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INFLUENCE OF SAWDUST AS AN AGGREGATE IN THE PRODUCTION OF INTERLOCKING PAVERS

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Abstract:
The study was conducted to determine the effect of incorporating sawdust into the production of interlocking pavers. Sawdust, stone dust, cement and sharp-sand were combined in different mixing ratios of 2:4:2:0, 2:3:2:1, 2:2:2:2, 3:1:2:2 and 0:3:2:3 respectively with five replicates of each treatment. The interlocking pavers produced were tested for weight, density, hardness, compressive and impact strength. The Analysis of Variance was conducted to test the significance of the strength properties of the pavers produced. The results showed that pavers produced with mixing ratio 0:3:2:3 has the highest mean density and mean compressive strength at 1.58kg/m^3 and 4.72N/mm^2 respectively, closely followed by ratio 2:2:2:2 which has the highest mean impact strength at 4.39J, compressive strength of 3.26N/mm^2, hardness of 1.70kg and mean density of 1.20kg/m^3. However there is no significant difference in the interlocking pavers' degree of resistance to abrasion (hardness). It can be concluded that optimum replacement of aggregates exists in ratio 2:2:2:2 where 25% of sawdust can be utilized in each unit of interlocking paver.

Key words: *compressive strength; density; hardness; interlocking pavers; sawdust.*

INTRODUCTION

The growth of industrial-scale forest industries in Nigeria has led to increases in the quantities of wood-waste generated by industry, including logging residues (defective logs and branches) and products of sawmilling such as sawdust and shavings. Certain industries are capable of utilizing such waste materials for the production of wood brick, wood composite products, pulp and paper.

The fact that huge wood wastes are generated in wood based industries is no gain saying. In fact, the rate of wood wastes generation in the wooden industries is at alarming rate. This is a major concern to wood based industries, wood users, other stakeholders and their major challenges is how it could be managed, reduced and utilized. Over the years, wood wastes have been a menace to our environment and health. This constitutes environmental pollution through the emission of poisonous gases during burning method of disposal.

However, in order to meet future wood products needs, one strategy is to convert various wood wastes into value added products. Such strategies are advanced technologies which ensure the use of wood residue likes sawdust for the production of wood based products. Hence, the utilization of wood wastes for the production of viable products will reduce the pressure mounted on the existing forest, increase the lumber recovery rate, maximize the use of exploited wood species and also encourages forest conservation.

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For this reason, wood waste management and utilization in wood based industries is a vital key issue that requires urgent attentions.

Concrete paving blocks has been extensively used in many countries for quite some time as a specialized problem-solving technique for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints. Concrete paver blocks were first introduced in Holland in the fifties as replacement of paver bricks which had become scarce due to the post-war building construction boom. These blocks were rectangular in shape and had more or less the same size as the bricks. During the past five decades, the block shape has steadily evolved from non-interlocking to partially interlocking to fully interlocking to multiply interlocking shapes (Koli *et al*. 2016).

An early version of interlocking concrete pavement dates back to the Roman Empire when The Appian Way was built from stone paving on an aggregate base in 312 B.C. Used as a main route for military supplies, it connected Rome to Brindisi, Apulia, in southeast Italy. The road is 350 miles long about 20 feet wide and has held up for more than 2,000 years (Matt and Ron 2015).

A special type of paver referred to as interlocking concrete pavers has emerged over the last couple of decades as a very popular alternative to concrete, bricks or clay (George 1999). Interlocking pavers are most commonly made from cement mixed with other constituents and tend to stimulate the effects of cobblestone pathways. These special interlocking features enable pavers to be easily installed without the use of mortar (Adedeji and Monehin 2010). Interlocking pavers connect together through the use of sand and can cover any patio, decking, driveway or walkway. It is available in many colors, shapes and designs ranging from 2 to 2.5 inches thick, similar to that of a regular block.

Segmental pavers have been used for thousands of years. The Romans built roads with them that are still there, but not until the mid 1940's that pavers began to be produced out of concrete (Robertson 1996). The first concrete pavers were shaped just like a brick and they were called Holland stones (Stella 1996). The strength of concrete pavers are achieved in three main ways; the amount of water (the less water, the stronger), the amount of cement in the mix (the more cement, the stronger) and lastly the amount and size of aggregates. Pavers need to withstand a minimum of 3.0N/mm^2 to meet industry standards (ASTM E-08 1998). Usually when tested they far exceed this minimum. That means a paving stone driveway is at least four times stronger than a regular concrete driveway (George 1999). The aim of this work is to produce pavers at different production variables and to test for strength on interlocking paver so as to measure the paver's ability to resist high-rate loading.

