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# Crushed Burnt Clay Bricks as Partial Replacement of Sand in Portland Cement Concrete – A Sustainable Construction Approach

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**Abstract:** The rapid pace of urbanization and infrastructure expansion has triggered a notable escalation in the generation of Construction and Demolition (C&D) waste. This investigation seeks to assess the performance of recycled fine aggregates from Crushed Burnt Clay Brick (CBCB) as a viable sustainable partial substitute for sand in the production of Portland cement concrete. Waste clay bricks were obtained from a land fill near Johannesburg, South Africa and were crushed. The fine particles that pass sieve 5 mm was utilized in this study. Concrete mixes with water- to- cement ratio of 0.55 was created to the control, and with an increase in percentage of CBCB were adjusted to 0.61, 0.66, 0.71, and 0.77. CBCB content of 0, 25, 50, 75, and 100% by mass was used to replace the crusher sand in the mixes. Standard tests were conducted to evaluate the workability, cube compressive strength, tensile strength, and drying shrinkage. While the samples for tensile strength were tested only after 28 days of a standard water curing, the samples for compressive strength were cured for 3, 7, and 28 days before testing. The results showed that up to 75% crusher sand substitution is possible for both tensile and compressive strengths. Also, an increase in CBCB content led to greater shrinkage. Consequently, incorporation of CBCB fines to replace natural sand in Portland cement concrete is viable. Such use can mitigate environmental impacts associated with sand mining and waste burnt clay bricks disposal.

## 1. Introduction

The rapid expansion of the construction industry has led to a heightened demand for resource materials. Today, structures such as buildings, bridges, roads, and railways are being constructed with increasing frequency, propelled by the growth in population and urbanization trends. This rise has necessitated the building of high-rise structures and the replacement of older, smaller buildings [1]. Concrete, a widely used material in the construction field across the globe, is expected to continue its prevalence [2]. It is a composite made of water, cement, and aggregates. These aggregates, which include sand and gravel, make up approximately 60% to 75% of the concrete's total volume and significantly affect both its fresh and hardened properties, mixture composition, and cost-effectiveness [3]. Portland cement concrete contains approximately 33% to 40% fine aggregates [4]. The demand for aggregates including sand is expected to double over the next 20-30 years [5]. Consequently, the extensive utilization of fine aggregates within the construction sector exerts a considerable impact on the natural environment, particularly influencing riverbeds, which serve as the primary sources of natural sand for industrial purposes.

Substantial quantities of construction and demolition (C&D) waste are produced annually during the activities of constructing, renovating, and demolishing buildings and infrastructure. It has been documented that the global annual generation of C&D waste surpasses 10 billion tons [6]. Developing nations encounter notable challenges in waste management stemming from insufficient practices [7]. Also, the pace of construction is rising due to rapid urbanization, industrialization, and economic growth in the developing countries [8]. Research estimates that, over the coming 50 years, bricks will continue to be the second most important building material, following concrete [9]. The disposal of numerous waste clay bricks in South Africa, resulting from construction and demolition debris,

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construction leftover and bricks' production waste, primarily involves landfilling. Nonetheless, these materials present an opportunity to be utilized in concrete manufacturing, serving as a partial substitute for natural aggregates.

The construction industry faces challenges due to depleting natural resources and the accumulation of C&D wastes, which frequently ends at landfills. Utilizing C&D wastes into concrete as partial replacements of natural aggregates in concrete is vital for reducing their environmental impact and preserving natural resources for future use [10]. To ensure sustainability, a key priority should be exploring every possible means to minimize waste from construction sites [2, 10].

Sustainable development encompasses energy conservation, environmental stewardship, and safeguarding nonrenewable resources. According to various findings, as noted in [11], the use of CBCB helps in lowering the reliance on natural resources and decreases landfill waste, thereby promoting environmental sustainability. The pozzolanic activity of crushed clay bricks improves the durability and lifespan of concrete, which in turn diminishes the ecological impact of construction ventures [12]. Various researchers have explored and advocated for the use of CBCB aggregate in concrete as a partial substitute. The study by Fadia [13] found that utilization of recycled aggregates from crushed clay reduces compressive and tensile strengths of concrete as compared to conventional concrete. In another study [14], substituting recycled clay brick aggregate (0, 50, or 100%) for fine aggregate increased the porosity and pore volume of the concrete; however, the chloride migration coefficient decreased because of the recycled clay brick's pozzolanic activity.

