Nigerian Journal of Environmental Sciences and Technology (NIJEST)
www.nijest.com
ISSN (Print): 2616-051X | ISSN (electronic): 2616-0501
Vol 3, No. 2 October 2019, pp 352 - 360

Strength and Workability Assessment of Concrete Produced by Partial Replacement of Cement with Waste Clay Bricks

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https://doi.org/10.36263/nijest.2019.02.0137

ABSTRACT

The use of waste clay bricks—which are abundant in the Niger Delta Region of Nigeria – as supplementary cementitious material, would enable the construction industry utilize thousands of tons of brick blocks that would have ended up as waste or landfill materials. This paper establishes the pozzolanic properties of these waste clay bricks in terms of strength and workability. Waste clay brick powders are introduced as partial replacement for cement in this research. All tests were done in accordance with relevant British Standards. It was observed that waste clay brick, as an admixture, increases the workability and consistency of fresh concrete. Also, an 11 percent increase in compressive strength was observed with a 10 percent partial replacement of cement with waste clay brick powders. An equation is developed to capture the marginal increase in compressive strength of concrete produced with waste clay bricks, even after 28 days, for a 10% partial replacement of cement.

Keywords: Cement, Strength, Compression, Aggregate and Regression.

1.0. Introduction

To preserve the environment, attempts have been made to employ waste materials in the production of concrete and in the construction of cost-effective housing. Proper utilization of discarded or waste materials in concrete production results in less expensive concrete and also offers a cost-effective ecological solution to waste management and disposal (Bahoria et al., 2013).

Concrete comprises of cement, aggregates and water (Devi and Gnanavel, 2014 and Naik, 2008) – with cement as the binder material and the most expensive component. Cement production emits a green-house gas known as carbon dioxide (CO_2). Imbabi et al (2012) estimated that cement production contributes 5% of the global green-house gas emissions. However, more recent works estimates that the total CO_2 produced by the production of cement clinkers and the combustion of fossil fuel required to heat raw materials during cement production could contribute to as much as 8.6% of global CO_2 emission (IEA, 2007 Miller et al, 2016). To manage the environmental effects of concrete production, modern techniques such as using milled brick blocks as an admixture or applying it directly to replace a portion of cement has become common practice and broadly viewed as acceptable in concrete works. It is important to note that supplementary cementitious materials reduce the amount of cement in concrete and thus reduces concrete's susceptibility to cracking, heat generation and carbon dioxide emission.

Research has confirmed the viability of certain construction waste products as suitable for use as supplementary cementitious materials, such as silica fume, blast furnace slag, fly ash, foundry sand, palm oil clinker (Rashad, 2016; Valcuende et al., 2015; Imbabi et al., 2012; Prabhu et al., 2014). These supplementary materials are grounded and heated to controlled temperatures to produce blended cements with improved economic and physical properties (Detwiler et al., 1996).

Elinwa et al (2005) reported that the use of sawdust ash or wood ash as partial substitute in the matrix for mortar and concrete work not only acts as an economic substitute but also a reliable disposal method of said waste.

Ranjodh et al. (2013) reported that brick dust can be used effectively to develop good quality selfcompacting fresh concrete with satisfactorily slump and setting time. The hardened properties of the self-compacting concrete improved daily till 28 days because of greater hydration of cement. Nassar and Soroushian (2012) reported that the chemical composition of glass powder makes it comparable to other cementitious materials. Hemraj and Kumavat, (2013) examined brick waste and inferred that it performs as a pozzolana and his results show that richer mixes give lower value of bulk density and higher values of compressive strength at replacement level up to 40% of sand, his findings contribute to the minimizing the impact waste using eco-efficient resources. Hasanpour (2013) also examined the possibility of using bricks powder/dust as replacement until 40%, he further established in his findings that although concrete developed may suffer slightly a loss in strength, his research confirmed brick powder has the potential to serve as pozzolana. The performance of grinded brick blocks powder in concrete works was researched experimentally.

Some recent studies have attempted to investigate the pozzolanicity of clay bricks. Ulukaya and 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 clay bricks significantly changes the mechanical properties of crushed brick-lime mortars. Bediako (2018) examined that optimum cement replacement in concrete, where cement is replaced with Ground Waste Clay Bricks (GWCB. Bediako (2018) observed that compressive strength results indicated that the optimum Portland cement replacement with Ground Waste Clay Bricks (GWCB) was at 30 wt.%.

