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An Empirical Study of Agro-Waste as Coarse Aggregate in Triple-Layer RCC Beams

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Abstract—**This paper examined the viability of using agricultural waste materials as coarse aggregate in three-layered concrete. Concrete layers included crushed stone, and coarse aggregate replacements of periwinkle shell, and clamshell. For each sample type, the layer depth, and mix ratio varied. The physical and mechanical properties of the concrete beams and cube samples were then determined. Test results showed that while the bending capacity, shear resistance, and tensile strength can be improved by employing the configurations of beam PC-3 and PC-5, other mechanical properties like compression strength cannot be improved. Clamshell and Periwinkle shells have many environmental benefits that make them suitable alternative aggregates in construction.**

Keywords- Stiffness, Ductility Index, Flexural Strength, Periwinkle shell, Clamshell.

I. Introduction

Concrete, a heterogeneous mixture of cement, aggregates, and water, is one of the most popular building materials used in the ever-growing construction industry. According to [1] the construction industry globally is expected to reach $10.5 trillion by 2023, with a 4.2% compound annual growth rate (CAGR) in 2018 and 2023. Due to the growing need to meet global demands (construction of structures for the ever-growing population), the demand for natural resources required for the production of concrete is high, hence resulting in a high cost of concrete production. The availability of these materials determines the global cost of concrete production. Also, in a bid to reduce the amount of global CO2 emission, with the construction industry responsible for 6% of CO2 during cement production [2], researchers have sought out alternative materials to replace/supplement cement in concrete. This intensive research has not been limited only to cement alternatives but also aggregate alternatives which in general contribute up to 75% of the volume of ordinary portland concrete [3], and their (gravel, and crushed stone) continuous use is considered unsustainable as the demand for these materials rapidly approaches the point of exceeding the rate of natural renewal [4]. This research has created the opportunity for the use of agro-waste in the construction industry. A varying number of agro-waste materials are being used in the production of concrete as a partial substitution for cement, aggregates, and reinforcing materials [5].

Offiong and Akpan (2017) [6] conducted research to assess the physio-chemical properties of periwinkle shell ash (PSA), a byproduct of periwinkle when used to partially replace cement in concrete. During this research, the compressive strength of PSA-cement concrete was investigated with calcined PSA used to replace cement up to 40%. [6] concluded that PSA calcined to a temperature range of 800-1000oC is structurally sound for use as a partial substitution for cement in concrete with PSA-cement concrete recording the highest strength activity index between that temperature range. Similarly, [7] conducted a study to investigate the effect on concrete when periwinkle shells are used as coarse aggregate. During this study, periwinkle shells were used to replace conventional coarse aggregates at varying replacement levels in concrete. In concluding compressive strength test conducted after 28-days, according to the [7], using 35.4 percent and 42.5 percent periwinkle inclusion for 1:2:4 and 1:3:6 concrete mixes, respectively, may minimize the cost of concrete production by 14.8 percent and 17.5 percent while maintaining the minimum 28-day predicted strength for both mixes.

Lately, the practice of multi-layers in structural applications has become prevalent in the construction industry. Quite a lot of scholars in the field of structural engineering have published on two or three-layer reinforced concrete (RC) beams, with the greater part of papers concentrating on the structural behaviour of composite sections such as steel-concrete assemblages, where the layers are connected by mechanical devices.

Dung et al., (2021) [8] used ANSYS software to simulate two-layered RC beams, after which they tested these two-layered reinforced concrete beams and looked at varying steel fiber to concrete configurations. The authors concluded that introducing steel fibers to concrete would meaningfully improve some mechanical properties, such as crack reduction and improved load capacity in beams. This result was confirmed by [9], who concluded that the load against vertical displacement and load against compression deformation relationships between two-layer and three-layer concrete beams do not change much in their study of multi-layer steel fiber reinforced concrete beams. [10] investigated the stability of a three-layer shear-deformable partial composite column. This study found that "increasing the interlayer slip modulus in composite column elements with partial interaction magnifies the shear deformation effects".

