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CHARACTERISATION AND PERFORMANCE EVALUATION OF WATER WORKS SLUDGE AS BRICKS MATERIAL

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ABSTRACT

Sludge collected from Lower Usuma Dam Water Treatment Plant (LUDWTP), Abuja, Nigeria was investigated for use as brick material. The reuse of sludge as brick material is a long-term approach to sludge disposal for economic and environmental sustainability. Characterisation and laboratory trials demonstrated that LUDWTP sludge could be used as a colorant and clay supplement in brick making. Five different mixing ratios of sludge at 0, 5, 10, 15 and 20 per cent of the total weight of sludge-clay mixtures were studied. Each batch of hand-mould produced green bricks was fired in a heat controlled furnace at elevated temperatures of 850^oC, 900^oC, 950^oC, 1000^oC, and 1050^oC respectively. The physical, mechanical and chemical properties of the produced sludge-clay burnt bricks (SCBB) were determined and evaluated according to Nigerian Standard Specifications (NIS 74:1976) and British Standard specifications (BS 3921: 1985) while various Indian Standard Code of Specification for burnt clay bricks were used for the performance evaluation as engineering materials. The results showed that LUDWTP sludge can be used to produce good quality brick for various engineering applications in construction and building. Also, the results of tests indicated that the firing temperature and the sludge proportion were the two key factors that determine the quality of bricks. Increasing the sludge content results in decreased compressive strength, decreased density and increased water absorption. The result also showed that increasing the sludge content improved workability and physical appearance (colour) of sludge –clay burnt bricks. Toxicity Characteristic Leaching Procedure (TCLP) tests of the sludge-brick showed that the metal leaching level is within the acceptable limits of Nigerian Environmental Standards and Regulations Enforcement Agency (NESREA) and US Environmental protection Agency (USEPA) limits.

Keywords: *Characterisation; performance; water works sludge; evaluation; building material.*

1. INTRODUCTION

Potable water treatment facilities remove impurities from raw water sources using various water treatment chemicals. The by-product from the purification process is called water treatment sludge. The composition and properties of water treatment sludge depends on the quality of raw water and the type of treatment chemical used in the treatment processes. Water treatment plants produce large quantities of sludge as a result of treatment processes of raw water such as coagulation, flocculation and filtration. Ultimate disposal of this sludge include land application, disposal in a sanitary sewer, disposal in surface waters and deep well injection of brine (Syed, 2000).

The handling and disposal of sludge is one of the most significant challenges in water works management. In many countries, sludge is a serious problem due to its high treatment costs and the risks to environment and human health. The sludge presents increasingly difficult problem to cities of all sizes because of the scarcity of suitable disposal sites, increasing labor costs, and environmental concerns. Some researchers have linked aluminium's contributory influence to occurrence of Alzheimer's, children mental retardation, and the common effects of heavy metals accumulation (Mohammed et al, 2008). Presently in Nigeria, most water works dispose sludge by returning it to water course or stock- pile in or around the treatment plants without further treatment which is against the local and International good practices for environmental sustainability.

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Brick manufacturing is a historic industry and the production process is well established.

Brickworks commonly operate in close proximity to clay quarries, owned by the same company to satisfy their needs for raw materials. The market for bricks has been presented with significant changes with the introduction of concrete blocks as the latter replaced "common" bricks in construction. This resulted in a shift of the market towards producing facing bricks, used for aesthetic purposes. The use of 'facing bricks', accounts for over 90% of demand and the production of facing bricks appears quite stable for the last seven years (Dunster and Petavratzi (2007) . Alternative materials are considered for use by brick manufacture as a potential cost effective solution to access materials with desirable compounds/ properties that will satisfy the demand for large portfolios of products with different aesthetic properties.

