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Dimensional stability of cement-bonded composite boards made from rattan cane particles

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Abstract—Laboratory-type 50-mm-thick cement-bonded particleboards were made from particles derived from rattan cane (*Laccosperma secundiflorum*) at three rattan to cement weight ratios (10:90, 15:85, 20:80), and two particle sizes (those retained on a 600 μm sieve and a 50:50 mixture of particles retained on 850 μm and 1.2 mm sieves). After board manufacture, which excluded pressing, ASTM test procedures were employed to obtain the water resistance properties, i.e., water absorption (WA) and thickness swelling (TS). Mean WA (after 2 and 24 h of immersion in cold water) ranged between 2.2 and 25.1%, and 3.8 and 28.6%, respectively. The corresponding mean TS values were 0.2 and 1.4%, and 0.6 and 1.7%, respectively. Analysis of variance showed that the rattan/cement mixing ratio, rattan particle size and the interaction of both variables had a significant effect on water absorption, but no significant effect on thickness swelling of the boards. Smaller rattan particle size (600 μm) and lower rattan content (10%) provided a better performance, in terms of water absorption. Also, while highly significant ($P < 0.05$) simple linear relationships were observed between water absorption and thickness swelling at 2 and 24 h, and between water absorption and board density, the relationship between thickness swelling and board density was not significantly correlated. The relatively low water absorption capacity of the boards suggests that they can be employed in outdoor situations, while the relatively low TS values show that the experimental boards were dimensionally stable.

Key words: Rattan; wood-cement particleboard; water absorption; thickness swelling dimensional stability.

INTRODUCTION

Low-cost housing has remained topmost on the policy agenda of the Nigerian government in the last few decades. The aim is to provide adequate shelter, made of indigenous and cheap but durable housing materials for many homeless Nigerians. This is because the use of conventional building materials to construct low-cost housing in the country is becoming impractical for reasons of inadequate sup-

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ply and exorbitant cost. Suitable alternatives are building construction materials that are available in huge, inexpensive quantities such as wood-cement particleboard (WCP).

WCP is a lightweight concrete, the basic mixture of WCP, which consists of cement, (usually Portland cement), wood material and water. WCP combines the good qualities of cement (relatively high resistance to water, fire, fungus, termite infestation and good sound insulation) and those of wood (comparatively low weight, good workability with normal wood-working tools and good mechanical properties). They are used in both exterior and interior applications such as cladding panels, fascia boards, ceilings, floorings and fire-resistant partitions. Besides, they can be produced in nearly all desired practical sizes; they can be sawn, bored and nailed like wood; they can be plastered and painted [1, 2].

Several lignocellulosic materials have been used for WCP production. A vast majority of these materials are wood and agricultural residues such waste wood of any kind including as sawdust, fronds of oil palms, sugar cane bagasse, cork waste and rattan furniture waste [3–6]. However, these and many other lignocellulosics are often produced in small, scattered areas around the country, making collection and transportation uneconomical. It is preferable, therefore, to site production sites in areas where the cultivation of certain plants is dominant. An example of such plants is rattan, a versatile climbing, spiny palm. One of the most commonly found rattan species in Nigeria is *Laccosperma secundiflorum* [5, 7].

Some of the advantages of using rattan for WCP production include the following: (i) short rotation: rattan can be harvested less than 7 years after planting; (ii) it is amenable to both agro-forestry and plantation establishment; (iii) rattan plants can be harvested periodically, using simple technology, over a long period of time [8]; (iv) the processing chain from harvesting of raw rattan to the manufacture of WCP involves low capital investment and high labour input thus making it suitable for small-scale industrial production; and (v) its use for WCP production will promote its efficient utilisation by minimising the wastage typically associated with its more popular use for furniture manufacture, which has been estimated at well over 30% of rattan stems harvested at any particular time [9]. It has also been reported that only about 20% of the over 600 known rattan species produce the most sought-after fine quality canes and are, therefore, of commercial value [10]. The remaining species with low quality canes that are not utilised due to inflexibility, tendency to breakage, poor mechanical properties, etc., can be used for WCP manufacture.

