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Impact of Chikoko Calcination Temperature on the Compressive Strength Properties of Blended Concrete

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ABSTRACT

The environmental impact of the cement industry necessitates the exploration of sustainable alternatives, such as supplementary cementitious materials (SCMs). Chikoko, a clay material from the Niger Delta, has shown potential as an SCM when calcined. This study investigates the impact of calcination temperature on the compressive strength of concrete blended with Chikoko. A total of 375 Samples were prepared with Chikoko calcined at temperatures ranging from 0°C to 800°C and cured for 7,14,21,28, 56 and 120 days. The results reveal that higher calcination temperatures significantly enhance compressive strength across various curing ages. At 200°C, concrete incorporating 10% Chikoko shows a 60.82% strength increase. At 400°C, the strength improvement reaches 93.51% at 7 days, indicating robust early strength development. Calcination at 600°C further enhances strength, with a 4.59% increase at 120 days. The highest improvements are observed at 800°C, with a 10.46% increase at 28 days and 7.39% at 120 days. Optimal Chikoko concentration consistently falls around 10%. The study concludes that higher calcination temperatures and longer curing times significantly boost compressive strength, providing valuable insights for optimizing the mechanical properties of Chikoko blended concrete in construction applications.

Keywords: compressive strength, calcination temperature, curing age, Chikoko

I. INTRODUCTION

Concrete, a fundamental material for modern infrastructure, significantly relies on Portland cement, which is a major source of CO_2 emissions, accounting for approximately 7-8% of global emissions (Scrivener et al., 2018). The development of supplementary cementitious materials (SCMs) that can partially replace Portland cement is crucial for reducing the environmental footprint of concrete production. Chikoko, a clay material found in the Niger Delta, shows promise as an SCM when calcined to enhance its pozzolanic properties (Escobar et al., 2020; Akinyele et al., 2019). Research indicates that calcined clays can improve concrete's mechanical properties (Akinyele et al., 2019; Gonçalves et al., 2016).

Studies by Ottos and Nyebuchi (2018), Otoko (2014), Orumu and Overo (2020), Onwuka and Sule (2017), and Sabir et al. (2001) have explored various natural and industrial by-products in concrete. While research on Chikoko-blended concrete is limited, it shows potential benefits. Calcined clays are abundant and have low carbon content, offering a way to reduce clinker levels in cement production (Zunino and Scrivener, 2020). Metakaolin, a well-known calcined clay, is valued for its pozzolanic properties (Sabir et al., 2001). The reactivity of clays depends on minerals like kaolinite, mica, and illite, and factors such as heat treatment and calciner environment (Beuntner and Thienel, 2015; Slade and Jones, 1992). Clays can be used as partial cement replacements and admixtures, enhancing concrete's sustainability and performance. Increasing clay content generally reduces concrete strength but improves environmental and durability indicators. The interaction between dissolved aluminum and silicon ions from calcined clay and calcium hydroxide forms hydrated Ca-Al-Si compounds, with solubility and Al3+ coordination transformation affected by dehydroxylation (Slade and Jones, 1992; Bich and Ambroise, 2009; Tironi et al., 2012).

Ottos and Onyebuchi (2018) used non-calcined Chikoko clay, recommending it for ≤10% cement replacement in mass concrete works. Using M20 and M25 concrete grades, they examined the effects of burnt Chikoko clay (BPC) as a cement replacement and admixture (5%-20% range), highlighting the need for further mineralogical analysis to optimize Chikoko clay's percentage for enhancing compressive strength.

However, the optimal calcination temperature for Chikoko and its impact on concrete compressive strength have not been extensively studied. This research aims to fill this gap by evaluating the effects of different calcination temperatures on the compressive strength of Chikoko-blended concrete.

II. MATERIALS AND METHODS

2.1. Materials

1. **Cement:**
   - Ordinary Portland Cement (OPC) was used as the primary binder in the concrete mixes.
2. **Aggregates:**
   - Fine aggregates (sand) and coarse aggregates (crushed stone) were sourced locally and used in the concrete mixtures.
3. **Chikoko:**
   - Chikoko, a locally available clay material, was collected from Delta state Nigeria, dried, and prepared for use as an admixture.
4. **Water:**
   - Potable water was used for mixing and curing the concrete samples.

2.2. Calcination Process

Figure 1: Calcination Process of Experimental Samples

The collected Chikoko was dried and calcined at five different temperatures: 0°C,200°C, 400°C, 600°C, and 800°Cfor 2 hours in aburning furnace. Each calcination process was carried out in a controlled furnace environment to ensure uniform heating and consistent calcination. The calcined Chikoko was then ground to a fine powder and used as a partial replacement for Portland cement in concrete mixtures.