The use of water treatment plant sludge in various industrial and commercial manufacturing processes has been reported in UK, USA, Taiwan and other parts of the world. Successful pilot and full-scale trials have been undertaken in brick manufacture. The mineralogical composition of the water treatment sludge is close to that of clay (Anyakora et al, 2012). This fact encourages the use of water treatment sludge in brick manufacture. Several trials have been reported in this purpose. (Godbold et al, (2003);Dunster and Petavratzi (2007) as contained in Terranova (2007); Chihpin et al, (2001) ;Monteiro et al,(2008);Mohammed et al, (2008) ;Oliveira et al (2008)

Bricks, one of the oldest building material continues to be the most popular and leading construction material because of being cheap, their attractive appearances and superior properties such as high compressive strength and durability, excellent fire and weather resistance, good thermal and sound insulation, easy to handle and work with(Duggal, 2012).
Utilization of sludge as an addition to construction and building material including building bricks, light weight artificial aggregates and cement like materials is a formidable strategy for economic and environmental sustainability. The use of water works sludge is becoming increasingly important because of their chemical composition. However, not much has been carried out to characterize this class of materials with a view to exploring their potentials as engineering materials in Nigeria.

The purpose of this work therefore is not to prove that water treatment plant sludge could find application in building and construction industry, but to investigate the properties and performance of water treatment plant sludge from a specific source i.e. Lower Usuma Dam Water Treatment Plant, Abuja, Nigeria, as clay supplement or colorant in facing bricks used in the building and construction industries.

2. MATERIALS AND METHODS

2.1. Materials

The sludge used in this study was the coagulant sludge collected from the clarifier of the Lower Usuma Dam Water Treatment Plant , Abuja, Nigeria. The sludge was dewatered by gravity thickening method and subsequently air-dried on a drying bed to achieve a moisture content of about 20 % (Anyakora et al, 2012). The dried sludge was used in brick making without further treatment.

The clay used in this study was commercial local clay obtained from Samaru village in Zaria, Kaduna state in Nigeria. The clay sample used was air - dried for seven days in a cool, dry place. After drying, grinding was carried out using a punner and hammer to break the lumps present in the soil.

Sieving of both samples was done according to AASHTO (1996) method using a wire mesh screen with aperture of about 4.76mm in diameter. Fine materials passing through the sieve were collected for use while those retained were poured away.

The oxide contents of the sludge and clay samples were determined using x-ray fluorescence machine. Particle size distribution optimum moisture content and Atterberg limits of the clay sample were determined in accordance with BS 1377 (1990). Subsequently, the mixtures with various proportions of sludge and claye were prepared in batches.

2.2 Preparation and testing of the brick samples

Batching method by weight was employed in mixing the bricks component to produce Laboratory-scale brick with nominal dimensions of (70mm × 70mm × 70mm). Several mixing and preparation techniques were attempted. The best sample preparation technique that gave the required physical and mechanical properties was adopted in the manufacturing method. To investigate the different effects of recycled sludge on the properties of clay sludge bricks, five groups of mixtures were randomly prepared. The percentages of sludge used as supplement for clay were 0%, 5%, 15%, and 20% by weight of the natural clay aggregate to produce the following mix: 0:100; 1:19; 1:10; 3:20 and 1:5. A total of 125 bricks were produced.

The mixing was done on an impermeable surface made free from all harmful materials by sweeping and brushing. The measured sample of brick material was spread using a shovel to a reasonably large surface area until a

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homogeneous mix with uniform colour was obtained. Sludge was then spread evenly on the material and the composite material thoroughly mixed with the shovel.

The dry mixture was spread again to receive water which was added gradually while mixing, until the optimum moisture content of the mixture was attained. Sufficient kneading was done mechanically to de-aerate the mixture and to reduce voids.

