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Production of High-Quality Sustainable Concrete through Incorporation Agricultural Residues

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Abstract

This study aimed at producing high-strength lightweight concrete using sustainable agricultural materials. Concrete units were fabricated by partially substituting fine aggregates with rice husk (RH) and incorporating cassava starch (CS) as an organic admixture. Eight concrete units were manufactured, and their mechanical properties assessed through procedures approved by ASTM standards. The results revealed that as the RH percentage increased from 0 to 15%, there was a decrease in the slump of the fresh concrete, dropping from 35.3 to 14.7 mm. The findings revealed that the concrete density decreased consistently, with the increment in the rice husk quantity (0-15%) integrated into the concrete. Similarly, it was observed that the addition of cassava starch led to an increase in both concrete density and compressive strength, irrespective of the content RH incorporated into the concrete. The compressive strength of the concrete, produced with 0, 5, 10, and 15% RH without the inclusion of CS, measured 19.7, 19.1, 16.8, and 15.2 MPa, respectively. In contrast, the counterparts (0, 5, 10, and 15% RH) manufactured with the addition of 1% CS exhibited compressive strengths of 21.4, 20.3, 18.1, and 16.5 MPa, respectively after 28 days of curing. The results demonstrated that addition of low RH volume and 1% CS can produce concrete with compressive strength appreciable for the construction of farm buildings. These results provide positive indications that agricultural residues can indeed be utilized to produce sustainable concrete for applications in agricultural production.

Keywords: Agricultural Technology; Climate Change; Concrete; Plants Residues; Sustainable Materialsy

Introduction

Farm structures are essential part of agricultural production, contributing significantly to the efficiency, productivity, and sustainability of farming unit operations. Farm structures include administrative buildings, crop processing structures, animals' houses, greenhouse, and storage buildings [1]. Concrete is a widely used material farm structures construction due to its durability, strength, and versatility. Concrete produced with quality materials tend to have excellent mechanical properties, making it suitable for supporting the live and dead loads of farm structures [2,3]. Farm structures foundations are constructed with various grades of concrete, as it is considered more durability and flexibly than other foundation construction materials. Engineering properties of concrete that enhance its utilization in the construction of buildings used for agricultural production are: high load-bearing capacity, durability, thermal resistance, fire resistance, design flexibility, insulation properties, and environmental friendliness [4].

Concrete is employed in constructing rigid pavements within farm premises to improve and facilitate farming operations. Similarly, in farm waste management system, concrete emerges as a sustainable material for constructing septic tanks owing to its high resistance to corrosion [5].

The primary materials used for concrete production include: cement, fine and coarse aggregates. The cement acts as the binding material, which plays a pivot role in binding the primary aggregates (sand and gravel) together. The fine aggregates (sand) contributes to the densification and workability of the concrete; hence, creating an improvement to the concrete's compressive strength. Sand improves the cohesion process within the concrete; therefore, minimizes particles segregation during the compaction and hydration unit operations in concrete production. Similarly, the coarse aggregates (gravel) which has larger particle size than the sand, contributes immensely to the compressive and tensile strengths of the product formed. Coarse aggregates enhance the ability of concrete structures to absorb larger compressive and tensile forces, consequently minimizing the risk of structural failures and building collapses. Adopting appropriate concrete mix design (cement-sand-gravel mix ratio combined with the use of well-graded sand and gravel, in concrete production lead to the production of high-quality (high mechanical strength and durability) concrete which can be used for various applications. The proper selection of concrete mix design and aggregates reduce the chances of segregation and bleeding during the hydration process.

The environmental impact and high carbon footprint associated with cement production has led to a growing interest in finding sustainable alternatives in the concrete industry [6]. Agricultural material residues are gaining attention as potential green substitutes for cement aggregates in concrete manufacturing due to their ready availability, environmental friendliness, and often, pozzolanic properties. Agricultural products commonly used as aggregates in concrete are: wood shavings, sawdust, animal bones, rice husk, periwinkle shells and wheat straw; while green pozzolanic materials used as substitute for cement during concrete production include plant ash and bagasse products, which contains applicable quantity of reactive silica and pozzolanic properties, which can enhance the strength and durability of the concrete produced. These green (agricultural) materials when incorporated into the concrete in the right quantity and under appropriate conditions, they can contribute to the production of high compressive strength lightweight concrete.

Materials and Methods

Materials

The materials used for the concrete production were marine sand, rice husk (RH), cassava starch (CS), cement and gravel. These materials were sourced from the farm structure laboratory of the Department of Agricultural Engineering, Delta State University of Science and Technology, Ozoro, Nigeria.

Methods

Concrete Mix Design: The mix design ratios adopted for concrete production in this study are outlined in Table 1.

Sample code	Cement (%)	Sand (%)	Gravel (%)	RH (%)	CS (%)
Sam 1	100	100	100	0	0
Sam 2	100	95	100	5	0
Sam 3	100	90	100	10	0
Sam 4	100	85	100	15	0
Sam 5	100	100	100	0	1
Sam 6	100	95	100	5	1
Sam 7	100	90	100	10	1
Sam 8	100	85	100	15	1

Table 1: Compositions of the concrete.

