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Estimation of Properties of Unfired Ceramic Products with Sawdust Additives *(pp.144-156)*

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Abstract

Previously obtained experimental data have been used to develop empirical models to estimate the physical and mechanical properties of unfired ceramic model products with sawdust additives. The models were herein used to study similar product development requiring additives such as straw to meet specific properties with further possible cost reduction. Results can also be used to implement and standardise methods presently observed to be used in producing inexpensive interior walls in many suburbs around the globe. Experimental results and empirical model equations for mixtures investigated, include 60% clay, 20 % cement, 0 – 5 % sawdust (X), which correspond to 20 – 15 % silica sand. The determined properties are respectively, % water absorption [17.54 to 29.70 %]; bulk density [1.69 to 1.43 g/cm^3]; modulus of rupture [54.03 to 7.67 MPa]; and compressive strength [23.20 to 5.86 MPa,]. Only the

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water absorption increased with increased values of sawdust while the bulk density, modulus of rupture and compressive strength indicated reduction. The model estimations were limited to sawdust additives not exceeding 4% for useful practical purposes.

Key Words: Unfired ceramic model products, Empirical model equations, Sawdust additives.

Introduction

It is essential to make exterior walls of buildings with materials and characteristics of high strength and resistance to external environmental factors. On the other hand, cost can be significantly reduced in the construction of interior walls by de-emphasizing the requirement of high strength for their material of construction.This work focused on developing empirical models, making use of previously obtained experimental data obtained elsewhere by Ohijeagbon(1998) to estimate the physical and mechanical properties of unfired ceramic model products with sawdust additives. This will offer useful information on similar product development requiring additives such as straw to meet specific properties with further possible cost reduction. It will also serve to standardise methods presently observed to be used in the production of inexpensive and poorly finished interior walls in building construction practices in Jimma, Ethiopia and possibly many other suburbs around the globe.

The physical properties, namely, %water absorption, and bulk density, as well as the mechanical properties, namely, modulus of rupture, and compressive strength of the ceramic product are the dependent variables, while the independent variables are the %silica, and %sawdust contained in the material components.

Review of Literature

In the past, emphasis had been on ceramic products, such as tiles and bricks, made from clay or a mixture of clays and other ceramic materials, which may either be “glazed” or “unglazed” to acquire specific physical properties and characteristics after firing at appropriate temperature (ASTM, 1985a). In recent times however, ceramic materials have been used to manufacture unfired sun-dried bricks, and laterite-cement blocks from various grades of clay materials (Adeyemi, 1987), particularly to obtain a significant reduction in the production cost: 30–35% lower than that of analogous ceramic bricks because the firing operation is excluded from the production cycle (Gorbacheva and Treshchev, 1999).

Investigations have been carried out by Ohijeagbon (1998) on experimental tiles produced in the laboratory using a vertical mould with a 90-degree angle construction.

The variables and properties of the model ceramic products based on earlier experimental data are related to one another by using appropriate mathematical functions to describe the behaviour of the system of results. The solution of the problem was then obtained by applying numerical techniques to the models using a continuous function to replace the discrete data points (Hoffmann, 2001) in order to obtain values other than the known discrete points.

Materials and Methods

Equipment and Working Materials

A simple vertical metal mould was constructed and used to manufacture experimental tiles of uniform thickness, and facial dimensions of 150mm x 150mm pressed in a mould having a 90-degree angle construction. The mould was made of parts which can easily be assembled and dismantled during or after a moulding operation.

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The raw materials used were clays, silica sand, Portland cement, portable water and saw dust. Cement was the binder while silica sand acted as a stabilizer for experimental tiles produced. Each of the components was mixed according to the variables under investigation (see Table 1) and stirred together for about 3 to 5 minutes before water (13% by mass) was added. The damped mixture was then thoroughly mixed together to eliminate lumps before moulding. Measured quantities for each tile mix was placed in the mould box and then pressed with a punch with a compaction load of 25KN. Cellophane was used to screen the interface of tiles materials and mould parts to avoid sticking of tiles to the mould during compaction. After moulding, the experimental tiles were cured and dried (Dharmendra et al., 1983) at room atmosphere (25-30 ^{0}C).

Experimental Methods

The experimental tests procedures to determine the physical and mechanical properties of tiles specimens were carried out both at the Civil Engineering Laboratory of the University of Ilorin and Kwara Polytechnicc in accordance with the American Society for Testing and Materials ASTM (1985a, b, c, d and e) standard methods and the values were computed and tabulated as shown in Table 1.

