Journal of Building Material Science
https://ojs.bilpublishing.com/index.php/jbms

ARTICLE

Effects of the Addition of Sawdust Ash and Iron Ore Tailings on the Characteristics of Clay Soil

Elinwa, Augustine Uchechukwu[1*] Mohammed, Abdulrahaman Shehu[2] Mohammed, Ahmed Bafeto[3]

1. Civil Engineering Department, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria
2. C/O Engineering and Construction Ltd, AY1 Faskari Road, sabo Gari, Tudun Wada, Kaduna, Kaduna State, Nigeria
3. Department of Civil Engineering, Federal Polytechnic Damaturu, Yobe State, Nigeria

ARTICLE INFO

Article history
Received: 18 September 2021
Accepted: 10 November 2021
Published Online: 20 December 2021

Keywords:
Additives
Firing temperature
Clay bricks
Bricks characteristics
Statistics
Regression models

ABSTRACT

An evaluation of the effects of additives and firing temperatures on clay bricks characteristics was studied. The two (2) additives used were sawdust ash (SDA) and iron ore tailing wastes (IOTW), and the five (5) firing temperatures of 400°C to 1200°C at intervals of 200°C were applied. The fired bricks were tested for linear shrinkage, water absorption, density, and compressive strength. The results of the investigations showed that firing temperature improved the clay brick characteristics across all replacement levels. However, the SDA additions increased the linear shrinkage and the water absorption but decreased the density and compressive strength. On the other hand, the addition of IOTW to the clay-SDA mixture, reduced both the linear shrinkage and water absorption of the clay bricks, and increased the density and compressive strength. The statistical values and the regression models derived on the experimental data using Minitab 18 Software were significant.

1. Introduction

The yardstick for the measurement of national progress is tied to the degree of contributions of the construction industry, and the building materials sector have been identified as the major contributor to the construction industry. Another area of concern in the construction industry is the rapid growth in construction works due to urbanization and the rate at which conventional materials for constructions are being depleted. These concerns are worsened by the pollution and degradation of the environments leading to depletion of the ozone layer and climate change.

The use of earth blocks and bricks dates back to thousands of years, and are man-made materials, made from the natural clay, and sundried. These were used for building houses by the low income groups. Burnt clay bricks are created from clay that are either molded, dry-pressed, or extruded and then dried and fired in a kiln. Researches on the improvement of clay bricks by addition and replacement materials have come of age because of the pressures on the conventional construction materials, and the advantages attached to the use of fired clay bricks. Fired bricks are inert materials which hardly react with

**Corresponding Author:*
Elinwa, Augustine Uchechukwu,
Civil Engineering Department, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria;
Email: auelinwa@gmail.com

other materials, and do not release toxic substance.

Sutau et al [1] studied the "characteristics of fired clay bricks with waste marble powder addition as building materials." Using semi pressing process, they produced fired clay bricks lightened by the addition of up to 35% wt. % waste marble powder and analyzed by XRF, XRD, TGA, and SEM, respectively. The brick mixtures containing waste marble powder at different proportions were formed, dried and then fired at 950 and 1050°C for 2h. Some of their findings were that the use of waste marble powder addition reduced the bulk density of the samples, and the porosity ratios up to about 40% improved with increasing of waste marble powder additions up to 30 wt. % for all samples. However, they concluded that the compressive strengths decreased until 8.2 MPa but enough according to the values required by the standard.

Bagasse was added in proportions of 5 to 20 wt. % and fired to different temperatures of 700 to 1000°C to produce lightweight clay brick ceramic [2]. They concluded that higher bagasse additions resulted in higher values of porosity and water absorption. Also, reported were reductions in thermal conductivity and bulk density, but the increased firing temperature resulted in a decrease in porosity and water absorption, higher thermal conductivity and bulk density.

Aouba et al [3] in their work examined the significance of adding organic matter coming from agricultural solid waste (olive stone flour), OSF, and wheat straw, WS, residue to improve thermal performance while maintaining load bearing capacity. Some of their findings were that the bulk density decreased for mixtures containing OSF, ranging from 6% to 19% compared to clay alone, and for WS mixtures, where the bulk density reduced from 4% to 20%.

A study on the use of palm oil waste to produce fired clay bricks was undertaken by Kadir et al [4]. They incorporated palm waste in the proportions of 1%, 5%, and 10% by wt. % of clay, and fired to temperature of 1050°C with heating rate of 1°C/min. The results of their findings showed that the replacements with 1%, to 5% of POW improved several properties of the fired clay bricks with a decrease of performance at higher replacement levels (20% and 30%).

Srisuwan et al [5] used wood ash at replacement levels of 0, 4, 8, 12, and 16 % by wt. % of clay soil to prepare samples of clay bricks that were fired to temperatures of 900°C to 1100°C, at 100°C increment. The aim of their study was to evaluate the effect of the addition of wood ash and the firing temperature on the physical characteristics of the fired clay bricks. They concluded that the physical properties and strength of the fired clay bricks depend on the wood ash content and firing temperature.

The effect of adding sawdust ash (SDA) to clay for the purpose of making bricks was undertaken by Elinwa [6]. The bricks were fired to temperatures of 200°C, 600°C, and 1200°C and cured for 1, 4 and 8 days, respectively. They made measurements on linear shrinkage, water absorption, and compressive strength of fired bricks. His work concluded that the compressive strength decreased as the SDA was increased, and the maximum compressive strength was achieved at a firing temperature of 600°C, curing for 1 day, and at 10 % wt. %SDA. Equally of note in his conclusion was that the water absorption increased as the SDA was increased but the values were within the code specification.

The present work is on using two additives, SDA and IOTW, with clay soil and firing the brick samples at five different firing temperatures of 400°C, 600°C, 800°C, 1000°C, and 1200°C, respectively. The aim of the research work was to address the research needs raised by Elinwa [6] on the low compressive strength of fired clay bricks with SDA, by using a ternary material that can improve the low compressive strength. This problem was addressed by adding IOTW to the clay-SDA bricks using experimental methods.

Highlights

- Characterization of the materials- clay, sawdust ash and iron ore waste tailings.
- Experiments to determine the effects of sawdust ash and iron ore waste tailings on linear shrinkage, water absorption, density and compressive strength.
- Effects of firing temperatures and additives on these characteristics.
- Statistical and regression models on the experimental data.

