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Mechanical Properties of Concrete with Burnt Pulverized Chikoko (BPC) as a Sustainable Binder Material

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Abstract-* Burnt Pulverized Chikoko (BPC) has shown potential as a supplementary cementitious material (SCM) for sustainable concrete production. This paper investigates the mechanical properties of concrete incorporating BPC as a partial replacement for cement. A comprehensive literature review provides insights into previous studies on BPC and other calcined clays. This study investigates the compressive strength performance of concrete mixes with varying mix proportions (1:1.5:3 and 1:2:4) under different replacement and admixture levels. The control mix (1:1.5:3) demonstrated consistent strength development, peaking at 27.78 N/mm² at 28 days, while the 1:2:4 mix achieved a slightly lower strength of 25.56 N/mm², highlighting the influence of reduced cement content. Partial replacement of cement (5–20%) showed mixed results: the 1:1.5:3 mix benefited at 5% and 10% replacement levels, achieving up to 30.44 N/mm² at 28 days, while higher replacement levels (15–20%) led to strength reductions due to dilution effects. In contrast, the 1:2:4 mix experienced limited improvements or reductions across all replacement levels. Admixture additions (5–20%) consistently enhanced strength for both mix proportions. The 1:1.5:3 mix achieved a peak strength of 32.89 N/mm² at 15% and 20% admixture levels, while the 1:2:4 mix reached a maximum of 30.22 N/mm² at 20% admixture. The results underscore the significant role of cement content, replacement levels, and admixture dosages in optimizing concrete strength development. These findings highlight BPC's potential as a sustainable alternative for reducing Portland cement usage and enhancing the sustainability of construction practices.

***Indexed Terms-* Burnt Pulverized Chikoko (BPC), Supplementary Cementitious Material (SCM), Sustainable Concrete, Compressive Strength, Cement Replacement, Admixture**

I. INTRODUCTION

The environmental impact of Portland cement production, which accounts for approximately 8% of global CO_2 emissions (World Economic Forum, 2022), has prompted significant research into alternative materials that reduce dependency on Ordinary Portland Cement (OPC). In particular, researchers have focused on exploring alternative binder materials that not only minimize the environmental footprint but also preserve or enhance the mechanical and durability properties of concrete. Among these alternatives, Supplementary Cementitious Materials (SCMs), such as fly ash, silica fume, and calcined clays, have shown considerable promise (Mehta & Monteiro, 2014).

Calcined clays, including metakaolin and Burnt Pulverized Chikoko (BPC), have been identified as particularly effective SCMs due to their pozzolanic properties, which promote the formation of calcium silicate hydrate (C-S-H) gel, a key contributor to the strength and durability of concrete (Sabir et al., 2001; Shah et al., 2020). When used as partial replacements for cement, these materials not only help lower CO_2 emissions but also improve the performance characteristics of concrete, particularly in terms of durability and resistance to chemical attacks.

BPC, a calcined derivative of Chikoko clay abundant in the Niger Delta regions of Nigeria, presents a promising low-carbon alternative to traditional cement due to its pozzolanic properties (Okere & Sule, 2019; Orumu & Overo, 2020). Studies by Onwuka and Sule (2017) have demonstrated that BPC enhances both the durability and workability of concrete, particularly when used at replacement levels of 10–20%. However, higher replacement levels may lead to a reduction in strength due to the dilution of the cementitious content.

Further research by Dumani and Mapiravana (2018) and Zayed (2018) has shown that calcined clays reduce the permeability of concrete and enhance its resistance to sulfate attack. Additionally, BPC offers significant environmental benefits, including a reduction in CO_2 emissions and the use of locally available materials, thus supporting sustainable construction practices (Okere & Sule, 2019).Although previous studies have highlighted the potential of BPC as a sustainable binder, there is limited research on its effects on the mechanical properties of concrete at various replacement levels. This study aims to fill this gap by providing experimental data on the compressive strength, workability, and durability performance of concrete incorporating BPC at different replacement levels.

II. MATERIALS AND METHODS

2.1 Materials

- Chikoko Clay: Locally sourced from Okrika in Rivers State, Nigeria, dried, with open burning and pulverized to a fine powder.
- Cement: Ordinary Portland Cement (OPC) conforming to ASTM C150 specifications.
- Fine Aggregates: River sand with a maximum particle size of 4.75 mm.
- Coarse Aggregates: Crushed granite with a maximum size of 12.7mm. The grading and properties of the coarse aggregate conformed to BS EN 12620.
- Water: Portable water conforming to ASTM C1602.
- Grinding Machine: The grinding machine was used for grinding the burnt chikoko samples into fine (powder) sizes passing 200µm in the civil engineering Laboratory Niger Delta University.