2.3. Concrete Mix Design

Concrete mixtures were prepared with a constant water-to-cement ratio of 0.5. The control mixture contained 100% Portland cement, while the experimental mixtures included 0%, 5%, 10%, 15%, and 20%, by weight of cement as replacement of cement with calcined Chikoko.

2.4 Specific Gravity

The specific gravity of a substance is the ratio of its unit weight to that of distilled water at 4°C, describing soil particles. For cement, it was determined using the pycnometer method. For clay samples and aggregates, it followed BS 1377: Part 2, 1975, using the glass jar method. Samples were washed, dried, and weighed (M1). Material was added and weighed (M2), then filled with water and weighed (M3). The jar with just water was weighed (M4). Specific gravity (Gs) was calculated as

$$\text{Specific gravity (Gs)} = {}^{(\text{M2} - \text{M1})}\!/_{\text{Ww}} \quad (1)$$

2.5 Atterberg Limits

The Atterberg Limit Test determines critical water contents at which soil changes behavior, defining the Liquid Limit (LL), Plastic Limit (PL), and Shrinkage Limit (SL). These limits are crucial for understanding soil consistency, plasticity, and workability.

Liquid Limit (LL): The water content where soil changes from plastic to liquid state, determined using the Casagrande cup. The cup drops until a groove in the soil closes, and the water content is recorded.

Plastic Limit (PL): The water content where soil changes from plastic to semi-solid state, determined by rolling soil into 3 mm threads until they crumble, then measuring the water content.

2.6. Compressive Strength Testing

Concrete specimens (150mm x 150mm x 150mm cubes) were cast anddemolded after 24 hours and cured in water at room temperature. Curing periods were set at 7, 14, 28, 56 and 120days to assess the development of compressive strength over time. Compressive test were conducted using a universal testing machine of 2000KN in the Department of Civil Engineering Niger Delta University, following ASTM C39/C39M standards. The compressive strength values were recorded and compared against the control samples and across different calcination temperatures and admixture concentrations,

III. RESULTS AND DISCUSSION

3.1 Specific Gravity Results

The average specific gravity of Chikoko was obtained as 2.69, and the data shown in Table 1.

Table 1. Specific gravity of Chikoko Clay

Sample Borehole Codes	Sample 1		Sample 2		Sample 3	
Sample Identification	1	2	1	2	1	2
Label on Pycnometer Bottle	A	B	C	D	G	H
WP = Mass of empty, clean pycnometer (grams)	36.54	36.54	36.54	36.54	36.54	36.54
WPS = Mass of empty pycnometer + dry soil (grams)	62.41	82.27	78.77	73.27	73.02	74.18
WB = Mass of pycnometer + dry soil + water (grams)	153.41	165.46	161.52	162.49	158.22	162.73
WA = Mass of pycnometer + water (grams)	137.37	137.37	137.37	137.37	137.37	137.37
Specific Gravity (GS)	2.63	2.59	2.34	3.16	2.33	3.07
Average Specific Gravity	2.61		2.75		2.70	

3.2 Atterberg Limits and Characterisation of Chikoko Soil

As illustrated in Figure 2, the liquid limit of the Chikoko soil sample was identified as 23.5%, while the plastic limit was determined to be 9.25% (Table 4.2). Accordingly, the plasticity index of the Chikoko soil sample was measured at ambient temperature and found to be 14.25%. Based on the plasticity chart of the (USCS), the Chikoko soil sample was categorized as clay with low plasticity (CL).