Hand-moulding method was used in brick moulding. The wooden mould size used for bricks casting was 70mm x 70mm x 70mm. The interior of the mould were lubricated with water to enhance easy removal of the moulded bricks and also to give the brick a smooth surface. After mould lubrication, the moist mixture was placed in each mould and then compacted with hand. The excess mixture was scraped off and the surface levelled using a straight edge iron. Five sludge-clay bricks series were made from each part of brick mixture with a Sample containing only clay mixture prepared as reference specimen. The mixture was covered with polyethylene bags for 7 days and later subjected to natural air drying in the laboratory for another 7 days at an average temperature of 23^{o}C and 76% relative humidity in the month of September 2012(raining season). Each of the five green brick series, were then fired at five different firing temperatures of 850^{o}C, 900^{o}C, 950^{o}C, 1000^{o}C and 1050^{o}C for 6 hours giving 25 different brick types. The heating rate of the furnace was 200°C/h from room temperature rise up to 600^{o}C afterwards the temperature was increased to the maximum experimental desired temperature and kept at this temperature for 3 hours. The low heating rate from room temperature to 600^{o}C is necessary in order to avoid cracks due to the alpha-beta quartz phase transition at 575^{o}C (Toledo *et al*, 2004). The fired bricks were slowly cooled in the furnace closed overnight. Finally, compressive strength, water absorption, density, shrinkage and weight loss on ignition were determined in accordance to NIS 74:1976 and (CNS, 1999).The test of toxicity characteristic leaching procedure was performed to investigate the leach ability of heavy metals using USEPA (1988) method. Also, various Indian Standard Code of Specification for burnt clay bricks were used for the performance evaluation as engineering materials.

3. RESULT AND DISCUSSIONS

3.1 **Characteristics of sludge and clay**

Table 1 shows the characteristics of LUDWTP sludge and clay while Figure 1 shows the particle size distribution of LUDWTP sludge and clay. From Table 1, it is obvious that the major chemical compositions of the sludge were silicon, aluminium, and iron oxides, which are similar to the major chemical compositions of the brick clay, but with higher alumina content. Also, from Table 1 and Fig .1, the sludge and clay can be classified as fine clayed sand and clayed soil respectively according to ASSHTO classifications.

As shown in plate I to V, the colour of the natural dried sludge changed from dark brown to reddish brown when thermally processed at high temperatures (700^{o}C to 1000^{o}C).This could be attributed to the presence of iron oxide giving it a distinct rust hue. This property is often desired in the colouration of brick products (Dunster and Petavratzi, 2007).

The results are in agreement with the Scanning Electron Microscope (SEM) image (Anyakora et al, 2012) which revealed that the microstructure of sludge comprised of flakes of fine kaolinite clay particles .The high content of alumina in the LUDWTP sludge was noted to be due to the presence of aluminium hydroxide (Alum) used as the coagulant. Also, according to Anyakora et al (2012), the X-ray diffractometer (XRD) result showed the presence of some minerals like kaolinite, quartz, and iron oxide matrices as identified by their prominent Peaks.

Table 1: Characteristics of LUDWTP sludge and clay

Property	Sludge	Clay
pH	6.3	7.76
Moisture content (%)	19.97	13.33
Condition of sample	Air dry	Air dry
Colour	Brown	Cream
Liquid limit (%)	_	35
Plastic limit (%)	Non-plastic	19.3
Plasticity index (%)	_	15.7
Percentage passing BS Sieve NO 200 (%)	32.06	88.1
Al_20_3	28.029	16.44

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SiO_2	29.6	60.75
K_2O	0.84	3.32
CaO	1.48	1.76
TiO_2	0.85	1.89
MnO	2.96	0.1
Fe_2O_3	8.05	3.64
CuO	0.044	ND
ZnO	0.078	ND
MgO	0.38	2.32
LOI	22.6	8.7

