

Assessing the Correlation between Brick Properties and Firing Hours of Locally Produced Clay-burnt Bricks in Taraba State, Nigeria

E. J. Bassah and W. K. Joshua

Abstract — The use of burnt-clay bricks is increasing in rural areas because of its availability and low cost. However, the burning of bricks locally at unknown temperatures will likely result in the production of bricks that are unfit for construction purposes. The study assesses the minimum number of days bricks require to attain the minimum stipulated standards for compressive strength and water absorption. The results obtained were compared to the NIS 87: 2000 standards to assess their conformity. From the study results, the mean compressive strength of bricks (1.576 N/mm², 2.306 N/mm², 3.634 N/mm²) at 48, 72 and 96 hours of firing fails to attain the target value of 5N/mm² as stipulated by the NIS building code. However, the mean compressive strength after 120 hours (5.386 N/mm²) attains the stipulated unit value. The water absorption rate displayed similar findings with mean values of 37.12%, 34.2%, 28.88% failing to conform with the stipulated 20% standards. However, the mean of water absorption after 120 hours (21.02%) has no significant difference and hence conforms to the stipulated value. This therefore means that bricks should be burnt far beyond the 120 hours in order to safely conform to 5N/mm² and 20% compressive strength and water absorption respectively.

Index Terms— burnt clay-bricks, compressive-strength, firing-time, water-absorption.

I. INTRODUCTION

The use of earth together with other natural materials such as stone and wood in the construction of load bearing structures have been in existence for centuries [1]. Clay bricks in either sunbaked or burnt form has been the major widespread practice in the construction of houses especially in rural areas. Sun-baked clay bricks are one of the earliest basic building materials used by man and indeed are still in use today [2]. Clay bricks are dated and found in the ruins of ancient civilization [3]. This is because sunbaked clay bricks are simple and easy to use with low cost, good thermal and acoustic properties and at the end of the building's life span, the clay material can easily be reused by crushing, wetting or returned to the ground without any interference with the environment [2]. Sun-baked clay bricks have been in use in Nigeria for centuries and is still very much in use today. Remote settlements in rural areas predominantly use these building materials due to their availability, ease of use, cost effective and thermal properties. Although sunbaked clay bricks have poor water absorption and compressive strength in comparison to fired clay bricks, they have been much more

environmentally friendly especially during molding, production and at the expiration of their life span [4].

Bricks are the most used construction materials for building houses in most countries especially developing countries. For hundreds of years now, bricks made from soil or earth have been considered and used as a construction material in combination with other natural materials such as wood and stone for load bearing structures [2], [5], [6]. Conventional bricks are produced from clay and fired at high temperatures for maximum strength, durability, and excellent water absorption rate [6], [7]. This has prompted for not just its wide use but also the promotion of sustainable development. The promotion of sustainable development has put pressure on all industries including the construction industries to adopt and implement cost-effective and environmentally friendly options in construction in order to protect the environment [8], [9].

For over seven decades now, the use of bricks has gone through several forms of transformation, making them an increasingly used building material [1]. Clay soil is continuously used especially in developing countries because it is cheap, readily available, and environmentally friendly. For instance, most countries that use clay bricks for construction works accounts for about 30% of the world population living in earthen housing [10]. In fact, the use of earth bricks for construction of houses is one of the ways to encourage and support the sustainable development goals.

Clay bricks are principal structural components of a masonry building and therefore an understanding of its properties is essential to assess the overall structural behavior of the building. For instance, the compressive strength of clay brick can be used to predict the general masonry compressive strength, which furthermore is the basis for estimating masonry modulus of elasticity and masonry stress-strain modulus [11]-[13]. Although bricks are building materials of excellent durability, their quality is still a major concern in most places of the world [3], [14]. In rural communities of developing countries for example, locally made bricks are molded and fired at unknown temperatures with no standards set to guide local communities on the quality of bricks they produce. Most people are unaware of the specifications in terms of compressive strength, durability, and water absorption of the bricks they produce. This trend calls for the continuous determination and monitoring of physical, chemical, and mechanical properties of earth bricks. It also

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makes the need for monitoring of brick properties a paramount issue especially in rural to semi-urban areas of Nigeria.

