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Enhancing the Performance of Concrete with Chikoko Admixture: A Comprehensive Study on Durability and Strength

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Abstract: This study explores high-performance concrete (HPC) focusing on workability, durability, and strength. A total of 1050 cubes were tested with various curing mediums like fresh water and chlorine to assess the effects of Chikoko, an admixture, on concrete containing uniformly or well-graded sand as fine aggregates. Multiple regression analysis was used to optimize the calcination temperature and admixture concentration of pulverized Chikoko in M25 concrete, with uniformly graded Abraka sand as the fine aggregate. The study found a quadratic relationship between admixture concentration (0–20%), with 10% CPC being the optimal level. The compressive strength of pulverized sand concrete improved significantly at this concentration, nullifying the strength advantage of natural sand over pulverized sand. The study also determined independent variables for optimization, resulting in notable improvements in chloride attack resistance and compressive strength compared to the natural sand control group. The research suggests that CPC-NS concrete meets high-performance concrete standards for strength and durability, while CPC-PS concrete can be used to make standard-strength concrete in areas without well-graded sands.

Keywords: High-performance concrete, Chikoko admixture, durability, compressive strength, chloride attack.

I. INTRODUCTION

High-performance concrete (HPC) has emerged as a critical material in modern construction, offering superior strength, durability, and workability compared to conventional concrete mixes. However, achieving optimal performance in HPC requires meticulous attention to various factors, including the selection of aggregates, cementitious materials, and admixtures. In recent years, researchers have explored the potential of novel admixtures, such as Chikoko, in enhancing the properties of concrete. Deltaic clay, also known as Chikoko, is a soft marine clay that can be found in the Niger Delta region of Nigeria and other parts of the world. It's a fibrous organic soil that's mostly made up of plant matter, (Ottos and Daniel, 2018). A very weak and abundant construction material that must be disposed of or stabilized with stabilizing agents as it relates to the foundation of structures.

Despite being a suboptimal foundation material, Chikoko clay stands out due to its high silica content, rendering it a natural pozzolan. This characteristic proves beneficial for fostering the development of secondary calcium silicate hydrate (C-S-H) gel when it reacts with the hydration by products of Portland cement. Several researchers have explored the potential of incorporating Chikoko clay as a partial replacement for cement in concrete production, as evidenced by studies such as those conducted by Orumu and Overo, (2020), Otoko, (2014), Onwuka and Sule, (2017), Ottos and Daniel, (2018), Beuntner and Thienel, (2015). As a replacement material, calcinated chikoko has its limitations as its increase in concrete results in linear reduction in strength, as reported by researchers. As an admixture, Orumu and Overo, (2020) are amongst the earliest researchers to discover remarkable increase in strength and hence it was recommended to be used in the production of high strength concretes.

This study aims to investigate the effects of Chikoko as an admixture on the workability, durability, and strength of concrete, with a focus on optimizing its concentration and calcination temperature for optimal performance.

II. OBJECTIVES

1. Explore the optimal concentration range for Chikoko admixture, with a focus on identifying the best admixture concentration for achieving high-performance concrete (HPC) standards.
2. Perform a multiple regression analysis to optimize the calcination temperature and concentration of pulverized Chikoko in Grade M25 concrete, using uniformly graded Abraka sand as fine aggregate.

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3. Compare the compressive strength and durability of concrete made with natural sand (NS) and pulverized sand (PS), both with and without Chikoko admixture.
4. Explore whether the use of Chikoko admixture enhances resistance to chloride attack and compressive strength compared to NS control variable

III. EXPERIMENTAL WORKS

A. Collection of Materials and Apparatus

With the aim of establishing a correlation between calcination temperature, concrete admixture concentration, and curing age on the physical, mechanical, durability as well as sustainability of Calcinated and Pulverised Chikoko (CPC) and CPC blended cement concrete using pulverised and natural Abraka sand as fine aggregate, the research employed the following materials and equipment's;

i. Chikoko (Deltaic Lateritic Soils).