John et al., (2020) [11] studied the effectiveness of two-layered RCC beams with different concrete grades. During this research, two-layered beams were cast with layers comprised of a layer of clamshell aggregate and another of conventional coarse aggregate (crushed stone) while the configuration variables included depth and mix ratio. [11] concluded that the amount of crushed stone aggregates can be reduced by creating a half layer of clamshell aggregate at the tensile zone and another half of crushed stone at the compressive zone. It was well noted that this configuration has the same load-carrying capacity as beams produced entirely of conventional coarse aggregates. Similarly, [12] investigated the effect on the mechanical properties of two-layered RCC beams with periwinkle shell as coarse aggregate, and depth and mix ratio as variables. [12] concluded that the inclusion of periwinkle-shell aggregate at both layers (compression and tension) not only improved the ultimate load-carrying capacity but also increased the ductility and toughness of the beam.

In this paper, the authors aim to investigate the mechanical properties of three-layered reinforced concrete beams. The sample beam layers are made up of periwinkle shell aggregate concrete, clamshell aggregate concrete, and normal concrete (conventional coarse aggregate). The choice of the locally sourced materials depended on three major factors: economical value, compatibility, and availability.

II. MATERIALS AND METHOD

A. *Materials*

Grade 42.5 Portland limestone cement conforming to [13], fresh river sand as fine aggregate conforming to [14], crushed stone as coarse aggregate conforming to [15], and clean water conforming to [16] was used to produce the test samples. Formworks and internal rebars used were according to [17] and [18] respectively.

B. *Method*

A total number of five varying sample configurations was used for constructing ten reinforced concrete rectangular beams for the purpose of carrying out this experimental investigation. Constructed beams measured (100 x 150 x 1200) mm and included deformed steel bars measuring 2Ø8mm at the tensile zone, 2Ø6mm at the compression zone, and Ø6mm along the shear span spaced at 225mm($^{C}/_{C}$). RCC beams were designed to meet the requirement of the Eurocode 3 and subjected to a two-point loading test in accordance with BS 1881-118 (1983). While cubes samples of (150 x 150 x 150) mm were cast. Beam configurations employed are described below:

Beam SG1: This represents the reference sample type constructed with crushed stone aggregate concrete with a single concrete mix ratio of 1:2:4. A schematic representation is shown in Figure 1(a).

Beam PC-1: This represents three-layered reinforced concrete beams shown in Figure 1(b), and produced with a crushed stone aggregate concrete mix of 1:2:4 occupying a depth of 90mm at the compression face (Layer I), a clamshell aggregate concrete mix of 1:2:3 occupying a depth of 30mm (Layer II), and periwinkle shell aggregate concrete mix of 1:2:1 occupying a depth of 30mm at the tension face (Layer III).

Beam PC-2: This represents three-layered reinforced concrete beams shown in Figure 1(c), and produced with a crushed stone aggregate concrete mix of 1:2:4 occupying a depth of 70mm at the compression face (Layer I), a clamshell aggregate concrete mix of 1:2:3 occupying a depth of 40mm (Layer II), and periwinkle shell aggregate concrete mix of 1:2:1 occupying a depth of 40mm at the tension face (Layer III).

Beam PC-3: This represents three-layered reinforced concrete beams shown in Figure 1(d), and produced with a crushed stone aggregate concrete mix of 1:2:4 occupying a depth of 90mm at the compression face (Layer I), periwinkle shell aggregate concrete mix of 1:2:1 occupying a depth of 30mm (Layer II), and clamshell aggregate concrete mix of 1:2:3 occupying a depth of 30mm at the tension face (Layer III).

Beam PC-4: This represents three-layered reinforced concrete beams shown in Figure 1(e), and produced with a crushed stone aggregate concrete mix of 1:2:4 occupying a depth of 70mm at the compression face (Layer I), periwinkle shell aggregate concrete mix of 1:2:1 occupying a depth of 40mm (Layer II), and clamshell aggregate concrete mix of 1:2:3 occupying a depth of 40mm at the tension face (Layer III).

