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A Study of the Physical and Chemical Properties of Olegokpa-Rukubi Clay Samples and the Suitability of Its Clay Bricks for Building Construction

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Abstract: *The chemical composition and the physical properties of Rukubi mixed clay sample were studied. The mixed clay sample was found to have a high quantity of Silica (SiO_2 = 41.95 %), average quantity of Alumina (Al_2O_3 = 27.38%) and iron (Fe_2O_3 = 15.95 %) and because the Alumina content is higher than the iron content, the mixed clay can be classified as an Alumina clay. The bricks made from this clay sample had compressive strength in the range 3.86 Nmm^{-2}- 8.56 Nmm^{-2}showing that the bricks are suitable for the construction of load bearing walls. The unfired bricks melted completely in water and had porosity of 50.25 % indicating that they are fragile and not durable. The fired bricks had lower porosity values and better water absorption abilities which indicate that they have better wear resistance, they could withstand high temperatures while presenting lower creep rate. There was a correlation between the bricks average porosity and average water absorption and bricks fired at 950 ℃ had the best durability of 26.33 %. The fired bricks had better abrasion resistances which corroborated the porosity test results. All the results obtained show that the fired Rukubi bricks satisfy the basic requirement for structural development and therefore are suitable for building construction.*

Keywords: *Rukubi clay bricks, Atterberg liqud limit, Compressive strength, Porosity, water absorption.*

I. Introduction

Clay bricks have been in use for decades, and can work well over a long period of time [1]. Its availability, versatility, ease of construction, excellent thermal mass properties among other properties has made it attractive for constructing buildings, terraces, and driveways and for demarcating open spaces. Initially of two colours only, clay bricks now come in a variety of colours and sizes and are now used for beautiful creations with unique and inspiring looks. Clay bricks can be kiln- fired at temperatures as high as 1200℃ without a significant change in structure and though they have low resistance against tension and torsion load; they are susceptible to seismic damage.

The decision to use bricks for building will depend on the chemical properties of the clay samples used for the brick block moulding as well as the physical characteristics of the brick blocks made from it. The durability or stability of a building structure or construction can be affected by the quality of building blocks used and these in turn will depend on certain physical characteristics such as porosity, cold water absorption and compressive strength among others of the blocks used. Though studies of these parameters have been carried out for clay deposits in Awgbu Anambra State [2], Makurdi clay in Benue State [3] and for flood plain deposits from four sites in North central Nigeria [4] , research on these parameters for clay samples in

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Nasarawa State is scarce and that for Rukubi clay samples in Doma local government area of Nasarawa State is none existent.

For the mixed clay sample taken from Awgbu, the liquid limit was 32.7 % , the plastic limit 13.5 % , the linear shrinkage 15.0 % while its specific gravity was 2.45. The compressive strength for the mixed clay sample were 1.70Nmm^{-2}, 2.50 Nmm^{-2}, and 3.81 Nmm^{-2} for bricks fired at temperatures 700 ℃ , 1000 ℃ , and 1100 ℃ respectively. The water absorption for this mixed clay sample was 16.50 % , 14.80 % and 12.20 % for bricks fired at 700 ℃ , 1000 ℃ , and 1100℃ , respectively. Furthermore for this mixed clay sample its bulk density decreased from 1.09 kg/m^3 to 1.07 kg/m^3.

For the two samples A and B of the Makurdi burnt bricks , the compressive strength of A was 3.46 Nmm^{-2} while that of B was 11.74 Nmm^{-2} , Water absorption was 16.49 % for sample A and 8.58 % for sample B while Abrasion resistance test gave an average durability of 9.32 % for sample A but 33.67 for sample B. The research carried out by Tse [4] showed that for the bricks made from samples collected from Makurdi, Katsina Ala , Naka and Nyaro-Tsambe respectively their average crushing strength were 98.63 Nmm^{-2}, 46.55 Nmm^{-2}, 42.03 Nmm^{-2} and 41.30 Nmm^{-2} respectively. The average bulk densities for Makurdi, Katsina Ala, Nyaro-Tsambe and Naka samples were respectively 1.39 g/cm^3, 1.63 g/cm^3, 1.71 g/cm^3 and 1.37 g/cm^3. While the linear shrinkage for these flood plain deposits ranged from 3.6 % to 15 %, their water absorption was in the range 3 % - 4 %.

