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# Effect of Green Admixtures on the Mechanical Properties of Concrete Composite

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## Abstract
*The study was carried out to evaluate the suitability of organic admixture in concrete production. Six sets of concrete were made by partially replacing the fine aggregates (sand) and coarse aggregates (gravel) with 0, 5, 10, 15, 20 and 25% of sawdust and periwinkle shells respectively, in the presence of 0, 0.5, 1, 1.5, 2 and 2.5% cassava starch. The compressive strength and density of the six concrete groups were tested, in accordance with American Society for Testing and Materials (ASTM) International approved guidelines. Findings from the laboratory investigations indicated that the sawdust and periwinkle admixtures generally reduced the concrete compressive strength, as their proportion in the concrete increased from 0 to 25%; while the cassava tends to increase the concrete's compressive strength. The compressive strength of the concrete declined from 25.2 to 10.3 MPa, 27.1 to 11.7 MPa, 30.7 to 13.6 MPa, 31.4 to 14.5 MPa, 30.9 to 14.2 MPa, and 28.4 to 13.8 MPa, after the incorporation of 25% sawdust and 25% periwinkle shells, as partial replacement for sand and gravels respectively, in the presence of 2.5% cassava starch. Furthermore, the results revealed that the compressive strength of the concrete increased non-linearly, as the cassava starch volume increased from 0 to 2.5%. However, the concrete set produced from 20% sawdust and 20% periwinkle shells was light-weight and its compressive strength was within the limit of 17 MPa recommended by Nigeria Industrial Standard (NIS) for light-weight concrete required for residential buildings construction. The findings of this study revealed that agricultural waste materials are suitable admixture materials in the concrete industry.*
**Keywords:** *Compressive strength, concrete, residential buildings, waste management, wood*

## INTRODUCTION
Concrete is a composite material that consists of primarily of cement, fine aggregates, and coarse aggregates. At times reinforcement materials and admixtures, which are considered as secondary materials, are added to concrete to improve its mechanical properties. Concrete has a lot of domestic and industrial applications, due to its appreciable mechanical properties, and ease of moulding into various shapes and sizes (Ravikumar *et al*., 2015; Eboibi *et al*., 2022). The mechanical properties of concrete govern its stability and durability, during field applications, as most concrete structural failures are attributed to poor quality concrete used for the construction of such structures (Oyawa *et al*., 2016). Some engineering structures where concrete are widely utilized include: bridges, rigid pavement (roads), dams, nuclear plants shield and vibration dampener (Nishant *et al*., 2016).

Concrete strength properties are highly influenced by the following factors: the cement grade and type used, the strength of the aggregates used, concrete production technique, mix ratio, curing duration and method adopted, and the addition of admixture and additives (Ajagbe *et al*., 2018; Akpokodje *et al*., 2019; Rahman 2020, Akpokodje *et al.,* 2020). Concrete produced with well-graded soil tends to have better (higher) compressive strength when compared to concrete produced with poorly graded soil with silt/clay. This was verified by researches carried out by Neville (2011) and Akpokodje *et al*. (2021a). Rahman (2020) reported that the compressive strength produced with different types of fine aggregates declined from 19.73 MPa to 13.61 MPa, as the fineness modulus of the sand decreased from 2.61 to 1.57. According to Erofeeva (2018), high-quality concrete plays a vital role in mechanical engineering jobs. Similarly, Kalashnikov *et al*. (2019) stated that high-quality concrete composite is a good substitute material for polymer composites, and concrete is more environmentally friendly than polymer.

According to Bu *et al*. (2017), a high percentage of fine aggregates in concrete have negative consequences on its strength properties, as the compressive and flexural strength of concrete is directly proportional to its sand content. Concrete being a composite material, its' compressive and tensile strengths are influenced by the volume of the matrix (cement gel) in the concrete. The lower cement-to-sand ratio tends to create a poor bonding effect situation, which can lead to the production of concrete with poor interfacial adhesion, among the fine aggregates, coarse aggregates, and the cement gel matrix (Eboibi *et al*., 2022; Papy and Timothée, 2023).

Additives and admixtures play an essential role in strength development and stability in concrete. Additives are usually used to substitute limestone cement, while admixtures are normally used to substitute the aggregates used for concrete production (Portland Cement Association [PCA], 2023). There are basically two types of additives, namely the inorganic ones and organic (green) ones. Recently, organic additives are been favoured over inorganic (synthesized) ones due to the problems of climate change and other related issues (Akpokodje *et al*., 2021b). Organic additives and admixture, being natural materials tend to be environmentally friendly, and readily/cheaply available; though some of their engineering properties may be lower than those of their manufactured counterparts (Daramola *et al*., 2018; Umurhurhu and Uguru, 2019). Sawdust has a lot of engineering applications ranging from a partial replacement for composite production (including concrete and sandcrete) to a bio-remediation enhancer (Uguru *et al*., 2020).