Bricks, when milled to powder, can serve as a supplementary cementitious material, although it has not yet acclaimed the same status commercially (Rashed, 2014). Thus, this work attempts to investigate the pozzolanic properties of waste brick blocks, especially those produced with clays from Bayelsa State, Nigeria.

2.0. Materials and Method

2.1. Materials

The materials used in this study are Portland cement, ground waste clay brick, aggregates, water. The Portland cement was a type I/II cement and Table 1 shows the chemical composition of the cement used in this research. The clay bricks, which were used as refractory surfaces for decommissioned kilns, were obtained in waste dumps in Bayelsa State but were manufactured in Warri, Delta states, using local clays. Table 2 shows the chemical composition of the waste brick clays used in this research. The studied potential pozzolan meets the ASTM C618 (ASTM, 2015) recommendation that for a suitable pozzolan, the summation of the SiO_2, Al_2O_3 and Fe_2O_3 must not be less than 70%.

The waste clay bricks obtained for this research were crushed to dust and processed into powdered form (see Figure 1). The aggregates (fine and coarse) used were obtained from the Wilberforce Islands in Bayelsa State in accordance with British Standards BS EN 12620:2013 (BSI, 2013). The maximum size of the coarse aggregate was 20mm. Clear portable water free from all harmful and extraneous matter was used for all the experiments as specified by the British Standards BS EN 1008:2002 (BSI, 2002).

Table 1: Major components of cement (Oriji and Dulu, 2015)

Oxide	Weight %
CaO	59.60%
Fe_2O_3	3.22%
SiO_2	20.62%
Al_2O_3	6.01%
MgO	3.65%
SO_3	2.46%
K_2O	0.71%

Table 2: Major components of clay bricks (Osarenmwinda and Abel, 2014)

Oxide	Weight %
CaO	0.72%
Fe_2O_3	11.8%
SiO_2	53.9%
Al_2O_3	17.75%
MgO	0.6%
ZnO	0.9%
Na_2O	0.8%
MnO	0.03
Cr_2O_3	0.04
K_2O	3.3%

Figure 1: Waste bricks in crushed and powder forms

The locally obtained waste clay bricks, along with some fine and coarse aggregates were packed in bags and were transported from the Wilberforce Islands to the laboratory of Civil Engineering in Niger Delta University. The brick samples were crushed and ground to powder form, while the coarse aggregates were washed clean of mud traces. Finally, sieve analysis and specific gravity test on the samples were carried out after 12 hours of sun drying. The coarse and fine aggregates (max. size of 20mm) were uniformly graded in accordance with British Standards BS EN 12620:2013 (BSI, 2013).

2.2. Method

The concrete samples were produced by batching by volume for compressive tests. A nominal mix ratio of 1:2:4 was adopted for concrete production using Portland cement. Produced concrete using this mix ratio was used as the control. The brick powder as a partial replacement for cement weights, i.e. a partial replacement of cement from 0 to 20 percent by weight was adopted. A water/cement ratio of 0.45 was adopted for the research work. Slump tests were conducted for every batch of concrete produced. 150mm x 150mm x 150mm cube moulds were employed to be placeholders for the concrete, while the required tamping continued until adequate compaction on each cube mould was obtained, then the surface was finished with a trowel. The cubes remained stationary for 24 hours before they were demolded and placed in a curing tank. A total of 80 concrete cubes were cast. Table 3 shows the quantity of constituents required to produce 1 cubic metre of each sample used in this experiment using a water to cement ratio of 0.55.