In the study conducted by [15] researchers investigated the impact of substituting fine aggregate with crushed clay brick debris at proportions of 5, 10, 15, and 20%. It was found that a 10% substitution led to optimal compressive strength compared to the control mixture. Additionally, research suggests that up to 50% of natural aggregates can be replaced with recycled material without negatively affecting mechanical properties such as tensile strength and water absorption [16]. The water absorption rate of recycled clay brick is expected to be higher than the natural fine aggregate. Incorporating recycled CBCB into concrete affects its shrinkage behavior, as substituting more recycled aggregates for natural ones enhances drying shrinkage [17]. The use of recycled crushed brick as a sand replacement in concrete offers both advantages and disadvantages, particularly in terms of mechanical properties, durability, and practical feasibility. It was found that incorporating of CBCB in place of natural fine aggregate during production of Portland cement concrete, reduced slump by roughly 71% at 50% replacement and 90% at full replacement, producing noticeably dry and difficult to work concrete [18]. While some results relating to the use of CBCB as a sand substitute in concrete exist, the physical and chemical properties differ worldwide, pointing out to the need for additional research involving local materials.

This study explored the feasibility of employing recycled crushed brick waste as a substitute for crusher sand in Portland cement concrete. The experimental work included X-ray fluorescence (XRF) and sieve analysis on CBCB prior to the use of the material. Concrete mixes containing CBCB of 0, 25, 50, 75, and 100% by mass of the fine aggregate were created. The effect of CBCB content on workability, compressive strength, direct tensile strength, and drying shrinkage of concrete were then assessed.

## 2. Materials and Experimental Design

Recycled clay bricks were sourced from a landfill (Latitude: -26.237°, Longitude: 27.943°) close to Johannesburg, South Africa, and were crushed. The fines that passed through a 5 mm sieve were used in this study. The chemical composition and particle size distribution were established for the Crushed Burnt Clay Bricks (CBCB). Control concrete mix (i.e., contains crusher sand) and mixes including CBCB with 25%, 50%, 75% and 100% by mass replacement of the natural sand were created. The mixes were used to cast standard cubes of 100 x 100 x 100 mm and drying shrinkage

beams of 100 x100 x300 mm. A total of seventy-five samples were prepared to evaluate the compressive strength according to SANS 5863-3:2006 [19], tensile strength as per SANS 6253:2006 [20] and drying shrinkage in accordance with the procedure described in SABS Method 1085:2021 [21]. Slump tests were conducted according to SANS 5862:2006 [22]. The physical properties of the coarse aggregate, crusher sand and CBCB were assessed and compared. Table 1 shows the constituent materials for the control mix and CBCB percentage replacements for one cubic meter.

***Table 1**: Mix composition of concrete cubes.*

| Replacement Level | Cement ($kg/m^3$) | Designed (w/c) | Adjusted (w/c) | Water (1) ($kg/m^3$) | Crusher Sand ($kg/m^3$) | CBCB ($kg/m^3$) | C-Aggregate (2) ($kg/m^3$) |
|---|---|---|---|---|---|---|---|
| 0%(Control) | 340 | 0.55 | 0.55 | 187.00 | 760 | 0.00 | 1113 |
| 25% | 340 | 0.55 | 0.61 | 207.40 | 570 | 190 | 1113 |
| 50% | 340 | 0.55 | 0.66 | 224.40 | 380 | 380 | 1113 |
| 75% | 340 | 0.55 | 0.71 | 241.40 | 190 | 570 | 1113 |
| 100% | 340 | 0.55 | 0.77 | 261.80 | 0.00 | 760 | 1113 |

([1]) For mixtures containing CBCB, water is added into the mix until the workability value approaches that of the control mix.
([2]) Granite stones with a maximum size of 22 mm.