Data such as these for Olegokpa -Rukubi clay samples does not exist and that is why this study was done. In this present study the chemical and physical properties of a mixed clay soil samples collected from a brick block site near Shina stream in Olegokpa, Rukubi village, in Nasarawa state was studied. Bricks were moulded using the same ratio of the three clay soil samples as do the local brick layers and dried. The bricks were divided into four groups A to D. While bricks in group A were not fired, those in groups B, C and D were fired at three different temperatures. The four groups of clay bricks were characterised to ascertain their suitability for construction of houses and other structures. Obtained results are discussed and compared to already existing results for other geographical regions of the Country (Nigeria).

Brick houses are not very common in the urban areas of Nasarawa State, Nigeria and it is hoped that the outcome of this study will encourage more prospective house owners to consider building their houses with clay bricks.

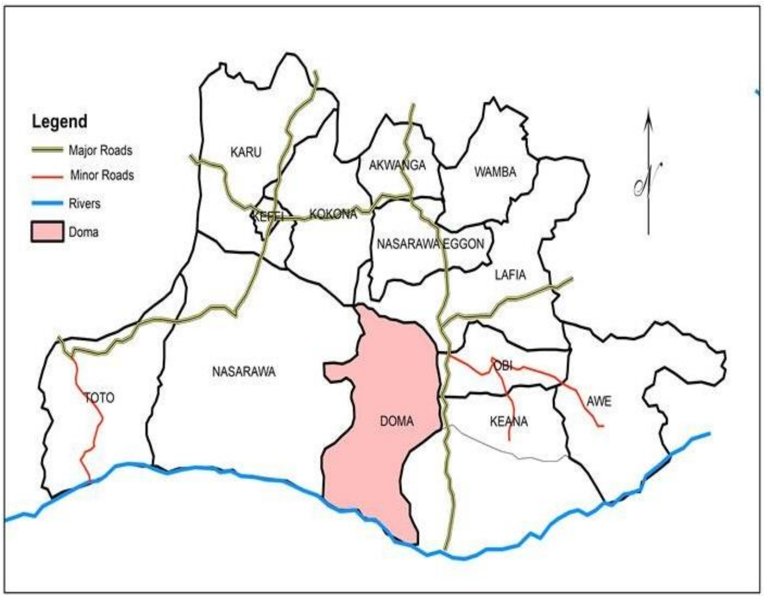

Figure 1: Nasarawa State map showing the study area Doma Local Government

II. Materials and Methods

Three different clay soil samples (10 kg each) of total mass 30 kg were collected from a brick block site near Shina stream in Olegokpa, Rukubi village in Doma LGA of Nasarawa State (Figure 1). Olegokpa at Rukubi in Doma local government area is on Latitude 7.92 ° N, Longitude 8.30 °E, with Relative Humidity 60 %. The three clay samples (Figure 2) were mixed together in the ratio 1:1:1 as used by the local brick layers of that village for moulding brick blocks. The pH of the mixed clay soil sample was determined in accordance with ASTM-D 4972-01 as reported by Chen et al [5] using the pH meter while the chemical composition of the clay was done using the X-ray florescence (XRF) technique. A compact energy dispersive X-ray spectrometer designed for the elemental analysis of a wide range of samples-the mini pal 4 version (PW 4039 X-ray spectrometer) with energy dispersive micro-processor controlled analytical instrument designed for the detection and measurement of elements in a sample was used for this analysis.

