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The Effect of Burnt Clay Brick Production Process on the Compressive Strength and WaterAbsorption Properties

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Abstract

Compressive strength and water absorption are important properties of burnt-clay brick. Compressive strength and water absorption are influenced by the manufacturing method and the firing processes of the brick. This study considered the effect of stacking distances of the brick in the field kiln from the heat source on compressive strength and water absorption properties. The bricks were sampled from three different field kiln site locations, Kastina-Ala, Zarki-Ibiam, and Jootar, Benue State Nigeria. Equal distribution for appropriate representation of the bricks in the kiln was guided by quartile (first, second, and third). Ten samples were collected at each stack quartile layer with a total of 30 bricks samples per field kiln. This gave a total of 90 burnt clay bricks samples for the compressive strength and water absorption rates analysis. The result of the analysis showed that the mean compressive strength of the burnt clay bricks decreased from the brick stacked at the lower quartile (Q_1) to the upper quartile (Q_3) with an average mean value of 4.04 N mm^{-2} (SD = 1.24 N mm^{-2}). The water absorption property of the burnt clay bricks decreased from the upper quartile (Q_3) to the lower quartile (Q_1) with the total average mean value of 17.45% (SD = 8.05%). The linear regression analysis between the compressive strength and the distances from the heating source showed *p*-value = 0.00 and the coefficient of the regression value = – 0.017 while that of water absorption properties gave *p*-value = 0.095 and coefficient of the regression = 0.029. The result means that the farther the distance of the brick from the fire, the lesser compressive strength, and the greater water absorption properties of the bricks. This was an indication that stack distance of the clay brick from the fire in the field kiln affects the brick quality.

Keywords: Burnt clay-bricks; Compressive strength; Water absorption; Stack layers

1. Introduction

Burnt clay brick is one of the versatile basic building and construction materials used in civil engineering work and landscape design [1, 2]. It is a processed earth-based material made with clay-rich soil and water. The abundance of these constituent natural elements, among other properties has affected its adoption in structural construction of building foundations, walls, piers, buttresses, arches, ducts, flues, lining, and chimneys of furnaces. However, studies have shown that the uptake of earthen materials for housing construction particularly in Africa is low [3]. The main concerns highlighted on the use of earthen materials in building and construction is about its durability and strength in the face of the ever-changing climate and environmental factors [4 – 6]. In addition, poorly produced bricks exhibit high breakage rate, cracks, defects and softening in a very damp condition

[1, 4 – 7]. The unsophisticated processes involved in brick making have technically affected the quality of bricks being produced [1, 7]. The craft and skills involved in the burnt clay brick production according to Abah et al [1], are mostly handled by uneducated people through the knowledge passed down from one generation to the other among them and in the process have been preserved. This time-proven method of burning clay bricks particularly in Nigeria are carried out at the village and rural enterprise levels with production technologies that vary with the size and scale of the producer for the purpose of generating minor or major incomes for their families and in some cases for personal use [1, 8]. Burnt clay bricks being an earthen construction material and a principal structural component of a masonry building through a lot of advantages it offers such as reduced cost of construction and impact to the environment, necessitate appropriate property determination for the desired overall structural behavior of the building.

Objective of the study

This study assessed the compressive strength and water absorption properties of burnt clay bricks in their respective distances from the heat source during firing stage of the brick production.

Summary of the firing process stage of burnt clay-brick

The four main stages involved in brick making identified by Agera et al [9] include clay winning and preparation, bricks shaping, drying, and firing. The firing is the last and the key process stage in the production process of burnt clay-brick that controls its properties [10 – 13]. The degree of temperature at which the clay is burnt influences the properties of the products [11]. Beamish and Donovan [7] summarized the firing stages into preheating, main firing, soaking, closing the field kiln, cooling, and opening of the field kiln. The firing of the clay bricks in the village and rural settings are usually done in a field kiln. Beamish and Donovan [7] presented specification for the building of a field kiln as the number of bricks, number of tunnels, length in bricks, width in bricks, and height in layers. It is required that the dry bricks be brought together and arranged systematically slightly in different arrangement to give more strength to the kiln and to prevent the bricks from collapsing outward as they shrink during the firing process. The kilns are usually well insulated to prevent excessive loss of heat during firing. The arrangement of the bricks in the kiln depicts different layers and distances from the heat source. At a temperature between 20 °C and 150 °C bricks lose most of the water added to the clay during the preparation phase. Between 150 °C and 600 °C, the clay brick loses its remaining water. Further firing at a high temperature above 900 °C causes a chemical reaction called vitrification – this causes the brick to become hard, abrasive, durable and resistant to weather and water [7].

