Exploring the Utilisation Potentials of Water Works Sludge as Laterite Brick Material

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Abstract

Sludge collected from a water treatment plant was investigated for use as suppliment for laterite in brick making. Five different mixing ratios of sludge at 0, 5, 10,15 and 20 percent of the total weight of sludge-laterite mixtures were studied. Each batch of hand-mould produced green bricks was fired in a heat controlled furnace at elevated temperatures of 850^{o}C, 900^{o}C, 950^{o}C, 1000^{o}C, and 1050^{o}C respectively. The physical, mechanical and chemical properties of the produced sludge-laterite burnt bricks (SLBB) were evaluated according to Nigerian Standard Specifications (NIS 74:1976) while various Indian Standard Code of Specification for burnt clay bricks were used to determine its applicability as building material. Results of tests indicated that the two key factors in the production of quality sludge-laterite brick were the firing temperature and the sludge proportion. Increasing the sludge content resulted in increased water absorption and decrease in compressive strength and density respectively, while increasing firing temperature caused a decrease in water absorption and increase in compressive strength and density of the sludge-laterite brick respectively. Similarly, increased sludge content and increased firing temperature increased the shrinkage and weight loss on ignition parameters of the sludge-laterite brick, but caused a corresponding decrease in water absorption. Additionally, the results showed that bricks of 10% sludge content fired at between 900^{o}C and 1000^{o}C met the compressive strength requirements of the Nigerian Industrial Standards. 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 USEPA. This information becomes very necessary to explicate the appropriate method, material proportion and firing temperature for making sludge- laterite burnt bricks, thus determining their suitability for use as construction materials for building houses and other similar engineering applications.

Keywords: Water works sludge, laterite, compressive strength, utilisation, brick, metal leaching.

1. Introduction

Potable water is a limited resource and its demand increases with urbanisation growth. Modern methods and technology are required for effective service delivery in the water industry. Sludge is an inevitable by-product in the production of potable water. 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 aluminums' contributory influence to occurrence of Alzheimer, children mental retardation, and the common effects of heavy metals accumulation [1] 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.

Large quantities of sludge are generated each year from water treatment plants in Nigeria. The common practice by most water treatment plants is disposal of sludge to the nearest watercourse around the treatment plant. This practice has been linked to adverse health and environmental effects that necessitated stringent environmental laws and regulations on sludge disposal [2], thus proper management of sludge becomes inevitable. The use of water works sludge is becoming increasingly important because of their chemical composition. Studies show that the reuse of water treatment sludge in various industrial and commercial manufacturing processes have been practiced in UK, USA, Taiwan, Egypt and other parts of the world [1]. Successful pilot and full-scale trials have been undertaken in clay brick manufacture,but literature is scarce on the use of sludge in the production of laterite bricks.

Water works sludge is a sustainable resource as long as the production of potable water remains a sustainable basic amenity. However, not much has been carried out to utilise sludge as building material in Nigeria. The mineralogical composition of sludge from water treatment plant is close to that of clay and laterite [3]. This fact encourages the use of water treatment sludge in laterite brick manufacture. Also, as the cost of laterite soil is cheaper than clay soil, it is expected that the cost of laterite bricks will be cheaper than clay bricks. This will create an opportunity for affordable housing in line with the Millenum Developement Goals (MDGs) for economic and environmental sustainability.

Laterite bricks nevertheless, have been the subject of new investigations in recent times. Laterite is the traditional building raw material available in most parts of tropical areas. The difference between laterite and clay lies mainly in the particle size. Laterite bricks fired at high temperature, present acceptable compressive strength, low density and are also resistant to erosion [4]. These properties make the study of brick attractive as structural material that can be used more effectively and economically in the design and construction of buildings.There are several research on the use of other wastes as admixture in producing laterite burnt bricks [4] but the lack of data on the engineering properties of sludge-laterite burnt bricks makes it difficult to predict its applicability as building material for safe structural design.

This work is aimed at studying the re-useability potentials of sludge from water treatment plant in the production of laboratory scale laterite burnt bricks. The suitable conditions of using dried sludge in producing hand mould laterite bricks under the criteria of Nigerian Industrial Standards (NIS) were investigated. The influence of sludge proportion in the raw materials, the temperature in relation to the brick qualities, and metal leachability were also examined.

2. Materials and methods

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 % [3]. The dried sludge was used in brick making without further treatment.