The cube and beam specimens were subjected to a standard water curing. Compressive strength tests were performed at 3, 7, and 28 days while cube split tensile strength tests were conducted at 28 days. The drying shrinkage measured using a digital extensometer. Specimens were oven-dried at 55 ± 5°C and cooled before measurement. Shrinkage readings were taken every 48 hours.

## 3. Results and Discussion

### 3.1 Chemical Composition of CBCB

The chemical composition of the crushed burnt clay bricks obtained using X-ray fluorescence spectrometer (XRF) technique revealed that the sum of $SiO_2$, $Al_2O_3$, & $Fe_2O_3$ is 89.83% and $SO_3$ content is 0.06%, which is less than 5.0% by mass. This qualifies the CBCB as class (F) pozzolan according to criteria presented in ASTM C- 618-19 [23].

One can speculate that in the presence of water, CBCB fines (< 0.075 mm) on the surface of the sand particles can chemically react with the calcium hydroxide produced during cement hydration, leading to the formation of additional calcium silicate hydrate (C-S-H) and, consequently, expected to enhanced strength over time

### 3.2 Particle size distribution

Figure 1 shows the Particle Size Distribution (PSD) for both the crusher sand and the CBCB sand. The results show that CBCB has a slightly more fines the crusher sand. The presence of finer materials increases the surface area and eventually the water demand.

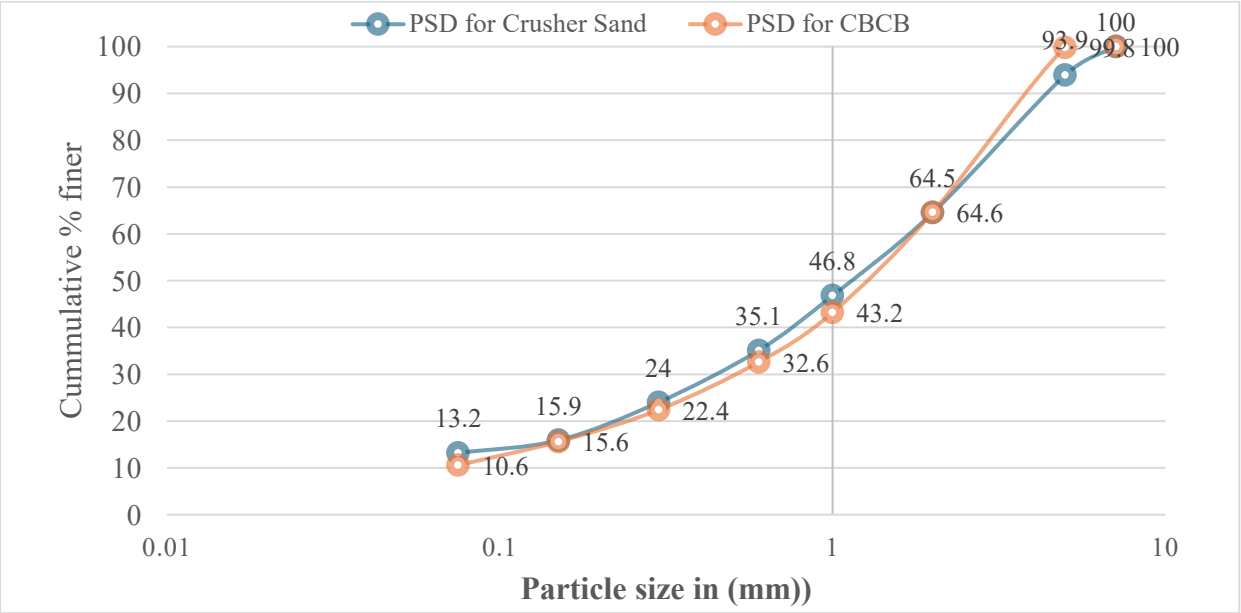



***Figure 1**: Particle size distribution for crusher sand and CBCB.*

### 3.3 Physical properties of crusher sand and CBCB

The physical property test results of coarse aggregate, recycled CBCB fine aggregate and crusher sand were evaluated as per the relevant SANS standard, and the results have been summarized in Table 2. Crusher sand demonstrates a superior density, reduced silt content, and significantly lower absorption compared to CBCB. Nevertheless, both materials exhibit similar fineness moduli, suggesting analogous particle size distributions.

