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PARTIAL REPLACEMENT OF CLAY WITH RIVER SAND IN THE PRODUCTION OF BURNT CLAY BRICKS

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ABSTRACT

This study investigates the partial replacement of clay with river sand in burnt clay production at 0 %, 5 %, 10 %, 15 %, 20 %, and 25 % river sand. Preliminary tests were conducted on the aggregates to determine its suitability. Experiment tests which include density, water absorption and compressive strength were also conducted. The density, water absorption and compressive strength values range from 1646-1743 kg/m^3, 9.97-14.79% and 2.94-5.76 N/mm^2 respectively. The results show that at 5% river sand replacement; the density increase with increase in sand content but gave the least value in water absorption capacity. Also, for the compressive test carried out, the samples at 5% river sand replacement gave the maximum compressive strength. It has therefore been established in this study that clay in partial replacement with river sand can improve the properties of burnt clay bricks especially when mixed at 5% river sand replacement with clay content as this gives the best possible outcome in the production of fired clay bricks carried out in this study. Conclusively, for most low cost residential buildings and other structural work where burnt clay brick is applicable for use, 5% river sand is recommended to improve the properties of the burnt clay bricks.

Keywords: Partial replacement, River sand, Burnt clay, Water absorption, Compressive strength

1.0 INTRODUCTION

The construction industry provides the facilities and infrastructure that people need to function and it is therefore the fundamental foundation on which humanity exists, develops and survives. However, approximately 50% of all global resources are consumed by the construction industry, representing six billion tonnes of industrial raw materials each year (Augenbroe *et al.*, 1998; Edwards and Hyett, 2001; Kim and Rigdon, 1998; Sev, 2009). There is today an ever increasing problem of providing adequate yet affordable housing in sufficient numbers in most developing countries. In the last few decades, resources have remained scarce, housing demands have risen and the urgency to provide immediate practical solutions has become more acute (Hadjri *et al.*, 2007). As prices of building materials increase sharply, there should therefore be a growing awareness to relate research to local materials as alternatives for the construction of functional but low-cost dwellings both in the urban and rural areas of developing countries. One of such local material that is being researched is clay brick.

Before the invention of cement, all forms of houses were constructed using locally available material such as clay bricks, thatched raffia palm and bamboo for roofing and Nigeria as a country has several large deposits of clay scattered all over the country which have not yet been exploited on a technical scale even till date (Saridharan and Venkatappa, 1973). Brick is a rectangular block of clay or a similar material that is baked until it is hard and then used for building houses, walls or other large permanent structures (Encarta English Dictionary, 2009). Usage of burnt bricks dates back to the stone age (i.e. 2500 BC) as recorded in the Bible story of "The Tower of Babel" in Genesis chapter 11 verse 3 where the people were said to "make bricks and burn them thoroughly." They had brick for stone, and asphalt for mortar (Maxwell, 2007 – NKJV).

Clay brick is the first man-made artificial building material and one of the oldest building materials known. Its widespread use is mainly due to the availability of clay in most countries. Its durability and aesthetic appeal also contribute to its extensive application in both load bearing and non-load bearing structures. The properties of clay units depend on the mineralogical compositions of the clays used to manufacture the unit, the manufacturing process and the firing temperature (Hendry, 1991). The raw materials for burnt brick production which comprise predominantly various proportions of sand, silt and clay soils are derived from the deposits along the flood plains of major rivers and seasonal streams. These deposits when mixed, kneaded, compacted in moulds and fired, produce bricks for building construction. It is however interesting to note that burnt bricks fired at a kiln temperature, of 1000 ^{o}C produce red to reddish brown bricks but beyond this temperature, a dark blue coloured vitrified clinker results which melts and fuses together in a heap usually discarded by natives and referred to as iron stone" (Tse and Akpen, 2008).