2. Material

The materials used for this work are clay soil, sawdust ash (SDA), iron ore tailing wastes (IOTW), and potable water. The clay was sourced along Bauchi- Kano road in Bauchi State, Nigeria, and was oven dried for 24 hours, crushed using pestle and mortar, and sieved through 2.0 mm sieve. Table 1 shows the clay soil characteristics and the particle size distribution. Table 2 shows the improvements results on the clay soil using SDA matched with also the improvement that was carried out on the clay soil-SDA mixture, using IOTW. The replacements for the clay soil were 0%, 5%, 10%, 20%, 30%, and 40% by wt. % of clay soil. The MDD of 1.49 mg-m^3 and maximum dry density (OMC) of 25.6% for this composite were achieved. Using these values of MDD and OMC for the

  DOI: https://doi.org/10.30564/jbms.v3i2.3732

clay-SDA mixture, three levels of improvement 10%, 20%, and 30% were chosen by replacing the clay soil-SDA mixture by IOTW by wt. %. The achieved lowest MDD was 1.44 mg-m^3 and OMC of 23.9 %.

Table 1. Characteristics of Clay Soil

Property	Average value (%)
Moisture Content (%)	
Liquid Limit (LL) (%)	12.2
Plastic Limit (PL) (%)	44.0
Plastic Index (PI) (%)	21.0
Linear Shrinkage (LS) (%)	23.0
Specific Gravity (SG)	12.2
Maximum Dry Density (MDD)	2.75
(mg-m^3)	1.65
Optimum Moisture Content	18.3
(OMC) (%)	
Particle Size Distribution	
Sand (%)	37.0
Silt (%)	38.4
Clay (%)	21.6
Gravel (%)	1.0

Table 2. Characteristics of Clay-SDA and Clay-SDA-IOT

Improvement Material	Mix No	MDD (mg-m^3)	OMC (%)
Sawdust ash (SDA)	MC-00	1.65	18.3
	MCS-05	1.65	19.8
	MCS-10	1.62	20.9
	MCS-20	1.59	24.0
	MCS-30	1.55	24.8
	MCS-40	1.49	25.6
Iron Ore Tailings (IOW)	MCS-10-I	1.44	23.9
	MCS-20-I	1.60	20.9
	MCS-30-I	1.64	19.7

The sawdust that was used for the production of the sawdust ash was from the Timber Market in Bauchi. This was processed using the Industrial Design Department kiln, Abubakar Tafawa Balewa University, Bauchi, Nigeria. The temperature range used for the calcination was between 400^{o}C and 600^{o}C and grinded using pestle and mortar and sieved through sieve 150 µm.

The iron ore tailing waste was obtained from Nigerian Iron Ore Mining Company (NIOMCO), Itakpe, Kogi State, Nigeria. The samples were crushed in a crushing machine and subsequently sieved through 212 µm sieve. The physical and chemical properties of both the clay soil, SDA and IOTW are shown in Table 3.

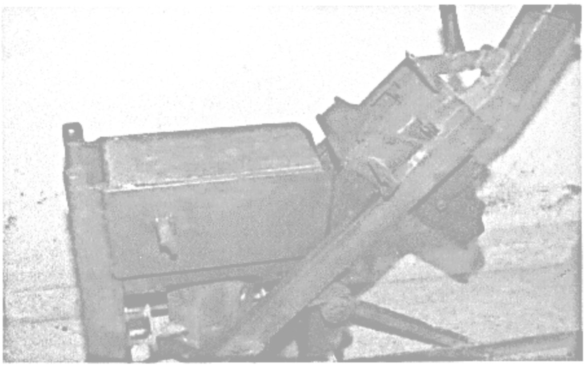
Table 3. Physical and Chemical Properties of SDA and IOT

Property	Value		
	Clay	SDA	IOTW
Specific Gravity	2.75	2.39	3.51
Moisture Content (%)	12.2	0.53	0.22
Bulk Density (kg/m^3)	-	1.21	1650
Fineness (m^2/g)	-	330	-
pH	-	10.0	13.11
Loss on Ignition (%)	-	0.45	-
	Value (%)		
SiO_2	48.5	67.7	77.2
Al_2O_3	16.4	2.8	2.62
Fe_2O_3	4.1	1.53	15.0
CaO	0.5	0.1	1.20
Total ($Na_2O + K_2O$)	-	-	1.20
MgO	0.7	2.0	0.30
K_2O	1.4	0.53	-
Na_2O	-	0.60	-
SO_3	0.01	1.53	0.08
TiO_2	0.80	< 0.001	0.20
P	-	-	0.08
Other compounds and elements	0.23	-	8.37

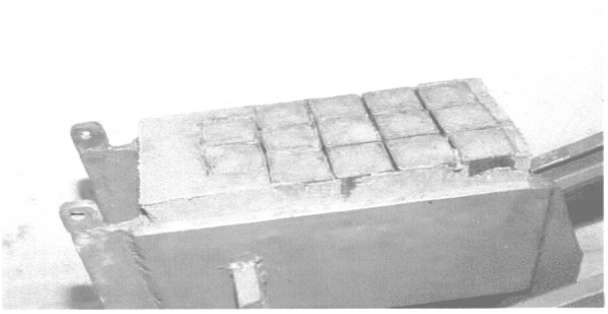
3. Experiment

The productions of the bricks were in three phases. The first was the control samples, made with 100% clay soil. They are fifteen (15) in number. The second phase was done using clay soil to which proportions of SDA of 5%, 10%, 20%, 30% and 40% by wt. % of clay soil were mixed with the clay soil. These are labelled as MCS-00. MCS-05, MCS-10, MCS-20, MCS-30, and MCS-40 and a total of 75 samples were made. The third phase was an improvement on the clay soil-SDA using IOTW of 10%, 20%, 30% by weight of the clay soil-SDA composite. This was applied at the 40% SDA replacement where the minimum MDD and maximum OMC were achieved. A total of 45 brick samples were produced in this case. A total of 135 clay bricks samples were prepared and cured for seven days. In each of the phase, the amount of water required to give optimum compaction was determined from the compaction tests at various replacement levels. The machine used for the production of the bricks was the mechanically hand-operated block press Model CINVA-RAM, at the laboratory of Building Department, Abubakar Tafawa Balewa University, Bauchi, Nigeria. The machine was designed with dimensions 295 mm x 140 mm x 90 mm. The inner compartment of the CINVA-RAM contained fifteen (15) hollow chamfered metallic cube molds of dimensions 40 mm and driven into the soil to about half their depth and the cover placed over them.

The whole assembly was pressed further until the whole depth of the mold penetrated the soil. The brick samples were compacted and extruded in this chamber. The extrusion of the samples were carried out using specially improvised extruder. The freshly extruded brick samples were placed on polythene leather giving enough spaces in-between for proper air circulation, and covered to prevent rapid or uneven curing. The curing was done for 7 days and oven dried at 50^{o}C for 24 hrs to remove any moisture remaining in the sample. The purpose of curing is to allow the limestone ($CaCO_3$) convert to quicklime during firing to hydrate without expansion in the volume of the bricks [6]. The process of producing the brick samples is shown in Plate 1 (a-c).



