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# EVALUATION OF THE SYNERGISTIC EFFECT OF CORN COB ASH (CCA) AND DATE PALM SEED ASH (DPSA) AS PARTIAL CEMENT REPLACEMENT ON THE MECHANICAL PROPERTIES OF CONCRETE

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## ABSTRACT

The production of Ordinary Portland Cement (OPC) is associated with high carbon dioxide emissions and energy consumption, creating the need for sustainable supplementary cementitious materials. This study investigated the synergistic effect of Corncob Ash (CCA) and Date Palm Seed Ash (DPSA) as partial cement replacements on the mechanical properties of concrete. CCA and DPSA were produced through controlled calcination at 600°C – 800°C and incorporated as binary (OPC–CCA and OPC–DPSA) and ternary (OPC–CCA–DPSA) blends at replacement levels of 5, 10, 15, and 20% by weight of cement. Cube and cylinder concrete specimens, designed for a target compressive strength of 30 MPa with a water-to-binder ratio of 0.50, were produced and cured for 7, 14, and 28 days and tested for workability, compressive and split tensile strengths in accordance with relevant British Standards. Strength increased with curing age for all mixes, with the binary blends outperforming the ternary blend. At 28 days, OPC–CCA and OPC–DPSA achieved optimum compressive strengths of 32.33 MPa and 32.00 MPa, respectively, at 5% replacement, while the ternary blend attained 28.33 MPa. OPC–DPSA recorded the highest split tensile strength of 3.61 MPa at 10% replacement, whereas the ternary blend reached 3.50 MPa. The study concludes that 5–10% replacement is optimal. Although the expected synergistic enhancement of the ternary blend was not fully realized, longer-term curing may improve its performance. Overall, CCA and DPSA show strong potential as sustainable supplementary cementitious materials that reduce cement consumption while maintaining satisfactory mechanical properties.

**Keywords:** Corncob ash; Date palm seed ash; Supplementary cementitious materials; Compressive strength; Split tensile strength; Sustainable concrete

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## 1. INTRODUCTION

Concrete remains the most widely used construction material worldwide because of its versatility, durability, and the availability of its constituent materials. However, its primary binding material, Ordinary Portland Cement (OPC), is highly energy-intensive to manufacture and is responsible for approximately 7–8% of global anthropogenic carbon dioxide (CO<sub>2</sub>) emissions (Chen et al., 2022).

As reported by Tijani et al. (2018) agricultural waste ashes have emerged as promising SCMs because they provide an environmentally friendly means of converting waste materials into value-added construction products. These materials are generally rich in reactive silica and alumina, enabling them to participate in pozzolanic reactions (Papadaki & Tsimas, 2002). Among the various agricultural wastes investigated as SCMs, Corncob Ash (CCA) and Date Palm Seed Ash (DPSA) have attracted increasing research interest because of their availability in many agricultural regions and their favourable chemical compositions. Previous investigations have shown that CCA possesses appreciable amounts of reactive silica capable of improving compressive strength and durability (Adesanya & Raheem, 2009; Apampa et al., 2023). Similarly, DPSA has demonstrated good pozzolanic characteristics, with studies reporting improvements in strength properties (Ahmad et al., 2023; Smith et al., 2020). Recent developments in blended cement technology have shifted attention from binary systems to ternary blended binders, where two or more SCMs are combined to exploit complementary physical and chemical characteristics.

This study therefore investigates the synergistic effect of CCA and DPSA as partial replacements for cement on the mechanical properties of concrete. Binary and ternary blended concretes were produced at varying replacement levels and evaluated through workability, compressive and split tensile strength tests. The findings are expected to provide further insight into the feasibility of utilizing locally available agricultural wastes as sustainable supplementary cementitious materials for low-carbon concrete production.

## **2. METHODOLOGY**

### **2.1 Materials**

Ordinary Portland Cement (OPC) conforming to BS EN 197-1 (2011) was used as the primary binder. Natural river sand conforming to BS EN 12620 (2002) and crushed granite with a nominal maximum size of 20 mm were used as fine and coarse aggregates, respectively. Potable water complying with BS EN 1008 (2002) was used for concrete mixing and curing. Corncob Ash (CCA) was obtained from Zabawa Village, Giwa Local Government Area, Kaduna State, while Date Palm Seed Ash (DPSA) was produced from date palm seeds sourced from Dutsinma Local Government Area, Katsina State, Nigeria. CCA and DPSA were produced through controlled thermal treatment at a temperature of 650°C and 750°C respectively.