Two different samples of deltaic lateritic soils were used in this study. The samples were obtained from locations, in Okrika in Rivers State and the transition zone.

ii. Coarse Aggregate

Crushed granite of maximum particle size of 12.7mm, played a pivotal role. The grading and properties of the coarse aggregate strictly followed the guidelines set forth in BS EN 12620. This deliberate choice of a particular grade for the coarse aggregate was made with the explicit intention of facilitating optimal and consistent compaction of concrete across all the test specimens.

iii. Fine Aggregate

Abraka river sand was used, it consisted of quartzite the grading properties conforming to BS EN 12620:2013.

iv. Cement

Cement, recognized as the preeminent binding material, stands as a ubiquitous and widely employed component in the construction of diverse engineering structures in contemporary times.The cement having compressive strength of $42.5N/mm^2$ is called 42.5 grade of cement and 50kg Dangote brand of cement was used in the investigation.

v. Grinding Machine

The grinding machine was used for pulverizing the calcined chikoko samples into fine (powder) sizes passing 75µm sieve

Plate 1: Grinding process of the chikoko Clay

vi. Water

The water used in concrete mixing, sourced from Niger Delta University's Civil Engineering Department, is deemed suitable and of good portable quality.

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B. Sample Preparation

Chikoko obtained from Okrika, was sundried for 7 days to drive off trapped moisture before subjected to calcination. Calcination was monitored using air inlet valves and a digital infrared thermometer at a rate of 10ºC per minute, plus an additional 30 minutes for homogeneity. Calcination temperatures used in this research exercise are ATM (25ºC), 200ºC, 400ºC, 600ºC, and 800ºC. Prior to concrete manufacture, calcined samples were pulverized and sieved to pass through a 75m sieve.

Plate 2. Calcination of Chikoko in Niger Delta University, Civil Engineering Department Lab

C. Specimen Production, Curing and Testing

In adherence to the standards outlined in BS 1881-113:2011, every concrete batch manufactured comprised three standard concrete cubes, each measuring 150 x 150 x 150 mm, of grade M25 at a water to binder ratio of 0.55 integrating Calcined and Pulverised Chikoko (CPC) as an admixture at concentrations of 0%, 5%, 10%,15% and 20%.

The concrete curing ages of 7days, 14days, 28days, 56days and 90days, for compressive strength, water absorption, chloride induced strength loss index and sulphate induced strength loss index. Each cube was tested using compression loading apparatus.

The maximum CS of the cubes were consolidated by taking their average, resulting in an overall average concrete compressive strength for the cube sets. The specific configuration of the concrete cube mixture is detailed in Table 3.1.

Table 3.1 Concrete cube production mixture configuration

Specimen details	Cement (kg)	Sand (kg)	Chippings (kg)	Chikoko (%)	Chikoko (kg)	W/Cem. Ratio	Water (kg)	No of cubes
0% CPC	3.75	7.5	15	0	0	0.55	2.06	3
5% CPC	3.75	7.5	15	0.05	0.1875	0.55	2.17	3
10% CPC	3.75	7.5	15	0.1	0.375	0.55	2.27	3
15% CPC	3.75	7.5	15	0.15	0.5625	0.55	2.37	3
20% CPC	3.75	7.5	15	0.2	0.75	0.55	2.48	3

D. Tests & Results on specimen:

Compressive Strength Test

The Compressive Strength of the cube specimens was evaluated in accordance with the guidelines specified in BS EN 12390-3 (2009). The cube specimens, each measuring 150mm x 150mm x 150mm, underwent submerged fresh water

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curing starting 24 hours after production, continuing until the day of testing. CS was determined by calculating the ratio of the crushing load at failure (in Newtons) to the area of the loaded cube. The compression testing machine is shown in Plate 3.

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{Load\ at\ failure(N)}{Area under loading(mm^2)} \qquad (3.1)$$

Plate 3.: Compression Testing Machine

Compressive strength (CS) is a crucial factor in assessing concrete's suitability for construction applications. Studies and experiments examining Chikoko additive concentration suggest that Chikoko has a significant impact on concrete CS.

Notably, a quadratic pattern emerges with optimal compressive strength occurring at Chikoko concentrations ranging from 5% to 15%, depending on curing ages. At non-calcined atmospheric conditions, Chikoko improves CS by about 16% to 40% at a 10% concentration across various curing ages, indicating its potential for concrete enhancement.

However, excessive use of Chikoko can inversely affect CS, as Ottos and Nyebuchi (2018) point out. They recommend not exceeding 10% replacement for mass concrete and non-load-bearing structures due to possible strength reduction. On the other hand, calcining Chikoko at higher temperatures (200°C, 400°C, 600°C, and 800°C) can further boost CS, with improvements at 200°C ranging from 36% to 61% compared to standard concrete.