Compaction of the samples (a)



Extrusion of the samples (b)

Curing of the samples (c)

Plate 1. Compaction, Extrusion and Curing of the Samples

Firing of the Samples

The brick samples were subjected to five different temperatures of firing at 400^{o}C, 600^{o}C, 800^{o}C, 1000^{o}C, and 1200^{o}C, in an electric oven, Model Alpha1, in the Faculty of Agriculture of the University. The heating velocity was kept approximately at 8^{o}C and was capable of achieving 1200^{o}C. To achieve uniformity in the heat flow in the furnace, the arrangement of the brick samples was such as to allow good spacing for proper circulation of heat. Heating of the brick samples was carried out at the stipulated temperatures, and at the attainment of each specified temperature, the brick samples were left in the chamber for approximately 2 hrs to attain a uniform temperature. They are then removed and cooled in air for 24 hrs. Three fired clay brick samples were tested for linear shrinkage, density, water absorption, and compressive strength. The average values are recorded as shown in Table 4.

Testing of the Fired Bricks

The linear shrinkage was tested at two stages; one after drying the bricks at 50^{o}C for 2 hours. The parameter measured was the drying shrinkage. The second process was firing the brick samples at the temperatures of 400, 600, 800, 1000, and 1200^{o}C, respectively. This was defined as the firing shrinkage. The linear shrinkage (total shrinkage) therefore, is the effect of both the drying and firing shrinkages, expressed as the percentage of the original length of the bricks This was done in accordance with ASTM C 210-95 [7]. The shrinkage was measured with the aid of digital vernier caliper readable to 01 mm. The linear shrinkage is the average of two sides of each brick and the average of three bricks were tested.

The density of the brick samples was first of all measured by weighing the bricks dry and dividing by the volume of each brick. After firing at each specified temperature, the volume of each brick was calculated by approximately taking the reduced lengths of the sides.

The water absorption of the fired brick is a measure of its porosity and carried out in accordance with ASTM C373-88 [8]. This was measured by immersion of the bricks in cold water for 24 hours and the water absorbed expressed as a percentage of its dry weight. Three (3) specimens were tested for each replacement level and temperature. The average of these values is recorded as the water absorption.

The compressive strength was carried out after testing for the water absorption, and allows to dry at 50^{o}C for 24 hours. Three specimens were tested for each firing temperature using the Universal Testing Machine, Model TQ SM 100 of 100 kN capacity. The average results are recorded. The results of the linear shrinkage, water absorption, density and compressive strength are shown in Table 4.

  DOI: https://doi.org/10.30564/jbms.v3i2.3732

Table 4. Results of SDA-IOT Brick

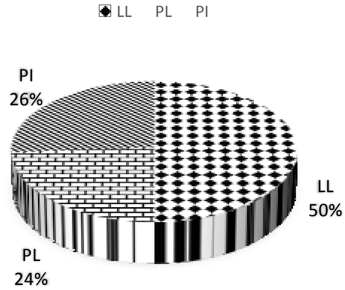
Property	Mix No	Temperature (°C)				
		400	600	800	1000	1200
Linear Shrinkage (%)	MC-00	6.2	6.5	7.1	7.7	8.3
	MCS-05	4.0	4.0	4.4	4.5	5.3
	MCS-10	3.0	3.7	4.2	4.5	5.0
	MCS-20	2.0	2.2	2.8	2.8	3.0
	MCS-30	1.3	1.9	2.3	2.8	2.9
	MCS-40	1.2	1.5	1.9	2.3	2.6
	MCS-10-I	3.3	3.9	4.0	4.1	4.1
	MCS-20-I	2.0	2.2	2.4	2.7	3.1
	MCS-30-I	1.6	1.9	2.1	2.6	2.7
Density (kg-m^3)	MC-00	2.17	2.12	2.05	2.02	2.00
	MCS-05	1.91	1.91	1.88	1.87	1.84
	MCS-10	1.83	1.79	1.77	1.76	1.71
	MCS-20	1.63	1.64	1.61	1.59	1.58
	MCS-30	1.63	1.60	1.58	1.57	1.54
	MCS-40	1.51	1.50	1.50	1.46	1.45
	MCS-10-I	1.98	1.97	1.95	1.95	1.89
	MCS-20-I	2.16	2.12	2.11	2.11	2.04
	MCS-30-I	2.32	2.32	2.29	2.29	2.27
Water Absorption (%)	MC-00	18.9	17.6	16.0	14.7	12.4
	MCS-05	19.2	18.6	18.5	17.9	14.8
	MCS-10	21.2	21.1	20.7	19.6	19.4
	MCS-20	27.4	26.7	26.6	26.5	23.3
	MCS-30	29.9	29.5	28.1	27.2	27.0
	MCS-40	35.8	33.7	33.5	30.6	27.3
	MCS-10-I	18.6	18.1	17.9	17.2	16.5
	MCS-20-I	16.3	15.9	15.4	14.9	13.1
	MCS-30-I	13.8	13.7	13.2	12.8	12.5
Compressive Strength (kN-m^2)	MC-00	4.5	5.9	7.5	8.2	5.8
	MCS-05	2.5	4.0	6.1	7.1	6.2
	MCS-10	1.8	3.5	3.7	3.8	3.9
	MCS-20	0.8	1.2	2.0	2.1	2.4
	MCS-30	0.6	0.6	1.0	1.0	0.6
	MCS-40	0.3	0.5	0.7	0.8	0.4
	MCS-10-I	2.8	5.0	6.1	6.7	7.4
	MCS-20-I	3.3	6.0	6.2	6.8	7.6
	MCS-30-I	3.4	6.1	6.3	7.5	8.5

4. Discussion

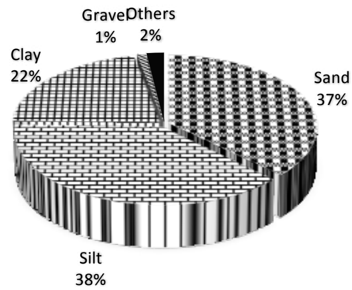
Characteristics of the clay soil

Figure 1a is on the Atterberg limit test. The values obtained showed that the clay belongs to the kaolinite group of clay minerals formed from the weathering of alkaline feldspar and alternate layers of silicon and aluminum. The plasticity index met the requirement of the standard (PI, 15 and 20). The specific gravity of the clay is 2.75. The grain size distribution from the composition of the clay indicated a gap graded soil with the composition shown in Figure 1b. This met the specification of the Standard for brick production [9].