Water Absorption

The mass of each specimen tested was first determined by weighing on a weighing balance and their values recorded, as the dry mass, M_d. Each specimen was then submerged in cold water for about 24 hours, after which the specimens were taken out of the water and their surfaces wiped with a piece of cloth to remove surface water. The new mass was determined by weighing and recorded as the saturated mass, M_s. The percentage water absorbed, otherwise known as "water absorption" were then calculated in accordance with the provisions of ASTM (1985b) by using the relation:

$$A = \frac{(M_s - M_d)}{M_d} \times 100\% \qquad (1)$$

where, A = % water absorption

Bulk Density

Test specimens were dried to constant mass after curing, and the dry mass, M_d was determined. The bulk density, B in grams per cubic centimetre, of a specimen is the quotient of the dry mass divided by volume. The volume, V was determined from the surface dimensions, namely length, width and thickness. The bulk density was then calculated (ASTM, 1985c) by the formula:

$$B = \frac{M_d}{V} \tag{2}$$

Modulus of Rupture

The specimens tested were placed horizontally and centrally on two vertical supports of the test rig in an overlapping manner. The specimens were then loaded centrally by means of an overhanging wire cord and a hanger hooked on the wire with which the specimens were loaded with known values of masses until failure occurred. The modulus of rupture for each specimen was calculated (ASTM, 1985d) as follows:

$$M = \frac{8PL}{\pi t^3} \tag{3}$$

where, M is the modulus of rupture (MPa), P is load at rupture (N), L is distance between supports (mm), and t is the average thickness of the specimen tested (mm).

Compressive Srength

Each test specimen was placed between the jaws of a manually operated hydraulic press machine. Load was then gradually applied on tiles via a cylindrical piece of metal of 19.5mm diameter and 30mm in length, until the first line crack was observed. The compressive strength for each specimen was calculated (ASTM, 1985e) as follows:

$$C_s = \frac{P_c}{A_c} \quad (4)$$

where, C_s is the compressive strength of the specimen (MPa), P_c is the total load on the specimen at failure (N) and A_c is the calculated area of the bearing surface on the specimen tested (mm^2).

Theoretical Methods

Quadratic Interpolation

Improvements of estimated values are possible by introducing a curvature into the line connecting the points. If three data points are available (Chapra and Canale, 1998), a second order quadratic polynomial is convenient for this purpose. This is given by;

$$f(x) = b_0 + b_1(X - X_0) + b_2(X - X_0)(X - X_1) \quad (5)$$

where, b_0, b_1, and b_2 are constants given by;

$$b_0 = f(X_0) \quad (6)$$

$$b_1 = \frac{f(X_1) - f(X_0)}{X_1 - X_0} \quad (7)$$

$$b_2 = \frac{\left\{\frac{f(X_2) - f(X_1)}{X_2 - X_1}\right\} - \left\{\frac{f(X_1) - f(X_0)}{X_1 - X_0}\right\}}{X_2 - X_0} \quad (8)$$

where, X_0, X_1, and X_2 are initial known discrete independent data points, while the corresponding dependent values are $f(X_0)$, $f(X_1)$, and $f(X_2)$ respectively. Equations (5) to (8) were used to determine empirical models for Water absorption (A), Bulk Density (B), Compressive Strength (C), and Modulus of Rupture (M) respectively as give in Figures 1 to 4.

Coefficient of Correlation

The amount of linear correlation between two variables is expressed by a coefficient of correlation, given by;

$$r = \frac{\sum(X - \overline{X})(Y - \overline{Y})}{\sqrt{\left\{\sum(X - \overline{X})^2\right\}\left\{\sum(Y - \overline{Y})^2\right\}}} \qquad (9)$$

where, $\overline{X}$ and $\overline{Y}$ being the mean values of the X and Y values respectively. The coefficient of correlation has been determined for each curve as shown in Figures 1 to 4.

Results and Discussion

Table 1 shows the results obtained for the physical and mechanical properties with respect to the materials mix variables.

Table 1: Effect of sawdust on properties of experimental tiles

Mix Variables		**Physical Properties**		**Mechanical Properties**	
Silica Sand (%)	Sawdust (%)	Water Absorption (%)	Bulk Density (g/cm^3)	Modulus of Rupture (MPa)	Compressive Strength (MPa)
20	0	17.54	1.69	54.03	23.20
18	2	20.28	1.68	34.28	15.07
15	5	29.70	1.43	7.67	5.86

The following shows the specifications of the material components used to produce the experimental tiles:

% of water by mass to: (silica + clay + cement + sawdust) = 13%
Dimensions of Tiles (Length x Width) = 150 x 150 mm
Base material = Laterite clay
% of Clay = 60 %
% of Cement = 20%
% Water Addition = 13%
Compaction Load = 25 KN

Maximum particle size of sieved clay used = 1000 μm

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Maximum particle size of silica sand used = 1000 μm
Maximum particle size of sawdust used = 1000 μm

Physical Properties
Water Absorption

Fig.1 shows the relationship between water absorption and the percentage sawdust content for the experimental tiles, the empirical tile models, and the empirical brick models. Their coefficients of correlation are also shown. The curves show increasing values of water absorption with increases in sawdust addition, due to higher moisture absorption capabilities of sawdust.

