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UTILIZATION OF WASTE CLAY BRICKS POWDER AS A PARTIAL CEMENT REPLACEMENT IN CONCRETE

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ABSTRACT

Cement production emits carbon dioxide (CO2), contributing to global greenhouse gas emissions. Waste Clay Bricks (WCB) are abundant in Minna and often disposed of in landfills, causing environmental pollution. This study investigates the pozzolanic properties of WCB and their effect on concrete strength. Pozzolanic reactivity was assessed using the Strength Activity Index (SAI) per ASTM C618. X-ray fluorescence (XRF) analysis determined the oxide composition of WCB powder, confirming its suitability as a pozzolanic material. Concrete specimens were prepared with 5%, 10%, 15%, and 20% WCB as partial cement replacements for grade 25 concrete, targeting a mean strength of 33.20 N/mm² at a 0.5 water/cement ratio. Aggregate tests, including sieve analysis, natural moisture content, specific gravity, and Bulk density, were conducted per British Standards. The oxide composition met ASTM C618 requirements, with SiO2, Al2O3, and Fe2O3 totalling 94%. WCB improved workability, with slump values of 64 mm, 71 mm, and 87 mm for 5%, 10%, and 15% replacements. Durability tests indicated increased permeability and shrinkage at higher WCB content. Compressive strength improved over time, reaching 18.5 N/mm² at 7 days, 22.4 N/mm² at 14 days, and 24.8 N/mm² at 21 days. At 28 days, 5% WCB achieved 25.41 N/mm², close to the control's 26.07 N/mm². Despite these improvements, higher replacement levels reduced strength. The findings suggest WCB can be utilized as a partial cement replacement, but its use should be limited to 5% for grade 25 concrete to maintain structural integrity and durability.

Keywords: Cement, Concrete, Compressive strength, Pozzolana, Waste Clay Bricks powder

INTRODUCTION

Concrete is the most broadly utilized man-made construction material on the Earth's surface (Plauška et al., 2018). Concrete is widely used in almost every sphere of construction, among others, buildings, infrastructure, and structures, and it is used for other developments (Foster, 2023). It consists of cement water mixed with sand, gravel, crushed stone or other inert material such as vermiculite or expanded slag (Abhijeet & Leena, 2024).

Despite extensive research on WCB's pozzolanic properties, there remains a gap in understanding its optimal replacement percentage for structural applications, particularly in tropical environments. This study aims to address this gap by evaluating the performance of WCB in Concrete, considering both its mechanical and durability properties.

Cement, a major binding material in making Concrete, influences the quality of the Concrete that is produced with it (Eneowaji & Ucheowaji, 2021). According to Schneider (2020), Portland cement production generates about one tonne of carbon dioxide (CO_2) into the atmosphere, which is 5% of global CO2 emissions. Beyond environmental benefits, the incorporation of WCB in Concrete offers economic advantages, including cost savings from reduced cement consumption, lower disposal costs, and improved energy efficiency in construction. Additionally, it promotes waste recycling, reducing the demand for virgin raw materials.

ASTM C618 defined pozzolana as "siliceous or siliceous and aluminous material which in themselves have little or no cementitious properties, but in finely divided form and the presence of moisture, they can react with calcium hydroxide which is liberated during the hydration of Portland cement at ordinary temperatures to form compounds possessing cementitious properties" (Aprianti, 2017). Pozzolanic materials do not harden in themselves when mixed with water, but when finely ground and in the presence of water, they react at normal ambient temperature with dissolved calcium hydroxide ($Ca(OH)_2$) to form strength-developing calcium silicate and calcium aluminates compounds. (BS EN 97-7:2000).

Although Clay brick waste has the potential to be used as supplementary cementitious material to replace calcined natural clays, it requires higher energy during milling processes (Costa & Gonçalves, 2022). The usage of the waste bricks in Concrete will enable the construction industries to utilize thousands of tons of brick blocks that would have ended up as waste or landfill materials (Letelier et al., 2018). WCB is a silicate solid waste that has great environmental and social significance (Cheng, 2016). According to the research by Aliabdo et al. (2014), the assessment of pozzolanic reactivity based on the strength activity index specified by ASTM C618 and outlined in ASTM C311 has not been previously reported by other researchers, implying that not all burned clay possess pozzolanic reactivity.

