Properties of Coconut Shells as Coarse Aggregate in Concrete Production: A Productive Waste Usage

Abdulsalam Olamilekan Oparinde [1], Peter Dayo Fakoyede [2], Isaac Ajibola Fakoya [3], Silifat Adeniran-Bakare [1], Grace Agbons Aruya [4], Ewemade Cornelius Enabulele [5], Olaniyi Benjamin Adeleke [6], Ogechukwu Israel Nzemeka [7], Oketoobo Akinola Oluwatimilehin [3]

[1] *Yaba College of Technology*
Herbert Macaulay Road, Opposite WAEC office, Yaba, Lagos State, Nigeria

[2] *Federal University Oye-Ekiti*
Oye-Are Road, Oye Ekiti, Ekiti State, Nigeria

[3] *Obafemi Awolowo University*
P. M. B. 13, Ile-Ife Osun, 220282, Nigeria

[4] *Auchi Polytechnic*
Along Benin-Okene Road, P. M. B. 13, Auchi, Edo State, Nigeria

[5] *The Federal University of Technology Akure*
P. M. B. 704, Akure, Ondo State, Nigeria

[6] *Federal Polytechnic Ede*
P. M. B. 231, Ede, Osun State, Nigeria

[7] *Federal Polytechnic Oko*
P. M. B. 21, Aguata Anambra State, Nigeria

DOI: 10.22178/pos.107-9

LCC Subject Category: T1-995

Received 25.06.2024
Accepted 28.08.2024
Published online 31.08.2024

Corresponding Author:
Peter Dayo Fakoyede
fakoyedepeterdayo@gmail.com

Abstract The properties of concrete using crushed coconut shells as crushed coconut shells replaced coarse aggregate at different percentage rates of 0, 50 and 100%, which was cured at 3, 7 and 28 days. The concrete tests were carried out on workability, compressive strength, split tensile strength, sieve analysis, specific gravity and water absorption of the aggregate compared to the control (standard concrete property). The result of the study is expected to promote the use of coconut shells as a substitute for conventional coarse aggregates, which tend to act as lightweight concrete as a potential building material.

Keywords: Coconut Shells; Concrete; Aggregate; Cement; Workability; Solid Waste.

INTRODUCTION

Concrete versatility allows for comparing various mix designs such as Coren, ACI, and DoE, which contribute to significant attributes of concrete such as durability, strength, and, most importantly, cost-effectiveness in production [1]. Concrete is the most widely used material in civil engineering because of its high quality and reliability. This material has a high compression and low tension; therefore, the use of concrete today indicates that we are in its age weight [2]. Furthermore, the cost of construction materials is increasing daily because of increased demand, resource scarcity, and rising energy prices. Using alternative elements has become a global concern regarding energy efficiency and natural resource conservation. Extensive research and development are being performed to determine the innovative materials required to generate sustainable and environmentally friendly construction materials. Effective and efficient use of waste material can help alleviate some of the issues with solid waste management [3]. Aggregates account for 70-80 % of the volume of concrete, and their impact on numerous concrete qualities and properties is undeniable [4]. Because concrete comprises separate aggregate components held together by cementing material, its properties are influenced mainly by the quality of the cement paste. The cement paste-aggregate connection also influences strength [2].

The world is evolving as certain materials need to be conserved, and the demand for using certain materials is increasing alarmingly. All over the world, treated and untreated industrial byproducts, agricultural wastes, domestic waste, nonindustrial waste, and so on are used as raw materials in concrete. Agro-industrial wastes are new and alternative building materials that are abundant. One of these wastes is a coconut shell; as of 2017 [5], infrastructure development across the world created a demand for construction materials, and considering concrete is the premier civil engineering construction material, this Agro-wastes material can serve as a replacement for the natural aggregate of concrete which tends to bring about conservation of these materials and economical production [6].

Other researchers have conducted projects using alternative waste materials and industrial byproducts such as fly ash, bottom ash, recycled aggregates, foundry sand, China clay sand, crumb rubber, and glass to replace natural aggregate and investigate the properties of concretes [1-6]. Apart from the materials, a few studies have shown that coconut shells, an agricultural byproduct, can also be used as concrete aggregate.

