MODELING AND SIMULATION OF MECHANICAL PROPERTIES OF PULVERIZED COW BONE AND LATERITIC PAVING TILES

Peter O. Omoniyi, Jacob O. Aweda, Idehai O. Ohijeagbon, Ridwan A. Busari and Mustapha Ndagi

University of Ilorin, Faculty of Engineering and Technology, Department of Mechanical Engineering, Ilorin, Kwara State, Nigeria; omoniyi.po@unilorin.edu.ng; jacobaweda@gmail.com, idehaiohi@yahoo.com, busari.ridwan01@gmail.com, ndagimustapha@gmail.com

ABSTRACT

This study included the experimental production and investigation of the mechanical properties of paving tiles produced from a mixture of laterite, silica sand, pulverized cow bones, and cement. Empirical models of compressive and flexural strength were also developed and herein presented for the paving tiles. The maximum compressive strength of the paving tiles were obtained for 20, 15, and 10% cement content as 5.05, 5.05 and 3.08 MPa, while the maximum flexural strength for similar values of cement content were obtained as 1.83, 1.21 and 0.26 MPa respectively. The results indicate that there was no noticeable difference in the values of the compressive strength at 20 and 15% cement content, while a sharp reduction of the mechanical properties was experienced as the cement content reduces from 15 to 10%. Recommended composition for paving tiles with pulverized cow bones composite is cement, 15%; pulverized cow bones, 30%; laterite 35% and silica sand, 20% respectively. Sustainable production of paving tiles and a sustainable environment can, therefore, be enhanced by replacing granite constituent with waste cow bones, which can easily be replicated by the empirical models herein developed.

KEYWORDS

Empirical models, Compressive strength, Flexural strength, Pulverized cow bones, Laterite

INTRODUCTION

Global consciousness on the environment has been on the increase in recent years, which has engineered several existing environmental protection programs not only to focus on protecting the natural resources, but also to instigate the judicious use of waste materials, and curtail the level of environmental damage. It is of good benefit and importance for developing countries around the world to seek means to create a sustainable development in order to key into such protection programs. The increasing population of the world has propelled both private and public organizations to constantly embark on infrastructural development, a scenario that has encouraged the use of building accessories and products such as paving tiles. It is therefore imperative to constantly explore sustainable materials to develop some of the infrastructural products that would guarantee a sustainable environment [1].

Several applications are being developed to make use of discarded animal bones, in the field of biomedical engineering; animal bones have been used as reinforcement and binding agents for different composite applications such as polyesters, epoxies etc. [2-3]. The potentials of pulverized animal bones as pozzolanic material was also established by Falade *et al.* [4] and was

----

found to exhibit good pozzolan character. Therefore, recycled waste bones are considered as a composite material for the production of paving tiles in this study.

Paving tiles are usually of different shapes and sizes; they range from square, rectangle, star shape etc. The standard thicknesses are usually 60 mm with common dimensions of 60 x 30, 40 x 40, and 30 x 30 cm [5-6]. In Nigeria, the conventional materials used in the production of paving tiles are granite, silica sand, and cement as a binder. Making use of bones in the production of paving tiles will not only help clean the environment of the ugly pile of bones in abattoirs but would also provide a sustainable means of production, due to its availability. Furthermore, the breaking strength of 9.9 kg makes it a suitable substitute for granite particles in paving tiles productions [7]. Several works have been conducted on the use of readily available and affordable materials in the manufacturing of paving tiles. Ohijeagbon *et al.* [1] used laterite as a partial replacement of granite in the production of interlocking tiles due to the availability of laterite. Ajao and Ohijeagbon [8] successfully utilized corncobs, an agro-waste and charcoal to produce paving tiles, but the sustainability of corncobs waste presents a limitation due to the seasonal availability of agricultural wastes. Therefore this study aim at investing the impact of pulverized cow bones on the mechanical propertie of paving tiles and creating a model to predict the mechanical properties of produced paving tiles for future application.

METHODS

Laboratory Experiment

The raw materials used were laterite, silica sand, pulverized cow bones and cement. The particle sizes of materials used were 1000, 500 and 4750 µm respectively. Mass of materials required to cast a unit tile were weighed according to the proportion of aggregate mix presented in Table 1. The constituents were thoroughly mixed together before the addition of water and further mixing was done to obtain a homogeneous mixture. Each unit of tile was mixed independently to avoid rapid setting of the mixture. A mold size of 200 × 100 × 60 mm was filled to its maximum volume, rammed with a 2.5 kg rammer with 28 blows; the surface was leveled and trimmed. This was done in accordance with Agunwa [9] and Omoniyi *et al.* [10].