The clay soil had a maximum dry density (MDD) of approximately 1.7 mg-m^{-3} with an optimum moisture content (OMC) of approximately 18%, obtained using the standard proctor compaction in accordance to BS 1377 Part 4 [10]. The lowest MDD and highest OMC for replacement levels of 5, 10, 20, 30, and 40 %, were achieved at 40 % wt. %SDA. These are 1.5 mg-m^3 and 25.6% for OMC. The lowest MDD and highest for the three levels of addition of IOTW (10, 20, and 30%), are 1.4 mg-m^3 and 23.9%. These are shown in Figure 2 (a and b). The various amounts of SiO_2 + Fe_2O_3 + Al_2O_3 for the clay soil, SDA and IOTW are approximately 69%, 72% and 90%, respectively, with a pH of 7, 10 and 13. The pH showed that the clay is little acidic while the SDA and IOTW are base in nature.

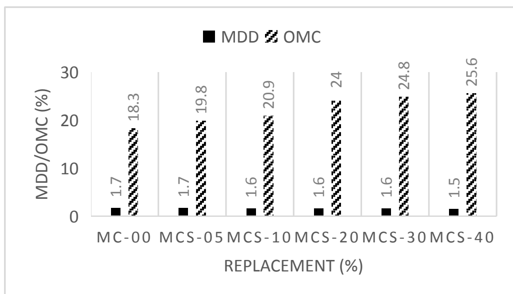


(a)- Atterberg Limit Test

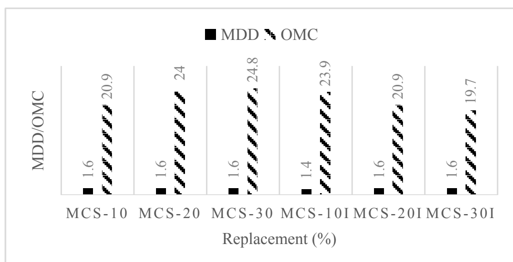


(b): Grain Size Distribution

Figure 1. Clay Soil Characteristics



(a)- Clay-SDA



(b) – Clay-SDA-IOTW:

Figure 2. Maximum Dry Density and Optimum Moisture Content

Properties of Fired SDA-IOTW Bricks

Linear Shrinkage

Firing temperatures affected the linear shrinkage of the clay bricks. Figure 3 showed that firing the clay bricks from 400°C to 1200°C achieved a shrinkage of approximately 6 to 8%. This could also be said for SDA replacements of 5, 10, 20, 30 and 40% by wt. % of clay, where reductions of 4-5%, 3-5%, 2-3%, 1.3-2.9%, 1.2-2.6%, respectively, were recorded. This strongly showed that firing temperatures affected to a great extent the linear shrinkage, and the best firing temperature was at 1200°C [3]. It has been reported in the literature that shrinkage occurred when the chemically and mechanically bound water evaporated [5]. This assertion can be said to be observed on the results obtained. It seemed that the addition of SDA which is pozzolanic in nature, achieved internal transformations necessary for structural changes and solidifications [5]. The addition of IOTW to the clay-SDA bricks was at three levels of 10%, 20% and 30%. The aim was to observe its effect on the clay-SDA bricks. The IOTW contained 90% the total sum of SiO_2 + Al_2O_3 + Fe_2O_3 with Fe_2O_3 approximately 15%. IOTW. Therefore it is a ferric oxide silicate material. This, as observed equally had some transformational effects on the stability of the clay-SDA-IOTW bricks. Therefore, the additions of SDA and IOTW to fired clay bricks affected the linear shrinkage (LS) [3,5].

Water Absorption

From Figure 4, the effect of firing temperatures for all classes of clay brick mixture showed reductions in water absorption as the firing temperatures increased (400-1200°C). Water absorption is a durability indicator and gives information about open porosity [3]. Therefore, firing temperatures of bricks have tremendous effects on the bricks. The higher the firing temperatures the lesser is the water absorption. For 100% clay samples (control) fired for the range of temperatures of 400-1200°C, the water absorption decreased from 18.9-12.4%. However, with the addition of SDA by wt. % of clay, the water absorptions are 19.2-14.8%, 21.2-19.4%, 27.4-23.3%, 29.9-27.0%, and 35.8-27.3%, for the same range of temperatures, 400-1200°C, respectively. This showed reduction with the firing temperature increased. It was equally observed that as the replacement with SDA increased the water absorption increased. This was clearly the case when a comparison of the clay bricks containing SDA are made with the control clay bricks (without SDA).The differences in the water absorption increased respectively from 1.6-19.4%, 12.2-54.5%, 35.0-87.9%, 58.2-117.7%, and 89.4-120.2%, with the firing temperatures of 400°C to 1200°C.Therefore, the effect of adding SDA to clay soil and firing can be said to increase the water absorption as the quantity of SDA was increased. This was also confirmed by the study of Srisuwan et al [5] and Elinwa [6], which stated that higher wood ash and SDA content affected an increase in porosity and water absorption. The addition of IOTW at three levels of 10%, 20% and 30% clay-SDA by wt. %, and compared with the same levels of addition in clay-SDA, showed immense improvement on the water absorption. The percentage water absorption reductions were therefore calculated as shown in Equation (1):

$$WA_R = \frac{(WA_{T\,CS} - WA_{T\,CSI})}{WA_{T\,CS}} \, x \, 100\,\% \tag{1}$$

Where

WA_R = % water absorption reduction

$WA_{T\,CS}$ = Water absorption of clay-SDA at the indicated firing temperature (%)

$WA_{T\,CSI}$ = Water absorption of clay-SDA-IOTW at the indicated temperature (%)

Example:

At 10 % replacement @ 400°C

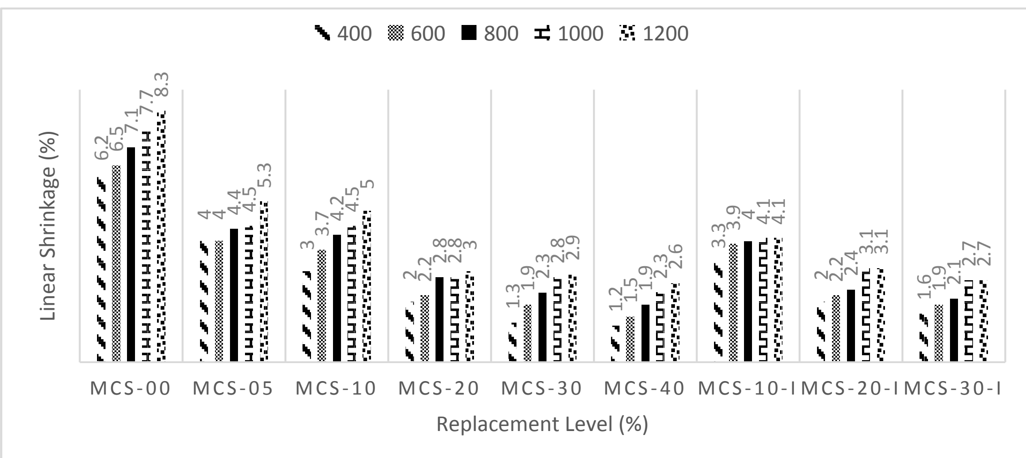


Figure 3. Linear Shrinkage (%)

DOI: https://doi.org/10.30564/jbms.v3i2.3732

$WA_{T\,CS} = 21.2\,\%$

$WA_{T\,CSI} = 18.6\,\%$

$WA_{R} = \frac{18.6-21.2}{21.2} \times 100\,\% = -12\,\%$*: The same is done for other firing temperatures.*

The reductions were approximately -12-15%, -42-44%, and -54-54%. The interpretation of which signified porosities of 25%, 7%, and 0%, respectively. The 0% porosity is a closed porosity. Therefore, addition of IOTW to clay bricks would improve the durability of the bricks.