Ulukaya & Yüzer (2016) examined the pozzolanicity of clay-fired bricks using direct and indirect methods. Their investigation revealed that clay treated at 850°C can be regarded as the best pozzolan, and the pozzolanicity of Waste Clay Bricks significantly changes the mechanical properties of crushed brick-lime mortars. Bediako (2018) investigated the pozzolanic potential of ground waste clay bricks (GWCB) as a partial replacement for Portland cement, finding that a 30 wt.% replacement optimized compressive strength due to a high pozzolanic reaction while also reducing the heat of hydration and recommended GWCB as a sustainable pozzolan for recycling waste from clamp-fired brick factories, particularly in West Africa.

Zou et al. (2024) studied the use of waste brick powder (WBP) as a partial replacement for Portland cement, finding that while increasing WBP content decreased cement performance due to its low pozzolanic activity, the addition of sodium sulphate improved early strength and reduced carbonation depth and chloride migration, with ternary cement containing

10% WBP and 40% GGBFS showing slightly lower strength and higher carbonation depth at later ages. Sulaiman et al. (2023) investigated the effect of integrating local clay brick waste as a partial fine aggregate replacement in Concrete, finding that the use of up to 10% crushed clay brick enhanced the compressive strength of Concrete, while higher amounts increased water absorption, thus helping reduce dependency on river sand and promoting environmental sustainability by diverting construction waste from landfills.

Ukwizagira et al. (2023) investigated the use of crushed clay brick (CCB) as a partial replacement for fine aggregate in Concrete, finding that up to 20% replacement resulted in a compressive strength of 27.45 MPa at 28 days, meeting the minimum strength requirement for M25 grade concrete, while higher replacement levels led to a significant reduction in strength. Cachim (2009) found that crushed bricks can replace up to 15% of natural aggregates in Concrete without reducing its properties, with up to 30% replacement causing strength reductions, and suggested that this Concrete could be suitable for precast applications depending on the type and manufacturing process of the bricks.

Liu et al. (2020) studied the utilization potential of aerated concrete block powder and clay brick powder from construction and demolition (C&D) waste, examining the energy consumption, particle size distribution, and their effects on mortar properties at cement replacement levels of 10%, 20%, and 30%. The study found that aerated concrete blocks were easier to crush but required more energy to grind into powder finer than 0.30 mm compared to sintered clay brick powder. The mortar strength improved with a 10% cement replacement using recycled powder, with aerated concrete block powder showing higher activity at smaller particle sizes, while the latter significantly reduced fluidity and caused increased shrinkage due to the presence of 2–3 μm pores.

MATERIALS AND METHODS

Materials

The materials used in this research were sourced locally and include: Ordinary Portland Cement (OPC); Waste Clay Bricks (WCB) powder; Fine aggregate; Coarse aggregate and Potable water.

The OPC was procured from a cement depot on Bosso Road, Minna, conforming to BS 12:1996 specifications for Portland cement. WCB powder was collected from Shelter Clay Company and subsequently pulverized in the Civil Engineering Laboratory at the Federal University of Technology Minna, Niger State. The pulverized WCB was sieved through a 0.075mm BS sieve and cleaned to remove debris and impurities that could affect cement hydration and bonding.

The oxide composition of WCB powder was analyzed using X-ray Fluorescence (XRF) at the Nigeria Geological Survey Centre, Kaduna, following BS ISO 29581-2:2010. Sieve analysis was conducted to determine the particle size distribution of WCB, while its fineness was assessed using the Blaine surface area test. Mineralogical composition and amorphous content were evaluated through X-ray Diffraction (XRD), and pozzolanic reactivity was determined using the Strength Activity Index (SAI) test, following ASTM C618 guidelines.