Used automobile engine oil was used to smear the inner surfaces of the mold preceding the filling up of the mold in order to avoid adhesion of the cast to the walls of the mold when unmolding. The paving tiles were unmolded after 24 hours and cured in water for twenty-one days (21) then sundried for another seven (7) days, making up a total curing duration of twenty-eight (28) days [9, 11-12].

Tab. 1 - Aggregate mix for experimental tiles.

Sample	Cement (% wt)	Pulverized Cow Bones (% wt)	Laterite (% wt)	Silica Sand (% wt)
A_1	20	30	40	10
A_2	20	20	25	35
A_3	20	10	20	50
A_4	20	5	20	55
B_1	15	30	35	20
B_2	15	20	35	30
B_3	15	10	35	40
B_4	15	5	30	50
C_1	10	30	30	30
C_2	10	20	45	25
C_3	10	10	50	30
C_4	10	5	40	45

Mechanical properties of lateritic tiles

Compressive strength

The test specimen was loaded into a universal testing machine. The load was slowly and carefully applied centrally on the tile specimens until the first sign of crack was observed and the load was then recorded. The compressive strength of each tile specimen was carried out in accordance with Equation (1) [13]:

$$\sigma = \frac{P_C}{A_C} \tag{1}$$

Where, *Pc* = maximum load on the specimen at failure, *Ac* = calculated cross-sectional area of the specimen and

σ = compressive strength of the test specimen.

Flexural strength

Universal Testing Machine was used in accordance with [8,14] to determine the flexural test. The specimen was supported horizontally on two vertical supports of known span and was loaded with known values of masses until failure occurred. The flexural strength for each tile specimen was then obtained using Equation (2):

$$R = \frac{3PL}{2bd^2} \tag{2}$$

Where, R = modulus of rupture, P = applied load at failure, L = length between the supports, b = width of the specimen and d = thickness of the specimen

Analysis of modeling of paving tiles

When a function with two or more independent variables (multivariate function) is given, multivariate approximation is necessary for interpolation, differentiation and integration [15]. Also, quadratic interpolation is possible, if three points are available for a set of data. A polynomial equation represented by Equation (3) is suitable to develop the models of mechanical properties of produced tiles [16-17]:

$$y = \alpha + \beta_1 X + \beta_2 X^2 + \beta_3 X^3 + \in \tag{3}$$

The dependent variable y denote compressive strength and modulus of rupture and independent variable X, is represented by the percentage of pulverized cow bones, $\in$ which is the error term.

Simple linear regression, which is a tool in predictive analysis, could be found suitable for modeling analysis as represented by Equation (4).

$$Y = ax + b + \in \tag{4}$$

Where, Y is the response variable, a, b are constants, x is the independent variable and $\in$ is the error term.

Equations (6) to (11) which were generated using the EXCEL spreadsheet were used in the determination of empirical model curves for compressive strength and flexural strength of lateritic paving tiles as shown in Figures 1 and 2.

Coefficient of Correlation

The coefficient of correlation as a measure of the relationship between two variables and was determined for each curve in Figures 1 and 2 by using Equation (5):

$$r = \frac{\sum(X - \overline{X})(Y - \overline{Y})}{\sqrt{\left\{\sum(X - \overline{X})^2\right\}\left\{\sum(Y - \overline{Y})^2\right\}}} \qquad (5)$$

Where, $\overline{X}$ and $\overline{Y}$ are the mean value of X and Y respectively.