The Density of the Bricks

Figure 5 showed the fired densities of the clay-SDA bricks and the three levels of clay-SDA-IOTW bricks. The bulk densities at the various firing temperatures were 2.17-2.0%, 1.91-1.84%, 1.83-1.71%, 1.63-1.54%, and 1.51-1.45%, for clay-SDA bricks at 0% to 40% of SDA by wt. % of clay. The clay-SDA brick densities decreased as the firing temperatures increased. The percentage decrease in the densities at firing temperatures of 600-1200°C compared to the firing temperature of 400°C were 12 %, 16 %, 25%, and 30%, respectively. The same observation was made by Srisuwan [5]. Some factors have been attributed to this behavior. These are due to increased consolidation or vitrification between the particles in the body as the firing temperature increased. The lower bulk densities of the samples with the SDA additives are presumed to be as a result of the lower densities of the SDA. Similar observation was made by Chopra S, as referenced in the works of Arthur and Gikunoo [11], and Srisuwan et al [5], respectively. The clay-SDA-IOTW bricks at three levels of IOTW additions ranged from 1.98-1.89 mg-m^3, 2.16-2.04 mg-m^3, 2.32-2.27 mg-m^3. This showed that the clay-SDA-IOTW increased at the three levels of IOTW additions. We can therefore conclude that the IOTW contributed to the high densities recorded as a result of the high density of IOTW material. The differences in increase of the densities attained at 600-1200°C compared with the 400°C firing temperature were 8% to 28%.

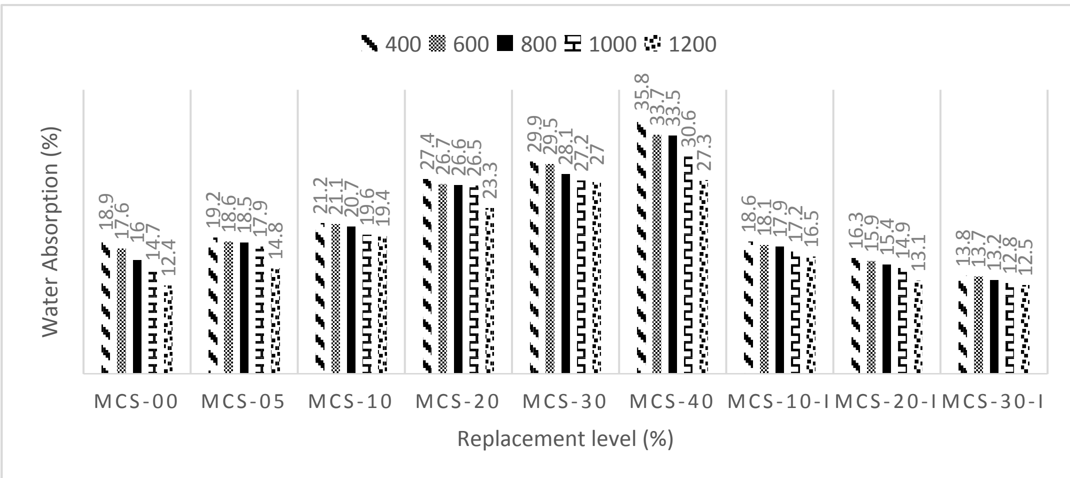


Figure 4. Water Absorption (%)

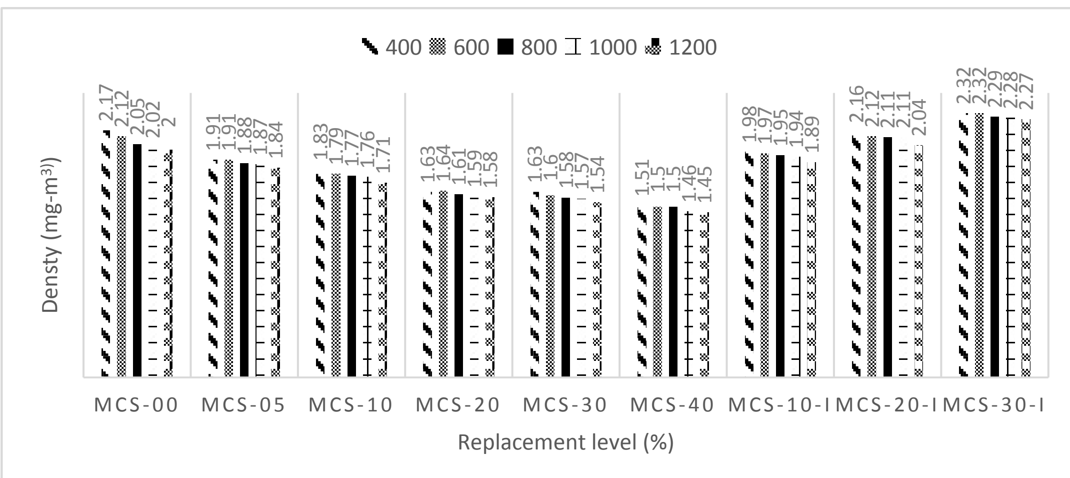


Figure 5. Density (mg-m^3)

 DOI: https://doi.org/10.30564/jbms.v3i2.3732

Compressive Strength

The compressive strength of clay-SDA and clay-SDA-IOTW, fired bricks are shown in Figure 6. Observations showed that at firing temperatures of 800°C and 1000°C, the 100% clay mixture (Control), gave the highest compressive strengths of 7.5 kN-m^2 and 8.2 kN-m^2, respectively. The mixture containing SDA, only the fired bricks with replacement of 5% SDA gave a strength of 7.1 kN-m^2 at 1000°C firing temperature. The same observation was made by Janbuala and Wasanapiarngong [2], using bagasse to produce lightweight clay bricks, and Srisuwan et al, [5], using wood ash. Other replacement levels and firing temperatures recorded low compressive strengths [3]. This has also been attributed to the low content of Al_2O_3 and mullites in SDA [6]. The three levels of additions of IOTW showed remarkable strength improvement over the clay-SDA fired bricks. The optimum compressive strength for each of the mix was at 1200°C and are given as 7.4 kN-m^2, 7.6 kN-m^2, and 8.5 kN-m^2, respectively.