Compressive strength and water absorption properties of bricks

Among the desirable properties of burnt clay-bricks, compressive strength and water absorption are the two major properties of bricks that can be used to predict load bearing properties and the ability of brick to withstand or resist cracking. According to Akinyele *et al.* [10], the compressive strength is an important indicator for measuring the engineering quality of a building material as it gives information about all the strength characteristic of the brick. The demonstration of good and strong quality of an earthen material from the amount of compaction, firing and the absence of impurities is usually through high compressive strength indication. The prediction of the general load-bearing properties of a masonry using the compressive strength also gives an insight in the modulus of elasticity and stress-strain modulus estimation of the masonry [14 – 16]. Okunade, [17] added that the compressive strength of the burnt clay brick affects other properties like flexure and resistance to abrasion. On the other hand, water absorption property of the burnt clay-brick is an essential factor for the determination of the burnt clay-bricks durability. Studies revealed that when water percolates through a wall built using an earth-based material, it reduces its durability [4 – 6, 10]. The water absorption of brick measures the available pore space within the brick. This is expressed in percentage of the brick weight and affected by the clay or soil properties, method of manufacturing and the degree of firing [13]. The decrease water absorption of clay bricks is usually achieved during the production stage of the burnt clay bricks through increased firing temperatures [10, 18]. The four basic classifications of burnt clay bricks based on compressive strength and water absorption properties are first-class burnt clay bricks (compressive strength 14 N mm^{-2} and water absorption $\geq$ 20%), second-class burnt clay bricks (compressive strength $\leq$7 N mm^{-2} and water absorption $\leq$ 22%), third-class (compressive strength 3.50 – 7 N mm^{-2} and water absorption 22 – 26%) and fourth-class (15 N mm^{-2} and low porosity) [10]. Studies in the literatures revealed that firing in general affect the compressive strength and water absorption properties of bricks [10, 13, 18]. However, there is no study in the literatures that considered variation effects of distances from the heat source on compressive strength and water absorption properties of burnt clay bricks.

2. Materials and Methods

Study Area

Bricks were sampled from field kiln sites within Benue State. The state lies within the lower river Benue trough in the middle belt region of Nigeria on the geographic coordinates of latitude 6°25′ and 8°8′ North, longitude 7°47′ and 10°0′ East [1]. Benue has a population density of 99 persons km^{-2} [1], and it is characterized by temperatures ranging from 23 °C to 30 °C with peak of 38 °C [19, 20]. The dominant soil in the study area is hydromorphic soil (Alluvial or fadama soil), with an annual rainfall range of 900 mm to 1,200 mm [19] averaging 1,050 mm. Benue state has Guinea Savannah vegetation characterized by grasses and a few scattered shrubs and trees [21]. The topography of Benue state is mainly undulating plains having occasional elevations of between 1,500 and 3,000 m above sea level [19]. The people are known for fishing, agricultural activities and brick making – evident in the ubiquitous building blocks for diverse local construction works [1].

Burnt clay-brick sampling

The bricks were sampled from three different field kiln sites locations, Kastina-Ala, Zarki-Ibiam and Jootar. The specification of the field kiln in these locations were tabulated in terms of the number of tunnels, length, width, height, and the number of bricks in layers of the kiln (Table 1).

Table 1 The specification of the field kiln at the study sites

Study sampling site locations	Number of tunnels (n)	Average dimension of the bricks (mm)	Kiln length (cm)	Kiln width (cm)	Kiln height (cm)	Number of layers (n)
Kastina-Ala	4	230 × 125 × 80	427.32	322.91	243.64	30
Zarki-Ibiam	4	230 × 122 × 70	413.50	320.52	240	32
Jootar	4	230 × 121 × 70	411	323.10	240.72	32

30 burnt clay-bricks were sampled per field kiln at the three sampling sites making a total of 90 burnt clay-bricks samples. The heights of the three-study field kiln considered for the burnt clay brick sampling were measured and statistically divided into four parts for equal distribution, appropriate representation, and information of the bricks in the kiln. This guided the sample collection from the kilns. The first selection point was the lower quartile (Q_1) which represented the set of bricks at the lower layers. The second quartile (Q_2) represents the set of bricks at the median layer while the third quartile (Q_3) were the set of bricks above the median layer and the top of the kiln. Ten samples were collected at each quartile per kiln and tabulated (Table 2).