Beam PC-5: This represents two-layered reinforced concrete beams shown in Figure 1(f) and produced with a combination of clamshell aggregate concrete mix of 1:2:3 and periwinkle shell aggregate concrete mix of 1:2:1 occupying a depth of 60mm at the tension zone (Layer I), and crushed stone aggregate concrete mix of 1:2:4 occupying a depth of 90mm at the compression face (Layer II).

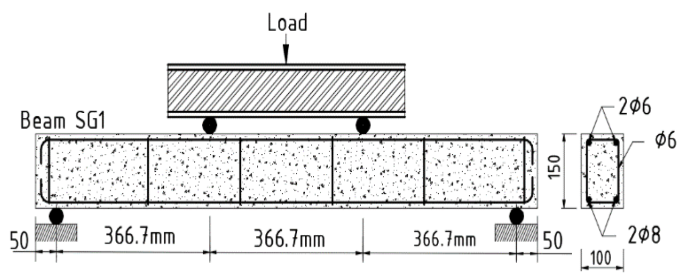

Figure 1(a). Beam SG1 Configuration

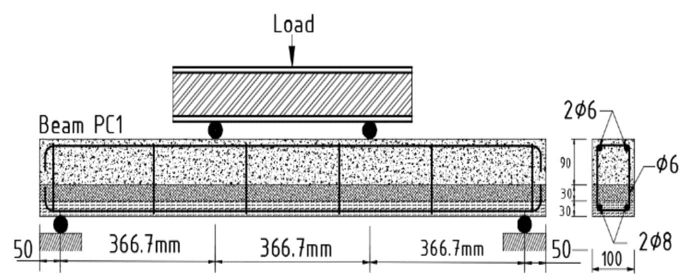

Figure 1(b). Beam PC1 Configuration

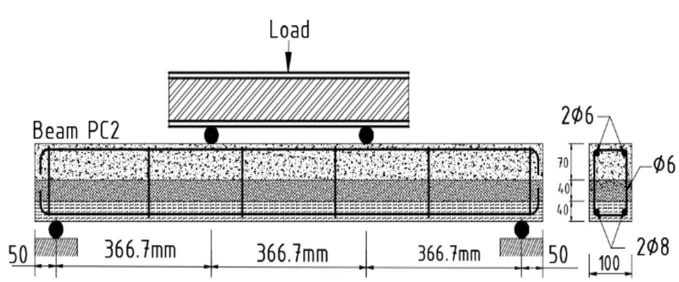

Figure 1(c). Beam PC2 Configuration

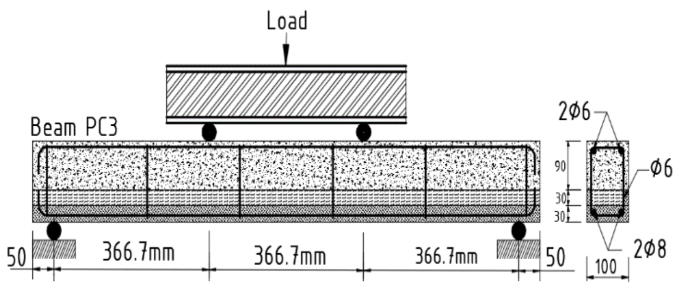

Figure 1(d). Beam PC3 Configuration

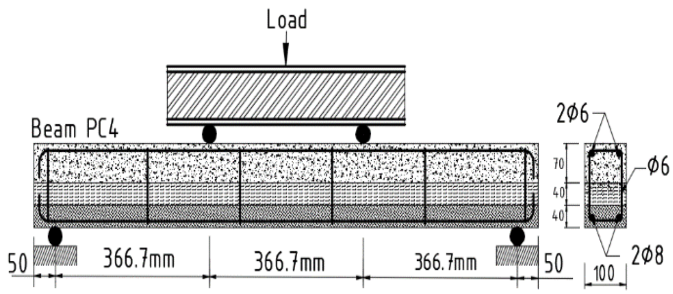

Figure 1(e). Beam PC4 Configuration

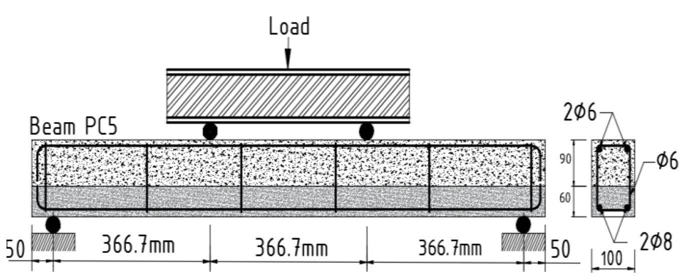

Figure 1(f). Beam PC5 Configuration

III. Results and Discussion

A. Stiffness

Figure 2 presents the load against deflection response of the beam specimens as a relationship curve when subjected to flexure. The ultimate load-carrying capacity of each beam sample is discussed below:

Beam SG1: On subjection to loading, beam SG1 yielded (cracked) at a yield load of 29.43kN at a deflection of 4.18mm. Further loading on beam SG1 caused it to fail at an ultimate failure load of 35.32kN and deflection of 7.68mm. Beam SG1 failed due to flexural shear occurring at mid-span.

Beam PC-1: On subjection to loading, beam PC-1 cracked at a yield load of 29.43kN at a deflection of 6.08mm. Further loading on beam PC-1 caused it to fail at an ultimate failure load of 31.39kN and deflection of 7.68mm. The load-carrying capacity of beam PC-1 is 11.12% lesser than the reference beam. Failure of beam PC-1 was due to flexure.

