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COMPARATIVE EVALUATION OF INNOVATIVE LATERITE-SAWDUST BLENDS AS ALTERNATIVE APPROACH TO BRICK PERFORMANCE: FOCUS ON STRENGTH AND DURABILITY

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Abstract - Energy consumption in conventional buildings has been steadily increasing due to the reliance on air conditioning for comfort. Heat during the day can easily penetrate through walls because of the high thermal conductivity of concrete, making rooms uncomfortably hot. Additionally, the rising costs of building materials have prompted research into available local materials and waste products that can serve as alternative building materials at little or no cost. In addressing these issues, this study aims to evaluate the strength performance of bricks produced from laterite and sawdust, which can help maintain a clean and cool environment. Two approaches were employed in this study: laboratory and mathematical modeling methods. Laboratory tests like; Natural moisture content; Specific gravity; Sieve analysis; Atterberg limits; Compaction tests were conducted on the laterite and sawdust materials for proper identification and classification. Forty bricks, measuring 220 mm x 110 mm x 66 mm, were produced for compressive strength and water absorption tests, with sawdust replacement levels of 0%, 2.5%, 5%, 10%, and 15%. These bricks were molded, dried, and fired in a furnace at a sustained temperature of 300 °C for two hours to enhance their strength. The laboratory analysis indicated that the laterite-sawdust bricks at the various percentage replacement gained strength of 0.66N/mm^2, 0.97N/mm^2, 0.768n/mm^2, 0.841N/mm^2 and 0.819N/mm^2 respectively. The optimum strength being at 2.5% sawdust replacement and these bricks can be used for non-load-bearing walls, although they exhibited a limited water absorption capacity. The mathematical model developed correlated well with the laboratory data, and the statistical assessment of the model's accuracy yielded a coefficient of determination (R^2) value of 0.9899 and a coefficient of correlation (CORR) value of 0.99.

Keywords: Laterite-Sawdust Bricks; Energy consumption; Mathematical modelling; Water Absorption capacity; Thermal conductivity; Sustainable materials

1. Introduction

In the recent past years, the use of recycled materials and alternaties in construction is on the rise because of the increasing cost of building materials and most time the need to preserve the depletion of existing raw materials thereby reducing negative effect of wastes (agricultural wastes, construction wastes, industry wastes) disposal to the ecosystem (Cusido *et al*, 2003). It is opined that sustainable building is an essential aspect to achieve ecologically responsible world thus, building materials chosen and used should be without any adverse effects on the environment. These alternatives should possess relatively the same or even better quality and durability to those of conventional materials, at much lower price (Zipeng et al., 2018). Laterite is a soil-rock type rich in iron and aluminium and commonly considered to be formed in hot and wet tropical areas (Guarav and Ajay, 2017; Oyelami and Van-Rooy, 2016). They are gotten from the wearing away of the parent rock (weathering). Most lateritic soils are rusty red in colour as it contains high iron oxide content (Guarav and Ajay, 2017) with the clay minerals playing important role in the binding process (Oyelami and Van Rooy, 2016; Saravanan and Venkatswara, 2023). Laterite can be taken as the best material in compressed earth bricks because of its well graded nature combining the cohesive and cohesion-less parts of the soil respectively (Oyelami and Van Rooy, 2016). The uses of laterite include as; Construction Material, Agriculture, Water Filtration, Art and Craft, Historical Monuments, Landscaping and Hardscaping, Erosion Control, Cultural and Traditional Practices, Aquarium Substrate (Akhilesh and Butala, 2020; Oyelami and Van Rooy, 2016). The use of laterite has enhanced the realization of decent housing thereby reducing problems of housing in Nigeria and Africa at large (Oyelami and Van Rooy, 2016). Lateritic soil has bearing capacity that is high due to low cohesion and high angle of internal friction and used as good engineering construction material (Oyelami and Van Rooy, 2016; Guarav and Ajay, 2017), hence the reduction of cement used in construction as it reduces the emission of carbon dioxide (CO_2) and other energies used in construction works (Djoumen *et al, 2023).*