MATERIALS AND METHODS

Materials collection

The materials used for this study includes sawdust, sand (sharp sand), stone dust, Ordinary Portland Cement (OPC), manual brick mold of dimensions 300×500×1500mm, 12×12×40mm and 40×40×40mm and additives (Calcium chloride). Sawdust of *Ceiba pentandra* was collected from Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan, Oyo state, Nigeria. The stone dust was obtained from Nursery A of the Federal College of Forestry, Jericho, Ibadan. The cement used was Ordinary Portland Cement which conformed to the BS12 (1996) requirements. Sharp sand was obtained from the banks of the stream situated inside Federal College of Forestry, Ibadan.

Materials preparation

The sawdust were sieved with 2mm sieve to obtain a uniformed particle size, and thereafter pre-treated in hot water at about 80^{0}C for a period of 1h. This pre-treatment process was carried out in order to facilitate the removal of water soluble sugars and other chemical substances present in the sawdust, which may possibly retard or completely inhibit the setting and curing of the cement. Hot water containing the leached chemicals was drained off; and later washed thoroughly in cold water for 20 minutes. Pre-treated sawdust was air-dried to constant moisture content of 12% and kept inside a laboratory environment prior to use.

The sand was thoroughly washed and flushed with water to reduce the levels of impurities and organic matter. The sand was later sun dried which conformed to BS 882 (1973). The water used was clean and free from any visible impurities which conformed to BS 3148 (1996) requirements.

The mould used was cleaned and lubricated. The different mixing ratios make up the treatments. This was weighed accordingly, mixed thoroughly and equal amount of water was added to the aggregates. Each treatment was poured into the moulds and placed in a spacious environment for aeration purpose. After 48h, each sample was demolded and laid out in the open air for another 48h for proper drying and solidification.

Blending of Production Variable

The required quantity of sawdust, stone dust and cement were measured and poured inside a plastic bowl. Water containing additive was then mixed with the contents of plastic bowl and then blended together using the hand until a lump-free furnish was obtained.

Pavers Formation, Pressing and curing

Mould of 300×500×150mm made with a wooden frame was used for pavers production; 12×12×40mm (impact test); 40×40×40mm (hardness and water absorption test); and 150×150×150mm (compressive strength). The mix was manually dispensed into locally fabricated mould followed by hand compacting in a pestle and mortar mode to increase the quantity of mix in the mould. The pre-compacted mix was followed by manual pressing using minimal hold-down pressure press to allow for the mixture to compact and initially set. Pre-pressing of the sawdust and sand mixtures is necessitated by the low density of the sawdust and low piston displacement capacity of the mould. All paver samples were cured at room temperature for 24h. Afterwards, the pavers' test samples were allowed to cure for a period of 28 days in the cure tank filled with lime-saturated water at 22°C. Then, the samples were dried for 24h in a ventilated oven at 105°C. The water absorption was obtained from the samples prepared for the unit weight tests.

TESTING

Physical Properties

1. Water Absorption: This was carried out by weighing the bricks one by one on a weighing balance and taking the reading of the initial weight (W_1). They were thereafter soaked in cold water for 120h after which the final weights (W_2) were taken. The water Absorption was calculated for each blocks by using:

$$\text{WA (\%)} = \left(\frac{W_2 - W_1}{W_1}\right) X100 \tag{1}$$

where: WA = water absorption;
W_1 = fresh (initial) weight (g);
W_2 = Dried (final) weight (g).

2. Density: This was determined using BS 1881 (1983). This was done after the pavers have been dried to a constant weight. It was then calculated by using:

$$D = \left(\frac{M}{V}\right) \tag{2}$$

where: D = density;
M = mass of the bricks after drying;
V = volume (size of the bricks).

Strength properties

The maximum compressive strength, hardness and impact tests was carried out at the Department of Civil Engineering Laboratory, Polytechnic, Ibadan, Oyo State, Nigeria Material Science and Engineering Department of the Obafemi Awolowo University (OAU), Ile-Ife, Osun State, Nigeria using 300×500×1500mm (pavers production), 12×12×40mm (impact test), and 150×1500×1500mm (hardness, compressive strength and water absorption test). Water absorption test was carried out at the Horticultural garden of the Horticulture and Landscape Department of the Federal College of Forestry, Jericho, Ibadan, Oyo State, Nigeria.

