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Effects of Sawdust Ash Activated with Calcium Carbide Waste on Engineering Properties of Igboora Burnt Laterite-Clay Bricks

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Abstract
The need to encourage the use of waste materials as stabilizer in bricks production cannot be overemphasized due to high cost of cement or lime for production of stabilized bricks. This research studied the potential of using wastes like saw dust ash (SDA) with calcium carbide waste (CaC_2) in stabilizing Igboora laterite-clay for burnt bricks production and its subsequent assessment for structural building bricks. Laterite-clay was treated with mixture of SDA at 0%, 4%, 8% and 12%, and CaC_2 at 0%, 2%, 4% and 6% respectively. The compressive strength of the burnt bricks increased from 8.65 N/mm^2 for untreated brick to a maximum value of 10.92 N/mm^2 for 8%SDA+4% CaC_2 treated burnt bricks. Treatment with waste mixtures above this content resulted in decreased strength. The water absorption of 16% for untreated burnt brick increased to a value of 18.9 % for 8%SDA+4% CaC_2 treated burnt brick. Treatment with higher waste mixture additions resulted in increased water absorption up to 19.5% for 12%SDA+6% CaC_2 treated burnt brick. The result of Energy Dispersion X-ray Spectrometer showed the presence of calcium, silicate and aluminate as a cementitious compound in the 8%SDA+4% CaC_2 treated burnt brick. The compressive strength value of 10.92 N/mm^2 is greater than 10.3 N/mm^2 which is the minimum value suitable for structural building bricks in grade negligible weather based on ASTM C62-99. Thus 8%SDA+4% CaC_2 treated burnt brick from Igboora laterite-clay is recommended for structural building bricks in grade negligible weather.

Keywords: Burnt bricks, compressive strength, rice husk ash, saw dust ash, water absorption.

Introduction
The demand for the building structures in Nigeria is increasing as a result of growing population and economy which has facilitated increase in demand of walling materials such as blocks and bricks as they are commonly utilized for walling in building construction. In Nigeria, majority of cities are fast becoming homes to scores of individuals due to influx, rapid-growing population and rapid urbanization, among other factors (Akpan 2019). With this trend, there has been increase in the demand for houses across the country. The housing deficit crisis in Nigeria has worsened in recent times with the statistics showing a deficit of at least 17.0 million (World bank 2018). There has been a steady rise in the housing deficit, from 7.0 million in 1991 to 14 million in 2010. From the report of the World Bank in 2018, Nigeria requires about 700,000 housing units annually, spanning through a 20-year period to accommodate the rising population. This is highly unattainable with current indices, coupled with the sluggish growth of housing sector in Nigeria (Akpan 2019).
The production cost of sandcrete, soil cement or soil lime bricks, which is used for walling in building structures have been high due to rising cost of industrial stabilizers such as cement and

lime (Ogunbiyi *et al*., 2014; Olutoge *et al*., 2018; Kongkajun *et al*., 2020). In attempt to address the need for cheap and environmentally friendly construction in the developing countries, the use of waste materials in production of bricks and other building materials have been encouraged (Olorunnisola, 2019; Ewemoje and Bademosi, 2019; Agboola *et al*., 2021).

Laterite is heterogenous in nature, containing different proportions of fine and coarse content, and the fractions of its particle play important roles on its suitability for the brick production. It has been ascertained that laterite soil having a clay fraction of between 30 to 40% are considered satisfactory for brick production, with the absence of processing defects after drying and firing such as cracks, fracture, deformation and volume change, while those having a clay fraction of more than 80% are considered unsuitable for brick making (Adedokun *et al., 2016*). The raw material for the production of burnt bricks therefore needs to be of appropriate composition especially in the tropics where prevailing conditions favor the formation of laterite soils which are the materials mainly used for making of the bricks.

The use of cementitious or pozzolans materials as admixture in brick making is common to increase the bond between soil particles and thus the strength of the brick (Binici *et al*., 2015). Pozzolans are defined as materials, which though not cementitious in themselves, contain constituents which will combine with alkalis at ordinary temperature in the presence of water to form insoluble compounds possessing cementitious properties (Munoz *et al* 2014). The example of traditional stabilizing material is cement or lime, but because of its expensive cost and depletion of ozone layer as a result of emission of CO_2 to the atmosphere during their production, has recently necessitated the use of non-traditional pozzolans admixture includes sawdust ash, palm kernel shell ash, rice husk ash, wood ash etc. (Eldagal, 2008).