### **2.2 Methods**

#### **2.2.1 Materials Characterization**

Preliminary characterization of the constituent materials was carried out before concrete production. Tests conducted on cement included specific gravity, standard consistency, setting time, and soundness. Fine and coarse aggregates were evaluated for grading, specific gravity, bulk density, water absorption, Aggregate Impact Value (AIV), and Aggregate Crushing Value (ACV), while the chemical compositions of CCA and DPSA were determined using X-ray fluorescence (XRF). All tests were performed in accordance with the relevant British Standards.

#### **2.2.2 Mix Design and Specimen Preparation**

One hundred and seventeen (117), 100 x 100 x 100mm cubes and Seventy eight (78), 100 x 200mm cylinder specimens were prepared. Design of Experiment (DoE) method was used to design a concrete mixtures for a target strength of 30 MPa, with a constant water-to-binder ratio of 0.50. Three binder systems were investigated: binary OPC–CCA, binary OPC–DPSA, and ternary OPC–CCA–DPSA blends. Cement replacement levels of 5%, 10%, 15%, and 20% by weight of cement were adopted alongside a control mix containing 100% OPC.

#### **2.2.3 Fresh and Hardened Properties of Concrete**

Fresh concrete workability was evaluated using the slump test in accordance with BS 1881-102 (1983). Hardened concrete was assessed through compressive strength and split tensile strength tests conducted at curing ages of 7, 14, and 28 days in accordance with BS EN 12390-3 (2002) and BS EN 12390-6 (2009), respectively. Compressive strength was determined from 100 × 100 × 100 mm cube specimens, while split tensile strength was measured using 100 × 200 mm cylinders.

#### **2.2.4 Statistical Analysis**

The experimental data for the ternary OPC–CCA–DPSA system were analysed using one-way analysis of variance (ANOVA) at a 95% confidence level ( $\alpha = 0.05$ ) to evaluate the effect of replacement level on compressive and split tensile strength at each curing age.

## **3. RESULTS AND DISCUSSION**

### **3.1 Characterization of Constituent Materials**

The physical properties of the Ordinary Portland Cement satisfied the requirements of BS EN 196, confirming its suitability for structural concrete production. Similarly, the fine and coarse

aggregates complied with the relevant British Standards, Fine aggregate; fineness modulus = 2.87827, specific gravity = 2.66, bulk density = 1433.3kg/m<sup>3</sup>, and Coarse aggregate; grading ≤ 20mm, specific gravity = 2.68, water absorption = 0.7, Aggregate Impact Value (AIV = 24.55), and Aggregate Crushing Value (ACV = 21.61), indicating their suitability for concrete manufacture. The results for chemical composition of CCA and DPSA are presented in Table 1.

Table 1: Chemical composition of CCA and DPSA

| Chemical Constituents (%) | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | CaO   | MgO  | Na <sub>2</sub> O | K <sub>2</sub> O | SO <sub>3</sub> | LOI  |
|---------------------------|------------------|--------------------------------|--------------------------------|-------|------|-------------------|------------------|-----------------|------|
| CCA                       | 62.30            | 6.25                           | 4.40                           | 10.57 | 1.86 | 0.36              | 3.89             | 1.02            | 3.50 |
| DPSA                      | 45.50            | 20.75                          | 7.25                           | 9.82  | 0.52 | 3.00              | 9.07             | 0.12            | 1.72 |

The XRF analysis revealed that the combined silica (SiO<sub>2</sub>), alumina (Al<sub>2</sub>O<sub>3</sub>), and iron oxide (Fe<sub>2</sub>O<sub>3</sub>) contents were 72.95% for CCA and 73.50% for DPSA, exceeding the 70% minimum specified by ASTM C618-19 (2019) for natural pozzolans. This confirms the pozzolanic potential of both agricultural ashes and supports their application as supplementary cementitious materials.

### 3.2 Fresh Properties of Concrete

The results for workability is presented in Figure 1. Workability of all concrete mixtures decreased progressively with increasing cement replacement irrespective of the binder system. The control concrete recorded the highest slump (60 mm), whereas slump values decreased to 23 mm for both binary mixes and 20 mm for the ternary blend at 20% replacement.

