Journal of Production Engineering
Vol.19 No.2

JPE (2016) Vol.19 (2) Original Scientific Paper
Ajao, K. S., Ohijeagbon, I. O., Adekunle, A. S., Olusegun, H. D.

DEVELOPMENT OF PAVING TILES COMPOUNDED WITH PULVERIZED CORNCOB CHARCOAL

Received: 01 November 2016 / Accepted: 03 December 2016

Abstract: *The current trend all over the world is to minimize environmental pollution through wastes recycling. Thus, paving tiles' specimens of dimensions 198mm x 98mm x 56mm were produced in the laboratory using various mix ratios of granite particles and pulverized corncob charcoal. Wood charcoal dust was used as control and cement as binder. Batching was by volume and a constant water/cement ratio of 0.7 was used. The tiles' physical and mechanical properties were determined. Results obtained showed that as the percentage of pulverized corncob charcoal in the mixture aggregate increases, the flexural strength, compressive strength and bulk density of the tiles decreases, while a progressive increase was experienced in water absorption for 20% and 15% cement addition. Significant similarities were observed in the properties of experimental tiles produced with addition of pulverized corncob charcoal and those with addition of wood charcoal dust which was used as control. 30% and 10% addition of pulverized corncob charcoal for 20% and 15% cement content tiles respectively were recommended. Recycling of corncob as a constituent material of paving tiles is feasible.*
Key words: *Paving Tiles, Granite Particles, Corncob Charcoal, Environmental Pollution, Recycling*

Razvoj elemenata za popločavanje obogaćenih sa usitnjenim izgorelim oklascima. *Aktualni trend u celom svetu je smanjenje zagađenja životne sredine primenom reciklaže otpada. S tim ciljem su u laboratoriji izrađeni elementi za popločavanje, dimenzija 198mm x 98 mm x 56mm, korišćenjem raznih vrsta odnosa granitnih čestica i usitnjenih izgorelih oklasaka. Usitnjen ćumur je korišćen u svrhu kontrole a cement kao vezivno sredstvo. Svaka šarža je bila iste zapremine i konstantnog odnosa voda/cement koji je iznosio 0,7. Fizičke i mehaničke osobina elemenata za popločavanje su bili određivani. Dobijeni rezultati pokazuju smanjenje savojne čvrstoće, otpornosti na sabijanje i gustine elemenata za popločavanje sa povećanjem procenta udela usitnjenih izgorelih oklasaka, dok je zabeleženo progresivno povećanje apsorpcije vode kod 20% i 15% cementne smeše. Velike sličnosti su bile primenćene u osobinama eksperimentalnih popločavajućih elemenata napravljenih sa dodatkom usitnjenih izgorelih oklasaka i onih sa dodatkom usitnjenog ćumura koji je bio korišćen kao kontrolni element. Na osnovu studije se preporučuje 30% i 10% dodatka usitnjenih izgorelih oklasaka na 20% odnosno 15% sadržaja cementa u elementima za popločavanje. Takođe je pokazana mogućnost reciklaže oklasaka kao materijala za izradu popločavajućih elemenata.*
Ključne reči: *elementi za popločavanje, granitne čestice, usitnjeni izgoreli oklasci, zagađenje životne sredine, reciklaža*

1. INTRODUCTION

In the effort of producing food for the world's growing population through agricultural activities, various agricultural residues are generated. Their indiscriminate disposal or open burning results in environmental pollution with emission of irritating smells and hazardous gases that poses serious challenges to sustainable healthy environment [1]. Thus, many researchers have attempted utilizing agricultural residues for various applications such as building construction material, in an environmentally and economically sustainable manner [2, 3, 4]. Corncob is one of the residues left over after extracting the corn. Large quantity of corncob is being discarded as waste into the environment most especially during harvest season because corn planting is predominantly focused on for the use of the kernel (grain).