Saw-dust, a by-product of wood is gotten from working operations like sawing, milling, planning, routing, drilling and sanding (Adebakin et al., 2012; Ugwu, 2019) by using wood working machinery, portable power tools or by use of hand tools. Saw-dust comprises of fine particles of wood which can be valuable in Manufacturing, Energy and Agricultural utilization (Rominiyi *et al.*, 2017; Adebakin et al, 2012) and can cause some hazards like fire and occupational dust exposures in some manufacturing industries (Owoyemi et al.,2016; Maharlika and Aida, 2020). The assessment of sawdust generated in Nigeria annually amounts to about 1.8million tons and about 5.2 million tons of wood wastes (Akinyele *et al.,* 2020). With this statistics, improper disposal of wood wastes could impact negatively on the environment affecting both the aquatic and terrestrial ecosystems (Akhilesh and Butala, 2020) leading to serious health issues. These wastes when burnt improperly, the greenhouse gases are released into the atmosphere (Owoyemi et al, 2016) posing a big threat to humans and the environment (Ugwu and Ugwuanyi, 2020). The increasing cost of building materials has compelled researchers towards the use of available local materials and wastes (sawdust) as alternative eco-friendly building materials. Saw-dust waste naturally possesses distinctive properties and potentials to absorb water (Ugwu, 2019) and as well retain water, hence its enhanced performance on bricks for improved thermal insulation (Mgbemene et al. 2019; De-Silva and Perera, 2018). Mwango and Kambole, (2019) worked on saw-dust composites and their study revealed some advantages of using saw-dust composites which include good modulus of elasticity, water and sound absorption, low heat conduction, good insulation and strength characteristics with these satisfying international specifications. Examples of these composites include particleboards, saw-dust concrete blocks or bricks (light weight porous bricks) and saw-dust concrete and are very attractive in the construction industry (Mwango and Kambole, 2019). There are indications from studies that the use of saw-dust composites in construction industry will help in curbing potential pollution (land, air), energy conservation and unnecessary cost arising from disposing saw-dust waste (Ugwu, 2019; Shohag et al, 2022; Saravanan and Venkateswara, 2023), hence the usefulness of saw-dust waste to the construction industry. Some studies have revealed that even beyond the strength of the bricks produced using wastes, sourcing of these waste materials tackles and solves the global waste problem in little ways with wastes (biodegradable and non-biodegradable) example sawdust, waste plastic, glass by-products, etc. incorporated in production of bricks (Oubaha et al., 2023; Shohag et al., 2022).

Light weight porous bricks are widely used for building in Nigeria, and it is observed that lateritic clay suitable for making these high strength bricks are readily available (Oyelemi and Van-Rooy, 2016). Light weight porous bricks tend to eliminate back problems associated with laying normal bricks, allowing for quicker and easier construction times hence, saving time and labour costs. Even though bricks are light weight, the bricks from green energy bricks are also structural and load bearing (Akinyele et al., 2020). Besides cracks, compressive strength and water absorption are the two major physical properties of bricks that are potential interpreters of their ability to sustain weathering effects (Akinyele et al., 2020). The use of lateritic clay soil and sawdust to produce bricks saves a lot of energy and economical (De-Silva and Perera, 2018; Shohag et al., 2022; Djoumen et al, 2023) and is one way to boost insulation capacity of bricks to thermal activities as bricks constitute a unique class amongst man made structural components for civil engineering work. In buildings, walls are constructed using bricks as, either load bearing or non-local bearing to provide shelter, protection, conveniently divide space, privacy, security for man and his properties (Saravanan & Venkateswara, 2023; Akinyele et al., 2020). Adebakin et al. (2012) showed in their study which investigated the use of sawdust as an admixture in sandcrete blocks production by partially replacing sand with sawdust, that sawdust-sandcrete blocks are eco-friendly and reduction of structural loadings due to the reduction in weight of blocks.

Researchers including Dymiotis and Gutlederer’s (2002); Thaicavil and Thomas, (2018), applied mathematical models in bricks study which predicted the strength of eco-friendly brick masonry work and reduced tedious laboratory experiments. This study is on the production of bricks from sawdust and laterite material for good mechanical strength, durability, and thermal insulation properties suitable for building applications. The addition of sawdust to the bricks is aimed to maintain a cool and comfortable environment within the building during hot weather. This is away from the normal bricks commonly used which in times of hot weather, heat can easily penetrate the building wall causing discomfort and restlessness. Two approaches were employed in this study viz: laboratory method and mathematical method. From these methods, useful data were generated. The produced bricks can be applied in; kiln and oven construction, heat and sound insulation in homes and buildings; local oven for bread industries; fence walls, load and non-load bearing walls for buildings. The mathematical model approach was able to predict the laboratory information on the bricks in reduced time to help reduce the tedious laboratory and experimental works involved facilitating data generation.