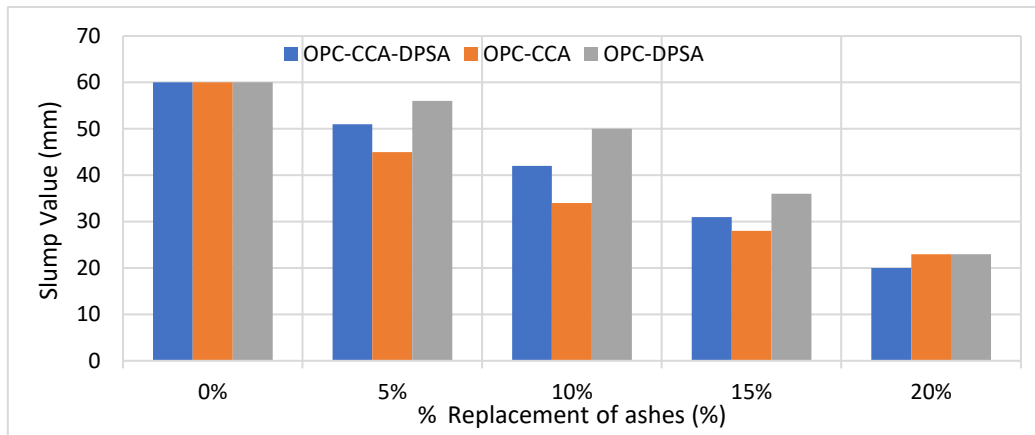


Figure 1: Slump values of control, binary and ternary concrete mixtures.

The reduction in workability is attributed to the higher specific surface area and increased water demand of CCA and DPSA, which reduced the amount of free water available for lubrication within the fresh concrete matrix.

### 3.3 Mechanical Properties

#### 3.3.1 Compressive strength

The results for compressive strength of all the mixtures are presented in Figures 2, 3, and 4. Generally, increase in compressive strength was observed for all the mixtures, as curing age increases, indicating continued cement hydration and pozzolanic activity. However, strength generally decreased with increasing cement replacement due to the cement dilution effect.

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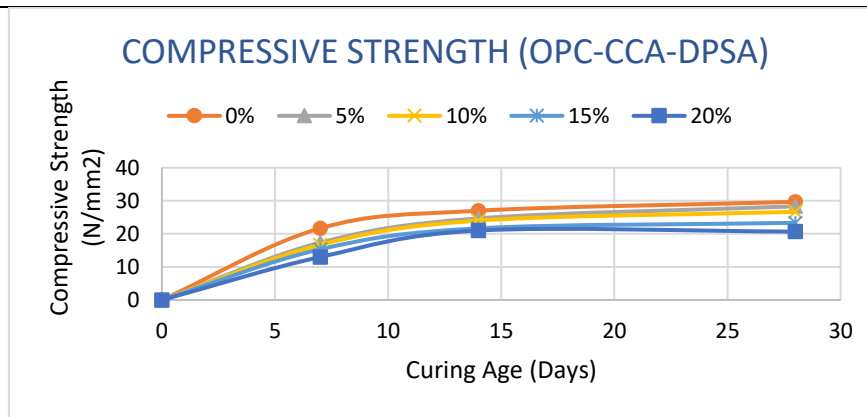


Figure 2: Compressive strength development of ternary concrete.

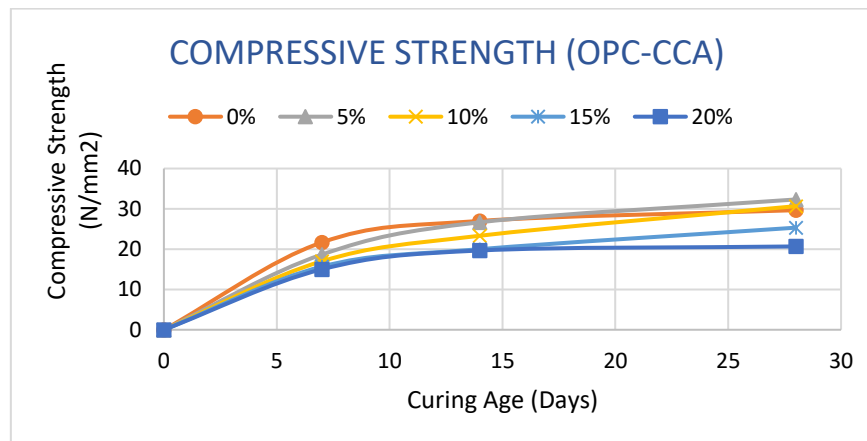


Figure 3: Compressive strength development of OPC-CCA concrete.