Over the last few years, there has been an increase in the production of corn globally owing to intensive agricultural activities in the wake of population growth. Consequently, significant increase was observed in the quantity of corncob discarded as waste into the environment. During the year 2001-2011, global production of corn rose from 599.35 million metric tonnes to 867.52 million metric tonnes [5]. Nigeria production of corn in the year 2013 was estimated at 10.4 million metric tonnes and for every one tonne of corn produced, about 160 – 180 kg corncob is generated [2, 6]. In the year 2013, 1.664 – 1.872 million metric tonnes of corncob was generated in Nigeria and recycling of this waste is therefore imperative. Research has shown that corncob can be used in the production of activated carbon [7, 8] which can be briquetted and used as alternative cooking fuel [9, 10], corncob ash can also be used as cement replacement in concrete work [3, 11, 12]. However, large proportion of corncob generated annually is not utilized and as such a proactive means of solving the problem of environmental pollution associated with its indiscriminate disposal is to explore further use that would bring about its large scale deployment. Thus, utilization of corncob as constituent material of paving tiles could provide a better way of evacuating it from the environment and eventually results in a sustainable economic benefit.

Paving tiles are manufactured concrete products, made in different shapes and sizes, used to finish off a paved area outside buildings, warehouses, museums, art galleries, commercial garages, halls, factories, walkways etc. for decorative and aesthetic purposes. Apart from providing aesthetic, they can also be used to aid drainage and level out a specific area so that excess water is drained away [13]. They are loosely laid and adhesives are not required in their installations; as a result, they can be removed and positioned as the need arises. The growth of paving tiles production in recent time is unprecedented due to continual development of infrastructure as a consequence of growing population and modernization.

The core material used in the production of paving tiles in Nigeria is granite particles popularly known as stone dust, usually sourced from quarry sites. The aim of this study is to harness corncob for use as a constituent material of paving tiles in order to reduce environmental pollution and increase the spectrum of value addition to farm produce. There had been several research efforts on the use of various agricultural residues and other wastes materials to obtain construction products. Semanda *et al*., [14] investigated the feasibility of using plastic and egg shell wastes together with white cement in the production of floor tile materials. Pinto *et al.,* [15] worked on a lightweight concrete using granulated corncob as aggregate. Techniti *et al.,* [4] conducted a complete characterization of ten different agricultural by-products, including corncob, with a view to using agricultural residues as secondary raw materials of construction. Mujedu *et al*., [11] studied the use of corncob ash and sawdust ash as cement substitute in concrete works with a view to enhancing the reduction of corncob and sawdust wastes and also reduce the cost of concrete production. However, detailed potentials of corncob are yet to be fully explored as large proportion still remains unused and discarded as waste into the environment. This study therefore investigates the feasibility of using corncob as partial replacement of granite particles in the production of paving tiles.

2. MATERIALS AND METHOD

2.1 Materials

The corncobs used for this study was sourced in dry form from a corn threshing site in Ilorin south, Kwara State, Nigeria; and then carbonized to remove non-carbon elements. A metallic drum of about 90cm in height and 60cm diameter was used as kiln; the fabrication of the kiln was based on the method used by D-Lab charcoal process [16]. The kiln was designed to create an environment that has limited supply of oxygen, so that the burning corncobs inside the kiln can carbonize and the resultant corncob charcoal was pulverized using mortar and pestle. Wood charcoal dust, which is a waste from production and sales of wood charcoal, was used as control; this was collected from a charcoal merchant in Ilorin south. Other materials that were used are ordinary Portland cement (Dangote 3X brand), granite particles (stone dust) and potable water.

Samples of experimental paving tiles were produced from the mixture of granite particles and pulverized corncob charcoal in varying proportions with 20% and 15% cement content. Similarly, samples of paving tiles with varying proportions of granite particles and wood charcoal dust with 20% and 15% cement content were produced to serve as control. The mixture proportions of granite particles, pulverized corncob charcoal and wood charcoal dust are as presented in tables 1 and 2 for 20% and 15% cement addition respectively..

Granite particles (%)	**Pulverized charcoal**		**Average mass (kg)**
	Corncob (%)	**Wood (%)**	
80	-	-	2.38
70	10	-	2.25
60	20	-	2.14
50	30	-	1.93
40	40	-	1.73
80	-	-	2.38
70	-	10	2.25
60	-	20	2.15
50	-	30	2.01
40	-	40	1.71

Table 1. Aggregate mix of experimental paving tiles with 20% cement content

Granite particles (%)	**Pulverized charcoal**		**Average mass (kg)**
	Corncob (%)	**Wood (%)**	
85	-	-	2.29
75	10	-	2.17
65	20	-	2.04
55	30	-	1.87
45	40	-	1.67
85	-	-	2.29
75	-	10	2.17
65	-	20	2.12
55	-	30	1.89
45	-	40	1.77