Table 1 – Coconut Production Countries

Country	Metric tons
Indonesia	18,983,378
Philippines	14,049,131
India	11,469,837
Nigeria	288,615

This work aims to provide more data on the sieve analysis of the waste material, compressive strength, and tensile strength of coconut shell concretes at 0%, 50% and 100% coconut shells (CS) replacements as a coarse aggregate, the workability of this coconut shell (CS) concrete and most especially to know its bulk density and water absorption of the aggregate itself using the mix proportion of $1{:}1\frac{1}{2}{:}3$. To study the change in properties of concrete with CS as coarse aggregate replacement.

Literature review

Concrete is a highly versatile construction material. Concrete is the most significant building material, producing almost 10 billion tons annually [7]. As a result, the concrete industry will require many natural resources to make concrete. Concrete production expands as infrastructure development and building activities increase [8]. The approach employed to conduct this test was based on British and American measuring standards adopted by all evaluated authors in carrying out the several CS tests. The utilisation of waste items, particularly CS coconut shell as one of the ingredients, should aid in preserving the natural aggregate. Although this waste product is utilised as fuel instead of coal, consider how it may be used as a substitute in the construction business. If this material is employed as an aggregate substitute, it can perform the same function as natural aggregates. The strategy to recycle and reuse this waste material to reduce the concentrated use of natural aggregates in construction should help conserve our natural building materials. Because of its excellent strength and modulus qualities, coconut shell filler can produce novel composites [9].

According to [8], a study was conducted to compare the replacement of aggregate using control concrete with average aggregate and coconut shell (CS) concrete with 10-20% coarse aggregate replacement with CS, and I compressive strength, split tensile strength, water absorption test, and moisture migration were investigated in the laboratory. It was discovered that workability reduces with increasing CS replacement [8]. According to [10], little study has been done on the mechanical qualities of coconut using coconut shells as an aggregate alternative. More research should be conducted on the material's durability [11]. Author [9] wanted to explore the water absorption and compressive strength based on coconut shell filler particles composite, and it was discovered that the density is 1.60 g/cm^3.

According to the author [12], using coconut shells as an aggregate in manufacturing reinforced pipes is encouraged. In addition, a few noteworthy features of coconut shell, such as water absorption and specific gravity, were explored, with the average moisture content and water absorption of coconut shell being 42% and 24%, respectively, and carried three-edge bearing test, hydrostatic test, and absorption test [12]. According to [13], the coconut shell is mainly utilised as an ornament and a source of activated carbon. In contrast, the powder shell is employed in the plastic, glue, and abrasive material production industries. More light is shed as coconut shells can be helpful in the construction industry since the coconut shell-cement composite is compatible and no pretreatment is required [13]. Most notably, [14] discovered that word-based compounds, which are complex and organic, will not contaminate or leach to form harmful substances once bonded with a concrete substrate. In research conducted by Olanipekun [15] on the comparative cost analysis and strength characteristics of concrete by using crushed granular coconut and palm kernel as substitute for conventional coarse aggregate in the following ratios: 0%, 25%, 50%, 75% and 100% with mix ratios (1:1:2 and 1:2:4). Considering the strength/economic ratio it was concluded that coconut shell is more suitable than palm kernel shell (PKS) when used as a facial replacement for conventional aggregate in concrete [10, 16]. However, concrete obtained from CS exhibited a higher compressive strength than PKS concrete in the two proportions [13]. Results also indicated a 30% and 42% cost reduction for concrete produced from coconut shells and palm kernel shells, respectively. Therefore, coconut shells were more suitable than palm kernel shells when used as a substitute for conventional aggregates in concrete production.

Another study on the long-term compressive and bond strength of coconut shell aggregate concrete examined how three different curing methods affected the performance of coconut shell aggregate concrete [11]. Biological deterioration was not visible because the concrete cubes regained strength even after 365 days. Under all curing circumstances, the final bond strength of coconut shell aggregate concrete was significantly higher than the theoretical bond strength as specified in BS 8110.

The primary reason for modifying proportioning and control processes for lightweight aggregate concrete compared to regular-weight concrete is that most lightweight aggregates absorb more at higher rates. When concrete is made with lightweight aggregates that have low initial moisture contents (usually less than 8 to 10 %) and relatively high rates of absorption, it may be desirable to mix aggregates with water for a short period before the addition of cement, admixtures, and air-entraining admixture to minimise slump loss [17]. Natural stone was replaced with coconut shells at three different percentages: 0%, 50%, and 100%. The primary goal of this study was to investigate the strength and physical parameters of CS concretes after typical water curing. The performance of the concretes was evaluated using physical and mechanical parameters such as compressive strength, workability, flexural strength, and splitting tensile strength.