2. Materials and Methods

Figure 1: Laterite material

2.1 Materials

The materials used in this study were all locally sourced and readily available encouraging production by the natives. They include.

i. Laterite; gotten from an excavated pit in ESUT, Agbani, Enugu State at a depth of about 8ft. The sample is reddish-brown in colour as in Figure 1.

ii. Sawdust; gotten from Timber shade, Enugu, Enugu State. The sawdust is in powdery form had a combination of pale yellow, brown and red colors due to the varieties of sawn timbers in Figure 2.

iii. Water; gotten from the laboratory water storage. The water was colourless and odourless.

iv. Fabricated 220 x 110 x 66mm wooden mould (Figure 3) constructed in the ESUT wood workshop with Afire hard wood bought from Kenyatta Timber Market.

Figure 2: Sawdust material

Figure 3: Greased wooden moulds

2.2 Methods

There are two approaches employed namely, Laboratory method and Mathematical model method.

2.2.1 Laboratory method

The laboratory approach employed the use of standard experimental tests in investigating the durability and sustainability of saw-dust bricks. The production of the lightweight porous bricks was conducted at Civil Engineering Department Laboratory of Enugu State University of Science and Technology. The laterite material was spread on a flat surface in the lab to air dry as seen in Figure 1. Other bigger and unwanted materials were handpicked and removed. The sawdust was also spread to air dry during which the unwanted materials were handpicked and removed as well. The standard laboratory tests were conducted on the materials.

2.2.2 Laboratory Tests

The tests performed on the laterite and saw-dust materials include Natural moisture content test; Specific gravity test; Sieve analysis; Atterberg limits; Compaction; Compressive strength; Water absorption test

Natural Moisture Content test (Laterite):

This test measures in a given soil mass the ratio of weight of water to the weight of the solids for natural water content

Specific Gravity Test (Laterite and Saw-dust)

This test measures the density of a liquid as compared to the density of an equal volume of water at a specific temperature.

Sieve Analysis Test (Laterite and Saw-dust):

The sieve analysis test was done on the laterite and saw-dust materials for the particle size distribution and classification.

Atterberg Limit Test (Laterite)

The atterberg limit test is a basic measure of the critical water contents of a soil sample (fine-grained soil); its shrinkage limit, plastic limit and liquid limit.

Compaction Test (Laterite)

This test is performed to determine the soil compaction level and is sometimes called the moisture content and dry density relationship of a soil.

Compressive Strength Test

This test was done to determine the strength capacity of the produced bricks.

Water Absorption Test

The water absorption capacity of the produced bricks was determined using this test. That is the ability of the bricks to be affected by water

2.3 Brick Production

The laterite clay was crushed using a mould and a rammer to further reduce the particle size to pass through sieve 1.18µm. The sawdust (wood dust) was already obtained in a powder like form but sieved further using the sieve 600µm to obtain a better granular form. 8.96kg of sieved lateritic clay soil was measured and put a tray. Then 0%, 2-5%, 5%, 10% and 15% of saw-dust replacement added in terms of weight respectively. The water added according to the moisture content and liquid limit tests. The mixing was done by manual hand mixing in flat smooth tray. After mixing for each saw-dust replacement, two parts of the sample were collected, weighed and placed in the oven to determine the natural moisture content. The mixture was placed in the fabricated wooden moulds (220 x 110 x 66mm) and pressed under pressure for good compaction as in Figure 4. The mould was laced with nylon to facilitate de-moulding because of the sticking nature of the laterite-sawdust mixture.

Figure 4: Mixing and casting the bricks

Figure 5: some moulded bricks

The bricks were de-moulded after 3 days under air drying. This was to allow the casted bricks to set well. The bricks were further air dried after de-moulding for 10days to reduce cracking of the bricks and further setting (Figure 5). After this, the bricks were further processed by sun drying for 14 days to dry well before again oven drying for 72hrs. This is to achieve a well dried brick. The bricks were fired in the furnace to attain their maximum strength at 300^{o}C sustained for 2 hours after which the fired bricks were allowed to cool down before removing from the furnace. The bricks were weighed before and after firing and crushed for its compressive strength test. Some of these fired bricks were used to perform the water absorption test for their behaviour when exposed to moisture.