***Table 2**: Physical test results of aggregates.*

| Type of Test | Coarse Aggregate | Crushed Sand | CBCB | Standard Applied |
|---|---|---|---|---|
| Silt content (%) | - | 4.8 | 12 | SANS 1083 |
| Fineness modulus (%) | 7.2 | 3.2 | 3.22 | SANS 1083:2017 |
| Moisture content (%) | 0.6 | 1.4 | 6.04 | SANS 3001-GR20:2010 |
| Loose Bulk Density (kg/m³) | 1,390 | 1,770 | 1,110 | SANS 5845:2006 |
| Compacted Bulk Density (kg/m³) | 1,500 | 1,880 | 1,286 | SANS 3001-AG23:2014 |
| Apparent Density (kg/m³) | 2,664 | 2,651 | 2,162 | SANS 3001-AG20/AG21 |
| Absorption capacity (%) | 0.6 | 1.6 | 13.8 | SANS 5843 |

### 3.4 Workability test

Figure 2 indicates that the slump value ranges between 68 and 86 mm**.** The slump value increases with the increase in the water-to-cement ratio for each mixture. Intuitively, the surface area and absorption capacity of the CBCB have played a role in terms of consuming the extra water (i.e., higher water-to cement ratio) added for the higher replacement percentage. Hence, to maintain workability, the amount of water requirement for CBCB mixtures should be increased as the percentage of replacement of CBCB increased.

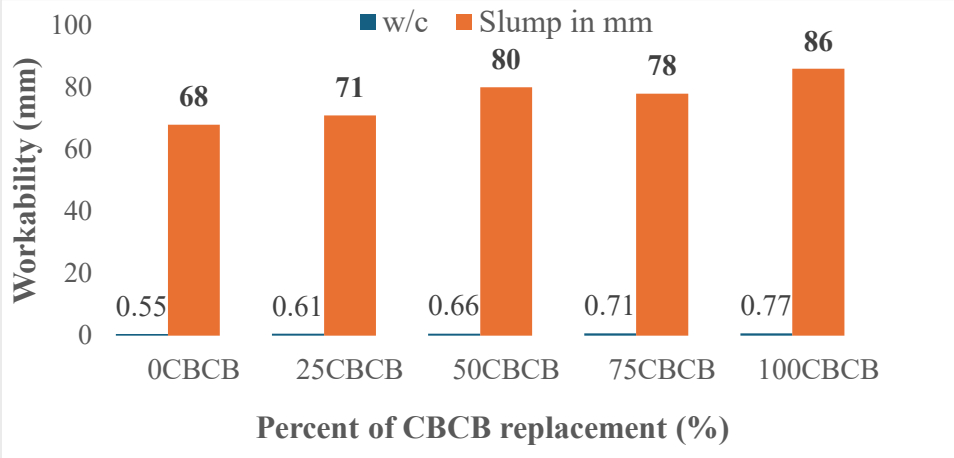



***Figure 2**: Slump test results with different w/c and CBCB percent replacement.*

### 3.5 Compressive Strength

The compressive strength test results are presented in Figure 3 below.