To obtain complete assurance that a useable WCP product can be made from a given lignocellulosic, it is often desirable to produce blocks or slabs using the unknown material and then test them physically. A common test usually recommended for WCP is dimensional stability. This is because one of the major problems that restrict the use of WCP in outdoor conditions with varying relative humidity is their dimensional instability [11]. The thickness swelling, measured by the water soaking method, i.e., water absorption after short-term and/or long term immersion, and the attendant changes in board dimensions, is usually taken as the primary measure of dimensional stability of these wood composite materials [12].

Previous studies have shown that both wood particle size and wood-cement mixing ratio are critical variables that contribute to the dimensional stability of WCP [3, 5, 11, 13–16]. The objective of this work, therefore, was to investigate the effects of the rattan/cement mixing ratio and rattan particle size on the water resistance behaviour of WCP produced from rattan cane particles.

MATERIALS AND METHODS

Material collection and preparation

Mature, freshly harvested rattan canes were obtained from harvesters at Sapele, Delta State, Nigeria. The canes were taken to the laboratory of the Department of Botany, University of Ibadan, Nigeria where they were identified as *L. secundiflorum*. They were subsequently subjected to preliminary processing involving manual scraping (deglazing) to remove the silicified epidermis (skin), followed by air-drying for four weeks and hammer milling. The particles obtained after hammer milling were sieved using a set comprising 2.4 mm, 1.2 mm, 850 μm and 600 μm sieves. The average moisture content of the sieved particles was determined using the oven drying method and was found to be about 11%.

Commercially available bags of fresh Portland cement of class strength 32.5 R grade (graded in accordance with BS EN 197-1:2000 [17]) were procured for use in board manufacture. Prior to, and throughout the test, the cement was stored at room temperature in an airtight plastic container to prevent strength degradation due to exposure to ambient weather conditions. To minimise possible contamination, distilled water stored at room temperature (20 ± 2°C) was used for mixing.

Experimental design

Two variables used for board production were rattan/cement mixing ratio (by weight) and rattan particle size. Three rattan/cement mixing ratios, i.e., 10 : 90, 15 : 85 and 20 : 80, were used. Two rattan particle sizes were also used. These were: (a) rattan particles that passed through the 850 μm sieve but were retained on the 600 μm sieve; and (b) a 50 : 50 mixture (by weight) of rattan particles that passed through the 2.4 mm sieve but were retained on the 1.2 mm, and those that passed through the 1.2 mm sieve but were retained on the 850 μm sieve. Three replicate samples were used for each test. This translates to a $2 \times 3 \times 3$ factorial treatment combination with 18 treatments in all.

Board fabrication and testing

For each board, the rattan cane particles were dry-mixed manually in a container with cement. Distilled water was added at the rate of 0.25 ml/g of cement

+ 2.7 ml/g of rattan. The use of this expression, developed by Weatherwax and Tarkow [18] and previously used by Moslemi and Lim [19], among others, was based on the assumption that the water requirement for the rattan/cement composite board production would be similar to that of other WCPs. Mixing continued until the particles were thoroughly coated with the cement paste. The blend was then poured into a plastic mould and compacted with a tamping bar. The mould size for the test specimens was 250 mm (length)×50 mm (width)×50 mm (height). The boards were kept in the mould under wet cloth for 24 h. After de-moulding, they were left under wet towels at normal room temperature (20 ± 2°C) for 6 days to prevent moisture loss through evaporation. They were then transferred to a conditioning room maintained at a constant temperature of 20 ± 2°C and a relative humidity of 65 ± 5% for another 21 days before testing.

Prior to testing, each board was weighed and its dimensions taken. The green (wet) density of each specimen was calculated by dividing the weight by its volume and the mean of three replicates was obtained. The moisture content of each board was also determined using the oven-drying method, with the oven temperature set at 103 ± 2°C. The density values were then corrected for the average moisture content.