2.2 Mix Proportions

Concrete mixes were prepared with BPC replacing OPC at levels of 10%, 20%, and 30% by weight. A control mix without BPC was included. A constant water-to-cementitious material ratio (w/cm) of 0.50 was maintained. Details of mix is shown in table 1-5.

Table 1: Mix details of concrete used for compressive strength test.

Specimen details	Cement (kg)	Chikoko (kg)	Sand (kg)	Chippings (kg)	Water (kg)	No of cubes
Control samples (0% chikoko replacement or admixture) 1:1.5:3	9.00	0	13.5	28	4.5	6
1:2:4	7.50	0	15	30	3.75	6

Table 2: Admixture 1:1.5:3

5% Chikoko powder	9.00	0.450	13.5	27	4.25	6
10% Chikoko powder	9.00	0.900	13.5	28	4.25	6
15% Chikoko powder	9.00	1.350	13.5	28	4.25	6
20% Chikoko powder	9.00	1.800	13.5	28	4.25	6

Table 3: Admixture 1:2:4

5% Chikoko powder	7.5	0.375	15	30	3.75	6
10% Chikoko powder	7.5	0.75	15	30	3.75	6
15% Chikoko powder	7.5	1.125	15	30	3.75	6
20% Chikoko powder	7.5	1.50	15	30	3.75	6

Table 4: Replacement 1:1.5:3

5% Chikoko powder	8.550	0.450	13.5	27	4.25	6
10% Chikoko powder	8.100	0.900	13.5	28	4.25	6
15% Chikoko powder	7.650	1.350	13.5	28	4.25	6
20% Chikoko powder	7.200	1.800	13.5	28	4.25	6

Table 5: Replacement 1:2:4

5% Chikoko powder	7.125	0.375	15	30	3.75	6
10% Chikoko powder	6.750	0.75	15	30	3.75	6
15% Chikoko powder	6.375	1.125	15	30	3.75	6
20% Chikoko powder	6.000	1.50	15	30	3.75	6

2.3 Experimental Procedure

In this study, concrete cubes measuring 150 × 150 × 150 mm were prepared to test the compressive strength. The cubes were cast using two different concrete mixes (1:2:4 and 1:1.5:3) with varying amounts (0%, 5%, 10%, 15%, and 20%) of Burnt Pulverized Chikoko (BPC) as a partial replacement for cement and as an admixture. The preparation began by mixing the cement and fine aggregates dry until a uniform color was achieved. Then, the coarse aggregates were added and mixed with the cement and fine aggregates. Water was introduced to the dry mix, and the entire batch was thoroughly mixed to ensure consistency. Prior to pouring the concrete, the interior surfaces of the moulds and the base plate were oiled.

After casting, the specimens were left to set for 24 hours before being demoulded. They were then submerged in clean, fresh water at room temperature for curing. The specimens were tested at three curing intervals: 7, 14, and 28 days, beginning from the time the water was added to the mix.

For the compressive strength testing, the concrete cubes were placed directly onto the testing machine plates without any cushioning material. The load was applied gradually and evenly until the specimen failed and was crushed.

Figure 1: Casting of concrete specimen

2.5 Workability

The compressive strength of a material is the uni-axial compressive stress reached when the material fails completely. A set of two cubes were tested in each case and the average value of these two was reported as shown in figure 3

Figure 2: Slump Test

III. RESULTS AND DISCUSSION

3.1 Sieve Analysis

This sieve analysis reveals a predominantly well-graded distribution of particles with a significant proportion of medium-sized aggregates in figures 3 and 4. The data provides valuable insights for selecting materials suitable for specific construction needs, particularly for achieving the desired strength and in concrete or other applications.