The fine aggregate used was sourced from a river in Bosso Village, Minna. It was well-graded, with particles passing through a 5mm sieve and retained on a 0.063mm sieve, conforming to BS 882:1992. The coarse aggregate consisted of gravel from crushed parent rock, with a maximum size of 20mm. Its physical properties were determined in the Civil Engineering Laboratory at the Federal University of Technology Minna, following BS 812:1989.

Potable water for mixing and curing concrete samples was obtained from the Civil Engineering Laboratory's tap at the Federal University of Technology Minna, as specified in BS 3148:1980.


Plate 1: Waste Clay Bricks in clay shelter


Plate 2: Waste Clay Bricks as landfill in Minna.


Plate 3: Pulverizing of Waste Clay Bricks

Methods

X-ray Fluorescence (XRF)

The chemical composition of the Waste Clay Bricks powder was examined in the Nigeria Geological Survey Centre, Kaduna, using X-ray fluorescence (XRF) to meet the standard requirements for pozzolanic material.

Sieve Analysis

Sieve analysis, also called particle size distribution, is a process whereby materials are separated into various factions within specific limits of the opening of standard test sieves following BS 812 (1975).

Natural Moisture Content

There is a variation in moisture content from one stockpile to another as a result of weather. The moisture content must be determined frequently (Neville 2010). The total water content of the moist aggregate is equal to the moisture content and absorption in the aggregate. Several methods are available, but accuracy depends on the sampling method. BS 812 part 109: 1990 prescribed the best method to be used in the laboratory. Three samples, each of Fine, were put into a clean tin container with a known weight, and then the sample and the weight of the container were determined. The samples were then left in the oven for 24 hours at a temperature of 100℃. It was removed and weighed. The average of the values was used. The moisture content was calculated using equation (1):

$$M.C = \frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight} \times 100 \quad (1)$$

Specific Gravity

Specific gravity, according to ASTM (127 – 93), is the ratio of the mass of a unit volume of material to the mass of the same (absolute) volume of water at the stated temperature. An

Empty bottle was cleaned, weighed and designated (m_1). The bottle was filled with one-third of the total volume of the sand sample, weighed and designated (m_2). The bottle was filled with distilled water, weighed and designated (m_3). Then, the content of the bottle was discarded, and it was rinsed thoroughly. The bottle was then filled with distilled water to the meniscus, weighed and designated (m_4). The Specific gravity (G_s) was calculated using the equation (2):

$$Gs = \frac{(m2 - m1)}{(m4 - m1) - (m3 - m2)} \quad (2)$$

Bulk density test

Bulk density is the mass of material in a given volume. It is used in converting quantities by mass to quantities by volume, and it is affected by several factors, which include the amount of moisture present and the amount of effort introduced in filling the measures. Bulk density depends on how densely the aggregate is packed and consequently on the size distribution and the shape of particles. The bulk density of the aggregates was carried out using a cube; the aggregates in the cube were compacted into three layers and 25 blows of tamped using the same procedure as prescribed by BS812 Part 105:1990.

Testing Procedures

Comprehensive tests were conducted, including:

i. Workability: Measured using the slump test following BS EN 12350-2.
ii. Setting Time: Determined using the Vicat apparatus per BS EN 196-3.
iii. Durability: Assessed through water absorption (BS 1881-122), sulfate resistance (ASTM C1012), and chloride permeability (ASTM C1202).
iv. Compressive Strength: Evaluated at 7, 14, 21, and 28 days following BS EN 12390-3.

Concrete Mix

The current British method for the design of normal weight concrete made with Portland cement produced by the Department of Environment (DOE), Building Research Establishment (BRE) Laboratory was adopted in designing the concrete mix and the compressive strengths of Concrete were determined at 7, 14, 21 and 28 days curing age.