The boards were tested for water absorption (WA) and thickness swelling (TS) in accordance with ASTM standard D 1037-96a [20]. The specimens were submerged horizontally under 25 mm of distilled water maintained at a temperature of 20 ± 2°C for 24 h. The amount of water absorbed after 2 and 24 h was calculated from the increase in weight of the specimen during submersion, while the water absorption was expressed as the percentage by weight based on the weight after conditioning. The thickness swelling was expressed as a percentage of the original thickness. The test results were subjected to statistical analysis including analysis of variance, correlation and regression.

RESULTS AND DISCUSSION

Water absorption

The mean WA for each board produced at the different rattan/cement mixing ratio and rattan particle size combinations after 2 and 24 h immersion in cold water is shown in Table 1. WA after 2 h of immersion in cold water ranged from 2.2 to 25.1%. Also, the WA after 24 h of immersion in cold water ranged from 3.8 to 28.6%. The WA after 24 h of immersion was relatively low in comparison with WA by WCP produced at similar density range (764–1340 kg/m^3) and soaked in cold water for 24 h, i.e., bagasse (41.52%), coconut husk (30.55%) and gmelina (*Gmelina arborea* Roxb.) sawdust (28.93%) [3] and spruce (S*tricka stiepensis*) (6.5–28.1%) [21]. This is probably due to the relatively higher cement contents of the rattan/cement boards (80–90%) compared to these other WCPs in which the cement content ranged from 72 to 75%. The relatively low WA values, however, suggest that the rattan/cement composite boards had low affinity for water.

Table 1.
Effect of rattan/cement mixing ratio and rattan particle size on water absorption and thickness swelling in the experimental boards

Board code no.	Rattan particle size (mm)	Rattan content in board (%)	Mean board density (kg/m^3)	Mean water absorption (%)		Mean thickness swelling (%)	
				2 h	24 h	2 h	24 h
1	0.6	10	1340	2.2 ± 0.3	3.8 ± 0.4	1.4 ± 0.6	1.7 ± 0.5
2	0.6	15	1081	6.9 ± 0.3	10.2 ± 0.4	0.4 ± 0.2	0.9 ± 0.5
3	0.6	20	940	22.5 ± 5.4	26.4 ± 5.2	0.6 ± 0.6	1.3 ± 0.3
4	0.85 and 1.2	10	1270	4.9 ± 0.1	8.2 ± 0.5	0.2 ± 0.1	0.6 ± 0.4
5	0.85 and 1.2	15	896	25.1 ± 4.3	28.6 ± 4.6	0.6 ± 0.6	1.2 ± 0.9
6	0.85 and 1.2	20	764	24.2 ± 0.4	26.7 ± 0.3	0.2 ± 0.04	0.8 ± 0.2

The boards produced with 600-μm rattan particles were denser and they generally absorbed less water (after 2 h and 24 h, respectively) than those produced with the 850 μm and 1.2 mm particle mixture at the three levels of rattan/cement mixture tested. This is probably because the fine particles required more cement binder during fabrication than the coarse particles. Though the rattan/cement mixing ratio (i.e., proportion by volume) was constant for each board type, the actual amount (weight) of cement used for the fabrication of boards of the same dimension from different rattan particle sizes varied. This was so because the bulk density of the different particle sizes also varied. This factor actually accounts for the variation in final board density values at the different rattan/cement mixing ratios. Also, boards produced with 600 μm rattan particles had less void spaces, that is, they were less porous in view of the relative closeness of the particle size with that of cement. This finding suggests that the smaller the particle size used for board production, the greater the board density, and the less the water absorption potential.