Figure 2: Cross section of the three clay samples obtained from Olegokpa

The three clay samples were dried at 105 ^{0}C for 24 hrs to remove moisture. In order to have a uniform particle size, the three clay samples were crushed and sieved to obtain the required size of particles. The pulverized samples were weighed, and preserved in an airtight plastic bag for analysis. The clay sample for the different analysis was obtained by mixing the three clay samples in the ratio of 1:1:1 as per the commercial brick standard composition. The obtained clay soil mixture was homogenized in a mixing bowl and 350 - 450 ml of water was added to make the mixture plastic. The plastic mixtures were passed into individual molds and compacted at 3 ton using compressive testing machine to form cubic bricks which were extruded using downward delivery method. Forty four (44) brick blocks each of dimensions $50\ mm \times 50\ mm \times 50\ mm$ were moulded, divided into four (4) groups with each group consisting of eleven clay bricks and labelled as samples A, B, C, and D for characterisation. Sample A were the unfired clay bricks, while samples B , C and D were bricks fired at 750 °C, 850 °C and 950 °C respectively (Figure 4). Brick blocks firing was done in a box furnace for 3 hrs and for each chosen firing temperature, the furnace was switched off and left to cool to room temperature before the bricks were taken to the laboratory for the determination of the required physical and mechanical properties. The analyses were done to ascertain the masonry strength of the bricks and therefore its suitability for building construction and other related structures. The characteristics of the bricks studied included its compressive strength, water absorption, Porosity, Abrasion resistance among others.

Physical properties of mixed clay soil sample

The properties studied include the Atterberg Liquid limit, the plastic limit and plasticity index.

Atterberg Liquid Limit (Liquid limit (LL) gives the minimum moisture content at which the soil will flow under its own weight and it is the water content at which 25 blows close the groove made in the soil sample [6]. Table 3 gives the obtained results and from Figure 3, the required Atterberg liquid limit was obtained.

Plastic limit (PL) is the minimum moisture content at which the soil can be rolled into threads of 3mm diameter without breaking up. This was determined with the help of the Scott volumeter while the Plasticity index (PI) is the measure of the water content range at which the soil remains plastic. It is the difference between liquid and plastic limits and is given as:

$\text{Plasticity Index (IP)} = \text{Liquid Limit (LL)} - \text{Plastic Limit(PL)}$

The porosity test of the clay soil sample was carried out because it gives an indication of the amount of water that a given volume of soil can hold. The quantity is an important parameter in areas where drinking water is provided by ground water reserves.

Compaction Test was done to determine the range of moisture content at which maximum compaction occurs provided the moisture content obtained during test is not exceeded.

Other parameters determined are the pH, specific gravity, linear shrinkage and maximum dry density as well as the Ash content of the mixed clay soil. Furthermore, the water absorption rate, and the organic content of the mixed clay sample were also determined. While the submersion test was used to test for the water absorption rate of the samples in accordance with ASTM-D2216 [7] the organic matter content in the mixed clay sample was determined using the method as stated by the American Society for Testing and Measurement (ASTM-D2974) [8] as reported by [9].

The Grain size analysis which gives the quantitative proportion by weight of the various sizes of particles present in the soil, and maximum dry density of the mixed clay soil were also determined. A group of ten sieves were well cleaned up, and assembled in the descending order of sieves sizes, with sieve number 10 the smallest size (75 μm) at the bottom and sieve number with the biggest size (3.35 mm) at the top. The pan was placed below sieve number 10.

Characterisation of the bricks

Water absorption Test

Pores make up a substantial portion of the brick volume and when bricks are exposed to rain when used for construction of a structure for instance, the rain water gets into the bricks through its pores. The distribution of pores in a brick depends on its firing temperature, the quality of the clay sample from which it is moulded as well as the additives and impurities it contains. The percentage water absorption which gives a measure of the capacity of the fluid to be held and circulated within the cubic burnt bricks and the green state (unfired brick) was determined in accordance with ASTM C67-05 and as reported by Ispir *et al* [10]. For each set of brick sample, 8 blocks were used. The initial weight of the brick was first measured after which it was submerged in water for 72 hrs. Its new weight was obtained and from these data the average percentage water absorption was determined.

Compressive strength

The compressive strength (σ) of clay bricks gives a measure of the brick's ability to withstand compressive loads in a structure. It gives the maximum compressive stress that the brick can withstand without fracture. This test was done using the Compression Testing Machine type ALPHA 4 and as described by ASTM C67-05.

Porosity of bricks

Porosity gives the volume of pores inside a brick and usually has a bearing on its compressive strength and water absorption. Bricks have fine capillaries through which moisture can travel and so its porosity has implications for how durable it can be and how well suited it can be for structures. The size of the pores as well as its shape can determine how much water or moisture it can hold. The method adopted for this analysis is as described by Kalu *et al* [2] and twelve (12) clay bricks were used for this analysis.