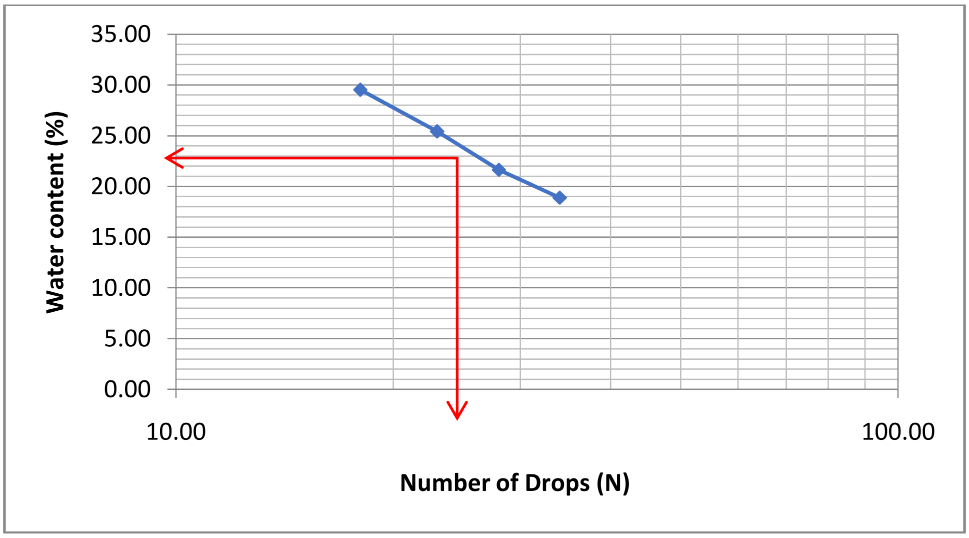

Figure 1. Liquid limit determination for Chikoko soil

Table 2. Plastic limit determination for the Chikoko soil sample

Sample label	**E**	**F**	**G**
Moisture can and lid number	5	6	7
Mc = Mass of empty clean can + lid (g)	8.02	7.98	8.00
Mcms = Mass of can, lid, and moist soil (g)	17.22	15.28	16.03

Mcds = Mass of can, lid, and dry soil (g)	16.54	14.63	15.30
Ms = Mass of soil solids (g)	8.52	6.65	7.30
Mw = Mass of pore water (g)	0.68	0.65	0.73
w = Water content (%)	7.98	9.77	10.00
Average moisture content (PL)	9.25		

3.3. Compressive Strength

The compressive strength of concrete increased with the calcination temperature up to 800°C, after which it slightly decreased. Concrete with 20% Chikoko calcined at 800°C exhibited the highest compressive strength, surpassing that of the control mixture by 15% at 28 days (Table 1). This improvement is attributed to the enhanced pozzolanic reaction between Chikoko and the hydration products of cement (Akinyele et al., 2019).

Table 3: Compressive Strength of Concrete with Varying Chikoko percentage Concentrations (Chikoko Produced at 0°C)

Chikoko Replacement Level (%)	Compressive Strength (MPa) - 7 days	Compressive Strength (MPa) - 14 days	Compressive Strength (MPa) –28 days	Compressive Strength (MPa) - 56 days	Compressive Strength (MPa) - 120 days
0	13.4	17.7	21.78	24.04	26.48
5	14.81	20.3	23.1	28.85	30.55
10	18.74	22.96	25.36	30.04	34.18
15	15.34	17.48	23.11	26.37	28.15
20	9.22	9.63	16.22	17.85	18.78

Table 4: Compressive Strength of Concrete with Varying Chikoko percentage Concentrations (Chikoko Produced at 200°C)

Chikoko Replacement Level (%)	Compressive Strength (MPa) - 7 days	Compressive Strength (MPa) - 14 days	Compressive Strength (MPa) –28 days	Compressive Strength (MPa) - 56 days 5	Compressive Strength (MPa) - 120 days
0	13.4	17.7	21.78	24.04	26.48
5	19.78	24.95	26.2	29.78	36.72
10	21.55	28.45	30.22	33.96	37
15	18.45	26.22	26.12	27.55	26.88
20	16.67	19.56	23	23.76	27.9

Table 5: Compressive Strength of Concrete with Varying Chikoko percentage Concentrations (Chikoko Produced at 400°C)

Chikoko Replacement Level (%)	Compressive Strength (MPa) - 7 days	Compressive Strength (MPa) - 14 days	Compressive Strength (MPa) –28 days	Compressive Strength (MPa) - 56 days 5	Compressive Strength (MPa) - 120 days
0	13.4	17.7	21.78	24.04	26.48
5	23.56	27.7	29.34	32.44	37.33
10	25.93	30.37	31.34	34.22	38.47
15	23.11	26.65	28.11	29.69	31.9

20	20.58	23.01	24.9	26.1	28.22

Table 6: Compressive Strength of Concrete with Varying Chikoko percentage Concentrations (Chikoko Produced at 600°C)

Chikoko Replacement Level (%)	Compressive Strength (MPa) - 7 days	Compressive Strength (MPa) - 14 days	Compressive Strength (MPa) –28 days	Compressive Strength (MPa) - 56 days 5	Compressive Strength (MPa) - 120 days
0	13.4	17.7	21.78	24.04	26.48
5	27.11	28.67	29.11	33.78	38.34
10	30.44	31.12	33.34	36.08	41.02
15	29.334	30.18	32.22	33.98	35.21
20	25.21	26.29	26.73	31.4	33.93

Table 7: Compressive Strength of Concrete with Varying Chikoko percentage Concentrations (Chikoko Produced at 800°C)

Chikoko Replacement Level (%)	Compressive Strength (MPa) - 7 days	Compressive Strength (MPa) - 14 days	Compressive Strength (MPa) –28 days	Compressive Strength (MPa) - 56 days 5	Compressive Strength (MPa) - 120 days
0	13.4	17.7	21.78	24.04	26.48
5	31.78	31.34	33.11	35.56	36.55
10	34	38	36.00	36.59	42.12
15	33.33	33.78	34.48	37.22	38.77
20	27.567	27.71	31.01	31.74	33.91