Although, there are numerous studies on the use of agricultural materials to substitute for inorganic materials in concrete composites (George, 2014; Joseph and Xavier, 2016; Esegbuyota *et al*., 2019), there is still a scarcity of information on the hybridization of organic materials, as admixtures in concrete production. Therefore, the main aim of this study is to evaluate the influence of sawdust, periwinkle shells, and cassava starch, as admixture materials in the concrete industry. The results obtained from this research will also be helpful in the waste management industry, as two of the admixture materials (sawdust and periwinkle shells) are considered as agricultural waste materials.

## MATERIALS AND METHODS

### Materials

***Cement***

Portland limestone cement (PLC) - grade 42.5, which is in compliance with recommendation of Nigeria Industrial Standard - NIS-444, was used to produce the concrete.

***Dried cassava starch***

The dried cassava starch was obtained from the food processing laboratory of the Department of Agricultural Engineering, Delta State University of Science and Technology, Ozoro, Nigeria.

***Fine aggregates***

Riverbed sand commonly called "sharp sand" was employed in the production of concrete. The sand was air-dried in the laboratory for two weeks to reduce its moisture content. Uguru *et al*. (2022) stated that soil moisture content has a tendency to interfere with concrete's mechanical properties, as very high soil moisture content tends to lower concrete compressive strength.

***Coarse aggregates***

Granite (Gauge 19 mm) was used as coarse aggregates (gravel), to produce the six groups of concrete investigated in this study.

***Sawdust and periwinkle shell***

The sawdust was obtained from a local sawmill in Ozoro community, Delta State, Nigeria; the periwinkle shells were gotten from the creeks of Niger Delta. Both the sawdust and periwinkle shells were dried in the open air, to reduce moisture, similar reason to the case of the fine aggregates.

### Methods

***Concrete mix ratio and mixing technique***

The manual mixing technique and batching by mass were adopted for concrete production. Also, a concrete mix ratio of 1:2:4 (cement-fine aggregates-coarse aggregates), and a water-cement (w/c) ratio of 0.55 were used to produce the six sets of concrete, evaluated in this research.

***Admixtures used***

The quantities of the sawdust and periwinkle shells used as partial replacements for fine and coarse aggregates are presented in Table 1. Also, the cassava starch was added based on the percentage weight fraction of the cement used to make the concrete.

**Table 1:** The concrete treatment plan

| Sample | Fine aggregates (kg) | Sawdust (kg) | Coarse aggregates (kg) | Periwinkle shell (kg) | Cassava starch (%) |
|---|---|---|---|---|---|
| Sample 1 – control | 10 | 0 (0%) | 20 | 0 (0%) | 0 |
| Sample 2 | 9.5 | 0.5 (5%) | 19 | 1 (5%) | 0.5 |
| Sample 3 | 9 | 1 (10%) | 18 | 2 (10%) | 1.0 |
| Sample 4 | 8.5 | 1.5 (15%) | 17 | 3 (15%) | 1.5 |
| Sample 5 | 8 | 2 (20%) | 16 | 4 (20%) | 2.0 |
| Sample 6 | 7.5 | 2.5 (25%) | 15 | 5 (25%) | 2.5 |

***Concrete production***

The concrete cement, sand and gravel were thoroughly mixed together using a spade. The weighed dried cassava starch was dissolved in the measured water used in producing the concrete; after which, the water was added to the dry mixture. Vigorous mixing of the concrete was continued until a consistency state was attained.

Thereafter, the concrete was poured into pre-prepared ASTM standard moulds (dimensions 0.15 m x 0.15 m x 0.15 m), in three layers. Each layer was rammed with a ramming rod (16 mm diameter mild steel rod) for 35 times. Then the cast concrete cubes were covered with a plastic sheet in a shady environment, to reduce the environment, delay setting time, and enhance the complete reaction of the cement with the water (Omoniyi *et al*., 2020; Uguru *et al*., 2022). Six groups of concrete were produced based on the experimental design.

***Curing***

The concrete cubes were cured by using the total water immersion technique, as explained by Esegbuyota *et al.* (2019). Then at curing day 28, the cubes from the six groups were removed from the water and allowed to dry for 2 h under room temperature and relative humidity.