The laterite used in this study was commercial local laterite obtained from *Biye* village in Zaria, Kaduna State, Nigeria. The laterite 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 using a wire mesh screen with aperture of about 4.76mm in diameter. Fine materials passing through the sieve were collected for use.

The oxide contents of the sludge and laterite samples were determined using x-ray fluorescence machine. Particle size distribution, optimum moisture content and Atterberg limits of the laterite sample were determined in accordance with British Standards Institute [5]. Subsequently, the mixtures with various proportions of sludge and laterite were prepared in batches.

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 laterite sludge bricks, five groups of mixtures were randomly prepared. The percentages of sludge used as suppliment for laterite were 0%, 5%, 15%, and 20% by weight of the natural laterite aggregate to produce the following mix: 0:100; 1:19; 1:10; 3:20 and 1:5 representing SLBB1, SLBB2, SLBB3, SLBB4 and SLBB5 respectively. 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 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 was 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-laterite bricks series were made from each part of brick mixture with a sample containing only laterite mixture prepared as reference specimen.

The mixture was then 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 risen up to 600^{o}C. Thereafter, the temperature was increased to the maximum experimental desired temperature and kept at that temperature for 3 hours.

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 [7] and CNS, 1999 [12].The test of toxicity characteristic leaching procedure was performed to investigate the leach ability of heavy metals using USEPA (1988) method [9].

3. Results and discussion

3.1. Characteristics of sludge, laterite and sludge-laterite brick mix

Table 1 shows the characteristics of sludge and laterite while Figure 1 shows the particle size distribution of sludge and laterite. From Table 1, it is obvious that the major chemical compositions of the sludge were silicon, aluminum, and iron oxides, which are similar to the major chemical compositions of the brick laterite, but with higher alumina content. Also, from Table 1 and Figure 1, the sludge and laterite can be classified as fine clayed sand and clayed soil respectively according to ASSHTO classifications [10].

Table 1. Characteristics of sludge and laterite

Property	Sludge	Laterite
pH	6.3	7.44
Natural Moisture content (%)	19.97	9.09
Al_20_3	28.029	22.3
SiO_2	29.6	52.9
K_2O	0.84	2.71
CaO	1.48	0.479
TiO_2	0.85	1.95
MnO	2.96	0.034
Fe_2O_3	8.05	11.05
CuO	0.044	ND
ZnO	0.078	ND
L.O.I	22.6	6.21
ASSHTO/HRB classification	A-3	A-7-6
Significant constituent material	Fine clayed sand	Clayed soil
Condition of sample	Air dried	Air dried
Colour	Brownish red	Reddish brown
Liquid limit (%)	-	43.5
Plastic limit (%)	Non plastic	22.3
Plasticity index (%)	-	21.2

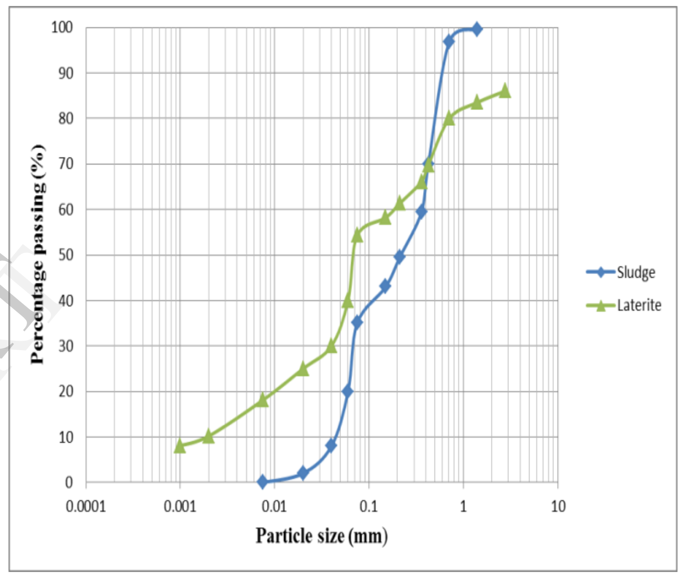

Figure 1. Particle size distribution of sludge and laterite

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 laterite mixture. Increasing the sludge proportions in the mixture resulted in an increase of OMC. The results of Atterberg's tests of sludge-laterite 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.