This study determined the effect of combined SDA and CaC_2 on the properties of burnt clay bricks using Igboora laterite-clay. The compressive strength and water absorption of SDA- CaC_2 treated burnt clay bricks were compared with those of untreated burnt clay bricks. The bricks were assessed for suitability of building bricks based on compressive strength and water absorption in accordance with ASTM C62-99 (2000).

Materials and Methods

Materials

The natural laterite-clay soil used for bricks production in this study was collected from a pit about 1m deep at Igboole area of Igboora, Oyo State, Nigeria. It is located in Ibarapa Central Local Government area of Oyo State and lies between coordinate of latitude 7.4368^0 North and longitudes 3.2885^0 East respectively.

The saw dust ash used for making SDA was obtained from Igboole saw mill at Igboora, Oyo State Nigeria and was incinerated into ash at the temperature of 600^oC in a drum. SDA passing through sieve No. 200 with a 0.075 mm aperture was used for the study in accordance with ASTM C311-16 (2016). The calcium carbide (CaC_2) was collected from a panel beater workshop in Ibadan and transported to Igboora for the study. The CaC_2 used was sundried, grinded and sieved through sieve No. 200 with a 0.075 mm aperture.

Methods

To prepare SDA- CaC_2 treated laterite-clay soil, the laterite-clay was mixed with combined SDA and CaC_2 admixture, the SDA at 0%, 4%, 8% and 12% and CaC_2 at 0%, 2%, 4% and 8% each (by weight of soil). Tests such as liquid limit (LL), plastic limit (PL), linear shrinkage (LS) and compaction characteristic test were conducted on untreated and SDA-CaC_2 treated laterite-clay in accordance with ASTM D4318 (2017) and ASTM D698-12 (2021) respectively. The compaction characteristic test was carried out at the energy level of the standard Proctor compaction using a 2.5 kg rammer (ASTM D698-12, 2021). SDA-CaC_2 treated clay were mixed with water at the optimum moisture contents (OMC) from standard Proctor compaction for clay bricks production. Using SDA- CaC_2 treated laterite-clay, bricks were moulded each with size 225 mm x 150 mm x 100 mm in a fabricated wooden mould cavity (Plate 1). The brick size was selected because it is commonly available in the study locality (ASTM C62-99 (2000). The compaction was thoroughly done in accordance with ASTM D698-12 (2021). The moulded brick was extruded by loosening the wooden mould at joints and the brick removed. The bricks were cured at room temperature ($27^oC \pm 2$) for 14 days prior to burning (Plate 2). This was to avoid rapid drying of bricks which likely results in cracks development. Six bricks were moulded from each mix ratio. After curing/drying at room temperature, the bricks were fired in an electric muffle furnace at 800^oC (Plate 3). Although, the electric furnace uses electricity as its source of energy, the temperature of 850^oC was selected because previous studies on bricks produced at this temperature produced the most refractory bricks out of temperatures of 800^oC, 950^oC and 1100^oC (Cultrone et al., 2020).

Plate 1: The wooden moulds used in making bricks

Plate 2: Bricks during curing

Plate 3: Bricks in the furnace during burning

The compressive strength of each brick was done in accordance with the specification of the Nigerian Industrial Standard (NIS 87, 2000) as contained in test for compressive strength using the Universal Testing Machine. Prior to strength testing, the burnt bricks were preconditioned by immersion in cold water at room temperature (27^{o}C ± 2^{o}C) for 24 hours. It was removed and all traces of water wiped off, then stored under moist conditions for 24 hours prior to testing. Each brick specimen was centrally positioned between the platens of the testing machine, and the load was gradually increased until failure (Plate 4).

To determine the durability in water environment, water absorption test was conducted. Five burnt bricks per mix ratio were totally immersed in cold water for 24 hours in accordance with Nigerian Industrial Standard (NIS 87, 2000).