Beam PC-2: Application of load resulted in an initial deflection of 7.25mm at a yield load of 29.43kN due to flexural stress.

Further loading resulted in complete failure at a load of 34.34kN and deflection of 9.59mm. The load-carrying capacity of beam PC-2 is 2.77% lesser than the reference beam. Beam PC-2 failed due to flexure occurring at mid-span.

Beam PC-3: Initial cracking occurred at a deflection of 5.44mm and load application of 29.43kN and completely failed at a load of 39.24kN at a deflection of 7.80mm due to shear failure. The load-carrying capacity of beam PC-3 is 9.99% higher than the reference beam.

Beam PC-4: The first crack developed at a deflection of 5.81mm at a yield load of 29.43kN. On continued load application, compression stresses were developed and led to the formation of flexural cracks. Beam PC-4 ultimately failed at a deflection of 6.89mm and failure load of 32.37kN. The load-carrying capacity of beam PC-4 is 8.35% lesser than the reference beam.

Beam PC-5: The beam yielded a deflection of 5.39mm and a load of 28.43kN. On continued loading, beam PC-5 failed due to flexural stress at a deflection of 7.29mm and an ultimate failure load of 39.24kN. In the comparison of beam PC-5 and the reference beam, beam PC-5 was confirmed to be 9.99% higher than the reference beam.

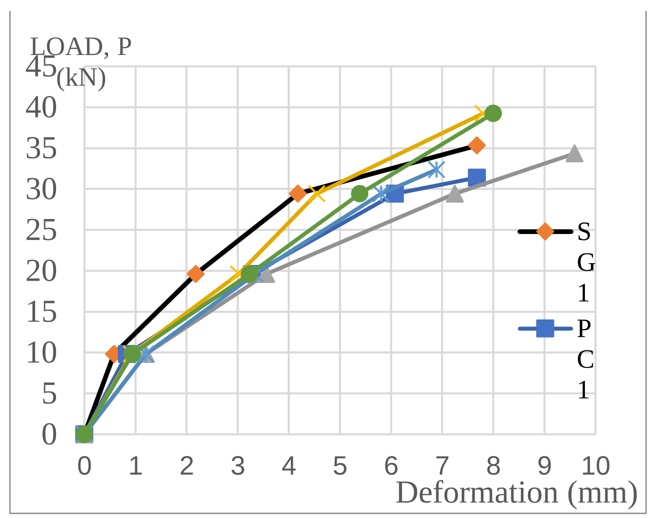

Figure 2. Failure Load vs Deformation for Sample Types

B. Ductility Index

In a comparison of their (sample beams) deformation at ultimate failure load and deformation at yield load, the ductility index of the sample beams is presented in Figure 3. Beam PC-3 exhibited a more ductile behavior than the other beam configurations with a ductility index of 1.43. However, beam PC-3 displayed a less ductile behavior compared to the reference beam (1.84).