**Laboratory analysis**

***Particle size distribution (PSD)***

Particle size grading was carried out on the fine aggregates to determine their suitability for concrete production. The ASTM C136 (2006) recommended procedures, as described by Uguru *et al.* (2022), were adopted for the PSD. During the PSD, 500 g of dried sand was weighed with a digital weighing balance and poured into a pre-arranged sieve set. Thereafter, the sieve was vibrated by using a mechanical sieve shaker for a duration of 20 min, the weight of each individual sieve was retaken, and the weight of sand retained in each sieve was calculated by using Equation 1.

*Weight of sand retained = Final sieve weight – initial sieve weight* 1

The soil classification was done by using the Unified Soil Classification System (USCS) - ASTM D2487-11, and the sand coefficient of uniformity (Cu) and Coefficient of Gradation (Cc), were calculated by using Equations 2 and 3 (Agbi *et al*., 2020).

$$C_U = \frac{D_{60}}{D_{10}} \quad (2)$$

$$C_C = \frac{{D_{30}}^2}{D_{60} \times D_{10}} \quad (3)$$

Where: $D_{60}$ is the 60% finer sand, $D_{30}$ is the 30% finer sand, and $D_{10}$ is the 10% finer sand (USCS, 2015; Agbi *et al*., 2020).

***Compressive strength***

On the 28th curing day, the compressive strength of the concrete cubes was measured through the aid of the concrete compression testing machine, in accordance with modified ASTM C39/C39M (2014) procedures. At the end of each test, the compressive strength of an individual concrete cube was determined through Equation 3 (Akpokodje *et al*., $2021_b$).

$$Compressive\ force = \frac{force\ at\ failure\ point}{net\ surface\ area\ of\ the\ cube} \quad (4)$$

***Concrete density***

The density of the concrete, by using the ASTM C642 (2021) procedures as explained by Suhad *et al.* (2016). The concrete cubes were taken from the curing tank and allowed to stand for 6 h so that the water could drain away from them gravitationally. Thereafter, the cubes were weighed with weighing balance, and the density was calculated through Equation 4 (Eboibi *et al*., 2022).

$$Concrete\ density = \frac{Mass\ of\ the\ concrete\ cube}{cube's\ volume} \quad (5)$$

## RESULTS AND DISCUSSION

### Particle size distribution

The results of the particle size grading are presented in Table 2 and Figure 1. Figure 1 shows the sieve analysis plot, and the plot revealed that the sand used was well graded, since it has a Cu value of 6.4, Cc value of 1.17, and fines of 3.4. ASTM D2487 (2017) recommended that well-graded sand should have Cu □ 6, Cc $\leq$ 3, and fine < 5.0. Akpokodje *et al.* (2019) stated that well-graded sand tends to produce high-quality concrete when compared with poorly graded sand.

**Table 2:** Sieve analysis result

| Sieve size (mm) | Weight retain | % retain | % Passing |
|---|---|---|---|
| 2.36 | 44 | 8.8 | 91.2 |
| 1.25 | 62 | 12.4 | 78.8 |
| 1 | 70 | 14 | 64.8 |
| 0.850 | 72 | 14.4 | 50.4 |
| 0.600 | 75 | 15 | 35.4 |
| 0.425 | 60 | 12 | 23.4 |
| 0.300 | 29 | 5.8 | 17.6 |
| 0.150 | 45 | 9 | 8.6 |
| 0.075 | 26 | 5.2 | 3.4 |
| **Pan** | **17** | **3.4** | **0** |