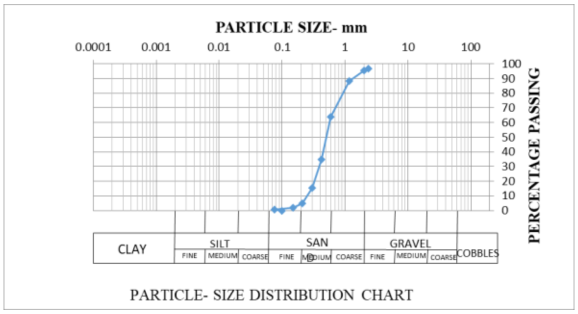

Figure 3: Sieve Analysis of Fine Aggregate

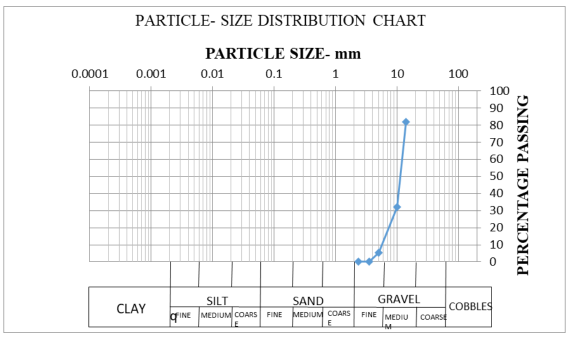

Figure 4: Sieve Analysis of Granite

3.2 Compressive Strength

The strength results of varying percentage replacement and curing ages is presented here

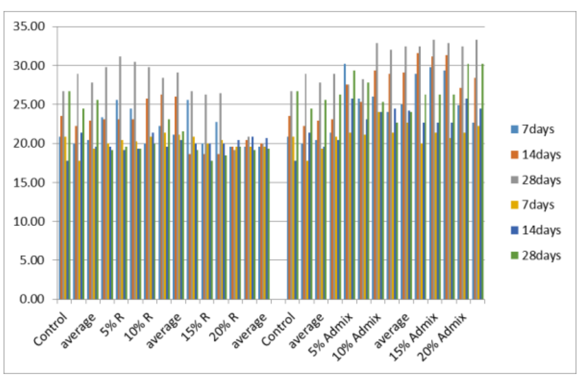

Figure 5: Compressive strength of concrete for all curing ages for 1:1.5:3 and 1:2:4 mix at varying percentage replacement of BPC

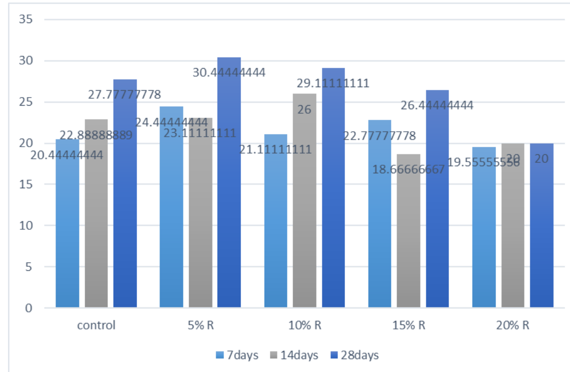

Figure 6: Cement Replacement for 1:1.5:3 Mix on Compressive Strength of Concrete incorporated with burnt pulverize Chickoko

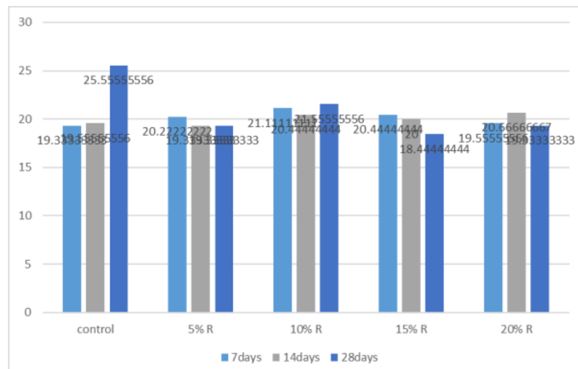

Figure 7: Cement Replacement for 1:2:4 Mix on Compressive Strength of Concrete incorporated with burnt pulverize Chickoko

a) Mix Proportions and Control Results

From figure 5- 7, the 1:1.5:3 control mix demonstrated a steady and consistent increase in compressive strength over time, culminating in a peak value of 27.78 N/mm² at 28 days. This suggests effective hydration and sufficient curing conditions that facilitated the complete development of the cement paste matrix, in line with findings by Neville (2011), who noted that cement-rich mixes often achieve higher long-term strength due to enhanced hydration. In comparison, the 1:2:4 control mix exhibited a slightly lower compressive strength of 25.56 N/mm² at 28 days. The slower rate of early strength gain, particularly at 14 days, emphasizes the effect of lower cement content on hydration kinetics, as supported by Mehta and Monteiro (2014), who attributed delayed hydration in leaner mixes to reduced calcium silicate availability.

