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Mechanical properties of high strength eco-concrete containing crushed waste clay brick aggregates as replacement for sand

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Abstract. Utilization of clay brick wastes for production of high strength eco-concrete enables the combat of raw resources depletion due to excessive mining as well as mitigating environmental pollution caused by demolition of old brick structures in an effort to achieve environmental sustainability in line with the sustainable development goals (SDGs). This study investigates the beneficial usage of crushed clay brick as partial replacement for natural sand in producing high strength eco-friendly concrete. The replacement percentages of the crushed clay brick in respect to sand are 0, 10, 20, 30, 40 and 50% by weight using a mix proportion ratio of 1:1:2 at a constant water-cement ratio of 0.25, aiming at the 28 days compressive strength of about 40 MPa. The chemical characterization of the crushed clay brick and cement was conducted via X-ray fluorescence (XRF). The mechanical properties tests were performed on about 80 specimens using 100 x 100 x 100 mm for cubes, 100 x 100 x 500 mm for beams and 100 x 200 mm diameter for cylinders after 7, 14 and 28 days of curing in water. Results showed that concrete containing crushed clay brick as partial replacement for sand compare favourably well with the control. Consequently, it is suggested that generated clay brick wastes can be crushed and used as replacement for natural sand for the production of eco-friendly high strength concrete.

Keywords: Clay brick wastes, High strength concrete, Compressive strength, Flexural strength, Split tensile strength, Sustainability

1. Introduction

The construction industry in recent times has seen growing attention and concern on the issue of waste generation and its efficient management in other to achieve sustainable construction for environmental sustainability and protection [1]. Statistics revealed by the Nigerian Environmental Society indicates that 60 million tons of wastes is generated annually with less than 10% of it being recycled [2]. According to the study conducted by [3] that clay brick is the second only to concrete as the most utilised construction material. Its widespread usage has led to the generation of high quantities of brick waste due to demolition of dilapidated old structures as a result of urbanization and improvement in technology [4]. Report by the Environmental Protection Agency suggests from 2012 to 2014, 400 million tons of brick waste was generated. With the vast majority it dumped in landfills or left undisposed. This in turn causes pollution since clay bricks are non-biodegradable wastes. Research by [4,5,] have shown clay brick shows consistent durable performance and pozzolanic properties The incorporation of crushed clay brick waste in concrete as partial replacement for natural sand offers a sustainable alternative for efficient management of clay brick wastes.

Heavy reliance on natural sand for construction has led to its sporadic and indiscriminate mining and dredging, which in turn has led to shortages due to the gradual depletion of the resource, ultimately resulting to scarcity, pollution of the environment and an increase in the price of the resource [6].

Lately, in developing nations the use and demand for concrete has been on the increase due to rapid infrastructural development and industrialization [7]. This increase has led to an upsurge in the volume of carbon (IV) oxide (CO_2) released into the environment as a result of the cement content present. Statistics show that the cement industry is responsible for 7% of the global CO_2 emissions, which is 1.35 billion tons annually [8]. CO_2 emissions have damning consequences to the environment most notably global warming and in a long run climate change. An effective technique used to clamp down CO_2 emissions from concrete is by partially blending the cement with alternative cementitious material (usually by industrial by products such as fly ash etc.). In this research calcined clay is blended with calcined clay to minimize emissions and produce an eco-friendly concrete.

Furthermore, the latest trend in the construction industry has seen the development of high rise, sophisticated and complex infrastructures. For this purpose high strength concrete is preferred to normal strength due to the superior and exceptional engineering properties it offers [9]. According to ACI high strength concrete is regarded as a high performance concrete with 28 compressive strength greater than 42 MPa or 6000 psi [10]. Whereas, studies by [11, 12] regarded HSC to be in the ranges of 50-150 MPa and greater 60 MPa respectively. The superior characteristics high strength concrete has over normal strength includes, higher compressive, tensile, flexural strengths, durability, toughness and stiffness [13]. The use of high strength concrete in construction not only assures greater safety but also addresses the issue of scarcity especially in crowded urban centre aiding full maximization of available space. Furthermore, the construction industry is also mindful of attaining sustainability, consequently the industry is focusing on reusing some generated waste materials as constituent materials for production of moderate and high strength concrete [17 -19]. The aim of this research is to determine the suitability of crushed clay brick wastes as an alternative to natural sand in the production of high strength concrete for sustainable construction.