1. Compressive strength: The tests was carried out using a universal-testing machine, in the Structures Testing Laboratory at the Department of Civil Engineering, Faculty of Engineering, polytechnic, Ibadan, with attention focused on the maximum load causing failure. The test pieces of dimension 150×150×150mm (Fig. 3.) were placed between a supporting base and a flat steel plate above it, onto which a plunger that applied a compressive load rested. The maximum load (Newton) was recorded per test specimen and the compressive stress was calculated as Force per unit area.

$$C = \left(\frac{F}{A}\right) \tag{3}$$

where: C= compression;
F= force applied;
A= area of the bricks.

2. Impact bending: The test was carried out using an IZOD impact testing machine. Test pieces of 12×12×40 (Fig. 2.) was placed on the machine with a hammer dropped upon the samples beam from successively increased height until rupture occurs. The height of the maximum drop that causes failure is a comparative value that represents the ability of the material (concrete) to absorb shock that causes stress beyond the proportional limit. The impact bending test was calculated using:

$$IB = \frac{3.Pmax.l}{2ba^2}$$

where: IB = Bending strength of the test pieces (J);
L = Distance between the supports (cm);
Pmax = Maximum load (Kg);
A = width of the test samples (cm);
b = Thickness of the test samples (cm).

3. Hardness: Rockwell hardness test method was adopted as defined in ASTME-18 (1997). A preliminary test force was applied to a sample 150×150×150mm (Fig. 3.) using a diamond indenter. After the preload, an additional load was applied to reach the total required test load. The major load was then released and the final position was measured against the position derived from the preload, the indentation depth variance between preload value and major load value.

DATA ANALYSIS

Analysis of variance (ANOVA) was conducted to show the variation in impact bending strength, compressive strength, hardness, water absorption and basic density in relation to the mixing ratios. All statistical tests were carried out at 95% confidence level while Duncan Multiple Range Test (DMRT) was used to separate the means difference.

Table 1

Mixing ratio (Treatment Formation) for the production of interlocking pavers

Treatments	Sawdust	Stone Dust	Cement	Sharp Sand
TR_1	2	4	2	-
TR_2	2	3	2	1
TR_3	2	2	2	2
TR_4	3	1	2	2
TR_5	-	3	2	3

RESULTS AND DISCUSSION

Table 2

Mean values for different strength properties of interlocking pavers produced

Physio-mechanical Test	2:4:2:0	2:3:2:1	2:2:2:2	3:1:2:2	0:3:2:3
Impact bending (J)	3.55	3.28	4.39	3.44	3.63
Compressive strength (N/m^2)	2.88	3.34	3.22	2.74	4.72
Hardness (Hb)	3.42	2.64	1.79	4.36	1.78
Absorption (%)	17.78	22.24	11.13	6.66	-
Density (kg/m^3)	1.19	1.21	1.20	1.09	1.58

Table 3

Variance ratio (F-calculated) from various ANOVA tables for Physio-Mechanical test carried out for interlocking pavers produced

	SV	DF	SS	MS	F
IMPACT BENDING	Treatments	4	3.63	0.91	165.58*
	Error	20	0.11	0.01	
	Total	24	3.74		
COMPRESSIVE STRENGTH	Treatments	4	12.27	3.07	2044*
	Error	20	0.3	0.11	
	Total	24	12.57		
HARDNESS	Treatments	4	25.46	6.37	636.50^{ns}
	Error	20	0.2	0.01	
	Total	24	25.66		
ABSORPTION	Treatments	4	1552.1	388.02	153977*
	Error	20	0.01	0.00025	
	Total	24	1552.1		
DENSITY	Treatments	4	0.71	0.18	141.72*
	Error	20	0.03	0.001	
	Total	24	0.74		

*Significance at ($p \leq 0.05$); ns: not significance at $p > 0.05$

Density

From the result in Table 2 above, it clearly shows that treatment 5 (0:3:2:2) had the highest density followed by treatment 2 (2:3:2:1) while treatment 4 (3:1:2:2) had the lowest density value. The result shows that 25% increase in the quantity of sawdust and increase the quantity of sharp sand resulted into increase in density of the pavers produced. The greater bonding quality and cohesive strength inherent in the interlocking pavers produced from high sharp sand and stone dust with 25% increase in sawdust contents ratio might have probably accounts for their increased density. All these observations are similar to the results obtained by Babatola *et al.* (2011) in the production of bricks using sawdust reinforced with sand and Lohani *et al*. (2012).

The result of ANOVA obtained for density indicates that there is significant difference among the density of the pavers samples produced from the five treatments.