Higher calcination temperatures, like 400°C, exhibit even greater enhancement, with up to 93% improvement at 10% concentration, demonstrating that optimal performance is closely tied to calcination processes and specific Chikoko concentrations.

The compressive strength of NS and PS concrete was compared to evaluate the impact of Chikoko. NS concrete exhibited an average 28-day compressive strength of 32.59 N/mm², while PS concrete had a lower 21.78 N/mm², indicating a 49.84% strength loss due to pulverization.

However, the study found a quadratic relationship between admixture concentration and compressive strength, with 10% CPC as the optimal concentration. At this level, the compressive strength of PS concrete improved by 16.4%, 38.75%, 43.89%, 53.08%, and 65.29% for CPC produced at ATM, 200, 400, 600, and 800 ºC, respectively. Notably, at 10% CPC produced at 600 ºC, the strength advantage of NS over PS was nullified.

Durability and Resistance to Attack

Durability, another key aspect of concrete performance, is influenced by Chikoko additive concentration and calcination temperature. Higher compressive strength often correlates with improved durability due to better resistance to environmental factors and mechanical stresses. Chikoko's potential to enhance CS suggests possible improvements in durability, particularly with optimal Chikoko concentrations and appropriate calcination temperatures.

The Studies at varying calcination temperatures (200°C, 400°C, 600°C, and 800°C) show that optimal concentrations between 5% and 15% yield greater CS, implying enhanced durability. Moreover, CS trends are quadratic, reinforcing the importance of optimal Chikoko concentrations for achieving durable concrete. Enhanced durability is critical for concrete used in various construction applications, emphasizing the need for thorough understanding of Chikoko's role in concrete longevity.

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To optimize CPC-NS concrete, independent variables of 14% CPC and 650 ºC calcination temperatures were identified. This optimization resulted in 16% chloride attack resistance reduction, and a compressive strength of 71 N/mm².
The relative improvements in NS concrete due to optimized CPC showed significant results: a 23.1% reduction in chloride attack resistance, and a remarkable 118% increase in compressive strength compared to NS control variables.

Strength Activity Index (SAI)

Strength Activity Index (SAI) according to ASTM C-618 and BS EN 12390-(3) is a numerical index that measures the percentage relativity between the CS of cement control concrete specimens and concrete specimens containing pozzolanic/hydraulic materials as concrete admixture.

According to the cited standards, the CS of pozzolana concrete (concrete containing pozzolans as a component of the binder) must not be than 75% of the control concrete specimen (concrete containing cement as 100% binder component). The strength activity index (SAI) measures the relative improvement in concrete CS with additives, serving as an indicator of additive effectiveness. Chikoko's SAI is influenced by concentration and calcination temperature.

Studies show that Chikoko can significantly boost concrete CS, leading to high SAI values. At 200°C calcination, SAI ranges from 36% to 61%, indicating considerable improvement over standard concrete. Higher calcination temperatures, like 400°C, yield even higher SAI, reaching 93% at 10% Chikoko concentration.

SAI trends also follow a quadratic pattern, with optimal Chikoko concentrations yielding peak compressive strength. Understanding SAI is crucial for determining the ideal Chikoko concentration and calcination temperature to maximize concrete performance. By identifying the optimal range, engineers can leverage Chikoko to enhance concrete strength and durability, improving its application in construction projects. Figure 4.1 to 4.7 shows results of partial replacement of cement with Chikoko Concentration on the Compressive Strength of Concrete (Chikoko Produced at Atmospheric temperature to a maximum of 800 ºC).