Plate 4: Brick during crushing for compressive strength

Scanning electron microscope analysis

To determine the changes in morphology of the laterite-clay soil particles, polished sections of burnt bricks made of untreated and 8% SDA+4% CaC_2 treated laterite-clay samples were analyzed using scanning electron microscopy (SEM) analysis. The SEM was performed using JOEL-JSM 7600F model. This was fitted with an energy dispersion x-ray spectrometer (EDX). The untreated burnt clay brick was selected to represent the control sample, while the 8% SDA+4% CaC_2 treated burnt clay brick represented the brick with the highest compressive strength. Point elemental analysis was performed on the crystal grains from different zones of the same sample using EDX to determine changes in the chemical composition due to the treatment.

Results and Discussion

Chemical composition

The chemical composition of laterite-clay, SDA and CaC_2 treated are presented in Table 1. The presence of high CaO (55.298 %) in SDA and (39.485 %) in CaC_2 is greater than 20 %. This is an indication of the materials with high reactivity and cementitious properties (Menéndez et al., 2021).

Table 1. Chemical Composition of Laterite-Clay, Sawdust Ash, and Calcium Carbide

Element	Laterite-clay (%)	SDA (%)	CaC_2 (%)
SiO_2	62.416	15.591	35.282
Al_2O_3	17.186	3.750	6.585
Fe_2O_3	11.655	2.035	7.507
CaO	0.972	55.298	39.485
MnO	0.502	0.168	2.284
SO_3	1.330	2.099	0.881
K_2O	1.162	10.387	5.926
Ag_2O	0.000	0.006	0.838

Note: SDA= Sawdust ash, CaC_2 = Calcium carbide waste

Index properties

The index properties of Lateite-clay soil, SDA and CaC_2 are presented in Table 2. The soil is classified as an A-6 based on ASSHTO classification (ASTM, 1992) and CL (low plasticity clay) based on USCS classification (USCS, 1962).

Table 2. Index Properties of Laterite-Clay, Sawdust Ash and Calcium Carbide

Index properties	Values
Percentage passing BS sieve No. 200	45.00
Liquid limit (%)	52.0
Plastic limit (%)	33.0
Plasticity index (%)	19.0
Linear shrinkage (%)	10.71
Specific gravity (G_s) of clay	2.55
Maximum dry density (Mg/m^3)	1.56
Optimum moisture content (OMC) (%)	18.4
G_s of Sawdust ash	2.25
G_s of Calcium carbide	2.20
AASHTO classification	A-7-5
Group index	0
USCS classification	MH-OH

Compaction properties of laterite-clay soil treated with SDA and CAC_2 admixture.

The compaction properties of Laterite-clay treated with different proportions of SDA and CaC_2 admixture is presented in Figs. 1 and 2. From Fig. 1, the OMC increased with increasing contents of SDA- CaC_2 admixture in all cases. The OMC content of 18.4% recorded for untreated laterite-clay increased to 25.1% for 12%SDA+6% CaC_2 treated laterite-clay. However, the maximum dry density (MDD) reduced with increasing SDA-CaC_2 content, as shown in Fig. 2. The MDD value of 1.56 Mg/m^3 for untreated laterite-clay reduced to a value of 1.42 Mg/m^3 for 12% SDA+6% CaC_2 treated laterite-clay. The increase in OMC with increasing SDA-CaC_2 content could be due to additional water needed by the hydration of SDA-CaC_2 admixture. Conversely, the decrease in MDD with increasing SDA-CaC_2 admixture could be due to flocculation and agglomeration of the clay. This in turn occupied larger spaces and led to reduced dry densities which is the ratio of mass versus volume (Vitale et al., 2020).