2. Materials and Method

Type I Ordinary Portland cement (OPC) of grade 42.5 was used in accordance to [14]. Calcined clay was obtained locally from factory. Clay brick waste was locally source within Ota community, located in Ogun state, Nigeria. It was crushed and to the stipulated fineness, then sieved through the 4.75mm BS mesh in other to ensure uniform particle sizes. The Ordinary Portland cement (OPC), Calcined clay and crushed clay brick aggregate (fine) were characterized physically and chemically. The granite and sand used in the concrete mixes were commercially sourced. Fineness modulus and particle size distribution of crushed clay brick and sand were determined through sieve analysis. The mix proportion of the concrete mixes were in accordance with the ASTM C109 [15], using the mix ratio of 1:1:2 (cement: sand: granite) at a constant water cement ratio of 0.25. In every mix, the binder consists of OPC blended with calcined clay (a pozzolan) in proportions of 0, 10 and 15%. The sand was partially replaced with crushed clay brick in proportions of 0, 10, 20, 30, 40 and 50%.

The binders were thoroughly mixed to ensure even distribution and uniformity. Concrete cubes of 100 x 100 x 100 mm in dimension were casted and tested for the compressive strength test. Concrete cylinders of 100 x 200 mm in diameter and length respectively were cast and used for Spilt tensile strength test, while beams of 100 x 100 x 500 mm for Flexural strength test. The mixes were demoulded after a day of being casted, then labelled appropriately for easy identification and cured by complete immersion in water until the due test time. Batching of concrete constituent materials is shown in Table 1.

Table 1. Batching of concrete constituent materials

Materials	Batching						
	0%	10%	15%	20%	30%	40%	50%
Cement (kg)	6.0	5.4	5.1	4.8	4.2	3.6	3.0
Sand (kg)	6.0	5.4	5.1	4.8	4.2	11	3.0
Water (kg)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Crushed clay brick (kg)	-	0.6	0.9	1.2	1.8	1.6	3.0
Granite (kg)	12.0	12.0	12.0	12.0	12.0	12.0	12.0

3. Results and Discussion

The particle size distribution for the various materials used in this research are presented in Figure 1. The materials includes; crushed clay brick aggregate (CCBA), natural sand and Portland cement. From Figure 1, it can be deduced that the crushed clay brick aggregate and natural sand showed similar uniformly gradation. Cement and calcined clay have very similar particle sizes. This indicates both cement and calcined clay, as well as clay brick aggregate and natural sand possess good potential of being suitable replacements to each other.

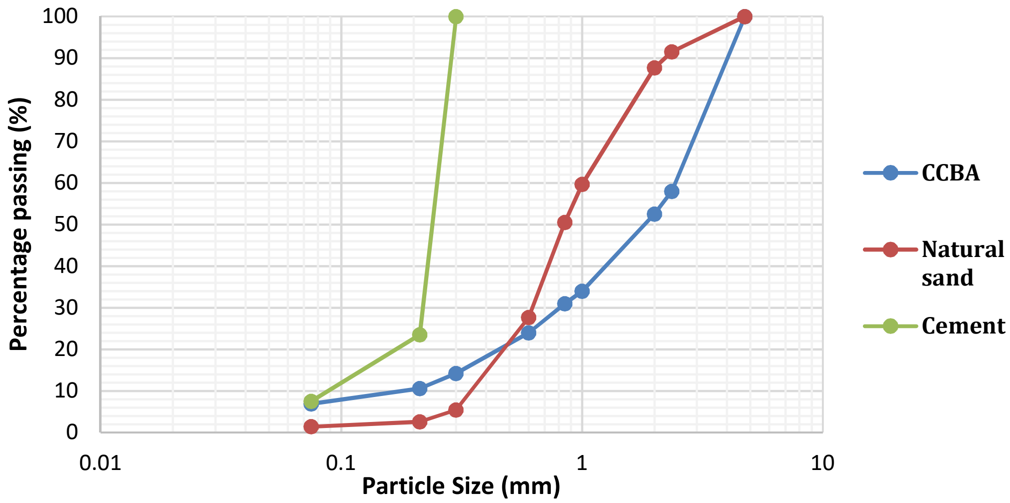

Figure 1. Particle size distribution of clay brick aggregate, Portland cement and natural sand

Moreso, Table 2 depicts the characterized physical properties of the concrete constituent materials. The chemical composition results obtained using the X-ray fluorescence (XRF) of cement and clay brick aggregate are represented in Figures 2 and 3. The oxide compositions results clearly indicated that clay brick waste materials possess high traces of silica and alumina at 60% and 14.3% respectively, which are in accordance with the requirement for a pozzolanic material. Furthermore, clay brick aggregate can be classified as a class N pozzolan based on ASTM C618 [16] recommendation because the sum of the percentage compositions of Fe_2O_3, SiO_2 and Al_2O_3 (87.3%) is above the minimum requirement of 70% for a class N pozzolan.