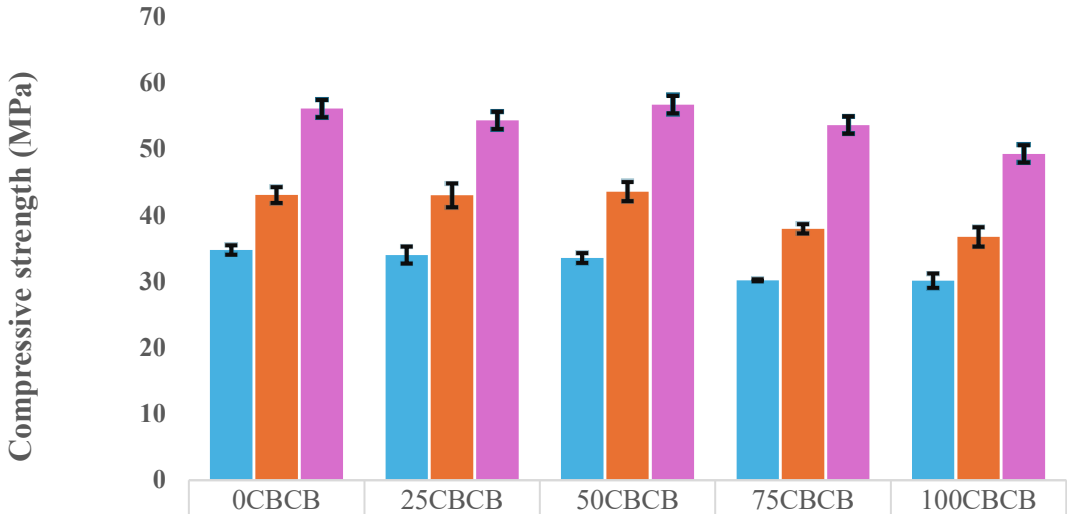



***Figure 3:** Compressive strength variation of with CBCB percentage and curing periods.*

Figure 3 details the compressive strength of concrete cubes at intervals of 3, 7, and 28 days, using varying CBCB replacement. The control mix (i.e., 0 CBCB), exhibits a strength increase from 34.77 MPa at 3 days to 56.13 MPa at 28 days. Remarkably, the 50CBCB mix achieves a slightly higher 28-day strength (56.72 MPa) compared to the control (56.13 MPa), suggesting a beneficial replacement threshold where CBCB enhances strength, owing to filler effects or improved packing. However, further increase in CBCB percentage lowers strength. There is a negligible decline in compressive strength for the mixes 75CBCB, but greater strength reduction is noticeable as CBCB replacement increases to 100%. In addition, the strength growth for mixes containing CBCB is comparable to that of the control mix. Additional investigation is needed beyond 28 days to determine if CBCB fines are reactive and can enhance long-term strength.

### 3.6 Direct Tensile Strength

The tensile strength test results at age of 28 days are presented in the Figure 4 below.

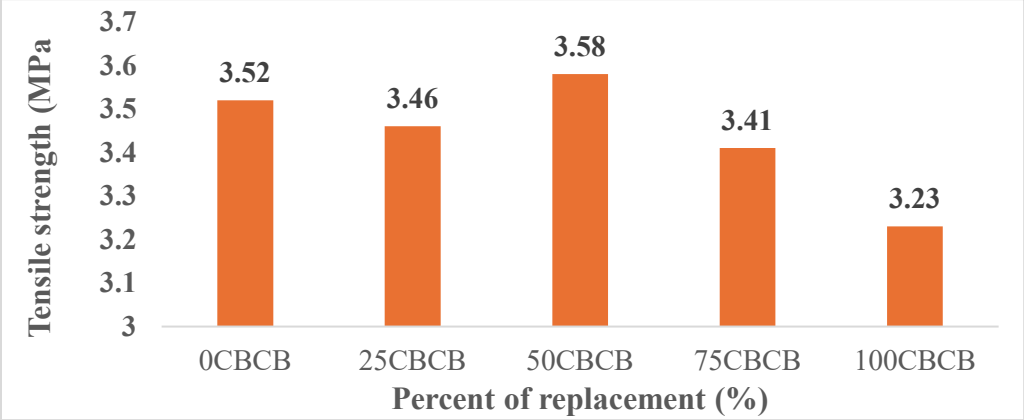



***Figure 4:*** *Tensile strength variation of with CBCB percentage.*

The control mixture, 0CBCB, has a tensile strength of 3.52 MPa Except for the 50CBCB mix, the tensile strength reduces as the CBCB replacement increases. Nonetheless, the decrease in tensile strength is minimal with a replacement of up to 75%, after which the reduction in tensile strength is comparatively significant.