Concrete Production: A conventional concrete mix ratio of 1:2:4 and a water-cement (w/c) ratio of 0.5 were used to produce the concrete. The concrete samples were produced in accordance with ASTM approved procedures. Batching was conducted by mass, and mixing was performed using a mechanical method to achieve a homogeneous mixture. The curing of the concrete was accomplished by completely immersing in water at room temperature ($35\pm5^{o}C$).

Laboratory Tests

Apart from the slump test that was carried out on the fresh concrete, the bulk density and compressive strength of the concrete were evaluated on the 28^{th} curing day.

Concrete Slump and Density: The slump was determined following the procedures sanctioned by ASTM International standards [7]. Similarly, the density of the concrete was measured in harmony with ASTM-approved procedures [8]. Subsequently, the concrete density was calculated using Equation 1 [6].

$$Density = \frac{mass}{volume} \quad \mathbf{1}$$

Compressive Strength: The compressive strength of each concrete sample was assessed following the procedures approved by ASTM, by utilizing the service of a Compression Testing Machine [9]. Then the compressive strength of the concrete cube was calculated through Equation 2 [6].

$$Compressive\,strength = \frac{Force}{Area} \quad 2$$

Statistical Analysis

All the experimental tests were conducted in triplicates, and the recorded mean values were used for analysis. The mean values were plotted using Microsoft Excel (version 2010).

Results and Discussion

Slump

The results of the concrete slump for the various concrete samples produced in the research are presented in Figure 1. It was noted that in the absence of CS, as the RH content increased from 0 to 15%, there was a decrease in the slump of the fresh concrete, dropping from 35.3 to 14.7 mm. Likewise, with the introduction of 1% cassava starch into the concrete, the slump decreased from 40.4 to 19.8 mm as the volume of RH increased from 0 to 15%. The lower slump values observed in concrete produced with RH can be attributed to the rough surface area of the husk. This structural pattern has the potential to create obstructions in the slump flow rate, impacting the concrete's ability to flow smoothly [5,10]. Prusty JK, et al. [11] reported that certain agricultural materials can retard the workability of concrete by diminishing its flow rate. Slump portrays the concrete consistency degree, offering valuable insights into its workability and compatibility.

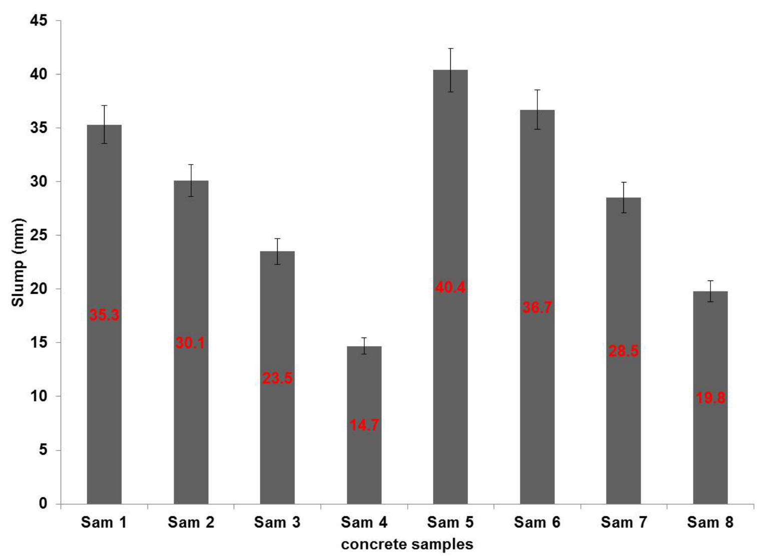

Figure 1: Concrete slump.

Bulk Density

Figure 2 illustrates the outcomes of concrete density after a 28-day curing period. Figure 2 revealed that the concrete samples coded Sam 1, Sam 2, Sam 3, Sam 4, Sam 5, Sam 6, Sam 7 and Sam 8 developed density of 2350, 2284, 2153, 1970, 2482, 2328, 2210 and 2050 kg/m^3, respectively, at the 28th curing day. This indicated that the presence of CS promotes densification, as evidenced by the higher dry concrete density observed in the concrete containing CS. Also it was noted that the bulk density of the concrete consistently decreased with the increment in RH content within the concrete units, ranging from 0 to 15%. This is similar to the findings of Eboibi O, et al. [10] where the density of concrete cubes demonstrated a proportional increase with the rising volume of incorporated cassava starch. Similarly, the results portrayed a consistent decline in concrete density with an increasing mass RH from 0 to 15%. This can be attributed to the lighter weight of RH compared to sand. Prusty JK, et al. [11] and Olaiya BC, et al. [12] reported similar findings in concrete produced with agricultural materials. They attributed the decrease in concrete density to the lightweight characteristics of agricultural residues.

