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Development and Evaluation of Cement-Bonded Composite Tiles Reinforced with *Cissus populnea* Fibres

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Abstract The feasibility of developing non-conventional composite tiles using fibres extracted from *Cissus populnea* was investigated. *C. populnea* stems were sourced from a local market in Ibadan, processed and used for cement composites tile production. A manually-operated tile making machine was designed and constructed. The machine was able to produce 50-pieces of 200x100x10.5 mm of composite-tiles per hour. The tiles were conditioned and tested for dimensional stability and mechanical properties in accordance with ASTM D 1037-00. Results obtained indicated that the tiles were dimensionally stable with low sorption and swelling rates but had moderate strength suitable as insulating components such as wall and floor tiles. Pre-treatment with calcium chloride significantly enhanced the dimensional stability but reduced the strength properties.

Keywords *Cissus populnea,* Cement composite tiles, Pre-treatment

1. Introduction

Tiles are hard-wearing building components made from porcelain, fired clay or ceramics with hard glaze and atimes from other materials such as glass, metals, corks and stones. They are usually flat in shape and can range from simple square tiles to complex mosaic. Tiles are often used to form wall and floor coverings due to their aesthetic and waterproof nature (Pirhonen *et al.,* 1996). They are becoming important housing components in Nigeria and as such their cost is increasing because majority of these items are imported. Consequently, tiles are not affordable by many Nigerians intending to own their personal housing units. A means of curtailing this setback is in the development of low cost non-conventional composite material made from available local resources (Olorunnisola, 2012).

Concrete tiles, made from the mixture of Portland cement and quarry sand (fine aggregate) (Neville and Brooks, 1987) is an example of low-cost non-conventional composite material. These materials are eco-friendly, easy to manufacture and install, durable, light in weight and can be used for interior / exterior wall cladding, partitioning etc. (Badejo 1987; 1989; 1998; Ramirez-Coretti et al., 1998; Mrema, 2006). The integration of non-conventional composites as components in building construction in Nigeria will augment the increasing need for affordable housing components by the populace. However, concrete is too stiff to flow and brittle. Consequently, it is not strong enough in tension to resist cracking (Kurtis, 2007).

Historically, natural fibres were empirically used to reinforce several construction materials, as the case for the production of textile material. Later, scientists started to study their application in concrete reinforcement. Natural fibres can be obtained at relatively low prices using locally available manual labor and techniques. They can be chemically or mechanically processed to enhance their properties; usually, these fibres are based on wood derivate cellulose. Such chemical or mechanical processes are commonly utilized in the developed countries; whereas, because of relatively high costs of processing, these technologies are rarely adopted in developing countries (ACI, 1998). The incorporation of fibres (unprocessed natural fibre) as concrete reinforcement reduces plastic shrinkage cracking, stops the spread of micro-cracks, increases the tensile strength of concrete and transforms a brittle material into a pseudo-ductile material (Swamy, and Mangat, 1975; Soroushian, 1991). One of the natural fibres yet to be considered is that of *Cissus populnea*, a strong woody climbing shrub, found throughout West Africa, (Iwe and Atta, 1993) which offer advantages such as availability, renewability, low cost and the simple technology for its extraction.

Also, the hand-moulding method locally employed in concrete tile production in Nigeria is time-wasting, coupled with its low production capacity. These factors motivated the design, fabrication and testing of a manually–operated composite-tile making machine. *C. populnea* contains sugars and extractives which may impair cement bond formation. Pre-treatments measures like soaking in water and / or

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application of chemical additives like calcium chloride have been found to remove / reduced these components thus enhancing strong crystalline bond formation. This work, therefore, also examined the influence of calcium chloride on the strength and sorption properties of cement composites produced.

2. Materials and Methods

Machine Design Considerations

The following factors were taken into consideration during the design and fabrication of the machine:

i) Mild steel was selected as the material of construction to enhance the strength and durability of the machine.
ii) All repair-prone components of the machine were bolted for ease of repair and maintenance.
iii) Noise-damping material (rubber) was incorporated to minimize the machine's operational-noise level to the barest minimum.
iv) All sharp edges of the machine were ground, and the joints were welded for safe machine operation.