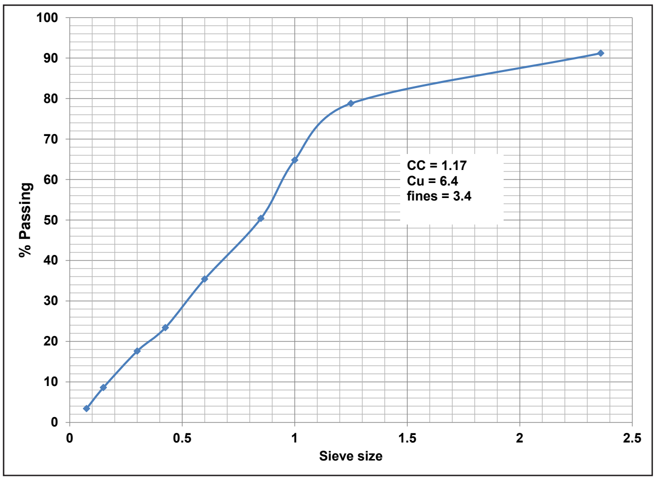


**Figure 1:** Plot of the sieve analysis

### Concrete density

The results of the concrete's density at the 28$^{th}$ curing day are presented in Figure 2. The results revealed the concrete density was directly proportional to its organic materials content. It was observed that as the sawdust and periwinkle content in the concrete increased from 0% to 25% respectively, in Samples 1, 2, 3, 4, 5 and 6, the concrete's density declined from 2467 to 1727 kg/m$^3$ (0% cassava starch), 2481 to 1754 kg/m$^3$ (0.5% cassava starch), 2515 to 1787 kg/m$^3$ (1.0% cassava starch), 2536 to 1802 kg/m$^3$ (1.5% cassava starch), 2558 to 1844 kg/m$^3$ (in 2.0% cassava starch), and 2566 to 1872 kg/m$^3$ (2.5% cassava starch). The reduction in density observed from the addition of periwinkle shells and sawdust was in conformity with the observations made by Bamidele (2002), who reported that the concrete produced with green materials (periwinkle shells) developed lower density than concrete made with granite.

These findings further revealed that the cassava starch relatively increased the concrete's density, as earlier affirmed by Akpokodje *et al.* (2020). Similarly, Eboibi *et al.* (2022) reported that concrete density tends to increase with an increment in the volume of corn starch in the concrete, and concrete produced with 2% of corn starch experienced an increment of approximately 8%, at the 28$^{th}$ curing day. Furthermore, Suhad *et al.* (2016) and Abalaka (2011) stated that natural starch does not only increase the concrete's compressive strength but also its density up to an appreciable level. The lower density observed in the concrete produced with sawdust and periwinkle shells affirmed previous ascertain that most natural reinforcement materials are lightweight, when compared to more synthesized reinforcement materials (Mokaloba and Batane, 2014; Dahiru *et al.*, 2018; Esegbuyota *et al.*, 2019; Obukoeroro and Uguru, 2021)

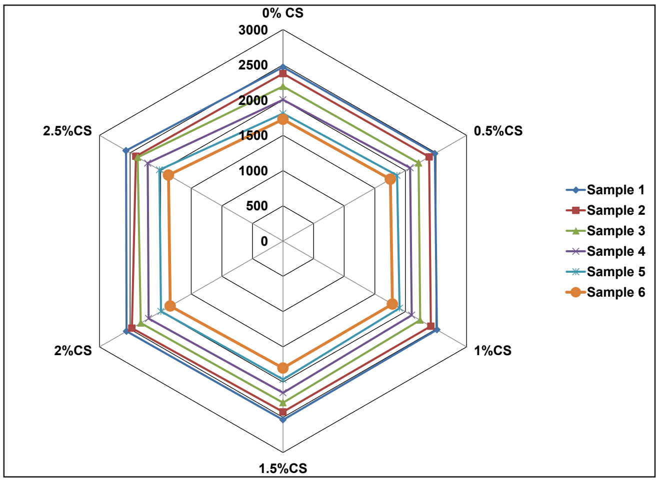


**Figure 2:** The concrete density

### Compressive strength

The concrete compressive strength result at curing day 28 is presented in Figure 3. The results revealed that the cassava starch, periwinkle shells and sawdust influenced the compressive strength of the concrete produced. It was noted that the compressive strength of the concrete non-linearly, as the cassava starch volume increases; such as the cassava starch increased from 0% to 2.5, Sample 1 (control sample) compressive strength increased from 25.2 to 28.4 MP; Samples 2, 3, 4, 5 and 6 compressive strength increased from 23.5 to 25.3 MPa, 19.9 to 21.2

MPa, 16.3 to 20.5 MPa, 14.1 to 16.9 MPa, and 10.3 to 13.8 MPa respectively. Similar results on the positive impact of organic starch, on concrete compressive strength were recovered by these researchers (Suhad *et al*., 2016; Joseph and Xavier, 2016; Agbi and Uguru, 2021). The higher compressive strength observed in the concrete treated with cassava starch could be attributed to the delay in setting time of the concrete, which will enhance the cement chemical reaction and workability of the concrete (Thanoon *et al*., 2023); thus producing concrete with higher compressive strength (Eboibi *et al*., 2022). It can be deducted from the findings that the optimal compressive strength was observed when the starch concentration was between 1.5 and 2%, depending on the volume of the organic aggregates. These optimal cassava starch concentration values are within the range of the results, presented by Akindahunsi and Uzoegbo (2015) for cassava and maize starch respectively.