The importance of locally manufactured bricks has been emphasized in many countries due to their effortless availability and low cost; also, bricks have been upgraded as one of the longest lasting and strongest materials, made from locally available sources. Common building brick is made of a mixture of clay that have been subjected to several processes, depending on the nature of the material, the method of manufacture and the character of the finished product (Edward and Robert, 2011; Raut *et al.,* 2011). Burnt brick is normally stronger than sun dried brick, but weaker than cement bricks in terms of strength and durability (Raut *et al.,* 2011). This drawback in the overall efficiency of the clay brick can be improved by doping with a suitable agricultural waste along with clay in the manufacturing process. Doping materials are used to upgrade the bond in-between the particles, thus the strength of the brick, which is either cementitious or pozzolanic materials (Alaa and Ali, 2013). Lime is a traditional pozzolanic material; wood ash, sawdust ash and fly ash are non-traditional pozzolanic materials. Rice husks, sawdust, coal are organic materials. These organic materials control the burning temperature of the bricks, which is of principal importance. The higher burning temperature produces the higher quality brick (Fernando, 2017).

Sand is often added to the clay during mixing by some manufacturers in order to reduce shrinkage, since the drying shrinkage is dependent upon pore spaces within the clay and the mixing water (Brownell, 1976). River sand can be mixed with clay soil and other materials to manufacture brick (Tamaraukuro and Japo, 2016). Adegoke and Ajayi, (2003), posited that a good material for shelter provision must allow participation from the community and thereby improving the economy of that community. This is what they called appropriate technology. Such materials must be readily available, appropriate (economically (i.e. affordable) and physically) to the environmental demands, thermally efficient and socially acceptable (Olusola, 2005). This research therefore seeks to investigate the applicability of river sand in partial replacement of clay in burnt clay brick production at varying mix ratios.

2.0 MATERIALS AND METHODS

The two major materials used in this work are clay and river sand. The clay was collected near the river bank of River Bar while the fine aggregate (river sand) was also collected from the middle of the same river located in Mbakya Mbayion Gboko Local Government Area of Benue State. Some tools and equipment were used such as hand trowel, shovel, head pans, digital weighing balance, scoop, tampering rod and compression testing machine. Preliminary test such as moisture content, particle size distribution, specific gravity, consistency limit test, and compaction test were performed. The moisture content, specific gravity and the sieve analysis of the sand used were determine according to BS EN 1097-5:2008; the consistency limit test according to BS 1377: 1990 and the compaction tests were also determine. Water used for mixing and curing was obtained from a potable source.

Production of Burnt Clay Bricks

The production of burnt clay bricks was carried out in four stages namely winning and clay preparation, moulding, drying and firing. Winning and clay preparation was the first step in the production of burnt clay bricks. The clay after manual collection was moved to an open air storage area where it was prepared for moulding. The clay samples were batched alongside the river sand at selected percentages of 0% 5%, 10%, 15%, 20% and 25% of dry weight of soil and was mixed thoroughly by adding water until approximately the optimum moisture content as determined during compaction was reached, in order to obtain a homogeneous mix. The resulted mix was plastic enough to facilitate moulding but not too plastic as that could result in warping, twisting or cracking during the drying phase. After preparation of the samples at varying mix, the batched materials were placed in a mould of size 215 mm x 103 mm x 65 mm. The freshly produced bricks were stored in the open air in rows. They were covered temporarily with dried grass to ensure protection against adverse weather condition for one week to ensure proper drying. The properly dried bricks were stacked with a provision for firing. The staked bricks were covered with a thick layer of soil paste to reduce the loss of heat during firing. These bricks were produced according to BS 3921:1985 specification.

Experimental Tests

(a) Density

Density test was conducted on the bricks produced. The mass and the volume of the bricks were determined. The mass was determine by weighing each brick on weighing balance while the volume of each brick was determined by taking the reduced lengths and height of the sides after firing. Equation (1) was used to calculate the density of bricks.

$$\rho = \frac{m}{v} \tag{1}$$

where,

ρ = density of brick, (kg/m^3)

m = mass of brick (kg)

v = volume of brick (m^3)

(b) Water Absorption Test

Moulded bricks were initially dried in an oven at a constant temperature of 105^{0}C after which they were cooled at room temperature and their weights were obtained as M_1. The dried samples were then immersed completely in water for 24 hours. Each sample was removed, wiped out of any traces of water with damp cloth and weighed as M_2. Water absorption after 24 hours immersion in water is given by the formula:

$$Wa = \frac{M_2 - M_1}{M_1} \times 100 \tag{2}$$

where,

Wa = water absorption, (%)