Basic statistics and sensitivity on data on the fired bricks

The aim of this exercise was to evaluate and validate the credibility of the data collected on the experiments. For variations to be properly accounted for, sufficient number of tests were required. This was important because it will form the basis for determining from such results the potential quality and strength of the data, and for expressing results in the most useful form. Statistical procedures provide a sound basis for determining from such results the potential quality and strength of our experimental data, and for expressing results in the most useful form. The basic characteristics of the fired brick data will assist in understanding better the interactions of the various materials used for the production of the bricks. Table 5 showed in details the degrees of the performances and interactions of the fired bricks carried out using the Minitab 18 Software. Measurements were made on the mean, standard error of the mean (SE.Mean), standard deviation (St.Dev) and coefficient of variation (Coef. Var), on the linear shrinkage, water absorption, density and compressive strength of the fired bricks.

The mean value characterizes the central tendency or location of the data, while the coefficient of variation provides a general feeling about the performance of the method and its distribution around the mean. This expresses the variation as a percentage of the mean. Thus, the larger the coefficient of variation is, the greater the spread in the data. The standard error of the mean (SE Mean) estimates the variability between sample means, and the standard deviation and thus, establishes a benchmark for estimating the overall variation of a process. Whereas, the standard error of the mean estimates the variability between samples, the standard deviation measures the variability within a single sample. The variance (standard deviation squared) measures how spread-out the data are about their mean. A higher standard deviation value indicates greater spread in the data. The greater the variance is the greater the spread in the data. Figures 7 showed the diagrammatical presentation of these statistics. The values achieved showed good performance of the fired clay-SDA and Clay-SDA-IOTW bricks. Table 6 showed the strength of the relationships between the various parameters studied. (Linear shrinkage, water absorption, density, and compressive strength). They showed high correlation values (r^2: > 86 %), signifying strong relationship between the firing temperatures and clay composites. They are equally significant with p-value < 0.05. Therefore, it can be concluded that the additives used and firing temperatures on clay bricks were the major influence in the production of bricks, and they affected the final product. Cultrone et al [12] held the same view.

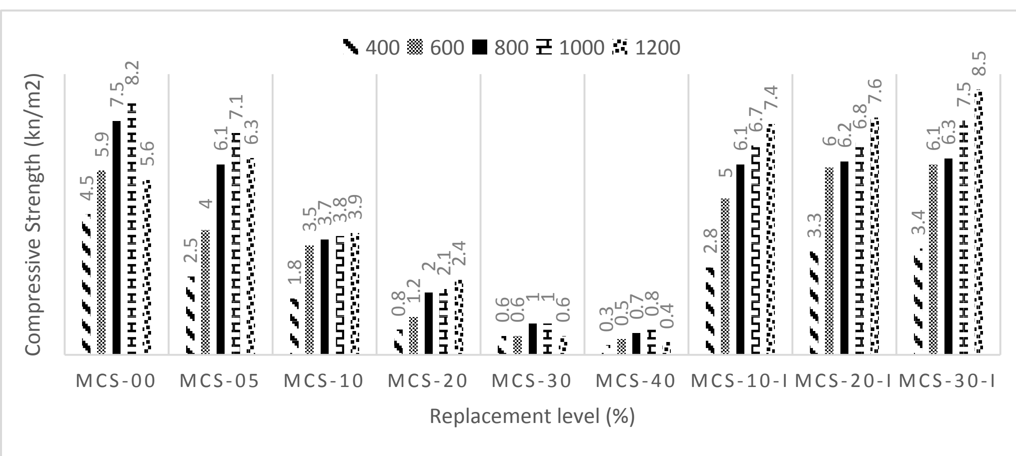


Figure 6. Compressive Strength (kN-m^2)

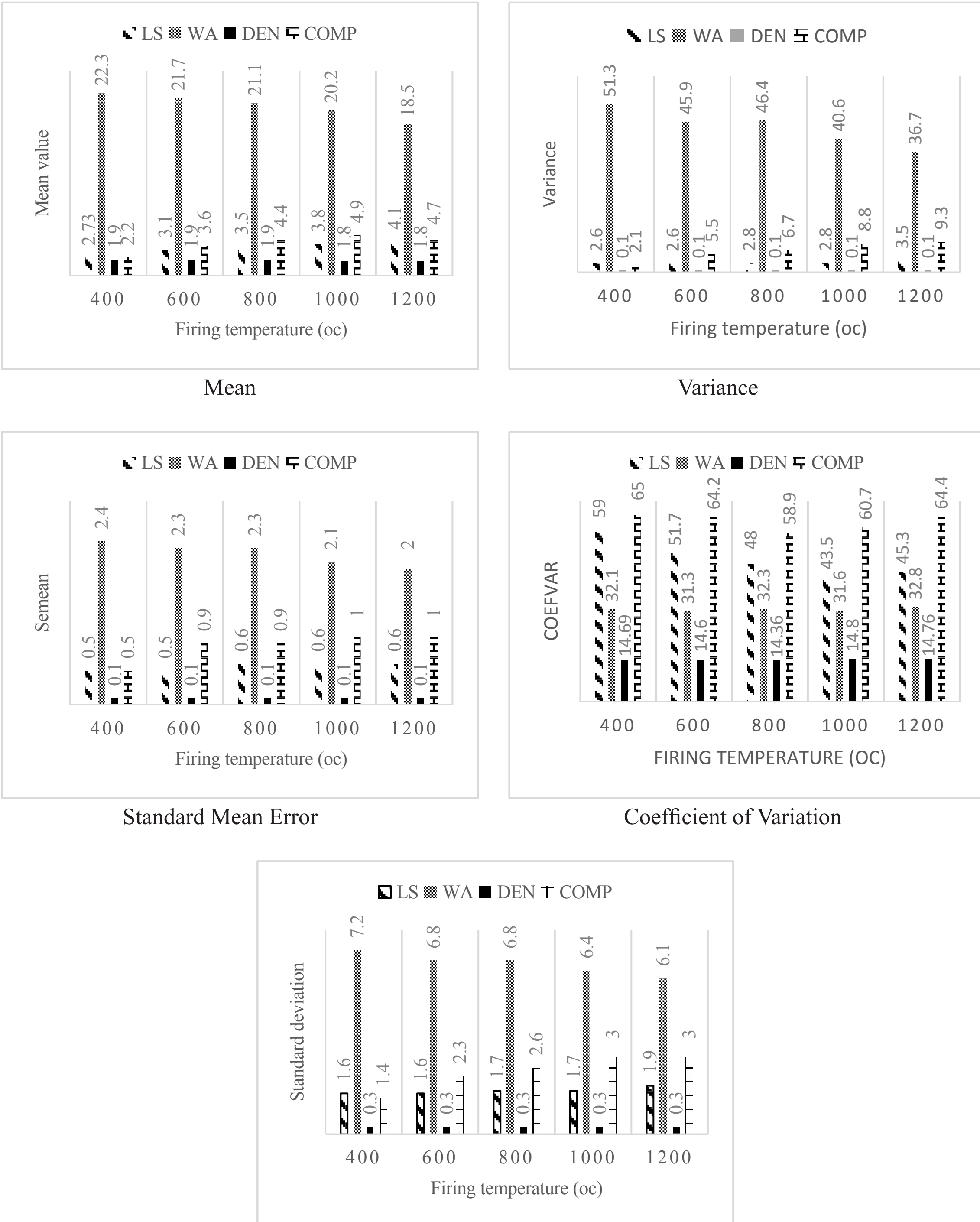
DOI: https://doi.org/10.30564/jbms.v3i2.3732