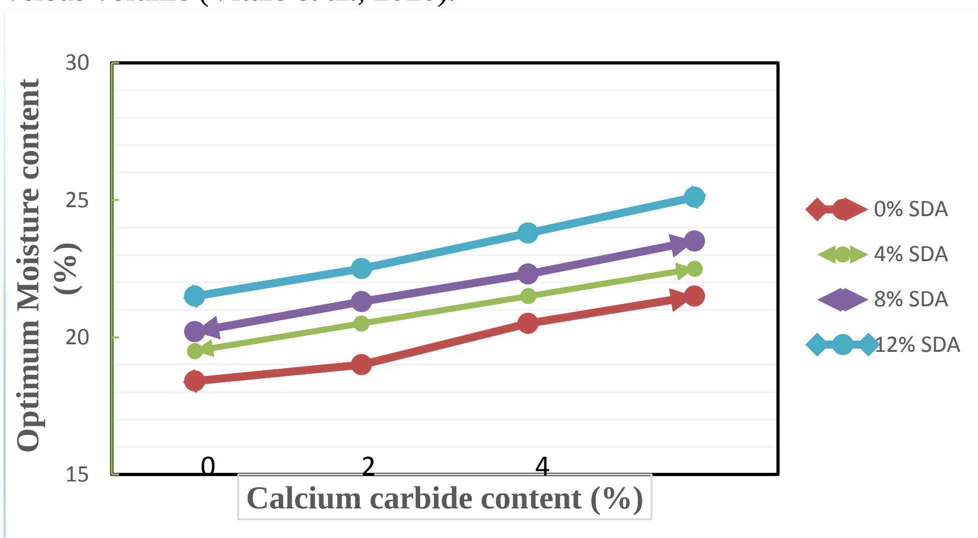


Figure 1: Variation of optimum moisture content with SDA-CaC_2- treated laterite-clay.

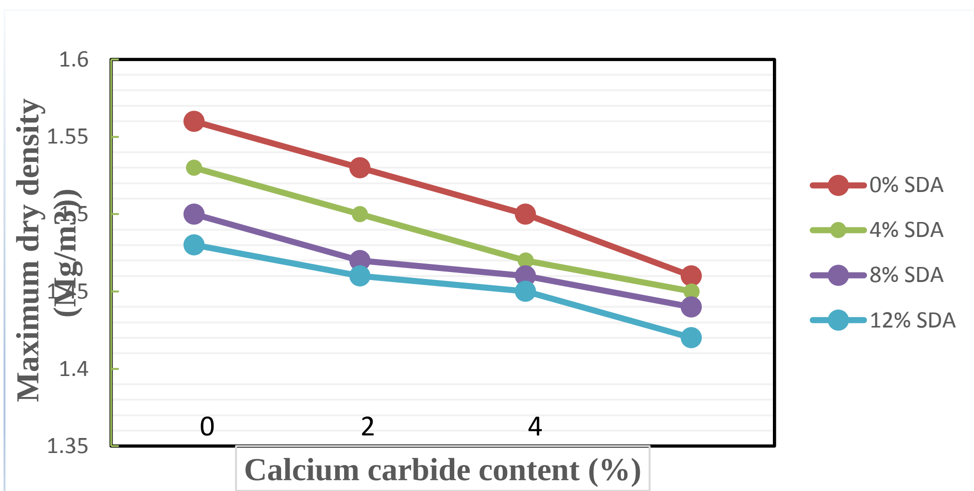


Figure 2: Variation of maximum dry density with SDA- CaC_2- treated laterite-clay

Compressive strength properties of SDA- CAC_2 treated burnt clay bricks

The highest compressive strength of 10.92 MN/m^2 was achieved in burnt clay bricks at 8% SDA+4% CaC_2 combination. This strength is higher than that of the control specimen sample of untreated burnt clay brick (8.6 MN/m^2). The result showed that the strength becomes lower with the additions of more than 8% SDA+4% CaC_2 to burnt clay. The variation of strength with different combinations of SDA- CaC_2 treated burnt clay bricks is presented in Fig. 3.