Bricks were dried and weighed (M_1) before immersion in water and re-weighed 24 hrs after immersion in water (M_2) and the porosity was calculated using Equation 1

Porosity = $\frac{M_2 - M_1}{\rho V} \times 100$ (1)

$(\rho = \text{density of water}, V = \text{volume of brick})$

Abrasion resistance test

The abrasion resistance of the bricks was also done to ascertain the ease with which the bricks can wear out when exposed to friction. This analysis is done to test a brick's ability to resist wearing from environmental factors. The test was done in accordance with ASTM D559/D559M-15 [11] and as reported by Danso and Akwaboah [12]. Abrasion Resistance test was done with twelve (12) clay bricks. Obtained results are as presented in Table 8.

III. Results and discussion

Chemical Composition of the Rukubi Clay

The chemical analysis carried out on the Rukubi mixed clay sample (Table 1) shows that it has a high quantity of Silica (SiO_2 = 41.95 %), average quantity of Iron Oxide and Aluminium content (Fe_2O_3 = 15.95 % and Al_2O_3 = 27.38%) respectively. With a higher Alumina than iron content, the mixed clay sample can be classified as Alumina clay [13] and conforms to the requirement for a good brick making on the basis of Alumina (Al_2O_3) or clay and silica (SiO_2) or sand content[14]. Table 1 shows the order of abundance of the major oxides as SiO_2 > Al_2O_3 > Fe_2O_3 > MgO > SO_3 > TiO_2. The analysis indicates a high Silica and Alumina content and conforms to the requirement for a good brick which is that it should contain between 20 % to 30 % of Alumina.

Physical property tests of the Rukubi mixed Clay sample

The tests carried out on the Rukubi Clay sample shows that its average moisture content is 36.04 %, while its average Plastic limit is 17.6 %,(Table 2). Its Atterberg liquid limit obtained from plotting the data in Table 3 to obtain Figure 3 is 34.3 %. While the plasticity index of the mixed clay sample was found to be 16.20 %, its obtained specific gravity was 2.56. The maximum dry density (MDD) of the mixed clay sample was 1160 kg/m^3 and its linear shrinkage (LS) was 7.10 %. The measured pH of the clay sample was 6.20, its Ash content 9.05 % and organic content 3.16 %. The result of the compaction test also showed that the clay sample has optimum compaction moisture content (OMC) of 33.5 %.

Table 1: Chemical composition of Rukubi mixed clay sample.

Elements	% composition by weight
SiO_2	41.95
Al_2O_3	27.38
Fe_2O_3	15.95
CaO	-0.65
MgO	-0.62
K_2O	0.32
Na_2O	0.23
P_2O_5	0.03
TiO_2	1.14
Mn_2O_3	0.16
SO_3	-0.14
Total SiO_2+Al_2O_3+Fe_2O_3	85.28

Table 2: Plastic Limit test results for the mixed clay sample

S/N	Sample label	Container Weight W_1 G	Wet soil+ Container Weight W_2 (g)	Dry soil + Container Weight W_3 (g)	Moisture weight (W_2-W_3) (g)	Dry soil weight (W_3-W_1) (g)	Moisture Content (%)	Average (%)
1	P_1	17.0	19.0	18.7	0.3	1.7	17.6	17.6
2	P_2	16.6	18.6	18.3	0.3	1.7	17.6	

Table 3: Atterberg Liquid Limit of Rukubi mixed clay Sample

S/N	Blows	Container	Container weight (W_1) g	Wet soil + Container weight (W_2) g	Dry soil + Container weight (W_3) g	Moisture weight (W_2-W_3) g	Dry soil weight (W_3-W_1) g	Moisture content (%)
1	13	L_1	16.50	27.40	24.50	2.90	8.00	36.30
2	20	L_2	16.20	27.80	24.80	3.00	8.60	34.90
3	34	L_3	15.90	30.80	27.10	3.70	11.20	33.00
4	45	L_4	16.40	29.10	26.10	3.00	9.70	30.90