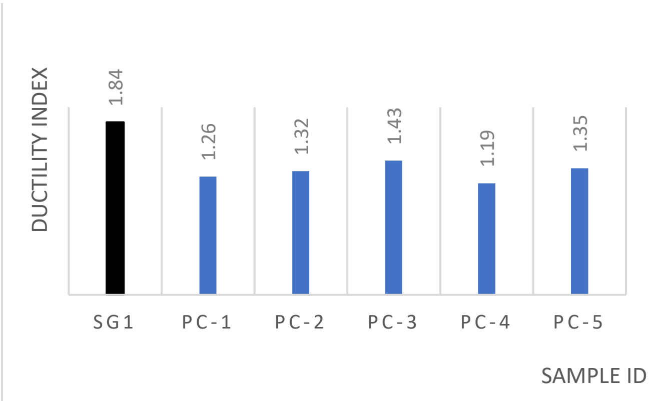

Figure 3. Ductility Index of Sample Beams

C. Bending Capacity

The bending capacity of the sample beams is shown in Figure 4. From Figure 4 it is observed that while beams PC-1, PC-2, and PC-4 recorded 6.28kNm, 6.87kNm, and 6.47kNm respectively, and failed to exceed the bending capacity of the reference beam (7.06kNm), which was at least 2.69% greater, beams PC-3 and PC-5 show an increased bending capacity of 11.19% compared to the reference beam with both beam samples recording a bending capacity of 7.85kNm each. This demonstrates that employing the configurations of both beam samples can improve the bending resistance of reinforced concrete beams.

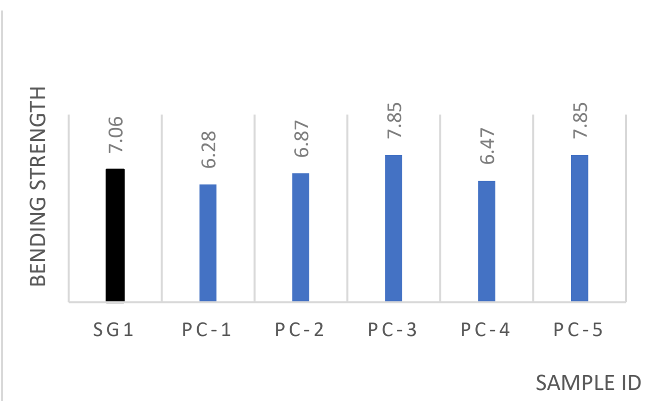

Figure 4. Bending Capacity of Sample Beams

D. Shear Strength

The shear strength of the sample beams is shown in Figure 5. From Figure 5 it is observed that while beams PC-1, PC-2, and PC-4 recorded 16.74kN/m^2, 18.31kN/m^2, and 17.26kN/m^2 respectively, and failed to exceed the shear capacity of the reference beam (18.84kN/m^2), which was at least 2.81% greater beams PC-3 and PC-5 show an increased bending capacity of 11.09% compared to the reference beam with both beam samples recording a shear strength of 20.93kN/m2 each. This demonstrates that employing the configurations of both beam samples can improve the resistance to shear of reinforced concrete beams.