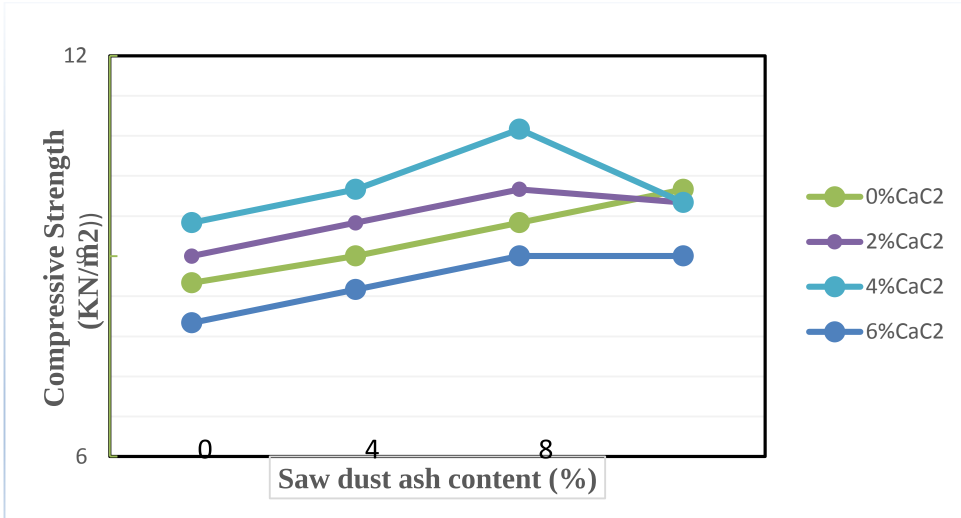


Figure 3: Variation of compressive strength with SDA- CaC_2 treated burnt laterite-clay brick.

The increase in strength of burnt bricks with additions of additives used is consistent with previous studies by Agbede and Joel (2011) and De Silva et al. (2018). In the current study, the increase in compressive strength of burnt bricks from 8.65 MN/m^2 at 0% SDA+0% CaC_2 to 10.92 MN/m^2 at 8% SDA+4% CaC_2 might be due to small formation of CSH and CAH. This is expected due to the presence of CaO in CaC_2 (Table1), which could react with silica and alumina from laterite-clay and SDA to form calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). This is further discussed in the SEM in Figs 5a-b below. Also, the increase in strength with small additions of SDA- CaC_2 might be due to the SiO_2+ Al_2O_3 percentage threshold beyond which the content is unreactive and undesirable. Previous studies (De Silva et al., 2018; Hwang and Huynh, 2015; Chindaprasirt et al., 2012) showed that higher SiO_2+ Al_2O_3 content beyond 3.8% in burnt clay bricks could result in looser brick structure. This is due to the increased amount of unreacted materials and the consequent larger porosity of the brick. Strength is one of the major properties used in assessment of bricks (ASTM C62-99, 2000). In the current study, the maximum compressive strength of 10.9 MN/m^2 achieved in the burnt clay brick treated with 8% SDA+4% CaC_2 is greater than 10.3 MN/m2 which is the minimum value suitable for structural building bricks in grade negligible weather (ASTM C62-99, 2000). Based on strength requirements, 8% SDA+4% CaC_2 treated burnt laterite-clay brick from Igboora laterite-clay A-7-5 is recommended for structural building bricks in grade negligible weather.

Water absorption

The variation of water absorption with different combinations of SDA- CaC_2 treated burnt clay bricks is presented in Figure 4. The results showed that water absorption increased with SDA and RHA additions. The water absorption value for untreated sample of 16% increased to a value of 18.9% for the sample with the highest strength (at 8%SDA+4% CaC_2). Samples treated with waste mixture above this content resulted in increased water absorption up to 19.5% for 12%SDA+6%CaC_2 treated samples. The increase in water absorption with SDA-CaC_2 additions might be due to increase in porosity compared with untreated burnt clay brick. Usually, agricultural waste treated burnt clay bricks do result in higher porosity than the corresponding untreated burnt clay bricks (Kazmi et al., 2016; De Silva, 2018). Water absorption is another important property for bricks assessment. In the current study, the water absorption of 18.9% was achieved in the sample with the highest strength (at 8% SDA+4% CaC_2). Based on ASTM C62- 99 (2000), this water absorption was compared with the maximum water absorption requirement for Severe Weathering (SW) (17%), Moderate Weathering (MW) (22%) and Negligible Weathering (NW) (no limit) conditions. Therefore 8% SDA+4% CaC_2 treated burnt laterite-clay brick is recommended for MW and NW weather environment.