b) Effects of Replacement Levels (R)
At a 5% replacement level, the 1:1.5:3 mix achieved notable strength improvements compared to the control, peaking at 30.44 N/mm² by 28 days. This aligns with research by Siddique and Khan (2011), which emphasizes that partial replacements can optimize particle packing and hydration. In contrast, the 1:2:4 mix displayed a significant reduction in strength at 7 days (19.33 N/mm²) and failed to show any notable improvement at later ages, likely due to insufficient binder content to offset the dilution effect. At 10% replacement, the 1:1.5:3 mix maintained its performance, with strength reaching 29.11 N/mm² at 28 days, while the 1:2:4 mix showed marginal early gains (21.11 N/mm²) at 7 days) but weakened to 20.00 N/mm² at 28 days. This trend reflects findings by Thomas et al. (2013), who observed that higher replacement levels could result in diminishing returns due to the reduced active cement fraction.

The 15% replacement level presented inconsistent trends for the 1:1.5:3 mix, with a drop in strength at 14 days but a modest recovery to 26.44 N/mm² at 28 days. For the 1:2:4 mix, compressive strength declined consistently across all curing periods, culminating in a low of 18.44 N/mm² at 28 days. These observations align with findings by Bentz et al. (2012), which noted that high replacement levels dilute the cementitious matrix, negatively affecting strength. At 20% replacement, both mixes experienced significant reductions in compressive strength. The 1:1.5:3 mix plateaued at 20.00 N/mm², slightly outperforming the 1:2:4 mix (19.33 N/mm²), indicating a pronounced dilution effect consistent with findings by Ghrici et al. (2007).

c) Effects of Admixture Levels
For a 5% admixture level, the 1:1.5:3 mix exhibited consistent strength improvements, culminating in 28.22 N/mm² at 28 days, while the 1:2:4 mix also improved significantly to reach 27.78 N/mm². These results are in line with the work of Yazıcı (2008), who reported enhanced strength development due to admixtures' water-reducing and workability-enhancing properties.

At a 10% admixture level, both mixes demonstrated substantial strength gains. The 1:1.5:3 mix achieved 32.44 N/mm², while the 1:2:4 mix attained 24.00 N/mm² at 28 days. The trends observed here are consistent with Neville's (2011) findings on the ability of admixtures to refine microstructure and reduce porosity. At 15% admixture, the highest strength values were recorded for both mixes, with the 1:1.5:3 mix peaking at 32.89 N/mm² and the 1:2:4 mix reaching 26.22 N/mm². These findings affirm the potential of admixtures to optimize cementitious matrix performance. At 20% admixture, the 1:1.5:3 mix maintained its high strength (32.89 N/mm²), while the 1:2:4 mix achieved its maximum strength of 30.22 N/mm², aligning with findings by Tan et al. (2018) regarding the beneficial effects of admixtures on leaner mixes at higher dosages.

IV. CONCLUSION

Burnt Pulverized Chikoko (BPC) demonstrates significant potential as a sustainable binder material in concrete. This study demonstrates the critical influence of mix proportions, cement replacement levels, and admixture dosages on the compressive strength of concrete. The 1:1.5:3 mix consistently outperformed the 1:2:4 mix, reflecting the importance of higher cement content in achieving better hydration and strength development. Partial replacement of cement with alternative materials yielded variable results: lower replacement levels (5–10%) enhanced strength in the 1:1.5:3 mix, while higher levels (15–20%) resulted in diminished strength due to the dilution effect on the binder matrix. In contrast, the 1:2:4 mix showed limited or negative effects across all replacement levels, indicating its reduced tolerance to cement substitution.

Admixture incorporation significantly improved the strength of both mixes, with optimal performance observed at higher dosages (15–20%). The 1:1.5:3 mix reached a peak strength of 32.89 N/mm², while the 1:2:4 mix achieved a maximum of 30.22 N/mm², demonstrating the potential of admixtures to enhance performance, even in lower cement content mixes. Overall, this study highlights the necessity of optimizing mix designs by carefully balancing cement content, replacement levels, and admixture dosage to achieve sustainable and high-strength concrete for diverse construction applications. Replacement levels of 10–20% optimize mechanical and durability properties while reducing cement usage and associated

CO_2 emissions. These findings support BPC's viability in sustainable construction practices, particularly in regions with abundant Chikoko clay. Future research should explore the long-term performance of BPC concrete under diverse environmental conditions.

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