Components of the Machine

The major components of the manually operated composite tile making machine (Figure 1) include the following:

i. Frame

The machine legs were made of mild steel (U-channel) of dimension 40 x 75 x 40 x 8mm, with 830mm length each. The bracings were made of mild steel angle iron of dimension 50 x 50 x 6mm having the lengths of 585mm and 470mm respectively.

ii. Vibrating System

The vibrating system consisted of a vibrating table, a set of compression springs, and a pulley system. The table was fabricated from mild steel plate of dimension. 609 x 482.6 x 2mm. It was braced underneath with 8mm iron rods, to guard against fatigue failure. The compression springs were also made of mild steel with height of 90mm, inner diameter 30mm, out diameter 35mm, and wire diameter of 5mm, and it was closed and ground at both ends for proper seating in the casing. The pulley system was made up of the rubber belt, and small and larger pulleys. The rubber belt has a length of 1.295m while the pulleys have diameters of 250mm and 75mm respectively.

iii. Moulding and Demoulding System

The moulding system consisted of a mould made of 2mm–thick metal plate. It was partitioned into 10 cells. Each cell has an area of 206.5mm^2 with 25.7mm height. The total surface area of the mould was (533 x 406) mm^2. The demoulding unit consisted of a shaft, a set of flat bars and lever for upward and downward movement of the mould. The lever was made of a hollow pipe of mild-steel make. The pipe had an internal diameter of 40mm with 4mm thickness and 900mm length. The flat bars were made of mild steel of 6mm thickness and 508mm and 203mm length respectively. The mild-steel shaft had 30mm diameter 920mm length.

iv. Pressing System

This unit was made up of a rigid and heavy mechanism that had an attached weight in form of mild steel plate of 15mm thickness. Whenever the presser is released on the cement-filled mould, a compressive stress is imposed on the loaded cement matrix thereby causing its compaction.

Collection of Materials for Composite Tile Production

Ordinary Portland Cement (OPC) was procured from a cement depot in Ojoo area of Ibadan, Oyo State, Nigeria in 50 Kg bags and properly stored before being used. Quarry Sand was procured from a concrete tiles maker in Ojoo area of Ibadan. The sand particle sizes range from 0.2 – 0.8mm. This served as fine aggregate in the concrete mix. Iron oxide, coloured cement, and white cement were purchased at Iwo Road area of Ibadan and used for making different coloured tile surfaces. Calcium Chloride was procured at Iwo Road area of Ibadan and was used as a cement accelerator. A wooden pallet of 420 x 500 mm dimension was made in the departmental workshop and served as rigid base to the plastic-pattern that was secured from a local market in Ibadan. The plastic pattern was used to create decorative impressions on the tiles.

Stems of *C. populnea* were sourced from a local market in Ibadan, Oyo state, Nigeria chopped into billets as shown in Figure 1 and cut into 0.25 – 0.50 cm lengths. These were soaked in ordinary tap water for 48 hours after which the samples were manually shredded while piths were removed. The remaining items were sun-dried to 15% moisture content and used for board production.

Figure 1. Billets of Dry Stems of *C. populnea*

Characterization of the '*Cissus populnea*' Fibres

For moisture content determination, the oven-dry method was adopted for this purpose. Three replicates of *Cissus* fibres were taken from different positions and their initial mass known and recorded. Fibres were placed in the oven at temperature of 90°C until constant fibre mass was attained at 20min interval. The final mass of the fibres were recorded, and the percentage moisture content calculated thus from the fibres weight difference.

For bulk density determination**,** a clean plastic container of known mass (Wo) and volume was filled to the brim with dry and fine particles of *cissus* fibres, and the new mass (W1) was recorded. The Bulk Density (BD) of the fibres was thus calculated:

$$BD = \frac{\text{Mass of fibres}}{\text{Volume 0f fibres/ container}} \quad (1)$$

Water absorption test was conducted on the fibres using 2 and 24 hours soaking periods. Fibres of a known mass were placed in three different water containers of known mass; then filled to the brim with fresh water. The water was later drained from the bottle through the perforated openings and all surface water was removed with a clean dry cloth. The specimens were re-weighed to the nearest 0.1 mg within few minutes of draining the water. The mass of empty containers, dry fibres and soaked fibres were recorded after 2nd and 24th hour of soaking. The percentage water absorption (WA) was calculated thus;