Table 2 The burnt brick sampling layers

Sampling site locations	Kilns		Q_1		Q_2		Q_3	
	H (cm)	L (n)	H (cm)	L (n)	H (cm)	L (n)	H (cm)	L (n)
Kastina-Ala	243.64	30	60.90	7 & 8	60	15	60.20	22 & 23
Zarki-Ibiam	240	32	121.80	8	120	16	120.41	32
Jootar	240.72	32	182.70	8	180	16	180.50	32

H = Height, L = Layers, Q_1 = 1st quartile, Q_2 = 2nd quartile, Q_3 = 3rd quartile

This was done to understand how the distance to the fire source affects the strength and water absorption of clay-bricks produced locally within the sampling areas. Physical observation of bricks during the sampling process helped to avoid defected brick samples containing cracks and large voids which would likely affect strength and water absorption properties of bricks [22].

Testing water absorption of bricks

The submersion test was employed to test for the water absorption rate of the samples as described in Promkotra and Kangsadan [23]. The burnt clay bricks were physically selected and measured before submerging in a water tank for 24 h. They were carefully wiped and then their weights were taken as W_2 before oven dried at 105 °C for 24 h. After drying, their weights were taken and denoted as W_1 and the water absorption was computed using the expression in equation (1).

$$\text{Water Absorption} = \frac{w_2 - w_1}{w_1} \times 100 \qquad (1)$$

*Where W_1 = *weight of oven dried bricks;* W_2 = *weight of saturated bricks*

Testing for compressive strength of bricks

The compressive strength of the brick samples was assessed using the Compression Testing Machine type ALPHA 4 as described by Prasetsan and Theppaya [22]. The bricks sizes were measured, and the areas of bricks were computed. The brick was screwed to the loading base of the machine and the load when the brick failed (crushing load) was denoted [23]. The compressive strength was then computed using the expression in equation (2).

$$\text{Compressive Strength}\left(\frac{N}{mm^2}\right) = \frac{N}{A} \qquad (2)$$

*Where N = crushing load (N); A = Area of brick (mm²)

Statistical analysis of the data samples

The computed results were analyzed using Statistical Package for the Social Sciences (SPSS) version 23 and the Microsoft Office Excel version 2010 software. The relationship between the compressive strength, water absorption and the stacking distance from the fire source were measured using Pearson's correlation and linear regression analyses computed at the significance confidence level of 0.05.

3. Results and Discussion

Compressive Strength ($N\ mm^{-2}$) Analysis of the burnt clay bricks

Table 3 shows the average compressive strength and the water absorption of the burnt clay brick obtained in this study. The descriptive statistical analysis of compressive strength and the water absorption with respect to the position in the field kiln presented in table 3 showed that the average compressive strength of the burnt clay bricks decreased from the lower quartile (Q_1) to the upper quartile (Q_3). The highest average compressive strength was recorded against the lower quartile (mean ± SD = 4.63 ± 1.52 $N\ mm^{-2}$) which were the bricks closest distance to the fire (Table 3). The total compressive strength means of burnt clay bricks (4.04 N mm^{-2} (SD = 1.24 N mm^{-2}) obtained in this study irrespective of the layer in the field kiln showed high compressive strength as such agreed with Iorakaa [24] that burnt clay bricks have high compressive strength. The outcome of the compressive strength showed that the firing process of the brick in the field kiln enhanced microscopic ceramic bonds within the clay which in turn gave the witnessed high compressive strength of the burnt clay bricks. The quality of the burnt clay bricks obtained in this study is consistent with the basic standard's compressive strength minima of 3.50 N mm^{-2} for proper performance [25, 26]. The high compressive strength values obtained at the different layer in the field kiln implies that the burnt clay bricks had other added advantages such as increased flexure and resistance to abrasion which makes it suitable to be adapted to all high performance and sustainable buildings [17].

Table 3 Compressive Strength (N mm^{-2}) analysis of the burnt clay bricks

Brick quality	Kiln stack layers	Min	Max	Mean	SD	SEM
Compressive strength	Q_3	2.64	5.54	3.52	0.70	0.13
	Q_2	2.03	6.90	3.97	1.12	0.20
	Q_1	3.11	7.96	4.63	1.52	0.28

Water absorption property (%) analysis of the burnt clay bricks

The susceptibility to water ingress assessed using the water absorption property of the burnt clay brick took the reverse other as compared to the compressive strength of the burnt clay bricks. The water absorption property of the burnt clay bricks decreased from the upper quartile (Q_3) to the lower quartile (Q_1), with the average mean value of the burnt clay brick at the upper quartile having the highest value (mean ± SD = 24.20 ± 8.57 %) (Table 4). The result showed that conformance to the water absorption property requirements was only attained in the lower and middle quartile of the field kiln as the water absorption property at the upper quartile was found to have exceeded the fundamental standard water absorption value of 20%.