Therefore, this study aims to assess the relationship and correlation between the compressive strength of locally burnt clay bricks that are fired at unknown temperatures, and the number of days it takes to attain maximum strength. It also aims to compare the water absorption of the bricks to ensure that both strength and water absorption are within the stipulated range described by the NIS 87:2000 building codes.

II. BRICK PROPERTIES

The rapid and frequent collapse of building especially in Nigeria necessitates the need to constantly evaluate the properties of construction materials including locally produced clay bricks [15]. The properties of bricks are often classified into physical, chemical, and mechanical. These properties can be affected by changes in soil properties, chemical compositions of the soil, firing temperature and duration [3], [16]. Compressive strength and water absorption are two major properties of bricks that can be used to predict brick's ability to withstand or resist cracking. The compressive strength of brick is highly affected by the firing temperature, method of production and the properties (chemical and mineralogical) of the raw materials used to mould the bricks [3], [17], [18]. On the other hand, water absorption of brick is the measure of available pore space within the brick. It is expressed in percentage of the brick weight and affected by the clay or soil properties, method of manufacturing and the degree of firing [3].

III. MATERIALS AND METHODS

A. Description of Test Samples

In this study, 20 brick samples were collected from a freshly stacked kiln in Jootar. The samples consist of bricks of varying dimensions ranging from 221 mm × 125 mm, 230 mm × 122 mm to 230 mm × 121 mm, (L x B) respectively. After 48 hours of firing, five brick samples were collected and denoted as A1, A2, A3, A4 & A5. A second sets of five samples was collected after 72hours of firing and denoted as B1, B2, B3, B4 & B5. A third set of five bricks were subsequently collected after 96 hours of firing and denoted as C1, C2, C3, C4 & C5 and lastly, a final set of five brick samples were collected after 120 hours of firing and denoted as D1, D2, D3, D4, & D5. The samples were analyzed for their compressive strength and water absorption rate and the results was recorded, tabulated, and shown in Table 1-4 below.

B. Determining the Compressive Strength of Bricks

The compressive strength was determined using the compression testing machine type ALPHA 4 as described by Presetsan & Theppaya [19]. The brick sizes were measured, and the area of bricks was computed using Equation 1 below. The brick sample was then screwed to the loading base of the testing machine and the load was applied gradually to a point when samples failed was noted (crushing load). The

compressive strength was then computed using Equation 2 below:

$$Area = L \times B \quad (1)$$

where

L = length of brick.

B = breadth of brick.

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

where

N = load applied.

A = Area of brick sample.

C. Determining the Water Absorption of Burnt Clay Bricks

Water absorption rates of bricks was determined using the submersion test as described by Promkotra & Kangsadan, [20]. Five brick samples were selected and assessed physically to ensure there were no physical defects that could undermine the results. The samples were then submerged in a water tank for 24hours. After 24hours, the samples were carefully removed and wiped before they were weighed and their weights were denoted W_2 ; before they were oven dried at 105 °C for 24 hours to ensure they were completely void of moisture and completely dry. After drying, their weights were taken and denoted as W_1 and the rate of absorption was computed using the expression in equation 3 below:

$$Water\ Absorption = \frac{w_2 - w_1}{w_1} \times 100 \quad (3)$$

where:

W_1 = weight of oven dried bricks.

W_2 = weight of saturated bricks.

IV. DATA ANALYSIS OF RESULTS

The results obtained were analyzed using Minitab software package version 18.0. The data were descriptively expressed, and values were given as mean ± standard deviation. A t -tests were used, and Spearman's correlation coefficients used to establish relationship and associations. P -values less than or equal to 0.05 were taken as statistically significant outcomes of the analysis.

V. RESULTS AND DISCUSSION

The result for compressive strength and water absorption of clay-burnt bricks were tabulated and presented in Table 1-4 below. Each of the five set of samples were analyzed separately to determine the p -value at 0.05 level of significance. The same was repeated for the water absorption and the outcome was discussed under the strength and the rate at which the brick samples absorb water.