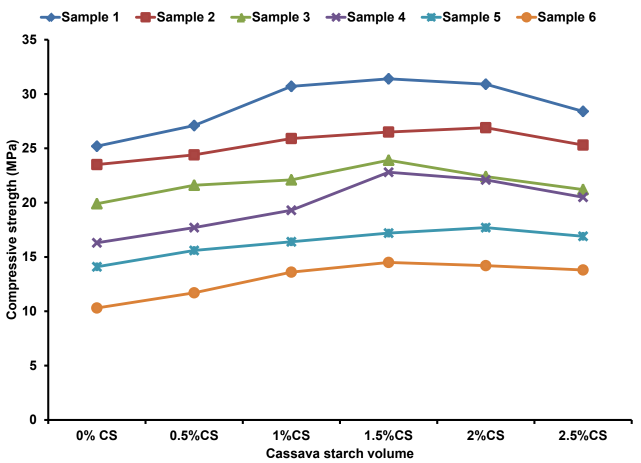


**Figure 3:** The concrete's compressive strength at the 28th water curing day

Also, Figure 3 shows that the presence of the sawdust and periwinkle shell, as a partial replacement (admixture) for fine and coarse aggregate, significantly reduced the compressive strength of the concrete. It was noted that the compressive strength of the concrete treated with 0, 0.5, 1, 1.5, 2 and 2.5% cassava starch declined from 25.2 to 10.3 MPa, 27.1 to 11.7 MPa, 30.7 to 13.6 MPa, 31.4 to 14.5 MPa, 30.9 to 14.2 MPa, and 28.4 to 13.8 MPa respectively, as the sawdust and periwinkle shells volumes increased from 0 to 25%. A similar reduction in the concrete's compressive strength as the volume of periwinkle shells increased was reported by Dahiru *et al*. (2018) and Eboibi *et al*. (2022). This could be partially attributed to the weaker strength properties of the green material when compared to the strength behaviours of the inorganic materials. Also, the higher percentage of sawdust and periwinkle shells in Samples 2- 6, could lead to poor bonding of the aggregates by the cement matrix (paste); hence creasing voids within the concrete, which can result in the development of concrete with lower compressive strength (Ettu *et al*., 2013; Edafiadhe *et al.,* 2019).

Although the compressive strength of the concrete produced with organic admixtures declined with increase in the admixtures volume, it was noted from the results that concrete produced with 15% partial replacement of fine and coarse aggregates, with sawdust and periwinkle shells, in the presence of cassava starch (0.5% to 2.5%) attained the compressive strength (17 MPa) recommended by Nigeria Industrial Standard (NIS) for light-weight concrete required for residential buildings construction. On the contrary, none of the concrete produced with 25% admixtures failed to attain the NIS recommendation, irrespective of the volume of cassava starch incorporated into the concrete; which is similar to the case of 20% periwinkle admixture to concrete production, as reported by Eboibi *et al.* (2022). The discrepancies observed in this study's results, when compared to other studies can be linked to the complex structural nature of the organic materials used for concrete production. Plants and animals' material engineering properties are greatly affected by pre-harvest and post-harvest operations, and modifying each of the operations can technically alter their engineering behaviors (Edafeadhe and Uguru, 2018; Uyeri and Uguru, 2018; Jahanbakhshi and Kheiralipour, 2019; Beautin Nirsha *et al*., 2023).

## CONCLUSION

The mechanical properties of cement composite produced from agricultural waste materials were evaluated in this study. Compressive strength and density of concrete with sawdust, periwinkle shells, and cassava starch were determined in accordance with the American Society of Testing Materials (ASTM) International approved procedures. Results obtained from the study revealed that sawdust and periwinkle shells - when used at lower quantities (≤ 20%), can be used as suitable partial replacements for fine and coarse aggregates during concrete production. Furthermore, it was noted from the results that the sawdust and periwinkle shells admixtures produced lightweight concrete, with appreciable compressive strength, which can be used in the construction of high-rising residential buildings. Also, the findings of this study depicted that cassava is a suitable concrete compressive strength enhancer, as it was able to increase the concrete's compressive strength by approximately 25%. It can be concluded that cassava starch, sawdust, and periwinkle shells are suitable materials for the production of lightweight concrete for civil engineering jobs.

**Conflict of Interest**

The authors declare that they have no conflict of interest.

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