Table 2. Aggregate Mix of Experimental Paving Tiles with 15% Cement Content

2.2 Moulding of the experimental paving tiles

The aggregate mixes of each batch of experimental paving tiles according to the proportion outlined in tables 1 and 2 were thoroughly mixed together so that homogeneity of the aggregated materials is achieved before the addition of potable water. The moulds were washed before the commencement of moulding so as to get rid of impurities that could lead to poor strength of the tiles. Also, the inner surfaces of the moulds were lubricated with a mixture of engine oil and diesel to ease removal of the tiles after production practiced by Enohuean and Omo-Irabor [17].

To achieve good surface finish of the products, cement mortar was firstly poured into the lubricated moulding containers and allowed to even out on the inner surfaces before the aggregate mixes were poured. The cast products were left for twenty-four hours to set and cure properly before they were removed from the moulds. After production, the experimental paving tiles were cured by sprinkling water on it morning and evening for seven days to prevent rapid drying which could lead to shrinkage cracking, dried under room temperature for sixteen days and sun-dried for five days [18]. This suggests that the experimental paving tiles were treated for twenty-eight days to attain adequate strength and free from cracks before the physical and mechanical properties tests were conducted on them.

2.3 Physical properties tests of experimental paving tiles

2.3.1 Determination of water absorption

The mass of each specimen of experimental paving tiles was determined firstly with weighing balance and their values recorded, as the dry mass, M_d. Each specimen was then submerged in cold water for twenty-four hours, after which the specimens were taken out and their surfaces wiped with a piece of cloth to remove excess water. The new mass of each specimen was determined with weighing balance and recorded as the saturated mass, M_s, the percentage water absorbed, otherwise known as "water absorption" was calculated using the relation in equation 2.1 [18].

$$A = \frac{M_s - M_d}{M_d} \times 100\% \qquad (2.1)$$

Where, A = Water absorption

2.3.2 Determination of bulk density

Experimental paving tiles specimens were dried to constant mass after curing, and the dry mass, $M_{d,}$ was determined. The bulk density, B (in grams per cubic centimeter), of a specimen is the quotient of the dry mass divided by volume of the specimen. The volume, V, was determined from the surface dimensions, and physical geometry of the specimen namely length, width and thickness. The bulk density was calculated using the relation in equation 2.2 [19].

$$B = \frac{M_d}{V} \qquad (2.2)$$

2.4 Mechanical properties tests of experimental paving tiles

2.4.1 Flexural strength

The flexural strength test was conducted with a universal testing machine (Avery Dennison, England), 600kN capacity. Each of the tested experimental paving tiles specimens was placed horizontally and centrally on the two knife-edge vertical supports in an overlapping manner and the distance between the supports was noted. The specimen was then loaded centrally through a vertical indenter on the machine until failure occurred. The flexural strength in N/mm^2 (MPa), expressed as modulus of rupture, was calculated using the relation in equation 2.3 [20].

$$M = \frac{8PL}{\pi T^3} \qquad (2.3)$$

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

2.4.2 Compressive strength

Each of the experimental paving tiles specimens was compressed with a compression testing machine and the load on the specimen at failure was noted. The compressive strength of each specimen was determined as the quotient of the average load on the specimen at failure to the area of bearing surface on the test specimen and calculated using the relation in equation 2.4 [20].

$$C_s = \frac{P_c}{A_c} \qquad (2.4)$$

Where,
C_s = Compressive strength of the specimen, MPa
P_c = Average load on the specimen at failure, N
A_c = Calculated area of the bearing surface on the test specimen, mm^2

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Raw Materials

The physical properties of the aggregated materials used for the production of the paving tiles investigated were determined and presented in table 3 below.