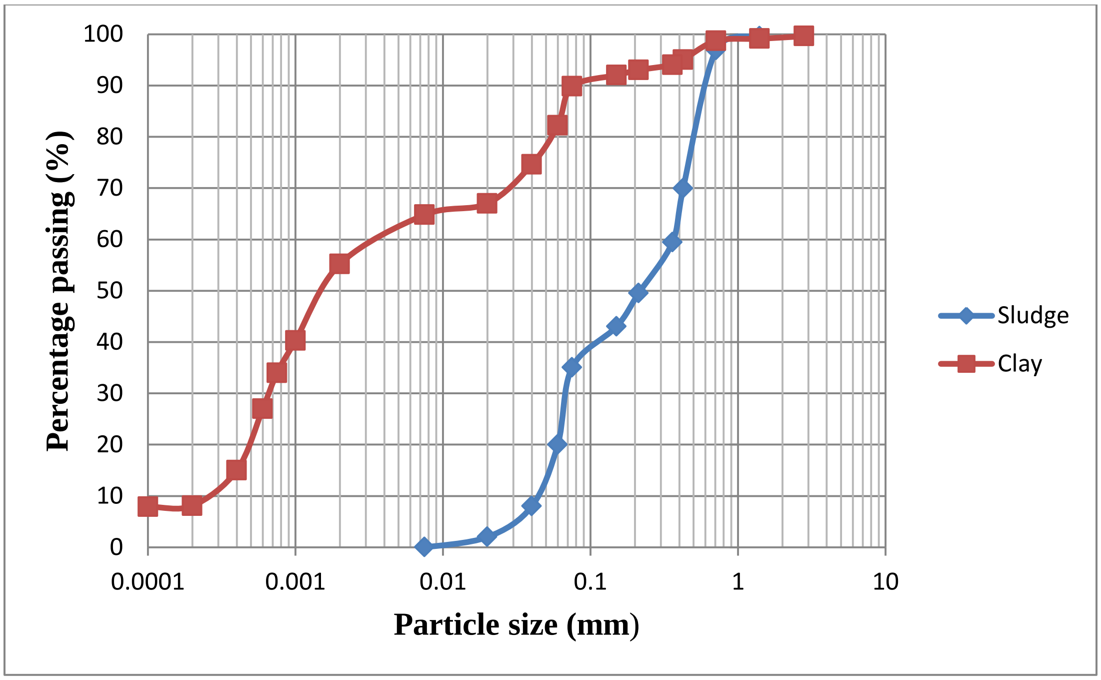

Fig. 1: Particle Size Distribution of LUDWTP sludge and clay

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Plate I: The Natural Dried Sludge

Plate II: Processed Sludge at 700^{0}C

Plate III: Processed Sludge at 800^{0}C

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Plate IV: Processed Sludge at 900^{o}C

Plate V: Processed Sludge at 1000^{0}C.

3.2 Sample Preparation:

The dry weights of raw materials and the batching proportions required to produce one lab-scale brick with nominal dimensions of (70mm × 70mm × 70mm) are shown in Table (2).Also, table 2 shows the effect of sludge proportion on the plasticity index of different batching proportions of the raw materials. The optimum moisture content (OMC) of a mixture was based on the moisture requirement in which maximum bonding among the mixture particles is retained. From table 2, it can be seen that the optimum moisture content increased as the quantity of sludge increases. The test results show that the OMC is 22% for only clay mixture. Increasing the sludge proportions in the mixture resulted in an increase of OMC. The results of Atterberg's tests of sludge–clay mixtures indicate that the value of plastic limit is inversely proportional to the amount of sludge in the brick. The plastic limit values shown in Table 3 indicate that up to 20% of sludge can be applied into brick without losing its plastic behaviour.

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Table 2: Effect of sludge proportion on the plasticity index of different batching proportions of the raw materials

Specimen	SCBB1	SCBB2	SCBB3	SCBB4	SCBB5
Sludge proportion (% by weight)	0	5	10	15	20
Clay proportion (% by weight)	100	95	90	85	80
Optimum moisture content (%)	24	24	26	28	30
Liquid limit (%)	35	35.4	36	37	38
Plastic limit (%)	19.3	20	22	24	26
Plasticity index	15.7	15.4	14	13	12