Using waste materials in buildings has various advantages, including cost savings, energy efficiency, and environmental protection. Waste disposal is a significant issue, and finding natural resources has become difficult owing to overexploitation. As an agricultural waste, coconut shells significantly contribute to the pollution problem. This research investigates the strength characteristics of concrete constructed with crushed granular coconut shells as a substitute for standard coarse aggregate (ACI Committee 211).

Characteristics to consider when selecting aggregate [18] include:

Cleanliness: Aggregates should be free of organic contaminants. The presence of organic material in aggregate leads to poor concrete. Oil, dust, or clay coatings on the aggregate should be avoided because they can interfere with adequate bonding.

Durability: Aggregate should be devoid of oil, dust, or clay coatings, as these might cause the material to deteriorate or change volume when exposed to the elements.

Particle shape and surface texture: Gross rough surfaces provide great friction strength and superior surface adherence to cement.

METHODOLOGY

Design of the study. The study adopts an experimental plan. This research worked based on the effects of coconut shells as a replacement for the concrete's compressive strength and tensile strength, which were determined through laboratory experiments using appropriate testing apparatus.

Samples. The primary samples of this study are as follows: 1) Concrete with granite in a ratio of 1:1$\frac{1}{2}$:3 for 12.5 mm granite; 2) Concrete with Coconut shell (CS) in ratio 1:1$\frac{1}{2}$:3 for CS.

The samples for this experiment are batched as follows:

1. Concrete of ratio 1:1$\frac{1}{2}$:3 as control (0%)
a) 1 head pan of cement.
b) 1$\frac{1}{2}$ head pan of sharp sand.
c) 3 head pans of granite

2. Concrete of ratio 1:1$\frac{1}{2}$:3 for substitution (50%)
a) 1 head pan of cement.
b) 1$\frac{1}{2}$ head pan of sand.
c) 1$\frac{1}{2}$ head pan of granite.
d) 1$\frac{1}{2}$ head pan of coconut shell (CS)

3. Concrete of ratio 1:1$\frac{1}{2}$:3 Substitution (100%)
a) 1 head pan of cement.
b) 1$\frac{1}{2}$ head pan of sharp sand.
c) s3 head pan of coconut shell (CS)

Instruments for data collection. The instruments used for data collection were grouped according to this type of experiment conducted. British Standard Specification and the American Association of State Highway and Transportation (AASHTO) are described sets of standardised tests for fresh and hardened concrete and coarse aggregates in the laboratory and the field.

These are: 1) Slump test apparatus; 2) Split tensile test apparatus; 3) Specific gravity and water absorption test; 4) Compressive stress test apparatus; 5) Sieve analysis test apparatus.

Method of data collection. Data for this study were collected from experiments conducted in the concrete laboratory. The experiments were conducted using the following types of experimental methods and specifications:

The grading was carried out on coconut shells and granite to check the sizes in the bulk quantity as specified by the American Association of State Highway and Transportation (AASHTO T30).

This was used to check the workability of the fresh concrete at a water/cement ratio of 0.45 as specified by British Standard about BS 1881; part 102, 1983.

The determination of the splitting tensile strength of cylindrical concrete samples such as moulded cylinders and drilled cores is outlined in this procedure. A diametric compressive load will be applied along the length of the sample at a continuous rate until failure occurs. This, as specified by ASTM C496. The determination of the test was carried out as specified by British Standard Specification (BS 812: Part 2: 1975)

It was carried out on each sample at 3, 7 and 28 days. This was carried out per the British Standard specification (BS 1881: Part 116: 1983.)

The data obtained from the results of the experiments were analysed using tables, graphs, and charts.

RESULTS AND DISCUSSION

This section principally deals with the results obtained from all tests: slump test, water absorption test, and compressive strength test for such aggregate size with sharp sand. It also briefly shows the sequence of the testing.

Table 2 – Sieve Analysis for Coarse Aggregates

Sieve Size, mm	MR, g	PR	CMR, g	CPR	Calc'd Percent Passing, PP	Agg. Corr. Factor from T-308, ACF	Reported Percent Passing, RPP
31.75	-	-	-	-	-	-	-
25.4	-	-	-	-	-	-	-
19.0	-	-	-	-	100	-	100
12.5	200	20	200	20	80	-	80
9.52	600	60	800	80	20	-	20
6.35	200	20	1000	100	-	-	-
4.76	-	-	-	-	-	-	-
dust	-	-	-	-	-	-	-

Notes: MR - mass retained; CMR - cumulative mass retained; PR - percentage retained; CPR - cumulative percentage retained; PP- percentage passing.