M_1 = weight of fired brick, (g)

M_2 = weight of wet brick, (g)

(c) Compressive Strength Test

After curing has been completed for the bricks to attain their full strength, each brick specimen were centrally positioned on the universal testing machine between the plates. Applied load was gradually increased on the specimen in order to crush it. The value at which the load failed was recorded. The compressive strength of the bricks was determined using Equation 3. Five bricks were tested for each replacement percentage and the average values were recorded in N/mm^2. The compressive strength of each brick was determined.

$$\sigma = \frac{F}{A} \tag{3}$$

where,

σ = Compressive strength, (N/mm^2)

F = Force applied before crushing, (N)

A = Area of brick, (mm^2)

3.0 RESULTS AND DISCUSSION

The natural moisture content of the clay sample gives 10.30 % of water. Table 1 shows the specific gravity results of the river sand in varying percentage of replacement. It could be seen that the values increase gradually from 2.44 at 0 % to 2.64 at 100%. At both 20% and 25%, the mixtures have the same specific gravity values which display a typical form of consistency. The mixture having no clay content with 100% river sand has a specific gravity of 2.64 while the mixture having no river sand with 100% clay has a specific gravity of specific gravity of 2.44. This result for river sand is typical for materials which composed mainly of quartz while that of clay is typical for materials with sedimentary clays as established by Terzaghi *et al.* (1996).

Table 1**:** Specific Gravity

River Sand Percentage	Specific Gravity Values
0 %	2.44
5 %	2.50
10 %	2.53
15 %	2.57
20 %	2.60
25 %	2.60
100 %	2.64

Table 2 reveals the Atterberg limit test results conducted on the mixture both with and without river sand in varying percentage of replacement. The Atterberg's limit values were observed to reduce with increase in river sand content.

Table 2: Summary of Atterberg Limits Test Results

River Sand (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)
0	35.50	19.60	15.90	9.30
5	31.50	18.00	13.50	5.70
10	29.80	17.00	12.80	4.30
15	27.50	16.60	10.90	3.60
20	26.40	16.10	10.30	2.90
25	25.80	16.30	9.50	2.50

It could be observed that the soil generally possess a low liquid limit (i.e. 35.50 % < 50.00 %). The liquid limit was observed to decrease from 35.50 % at 0 % River Sand to a minimum value of 25.80 % at 25 % River Sand. The same condition occurs for plastic limit (PL). These results therefore affect the outcome of the plasticity index. According to American Association of State Highway and Transportation Officials (AASHTO) soil classification system and Unified soil classification system (USCS) classification, the mixtures is classified as A-7-6 and CH soil respectively. Also, according to the classification of Chen, (1988), it can be described as having medium swell potential.

Table 3 summarizes the compaction test results. From the test results, the maximum dry density (MDD) of the sample ranged from 1.53 to 1.65 g/cm^3 and the optimum moisture content ranges 17.60 to 18.00%.

Table 3: Summary of Compaction Test Results

River Sand (%)	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)
0	1.53	18.00
5	1.60	17.90
10	1.61	17.70
15	1.61	17.60
20	1.63	17.70
25	1.65	17.80

It could be observed from Table 3 that optimum moisture content of the soil decreases with increase in river sand content while maximum dry density of the soil increased considerably with increase in river sand. This may be attributed to the molecular rearrangement resulting in the formation of transitional compounds of different densities.

The particle size distribution test results done on the clay sample using hydrometer analysis method and that performed on the river sand were presented in charts. Figures 1 and 2 show the result of the particle size distribution of both the clay and the river sand.