The reported loss on ignition (LOI) is less than 10%, while the SO_3 (0.4) is less than 4%. Based on this it is expected the crushed clay brick aggregate is expected to contribute additional pozzolanic reactivity to achieve higher concrete strength. Unlike Portland cement, fired clay brick contains little to no traces of $CaCO_3$ which is majorly responsible for CO_2 emissions from cement. The adoption of calcined clay as pozzolan which aid in the mitigation of CO_2 emission. This clearly indicates clay brick used as crushed aggregates is environmentally friendly and compatible for sustainable construction.

Table 2. Physical properties of concrete components

Properties	Portland Cement	CCBA	Sand	Granite
Fineness Modulus		2.60	2.69	5.12
Specific gravity	3.15	2.52	2.62	2.70
Water absorption (%)		0.15	0.45	0.50

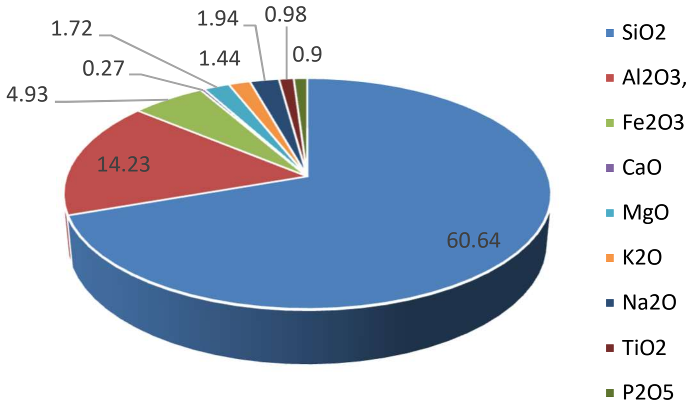

Figure 2. Chemical composition of crushed clay brick aggregate

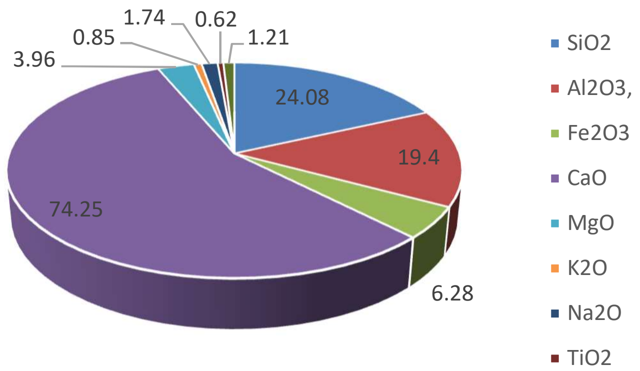

Figure 3. Chemical composition of cement

Figure 4 shows the compressive strength of the concrete mixes at different replacement percentages of sand with finely crushed and graded clay brick aggregate. The results clearly indicate a significant increase in the strength of concrete samples as the age of curing increases. However, the compressive strength of the concrete mixes shows a decreasing trends as the percentage replacement of clay brick aggregate increases, with the exception of CCBA 10% with showed an increase in strength. Similarly, flexural strength and the split tensile strength in Figures 5 and 6 values also show the same trends exhibited by the compressive strength.