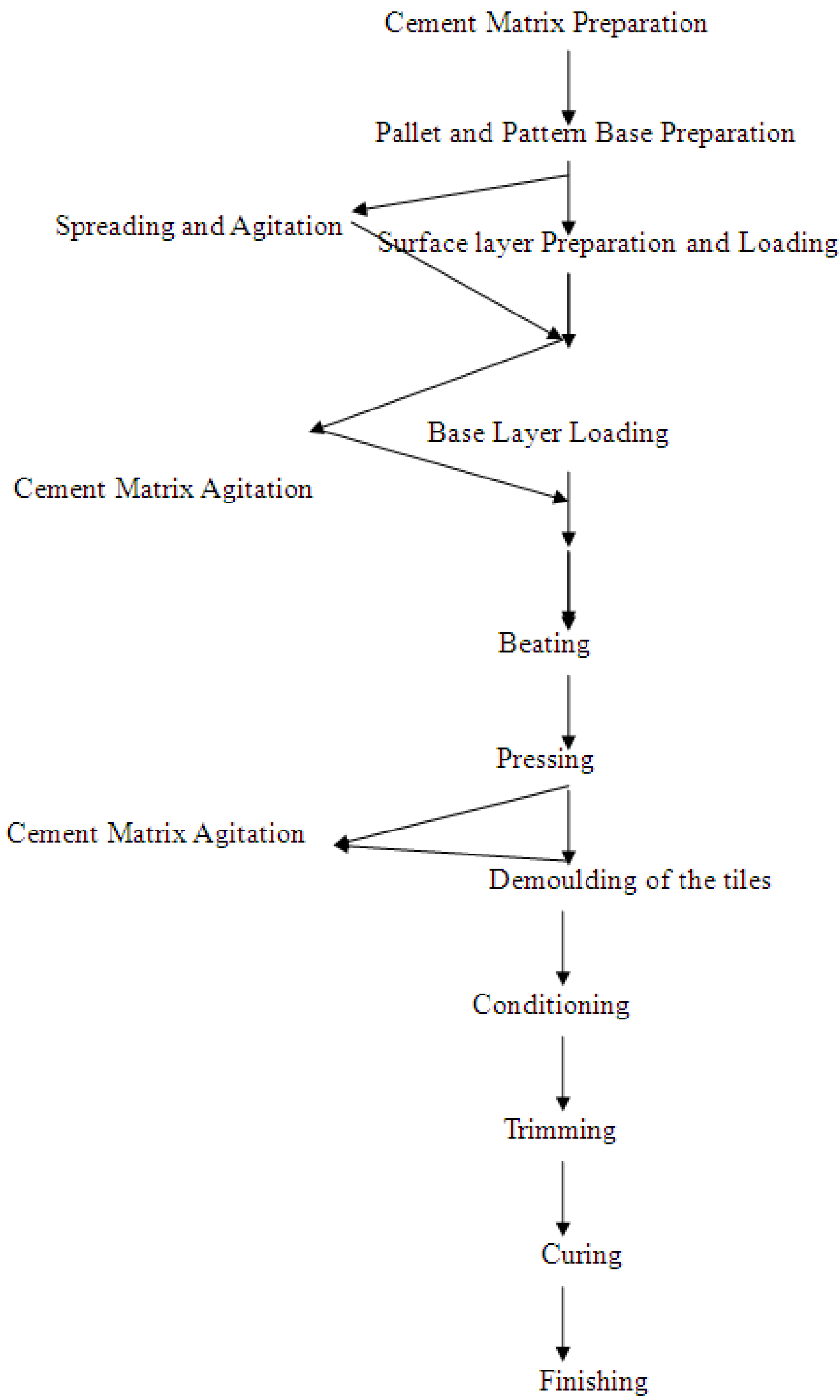

Figure 2. Tile Production Flow Chart

$$WA = \left(\frac{W_1 - W_0}{W_0}\right) \times 100\ \% \quad (2)$$

Where;

W_1 = Mass of soaked fibres

W_0 = Mass of dry fibres

Tile Production and Evaluation

Two layered composites tiles were made from mixtures of 0.025% of *C. populnea* fibres (based on cement weight), sand-cement ratio of 3:1 and 0.65 water-cement ratio at 0 and 2% calcium chloride additive concentrations respectively. Figure 2 shows the tiles production flow chart. The composite-tiles comprise two layers of cement matrix i.e. surface and base layers. The surface layer was made from the slurry, as the product, of the mixing of the pre-determined quantity of White OPC and fresh water. The slurry was cast into the mould under-laid with a plastic-pattern base placed on a wooden pallet; flattened, agitated and allowed to harden for few minutes before the base layer was cast onto it.