Physical properties	Granite particles	Corncob charcoal	Wood charcoal
Colour	Ash	Black	Black
Density (g/cm^3)	1.69	0.40	0.67
Moisture content (%)	0.08	3.15	5.10
Maximum mass retained on sieve (%)	35.0	37.7	52.3
Mesh size of occurrence (mm)	0.00	0.50	0.00

Table 3. Physical properties of raw materials

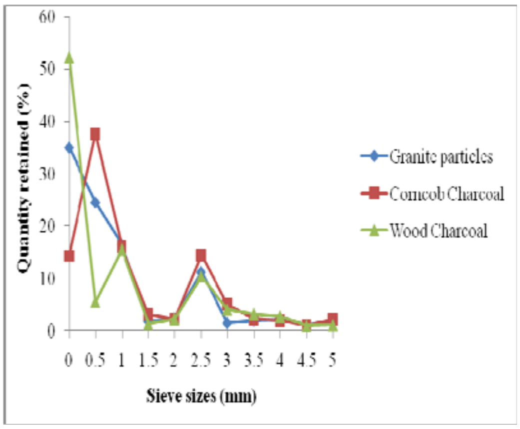

Fig. 1. Sieve analysis of aggregated materials

From the results of sieve analysis of raw materials, 91.6% granite particles, 87.8% pulverized corncob charcoal and 87.6% wood charcoal dust were retained within the 2.5mm sieve size. Hence, maximum particles size of 2.5mm was used for all aggregated materials to ensure maximum materials utilization.

3.2 Physical and mechanical properties of the experimental paving tiles

The experimental paving tiles developed were subjected to various physical and mechanical properties test to study the effects of varying granite and pulverized corncob charcoal contents on the bulk density, water absorption, drying shrinkage, flexural strength (modulus of rupture) and compressive strength of the tiles respectively.

The results of these tests were analyzed to determine the feasibility of using pulverized corncob charcoal as partial replacement of granite particles in the manufacturing of paving tiles. Three (3) samples per batch were tested for each of the properties determined, and the average values were recorded.

3.2.1 Bulk density

Figure 2 shows the variation of bulk density of the experimental paving tiles with the percentage granite particles, pulverized corncob charcoal and wood charcoal dust content for 20% and 15% cement addition respectively**.** A progressive decrease in bulk density was experienced as the percentage of pulverized corncob charcoal and wood charcoal dust content in the aggregate mix increases with decreasing percentage of granite particles content. The decreasing bulk density of the tiles was as a result of lower densities of the pulverized corncob charcoal and wood charcoal dust compared to that of granite particles, which was reducing as the pulverized corncob charcoal and wood charcoal dust content was increasing in the mixture aggregate. Samples produced with 20% cement content had a slightly higher bulk density compared to those produced with 15% cement content. This was as a result of higher bonding strength developed in the 20% cement content tiles, as there is tendency of more peripheral particles to be lost in the 15% cement content tiles during production process than in the 20% cement content tiles.

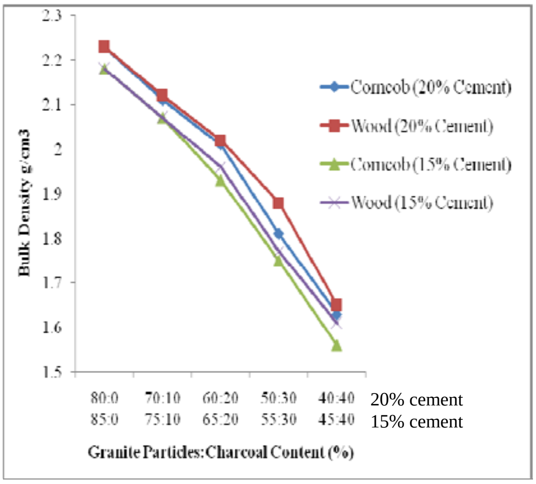

Fig.2. Variation of bulk density withtiles composition

Also, the bulk density of the granite particles/wood charcoal dust samples were slightly higher than that of the granite particles/pulverized corncob charcoal samples of equal mixture aggregate. This was attributed to higher density of the wood charcoal dust compared to that of the pulverized corncob charcoal.