Water Absorption

Table 1 shows the mean values for percentage water absorption (WA) after immersion in cold water. The mean values for WA ranged from 6.66% to 22.24%. Result shows that increase in sand and stone dust increases the weight of the pavers produced which might be responsible for the weight gained after soaking in cold water. The lowest values were obtained from the control interlocking pavers produced at mixing ratio 0:3:2:2. The highest water absorption recorded was 22.24% at ratio 2:3:2:1 which was a little bit high. However, ratio 3:1:2:2 produced more dimensionally stable pavers with water absorption of 6.66%. These observations are similar to the results obtained by Lohani *et al*. (2012) and Badejo *et al*. (2012) in the production of wood waste bricks using sawdust reinforced with sand.

ANOVA result obtained for absorption test indicates that there is significant difference in the rate of absorption of the treatments at 5% P-level.

Compressive Strength

The compressive strength of the interlocking pavers increased with increase in stone dust as shown in Table 2 above. The least compressive strenght pavers (Fig. 3.) were produced from the lowest mixing ratio of stone dust to sand and with high sawdust content (3:1:2:2). The strength dramatically increased with an increase in the replacement level of sawdust with more of stone dust and sand. The highest mean value recorded was 4.72N/mm^2 at T_5 which were lesser to what was recorded by Gong *et al.* (1993). He reported that the compression strength values required for materials to be used as pavements range from 20 - 25N/mm^2 while that for beams ranges from 20-35N/mm^2 and up to 65N/mm^2 for reinforced concrete depending on the expected loads but complies with the 3.0N/mm^2 minimum requirement for lightweight concrete according to David (2008) in a review of variables that influences measured concrete compressive strength.

Impact Bending

The mean values for the strength properties are presented in Table 2. For the impact bending test, treatment 3 had the highest value (4.39J) followed by treatment 5 (3.63J) followed by T_2 (3.34N/mm^2). ANOVA result on impact bending strength of the test samples indicates that there is significant difference at 5% P-level between the samples. However T_3 (with a mixing ratio of 2:2:2:2) has the highest impact strength, conforming to the findings of Olutoge (2010) in a study where sawdust was used as partial replacement for granite in lightweight concrete production.

Hardness

Samples from T_3 (2:2:2:2) was found to be hardest, closely followed by T_2 (2:0:3:3), while T_4 (3:1:2:2) has the lowest hardness value. This finding is in accordance with the requirement of ASTM E18 (1997) which gives the minimum hardness value of lightweight concrete as not higher than 2.0kg. ANOVA results for hardness indicates that there exists significant difference in the degree of resistance to abrasion of the test samples at 5% P-level. Follow-up test however indicates that T_3 and T_5 are not significantly different from each other.

CONCLUSION AND RECOMMENDATIONS

The interlocking pavers produced from mixing ratio 2:2:2:2 has the highest strength capacity in terms of compression, impact bending, hardness, and density with the exception of T_5 (2:0:3:3) which is the control. Therefore, optimum replacement of stone-dust with sawdust exists at ratio (2:2:2:2).

From the above conclusions, the following recommendations are made:

i. Replacement of sawdust by volume adjustment is recommended in order to achieve higher strength of material concrete.

ii. Organic materials are subject to deterioration over time hence sawdust concrete applications should be regularly maintained and replaced when necessary.
iii. Further studies on different wood species of sawdust should be carried out so as to determine the strength properties of lightweight concrete produced thereof.

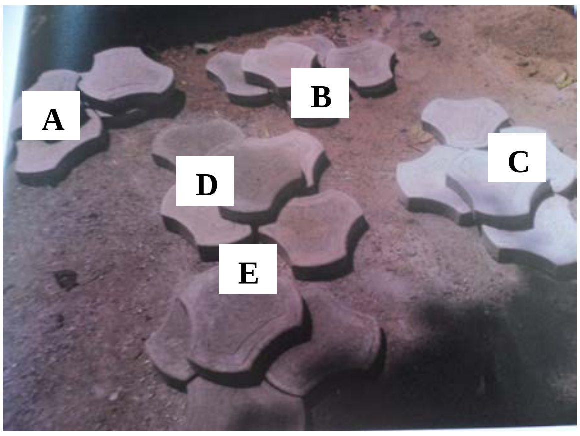

Fig. 1.
Interlocking pavers arranged according to mixing ratio of sawdust: stone dust: cement: sharp sand (A-2:2:4:0, B-2:3:2:1, C-2:2:2:2, D-3:1:2:2, E-0:3:2:3).

Fig. 2.
Test Sample (12×12×40mm) for Impact Strength properties.

Fig. 3.
Test Sample (150×150×150mm) for Hardness, compressive strength test and water absorption properties.

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