Table 3: Mix quantities for 1 cubic metre of samples

Mix name	Cement (kg)	Brick powder (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
CON (Control)	300	0	690	1250
SAMPLE 1 (2% Cement replacement)	294	6	690	1250
SAMPLE 2 (5% Cement replacement)	285	15	690	1250
SAMPLE 3 (7% Cement replacement)	279	21	690	1250
SAMPLE 4 (8 % Cement replacement)	276	24	690	1250
SAMPLE 5 (10 % Cement replacement)	270	30	690	1250
SAMPLE 6 (12% Cement replacement)	264	36	690	1250
SAMPLE 7 (15 % Cement replacement)	255	45	690	1250
SAMPLE 8 (18 % Cement replacement)	246	54	690	1250
SAMPLE 9 (20% Cement replacement)	240	60	690	1250

2.2.1. Compressive Strength Test

An Avery compression machine was used for the compression test experiment. The cast cubes are placed in the Avery compressive testing machine and loaded until their various compressive strengths were obtained. The cube strengths were obtained at 7, 14, 21, 28, 52 and 90 days. These tests performed were in accordance with the specifications in BS EN 12390-3:2019 (BSI, 2019a).

2.2.2. Workability test

The workability of the fresh concrete for all the samples was determined by the slump test. These tests were performed in accordance with the specifications in BS EN 12350-2:2019 (BSI, 2019b).

3.0. Results and Discussion

Experimental results showed that there was a marginal strength gain in concrete with a 10 percent partial replacement of cement with the waste clay bricks studied. An average of 11% increase in compressive strength was achieved with 10 percent partial replacement of cement with the waste clay bricks studied. However, as percentage replacement exceeds 10 percent, the positive impact of the pozzolan on the strength of concrete diminished. Interestingly, at 20 percent partial replacement of cement, there was no substantial strength loss in concrete, when compared with concrete made without partial replacement of cement. These results are similar to Bediako's (2018) findings. Bediako (2018) observed that the compressive strength performance of the control mortar, in his work, and mortars that contained 10 wt.% and 20 wt.% of Ground Waste Clay Bricks (GWCB) were statistically insignificant at 3, 7 and 28 days. In his work, the strength performance observed indicated that the optimum mortar mix was at Portland cement replacement with GWCB at 30 wt.%. This mix was approximately 11% higher in strength at the curing periods when compared with the control mortar. The optimal replacement level which improved the strength of mortar much better than the control mortar could be attributed to the degree of pozzolanic reaction. Bediako (2018) also mentioned that the achievement of maximum strength means that the cement replacement content with a pozzolan is sufficient to convert cement hydration product i.e. calcium hydroxide into calcium silicate and aluminate hydrates which enhance strength properties.

This result of this work aligns with the findings of Bediako (2018). Bediako (2018) observed that the compressive strength performance of the control mortar, in his work, and mortars that contained 10 wt.% and 20 wt. of Ground Waste Clay Bricks (GWCB) at 3, 7 and 28 days were statistically insignificant.

This work shows that despite the composition of local waste clay bricks used in this work, it is able to react cement hydration products i.e. calcium hydroxide, into calcium silicate and aluminate hydrates which enhance strength properties. Hence, a marginal increase in strength is observed. However, further work is required to understand the hydration process and chemistry of the reaction.

Figures 2 and 3 present a comparison of strength developed with the partial replacement of cement with waste clay bricks. It is also observed that while the long-term strengths of normal concrete did not significantly increase from its value at 28 days up to 90 days (See Figures 4 and 5), the strength of concrete made with waste clay bricks increased by 10 percent at 90 days, when compared to its 28day strength.

Using least square regression approach, as shown in Equations 1, where f_{cu} and x are dependent and independent variables, respectively; r_i is the residual; β is a vector in the model function f (x, β)

$$r_i = f_{cu} - f(x, \beta) \quad (1)$$

And by minimizing the sum, S, of the squared residual, r_i, in Equation (2), we obtain the relationship in Equation (3)

$$S = \sum r_i^2 \quad (2)$$

$$f_{cu} = 19.8 In(x) + 16.4 \quad (3)$$

Equation 3 represents the relationship between strength development and duration for a 10 % partial replacement of sand with brick blocks. f_{cu} represents the compressive strength and x represents duration in days. This equation predicts the compressive strength development between 0 to 90 days.