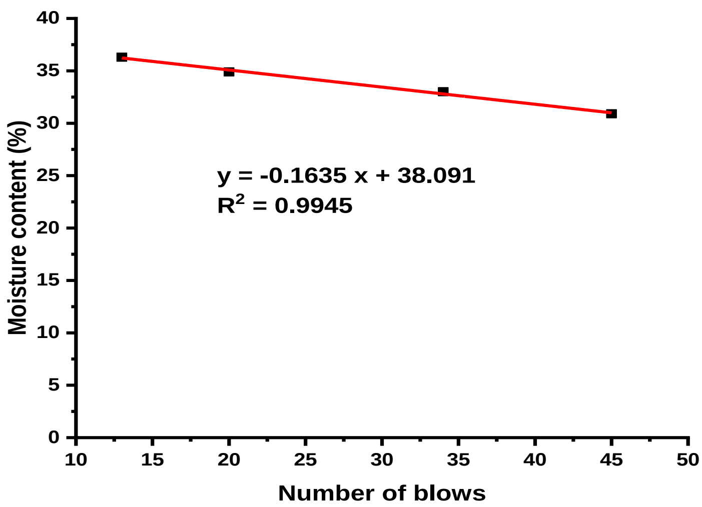

Figure 3: Atterberg liquid limit plot

Table 4: Grain size (Sieve) analysis of the Rukubi mixed clay sample

Sieve Size	Weight of sieve (g)	Weight of sieve + sample retained(g)	Weight of sample retained(g)	% Retained	% Passing
3.35 mm	468.9	488.91	20.01	4.00	96.00
2.36 mm	423.4	444.2	20.8	4.16	91.84
1.70 mm	418.1	442.9	24.80	4.96	86.88
1.18 mm	387.9	416.8	28.90	5.78	81.10
850 µm	356.3	392.6	36.30	7.26	73.84
600 µm	468.4	509.1	40.70	8.14	65.70
425 µm	416.4	449.1	32.70	6.54	59.16
300 µm	314.7	417.9	103.20	20.64	38.52
150 µm	421.1	537.7	116.60	23.32	15.20
75 µm	409.6	466.o	56.40	11.28	3.92
PAN	271.2	290.6	19.40	3.88	0.04
Total			499.81		

Table 4 shows that the proportion of the soil sample passing through the 75 μm sieve and representing silt particles in the clay sample is 3.92 %. This added to the proportion of Alumina (Al_2O_3) was 27.78 % giving a total of 31.30 % which is less than 50 % by weight indicating the soil sample fits well into the Rajput.(2006) specification [14] for a good brick making earth.

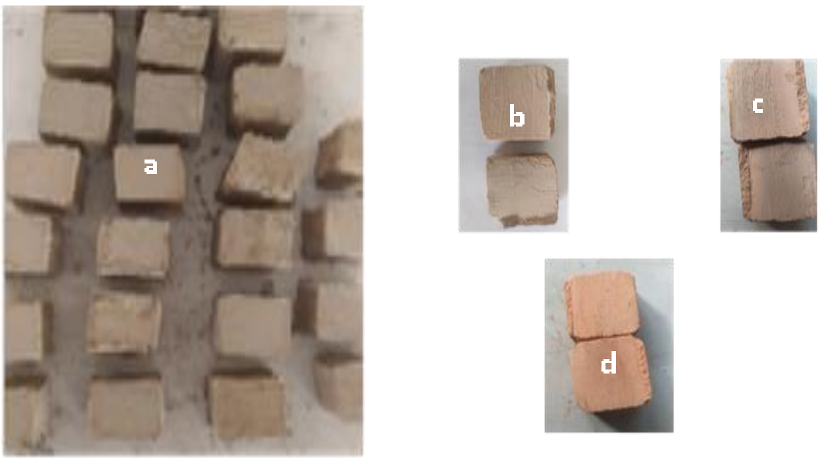

Figure 4: Cross section of Brick blocks **(a)** not fired, **(b)** fired at 750 °C, (c)fired at 850 °C and **(d)** fired at 950 °C