RESULTS

Empirical Modeling of Compressive Strength
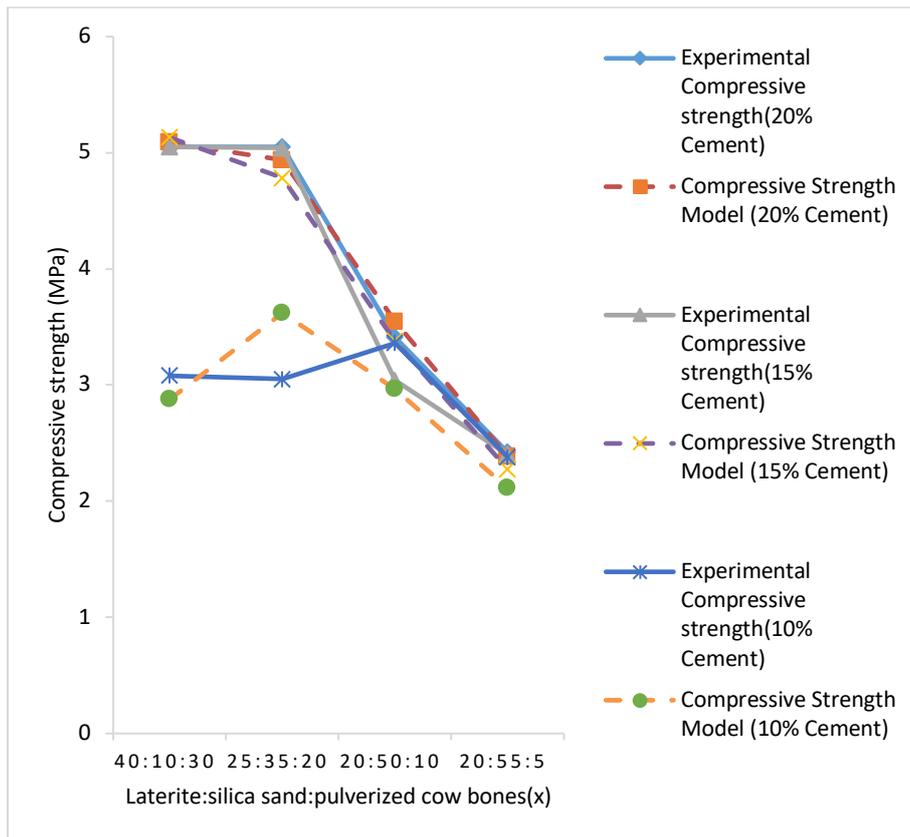
Fig. 1- Relationship between compressive strength and material composition

The compressive strength is shown in Figure 1 and Table 2 was found to decrease as the percentage of pulverized cow bones decreases in the composition of the paving tiles; this is due to the reinforcement the pulverized cow bones added to the strength of produced tiles. The reduction in compressive strength could also be attributed to the cement content, due to the fact that samples of paving tiles with 5-10% cement content had lower compressive strength. Samples with a laterite ratio of up to 25% and above exhibited an improved compressive strength due to the bonding properties of laterite. Equation (6) to (8), show the empirical model developed for determining the compressive strength of lateritic paving tiles at different cement composition of

----

20%, 15% and 10% respectively. The standard error E_{c1}, E_{c2}, E_{c3} and coefficient of correlation for each model show a good relation among the variables.

$$C_1 = -0.00621x^2 + 0.325407x + 0.913411 ; r = 0.9968 , \ E_{c1} = \pm 0.0338\,\text{MPa} \qquad (6)$$

$$C_2 = -0.0053x^2 + 0.29963x + 0.909865 ; r = 0.9821 , \ E_{c2} = \pm 0.2010\,\text{MPa} \qquad (7)$$

$$C_3 = -0.00699 + 0.275405 + 0.910162 ; r = 0.7076 , \ E_{c3} = \pm 0.5944\,\text{MPa} \qquad (8)$$