Table 5. Basic Statistics of SDA Ash-Lateritic Bricks

Property	Temp (oC)	Mean	SE Mean	StDev	Variance	CoefVar
Linear Shrinkage (%)	400	2.73	0.5	1.6	2.6	59.0
	600	3.1	0.5	1.6	2.6	51.7
	800	3.5	0.6	1.7	2.8	48.0
	1000	3.8	0.6	1.7	2.8	43.5
	1200	4.1	0.6	1.9	3.5	45.3
Water Absorption (%)	400	22.3	2.4	7.2	51.3	32.1
	600	21.7	2.3	6.8	45.9	31.3
	800	21.1	2.3	6.8	46.4	32.3
	1000	20.2	2.1	6.4	40.6	31.6
	1200	18.5	2.0	6.1	36.7	32.8
Density (mg-m^3}	400	1.9	0.1	0.3	0.1	14.69
	600	1.9	0.1	0.3	0.1	14.60
	800	1.9	0.1	0.3	0.1	14.36
	1000	1.8	0.1	0.3	0.1	14.80
	1200	1.8	0.1	0.3	0.1	14.76
Compressive Strength (kN-m^2)	400	2.2	0.5	1.4	2.1	65.0
	600	3.6	0.9	2.3	5.5	64.2
	800	4.4	0.9	2.6	6.7	58.9
	1000	4.9	1.0	3.0	8.8	60.7
	1200	4.7	1.0	3.0	9.3	64.4

Table 6. Correlation and P-Values of Sawdust Ash Lateritic Bricks

Property	**Temp (oC)**	**400**	**600**	**800**	**1000**
Linear Shrinkage (%)	600	0.990 (0.000)			
	800	0.987 (0.000)	0.995 (0.000)		
	1000	0.977 (0.000)	0.986 (0.000)	0.988 (0.000)	
	1200	0.977 (0.000)	0.979 (0.000)	0.988 (0.000)	0.992 (0.000)
Water Absorption (%)	600	0.997 (0.000)			
	800	0.994 (0.000)	0.997 (0.000)		
	1000	0.981 (0.000)	0.990 (0.000)	0.995 (0.000)	
	1200	0.951 (0.000)	0.970 (0.000)	0.969 (0.000)	0.978 (0.000)
Density (mg-m3)	600	0.997 (0.000)			
	800	0.994 (0.000)	0.998 (0.000)		
	1000	0.992 (0.000)	0.996 (0.000)	0.999 (0.000)	
	1200	0.990 (0.000)	0.997 (0.000)	0.998 (0.000)	0.997 (0.000)
Compressive Strength (kN-m2)	600	0.961 (0.000)			
	800	0.970 (0.000)	0.964 (0.000)		
	1000	0.961 (0.000)	0.960 (0.000)	0.997 (0.000)	
	1200	0.855 (0.000)	0.947 (0.000)	0.923 (0.000)	0.933 (0.000)



Mean

Variance

Standard Mean Error

Coefficient of Variation

Standard Deviation

Figure 7. Basic Statistical Indicators of Fired Bricks

Linear Regression Model of the Clay-SDA Fired Bricks

Linear regression analysis was performed on the experimental data collected on the clay-SDA fired brick samples. The table of values is shown in Table 7. The normality and residual plots are shown in Figure 8. The regression models are significant with p-values < 0.005. The constant and mix are equally significant. However, the p-value for the Temp are greater than 0.005 for the water absorption and density, respectively. These values (water absorption and density) do not invalidate the significance of the regression models but may indicate that the evidence is not strong enough to suggest an effect exists.

  DOI: https://doi.org/10.30564/jbms.v3i2.3732

Table 7. Regression Model Data

Property	Transformation	Equation			Characteristic		Static		
		Const	Mix	Temp	S	R^2	Var	*p*-value	Signif
WA	Box-Cox Rounded λ = 0.25 Estimated λ = 0.25 95 % CI for λ = (0.10, 0.40)	+9.96	+3.90	-0.07	2.0265	91.97	Const Mix Temp RegModel	0.000 0.000 0.838 0.000	Signif Signif NSignif Signif
Density	None	+2.13	-0.11	-0.001	0.0677	89.11	Const Mix Temp RegModel	0.000 0.000 0.894 0.000	Signif Signif NSignif Signif
(Comp)^2	None	+1.85	-0.16	-0.04	0.1306	82.70	Const Mix Temp RegModel	0.000 0.000 0.041 0.000	Signif Signif Signif Signif

