

# TROPICAL HARDWOOD UTILIZATION IN WOOD-CEMENT COMPOSITE MANUFACTURE IN NIGERIA- A REVIEW

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## ABSTRACT

One of the major sources of wood material for cement composite production in Nigeria is sawdust obtained from hardwood sawmills. However, tropical hardwoods are known for their tendency to inhibit the setting of Portland cement and are, therefore, usually subjected to one form of pre-treatment or another. Information on the fabrication of cement-bonded composites with Nigerian hardwood species articles already published is scattered in various journals and need to be compiled. This paper, therefore, presents a review of the Nigerian-grown tropical hardwood species tested for wood-cement composite production and their effects on the hydration, strength and sorption properties of cement-bonded composites. It also highlights the prospects and challenges of cement-bonded composite manufacture in Nigeria. Findings showed that the major species tested include *Terminalia superba*, *Triplochiton scleroxylon*, *Mitragyna ciliata*, *Ceiba pentandra*, *Tectona grandis* Linn. F., *Melia composita* Willd., *Gmelina arborea* Roxb., *Antiaris africana* Eng, and *Brachystegia Kennedyi* Hoyle. Pre-treatment measures -tested on these species cold and water extraction was effective for species others including *Triplochiton scleroxylon*

## KEYWORDS:

Tropical hardwood; cement inhibition; composites

## INTRODUCTION

One of the solutions to housing problem in the developing world is the development of low cost building materials that satisfy the production, construction, economic, cultural, safety, and health requirements, as well as lack of infrastructure in such countries (Hachmi et al. 1990, Ramirez Coretti et al. 1998, Alberto et al. 2000). Wood-cement composite panels, a set of lightweight concrete products in which wood particles, shavings, strands, or chips serve as aggregate in cement-water mixtures, appear to have the potential to satisfy these requirements. Some of the admirable properties of wood-cement composite that include relatively high strength to weight ratio, durability; high resistance to moisture uptake; nailability; ease of sawing; excellent insulation against noise and heat; and high resistance against fire, insect and fungus attack. The panels do not emit gasses or leak harmful chemicals (Badejo 1988, 1989, Ramirez Coretti et al. 1998). They can be made from non-commercial or low-value tree species.

However, not all wood species are suitable for wood-cement composite production due to the problem of incompatibility with Portland cement. This complex problem has generally been associated with the low molecular weight sugar, carbohydrate and phenolic extractive contents (Tachi et al. 1989, Imai et al. 1995, Semple et al. 2002, Jorge et al, 2004); type of wood used, i.e., hardwood (more inhibitory) or softwood (Defo et al. 2004), age of the tree, i.e., juvenile (less inhibitory) or mature (Semple and Evans 2000); hemicellulose content (low content = less inhibition) (Alberto et al. 2000); portion of the wood tested, i.e., sapwood (less inhibitory) or heartwood (Biblis and Lo 1968, Yasuda et al. 1992, Semple and Evans 2000); and degree of decay (less decay = less inhibition) and fungus stain (more stain = less inhibition) (Biblis and Lo 1968). Also a number of methods have been developed for pre-treating wood particles to enhance their compatibility with Portland cement (Blankenhorn et al. 1994). These include air drying, aqueous extraction, use of chemical accelerators, etc. Hence, preliminary evaluation of candidate species for composite production is often recommended.

The vegetation of Nigeria can be broadly classified into two, i.e., forests and savannah. The forests can be further subdivided into three types, i.e., mangrove, fresh water swamps, and tropical rain forest; while the savannah can be subdivided into the five types, i.e., sahel, sudan, northern guinea, southern guinea, and derived savannah. The diversity in vegetation makes possible the growth of different tropical hardwood species, a few of which have been tested and are being used for industrial production of cement-bonded composites in the country.

The oldest and most common method for assessing the compatibility of lignocelluloses with Portland cement is to determine its hydration process characteristics as compared to that of reference Portland cement. To measure the level of cement hydration inhibition in a determined period, Weatherwax and Tarkow (1964) coined the term *inhibitory index* (I), i.e.,

$$I = 100 (t_0 - t_s) / t_s \quad (1)$$

Where:  $t_0$  = Time required for the wood-cement mixture to attain maximum hydration temperature

$t_s$  = Time required for the reference cement to attain maximum hydration temperature

In typical hydration tests, 15- 20 g of the lignocellulose particles, 200 g of ordinary Portland cement and 93 ml of de-ionized water were mixed in a polyethylene bag to form homogeneous slurry. For the control experiment, 200 g of neat cement is mixed with 90 ml de-ionized water. The tests are performed in a set of well insulated thermos flasks. Temperature rise is monitored for about 24 h using thermocouples to determine the maximum temperature attained by both the reference cement (control) and the wood-cement mixtures (Moslemi and Lim 1984, Hachmi *et al.* 1990).