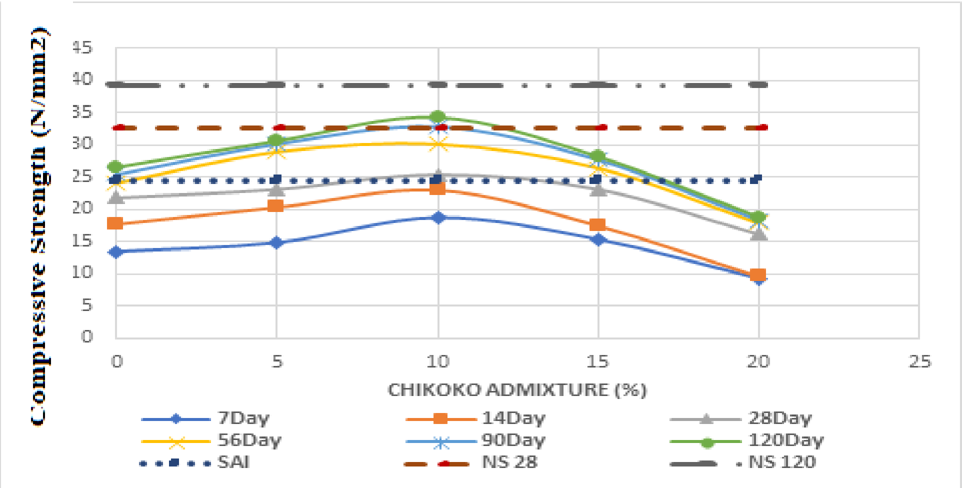

Figure 4.1: Partial replacement of cement with Chikoko Concentration on the CS of Concrete (Chikoko Produced at Atmospheric temperature)

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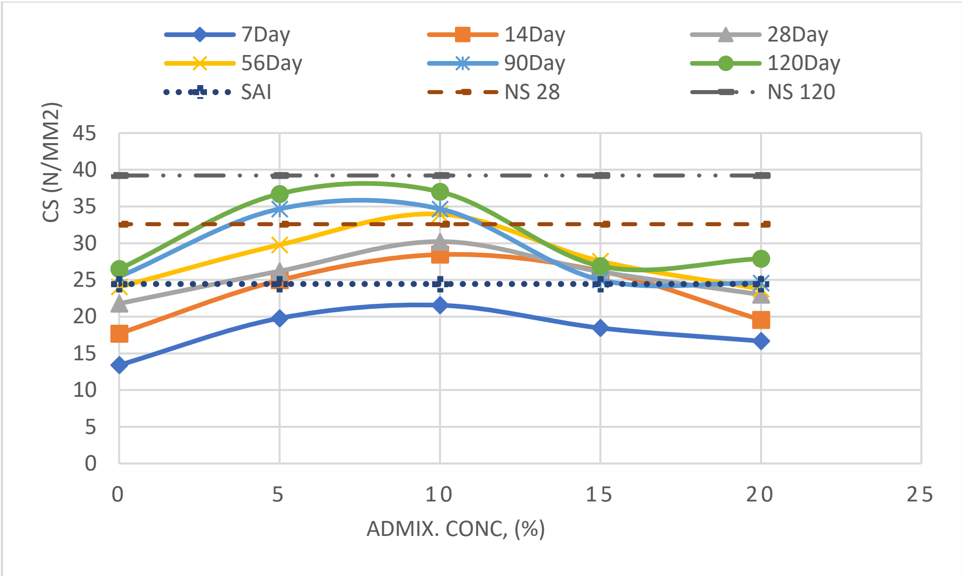

Figure 4.2. Partial replacement of cement with Chikoko Concentration on the CS of Concrete (Chikoko Produced at 200ºC)

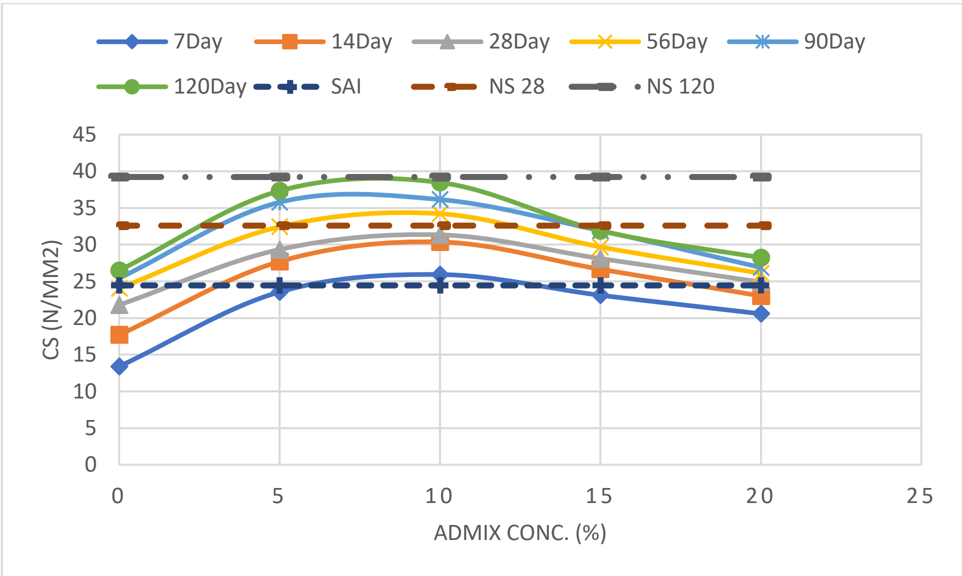

Figure 4.3: Partial replacement of cement with Chikoko Concentration on the CS of Concrete (Chikoko Produced at 400ºC)