Table 4 Water absorption property (%) analysis of the burnt clay bricks

Brick quality	Kiln stack layers	Min	Max	Mean	SD	SEM
Water absorption	Q_3	10	40.60	24.20	8.57	1.56
	Q_2	9.05	27.77	17.27	4.25	0.78
	Q_1	2.99	18.43	10.87	3.93	0.72

Correlations analysis between the compressive strength and water absorption

The implication of the burnt clay brick porosity on the compressive strength analyzed using correlation analysis gave a negative correlation coefficient r-value of – 0.452 significant at $p = 0.00$. A negative correlation coefficient value between two variables implies that as one of the variables increases, the other decreases. The negative value for the correlation coefficient obtained in this study showed that the water absorption property of the burnt clay bricks resulted in the increased compressive strength of the burnt clay brick. The result of this study followed the general manufacturing process quality of burnt clay brick that compressive strength increases with decreasing porosity [27].

Table 5 Correlations analysis between the compressive strength and water absorption

No of burnt clay bricks	Compressive strength (mean ± SD(N mm^{-2}))	Water absorption (mean ± SD (%)	r-value	P-value
90	4.04 ± 1.24	17.45 ± 8.05	–0.452*	0.00

*. Correlation is significant at the 0.05 level (2-tailed).

According to studies, the firing process affects the mechanical properties of the burnt clay bricks [28]. The p-values and the coefficient of the regression between the mechanical properties (compressive strength and water absorption properties) of the burnt clay bricks and the distance from the heating source helped in the determination of the statistical significance and the nature of the relationship between these variables. The result obtained in this study showed that the distance is significant in the value of the compressive strength obtained as the p-value obtained is less than 0.05. The negative coefficient value obtained suggested that the compressive strength of the burnt clay brick decreased with increased distance of the brick from the fire. What this result implies is that the higher compressive strength of the brick is achieved with lesser distance from the heating source.

Table 6 Linear regression between the compressive strength and distance

Term	Coef. a	SE Coef.	T-value	P-value	Beta Coef.
Constant	6.08	0.26	6.29	23.81	
Distance	– 0.02	0.00	1.69	– 8.62	– 0.68

a. Predictors: (Constant), Distance, b. Dependent Variable: Compressive strength Model Summary: R = 0.68, R^2 = 0.46, R^2adj = 0.45

For the water absorption property of the burnt clay brick, distance is not statistically significant because the p-value (0.10) is greater than 0.05, which is the value for the significance level. The coefficient in the regression analysis is positive (0.03), which was an indication that the water absorption property of the burnt clay bricks increases with farther distance from the fire. This result implies that the quality of the bricks closer to the burning fire was higher than those bricks that are farther away. In general, this study agreed with other works in the literature that the heating process of the burnt clay brick affects the quality of the brick [28].

Table 7 Linear regression between the water absorption and distance

Term	Coef. a	SE Coef.	T-value	P-value	Beta Coef.
Constant	13.97	2.22	6.29	0.00	
Distance	0.03	0.02	1.69	0.01	0.18

a. Predictors: (Constant), Distance; b. Dependent Variable: Water absorption; Model Summary: R = 0.18, R^2 = 0.03, R^2adj = 0.02

4. Conclusion

Bricks as building materials exhibit good physical and mechanical qualities for all high performance and sustainable buildings, and this depends on the clay composition and the firing process. The compressive strength and water absorption property of the burnt clay brick evaluated in this study for their position in the field kiln showed that the stacking distances of the bricks from the heating source affect the compressive strength and the water absorption properties of the burnt clay bricks. The average mean values of the compressive strength and water absorption of the burnt clay brick were in conformance to the standard minimum quality of 3.50 N mm^{-2} compressive strength and 20% water absorption property. The result showed that the farther the brick stack distances of the bricks from the fire, the lesser the compressive strength. The water absorption property increased with increased stack distance from the fire. This result means that the quality of the burnt clay brick closer to the heat sources was higher than those farther away from the heat source. However, this study did not determine the temperature of the heat at the various layers of the stack distances assessed. Further studies are recommended that will investigate and regulate the temperature distribution of the field kiln as well as determine the number of burnt clay bricks without defect at each layer of the field kiln stack.

5. Suggestion

The findings suggest that the stacking distance of bricks from the heat source in a kiln, significantly affects the brick properties. The closer the bricks to the heat source, the better their compressive strength and water absorption. Although average means were both in conformity to stipulated standards, only bricks closer to the heat source were considered adequate for construction.

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