3.3 **Compressive strength of sludge-clay burnt bricks**

Figure 2 shows the result of the compressive strength of sludge-clay burnt bricks. Compressive strength determines the applicability potentials of the bricks, which is usually affected by the porosity, pore size, and type of crystallization. The results in Fig. 2 indicate that the strength is greatly dependent on the amount of sludge in the brick and the firing temperature. The values ranged between 0.97N/mm^2 and 12.98 N/mm^2. With addition of 10% and 20% sludge to clay, the sludge-clay brick strength achieved at 900^{o}C and 1000^o C respectively met minimum requirement of 2.5N/mm2 (NIS: 74, 1976) as building bricks. Also, with addition of 10% and 20% sludge to clay, the sludge-clay brick strength achieved at 900^{o}C and 1050^{o}C respectively met the minimum requirement of the 5 N/mm2 (BS 3921, 1985). Thus, seventeen sludge-clay brick types exhibited compressive strength, which met the requirements of building bricks according to (NIS 74:1976) and (BS 3921, 1985) respectively. The significant effect of firing temperature on compressive strength is attributed to the completion of the crystallization process and effective sintering at high temperatures. On the contrary, the effect of the sludge ratio is attributed to the low silica content in sludge and consequential decrease in the compressive strength by increased sludge ratio.

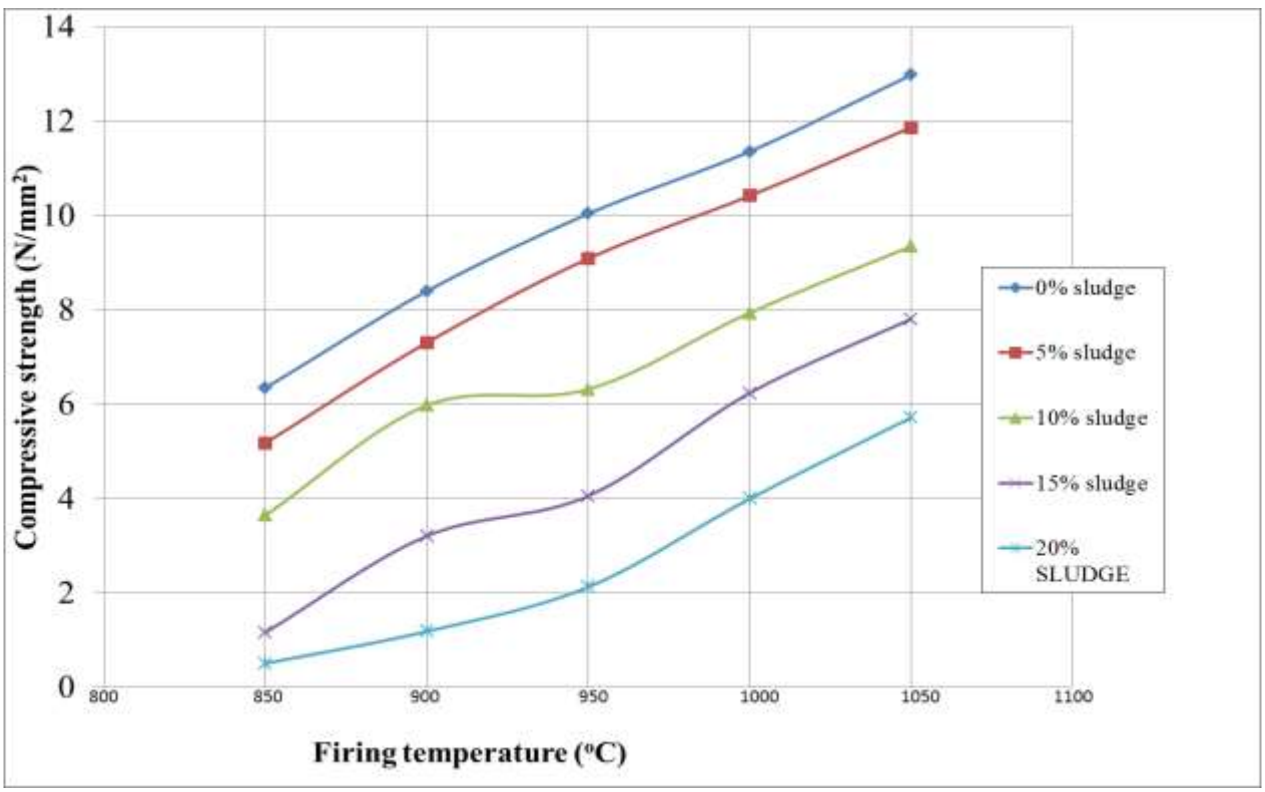

Fig. 2. The compressive strength of sludge-clay burnt bricks.