3.2.2 Water absorption

The water absorption results obtained after 24 hours of soaking experimental paving tiles in water showed that water absorption capacity increased with increased percentage of pulverized corncob charcoal and wood charcoal dust content and with decreasing percentage of granite particles content in the mixture aggregate Fig. 3. The increased water absorption experienced in the tiles indicated that the pulverized corncob charcoal and wood charcoal dust were more porous compared to the granite particles. It was also observed that 15% cement content samples absorbed more water compared to 20% cement content samples. This was consistent with the finding of Semanda et al. [14]. The reduced water absorption rate of the 20% cement content samples was due to increased interfacial bonding between cement and aggregated materials but the reduced porosity was as a result of more cement content in the mixture, which might have lead to better curing process. The granite particles/pulverized corncob charcoal samples had slightly higher water absorption rate compared to that of granite particles/wood charcoal dust samples. This may be traced to difference in their particle size distribution as indicated in the sieve analysis results (table 3 and figure 1). The pulverized corncob charcoal used is coarser than the wood charcoal dust used as control, resulting in more porosity in the pulverized corncob charcoal tiles' samples.

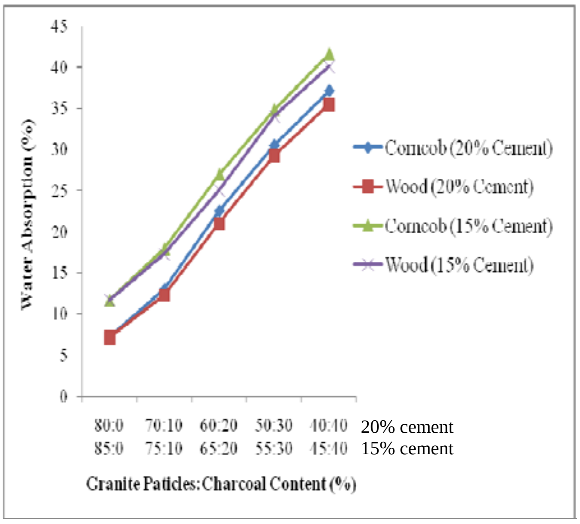

Fig. 3. Comparison of water absorption with tiles composition

3.2.3 Flexural strength

Figure 4 shows the variation of flexural strength of the experimental paving tiles with the percentage granite particles, pulverized corncob charcoal and wood charcoal dust content for 20% and 15% cement addition respectively**.** The flexural strength of the experimental tiles was observed to decrease with increasing percentage of pulverized corncob charcoal and wood charcoal dust content and with decreasing percentage of granite particles content in the mixture aggregate. This was attributed to the reduction in cohesive forces between granite particles as the percentage of pulverized corncob charcoal and wood charcoal dust content increases in the mixture aggregate.

Granite particles/wood charcoal dust samples had slightly higher flexural strength compared to that of granite particles/pulverized corncob charcoal samples. The higher flexural strength in the wood charcoal dust samples was as a result of better interfacial bonding developed in the tiles due to the finer particles size of the wood charcoal dust compared to the pulverized corncob charcoal samples as indicated in the sieve analysis results. Also, the flexural strength of the 20% cement tiles was higher than that of 15% cement tiles.

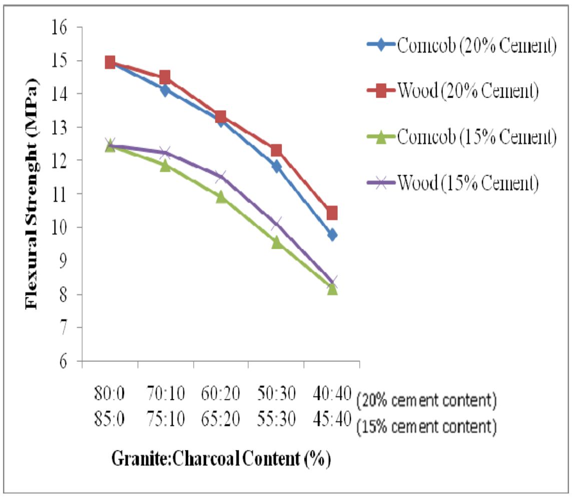

Fig. 4. Behaviour of flexural strength with tiles composition

3.2.4 Compressive strength

The variation of compressive strength of the experimental paving tiles with the percentage granite particles, pulverized corncob charcoal and wood charcoal dust content for 20% and 15% cement addition respectively was depicted in Fig. 5**.** The compressive strength of the experimental tiles was observed to decrease with increasing percentage of pulverized corncob charcoal and wood charcoal dust content with decreasing percentage of granite particles content in the mixture aggregate. The decrease in the compressive strength of the tiles with the addition of pulverized corncob charcoal and wood charcoal dust is due to the fact that pulverized corncob charcoal and wood charcoal dust does not have the compression qualities of the conventional aggregates.