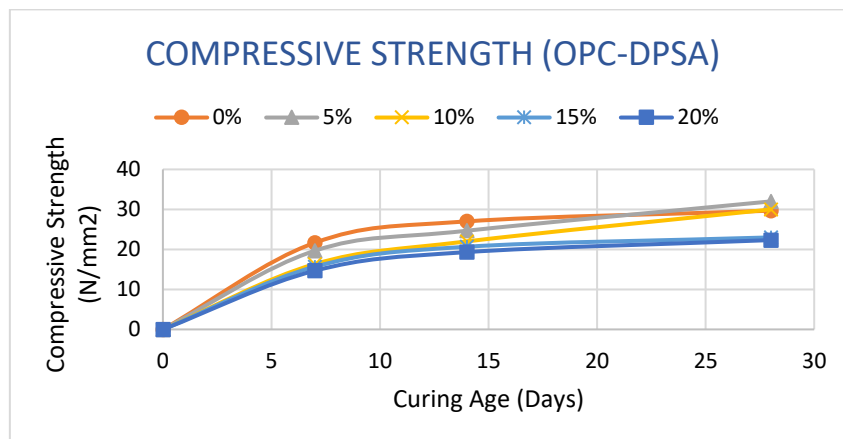


Figure 4: Compressive strength development of OPC-DPSA concrete.

For the ternary OPC-CCA-DPSA concrete, the 28-day compressive strength decreased from 29.67 MPa for the control to 28.33, 26.67, 23.33, and 20.67 MPa at 5%, 10%, 15%, and 20% replacement, respectively. The 5% replacement retained approximately 95.5% of the control strength, suggesting that limited incorporation of both ashes contributed to strength development through secondary pozzolanic reactions.

The binary mixtures exhibited superior performance. At 28 days, OPC-CCA achieved a maximum compressive strength of 32.33 MPa at 5% replacement, while OPC-DPSA attained 32.00 MPa at the same replacement level, both exceeding the control concrete. The ternary blend, however, did not demonstrate the anticipated synergistic improvement. These observations agree with previous studies reporting that agricultural waste ashes produce optimum strength at relatively low replacement levels, beyond which the dilution effect predominates over the benefits of pozzolanic activity (Adesanya & Raheem, 2009; Kavitha et al., 2022; Shakir et al., 2021).

### 3.3.2 Split Tensile Strength

Split tensile strength increased with curing age for all mixtures as shown in Figures 5, 6, and 7, confirming continued hydration and microstructural refinement. Similar to compressive strength, low replacement levels improved tensile performance, whereas higher replacement levels (15–20%) resulted in strength reduction. The ternary concrete achieved its highest split tensile strength of 3.50 MPa at 10% replacement, slightly exceeding the control value of 3.42 MPa. Among the binary blends, OPC–DPSA produced the highest tensile strength of 3.61 MPa at 10% replacement, followed by OPC–CCA with 3.50 MPa at 5% replacement.

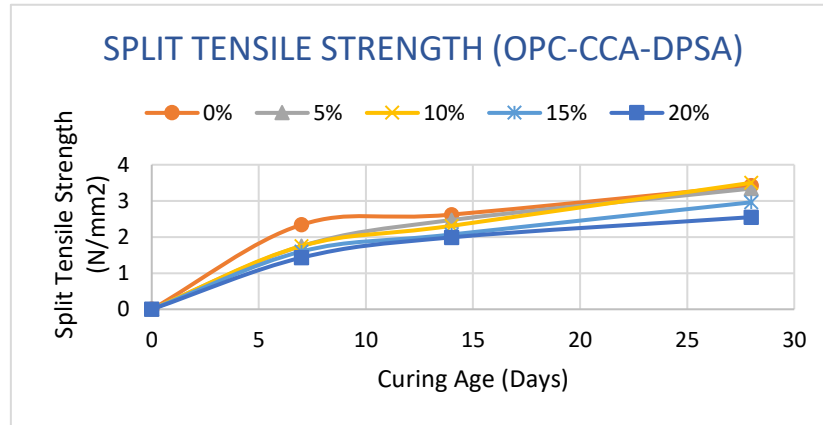


Figure 5: Split tensile strength development of ternary concrete.

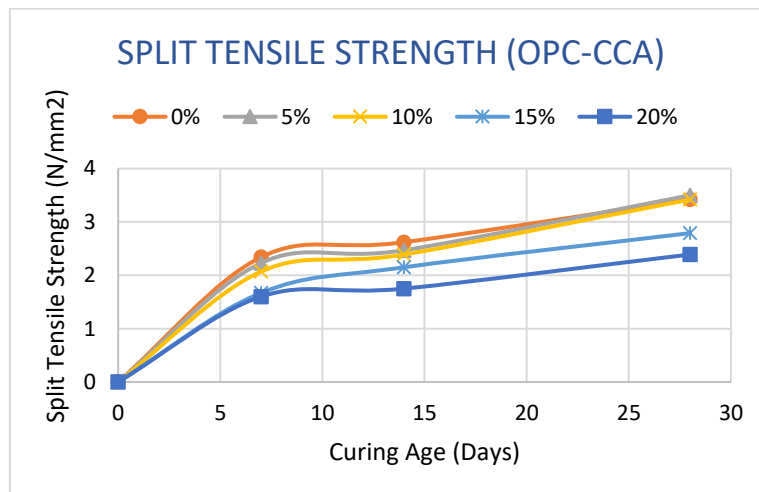


Figure 6: Split tensile strength development of OPC–CCA concrete.