Concrete mix proportions were designed using the DOE method to achieve a target compressive strength of 33.20 N/mm². Adjustments were made to account for the WCB powder's influence on workability and water demand by modifying the binder-to-aggregate ratio. The water-to-cementitious material ratio was maintained at 0.5 for consistency across mixes. The control sample for the normal weight concrete mix design is required to satisfy the following requirements;

i. 28 day characteristics concrete cube compressive strength. F_c=25 N/mm^2
ii. Assumed Slump, 60 mm
iii. Crushed aggregate with a maximum size of 20 mm)
iv. Specific gravity of aggregate. 2.7
v. The percentage defective permitted below the characteristics strength, 1.64
vi. Standard deviation, 5
vii. Type of cement used - OPC (strength class of cement = 42.5)
viii. Target mean strength, $F_m = F_c + M = 25 + (1.64 \times 5) = 33.2$ N/mm^2

Batching and mixing

The batching and mixing of material was performed by weighing the aggregate, cement and water. The percentages of cement replacement by Waste Clay Brick powder are 0, 5, 10, 15 and 20%. The selected replacement levels (5%, 10%, 15%, and 20%) were based on findings from previous studies and preliminary tests that indicated significant variations in mechanical performance within this range (Lal et al., 2024). The aim was to assess the optimum percentage that balances strength, durability, and workability without compromising structural integrity. The water cement ratio was 0.5. The 0% replacement is the control sample.

Sample preparation

The constituent materials were batched by weight following values from the concrete mix design. 150mm x 150mm x 150mm cubes were used to cast all mixed Concrete. Concrete was mixed, placed and compacted into three layers and 25 blows were tamped for each layer. The sample was removed from the cube after 24 hours and kept in a curing tank for 7, 14, 21 and 28 days, respectively. A total number of 100 concrete cubes were cast to determine the compressive strength.

Table 1: Materials Requirements to Produce 1m^3 of C25 concrete

Materials	Cement	Fine Aggregate	Coarse Aggregate	Water
Quantity (Kg/m^3)	410.0	721.6	1038.4	205.0
Ratio	1.00	1.76	2.54	0.50

Table 2: Constituent Materials of Concrete Samples

Concrete Samples	Constituent Materials(Kg/m^3)				
	Water	Cement	Waste Clay Bricks	Fine Aggregate	Coarse Aggregate
Concrete with 0% WCB	205	410	0	721.6	1038.4
Concrete with 5% WCB	205	389.5	20.5	721.6	1038.4
Concrete with 10% WCB	205	369	41	721.6	1038.4
Concrete with 15% WCB	205	348.5	61.5	721.6	1038.4
Concrete with 20% WCB	205	328	82	721.6	1038.4

RESULTS AND DISCUSSION

Chemical Composition of Pulverized Waste Clay Bricks

Table 3 shows the chemical composition of the waste brick clays used in this research. The Waste Clay Bricks powder obtained for this research meets the ASTM C618 (ASTM, 2015) recommendation that for suitable pozzolanic materials, the summation of the SiO_2, Al_2O_3 and Fe_2O_3 was 94%, which according to ASTM C618 must not be less than 70%.

Table 3: Chemical Composition of Pulverized Waste Clay Bricks

Major oxides composition	Pulverized Waste Clay Bricks sample (%)
SiO_2	58.40
Al_2O_3	16.30
P_2O_5	0.01
SO_3	0.30
CaO	2.00
MgO	Nd
TiO_2	1.04
Na_2O	0.12
K_2O	0.40
MnO	0.04
Fe_2O_3	19.30
L.O.I	2.02

Nd: Not detected.

Particles Size Distribution

Figure 1 shows the result for the particle size distribution of coarse aggregate. The result revealed that the coarse aggregate is a single-size aggregate of 20mm nominal size, confirming the aggregate suitable for construction work (BS 882, 1992). The result shown in Figure 2 revealed that the sand is a fine-grading aggregate size, confirming that the aggregate is suitable for construction work (BS 882, 1992).