TABLE I: BATCH A RESULTS FOR THE COMPRESSIVE STRENGTH & WATER ABSORPTION OF BURNT BRICKS

Batch No.	Area (mm ²)	Load (KN)	Compressive Strength (N/mm ²)	Water Absorption (%)	Firing Time (hours)
A1	27830	47	1.68	38	48
A2	27831	42	1.50	35.2	48
A3	28060	48.5	1.72	38.5	48
A4	27750	45	1.56	37.6	48
A5	28520	40.5	1.42	36.3	48

TABLE II: BATCH B RESULTS FOR THE COMPRESSIVE STRENGTH & WATER ABSORPTION OF BURNT BRICKS

Batch No	Area (mm ²)	Load (KN)	Compressive Strength (N/mm ²)	Water Absorption (%)	Firing Time (hours)
B1	27832	66	2.37	35.1	72
B2	28560	69	2.41	35.6	72
B3	27830	68	2.44	34	72
B4	27832	55.8	2	32.8	72
B5	27831	64.5	2.31	33.5	72

TABLE III: BATCH C RESULTS FOR THE COMPRESSIVE STRENGTH & WATER ABSORPTION OF BURNT BRICKS

Batch No	Area (mm ²)	Load (KN)	Compressive Strength (N/mm ²)	Water Absorption (%)	Firing Time (hours)
C1	28748	88	3.06	30.9	96
C2	27829	92	3.3	31.3	96
C3	28065	120	4.2	26	96
C4	27832	88	3.16	30	96
C5	28060	125	4.45	26.2	96

TABLE IV: BATCH D RESULTS FOR THE COMPRESSIVE STRENGTH & WATER ABSORPTION OF BURNT BRICKS

Batch No	Area (mm ²)	Load (KN)	Compressive Strength (N/mm ²)	Water Absorption (%)	Firing Time (hours)
D1	27834	160	5.75	20.8	120
D2	27832	140	5.03	20	120
D3	27831	137	4.92	21.5	120
D4	27830	158	5.67	22.3	120
D5	27830	155	5.56	20.5	120

A. Compressive Strength

The compressive strength of building materials is regarded as one of the most important engineering characteristics indexed for building materials [21]. The NIS 87: 2000 specifies an average of 5 N/mm² as the allowable compressive strength of burnt-clay bricks. Although, the standard allows for a minimum load bearing unit of 2.5 N/mm² [15], the recommended standard for most codes stipulates 5 N/mm².

The result for batch A bricks shows that the mean compressive strength is significantly different from the standard stipulated load bearing unit of 5 N/mm². The 1-sample t Test for the mean reveals a p-value of 0.001, a mean of 1.576 N/mm² and a standard deviation of 0.12442 N/mm². The results indicate that after 48 hours of firing, bricks are still less than the standard load bearing unit and hence unsuitable for any construction purpose.

The 1-sample t Test for the second batch (batch B), indicate that after 72 hours of firing, the sample is still not fit for construction. The 1-sample t Test indicates a 2.306 N/mm² mean unit, p-value of 0.001 and a standard deviation of 0.17785 N/mm². At 0.05 level of significance, the mean

differs from the stipulated standard value and hence the reason it is still unfit for construction.

At 96 hours of firing, the 1-sample t Test indicates that the samples have a mean value of 3.634 N/mm², p-value of 0.009, and standard deviation of 0.64264 N/mm². However, at 0.05 level of significance, the study concludes that the mean is significantly different from the target value of 5 N/mm² stipulated by the standard building code.

Finally, after 120 hours of firing, batch D samples shows that the mean value was not significantly different from the target value. The analysis indicates a mean of 5.386 N/mm², p-value of 0.087 and a standard deviation of 0.38318 N/mm². Hence, the study can conclude that bricks begin to attain the stipulated or target value of 5 N/mm² and can be used for construction. The general increase in strength after days of firing conforms to studies on how brick quality is improved with higher temperature [7], [22], [23]. Therefore, it is recommended that local brick manufacturers fire beyond the 120 hours to attain higher values for compressive strength before using such bricks for construction.