Subsequently, a known quantity of *Cissus populnea* fibres (4% by weight of OPC) was measured and mixed with cement matrix made from the mixture of dry quarry sand-cement ratio 3:1, 0.65 water-cement ratios and the pre-determined quantity of fresh commercial-grade grey-coloured OPC. The mixture was thoroughly blended until slurry of uniform viscosity was formed. At all stages up to the time of use, cement was kept dry so as to prevent or minimize deterioration from the effects of moisture, atmospheric humidity and carbonation.

The prepared slurry was cast, as base layer, onto the surface layer in the mould and agitated using vibrating table until the slurry began to bleed. The slurry was then pressed and compacted. The tiles were formed after compaction and later de-moulded. The de-moulded tiles were covered for 24 hours with nylon sheets to prevent loss of heat of hydration and moisture evaporation. After 24 hours, the nylon sheets were removed and the tiles were then kept under wet condition for 6 days after which they were carefully trimmed to shape and conditioned at room temperature for another 21 days. The samples were then tested for dimensional stability (water absorption (WA) and thickness swelling (TS)) after 2 and then 24 hours soak in water and mechanical properties (Moduli of Rupture (MOR) and Elasticity (MOE) on a M500-25KN Testometric Universal Testing Machine at 2mm/min cross-head speed in accordance with ASTM D 1037-00 (2003). Impact test was based on repeated blows from increasing heights on a flat surface of the boards while noting the height of the ball that caused the failure impact.

3. Results and Discussion

Physical Properties of the *Cissus populnea* Fibres

As shown in Table 1, the average oven-dry moisture content of the *C. populnea* fibres was 16% which is below the Fibre Saturation Point (FSP) of wood usually taken to be between 25 and 30%. As reported by Simantupang and Schwarts (1976), a fibre must reach FSP before being thoroughly blended with cement. The use of the fibres at this moisture content for cement-bonded composite production, therefore adds no extra water to the cement matrix; unlike fibres with the moisture content above FSP.

The average bulk density of the fibres was 0.15g/cm^3. This value is relatively lower than the bulk densities of other common natural fibres used as reinforcement in composite production such as Coir fibres (1.15g/cm^3), Sisal fibres (1.45 g/cm^3), banana fibres (1.35 g/cm^3), bamboo fibres (0.91 g/cm^3), as reported by Rao and Rao (2007). The *C. populnea* composites are therefore likely to be lighter than composites produced using other natural fibres.

The percentage water absorption of the fibres after at 2- and 24-hour soaking periods were 226% and 375% respectively. These values are comparable with the water absorption rates of other known fibres that have been used for composite making such as Sisal fibres (110%), Coir fibres (98%), Bamboo fibres (145%), Banana fibres (407%) as reported by Torgal and Said (2002). Increase in fibre quantity increases the rate of water absorption, so care must be taken in determining the quantity of *C. populnea* fibres to be used for composite production. The reason for the high water absorption of the *C. populnea* fibre may be due to the hydrophilic nature of the fibres and also the presence of mucus in its cell walls. Composites in which the fibres are used may therefore, stand the risk of cyclic water absorption if used outdoor, thereby affecting adversely their flexural strength. Also, the fibres may suffer volumetric changes therefore affecting their adherence to the cement matrix which may eventually cause composite cracking (Coutts, 2005). To preserve the fibres against water absorption, they may be subjected to surface treatment with 10% NaOH solution, coating with water-repellant and total extraction of the mucus.

Table 1. Physical Properties of *Cissus populnea* Fibre

Property	Value
Mean M.C (%)	16
Mean Bulk Density (g/cm^3)	0.15
Mean water absorption (%)	226 (*2hr*), 375 (*24hr*)

Machine Description and Products

Figure 3 shows a side view of the manually-operated composite-tile making machine, while Figure 4 shows the tiles that were produced with the machine. The machine is 1.36 m tall, 0.59m wide at the front, 0.47m wide on both sides, and weighs of 1.7KN. The machine capacity is 1m^2 (50-pieces) of 200x100x10.5 mm composite-tiles per hour. The total cost of a one-off prototype of the machine was sixty thousand Naira (approximately 450 US Dollars).