2.4 Mathematical Model Development

This approach involves generating a non-linear regression model that can predict the compressive strength of sawdust-laterite bricks considering the laterite-sawdust percentage replacements, weight of the bricks before and after firing in furnace.

2.5 Statistical Assessment and Verification

This process was to assess and verify the developed model for accuracy and reliability. The statistical evaluation criteria used was Coefficient of Determination R^2 and Coefficient of Correlation CORR verified using the laboratory results

3.0 Results and Discussion

The results of the tests performed showed that the average moisture content of the laterite soil is 16.25%. Specific gravity of the laterite and saw-dust respectively are 2.11 and 1.24. The atterberg limit test yielded that the liquid limit

(LL) as 38%, plastic limit (PL) as 4.05% and plasticity index (PI) as 34.20%. This high value of consistency indicated the presence of high clay content. From the soil classification system according to AASHTO (American Association of State Highway and Transportation Officials), the soil used in this study is classified as A-6, revealing that the soil is clayey. The texture of the mixed samples got rougher with increased sawdust addition and kneading or mixing the samples was easier with increase of saw-dust content. Also, the addition of sawdust made the mixture to become lighter in colour than without saw-dust and compaction was easier too. The bricks took a long time to set which made the de-moulding of the bricks difficult. There was an obvious shrinkage in the size of the bricks a few days after moulding especially for bricks with more saw-dust content. Figure 6 showed the weight of the bricks before and after firing in the furnace. The firing in the furnace was to add more strength to the bricks. The firing showed that bricks weight after firing reduced when compared to its weight before firing as a result of more water loss in the bricks.

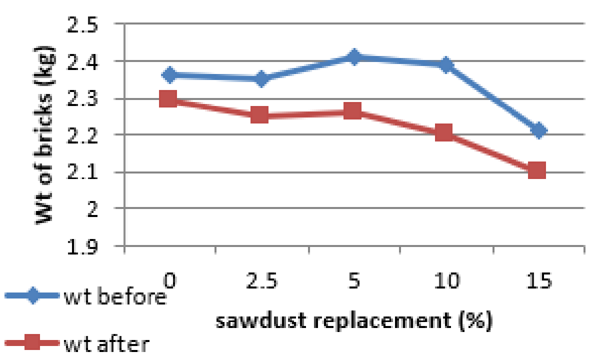

Figure 6: Weight of the bricks before and after firing

Figure 6 further showed that as the percentage saw-dust replacement increases, there is reduced weight in the bricks. This reflected in the compressive strength of the bricks from Figure 7 which revealed that optimum strength attained by the bricks was at 2.5% sawdust replacement. Though the strength of the produced bricks was lower than the standard, which can be from the type of laterite soil used, the method employed in producing the bricks. But there is evidence of increase in strength from the saw-dust replacement.

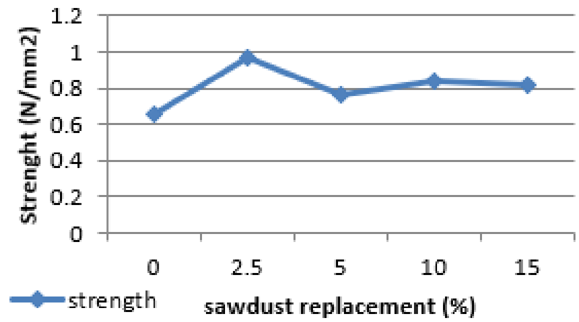

Figure 7: Compressive strength of the bricks

It was observed that from Figure 8 and Figure 9, the bricks at saw-dust replacement of 0% , 2.5% and 5% was totally dissolved in water while 10% and 15% attained water absorption capacity of 13.18% and 14.74% respectively after 24 hours immersion. One can say that 10% and 15% saw-dust replacement bricks performed better under prolonged moist condition. Maybe because of the high saw-dust content that absorbed most of the water and this retained water in the bricks will tend to lower its thermal conductivity and keep the room environment cool.