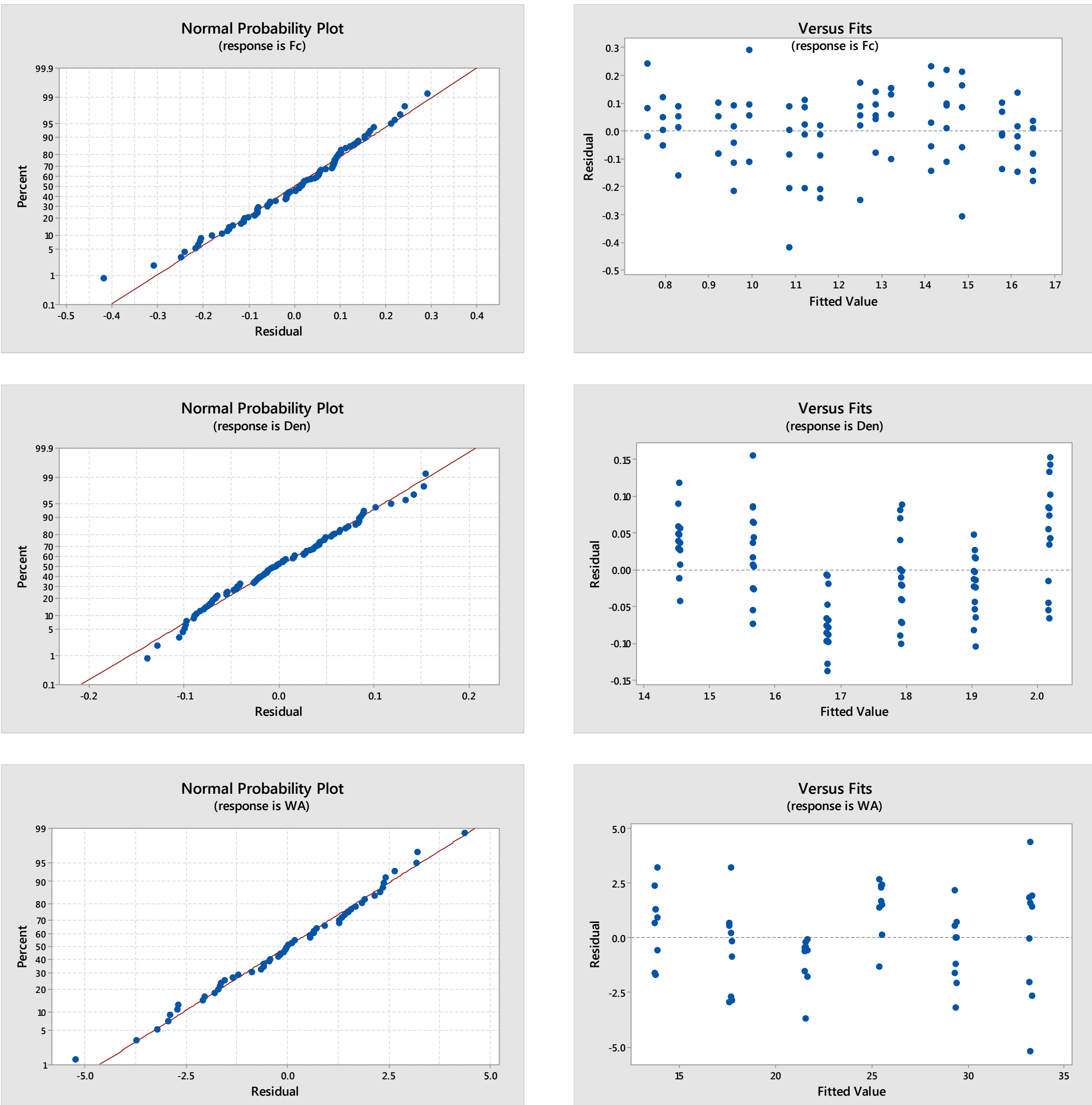


Figure 8. Normality and Residual Plots of the Regression Models

5. Conclusions

This work addresses the changes in properties of clay-based bricks upon the addition of two waste materials, namely a sawdust ash (SDA) and iron ore tailing wastes (IOTW). It is advocated in this research that such practice would bring benefits to both the waste producers and the ceramic industries. An evaluation and effect, on the use of additives (SDA and IOTW), and the firing temperatures, have been carried out on clay samples, using experimental data, to ascertain the levels of their effectiveness in fired clay bricks. The followings are the conclusions derived from the work.

1) The linear shrinkage increased as the firing temperatures increased for all types of clay bricks considered. However, the additions of SDA and IOTW had different level of effects on the fired clay bricks. The linear shrinkage was reduced by their inclusion but better performance was recorded for the fire brick samples containing IOTW.

2) The water absorption, a property of durability was reduced for all types of clay bricks as the firing temperature was increased. The addition of SDA recorded higher values of water absorption than the control bricks, signifying not a suitable material when water absorption is considered. However, the values obtained when IOTW was added showed that the defects in using SDA can be remedied using IOTW.

3) The density of the clay bricks is affected by the firing temperatures across all types of clay bricks and more pronounced with the addition of SDA. From the data obtained, addition of SDA and firing to different temperature will produce lightweight bricks. These defects again are corrected using IOTW.

4) The compressive strength increased both with firing temperatures and percentage replacements for all the types of clay bricks considered. The optimum firing temperature for the control samples was 1000^{o}C. The same firing temperature was attained for 5 % wt. % SDA. A much reduced strengths was recorded for other replacements. Therefore, the use of SDA will not improve the compressive strength of fired clay bricks. However, the inclusion of IOTW markedly improved the compressive strength. The best firing temperature was 1200^{o}C at all the three additions. The sensitivity analysis and regression models showed that the use of SDA and IOTW for clay bricks will produce good fired bricks judging from the data collected on the experimental works.

References

[1] M Sutau, H Alptckin, E Erdogmus, Y Er, O Gencel (2015). "Characteristics of fired clay bricks with waste marble power addition as building materials," Construction and Building Materials, 82, 1-8.

[2] S Janbuala and T Wasanapiarnpong (2016). "Light-weight clay brick ceramic prepared with bagasse addition." ARPN Journal of Engineering and Applied Sciences, 11 (13), 8380-8384.

[3] Aouba, Laila and Bories, Cécile and Coutand, Marie and Perrin, Bernard and Lemercier, Hervé *Properties of fired clay bricks with incorporated biomasses: Cases of Olive Stone Flour and Wheat Straw residues.* (2016) Construction and Building Materials, 102 (Part. 1). 7-13. ISSN 0950-0618.

[4] AA Kadir, NA Sarani, MMAB Abdullahi, MC Perju, AV Sandu (2017). "Study on fired clay bricks by replacing clay with palm oil waste: Effects on physical and mechanical properties," International Conference on Innovative Research – ICIR EUROINVENT IOP Conf. Series: Materials Science and Engineering 209, 012037.
DOI: 10.1088/1757 – 899x/209/1/01 037.

[5] Srisuwan A, Sompech S, Saengthong C, Thaomola S, Chindraprasirt P, and Phonphuak N (2020). "Preparation and properties of fired clay bricks with added wood ash." Journal of Metals, Materials and Minerals, 30, (4), 84-89.

[6] Elinwa AU (2006). "Effect of addition of sawdust ash to clay bricks." Civil Engineering and Environment Systems, 23 (4), 263-270.

[7] ASTM C210-95 (2019). Standard Test Method for Reheat Change of Insulating Firebrick.

[8] ASTM C 373-88 (2006). Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products.

[9] ASTM C216-19 (2019). Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale).

[10] BS 1377-4:1990. Methods of Test for Soils for Civil Engineering Purposes. Compaction-Related Tests – BSI British Standards.

[11] E. K. Arthur & E. Gikunoo | (2020) Property analysis of thermal insulating materials made from Ghanaian anthill clay deposits. Cogent Engineering, 7:1, 1827493.
DOI: 10.1080/23311916.2020.1827493.

[12] G Cultrone, E Sebastian, MJ de la Torre (2005). "Mineralogy and physical behavior of solid bricks with additives." Construction and Building Materials, 19, 39-48.

  DOI: https://doi.org/10.30564/jbms.v3i2.3732