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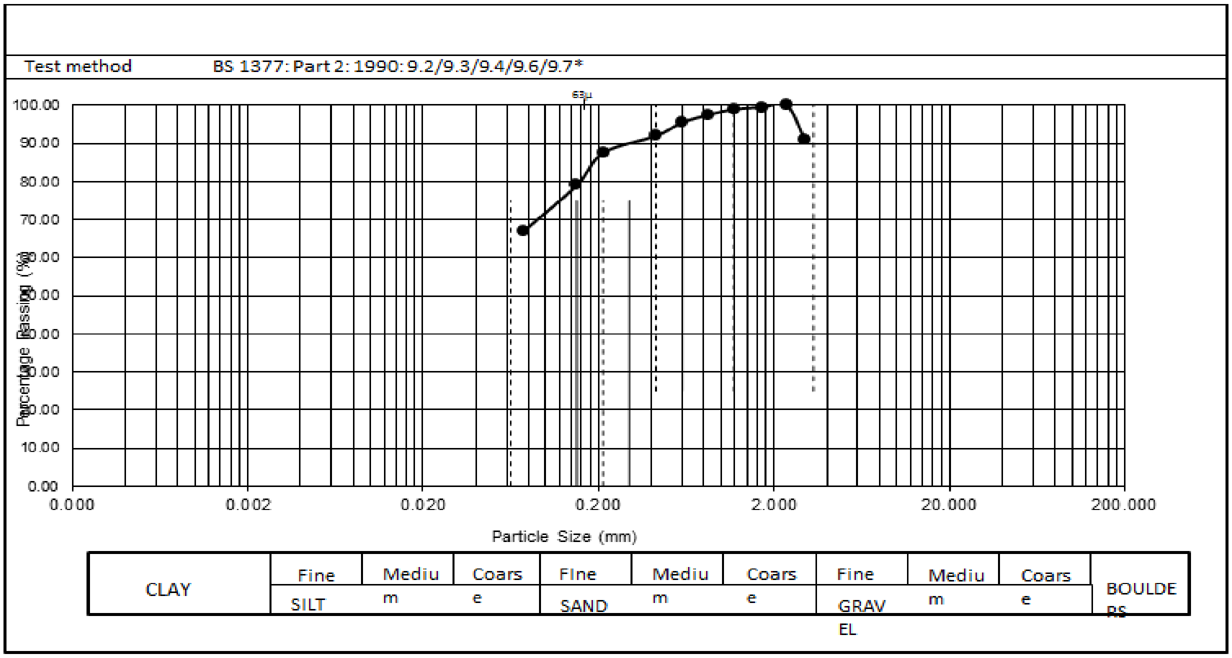