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

Specimen	SLBB1	SLBB2	SLBB3	SLBB4	SLBB5
Sludge proportion (% by weight)	0	5	10	15	20
Laterite proportion (% by weight)	100	95	90	85	80
Optimum moisture content (%)	22	22	24	26	28
Liquid limit (%)	43.5	44	46	48	49.5
Plastic limit (%)	22.3	23.5	26	29	32
Plasticity index	21.2	20.5	20	19	17.5

3.2. Compressive strength of the bricks

Figure 2 shows the result of compressive strength of the bricks. Compressive strength determines the applicability potentials of the bricks. The results in Figure 2 indicate that the strength is greatly dependent on the amount of sludge in the brick and the firing temperature. The values ranged betweeen 0.41N/mm^2 and 3.98N/mm^2. The Standards Organization of Nigeria (SON) stipulates that the dry strength of bricks for building should be a minimum of 2.5N/mm^2 (NIS: 74, 1976) [7]. Also, the British Standards Institute (BS 368, 1976) [8] specifies 2.75 N/mm^2 and 1.38 N/mm^2 respectively as minimum values of crushing strength for bricks to be used in 2-storey buildings and non-load bearing walls. Thus, six sludge-laterite brick types exhibited compressive strength higher than 2.5N/mm^2, which met the requirements of building bricks according to (NIS 74:1976) [7] and (BS 368,1976) [8].

Sludge-laterite bricks with strength values of 1.2N/mm^2 to 2.49 N/mm^2 could be used for non-load bearing applications in producing jallis bricks used for providing screen on veranda and construction of parapets or boundary walls (IS:7556)[11]. The significant effect of firing temperature on compressive strength is attributed to the completion of the crystallization process and effective sintering at high temperatures. The results from this work showed that compressive strength increased with increased temperature as expected. On the contrary, the effect of the sludge ratio is attributed to the low silica content in sludge and consequent decrease in the compressive strength by increased sludge ratio.

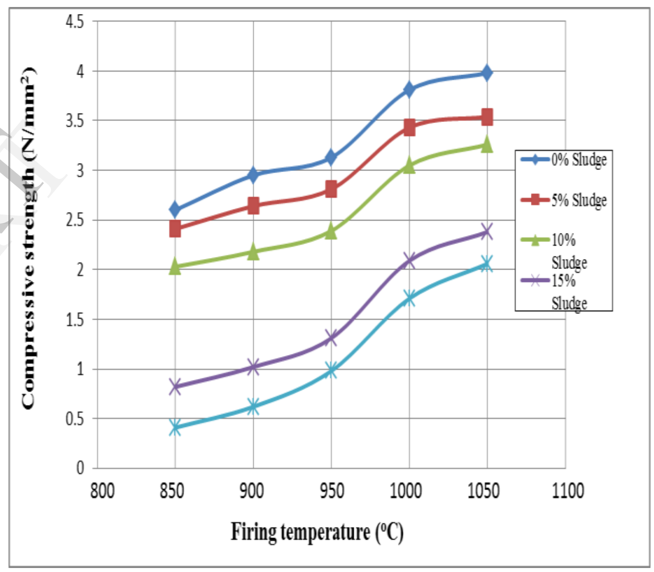

Figure 2. The compressive strength of bricks

3.3. Water absorption of bricks

Figure 3 shows the result of the water absorption of bricks. Water absorption is a key factor that affects the durability of bricks, thus the less water infiltration to brick, the more durable is the brick. The water absorption test results for different proportions of sludge in the mixture fired at different temperatures shown in Figure 3 indicates that the water absorption for the bricks increased with increase in sludge content but decreased with firing temperature. The results of water absorption test ranged between 25% and 31.09%.There were five brick types that exhibited water absorption less than 25%, which met the requirements (NIS 74:1976) [7]. 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.