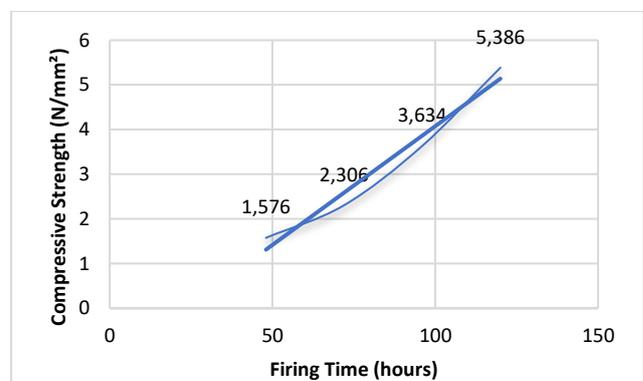


Fig. 1. Sample mean of compressive strength of bricks against firing time of bricks.

B. Water Absorption

The 1-sample t Test for water absorption of batch A samples (at 48 hours of firing) indicate a p-value of 0.001 which indicates that it is significantly different from the stipulated unit of 20% water absorption. The analysis shows a mean unit value of 37.12%, and a standard deviation of 1.3480%. The water absorption at this stage shows that the bricks are not ideal for any construction especially since the study area is characterized by annual precipitation of over 900 mm per annum [24].

Batch B analysis also indicates similar findings with mean value of 34.2%, p-value of 0.001 and a standard deviation of 1.1467%. At 0.05 level of significance, the mean value differs significantly from the stipulated standard of 20% for water absorption of burnt clay bricks.

The analysis for batch C shows that after 96 hours of firing, the mean of water absorption is still significantly different from the target value of 20%. The results indicates a mean value of 28.88%, p-value of 0.002 and standard deviation of 2.5821%, therefore it can be concluded that at 0.05 level of significance, the mean differs and is still much more than the stipulated value.

Finally, the mean after 120 hours of firing indicates a mean of 21.02%, p-value of 0.064 and a standard deviation of

0.89833%. This further indicates that the mean is not significantly different from the target value of 20% and hence adequate for construction purposes. Although, we recommend firing beyond 120 hours to further reduce the water absorption rate so as to make the bricks suitable for all kinds of construction.

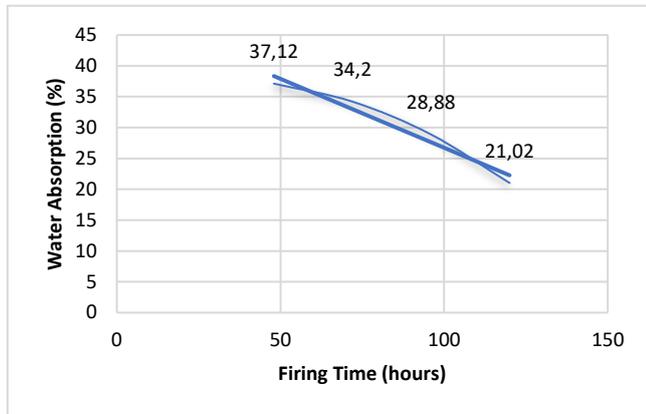


Fig. 2. Sample mean of water absorption of bricks against firing time of bricks.

VI. CONCLUSION

The study was able to show that the process involved in burning clay bricks at unknown temperature requires a minimum of 120 hours to attain the minimum unit value for both compressive strength and water absorption. The findings also show that the brick strength increases with the number of hours the bricks are fired. However, the study findings suggest that bricks should be fired beyond 120 hours especially since the firing temperature is unknown. This is important because at 120 hours, the bricks barely attain the minimum strength and water absorption rates. Therefore, firing of up to 168 hours will likely reduce the water absorption rate to below the stipulated 20% and increase the compressive strength to above 5 N/mm². Finally, the monitoring of brick manufacturing should be encouraged within the local communities of Taraba and Benue due to their high use of burnt clay bricks for construction.

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