Table 3 – Slump Test

Sample ID	Sample, %	Height before slump	Height after a slump, mm	Slump, mm	Degree of workability
A	0	300	251	49	Low
B	50	300	253	47	low
C	100	300	255	45	low

Table 4 – Compressive Strength Test For 0%

Age, days	Cube No	Concrete cube weight, kg	Average compressive load	Area of cube, mm²	Compressive strength, N/mm²
3	A1	6	224100	22500	9.96
7	A2	7	244000	22500	10.84
28	A3	7.9	356000	22500	15.82

Table 5 – Compressive Strength Test For 50%

Age, days	Cube No	Concrete cube weight, kg	Average compressive load	Area of cube, mm²	Compressive strength, N/mm²
3	B1	4	140000	22500	6.22
7	B2	5.3	199000	22500	8.84
28	B3	6.7	252000	22500	11.20

Table 6 – Compressive Strength Test Result For 100%

Age, days	Cube No	Concrete cube weight, kg	Average compressive load	Area of cube, mm²	Compressive strength, N/mm²
3	C1	3.6	59000	22500	2.62
7	C2	4.1	83000	22500	3.69
28	C3	5.0	82000	22500	3.64

Table 7 – Compressive Strength Test For A, B and C

Age, days	A	B	C
3	9.96	6.22	2.62
7	10.84	8.84	3.69
28	15.82	11.2	3.64

Table 8 – Split Tensile Test Result For A

Age, days	Cube No	Concrete cube weight, kg	Average load, P	Slit tensile strength, N/mm²
3	A1	3	65000	2.047
7	A2	4	66000	2.090
28	A3	5	75084	2.390

Table 9 – Split Tensile Test Result For B

Age, days	Cube No	Concrete cube weight, kg	Average load, P	Slit tensile strength, N/mm²
3	B1	3	24000	0.764
7	B2	3.5	31000	0.975
28	B3	4.2	52779	1.680

Tabe 10 – Split Tensile Test Result For C

Age, days	Cube No	Concrete cube weight, kg	Average load, P	Slit tensile strength, N/mm²
3	C1	2	14000	0.445
7	C2	3.6	30000	0.955
28	C3	4.4	42412	1.350

Table 11 – Split Tensile Test for A, B and C

Age, days	A, N/mm²	B, N/mm²	C, N/mm²
3	2.047	0.764	0.445
7	2.09	0.975	0.955
28	2.39	1.68	1.35

Table 12 – Relative Density and Water Absorption Test Result

Test	Result
Relative density	1.1
Water absorption	22.3%

The above tables show the results of the experiment carried out on the special concrete (CS concrete) to show the effect of using coconut shell as one of the constituents of concrete in replacement with granite in a percentage of 0, 50 and 100% for curing of 3, 7 and 28 days.

In the above table, we checked for the particle size distribution after the coconut shell was broken down to be precise on the sizes of aggregate to be experimented on to know its effect on the compressive strength and tensile strength of the concrete.

Also, one of the considerations was checking the effect of workability of the concrete by comparing the control concrete (regular concrete) with the particular concrete (CS concrete) using the slump cone test, which complies with the British Standard about BS 1881; part 102, 1983. Using a water-cement ratio of 0.45 with a coarse aggregate size of 12.5 (1/2 In.)

More so, we had to know the effect of water absorption and specific gravity on the fresh concrete, which abides with the British Standard Specification (BS 812: Part 2: 1975) because of the porous surface of the CS, which can lead to an inadequate amount of water cement ratio.

The table also shows the effect of curing age on the compressive and tensile strength after it was tested, which complied with British Standard (BS 1881: Part 116: 1983) and ASTM C496, respectively.

Conclusively, Table 12 shows the water absorption and the relative density of the coconut shell, which complied with the BS 812: Part 2: 1975

Table 2 shows the sieve analysis (grading) of the coconut shell as coarse aggregate, which the report gives passes of aggregate through 19.0 mm, 12.50, and 9.52 sieve size and retained on 12.5, 9.52 and 6.35. These let us know the choice of aggregate to be used, and we considered the aggregate size 12.5 (1/2 In).