Empirical modeling of flexural strength
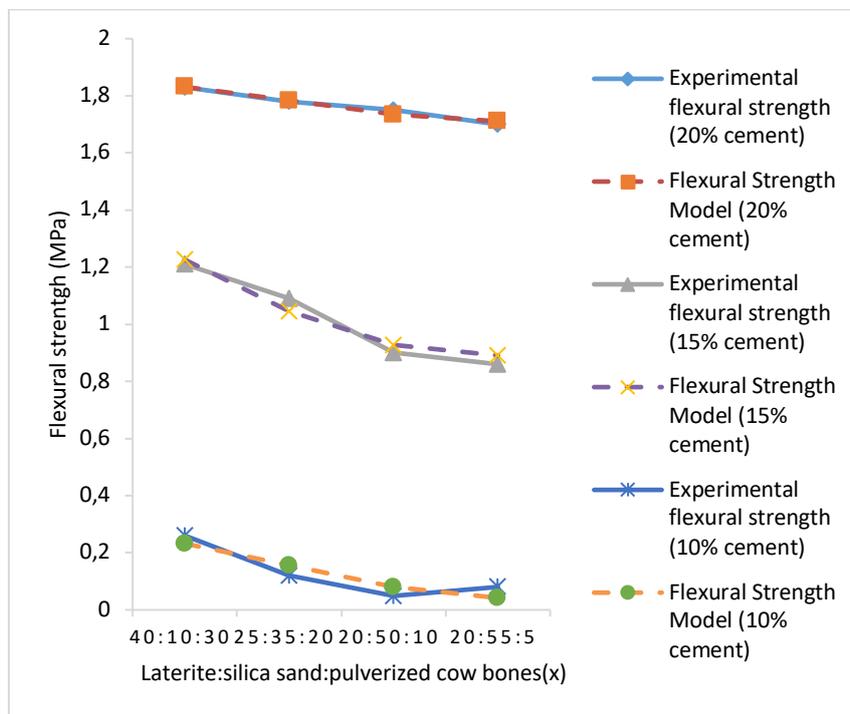
Fig. 2- Relationship between compressive strength and material composition among methods.

Figure 2 and Table 2 show the relationship between the flexural strength and composition of produced tiles at different cement compositions of 20, 15 and 10% respectively. Flexural strength was observed to decrease with an increase in silica sand addition, due to the grittiness of the material which reduces the bonding strength of the products. Conversely, flexural strength increases as the percentage composition of laterite and pulverized cow bones also increases. This was due to the adhesive properties of laterite and reinforcing properties of pulverized cow bones. Equations (9) and (11) represent the models of flexural strength and were observed to exhibit a linear relationship due to the close variation of the material composition at each mix.

$$F_1 = 0.004812x + 1.6868 ; r = 0.9798 ; \ E_{f1} = \pm 0.0003\,\text{MPa} \qquad (9)$$

$$F_2 = 0.00031x^2 + 0.00257x + 0.87036 ; r = 0.9787 ; \ E_{f2} = \pm 0.0039\,\text{MPa} \qquad (10)$$

$$F_3 = 0.007612x + 0.003809 ; r = 0.9078 ; \ E_{f3} = \pm 0.0046\,\text{MPa} \qquad (11)$$

Tab. 2 - Experimental and estimated values of effect of pulverized cow bones on mechanical properties of tiles.

Sample	Cement (% wt)	Pulverized Cow Bones(% wt)	Laterite (% wt)	Silica Sand(% wt)	Mechanical Properties			
					Compressive strength (MPa)		Flexural Strength (MPa)	
					+	++	+	++
A_1	20	30	40	10	5.05	5.09	1.83	1.83
A_2	20	20	25	35	5.05	4.94	1.78	1.78
A_3	20	10	20	50	3.41	3.55	1.75	1.73
A_4	20	5	20	55	2.42	2.39	1.70	1.71
B_1	15	30	35	20	5.05	5.13	1.21	1.23
B_2	15	20	35	30	5.04	4.78	1.09	1.05
B_3	15	10	35	40	3.04	3.38	0.90	0.93
B_4	15	5	30	50	2.40	2.28	0.86	0.89
C_1	10	30	30	30	3.08	2.88	0.26	0.23
C_2	10	20	45	25	3.05	3.62	0.12	0.16
C_3	10	10	50	30	3.36	2.96	0.05	0.08
C_4	10	5	40	45	2.38	2.11	0.08	0.04

+Experimental tile specimens, ++Modeled tile specimens

CONCLUSION

Empirical models of the mechanical properties of paving tiles produced from aggregates of laterite, silica sand pulverized cow bones and cement, for cement addition of 20, 15 and 10% respectively were developed in this study and the models have been able to predict the trends of the mechanical properties of produced paving tiles. The maximum compressive and flexural strength of about 5.10 and 1.83 MPa were obtained at a composite composition of 30:10:40 of pulverized cow bones to silica sand to laterite. These were found to conform to the Nigerian Industrial Standard [18], which approves 2.5 MPa for load-bearing and 1.8 MPa for non-load bearing blocks. The higher the cement and pulverized cow bone content, the higher the compressive and flexural strength obtained. The use of pulverized cow bones as a constituent of paving tiles was found feasible and a viable means of reducing the environmental pollution. Also, replacing the more expensive granite constituent with waste cow bones would result in the cheaper production cost of paving tiles, creating a more sustainable environment. Developed empirical models from this study are useful for further investigation and product development of a similar nature.