Regression analysis showed that the WA values at 2 h and 24 h positively correlated to each other while also being positively correlated with board density. Analyses of variance (ANOVA) to test the significance of these relationships showed that highly significant simple linear relationships exist. The linear regression equations are as follows:

$$\mathrm{WA}_{24} = 2.56 + 1.03\ \mathrm{WA}_2 \qquad R = 0.997,$$
$$R^2 = 0.995 \text{ (0.05 level of significance)} \tag{1}$$

$$\mathrm{WA}_2 = 61.047 - 0.05D \qquad R = 0.935,$$
$$R^2 = 0.84 \text{ (0.05 level of significance)} \tag{2}$$

$$\mathrm{WA}_{24} = 65.55 - 0.05D \qquad R = 0.932,$$
$$R^2 = 0.84 \text{ (0.05 level of significance)} \tag{3}$$

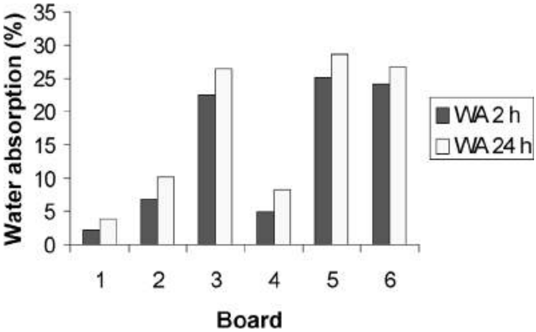

Figure 1. Water absorption in experimental boards after 2 and 24 h.

Table 2.
Analysis of variance on the effects of rattan content and particle size on water absorption and thickness swelling of the experimental boards

Source of variation	Degrees of freedom	Mean squares (WA)		Mean squares (TS)	
		2 h	24 h	2 h	24 h
Replication	2	10.04	8.89	0.095	0.43
Rattan content (RC)	2	599.72*	650.94*	0.25	0.035
Particle size (PC)	1	259.09*	265.57*	0.82	1.01
Interaction (RC×PC)	2	129.18*	134.47*	0.70	0.72
Error	10	7.59	7.97	0.21	0.21
Total	17				

* Significant at 0.05 level.

where WA_2 and WA_{24} are percentage water absorption after 2 and 24 h, respectively, D is board density, R is co-efficient of correlation and R^2 is co-efficient of determination.

The fitted regression equations can be used for prediction purposes for boards made in a similar way and with similar materials.

Further comparison of WA at 2 h and 24 h for all the boards (Fig. 1) showed a minimal increase in the 22-h interval. The increase in water absorption ranged between 1.67 and 3.9% for all experimental boards. A relatively slow water absorption rate is an indication of the boards' suitability for exterior use where they could be in constant exposure to moisture and varying humidity conditions. It is also a measure of its durability since the durability of a cementitious material depends on its ability to allow the transport of fluids through it [22].

The ANOVA test (Table 2) showed that the rattan/cement mixing ratio, rattan particle size, and the interaction of both variables had a significant effect on WA of the boards. As the rattan content and particle size increased, the ability of the boards to absorb water increased significantly. This may be explained by the fact that rattan, like other lignocellulosics, is hygroscopic, with a relatively high affinity for water. As noted by Liese [9], the moisture content of freshly harvested rattan cane may be as high as 160%. Also, the smaller rattan particles were apparently better encapsulated by the cement matrix. Besides, as earlier mentioned, the boards fabricated with smaller rattan particles were produced using larger quantities of cement. This may also have resulted in their lower water uptake than larger particle size at the same rattan/cement mixing ratio.

Thickness swelling

The mean TS for the boards after 2 h and 24 h immersion in cold water respectively is shown in Table 1. The range of values obtained for TS after 2 h of immersion was 0.2–1.4%, while that obtained following 24 h of immersion was 0.6–1.7%. These values are again relatively low in comparison with TS by WCP produced at similar density range and soaked for the same time duration from bagasse (3.98%), gmelina sawdust (4.45%) [3] and spruce (1.01–3.4%) [21]; but slightly higher than boards produced from coconut husk (0.25%) [3]. Hence, it can be said that the unpressed rattan/cement boards are relatively dimensionally stable when exposed to water at room temperatures.