Water absorption results

The obtained initial weight of two unfired bricks labelled as sample A_1 and sample A_2 were 201 g and 221 g. while those bricks of groups B, C and D, labelled also as B_1, B_2; C_1 and C_2; D_1 and D_2, were placed in eight different labelled containers of same capacity and after 72 hrs immersion of the bricks in water, it was discovered that sample A bricks which were the unfired bricks completely melted in the water while the fired

bricks did not. Sample B bricks had an average water absorption of 17.9 %, sample C bricks an average water absorption of 18.4 % while sample D bricks had an average water absorption of 18.10 % (Table 5). These values fall within the limit of 20 % by weight as specified by Rajput.(2006) for building bricks [14] and are within the 20 % maximum cold-water absorption range specified by BDA, 1975: IS 1077 [15-17].
The obtained values are in agreement with those reported by Ibanga and Ahmed [18] and though lower than 14.8 % reported for Ibaji burnt clay bricks [19] the values are higher than 16.49 % reported for Makurdi Burnt Bricks [3].

Table 5: Water Absorption by Rukubi bricks fired at 750 °C, 850 °C and 950 °C

	B (750 °C)		C (850 °C)		D (950 °C)	
Test no.	1	2	1	2	1	2
Initial weight of specimen W_1(g)	238	231	215	226	225	217
Final weight of specimen W_2 (g)	280	273	256	266	266	256
Weight of water absorbed (g)	42	42	41	40	41	39
%Water absorption	17.6	18.2	19.1	17.7	18.2	18.0
Average % Water Absorption	17.9		18.4		18.1	

Compressive Strength results

The compressive strength study was done with twelve (12) clay bricks. The testing was done using the compressive testing machine (Alpha 4) and in accordance with ASTM C 67-05. Results from this test gives the maximum compressive stress a material can withstand without fracture. The results obtained for the Rukubi clay bricks (Table 6) shows that for the unfired bricks (sample A) its average compressive strength is 3.86 N/mm^2. The average compressive strength of the bricks increased as the firing temperature was raised perhaps due to the fusing of clay particles with one another to form a stronger bond. For sample B bricks, the average compressive strength was 4.94 N/$mm^2$and for sample C bricks it was 5.19 N/mm^2, while for sample D bricks it was 8.56 N/mm^2. The obtained values fall within the range reported for the Makurdi Burnt bricks, and within the range specified for building construction by NIS 87:2004 though the obtained values are higher than 2.8 N/mm^2 stipulated for constructing load bearing walls and 2.0 N/mm^2 recommended for non-load bearing walls. Furthermore, the obtained values are all above the minimum (3.5 N/mm^2) compressive strength fixed for bricks and therefore the Rukubi burnt clay bricks satisfy the basic requirement for structural development (BDA, 1974: IS 1077) and are deemed suitable for building construction.

Table 6: Compressive strength of Rukubi clay Bricks (for concrete mix period 3 hrs)

S/N	Brick sample	Weight of cube (kg)	density of cube (kg/m^3)	Crushing load (kN)	Area (mm^2)	Crushing strength (N/mm^2)	Avg. strength (N/mm^2)
1	A_1	228	1.824	60	2500	3.41	
2	A_2	225	1.800	76	2500	4.32	3.86
3	A_3	225	1.800	68	2500	3.86	
4	B_1 (750 °C)	237	1.896	73	2500	4.15	
5	B_2 (750 °C)	217	1.736	1.13	2500	6.42	4.94
6	B_3 (750 °C)	229	1.832	75	2500	4.26	
7	C_1 (850 °C)	199	1.592	85	2500	4.83	
8	C_2 (850 °C)	190	1.520	90	2500	5.11	5.19
9	C_3 (850 °C)	198	1.512	99	2500	5.62	
10	D_1 (950 °C)	203	1.624	122	2500	6.93	
11	D_2 (950 °C)	213	1.704	145	2500	8.24	8.56
12	D_3 (950 °C)	201	1.608	185	2500	10.51	

Porosity test result

The average porosity of the brick samples ranged from 26.33 % to 50.25 % with the unfired bricks having the highest average porosity value (50.25 %) which indicates that the bricks are fragile, lack strength and may not be durable. This average porosity values fall within the acceptable level for medium and high heat duty fire. The bricks fired had reduced average porosity values as the brick firing temperature increased (Table 7). The bricks fired at 950 °C had the least porosity values showing that they are likely to exhibit better wear resistance ability, high-temperature stability and lower creep rate. There was a correlation between the bricks average porosity values and their average water absorption percentages [20].