Figure 1: Particle Size Distribution of Clay Sample

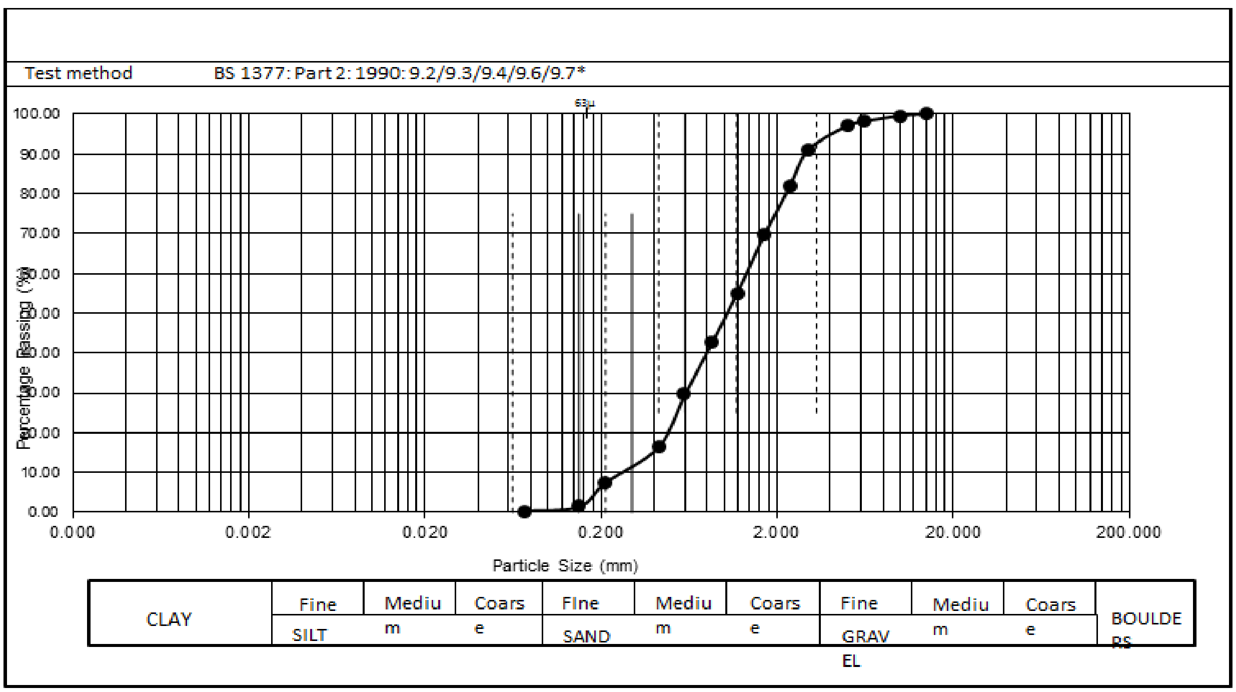

Figure 2: Particle Size Distribution of River Sand

From the hydrometer analysis, it was found that the sample contained 13.5 % clay, 47 % silt and 39.5 % sand with low liquid and plastic limit. This low liquid and plastic limit can be traced to the high content of silt and sand present. The sand is mainly medium to fine grained. Therefore the soil sample is classified as silty-sand-clay. The sand, silt and clay particles present in the soil

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samples are important in achieving a higher degree of compaction and the desired densification. The coefficient of uniformity (Cu) and the coefficient of curvature (Cc) of river sand were gotten to be 4.28 and 1.0 respectively. Therefore the river sand was classified as a well-graded medium sand.

3.1 Density

Table 4 summarizes the density result of the bricks produced. It shows that the density ranges from 1646 to 1743 kg/m^3. It increases with increase in river sand content. All the density values gotten for the partial replacement of the river sand satisfy the requirements as provided by BS 3921: (1985) for bricks. Only bricks produced at 0% river sand (i.e. 100 % clay) did not satisfy the requirements which stated the minimum density value of 1650 kg/m^3.

Table 4: Density Test Results

River Sand (%)	Average Mass of Brick (m) (kg)	Volume of Brick (v) (m^3)	Density = m/v (Kg/m^3)
0	2.37	0.00144	1646
5	2.42	0.00144	1681
10	2.43	0.00144	1688
15	2.48	0.00144	1722
20	2.49	0.00144	1729
25	2.51	0.00144	1743

3.2 Water Absorption

Table 5 and Figure 3 show the water absorption results carried out on twelve samples, the results gotten ranges from 9.97 to 14.79 %. In Figure 3, a sharp increase was observed in the percentage of water absorption at 10% river sand content increased to 10 %. There was further increase in the water absorption at 10% replacement which resulted from the high porosity of the river sand. The least value of water absorption at 5 % river sand shows that the particles were closely packed.

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Table 5: Water Absorption Test Results at Varying River Sand Replacement

River Sand (%)	Sample number	Initial Wt. of Specimen W_1 (g)	Final Wt. of Specimen W_2 (g)	% Water Absorption	Average. %Water Absorption
0	A	2498	2813	12.61	
	B	2546	2833	11.27	11.94
5	A	2323	2553	9.91	
	B	2453	2699	10.02	9.97
10	A	2450	2772	13.14	
	B	2472	2812	13.75	13.45
15	A	2350	2675	13.83	
	B	2395	2730	13.99	13.91
20	A	2458	2804	14.08	
	B	2401	2759	14.91	14.50
25	A	2505	2878	14.89	
	B	2485	2850	14.69	14.79