Paving tiles with higher cement content exhibited higher compressive strength because of better curing and hardening process that occurred in the tiles compared to that of lower cement content. Results obtained showed that granite particles/wood charcoal dust samples had a compressive strength slightly higher than that of the granite particles/pulverized corncob charcoal samples. This was attributed to the finer particles size of the wood charcoal dust compared to pulverized corncob charcoal used, or lower density of the pulverized corncob charcoal compared to the wood charcoal dust.

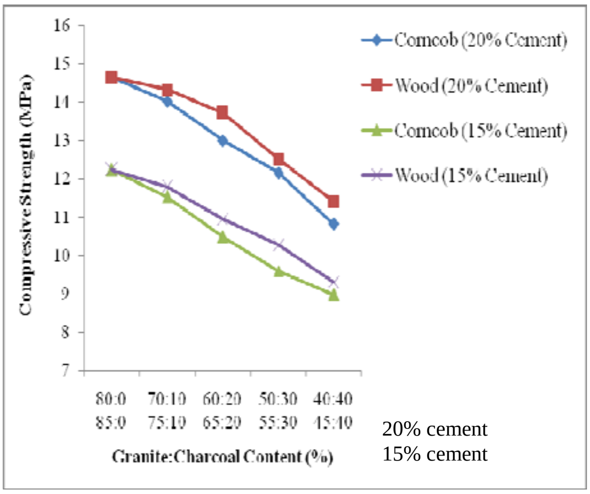

Fig. 5. Variation of compressive strength with tiles composition

4. CONCLUSION

Based on the results obtained from this study, the conclusions drawn can be summarized by the following points:

1. Better mechanical and physical properties namely: flexural strength, compressive strength and water absorption were obtained in the 20% cement content paving tiles compared to 15% cement content paving tiles.
2. As the percentage of pulverized corncob charcoal in the mixture aggregate increases, the flexural strength, compressive strength and bulk density of the tiles decreases, while a progressive increase was experienced in water absorption.
3. Pulverized corncob charcoal samples compared favorably in both physical and mechanical properties with wood charcoal dust samples used as control.
4. The compressive strengths of samples produced with 30% and 10% addition of pulverized corncob charcoal with 20% and 15% cement content are 12.15MPa and 11.53MPa respectively as against 12.86MPa obtained for field samples from selected commercial producers in Ilorin which were found to be produced with average cement content of 15.17% [21].
5. 30% and 10% addition of pulverized corncob charcoal for 20% and 15% cement content respectively are suitable for acceptable strength paving tiles.
6. Recycling of corncob as a constituent material of paving tiles is a viable means of addressing the challenge of environmental pollution caused by its improper disposal.

5. REFERENCES

[1] Agrawal, S., Trivedi, R. C., and Sengupta, B. *Air pollution due to burning of agriculture residue,* Indian Journal of Air Pollution Control, Vol.8(1), pp. 51-59, 2008.

[2] Pinto, J., Paiva, A., Varum, H., Costa, A., Cruz, D., Pereira, S., Fernandes, L., Tavares, P. and Agarwal, J. *Corn's cob as a potential ecological thermal insulation material.* Energy and Buildings, 43, pp. 1985-1990, 2011.

[3] Ettu, L. O., Osadebe, N. N. and Mbajiorgu, M. S. W. *Suitability of Nigerian agricultural by-products as cement replacement for concrete making.* International Journal of Modern Engineering Research (IJMER), Vol.3(2), pp. 1180-1185, 2013.

[4] Techniti, S., Anastasiadou, K., Vamvuka, D. and Gidarakos, E. *Investigating the recycling of agricultural biomass waste in construction materials.* Third International Conference on Industrial and Hazardous Waste Management, Crete-Chania, Greece. 2012.

[5] Zhang, Y., Ghaly, A. E., and Bingxi, L. *Physical properties of corn residues.* American Journal of Biochemistry and Biotechnology, Vol.8(2), pp. 44-53, 2012.

[6] Food and Agricultural Organization of United Nations [on-line], Accessed 30th November, 2015. http://faostat3.fao.org

[7] Kazmierczak, J., Nowicki, P. and Piertrzak, R. *Sorption properties of activated carbons obtained from corncobs by chemical and physical activation.* Open Access-Springerlink.Com, Vol.19, pp. 273-281, 2013.