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3.4 **Water absorption of sludge-clay burnt bricks**

Figure 3 shows the result of the water absorption of sludge-clay burnt bricks. Water absorption is a key factor that affects the durability of bricks, thus the less water infiltrates into brick, and the more durable is the brick. The water absorption test results for different proportions of sludge in the mixture fired at different temperatures as shown in Fig. 3 indicates that the water absorption for the bricks increases with increased sludge content and decreased firing temperature. The results of water absorption test ranged between 14.07 and 31 per cent. With addition of 5% and 20% sludge to clay, the sludge-clay brick water absorption obtained at 1050°C and 950 °C respectively met minimum requirement of 25% (NIS: 74, 1976) as building bricks. Also, with addition of 5% and 15% sludge to clay, the sludge-clay brick water absorption obtained at 900 C and 1050°C respectively met the minimum requirement of the 20% (BS 3921, 1985). Thus, seventeen sludge-clay brick types and ten clay-brick type respectively exhibited water absorption values which met the requirements of building bricks according to (NIS 74:1976) and (BS 3921, 1985) respectively. The effect of firing temperatures on water absorption is attributable to the fact that increasing firing temperature ensures the completion of the crystallization process and closes the open pores in the sinter. While the effect of the sludge ratio is explained by the fact that when the mixture contains a rather higher amount of sludge, the adhesiveness of the mixture decreases, but the internal pore size of the brick increases.