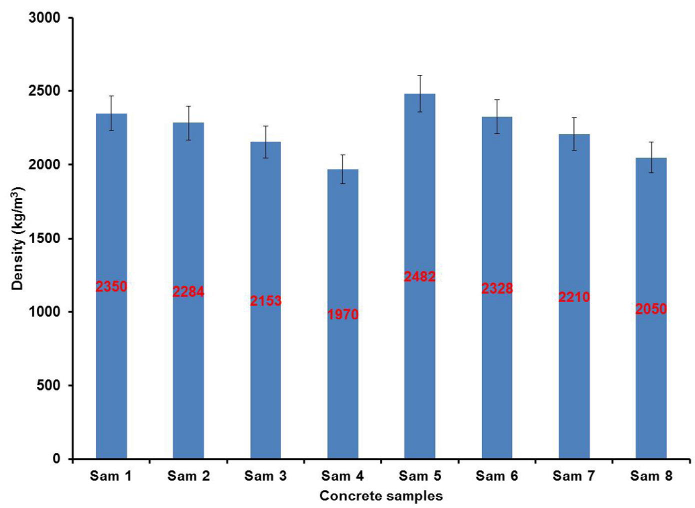

Figure 2: Concrete density.

Compressive Strength

Figure 3 revealed the compressive strength of the green concrete. The Sam 1, Sam 2, Sam 3, Sam 4, Sam 5, Sam 6, Sam 7 and Sam 8 concrete samples developed compressive strength of 19.7, 19.1, 16.8, 15.2, 21.4, 20.3, 18.1 and 16.5 MPa, respectively, after 28 curing days. It was noted that the CS and RH has significantly influenced the strength development of the concrete within the 28 curing days. Generally, the concrete produced with starch incursion had higher compressive strength compared to the concrete manufactured without starch incursion. Starch acts as water-retaining agent in cement mortar, which can extend the concrete setting time; hence encouraging better hydration reaction of the cement gel. Retardation of setting time helps in monitoring amount of heat generated during the cement hydration procedure. This is will minimize the occurrence of thermal cracking, which will result in weakening of the concrete mix [13]. The addition of corn starch solution to concrete can lead to a significant improvement in compressive strength, particularly when the solution is optimized at a concentration of around 1% [14].

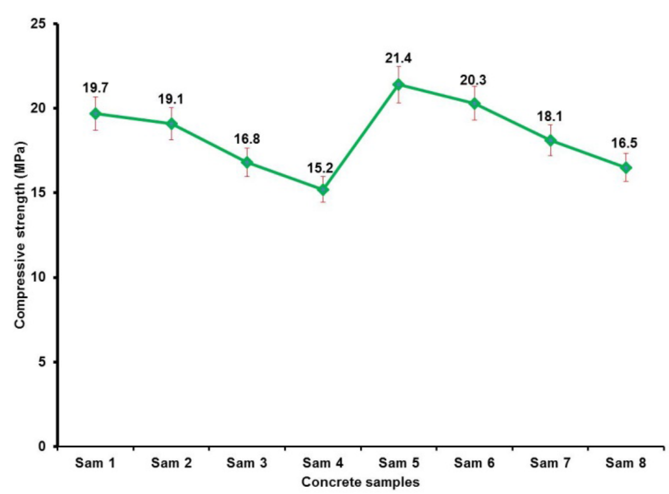

Figure 3: Concrete compressive strength.

The rice husk exhibits dual functionality in the concrete created, as both a reinforcement material - as partial replacement for the fine aggregates, and a pozzolanic material as sustainable substitute for cement. This dual role contributes to the overall improvement in the strength and durability of the concrete produced. Pozzolanic materials in the presence of water react with calcium hydroxide produce additional cementitious compounds (such as calcium silicate hydrate), which have the ability of enhancing the concrete mechanical properties [15]. This research finding is similar to observations made by Oluwabusayo OD, et al. [16] and Adebola JA, et al. [17] on production of bio-concrete with appreciable compressive strength. The incorporation of low volumes from RH and cassava products in bio-concrete during the production stage, contribute to the appreciable compressive strength developed by the concrete blocks. The observed low compressive strength in the concrete containing 15% RH can be attributed to inadequate bonding between the substantial volume of RH and the cement matrix [10]. Consequently, this results in the creation of concrete characterized by a weakened microstructural strength, rendering it unable to withstand high compression loads effectively.

Conclusion

Concrete stands out as one of the most commonly utilized building materials in agricultural production. This study was conducted to produce high quality light-weight concrete units from sustainable agricultural materials. Several concrete units were manufactured through the partial replacement of fine aggregates with rice husk, and cassava starch as organic admixture. While the results demonstrated a gradual decline in both concrete density and compressive strength with the increasing quantity of rice husk (0–15%) integrated into the concrete, it is noteworthy that the compressive strength remained at an appreciable level for the construction of farm buildings. Likewise, it was noted that the CS initiated increment in the concrete density and compressive strength, regardless of the volume of RH added to the concrete. These outcomes are positive indications that agricultural residues can be used to produce sustainable concrete for agricultural production.

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