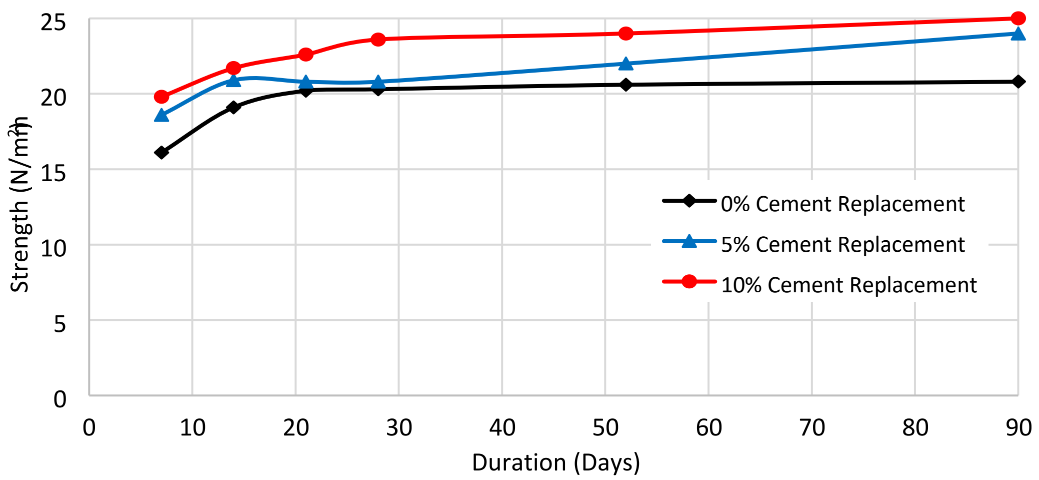

Figure 2: Strength development with 0 – 10 percent partial replacement of cement with brick blocks

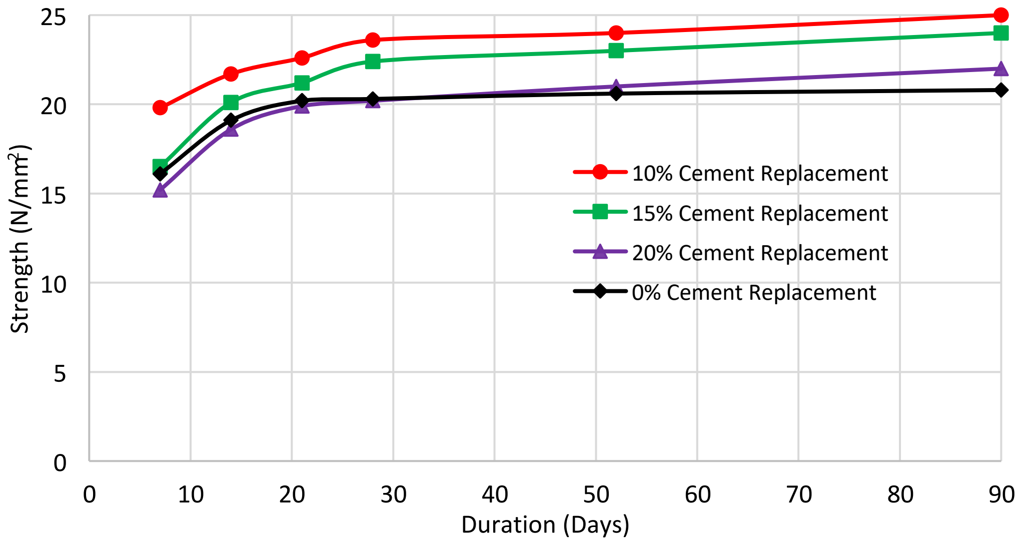

Figure 3: Strength development with 10 – 20 percent partial replacement of cement with brick blocks