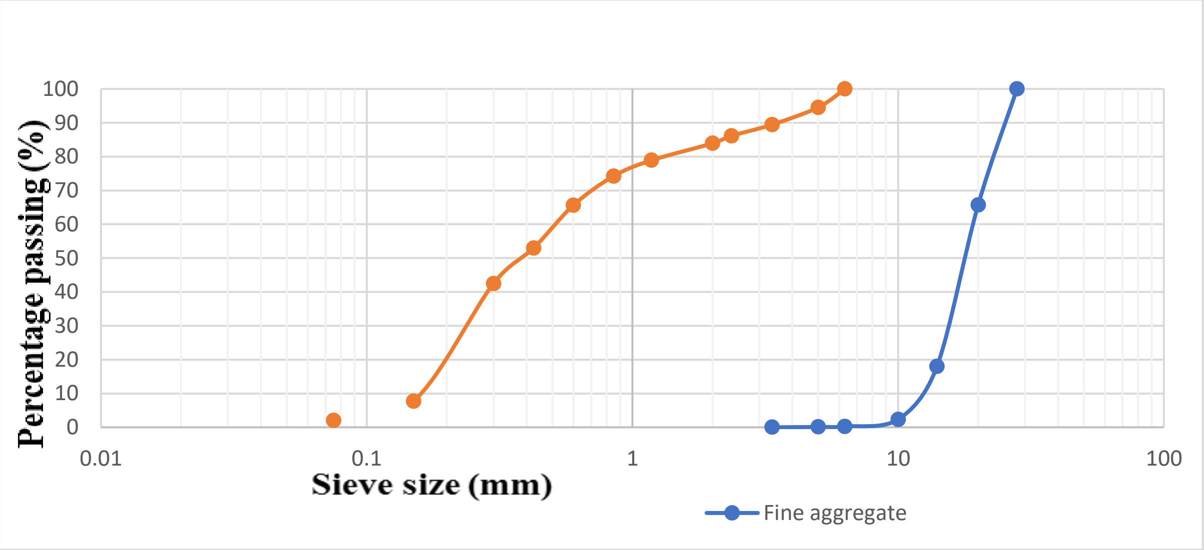

Figure 1: Sieve Analysis for Fine Aggregate and Coarse Aggregate

Natural Moisture Content

The average moisture content of sand obtained from Table 4 is 7%, which falls between the ranges of 5 to 15% (BS 812: Part 109, 1990). The moisture content of soil depends on the void ratio of the soil; thus, this value is indicative of the void spaces present in the soil and the specific gravity. It should be noted that the natural moisture content of soils is also dependent on the prevailing climatic conditions such as temperature, rainfall quantity, and water table level in the study area where the samples were retrieved.

Table 4: Natural Moisture Content of fine aggregate

Test	1	2
Weight of can W_1 (g)	24.7	24.8
Weight of can + wet sample w_2 (g)	148.3	119.7
Weight of can + dry sample w_3 (g)	141.2	112.6
Moisture content $(w_2-w_3)/(w_3-w_1)$	0.06	0.08
Mean moisture content (%)	7	

Specific Gravity

The specific gravity of the sand and gravel were found to be 2.62 and 2.66. The value obtained falls within the limit for natural aggregates with the value of specific gravity between 2.6 and 2.7, as prescribed by BS 812 part 109: 1990.

Table 5: Specific Gravity

Data	Sand		Granite	
	Test 1	**Test 2**	**Test 1**	**Test 2**
Mass of cylinder+ sample + water (m_3) [g]	1685	1678	1732.90	1730.9
Mass of cylinder + dry sample (m_2) [g]	424.5	420	481	480
Mass of cylinder + water (m_4) [g]	1495.9	1493.5	1507.1	1506.9
Mass of cylinder (m_1) [g]	120.1	120.1	120.1	120.1
($m_2 - m_1$) [g]	304.4	299.9	360.9	359.9
($m_4 - m_1$) [g]	980.3	977.9	991.5	991.3
($m_3 - m_2$) [g]	865.0	862.5	856.4	855.4
($m_4 - m_1$) - ($m_3 - m_2$) [g]	115.3	115.4	135.1	135.9
Specific gravity of the particles $G_s = \frac{(m2 - m1)}{(m4 - m1) - (m3 - m2)}$	2.64	2.60	2.67	2.65
Mean of specific gravity	2.62		2.66	

Bulk density test

The average bulk density of fine aggregate was found to be 1620.59kg/m^{3,} which fall within the standard range of 1300-1800kg in accordance with (BS 812: Part 109, 1990). This implies that the aggregate is well-parked and densely composed.