Water Absorption and Thickness Swelling

The results of the WA and TS are shown in Table 2. The WA and TS after 2 and then 24 h ranged from 5.5 to 6.6% and 0.7 to 2.5% respectively. These values compared favourably with those reported for wood and rattan cement composites (WA: 2.2 – 28.6%; TS: 0.2 – 8.8%) (Badejo, 1987; 1989; Fuwape and Oyagade, (1993); Olorunnisola *et al*. (2005). The composite tiles had low water absorption and swelling rates and can be used in both outdoor and indoor applications. The application of 2% $CaCl_2$ significantly ($P < 0.05$) reduced the WA and TS of the *C. populnea* composites in comparison with the control. However, no significant difference existed in the soaking times (2 and 24 h) of the *C. populnea* composites (Table 3). What this suggests is that $CaCl_2$ enhanced the bond formation between *C. populnea* fibres and cement thereby reducing the water sorption and swelling rates of the composites.

As shown in figure 5, there was linear relationship between the WA and TS. What this suggests is that the WA can be used to predict the TS of the composites tiles.

Flexural Test

The result of the MOR, MOE and impact tests of the composite tiles are shown in Table 4. The MOR, MOE and impact strength ranged between 3.3 – 3.5 N/mm^2, 1643.4 – 1702.6 N/mm^2, and 2575.1 – 2949.0 Nm respectively. These values compared favourably with those for wood and rattan cement composites (0.8 – 24.0 N/mm^2 and 130.0 – 8658.0 N/mm^2) (Badejo, 1987; 1989; Fuwape and Oyagade, (1993); Olorunnisola *et al*. (2005)). The relatively low MOR and MOE obtained in this study may be due to the low bulk density of the fibres. The low strength values indicate that the composite tiles may not be suitable for structural application but as non-load bearing wall and floor tiles. The incorporation of 2% $CaCl_2$ generally reduced the flexural properties of the composites, though the reduction was not significant. What this suggests is that the application of 2% $CaCl_2$ did not enhance the strength properties of *C. populnea* composites. Juaruz *et al.*, (2007) had observed that the addition of $CaCl_2$ to cement composites tends to cause reduction in some of its original strength due to salt penetration into capillary pores. Therefore, when composites become dry, the salt solution evaporates resulting in salt crystallization and subsequent internal fractures as a result of crystal growth expansion in the cement matrix. This process may eventually result in loss of strength in composites treated with $CaCl_2$.

Figure 3. Side View of the Tile –Making Machine

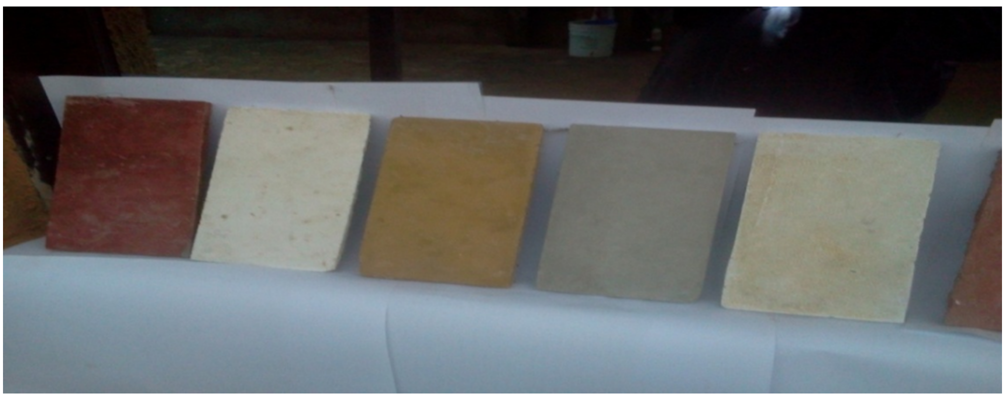

Figure 4. The Front Views of the various Coloured Composite-Tiles

Table 2. Water Absorption and Thickness Swelling of *C. populnea* composites

	Water Absorption (WA %)		Thickness Swelling (TS %)	
Additive Concentration (%)	2h	24h	2h	24h
Control (0)	6.6^{A} (0.14)	6.6^{A} (0.14)	1.7^{AB} (0.22)	2.5^{A} (0.55)
3	5.5^{B} (0.36)	5.8^{B} (0.34)	0.7^{B} (0.54)	1.0^{B} (0.65)