Table 3 shows the result of the slump test for checking the workability of the fresh concrete with an aggregate size of 12.5 at percentages of 0%, 50% and 100% substitution at a water/cement ratio of 0.45, which reports the workability of the concrete to be low falling under the category of slump 10-40 mm.

Based on the report extract from Tables 4 to 5 shows that the compressive strength of the concrete increases concerning the increase in curing age/days at range 5.86 N/mm^2, 4.98 N/mm^2, and 1.02 N/mm^2 for samples A, B and C, respectively.

The split tensile test result, which is in Table 6-8, shows the report of the samples, which varies from a range of 0.34 N/mm^2, 0.916 N/mm^2 and 0.905 N/mm^2 for samples A, B and C for curing ages of 3, 7 and 28 days, respectively.

CONCLUSIONS

The subsequent conclusions remained inferred after thoroughly investigating the results deduced from the project study through the graph plotted.

1. The compressive strength of the concrete cubes increases with age because concrete gains more strength during the curing age.

2. Coconut shells with a smooth surface have lower workability using a grading size of coarse aggregate of 12.5 (1/2 In) with a water-cement ratio of 0.45.

3. The strength test with different mixes shows that coconut shell concrete, where 50% of the coarse aggregate was replaced, shows properties like lightweight concrete, which can be used as filler material in framed structures.

4. The self-weight of the material is an advantage as it applies to the structure.

5. The compressive strength of concrete reduces as the replacement with coconut shell increases, which applies to the split tensile strength.

6. Additionally, using coconut shells in concrete can help reduce waste.

7. The overall strength decreases as the replacement increases compared to the control concrete.

8. Conclusively, the concrete mixed with granite as coarse aggregate has the highest strength compared to all other replacement samples because the mechanical properties of aggregate are of interest. The mechanical property that gives granite an edge over the other coarse aggregates is its toughness, which helps resist any failure by impact.

To ensure the safety of structures, the paramount aim of researching the effect of aggregate sizes on the compressive strength of concrete is achieved by stakeholders in construction work. The following measures are recommended.

1. The replacement of coarse aggregate with coconut shell should be 10%-30% to increase strength.

2. The coconut shell should be soaked to improve the saturation of the material, which will give an advantage to the water/cement ratio.

3. The curing age of the concrete material should be increased as it aids in the increase in strength of the concrete during testing.

4. This project should be continued to aid more understanding. Most significantly, tests should be carried out on the quality of the coconut shell with time to see if it disintegrates.

5. Standardised equipment should be used as the ASTM and BS codes recommend to aid result alignment.

6. The water-cement ratio should not be less than 0.45 to aid the workability and adequate mixing of material.

APPENDIX

1. Relative density and water absorption

Objective. This procedure specifies two methods for determining aggregates' relative density and water absorption. The methods are used for aggregates intended for road construction or concrete mixes.

Relative density on a saturated surface-dry basis, q_s, are used for pavement materials to be tested for mechanical properties and calculations in concrete mix design.

Water absorption, wabs, is used for calculations in the concrete mix design.

Apparent relative density, qa, may be used in production control to check if the density of the aggregate varies.

Main Principles. The preferred method described is a glass vessel method for aggregates between 5 mm and 40 mm in size. A subsidiary wire basket method for aggregates more significant than 10 mm is also described.

Required equipment.

- A drying oven with a temperature of 105 ± 5 °C;

- A balance readable to 0.5 g;

- A wide-mouthed glass vessel of 1.0 litres to 1.5 litres' capacity, with A flat ground lip and a plane ground glass digs to cover it, giving a watertight fit;

- Two dry, soft, absorbent clothes;

- A shallow tray;

- An airtight container large enough to take the sample;

- A 5 mm test sieve;

- Water free of impurities (e.g., dissolved air). Freshly boiled tap water cooled to room temperature may be used.

Sample Preparation. A sample of about 1 kg of the aggregate shall be used. The sample shall be thoroughly washed on the 5 mm test sieve to remove finer particles, e.g., clay, silt, and dust and drained.

Test Procedure

Step 1: Immerse the test sample in water in a glass vessel or jar for 24 ± 0.5 hours. The vessel should be gently stirred to release any trapped air. This can be accomplished by rapidly rotating the vessel clockwise and anticlockwise between the operator's hands. Overfill the vessel with water and slip the plane ground glass to discover the opening and ensure no air is trapped inside. Then, dry and weigh the vessel (mass B).