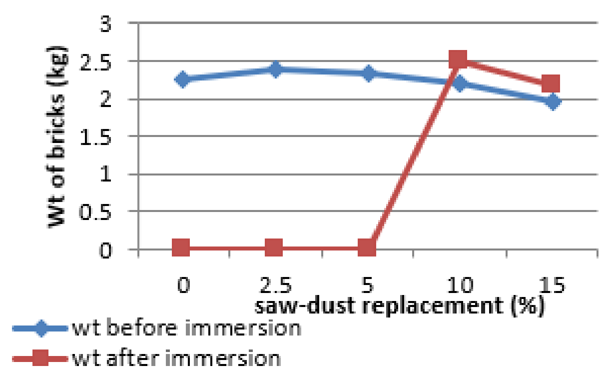

Figure 8: weight at immersion of the bricks

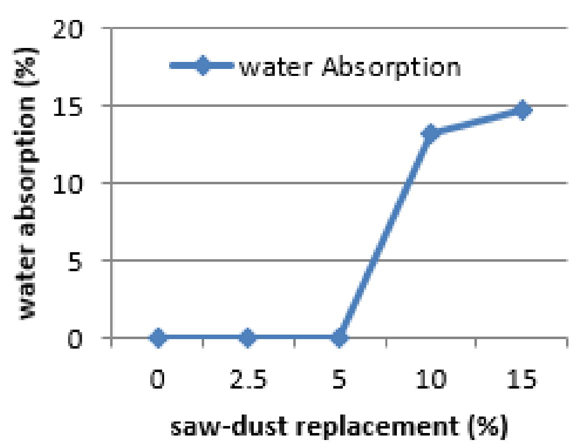

Figure 9: Water absorption of the bricks

The presence of sawdust in the bricks varied directly with the moisture content of the bricks indicating that the higher the percentage replacement, the higher the moisture content of the bricks; at 0%, 2.5%, 5%, 10% and 15% saw-dust replacement, the bricks moisture content gave; 21.64%, 31.09%, 34.29%, 39.30% and 43.89% respectively. The sawdust absorbed more water during mixing making it have a shorter time to completely knead into a homogeneous mix.

3.1 Mathematical Model Development

Mathematical model was developed to predict the average compressive strength of Lateritic bricks blended with (sawdust) Timber Waste (TW) at various percentage replacement content. The dependent variable is the Average compressive strength while the independent variable is saw-dust waste content. The model equation is shown in Equation 1.

$$F_c = \beta_1 e^{\beta_2 \delta} \qquad (1)$$

F_c means average bricks compressive strength in N/mm^2, δ is the Timber Waste content (%), β_1 and β_2 are constants. Applying natural logarithm on both sides of equation 1 we obtain.

$$lnF_c = ln\beta_1 + \beta_2\delta \qquad (2)$$

$lnF_c \equiv Y, ln\beta_1 \equiv a, \delta \equiv x,$ and $\beta_2 \equiv b.$

$$\therefore\ Y = a + bx \qquad (3)$$

By the process of calibration, the constants a and b can be determined using Equations 4 and 5 thus.

$$a = \frac{n\sum Y}{n} - b\frac{\sum x}{n} \qquad (4)$$

$$b = \frac{n\sum Yx - \sum x \sum y}{n\sum x^2 - (\sum x)^2} \qquad (5)$$

Mathematical model was further developed to predict the weight of the lateritic bricks after firing. The dependent variable is the weight of the bricks after firing while the independent variables are the saw-dust waste content and weight of the bricks before firing. The model equation is as shown in Equation 6.

$$W_{AF} = a + b\delta + cW_{BF} \qquad (6)$$

W_{AF} is the Weight of the Lateritic bricks after firing (kg), W_{BF} is the Weight of the Lateritic bricks before firing (kg), δ is the Timber Waste (TW) content (%) and a, b and c are constants. Equation 3.6 can be transformed to a polynomial equation thus.

$$Y = a + bx_1 + cx_2 \qquad (7)$$

In determining the constants, a, b and c, using Equation 8 thus.

$$\begin{aligned} an + b\sum x_1 + c\sum x_2 &= \sum Y \\ a\sum x_1 + b\sum x_1^2 + c\sum x_1 x_2 &= \sum Yx_2 \qquad (8) \\ a\sum x_2 + b\sum x_1 x_2 + c\sum x_2^2 &= \sum Yx_2 \end{aligned}$$