*Means with the same letters are not significantly (P < 0.05) different
*Standard deviation in Parentheses

Table 3. Duncan's Multiple Range Test of Water Absorption and Thickness Swelling of *C. populnea* composites

	WA (%)	TS (%)
Additive Concentration (%)		
Control (0)	6.6^{A} (0.13)	2.1^{A} (0.57)
3	5.6^{B} (0.34)	0.9^{B} (0.55)
Soaking Time (h)		
2	6.0^{A} (0.64)	1.2^{A} (0.65)
24	6.2^{A} (0.51)	1.7^{A} (0.99)

*Means with the same letters are not significantly (P < 0.05) different
*Standard deviation in Parentheses

Table 4. Flexural Properties of *C. populnea* composites

Additive Concentration (%)	MOR (N/mm^2)	MOE (N/mm^2)	Impact Strength (Nm)
Control (0)	3.5^{A} (0.20)	1702.6^{A} (317.6)	2949.0^{A} (637.2)
3	3.3^{A} (0.28)	1643.4^{A} (402.4)	2575.1^{A} (637.2)

*Means with the same letters are not significantly (P < 0.05) different
*Standard deviation in Parentheses

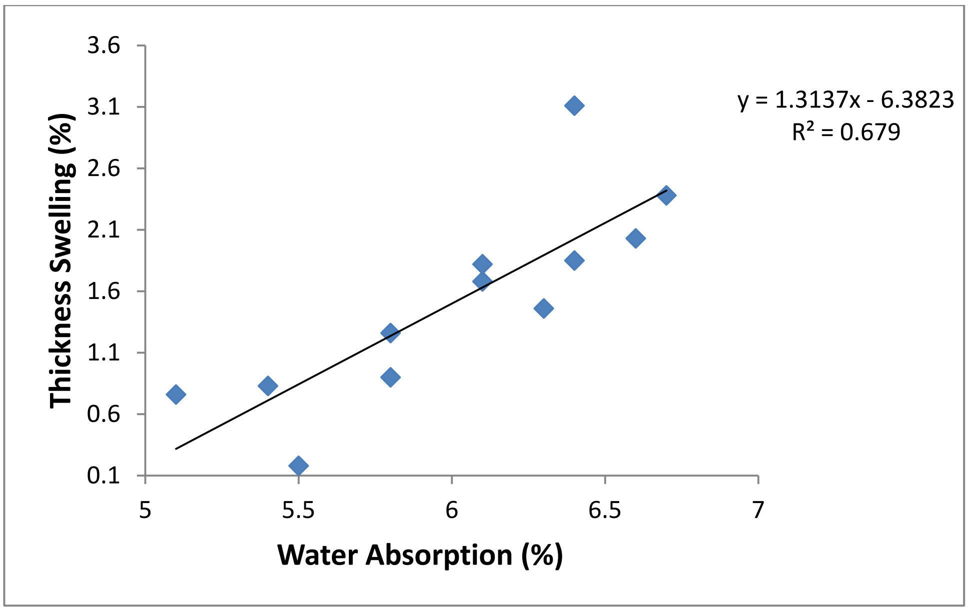

Figure 5. Relationship between WA and Ts of C. populnea Composites

4. Conclusions

A manually-operated fibre –reinforced composite tile making machine was designed, fabricated and evaluated. Composites tiles were made from *Cissus populnea* fibres. The machine had the capacity of producing at least 1m² (50-pieces) of 200x100x10mm composite-tiles per hour. The tiles were dimensionally stable with low sorption and swelling rates and had moderate strength suitable for non-load bearing indoor and outdoor applications. The application of 2% $CaCl_2$ significantly enhanced only the dimensional stability of the composite tiles.

REFERENCES

[1] ACI Committee 544, 1998. State-of-the-art on fiber reinforced concrete. ACI. Manual of. . Concrete practice, Part 5; P. 544.1R-1-544.1R-66.

[2] American Society for Testing and Materials ASTM D 1037-00. 2003. Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. Vol. 04, 10.