Table 6: Bulk density test

Data	Sand		Gravel	
	Test 1	**Test 2**	**Test 1**	**Test 2**
Weight of empty cylinder (w_1) [kg]	1.09	1.09	1.09	1.09
Weight of empty cylinder + weight of compacted materials (w_2) [kg]	3.84	3.86	3.77	3.52
Weight of compacted materials (w_3) [kg]	2.75	2.76	2.68	2.43
Volume of Cylinder (v) [m^3]	0.0017	0.0017	0.0017	0.0017
Compacted Bulk density (w_3/v) [Kg/m^3]	1617.64	1623.53	1576.47	1429.41
Mean Bulk density [Kg/m^3]	1620.59		1502.94	

Workability

The workability of fresh concrete, as indicated by slump values, improved with increasing WCB replacement. At 0% WCB, the slump remained at 55 mm across all curing ages, serving as a reference for comparison. However, as WCB content increased, slump values consistently rose, reaching 64 mm, 71 mm, 87 mm, and 95 mm for 5%, 10%, 15%, and 20% WCB replacements, respectively. This trend suggests that the inclusion of WCB enhances the flowability of the concrete mix. The improvement in workability can be attributed to several factors, including the particle shape and surface texture of WCB aggregates, which may reduce internal friction, allowing the mix to flow more easily. Additionally, WCB's water absorption characteristics could influence paste consistency, potentially altering the distribution of free water in the mix. The results indicate that WCB-modified concrete may be beneficial in applications where higher workability is desirable, such as pumped concrete or self-compacting mixtures. However, careful mix design adjustments may be necessary to maintain an optimal balance between workability and strength.

Table 7: Slump test

WCB (%)	Slump (mm)
0%	55
5%	64
10%	71
15%	87
20%	95

Compressive Strength Result

The early-age compressive strength results at 7, 14, and 21 days demonstrate a gradual reduction in strength with increasing WCB replacement. At 7 days, the strength decreased from 20.95 N/mm² (0% WCB) to 18.04 N/mm² (20% WCB), indicating a lower rate of early hydration due to the partial replacement of cement with WCB. A similar trend was observed at 14 days, where the strength reduced from 22.05 N/mm² (0% WCB) to 19.53 N/mm² (20% WCB). By 21 days, the strength continued to decline, with values ranging from 23.23 N/mm² (0% WCB) to 20.86 N/mm² (20% WCB).
The progressive strength gain observed across these curing ages suggests that hydration reactions remain active despite the presence of WCB. However, the reduction in early strength can be attributed to two primary factors: (1) the dilution effect, where a portion of cement is replaced by WCB, leading to lower production of hydration products, and (2) increased porosity at the interfacial transition zone (ITZ) between WCB particles and the cement paste, which may weaken the overall bonding structure. These factors contribute to the observed decline in strength, particularly at early curing ages.
Despite this reduction, the results indicate that WCB-modified concrete maintains adequate early-age strength for structural applications. The continuous strength development over time suggests that the hydration process is not significantly hindered, and further optimization—such as incorporating pozzolanic activators, adjusting the water-to-binder ratio, or using supplementary cementitious materials—could help mitigate early strength losses while retaining the workability benefits.
The compressive strength result presented in Figure 3 shows clearly that the mix with 5% of Waste Clay Bricks powder (25.41N/mm^2) attains the design target compressive strength

value at 28days ($25N/mm^2$), which is closer to the compressive strength of the control mix concrete ($26.07N/mm^2$) for all curing ages. The compressive strength decreased gradually at 10, 15 and 20% partial replacement Waste Clay Bricks powder.