[8] Adie, D. B., Lukman, S., Saulawa, B. S. and Yahaya, I. *Comparative Analysis of Filtration using Corncob, Bone char and Wood chippings.* International Journal of Applied Science and Technology, Vol. 3(3), pp. 146-152, 2013.

[9] Zubair, A., and Gana, S. A. *Production and characterization of briquette charcoal by carbonization of agro-waste.* Journal of Energy and Power, Vol.4, No.2, pp. 41-47, 2014.

[10] Oladeji, J. T. *Fuel characterization of briquettes produced from corncob and rice husk residues.* The Pacific Journal of Science and Technology, Vol.11(1), pp. 101-106, 2010.

[11] Mujedu, K. A., Adebara, S. A., and Lamidi, I. O. *The use of corncob ash and sawdust ash as cement replacement in concrete works.* The International Journal of Engineering and Science, Vol. 3(4), pp. 22-28, 2014.

[12] Raheem, A. A. and Adesanya, D. A. *A study of thermal conductivity of corncob ash blended cement mortar.* The Pacific Journal of Science and Technology, Vol. 12(2), pp. 106-111. 2011.

[13] Kumar, R. S. *Clay pavers – An external flooring material*. International Journal of Physical and Social Sciences, Vol. 2(5), pp. 145-160, 2012.

[14] Semanda, J., Mutuku, R. N., and Kakuli, J. W. "The Effect of Cement-Waste Mixes on the Physical and Strength Properties of Floor Tiles" European International Journal of Science and Technology, Vol. 3,(9), pp. 32-43, 2014.

[15] Pinto, J., Vieira, B., Pereira, H., Jacinto, C., Vilela, P., Paiva, A., Pereira, S. and Varum, H. *Corncob lightweight concrete for non-structural applications*. Construction and Building Materials, Vol. 34, pp. 346-351, 2012.

[16] D-Lab Charcoal Process [on-line], copyright @ Massachusetts Institute of Technology, Accessed 14th August, 2015. http://d-lab.mit.edu

[17] Enohuean, M. N. and Omo-Irabor, I. E. *Students work experience programme: Terrazzo flooring and moulding of interlocking tiles*. Journal of Advancement in Engineering and Technology, Vol. 2(2), pp. 1-5, 2015.

[18] Ohijeagbon, I. O., Olusegun, H. D., Adekunle, A. S., Adewoye, O. S., and Oladiji, A. O. *Impact of suitable replacement of granite particles on interlocking tiles.* Journal of Engineering Science and Technology Review, Vol. 5(2), pp. 51-56, 2012.

[19] Ohijeagbon, I. O. and Adeyemi, M. B. *Properties of clay/silica/cement tiles.* Nigerian Journal of Technological Development, Vol. 3(2), pp. 102-107, 2003.

[20] Olusegun, H. D., Adekunle, A. S., Ogundele, O. S., and Ohijeagbon, I. O. *Composite analysis of laterite-granite concrete tiles*. Epistemics in Science, Engineering and Technology, Vol. 1(1), pp. 53-59, 2011.

[21] Ogundipe, O. L. *Comparative analysis of locally produced interlocking tiles.* B.Eng. Project Report, Mechanical Engineering Department, University of Ilorin, Ilorin, Nigeria. (2010).

Authors: **Lecturer. Suleiman K Ajao,** University of Ilorin, Department of Materials and Metallurgical Engineering, P.M.B. 1515, Ilorin, Nigeria. Phone:234-8141849056.

Senior Lecturer. Dr. Idehai O Ohijeagbon, University of Ilorin, Department of Mechanical Engineering, P.M.B. 1515, Ilorin, Nigeria. Phone:234-7030092411.

Senior Lecturer. Dr. Adebayo S. Adekunle, University of Ilorin, Department of Mechanical Engineering, P.M.B. 1515, Ilorin, Nigeria. Phone:234-8033591465. **Professor. Prof. Henry D. Olusegun,** Federal University of Technology Minna, Department of Mechanical Engineering, Minna, Nigeria, Phone: 234-8034501122.

e-mail: suleimanajao@gmail.com
idehaiohi@yahoo.com
adekunlebayo@yahoo.com
olusegunhenry@yahoo.com