[3] Badejo, S.O.O. 1987. An investigation of the influence of cement binder content on the properties of cement-bonded particleboard from four tropical hardwoods. *Malaysian Forester* 50.1:107-120.

[4] Badejo, S.O.O. 1989. Influences of pre-treatment temperature and additive concentration on the properties of cement-bonded particleboard from plantation–grown tropical hardwoods. *Tropical Science*. 29: 285-296.

[5] Badejo, S.O.O. 1998. Re-cycling of wood waste for the manufacture of structural laminated cement bonded particleboard. P165-170. In: International Conference on the value added processing of lesser used timber species. City hotel Kumasi, Ghana, 17-19 February, 1998.

[6] BS 3797, 1990. Specification of lightweight aggregates for masonry units and structural concrete. Published British Standard

[7] Coutts, R.S.P. 2005. A review of Australian research into natural fiber cement composites. *Cement and Concrete Composites*. 27:518-526.

[8] Fuwape, J.A. and Oyagade, A.O. 1993. Bending strength and dimensional stability of tropical wood-cement particleboard. *Bioresources Technology* 44: 77-79.

[9] Iwe, M.O and Atta, C. 1993. Functional properties of the active ingredients of C. populnea., Crill. Perr. pp. 29-53.

[10] Juarez, C., Duran, A., Valdez, P. and Fajardo, G. 2007. Performance of Agave lechuguilla natural fiber. in Portland cement composites exposed to severe environment conditions. Building and Environment 42:1151–1157.

[11] Kurtis, K.E. 2007. CEE 8813 Materials Science of Concrete, <http://www.ce.gatech.edu/%7Ekkurtis/concrete.html>, accessed March 2007.

[12] Olorunnisola, A.O. Pitman, A. and Mansfield-William, H. 2005. Strength *Properties and potential uses of Rattan-Cement Composites*. *Journal of Bamboo and Rattan* 4.4: 343-352.

[13] Olorunnisola, A.O. 2009. Effects of husk particle size and calcium chloride on strength and sorption properties of coconut husk–cement composites industrial crops and products 2 9: 495–501.

[14] Olorunnisola, A.O. 2012. Looking beyond the challenges of affordable housing development in Nigeria: Capitalizing on the engineering opportunities. The 18th Engr. Oluwemimo Arokodare Memorial Lecture delivered at the conference centre, University of Ibadan, august 27th, 2012. 40pp.

[15] Neville, A.M. and Brooks, J.J. 1987. *Concrete Technology*. Longman Group, United Kingdom. 424pp.

[16] Mrema, A.L. 2006. Cement bonded wood wool boards from Podocarpus species for low cost housing. *Journal of Civil Engineering Research and Practice*. 3(1):51-64.

[17] Pirhonen, M.U., Lidell, M.C., Rowley, D.L., Lee, S.W., Jin, S.M., Liang, Y.Q., Silverstone, S., Keen, N.T., Hutcheson, S.W. 1996. Home dampness, moulds and their influence on respiratory infections and symptoms in adults in Finland. Eur. Resp. Jour. 9:2618-2622.

[18] Remirez_Coretti, A., Eckelman, C.A. and Wolfe, R.E. 1998. Inorganic-bonded composites wood panel system for low-cost housing: A Central American perspective. *Forest Products Journal* 48(4): 62-68.

[19] Rao, K.M.M. and K.M. Rao, 2007. Extraction and tensile properties of natural fibres: Vakka, date and bamboo. Composite Structures, 77(3), pp. 288-295.

[20] Simantupang, M.H; Schwartz, G.H, 1976. Small Scale Plants for the Manufacture of Mineral Bonded Wood Composites. Special Paper Presented at the World Forestry Congress

[21] Soroushian, P and Marikunte, S. 1991 Moisture sensitivity of cellulose fiber reinforced cement. Durability of Concrete V.2, SP-126, Detroit: American Concrete Institute, 1991:821-835.

[22] Swamy, R.N. and Mangat, P.S. 1975, "The Onset of Cracking and Ductility of Fibre Concrete" In Cement and Concrete Research, (1975), Vol.5, USA, PP.37-53.

[23] Torgal, F.P. and Said, J. 2002. Vegetable Fibre Reinforced Concrete Composite. A Publication by the C-TAC Research Unit, University of Minho, Guimarães, Portugal. 6 pp.