Step 2: Empty the vessel, drain the aggregate, and replace it with water before sliding the glass disc back into place, as in Step 1. Then, dry and weigh the vessel (mass C).

Step 3: Spread the aggregate on a dry surface.

Step 4: Spread the aggregates out not more than one stone deep on the second dry cloth and leave it exposed to air away from direct sunlight until all visible water films are removed, but the aggregate still has a damp appearance. Then, weigh the aggregates (mass A).

Step 5: Dry the aggregates in a shallow tray in the oven at 105 °C for 24 ±0.5 hours.

Step 6: Cool the sample in an airtight container and weigh (mass D).

where A is the mass of the saturated surface-dry aggregate in air (in g); B is the mass of the vessel containing the sample and filled with water (in g); C is the mass of the vessel filled with water only (in g); D is the mass of the oven-dry aggregate in air (in g).

2. Split Tensile Test

Equipment and tools: Compression Testing Machine; Combination and Centering Square; Pi Tape; Calipers; Ruler.

Materials: Concrete Samples (Cylinders); Bearing Strips; Fine Point Permanent Markers.

Procedure:

a) Verify that the compression-testing machine is in working order and that it has been calibrated for operating procedure.

b) The compression-testing machine should be calibrated on an annual basis. It should also be noted that the calibration of these machines is limited to 100,000 lb. of compressive force due to the size of the compressive machine and the size of the calibration load cells available at FSEL.

c) Prepare concrete samples for splitting tensile testing.

d) Verify that the samples do not have any significant defects that may affect the quality of the test results.

e) Carry out tests and get readings.

3. Compressive strength

Objective. All concrete designs are based on a specific strength of concrete. This may vary from project to project but is usually 15–50 MPa.

This procedure describes the method for determining the compressive strength of concrete cubes. Concrete strength is usually tested at an ace of 28 days.

Main Principles. Test specimens shall be concrete cubes made, cured, and stored by BS 1881. Do not test cubes made in poorly assembled moulds or misshapen. State the reasons in the test report. Remove any projecting fins.

Required equipment: 1) Compression Testing Machine; 2) Auxiliary Plants When auxiliary platen is used, the top auxiliary platen shall rest on and be aligned with the cube; 3) A balance with a minimum of 10 kg capacity, readable and accurate to 1 g.

Test procedure:

Step 1: Weigh each specimen, whether received or saturated.

Step 2: Check nominal dimensions and measure each specimen.

Step 3: Determine the density for each specimen.

Step 4: Immerse any cubes that have not been cured in water or whose surfaces have dried in water for at least 5 minutes. Test the cubes from the curing or density water tank while wet.

Step 5: Carefully centre the cube on the lower plate, ensuring that the load is delivered to two opposing cast faces of the cube.

Step 6: Without shock, apply and raise the load continuously at a nominal rate between 12 MPa/min. and 24 MPa/min. Record the maximum load applied to the cube until no more significant load can be sustained.

Calculations. Calculate the cross-sectional area of the cube face from the checked nominal or measured dimensions. Calculate the compressive strength of each cube by dividing the maximum load by the cross-sectional area. Express the result to the nearest 0.5 MPa (N/mm^2). Calculate the average test results for the two specimens of the same size and dimension made from the same sample of fresh concrete. This is reported as the Compressive Strength of the test sample.

4. Sieve analysis test

This procedure covers the mechanical analysis of aggregate recovered from bituminous mix samples by AASHTO T 30. This FOP utilises the aggregate recovered from the ignition oven used in AASHTO T 308. AASHTO T 30 was developed to analyse extracted aggregate and thus includes references to extracted bitumen and filter elements, which do not apply.

Sieve analyses determine the gradation or distribution of aggregate particles within a given sample to determine compliance with design and production standards.

Apparatus: a) Balance or scale: Capacity sufficient for the sample mass, accurate to 0.1 % of the sample mass or readable to 0.1 g; b) Sieves; c) Mechanical sieve shaker; d) Suitable drying equipment (see FOP for AASHTO T 255)

Containers and utensils: A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

Sample Sieving: 1) In this procedure, the sample must be shaken over nested sieves. Sieves are selected to furnish information required by the specification; 2) Sieves are nested to decrease size from the top to the bottom, and the sample, or a portion of the sample, is placed on the top sieve; 3) Sieves are shaken in a mechanical shaker for approximately 10 minutes, or the minimum time determined to provide complete separation for the sieve shaker being used as established by the Time Evaluation.