3.2 Model Verification

In the determining the strength properties of Laterite-Sawdust blended bricks, the graph of average compressive strength against saw-dust waste content is as shown in Figure 10. The highest value of average compressive strength of the laterite-sawdust blended bricks was recorded as 0.97N/mm^2 at 2.5% saw-dust waste content. Therefore, according to the study, the optimum saw-dust waste content is 2.5%. It is also worthy of note that the control which is 0% saw-dust waste content had the least average compressive strength value of 0.66N/mm^2. This is a veritable indication that the addition of saw-dust waste to laterite in local bricks production will generally lead to enhanced strength properties.

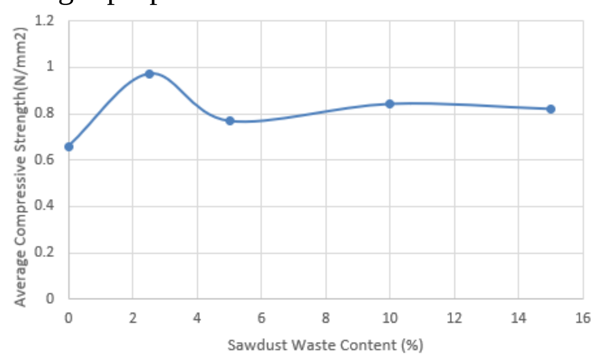

Figure 10: Average compressive strength against sawdust waste content

In comparing the plots of the brick's average compressive strength of the laboratory observed and the compressive strength of the predicted from Equation 9 and given in Figure 11, it is shown that developed model made a fairly accurate prediction on the average compressive strength. From statistical assessment, the model gave coefficient of determination R^2 value of 0.9899 as shown in Figure 12, resulting to coefficient of correlation CORR value of 0.99 and it is accurate.

$$F_c = 0.7729e^{0.0063\delta} \qquad (9)$$

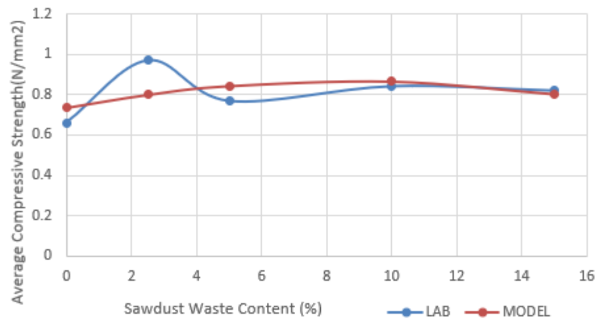

Figure 11: Model verification of average compressive strength of the Lateritic bricks

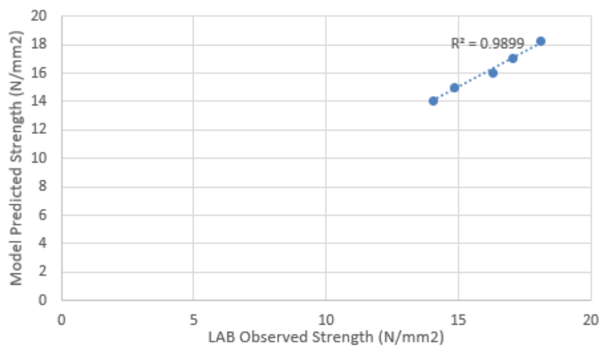

Figure 12: Coefficient of determination of the average compressive strength

In the determination of the weight of the laterite-sawdust blended bricks both before and after firing, Figure 13 shows the plots of the weight of bricks against the saw-dust waste content. Due to the loss of moisture during firing, the bricks had more weights before than after firing. However, at 2.5% saw-dust content the bricks had uniform weights before and after firing.