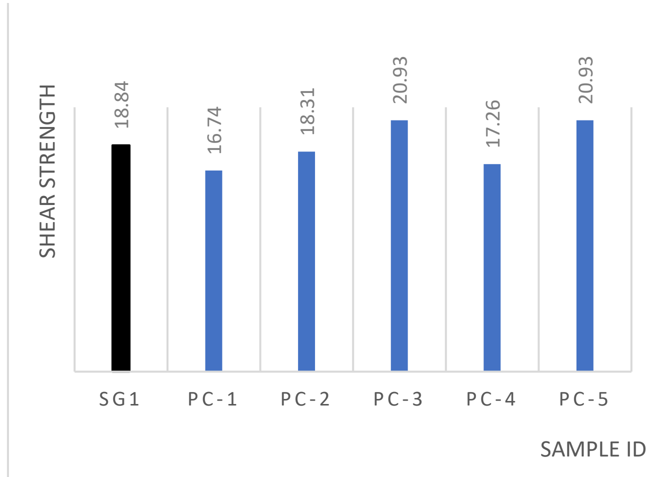

Figure 5. Shear Strength of Sample Beams

E. Tensile Strength

The tensile strength of the sample beams is shown in Figure 6. From Figure 6 it is observed that while beams PC-1, PC-2, and PC-4 recorded 8.37kN, 9.16kN, and 8.63kN respectively, and failed to exceed the bending capacity of the reference beam (9.42kN), which was at least 2.76% greater, beams PC-3 and PC-5 show an increased bending capacity of 11.04% compared to the reference beam with both beam samples recording a bending capacity of 10.46kN each. This demonstrates that employing the configurations of both beam samples can improve the resistance of reinforced concrete beams to tensile stresses.

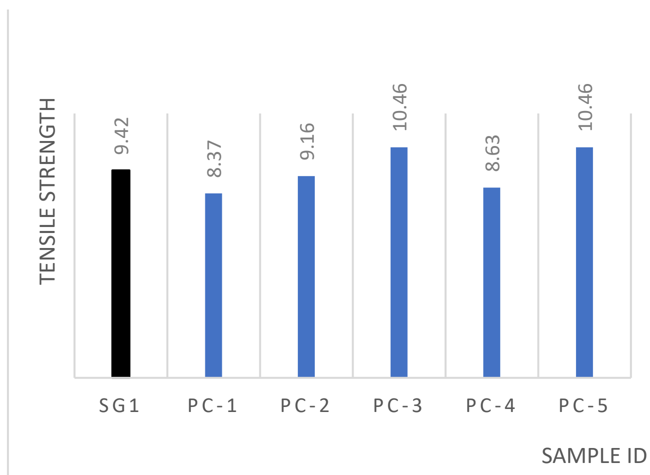

Figure 6. Tensile Strength of Sample Beams

F. Compressive Strength

Figure 7 demonstrates the compressive strength of concrete cubes of sample types. Compressive strength test results after 28 days show that none of the sample configurations exceeded the compressive strength of the reference sample(20.13MPa) which was at least 19.72% greater. Conclusively, the resistance to compression cannot be improved with these configurations.

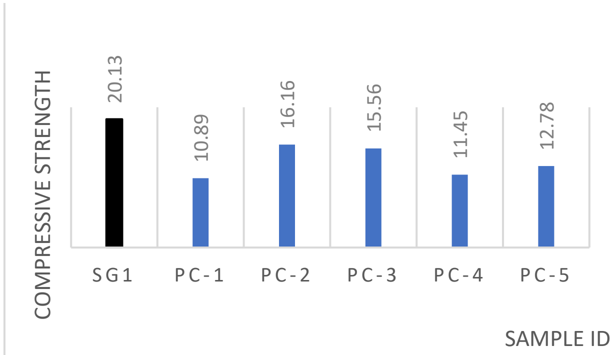

Figure 7. 28-day Compressive Strength of Sample Cubes

IV. CONCLUSION

Based on the findings, the following conclusions were made:

While the designs of beam PC-3 and beam PC-5 can enhance shear resistance, bending capacity, and shear and tensile strength, other mechanical parameters such as compression strength cannot be improved when compared to the control beam. The study also revealed that agro-waste can be used as coarse aggregate in three-layer RC beams.

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