Table 7: Summary of Porosity Test of the Rukubi brick block samples at various firing temperatures

S/N	Sample	Firing Temp. (°C)	Porosity	Average Porosity
1.	A_1	-	49.5	
2.	A_2	-	47.9	50.25
3.	A_3	-	52.6	
4.	B_1	750 °C	31.9	
5.	B_2	750 °C	34.5	34.97
6.	B_3	750 °C	38.5	
7.	C_1	850 °C	30.0	
8.	C_2	850 °C	29.2	28.53
9.	C_3	850 °C	26.4	
10	D_1	950°C	26.1	
11.	D_2	950 °C	26.8	26.33
12.	D_3	950 °C	26.1	

Abrasion Resistance test result

. Results obtained are as presented in Table 8 and shows that the average percentage durability increases as the firing temperature of the clay bricks increases. The durability percentage was 42.25 % for the unfired bricks (sample A) but 52.33 %, 52.98 % and 54.15 % for brick samples B, C, and D fired at 750 °C, 850 °C and

950 °C respectively. These abrasive resistance values are higher than those reported by Olawuyi *et al* for Makurdi burnt bricks [3] which were in the range 9.32 % - 33.67 %. Clay bricks fired at 950 °C have the highest ability to withstand effects of abrasion and therefore have the highest abrasion resistance value which corroborates the porosity test results.

Table 8: Results of Abrasive Resistance Test on the Produced Rukubi Burnt Bricks

Sample No.	Initial weight of specimen W_1(g)	Weight after 100 revolutions W_3(g)	% Durability $100 - \frac{(W_1 - W_3)}{W_1} \times 100$	Average % Durability
A_1	3520.0	1439.68	40.90	
A_2	3580.0	1535.82	42.90	42.25
A_3	3465.0	1488.22	42.95	
B_1	3320.0	1852.60	55.80	
B_2	3280.0	1531.76	46.70	52.33
B_3	3461.0	1886.25	54.50	
C_1	3350.0	1574.50	47.00	
C_2	3520.0	1793.44	50.95	52.98
C_3	3150.0	1921.50	61.00	
D_1	3350.0	1876.00	56.00	
D_2	3320.0	1694.94	50.45	54.15
D_3	3150.0	1764.00	56.00	

IV. Conclusion

This study was carried out to ascertain the suitability of Rukubi mixed clay soil for brick moulding and to know if the bricks moulded from this mixed clay soil are suitable for the construction of houses and other structures. The Rukubi mixed clay sample was found to be made up of a higher percentage of Alumina than iron and from results of its grain size analysis can be classified as Alumina clay and therefore considered a good brick making earth. The mixed clay sample with an average moisture content of 36.04 % and an optimum compaction moisture content of 33.5 % had an average Plastic limit of 17.6 %, and Atterberg liquid limit of 34.3 %.

Bricks made from Rukubi mixed clay soil had compressive strength values which increased with firing temperature and ranged from 3.86 Nmm^{-2} to 8.56 Nmm^{-2} These values are higher than 2.8 Nmm^{-2} recommended for load bearing walls. The unfired bricks had an average porosity of 50.25 % and melted completely when immersed in water therefore the unfired bricks are fragile, not likely to be durable and therefore unsuitable for building any structure. Conversely, the bricks fired at 950 °C had the least porosity of 26.33 % indicating that they are likely to exhibit better wear resistance, a high temperature stability and lower creep rate.

The average water absorption ability of the Rukubi bricks fall within the acceptable 20 % maximum cold-water absorption range and there is a correlation between the bricks average porosity and average water absorption values. Furthermore the abrasion resistance was in the range 42.25 % to 54,15 % with the bricks fired at 950 °C exhibiting the highest ability to withstand effects of abrasion. This abrasion test results corroborates the porosity test results.

Results obtained from this study confirm the suitability of Rukubi mixed clay sample for brick moulding and the suitability of the bricks for constructing houses and walls. Prospective property developers are therefore encouraged to explore the option of building their next structures with fired Rukubi bricks.

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