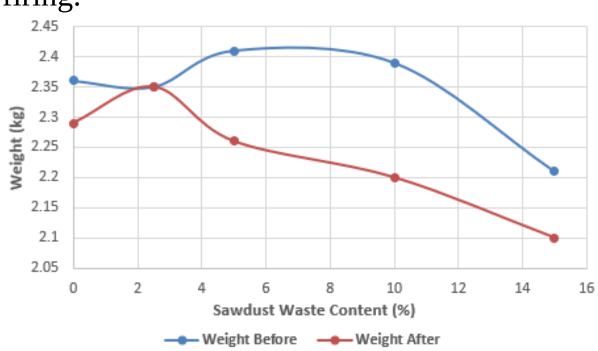

Figure 13: Plots of weight of the bricks before and after firing

Comparison of the plots of the weight of the bricks after firing for the laboratory observed and the predicted from Equation (10) and as seen in Figure 14, that the developed model accurately predicted the weight after firing or heating in the furnace. The accuracy of the model gave coefficient of determination R^2 value of 0.8681 from Figure 15, giving coefficient of correlation CORR value of 0.93.

$$W_{AF} = 2.0025 - 0.0135\delta + 0.1387W_{BF} \quad (10)$$

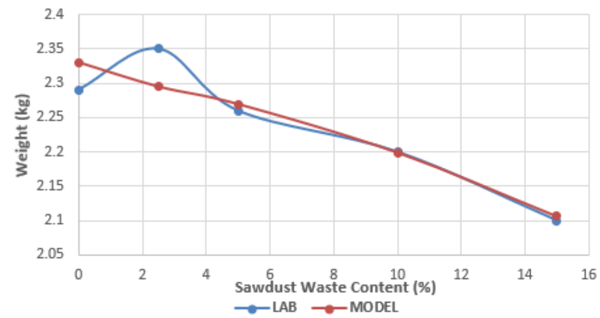

Figure 14: Model verification of the weight of bricks after firing

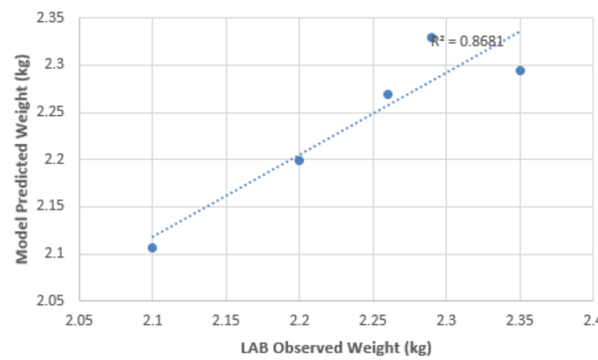

Figure 15: Coefficient of determination of weight of bricks after firing

4. Conclusion and Recommendation

The results from this analysis have shown the importance of recycling wastes for use in the construction industry. The use of sawdust and laterite in bricks production indicated the usefulness of waste in keeping the environment cool, calm and comfortable. The use of sawdust also showed the strength of the bricks produced at the various replacement levels according to Figure 7. with the optimum strength at 2.5% saw-dust replacement. Table 1 showed that the presence of sawdust in the bricks varied directly with the moisture content of the bricks indicating the higher the percentage replacement, the more moisture content of the bricks from the high water-absorption capacity of saw-dust content. The AASHTO standard of soil classification revealed that the soil used in this study is of class A-6 which are not adequate as a construction material for subgrade or sub-base materials in road construction unless when stabilized. A-6 class of laterite are also not so good in bricks production, hence the slow strength attained by the produced bricks. A-7 class of laterite are best in bricks production. The 2.5% sawdust bricks gave a better strength when compared to others. It is also worthy of note that the control 0% saw-dust waste content had the least average compressive strength value of 0.66N/mm^2 in Figure 7 indicating that the addition of saw-dust waste to laterite in local bricks production generally lead to enhanced strength properties. In comparison of the average compressive strength of the bricks for laboratory observed with the predicted model considering Equation 9 and Figure 11, it was shown that the developed model made a fairly accurate and significant agreement on the prediction of the compressive strength. From statistical assessment, the model gave coefficient of determination R^2 value of 0.9899 as shown in Figure 12, resulting to coefficient of correlation (CORR) value of 0.99 and it is accurate. Comparison of the weight of the bricks after firing for the laboratory observed and the predicted from Equation 10 and Figure 14 revealed that the developed model accurately predicted the bricks weight after firing or heating in the furnace. The coefficient of determination R^2 value of 0.8681 was gotten as shown in Figure 15, resulting to coefficient of correlation CORR value of 0.93. The model predicted the laboratory results accurately, hence recommended to reduce tedious laboratory works and when quick and reliable data is required.

Declaration of Conflict of Interest

There is no conflict of interest regarding the publication of this works.

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