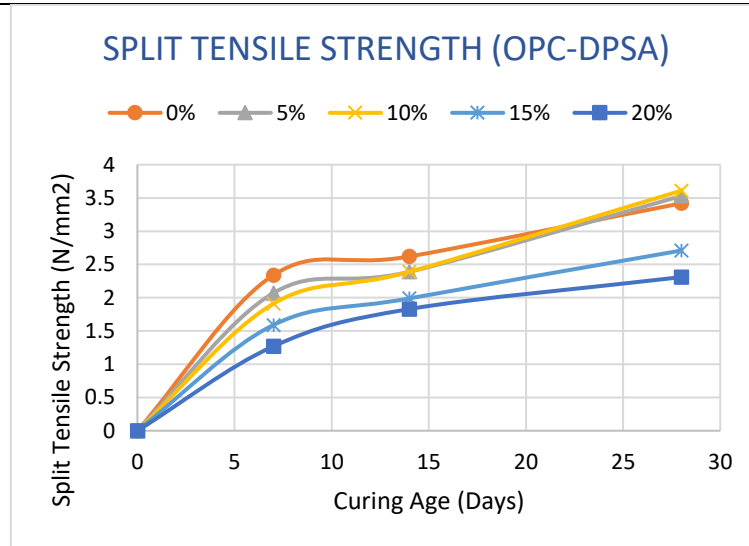


Figure 7: Split tensile strength development of OPC-DPSA concrete.

Although the ternary blend improved the tensile strength relative to the control, it did not outperform the best-performing binary mixture, indicating that the expected synergistic enhancement was not fully realized within the 28-day curing period. The findings are consistent with previous studies which reported that supplementary cementitious materials enhance concrete performance only within an optimum replacement range (Nasir & Al-kutti, 2019; Aswin et al., 2021).

### 3.4 Statistical Analysis

The one-way ANOVA results as presented in Table 2, showed that replacement level significantly influenced the compressive strength of the ternary OPC-CCA-DPSA concrete at 7, 14, and 28 days, with  $p$ -values of 0.0256, 0.0334, and  $<0.001$ , respectively. Similarly, split tensile strength was significantly affected at 7, 14, and 28 days, with  $p$ -values of 0.0245, 0.0063, and 0.0314, respectively.

Table 2: ANOVA result for Compressive and Split tensile strength

| Test – Curing age                | F-statistic | F-critical | P-value | Result ( $\alpha = 0.05$ ) |
|----------------------------------|-------------|------------|---------|----------------------------|
| Compressive Strength – 7 Days    | 4.43        | 3.48       | 0.0256  | Significant                |
| Compressive Strength – 14 Days   | 4.04        | 3.48       | 0.0334  | Significant                |
| Compressive Strength – 28 Days   | 43.82       | 3.48       | 2.62e-6 | Significant                |
| Split Tensile Strength – 7 Days  | 7.47        | 5.19       | 0.0245  | Significant                |
| Split Tensile Strength – 14 Days | 14.00       | 5.19       | 0.0063  | Significant                |
| Split Tensile Strength – 28 Days | 6.60        | 5.19       | 0.0314  | Significant                |

The results confirm that changes in CCA-DPSA replacement level significantly influenced the mechanical performance of the ternary concrete. The optimum performance occurred at low replacement levels.

## 4. CONCLUSION

This study evaluated the mechanical performance of binary and ternary concrete. Both ashes showed pozzolanic potential, while increasing replacement reduced workability. Strength generally increased with curing age, with the ternary mixture achieving optimum compressive strength of 28.33

MPa at 5% replacement and split tensile strength of 3.50 MPa at 10% after 28 days. One-way ANOVA confirmed that replacement level significantly affected both properties. However, the ternary blend did not outperform the binary systems at 28 days. Thus, the anticipated synergistic enhancement was not fully realized within the 28-day period. Longer curing periods, varied CCA-DPSA ratios, and microstructural and durability investigations are recommended to determine whether delayed pozzolanic reactions can improve ternary performance and establish an optimum blend.

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