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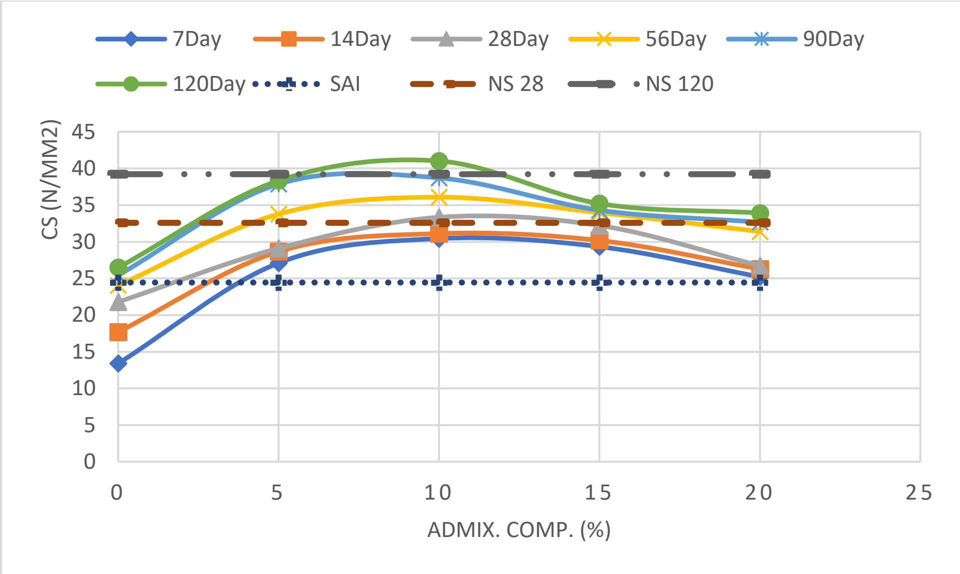

Figure 4.4: Partial replacement of cement with Chikoko Concentration on the CS of Concrete (Chikoko Produced at 600ºC)

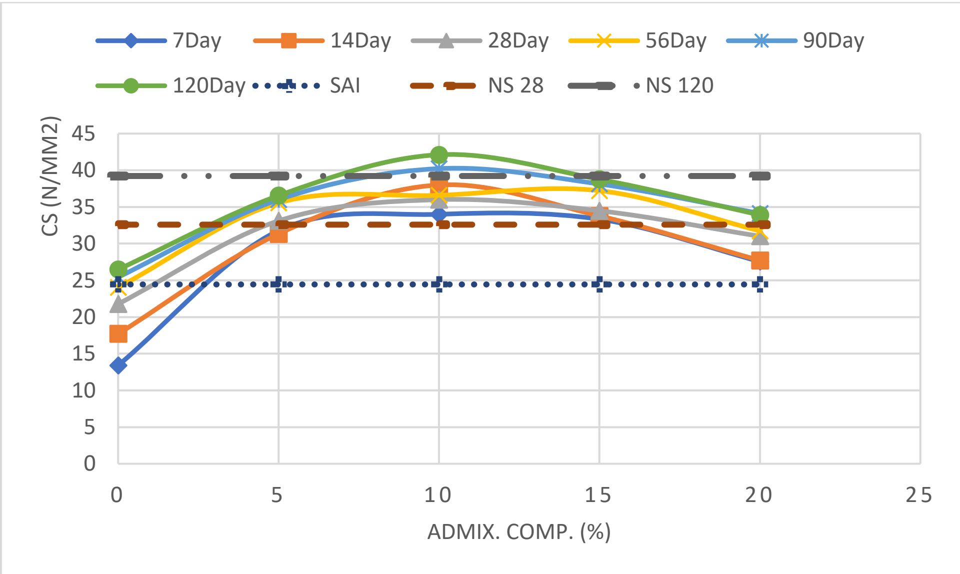

Figure 4.5. Partial replacement of cement with Chikoko Concentration on the CS of Concrete (Chikoko Produced at 800ºC).