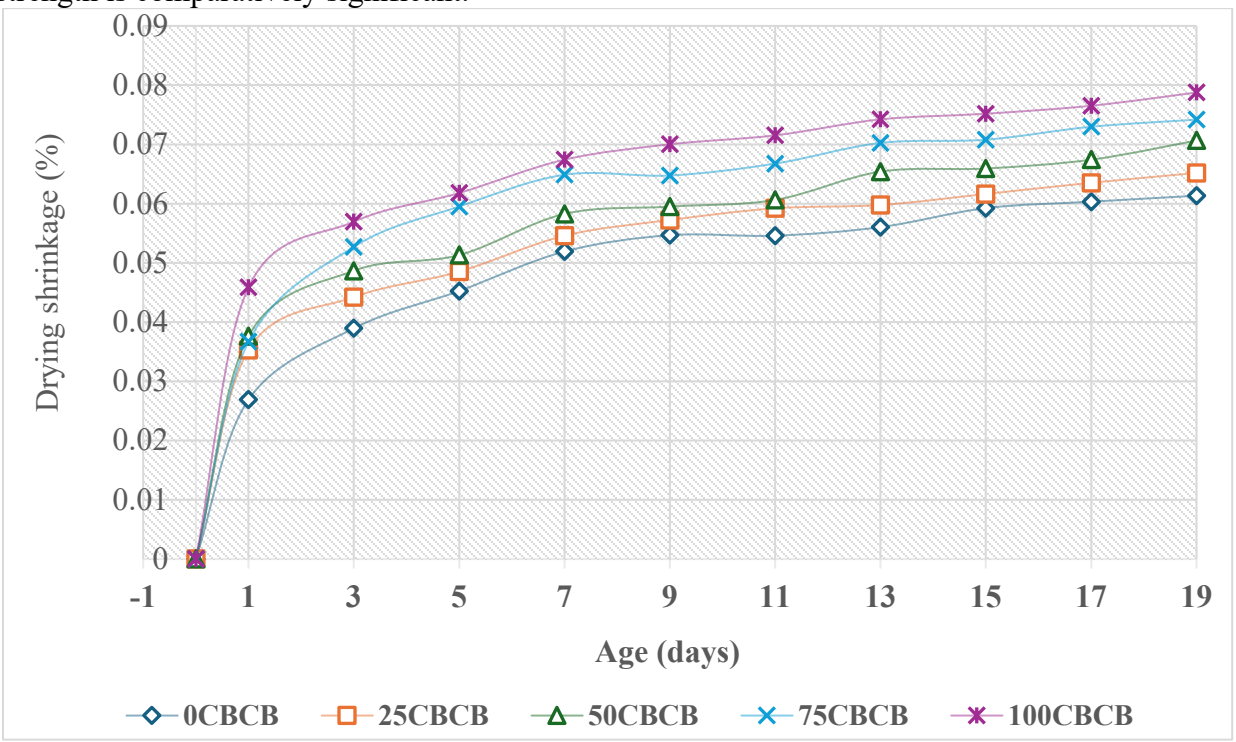



***Figure 5****: Accelerated drying shrinkage strain test results.*

### 3.7 Accelerated Drying Shrinkage Tests

Figure 5 shows the drying results obtained after 19 days. The result reveals that increasing the CBCB fines replacement increases drying shrinkage. The control mix (0CBCB) displays the minimal shrinkage strain, while the 100CBCB mix demonstrates the maximal shrinkage strain. An initial considerable rise in shrinkage observed, followed by a deceleration in the shrinkage rate across all mixes. The high-water absorption of the CBCB fines influences the mix's free water content, thereby impacting drying shrinkage strain. The increase in drying shrinkage associated with higher CBCB contents can be attributed to the absorption capacity of burnt clay bricks

## 4. Conclusion

In this study, the effect of Crushed Burnt Clay Bricks (CBCB) used as a crusher sand replacement on physical and mechanical properties of concrete was assessed. Based on the experimental results, the following conclusions drafted:

- Crushed Burnt Clay Bricks (CBCB) had high water absorption capacity and higher silt content than crusher sand, which affect the fresh and hardened states of concrete.
- The research indicates that CBCB is highly effective as a partial replacement for fine aggregates (crusher sands) in concrete, though only up to the feasible limits.
- Up to 75% crusher sand can be replaced with CBCB with negligible reduction in compressive and tensile strengths of concrete. However, with excessive CBCB replacement both compressive and tensile strengths decreased.
- The drying shrinkage increased with increasing CBCB replacement percentage. This attributes to the high-water absorption capacity.

From this research, the construction, and the demolition CBCB wastes could replace the crusher sand up to 75%, and this could reduce environmental impacts due to waste disposal and sand mining.

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