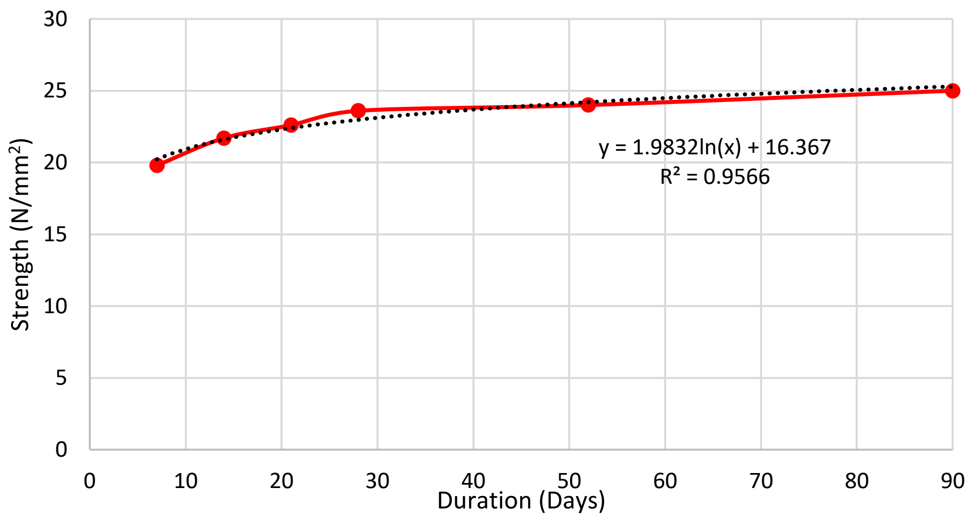

Figure 4: Regression curve showing relationship between strength and duration for 10% cement replacement with brick blocks

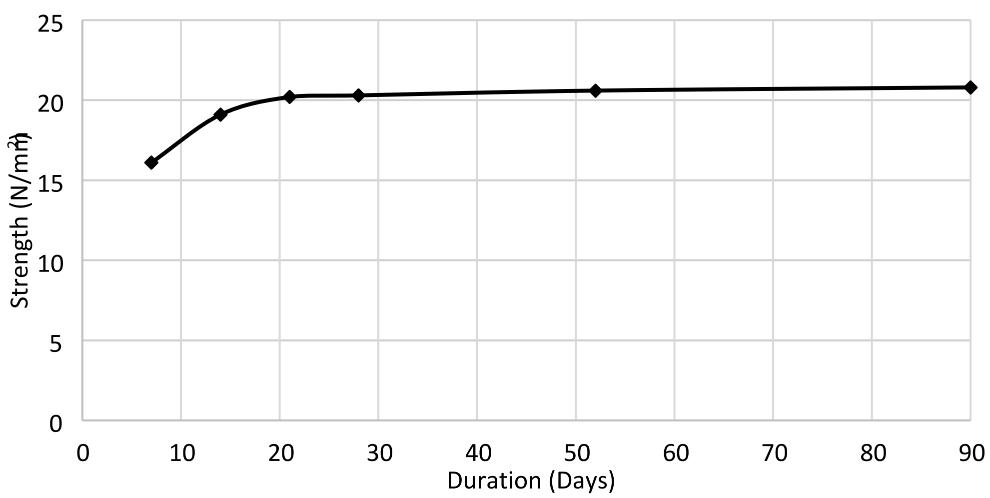

Figure 5: Regression curve showing relationship between strength and duration for 0% cement replacement with brick blocks

Slump test results shown in Table 4 for the various concretes produced show that an increasing slump is achieved with an increasing cement replacement with brick blocks. This implies that with additional volume of fines from the brick blocks, consistency and workability increased in produced concrete. This result is indicative of a reduced water demand with increasing brick content.

Table 4: Slump test results

Percentage Replacement	Slump (in mm)
0%	50
5%	55
10%	58
15%	63
20%	75

4.0. Conclusions

Based on the outcome of the present investigation on the suitability of waste clay bricks as admixture in concrete works, the following conclusion can be drawn:

i. Waste clay brick studied possess sufficient pozzolanic properties and can be used effectively as a supplementary cementitious material.

ii. By replacing cement with waste clay bricks, in concrete production, a marginal increase in compressive strength can be achieved.

iii. Waste clay bricks increases the durability of concrete with marginal increase in compressive strength, even after 28 day

iv. An optimum strength of concrete is achieved with a 10 percent cement replacement with waste clay bricks.

v. The workability and constituency of concrete is improved with the addition of waste clay bricks to cement in concrete production.

It is recommended that a further study on the microscopic interaction of waste clay bricks and cement during hydration process be undertaken in order to fully understand the process of strength increase associated with the addition of bricks in concrete production.

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Cite this article as:

Nwankwo E. and John A. T., 2019. Strength and Workability Assessment of Concrete Produced by Partial Replacement of Cement with Waste Clay Bricks. *Nigerian Journal of Environmental Sciences and Technology*, 3(2), pp. 352-360. https://doi.org/10.36263/nijest.2019.02.0137