Procedure:

1. Using the aggregate sample obtained from the FOP for AASHTO T 308, determine and record the mass of the sample to 0.1 g (M).

2. Nest a sieve, such as a 2.0 mm (No. 10), above the 75 μm (No. 200) sieve.

3. Place the test sample in a container and add sufficient water to cover it. Add a detergent, dispersing agent, or other wetting solution to the water to thoroughly separate the material finer than the 75 μm (No 200) sieve from the coarser particles. There should be enough wetting agents

to produce a small amount of suds when the sample is agitated. Excessive suds may overflow the sieves and carry material away with them.

4. Agitate vigorously to ensure complete separation of the material finer than 75μm (No 200) from coarser particles and bring the delicate material into suspension above the coarser material. When using a mechanical washing device, exercise caution to avoid sample degradation.

Note 1: When mechanical washing equipment is used, introducing water, agitating, and decanting may be a continuous operation. Do not overflow or overload the 75 μ (No. 200) sieve.

Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, careful not to pour out the coarser particles.

Add a second water change to the sample remaining in the container, agitate, and repeat Step 5. Repeat the operation until the wash water is clear. Continue washing until the agent is removed.

Rinse the material on the nested sieve until water passing through the sieve is clear.

Remove the upper sieve and return the material retained to the washed sample.

Rinse the material retained on the 0.75 mm (No 200) sieve until water passing through the sieve is clear.

Return all material retained on the 0.75 mm (No 200) sieve to the washed sample by flushing it into it.

Dry the washed aggregate to constant mass per the FOP for AASHTO T 255, and then cool before sieving. Record the "dry mass after washing."

Select sieves to furnish information required by the specifications. Nest the sieves in order of decreasing size from top to bottom and place the sample on the top sieve or a portion of the sample.

Place sieves in a mechanical shaker and shake for the minimum time determined to provide complete separation for the sieve shaker being used (approximately 10 minutes).

Note 2: Excessive shaking (more than 10 minutes) may result in sample degradation.

Determine the mass retained on each sieve (individual/cumulative) to the nearest 0.1 g. Ensure that all material trapped in entire openings of the sieves is cleaned out and included in the mass retained.

Note 3: For sieves No 4 and more extensive, material trapped in less than a whole opening shall be checked by sieving over a full opening. Use coarse wire brushes to clean the 600 μm (No 30) and more giant sieves and soft bristle brushes for smaller sieves.

5. Slump test

Objective. The Slump Test is one of several methods for determining the workability of fresh concrete.

Main Principles. The slump test is done by filling a specified mould with freshly mixed concrete and measuring the slump after the mould removal. The method applies to medium to high workability cohesive concrete with a maximum aggregate size of 40 mm.

Required equipment. A slump mould of galvanised iron or steel. The mould shall be in the form of a gut-off gone with the following internal dimensions: diameter of base: 200 ± 2 mm; diameter of top: 100 ± 2 mm; height: 300 ± 2 mm; Scoop; Sampling tray; shovel; Tamping rod, made from straight steel bar, 16 mm diameter and 600 mm long; the rule graduated from 0 mm to 300 mm at 5 mm intervals, with the zero point at one end.

Sampling. The sample can be taken from a laboratory mix a maximum of 2 minutes after mixing, and determination of slump should commence instantly. If the concrete is delivered in a mixing truck, the slump may be measured using a sample from the initial discharge.

Test Procedure

Step 1: Ensure that the mould's inner surface is clean and damp or dry. Place the bottom of the mould on a clean, smooth, horizontal, firm, and non-absorbent surface (e.g., a steel plate.

Step 2: While firmly holding the mould, fill it with fresh concrete within 2 minutes after mixing. The mould shall be filled in three layers, each approximately one-third of the height of the mould when tamped.

Step 3: Tamp each layer with 25 strokes of the tamping rod, distributed uniformly over the gross section of the layer. Tamp each layer to its full depth.

Step 4: Heap the concrete above the mould before the top layer is tamped. After the top layer has been tamped, strike off the concrete level with the top of the mould with a sawing motion of the tamping rod.

Step 5: With the mould still held down, clean away excess concrete found outside of the mould.

Step 6: Remove the mould from the concrete by raising it vertically, slowly, and carefully for 5 to 10 seconds. The entire operation, from the start of filling to the removal of the mould, shall be carried out without interruption and completed within 2 ½ minutes.