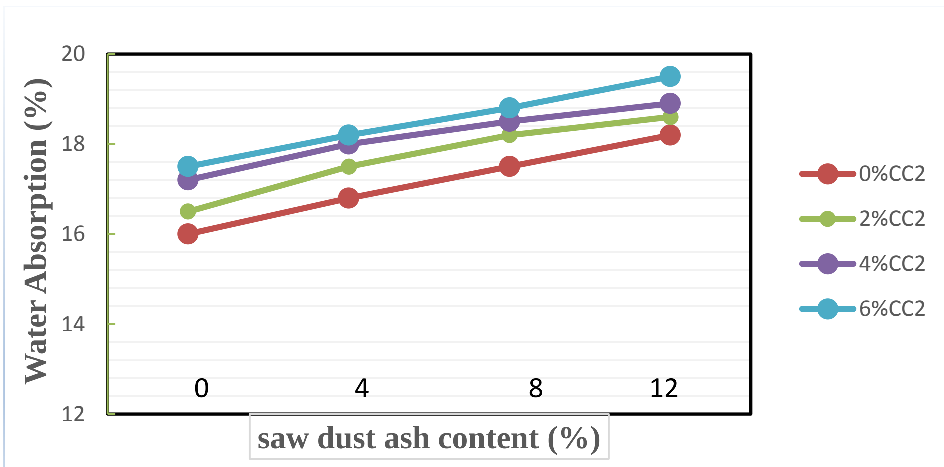
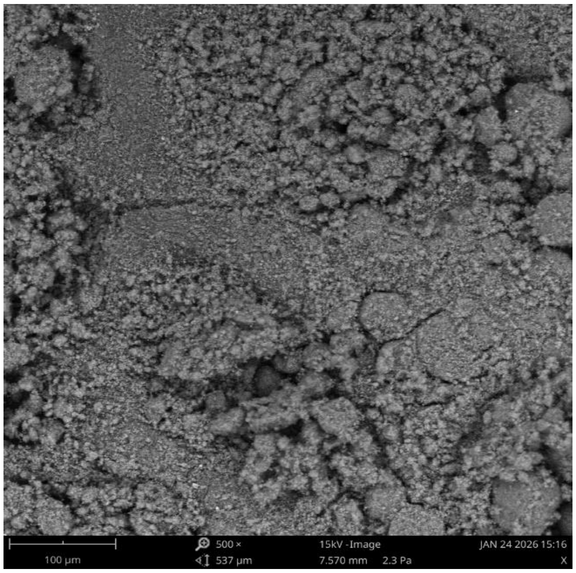


Figure 4: Variation of water absorption with SDA- CaC_2 treated burnt laterite-clay brick.

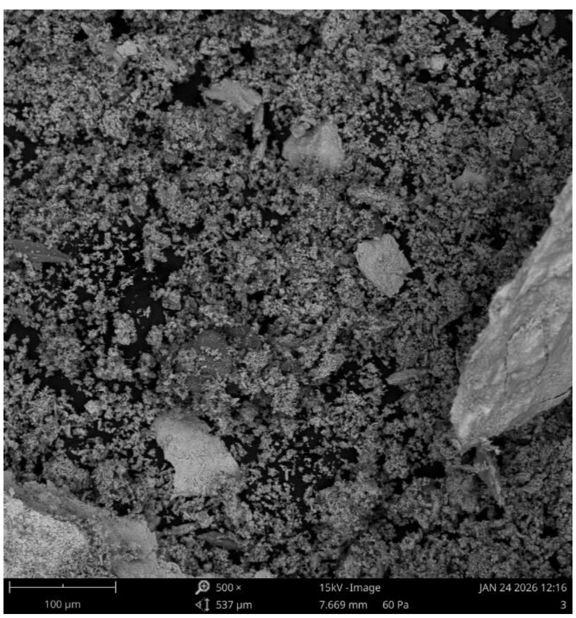
Scanning electron microscope analysis.