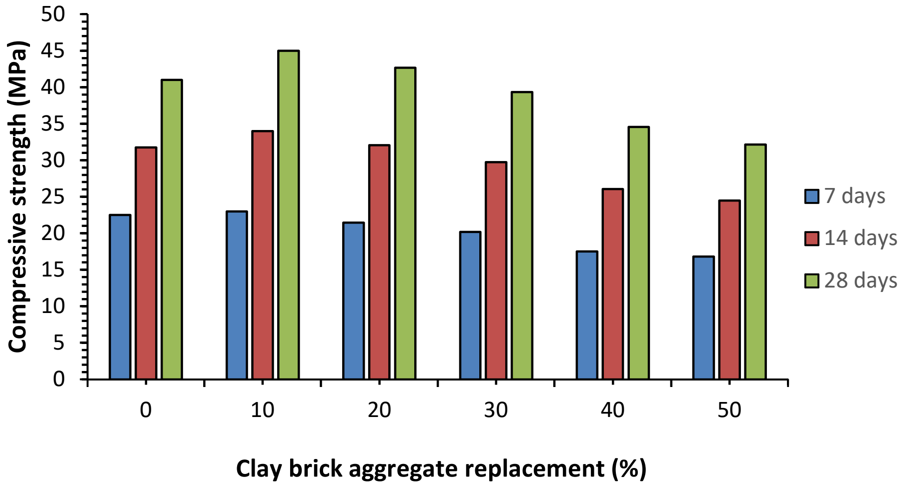

Figure 4. Compressive strength development of concrete after various curing days

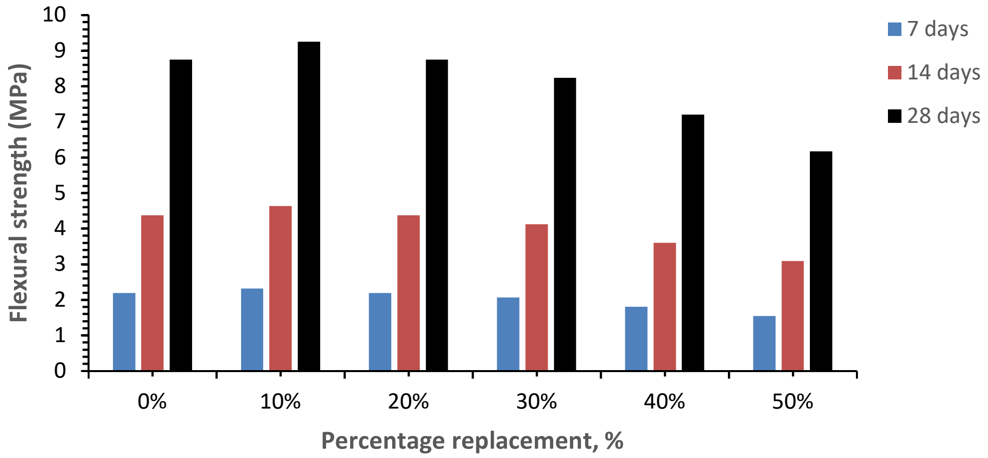

Figure 5. Flexural strength development of concrete mixes

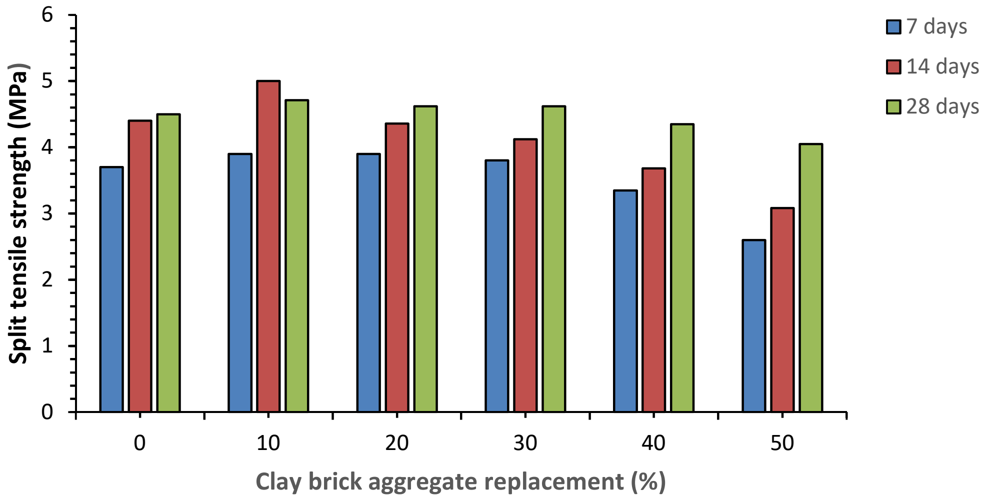

Figure 6. Split tensile strength development of concrete mixes at different days

4. Conclusion

This study investigates the sustainable reuse clay brick waste as substitute for natural sand in concrete production. The following conclusions can be drawn from this study:

i. The chemical compositions of clay brick aggregate indicates that the material can be classify as class N pozzolan material following the report of ASTM C618 on pozzolanic materials.
ii. The strength of concrete was significantly improve with 10% addition of CBA. However, the highest strength was achieved with a calcined clay replacement of 10% CBP. Suggesting that the optimum CBA content in concrete is 10%.
iii. This study clearly indicate that clay brick aggregate can be adopted as concrete component as an innovative construction material in sustainable infrastructural development.

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