3.4 Effect of Calcination Temperatureon the compressive strength of concrete blended with Chickoko

Table 4.0 the compressive strength of concrete incorporating Chikoko, when calcined at various temperatures, displays significant variations over different curing ages. At a calcination temperature of 200°C, the compressive strength of Chikoko blended concrete shows a marked improvement compared to non-calcined Chikoko as shown in Table 3. This enhancement is consistently observed across all curing ages. After 7 days, the initial strength is moderate, reflecting the early stages of hydration and pozzolanic reaction. By 28 days, there is a substantial increase in strength, indicating a mature stage of concrete curing. At 120 days, the strength continues to rise and stabilizes as the concrete reaches full maturity. The optimal concentration of Chikoko admixture at this temperature is between 5% and 10%, with the most significant improvements noted at 10%, achieving up to a 60.82% increase in compressive strength compared to control samples.

When calcined at 400°C shown in Table 5, Chikoko exhibits even greater enhancements in compressive strength across all curing ages, surpassing the results observed at 200°C. At 7 days, the early strength development is significant, with a 93.51% increase over control samples. By 14 days, the strength continues to rise, showing a 71.58% improvement. At 28 days, the strength remains high, with a 43.89% increase, indicating robust pozzolanic activity. At 56 days, the improvement is sustained at 42.35%, and at 90 days, it remains strong at 42.15%. By 120 days, the compressive strength shows a 45.28% increase, stabilizing at high values. Optimal concentrations at this temperature range between 5% and 15%, with peak performance at 10%, confirming significant benefits from higher calcination temperatures (Mehta & Monteiro, 2014; Slade & Jones, 1992).

Table 6,illustrates Calcination at 600°C further enhances the compressive strength, maintaining a quadratic trend across all curing ages. At 7 days, early strength development is strong, although slightly less than at 400°C. By 28 days, the compressive strength reaches 33.34 N/mm², slightly above the control value of 32.59 N/mm². At 120 days, the compressive strength is

41.02 N/mm², which is 4.59% higher than the control value of 39.22 N/mm². Optimal admixture concentrations are found to be between 7.5% and 12.5%, with 10% showing consistent strength improvement, indicating the continued benefits of higher calcination temperatures (Thienel & Beuntner, 2015).

At 800°C, Chikoko exhibits the highest compressive strength improvements across all curing ages. At 7 days, early strength improvement continues with significant gains compared to lower temperatures as shown in Table 7, by 28 days, compressive strength increases by 10.46%, showing enhanced pozzolanic reactivity. At 120 days, the compressive strength increase is 7.39%, indicating robust and sustained strength development. Using a 10% admixture, the compressive strength values across different calcination temperatures show clear improvements: 25.36 N/mm² at atmospheric temperature, 30.22 N/mm² at 200°C, 31.34 N/mm² at 400°C, 33.34 N/mm² at 600°C, and 36.00 N/mm² at 800°C. These values represent strength slope increments of 19.16% between atmospheric temperature and 200°C; 3.17% between 200°C and 400°C; 6.38% between 400°C and 600°C; and 7.98% between 600°C and 800°C (Shah et al., 2020).

Conclusively, the comparative analysis across varying calcination temperatures and curing ages reveals a consistent pattern of increasing compressive strength with higher calcination temperatures and longer curing times. The quadratic relationship between Chikoko concentration and compressive strength is evident at all temperatures, with 400°C and 800°C showing the most significant improvements. Optimal calcination temperatures and admixture concentrations are crucial for maximizing the mechanical properties of Chikoko blended concrete, providing valuable insights for enhancing concrete performance in construction applications (Neville, 1995; Gartner, 2004).

IV. CONCLUSION

This study demonstrates that calcination temperature significantly enhances the compressive strength of Chikoko blended concrete. At 200°C, a marked improvement is observed, with a 60.82% increase at 10% Chikoko concentration. At 400°C, the strength improvement is even more pronounced, achieving a 93.51% increase at 7 days. Calcination at 600°C continues to show strength gains, with a 4.59% increase at 120 days. The highest improvements occur at 800°C, with a 10.46% increase at 28 days and 7.39% at 120 days. The optimal Chikoko concentration is consistently around 10%. Overall, higher calcination temperatures and longer curing times significantly enhance compressive strength, with 400°C and 800°C showing the most substantial benefits. These findings provide valuable insights for optimizing the mechanical properties of Chikoko blended concrete in construction applications as well as the potential of calcined Chikoko as a sustainable SCM in concrete production, contributing to the reduction of the carbon footprint in the construction industry.

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