A plausible reason for the relatively low TS observed is that the boards were not under appreciable stress/strain recovery since they were not subjected to any serious pressure during and after casting as was reported for the WCPs in all the aforementioned previous studies. As noted by Badejo [11] and Xu and Winistorfer [12], a major component of TS comes from the release of the compressive stress (or strain) incorporated into a composite at pressing during manufacture.

As shown in Fig. 2, the TS of boards produced with a mixture of 850 μm and 1.2 mm particles was relatively lower than those produced with the 600 μm particles, even though the WA values (after 2 h and 24 h, respectively) were relatively higher. What this suggests is that smaller thickness of cement binder between particles due to the greater surface area of the small particles resulted in less resistance to swelling. Badejo [14] reported a similar finding in which WCPs

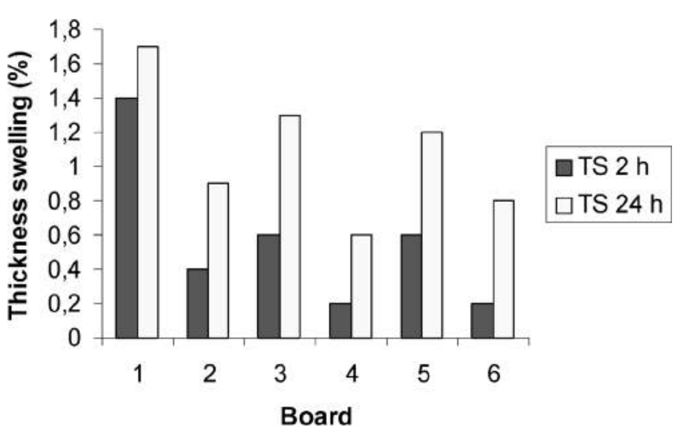

Figure 2. Thickness swelling of experimental boards after 2 and 24 h.

produced with longer and thinner flakes exhibited less TS than those produced with finer particles. The ANOVA test (Table 2) however showed that the rattan: cement mixing ratio, rattan particle size, and the interaction of both variables had no significant effect ($P > 0.05$) on the TS of the boards.

Regression equations were also developed to relate TS at the two time intervals with board density, i.e.:

$$TS_{24} = 0.54 + 0.92\,TS_2 \qquad R = 0.95 \qquad R^2 = 0.89 \tag{4}$$

$$TS_2 = -0.42 + 0.001D \qquad R = 0.50 \qquad R^2 = 0.253 \tag{5}$$

$$TS_{24} = 0.51 + 0.0005D \qquad R = 0.29 \qquad R^2 = -0.15 \tag{6}$$

where TS_2 and TS_{24} are percentage thickness swelling after 2 and 24 h, respectively, while all other variables are as previously defined.

A strong linear relationship between TS after 2 and 24 h of immersion in cold water respectively is evident from equation (4). However, the relatively low coefficients of correlation and determination in equations (5) and (6) show that there was no significant linear relationship between the measured TS and the density of the boards.

CONCLUSIONS

Rattan/cement composite board was produced using three rattan/cement mixing ratios and two rattan particle sizes. From the data collected and their statistical analyses, the following conclusions are drawn:

1. The water absorption capacity of the un-pressed rattan/cement composite boards fabricated was relatively low. This is an indication that the boards can be employed in outdoor situations where they could be in constant exposure to cold water.
2. The dimensional stability of the rattan/cement composite boards was relatively high in comparison with WCP from some other lignocellulosic materials reported in the literature. This was attributed to relatively low strain recovery due to the fact that the boards were not subjected to external pressure during manufacture.
3. The rattan/cement mixing ratio, rattan particle size and the interaction of both variables had a significant effect on water absorption, but no significant effect on thickness swelling of the boards. Smaller rattan particle size (600 μm) and lower rattan content (10%) provided a better performance, in terms of water absorption.
4. There was a highly significant linear relationship and a positive correlation between water absorption and thickness swelling at 2 and 24 h, and a significant negative correlation between water absorption and board density, while thickness swelling was not significantly correlated with board density.

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