Step 7: Immediately after removing the mould, measure the slump to the nearest 5 mm by using the rule to determine the difference between the mould height and the highest point of the tested specimen.

REFERENCES

1. Peter Dayo Fakoyede, Oparinde Abdulsalam Olamilekan, Adeleke Olaniyi Benjamin, Ewemade Cornelius Enabulele, Nzemeka Ogechukwu Israel, Grace Agbons Aruya, Jimoh Bode Jacob, Chibuike Godswill Nzeanorue, Habeeb Yusuf Akanji, & Ikudehinbu Temitope. (2024). Comparison of Coren mix design with other international mix (ACI and DoE) design methods. *World Journal of Advanced Research and Reviews, 23*(1), 2522–2539. doi: 10.30574/wjarr.2024.23.1.2230

2. Shetty, M. S. (2006). *Concrete technology, theory and practice*. N. d.: Chand (S.) & Co Ltd.

3. Iyeke, D. (2011). *Status of Waste Management. Integrated Waste Management* (Vol. II). doi: 10.5772/20439

4. Gunasekaran, K., Kumar, P. S., & Lakshmipathy, M. (2011). Mechanical and bond properties of coconut shell concrete. *Construction and Building Materials, 25*(1), 92–98. doi: 10.1016/j.conbuildmat.2010.06.053

5. Wikipedia. (N. d.). *List of countries by coconut production*. Retrieved from https://en.wikipedia.org/wiki/List_of_countries_by_coconut_production

6. Langer, W., Drew, L., Sachs, J. (2004). *Aggregate and the environment*. N. d.: American Geological Institute.

7. Meyer, C. (2009). The greening of the concrete industry. *Cement and Concrete Composites, 31*(8), 601–605. doi: 10.1016/j.cemconcomp.2008.12.010

8. Yerramala, A., & Ramachandrudu. (2012). Properties of concrete with coconut shells as aggregate replacement. *International Journal of Engineering Inventions, 1*(6), 21–31.

9. Bhaskar, J., Singh V. K. (2012). Water Absorption and Compressive Properties of Coconut Shell Particle Reinforced-Epoxy Composite. *Journal of Materials and Environmental Sciences, 4*(1), 113–118.

10. Olanipekun, E. A., Olusola, K. O., & Ata, O. (2006). A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. *Building and Environment, 41*(3), 297–301. doi: 10.1016/j.buildenv.2005.01.029

11. Gunasekaran, K., Annadurai, R., & Kumar, P. S. (2012). Long term study on compressive and bond strength of coconut shell aggregate concrete. *Construction and Building Materials, 28*(1), 208–215. doi: 10.1016/j.conbuildmat.2011.08.072

12. Gunasekaran, K., Annadurai, R., Chandar, S. P., & Anandh, S. (2017). Study for the relevance of coconut shell aggregate concrete non-pressure pipe. *Ain Shams Engineering Journal, 8*(4), 523–530. doi: 10.1016/j.asej.2016.02.011

13. Kaur, M., & Kaur, M. (2012). A Review on Utilisation of Coconut Shell as Coarse Aggregates in Mass Concrete. *International Journal of Applied Engineering Research, 7*(11), 1–3.

14. Basri, H. B., Mannan, M. A., & Zain, M. F. M. (1999). Concrete using waste oil palm shells as aggregate. *Cement and Concrete Research, 29*(4), 619–622. doi: 10.1016/s0008-8846(98)00233-6

15. Olanipekun, E. A., Olusola, K. O., & Ata, O. (2006). A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. *Building and Environment, 41*(3), 297–301. doi: 10.1016/j.buildenv.2005.01.029

16. Md. Sadiqu, N., Rahman Sob, H., Shiblee Sa, Md., & Saiful Isl, Md. (2012). The Use of Coconut Fibre in the Production of Structural Lightweight Concrete. *Journal of Applied Sciences, 12*(9), 831–839. doi: 10.3923/jas.2012.831.839

17. Johnson Alengaram, U., Mahmud, H., & Jumaat, M. Z. (2010). Development of lightweight concrete using industrial waste material, palm kernel shell as lightweight aggregate and its properties. *2010 2nd International Conference on Chemical, Biological and Environmental Engineering, 3*, 277–281. doi: 10.1109/icbee.2010.5649228

18. Shirley, D. E. (1995). *Introduction to Concrete*. London: Macmillan Press.