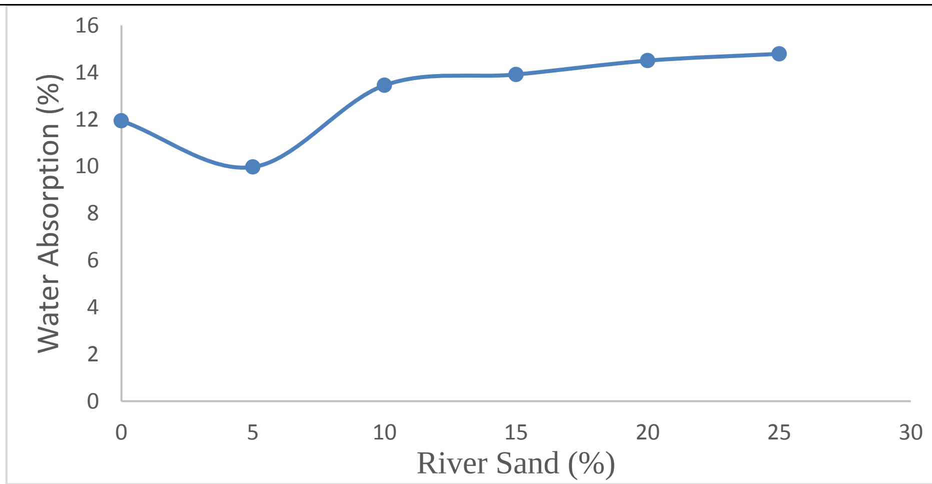

Figure 3: Water Absorption of Clay Burnt Bricks Replaced with River Sand

3.3 Compressive Strength

Table 6 and Figure 4 show the compressive strength result. The compressive strength results ranges from 2.94 and 5.76 N/mm^2. It can be seen that the value of the compressive strength increase from 5.11 at 0% replacement to a value of 5.76 N/mm^2 at 5 % river sand replacement. After the increment, a steady decrease was observed in the compressive strength as the percentage replacement of river sand increases in the brick produced.

Table 6: Results of Compressive Strength Test

River Sand (%)	Average Mass (kg)	Average Crushing load (KN)	Specimen Area (mm^2)	Compressive Strength (N/mm^2)
0	2.37	113.2	22145	5.11
5	2.42	127.6	22145	5.76
10	2.43	103.6	22145	4.68
15	2.48	91.2	22145	4.12
20	2.49	79.4	22145	3.59
25	2.51	65.0	22145	2.94

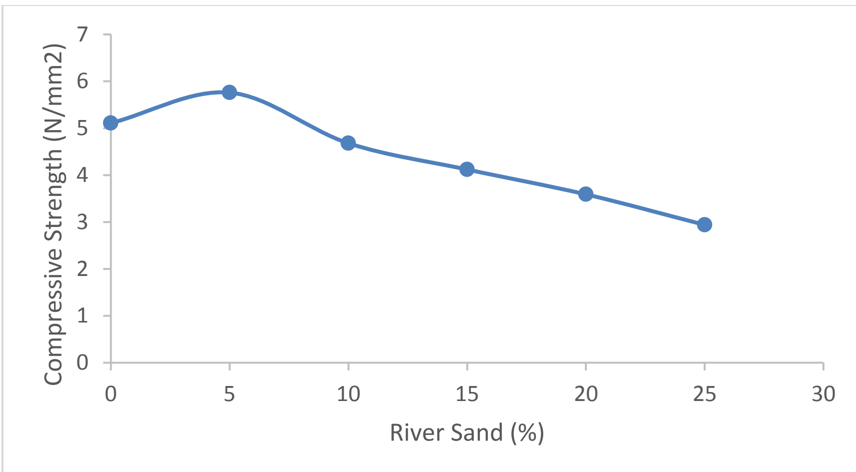

Figure 4: Compressive Strength of Burnt Clay Bricks Doped with River Sand

The compressive strength of all the clay burnt bricks produced exceed the minimum strength specified by Nigerian Industrial Standard (NIS) 87:2004 which is 2.8 N/mm^2 for the construction of low-rise buildings like residential houses.

4.0 CONCLUSION

The replacement of burnt clay bricks with river sand at varying ratio has been carried out in this research. The various preliminary tests performed show satisfactory results. The experimental test which includes the density, water absorption capacity and the compressive test carried out shows that at 5% river sand replacement; the density increase with increase in sand content but gave the least value in water absorption capacity. Also, for the compressive test carried out, the samples at 5% river sand replacement gave the maximum compressive strength. It can therefore be established that 5% river sand replacement with clay gives the best possible outcome in the production of fired clay bricks.

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