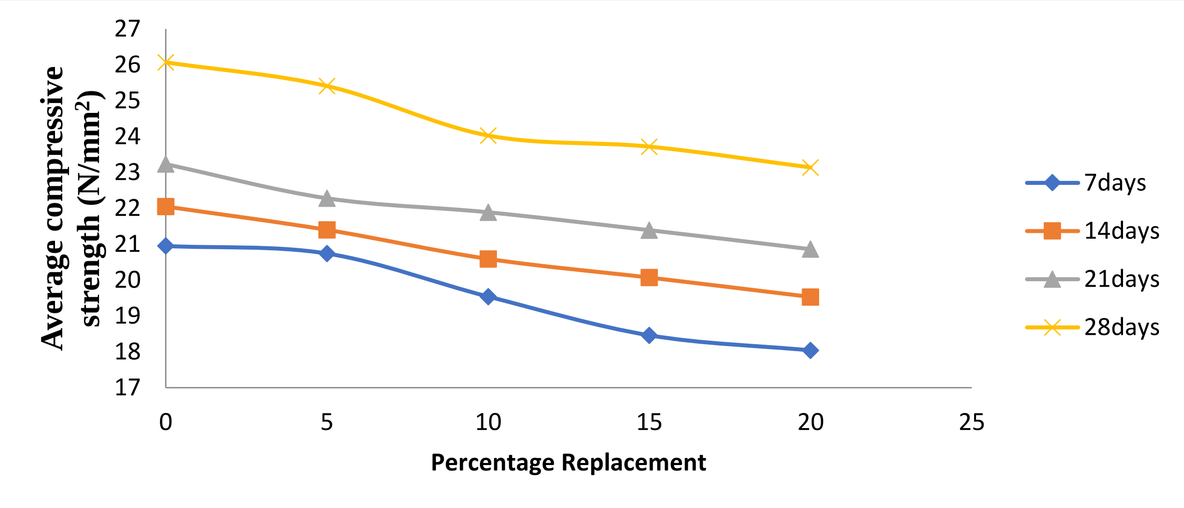

Figure 2: Compressive strength of Concrete

CONCLUSION

From the outcome of this study, the following conclusions were drawn: The chemical composition of Waste Clay Bricks powder obtained for this research meets the ASTM C618 (ASTM, 2015) recommendation that for suitable pozzolanic materials, the summation of the SiO_2, Al_2O_3 and Fe_2O_3 was 94%, which, according to ASTM C618 must not be less than 70%. The fine aggregate samples were characterized as medium grading using the tabular data in BS 882:1990, and they also satisfied the overall grading limits for natural fine aggregates. The compressive strength of Concrete for the control specimen was higher than that of the mix, with various percentages of powder replacement for waste clay bricks. However, 5% of Waste Clay Bricks powder attains the design compressive strength value, which is closer to the compressive strength of the control mix Concrete for all curing ages. Hence, the use of Waste Clay Bricks powder to replace cement should be limited to 5%. Concrete produced shows an increase in slump with an increasing cement replacement with Waste Clay Bricks powder. As much of the total cost of cement in the conventional method can be saved by this procedure. Limitations in Statistical Analysis: This study did not incorporate advanced statistical methods such as ANOVA or regression analysis. However, trends in compressive strength were observed and analyzed based on experimental data. The use of waste clay brick powder as a partial cement replacement in Concrete provides both environmental and economic sustainability benefits. It helps reduce CO_2 emissions by lowering cement demand, minimizes landfill waste, conserves natural resources, and decreases energy consumption in production. Economically, it lowers material and disposal costs, promotes job creation in the recycling industry, and enhances concrete durability, reducing maintenance expenses. Overall, this approach supports sustainable construction by improving cost efficiency while reducing the environmental impact of cement production. Based on the outcome of the research, it is recommended that further research on flexural and splitting tensile strength should be carried out on the concrete with partial replacement of cement with clay brick powder. Future studies should consider statistical validation to enhance result interpretation and reliability.

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