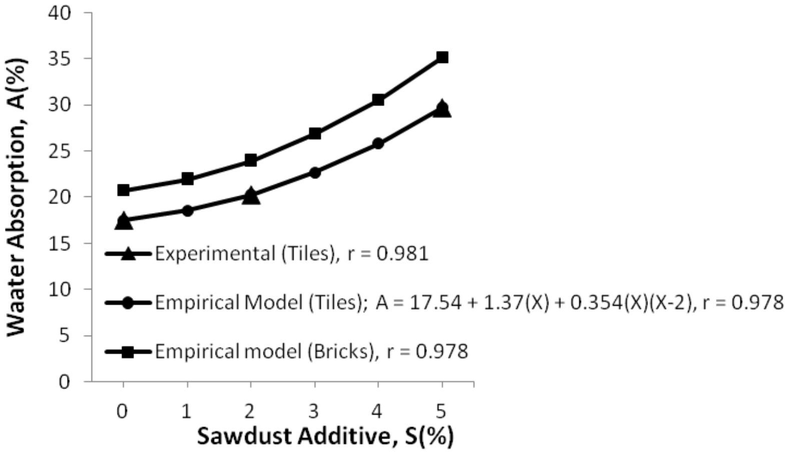

Figure 1: Water Absorption, A versus Sawdust Addititive, S

Bulk Density

Fig.2 shows the relationship between bulk density and percentage sawdust content for the tiles and the bricks. The figure reveals decreasing values of bulk density with increases in sawdust addition, due to lower relative density of sawdust as compared with other material constituents in the specimens.

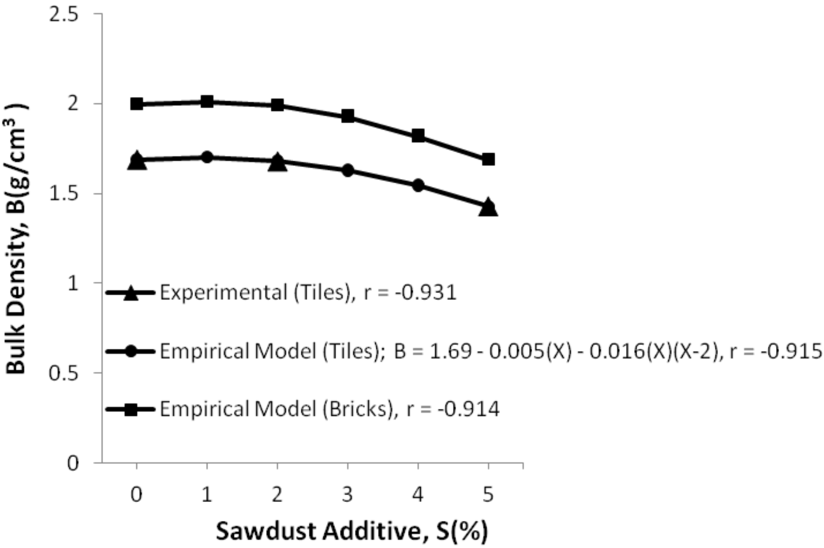

Figure 2: Bulk Density, B versus Sawdust Addititive, S

Mechanical Properties

Both the modulus of rupture and compressive strength are found to reduce with increasing amounts of sawdust addition. These weaknesses of strength could no longer be tolerated above sawdust addition of 5%, due to poor quality outcome of experimental specimen at this stage. The linear characteristics of the mechanical properties is as a result of the close range of mix variations, i.e. 0 to 5% saw dust addition, equivalent to 20 to 15% silica sand. Previous studies by Ohijeagbon (1998) revealed a pronounced curvature for a wider range of material mix variation.

The relationships between the modulus of rupture and sawdust percentage content on one hand, and the compressive strength and sawdust percentage content on the other hand, are shown respectively in Figs.3 and 4.