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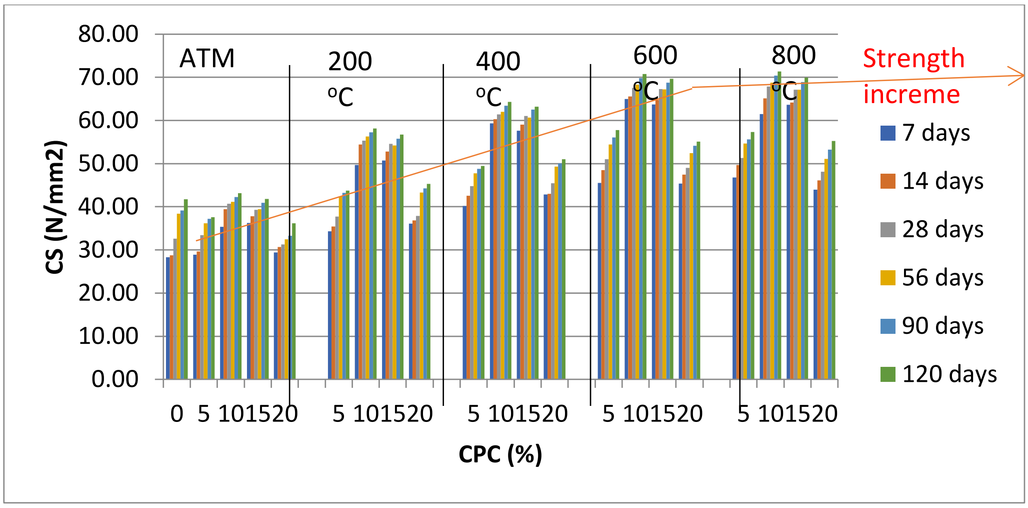

Figure 4.6: Compressive Strength of CPC-NS Concrete Cured in fresh water

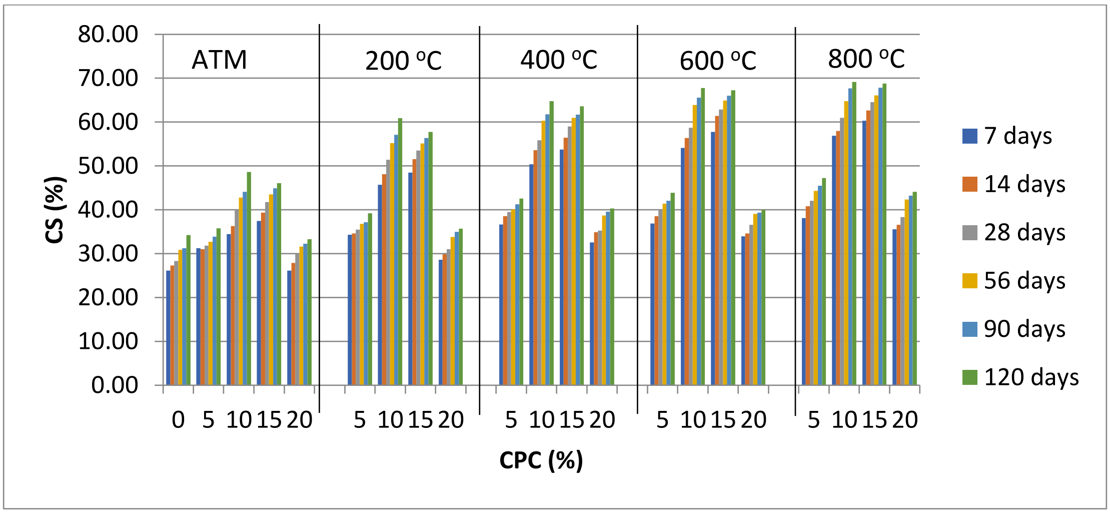

Figure 4.7: Compressive Strength of CPC-NS concrete cured in chloride solution

IV CONCLUSION

The results suggest that Chikoko can be used as an effective admixture in high-performance concrete. The study highlighted the critical role of calcination temperature and admixture concentration in achieving optimal compressive strength and durability. At a concentration of 10% CPC with a calcination temperature of 600 °C, PS concrete achieved compressive strength levels comparable to NS concrete, suggesting that CPC-PS concrete is a viable alternative in regions with limited access to well-graded sands.

Additionally, the optimized CPC-NS concrete demonstrated high durability and strength, meeting the standards for HPC. The substantial increase in compressive strength and sulphate attack resistance makes this composition an attractive option for various construction applications, particularly in aggressive environments.

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