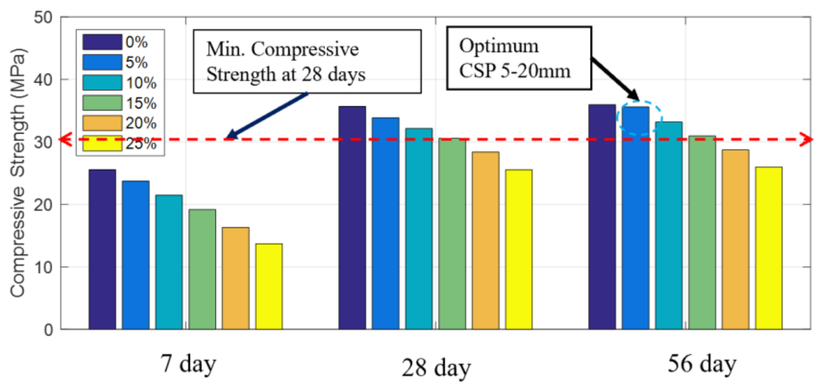
In addition, when compared to coarse aggregate, the increased surface area of CSP 5-14 mm and CSP 5-20 concrete may have resulted in a reduction in compressive strength, necessitating the use of more cement paste for adequate bonding. Again, the reduction in concrete density caused by the addition of 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 [52] minimum criterion of 17MPa for structural concrete. This is because coconut shell particles have an aggregate crushing value (ACV) which conforms to standard [21]. 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 sizes 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. After 7, 28, and 56 days of curing, Table IV illustrates the average compressive strength of control and modified concrete.

F. Split Tensile Strength of Control and CSP Concrete

Figure 9 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 [17], [53] for palm kernel shell and coconut shell concrete. 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. Moreover, bond failure between the aggregate and the cement paste was the primary cause of failure. Furthermore, as shown in Figure 9, the split 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 a 10% replacement. This could have also contributed to the increased surface area covered by CSP 5-14 mm because the particles are smaller. Table V shows the average splitting tensile strength of control and modified concrete after 7 and 28 days of curing.

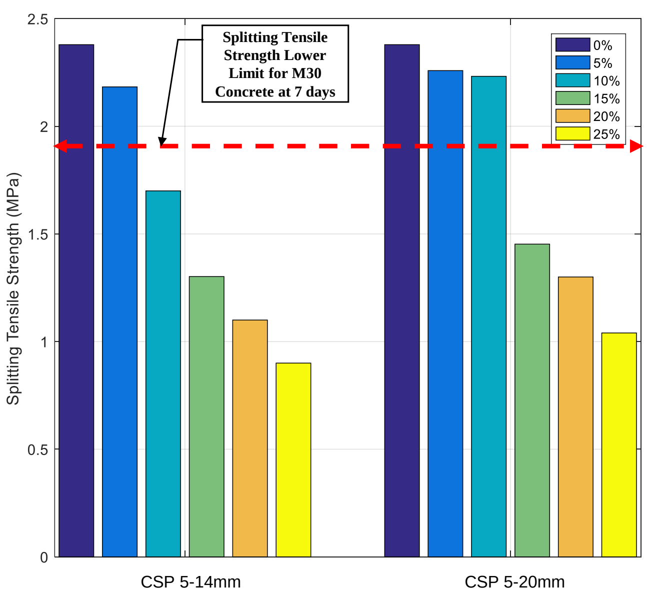


(a) CSP 5-14 mm Compressive Strength



(b) CSP 5-20 mm Compressive Strength

Fig.8Compressive strength of control and CSP after 7, 28, and 56 days curing period



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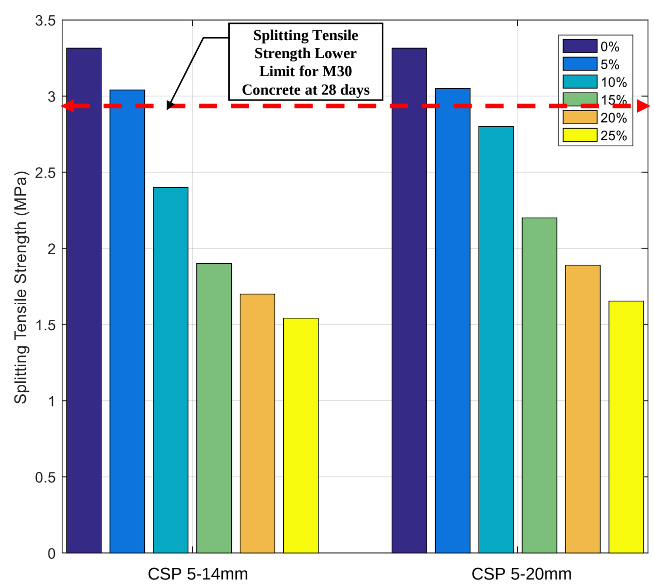

(b)

Fig.9 Split tensile strength of control and CSP after 7- and 28-days curing period

Table IV: Average compressive strength for control and CSP concrete

Percent Replacement	7 days		28 days		56 days	
	CSP 5-14 MPa	CSP 5-20 MPa	CSP 5-14 MPa	CSP 5-20 MPa	CSP 5-14 MPa	CSP 5-20 MPa
0%	25.6	25.6	35.7	35.7	35.9	35.9
5%	22.9	23.7	34.1	33.9	34.1	35.6
10%	18.9	21.5	31.6	32.1	32.8	33.2
15%	15.9	19.2	29.6	30.6	29.8	30.9
20%	13.8	16.3	26.1	28.4	26.6	28.7
25%	12.6	13.7	22.9	25.5	23.0	26.0

Table V: Split tensile strength of control and CSP concrete

Percent Replacement	7 days		28 days	
	CSP 5-14 MPa	CSP 5-20 MPa	CSP 5-14 MPa	CSP 5-20 MPa
0%	2.4	2.4	3.3	3.3
5%	2.2	2.3	3.0	3.1
10%	1.7	2.2	2.4	2.8
15%	1.3	1.5	1.9	2.2
20%	1.1	1.3	1.7	1.9
25%	0.9	1.0	1.5	1.7

IV. CONCLUSION

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

1) This study revealed that CSP (5-20 and 5-14 mm) derived from discarded coconut shells could be used as a partial substitute for coarse aggregate in structural concrete production, with up to 15% and 10% by weight substitution.

2) The workability of fresh concrete decreases as the CSP concentration rises, which was in contrast to the density.

3) At 7, 28, and 56 days of curing, the compressive strength of concrete containing CSP 5-14 and 5-20 mm attained its maximum value at 5% partial coarse aggregate replacement.

4) The compressive and split tensile strength of concrete containing partial substitutes of coconut shell particles is reduced due to the increased surface area.

5) The coconut shell particle concrete of 5-20 mm produced a less negative effect on the properties of concrete than CSP 5-14 mm. 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, high strength and density, and less water absorption.

6) 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). Comprehensive investigations are still required to improve the physical and mechanical properties with an increase in CSP substitution.

7) Coconut shell particles having a maximum aggregate size of 10 mm or smaller need to be investigated in a comparative study with other aggregates.

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