ACKNOWLEDGEMENTS

REFERENCES

[1] Ohijeagon I.O., Olusegun H.D., Adekunle A.S., Adewoye O.S., Oladiji A.O., 2012. Impact of Suitable Replacement of Granite-Particles on Interlocking Tiles. Journal of Engineering Science and Technology Reviews vol. 5: 51-56.

[2] Oladele O.I., 2013. Development of Bone Ash and Bone Particulate Reinforced Polyester Composites for Biomedical Application. Leonardo Journal of Practices and Technology vol. 22: 15-26.

[3] Yadav P., Dhar, S., Vijaykumar K., 2013. Establish a Methodology for Predicting the Mechanical Properties of Composite Materials, International Journal of Engineering Science and Innovative Technology, 60-67.

[4] Falade F., Ikponmwosa E., Fapohunda C., 2012. Potential of Pulverized Bones as Pozzollanic Material. International Journal of Scientific & Engineering Research vol. 3.

[5] Olusegun H.D., Adekunle A.S., Ogundele S., Ohijeagbon I.O., 2014. Analysis of Laterite- Granite Concrete Tiles Composite, International Journal of Engineering, 193-198.

[6] Ohijeagbon I. O., Adekunle A. S., Omoniyi P. O., Adeboye B. B., Ajao K. S., 2019. Impact of Production Methods on Some Engineering Properties of Interlocking Tiles. Adeleke University Journal of Engineering and Technology vol. 2: 99-108.

[7] Kim W.K., Donalson L.M., Herrera P., Woodward C.L., Kubena L.F., Nisbet D.J., Ricke S.C., 2004. Effects of Bone Preparation Methods (Fresh, Dry, Fat-Free Dry) on Bone Parameters and the Correlation Between Bone Breaking Strength and other Bone Parameters. Poultry Science Association Report vol. 83: 1663-1666.

[8] Ajao K.S., Ohijeagbon I.O., 2016. Recycling of Ago-Waste to Produce Sustainable Paving Tiles, International Conference Proceedings, Awka, Nigeria.

[9] Agunwa J.J., 2009. Study of Compressive Strengths of Laterite-Cement Mixes as Building Materials. AU J. T technical Report vol. 13: 114-120.

[10] Omoniyi P.O., Ohijeagbon I. O., Aweda J. O., Abolusoro, O. P., Akinlabi E. T., 2020. Experimental Data on the Compressive and Flexural Strength of Lateritic Paving Tiles Compounded with Pulverize Cow Bone. Data in Brief vol. 33: 1-8.

[11] Omoniyi P. O., Ohijeagbon I. O., Aweda J. O., Ibitoye S. E., 2018. Investigation of Brinell Hardness and Compressive Strength of Pulverized Cow Bones and Lateritic Paving Tiles. Adeleke University Journal of Engineering and Technology vol. 1: 59-69.

[12] Aweda J. O., Omoniyi P. O., Ohijeagbon I. O., 2018. Suitability of Pulverized Cow Bones as a Paving Tile Constituent. IOP Conference Series: Material Science and Engineering, vol. 413.

[13] EN-12390-3, Testing Hardened Concrete-Part 3: Compressive Strength of Test Specimen, 2001.

[14] EN-12390-5, Testing Hardened Concrete, Flexural Strength of Test Specimens, 2001.

[15] Olusegun H.D., Ohijeagbon I.O., Adekunle A.S., Oladosu O.A., Ogundele S. O., 2009. Modelling Characteristics of Lateritic and Granite Composite Tiles. International Electronic Engineering Mathematical Society. Vol. 7: 127-138.

[16] Vandebogert K., 2017. Quadratic Interpolation [online] http://people.math.sc.edu/kellerlv/Quadraic_Interpolation.pdf.

[17] Ohijeagbon I.O., 2008. The Estimation of Properties of Unfired Ceramic Products with Sawdust Additivies, African Reserch Review vol. 2: 144-156.

[18] NIS87, 2004. Standards for Sandcrete Blocks, Lagos: Nigerian Industrial Standard.