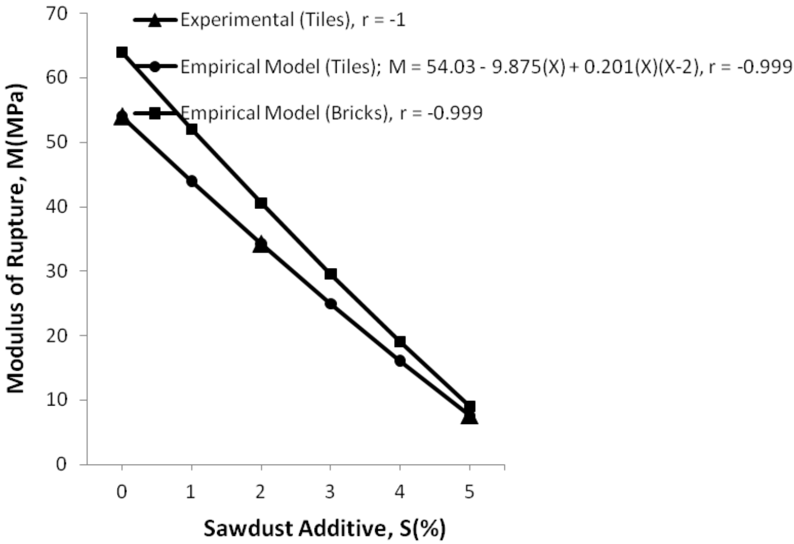

Figure 3: Modulus of Rupture, M versus Sawdust Additive, S

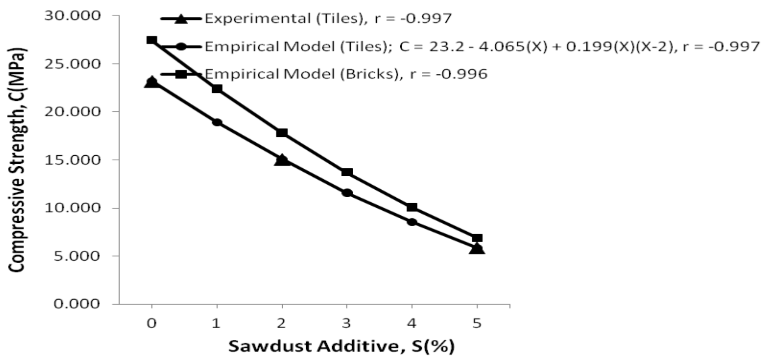

Figure 4: Compressive Strength, C versus Sawdust Additive, S

Computation of Estimated Empirical Values of Properties of Model Specimens

The density of solid clay bricks is about 2,000 kg/m³ (2.00 g/cm^3). In England clay bricks can have strengths of up to 100 MPa, although according to WIKIPEDIA (2008), a common house brick is likely to show a range of 20–40 MPa.

The estimated bulk density of the model bricks were obtained by making use of the initial value of 2.00 g/cm^3 with no sawdust addition and interpolating with each corresponding model data point values respectively from 0 to 5 % sawdust addition as shown in Table 2. Using the computed estimated values of bulk density of model bricks and tiles, together with corresponding values of model tiles' properties the other values of properties, namely, water absorption, modulus of rupture, and compressive strength of the model brick specimens were analytically computed by interpolation at each data state as shown in Table 2.

Table 2: Estimated (Empirical values) of effect of sawdust on properties of model tiles and bricks specimens

Mix Variables		Physical Properties				Mechanical Properties			
Silica Sand (%)	Sawdust (%)	Water Absorption (%)		Bulk Density (g/cm^3)		Modulus of Rupture (MPa)		Compressive Strength (MPa)	
		*	**	*	**	*	**	*	**
20	0	17.54	20.76	1.69	2.00	54.03	63.94	23.2	27.46
19	1	18.56	21.96	1.70	2.01	43.95	52.01	18.94	22.41
18	2	20.28	24.00	1.68	1.99	34.28	40.57	15.07	17.83
17	3	22.71	26.88	1.63	1.93	25.01	29.60	11.6	13.73
16	4	25.85	30.59	1.54	1.82	16.14	19.10	8.53	10.09
15	5	29.7	35.15	1.43	1.69	7.67	9.08	5.86	6.93

* For model tiles specimens, ** For Model bricks specimens

Conclusion

Estimation of properties of unfired ceramic products with sawdust additives is very much possible, if the nominal bulk density of the product is known. The percentage changes in the data of bulk density of the primary empirical model together with the previously known value of bulk density of an unfired ceramic product desired with sawdust additives can hence be used to estimate equivalent values of bulk density of the expected model product. Computing the other properties can then proceed, using the already determined equivalent bulk density of the new model specimen and the other properties estimated earlier from the primary model specimen. These model estimations may be extended to include similar additives such as straw in unfired ceramic specimens or products. It should however be noted that the model estimations of properties are only limited to sawdust additives not exceeding 4% for useful practical purposes as observed from experimental studies. With the base-clay material and cement for bonding and strength totalling 80 %, while silica sand and sawdust making up the remaining 20 %. The ratio of water to the entire material constituent is 13 %.

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