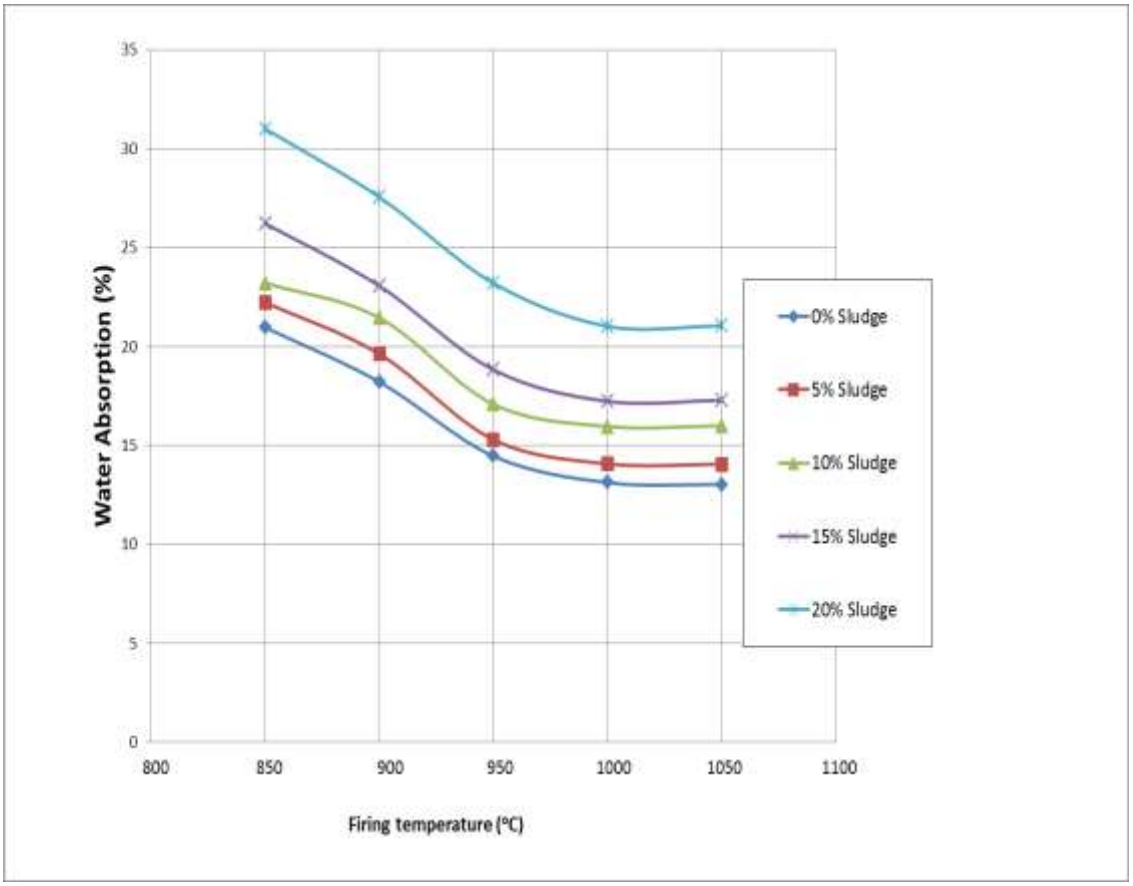

Fig. 3. The water absorption of sludge-clay burnt bricks

3.5 **Density of sludge-clay burnt bricks**

Figure 4 shows the result of the density of sludge-clay burnt bricks**.** The bricks made with clay normally have a bulk density of 1.8–2.0 g/cm^3 (CNS, 1999). The measurements of brick density for different proportions of sludge fired at five different temperatures are demonstrated in Fig. 4. As shown, the density of the bricks is inversely proportional to the quantity of sludge added in the mixture. This finding is closely related to the quantity of water absorbed as demonstrated in Fig. 3. When the mixture absorbs more water, the brick exhibits a larger pore size,

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resulting in a light density. The firing temperature can also affect the density of the bricks. The results show that increasing the temperature results in an increase in brick density, thus SCBB2 fired at temperatures 1000^{o}C and 1050^{o}C respectively met the requirements of (CNS, 1999).