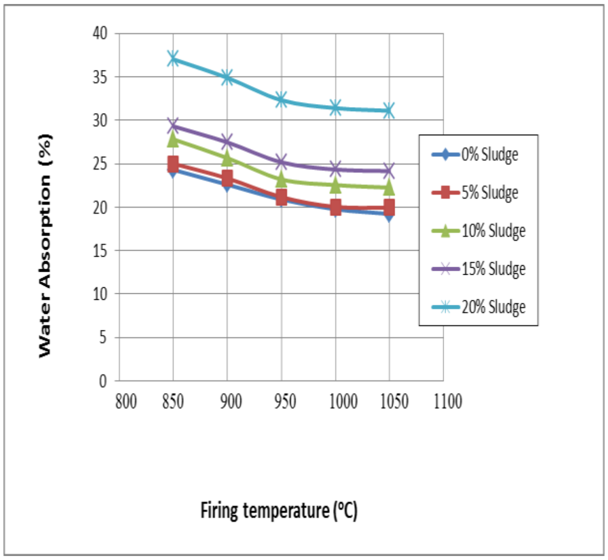

Figure 3. The water absorption of bricks

3.4. Density of brick

Figure 4 shows the result of the density of brick**.** The bricks made with clay normally have a bulk density of 1.8–2.0 g/cm (CNS,1999) [12]. The measurement of brick density for different proportions of sludge fired at four temperatures are demonstrated in Figure 4. The results indicate that the density of brick is inversely proportional to the quantity of sludge added to the mixture. This finding is closely related to the quantity of water absorbed as demonstrated in Figure 3. When the mixture absorbs more water, the brick exhibits a larger pore size, resulting in a light density. The firing temperature can also affect the density of the brick. The results show that increasing the temperature results in an increase in brick density.

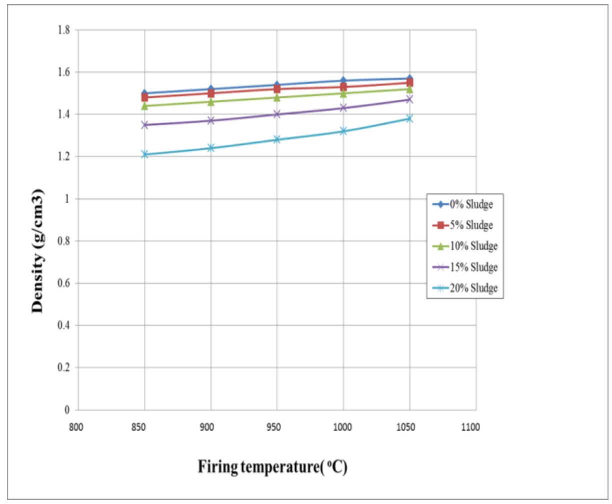

Figure 4. The density of bricks

3.5. Brick shrinkage

The result of brick shrinkage is shown in Figure 5**.** The quality of brick can be further assured according to the degree of shrinkage. Normally, a good quality of brick exhibits a shrinkage below 8%. (CNS, 1999) [12]. As shown in Figure 5, the percentage of shrinkage increases with increasing sludge content, though in this case it is non significant. As the swellability and the organic content of the sludge are much higher than those of laterite, the addition of sludge in the mixture is expected to enlarge the degree of shrinkage. As a result, the quality of a brick is downgraded. The firing temperature is another important parameter affecting the degree of shrinkage. In general, increasing the temperature results in an increase of shrinkage as shown in Figure 5, thus, the proportion of sludge in the mixture and the firing temperature are the two key factors to be controlled to minimize the shrinkage in the firing process. The bricks produced did not show any deformation on uneven surfaces occurring at all firing temperatures. This may be attributed to the gradual heating maintained from room temperature to 600^{o}C necessary to avoid cracks arising from the alpha-beta quartz phase transition at 575^{o}C [6].