The SEM images of samples for untreated and 8%SDA+4% CaC_2 treated burnt laterite-clay brick are presented in Figures 5a-b. The results of elemental analysis from EDX on the same samples are also contained in Figures 5a-b. the samples of untreated burnt laterite-clay brick (the control) and that with the highest strength were selected for SEM and EDX. The elemental analyses of the untreated brick show highest composition of Si (46.35%) followed by Al (26.61%) and Fe (26.61%) respectively, the least is Ca (0%). The high composition of Si and Al indicates the characteristic of clay composition. For the 8%SDA+4% CaC_2 treated burnt laterite-clay brick, the highest composition is Ca (39.21%) followed by K (19.65%), Fe (12.77%) and Si (11.71%) respectively, then the least are Na and Mn (0%) respectively. The high composition of Ca, K, Al and Si depicts the characteristic of cementious compound CSH and CAH (Bye, 2011). Due to large composition of Ca (39.21%) in the 8%SDA+4%CaC_2 treated clay brick, there is noticeable difference between the SEM image of untreated and that of 8%SDA+4% CaC_2 treated brick (Figure 5a-5b). This is expected since the possible corresponding cementous compounds of CSH and CAH resulting from Ca, Si and Al is noticeable in large quantity. The increase in Ca content is consistent with the strength increase of the burnt bricks from 8.65 MN/m^2 at untreated burnt clay bricks to 10.92 MN/m^2 at 8% SDA+4% CaC_2 treated burnt bricks.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	23.60	38.20
14	Si	Silicon	46.35	37.73
13	Al	Aluminium	26.61	20.81
22	Ti	Titanium	0.87	1.20
11	Na	Sodium	1.41	0.94
19	K	Potassium	0.69	0.79
12	Mg	Magnesium	0.47	0.33
20	Ca	Calcium	0.00	0.00
23	V	Vanadium	0.00	0.00
25	Mn	Manganese	0.00	0.00
15	P	Phosphorus	0.00	0.00
16	S	Sulfur	0.00	0.00
17	Cl	Chlorine	0.00	0.00

(a)



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	36.72	39.21
19	K	Potassium	18.86	19.65
26	Fe	Iron	8.58	12.77
14	Si	Silicon	15.65	11.71
13	Al	Aluminium	8.38	6.02
16	S	Sulfur	4.80	4.10
22	Ti	Titanium	1.39	1.77
15	P	Phosphorus	1.97	1.63
12	Mg	Magnesium	2.42	1.56
23	V	Vanadium	0.96	1.31
17	Cl	Chlorine	0.28	0.27
11	Na	Sodium	0.00	0.00
25	Mn	Manganese	0.00	0.00

(b)

Figure 5: The SEM and point elemental analysis (a) Untreated burnt clay brick at 0%SDA+0%RHA (b) 8%SDA+4% SDA and CC_2 treated burnt laterite-clay brick

Conclusion

From this study on the effect of SDA+ CaC_2 additions on the compressive strength and water absorption properties of burnt laterite-clay brick, the following conclusions were drawn:

1. The Igboora laterite-clay soil used for this research is classified as A-7-5 and MH-OH, based on AASHTO and USCS classification respectively.

2. The additions of 8%SDA+4% CaC_2 to the laterite-clay for burnt clay brick production resulted in compressive strength increase. The compressive strength of untreated burnt laterite-clay brick which is 8.65 MN/m^2 increased to 10.92 MN/m^2 for the 8%SDA+4% CaC_2 treated burnt clay brick.
3. Higher additions of SDA+ CaC_2 resulted in strength reductions. Based on strength requirements (ASTM C62 99, 2000), the compressive strength of 10.92 MN/m^2 is greater than 10.3 MN/m^2, therefore adequate for structural building bricks in Grade NW condition.
4. The water absorption for 8%SDA+4% CaC_2 treated burnt clay brick is 18.9%. Based on water absorption requirements (ASTM C62-99, 2000), this value is less than the maximum value for Grade SW, MW and NW conditions. Therefore, 8%SDA+4% CaC_2 treated burnt laterite-clay brick is recommended for Grade SW, MW and NW conditions.
5. EDX results show the presence of Ca, Si and Al in the 8%SDA+4% CaC_2 treated burnt clay brick, hence suggest the possible presence of cementitious compounds of CSH and CAH. Based on combined strength and water absorption requirements, this study recommends that the treatment of igboora laterite-clay A-7-5 with 8%SDA+4% CaC_2 for burnt laterite-clay brick is adequate for structural building bricks in Grade NW condition.

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