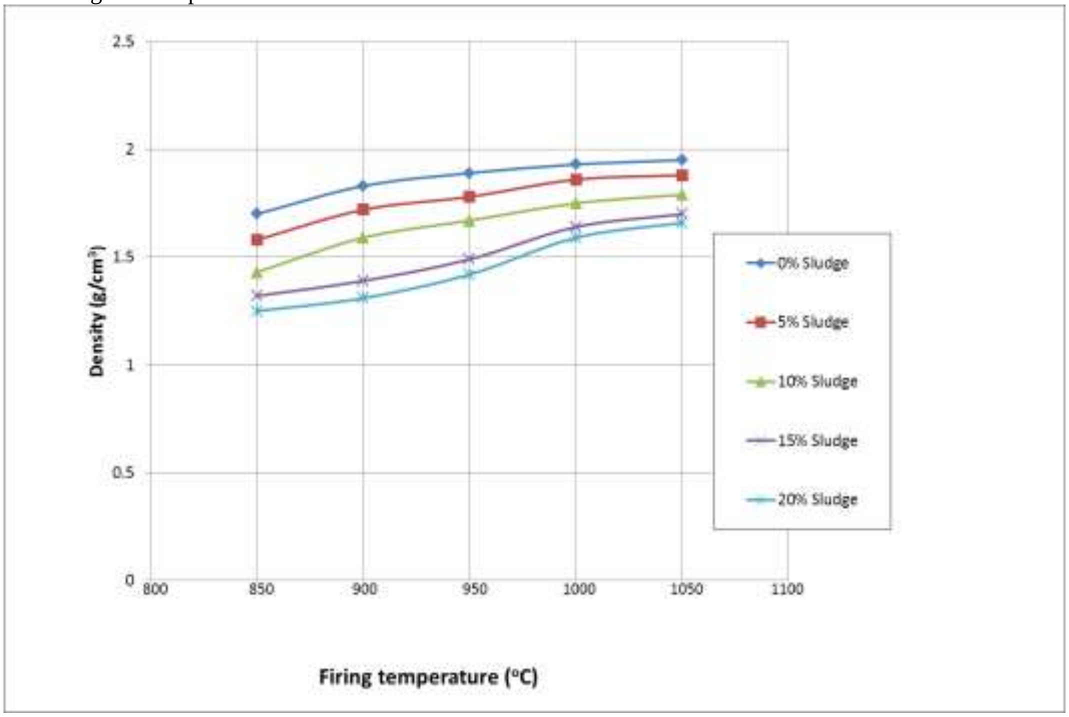

Fig. 4. The density of sludge-clay burnt bricks

3.6 Efflorescence test of sludge-clay burnt bricks

The efflorescence test was performed in accordance with (NIS 74:1976). The result showed that efflorescence was of "Nil" class for all of the clay brick types, which comply with the requirements of the (NIS 74:1976) and (BS 3921:1985)This result could be considered as an indicator for the very low values of soluble salts content of the brick.

3.7 TCLP test of sludge-clay burnt bricks

Table 3 shows the result of TCLP test of the sludge-clay burnt bricks. The test of toxicity characteristic leaching procedure was performed to investigate the leachability of heavy metals using USEPA (1988) method. It is evident from the result that, aluminium, chromium and zinc leached from both the sludge brick and brick containing 20% sludge. The concentrations are much less than those of the Nigerian-USEPA regulated TCLP limits. Other leached metals from either dried sludge or bricks are of insignificant concern since there were no limits for them as at the time of this report. Thus the leachability potentials of heavy metals are below the acceptable environmental limits.

Table 3: TCLP test results of sludge and sludge-clay burnt bricks

Metals (mg/l)	Dried Sludge	CSBB (850^{o}C)	CSBB (900^{o}C)	CSBB (950^{o}C)	CSBB (1000^{o}C)	CSBB (1050^{o}C)	TCLP (NESREA)	TCLP (USEPA)
Cd	0.009	0.003	0.003	0.003	0.003	0.003	1	1
Cr (Total)	0.193	0.049	0.049	0.049	0.049	0.049	5	5
Cu	0	0.047	0.045	0.043	0.043	0.043	NL	NL
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.2	0.2
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	5	5
Zn	0.034	0.12	0.11	0.102	0.102	0.102	NL	NL
Fe	0.844	0.685	0.685	0.685	0.685	0.685	NL	NL

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Mn	2.007	0.045	0.045	0.045	0.045	0.045	NL	NL
Ni	0.062	0.077	0.077	0.077	0.077	0.077	NL	NL
Al	20.649	5.18	5.12	5.015	5.015	5.015	NL	NL

NL= No limit

3.8 Performance evaluation of sludge-clay burnt bricks

SCBB2 fired at 1050°C has a compressive strength of 11.87N/mm2 and water absorption value of 14.07% while SCBB4 fired at 950°C has a compressive strength of 4.06N/mm2 and water absorption value of 18.82% respectively. Thus, they can be used in making burnt clay soling bricks (IS: 5779) used for soling of roads (Duggal,2012).

SCBB2 fired at 900°C, SCBB3 and SCBB4 fired between 950°C and 1050° C respectively can be used in making burnt clay hollow blocks(IS:3952) used to reduce the dead weight of the masonry, used for exterior as well as partitioning walls. They also reduce the transmission of heat, sound, and dampness in buildings (Duggal, 2012).

SCBB2 fired at 1000°C and 1050°C can be used in making burnt clay jallis (IS: 7556) used for providing a screen on veranda and construction of parapet or boundary walls. (Duggal,2012).

4. CONCLUSIONS

The results of this work has demonstrated that sludge clay burnt bricks can be successfully produced using water treatment plant sludge as supplement for clay under the conditions of firing temperatures, and manufacturing methods used in this study. The proportion of sludge in the mixture and the firing temperature are the two key factors affecting the quality of brick. Thus, LUDWTP sludge can be used to produce good quality brick for various engineering applications in construction and building within the acceptable Nigerian(NIS 74:1976) and international (BS 3921, 1985) standards .The leach ability potentials of heavy metals from bricks is below the acceptable Nigerian –US environmental protection limits. This study showed that water treatment plant sludge could be used as brick material for improved workability and physical appearance for economic and environmental sustainability.

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