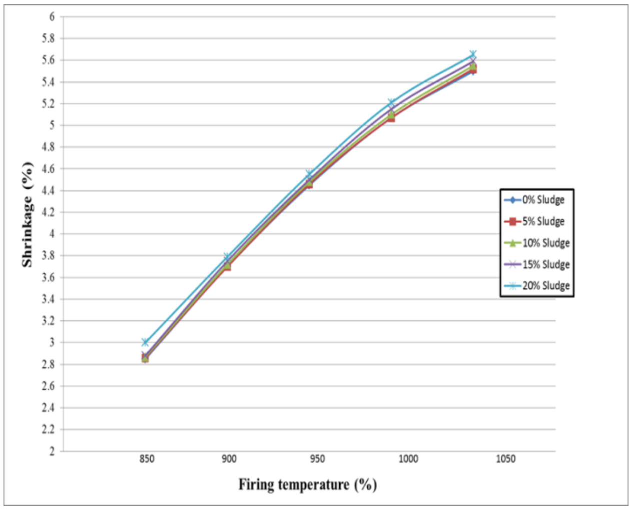

Figure 5. The shrinkage of brick

3.6. Brick weight loss on ignition

Figure 6 shows the result of weight loss on ignition of brick which indicates that increasing the sludge proportion and temperature resulted in increase in brick weight loss on ignition. As can be seen in Fig 6, the weight loss on ignition between 0% and 5% sludge addition is non-significant as compared to other sludge laterite mixing ratios. The weight loss criterion for a normal clay brick is 15% (CNS, 1999) [12]. With less than 10% sludge addition, all the produced bricks met the criteria. However, upon the addition of sludge in the mixture, the loss of weight apparently increased as aresult of organic matter loss from sludge. Furthermore, the brick weight loss on ignition also depends on the inorganic substances in both laterite and sludge being burnt-off during the firing process.

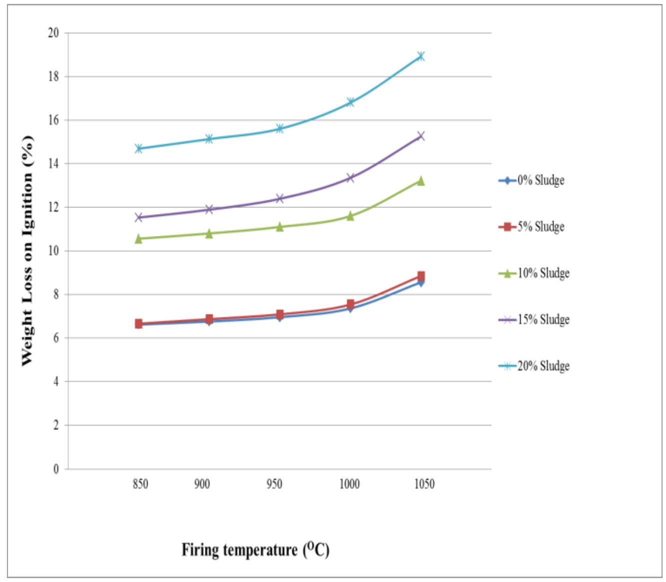

Figure 6. The weight loss on ignition of brick

3.7. Efflorescence test of brick

The efflorescence test was performed in accordance with (NIS 74:1976) [7]. The result showed that efflorescence was of “Nil” class for all of the laterite brick types, which comply with the requirements of the (NIS 74:1976) [7]. This result could be considered as an indicator for the very low values of soluble salts content of the brick.

3.8. TCLP test of brick

Table 3 shows the result of TCLP test of the brick. The test of toxicity characteristic leaching procedure was performed to investigate the leachability of heavy metals using USEPA (1988) [9] method. It is evident from the result that, aluminium, chromium and zinc leached from both the sludge and sludge-laterite brick containing 20% sludge. The concentrations are much less than those of the NESREA and 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 bricks with 20% sludge (SLBB5)

Metals (mg/l)	Dried Sludge	SLBB (850°C)	SLBB (900 °C)	SLBB (950 °C)	SLBB (1000 °C)	SLBB (1050 °C)	TCLP NESREA/ USEPA
Cd	0.009	0.004	0.004	0.004	0.004	0.004	1
Cr (Total)	0.193	0.052	0.052	0.052	0.052	0.052	5
Cu	0	0.045	0.044	0.042	0.042	0.042	NL
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.2
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	5
Zn	0.034	0.13	0.11	0.09	0.09	0.09	NL
Fe	0.844	0.73	0.73	0.73	0.73	0.73	NL
Mn	2.007	0.037	0.037	0.037	0.037	0.037	NL
Ni	0.062	0.075	0.075	0.075	0.075	0.075	NL
Al	20.649	5.34	5.32	5.32	5.32	5.32	NL

NL= No limit

4. Conclusions

The results of this work has demonstrated that sludge-laterite brick can be successfully produced using water treatment plant sludge as suppliment for laterite 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, the proportion of sludge in brick is 10%, with a 24% optimum moisture content, and firing temperature between of 900°C and 1000 °C to produce a good quality brick within Nigerian acceptable building bricks standards (NIS 74:1976) [7] is recommended. The leachability potentials of heavy metals from bricks is below the acceptable Nigerian environmental protection limits. This study showed that water treatment plant sludge could be used as brick material for economic and environmental sustainability.

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