A number of parameters have been proposed for measuring inhibitory index of wood-cement mixtures such as maximum hydration temperature, time taken to attain maximum hydration temperature, the slope of the hydration temperature curve, and heat evolution. Recording these parameters makes possible the classification of various lignocelluloses according to their degree of compatibility with ordinary Portland cement. Thus, the hydration technique has been used in different ways by several researchers including Sandermann *et al.* (1960), Weatherwax and Tarkow (1964) and Biblis and Lo (1968), Moslemi and Lim (1984), Hachmi *et al.* (1990), Alberto *et al.* (2000), Semple *et al.*, (2002), and Karade *et al.* (2003). However, many of the studies reported on the inhibitory indices of Nigerian hardwoods were based on Weatherwax and Tarkow (1964). This paper presents a review of the Nigerian hardwood species that have been tested and the effects various pre-treatment measures on the hydration behaviour, strength and sorption properties of cement-bonded composites. It also highlights the prospects and challenges of cement-bonded composite manufacture in Nigeria.

## **NIGERIAN HARDWOODS TESTED FOR CEMENT-BONDED COMPOSITE MANUFACTURE**

The Forestry Research Institute of Nigeria, located in Ibadan, Oyo State, initiated research investigations on the production of cement-bonded particleboard with hardwood species available in Nigeria in 1979. Since then, not less than seventeen hardwood species have been tested for wood-cement composite manufacture as shown in Table 1. Many of them were chosen based on their relative abundance in the natural and plantation forests. The most commonly tested species in the studies reviewed was Gmelina (*Gmelina arborea*), an exotic species native to the tropical Asian and Australian regions and the predominant plantation-grown species in Nigeria (Badejo 1989, Oyagade 1994). Another popular exotic species that has been tested is Teak (*Tectona grandis*). The densities of many of the hardwoods tested are relatively low as shown in Table 1. The general belief is that low density wood species which are generally easier to shred are more preferable for wood-cement particleboard production (Johansson 1994). However, apart from Badejo (1989) who indicated the use of 10-year old *Tectona grandis*, *Melia composita* and *Gmelina arborea* Roxb., and Oyagade (2000) who tested 7 year old *Gmelina arborea*, none of the other studies reviewed indicated the ages of the wood samples, the part(s) of the wood (sapwood or heartwood), or the degree of decay and/or fungus infestation (if any).

## **CHEMICAL CONSTITUENTS OF NIGERIAN HARDWOODS TESTED**

It has been established that hardwoods in general and tropical hardwoods in particular tend to inhibit the setting of cement more than softwoods, given their relatively higher sugar and phenolic extractive contents

(Weatherwax and Tarkow 1964, Moslemi and Lim 1984, Zhengtian and Moslemi 1986, Oyagade 1994, Alberto *et al.* 2000).

**Table 1: Nigerian Grown Hardwood Species Tested for Cement-Bonded Composite Manufacture**

S/No	Species	Approximate Density (kg/m <sup>3</sup> ) (at 12% moisture content)	Test References
1	<i>Afzelia africana</i>	730 – 900	Olorunnisola (2007, 2009)
2	<i>Alstonia congensis</i>	330 - 435	Oyagade (1994)
3	<i>Antiaris africana</i>	≥ 435	Oyagade (1994), Sadiku and Sanusi (2014)
4	<i>Brachystegia kennedyi</i> Hoyle	500 - 835	Badejo (1987)
5	<i>Ceiba pentandra</i>	210 - 360	Badejo (1987), Olorunnisola (2007, 2009)
6	<i>Cordia millenni</i>	330 - 500	Oyagade (1994)
7	<i>Gmelina arborea</i> Roxb.	≥ 410	Badejo (1989), Oyagade (1994), Oyagade (2000), Aladenola <i>et al.</i> (2008)
8	<i>Khaya ivorensis</i> A.Char	410 - 570	Badejo (1987), Badejo (1988), Oyagade (1994)
9	<i>Melia composita</i> Willd	510 - 660	Badejo (1989)
10	<i>Melicia excelsa</i>	510 – 800	Olorunnisola (2009)
11	<i>Mitragyna ciliata</i>	510 - 640	Badejo (1987)
12	<i>Nesogordonia papaverifera</i>	730 – 800	Oyagade (1994)
13	<i>Pterygota macrocarpa</i>	≥ 632	Olorunnisola (2009)
14	<i>Tectona grandis</i> Linn f.	580 – 800	Badejo (1989)
15	<i>Terminalia superba</i>	410 - 570	Badejo (1987), Badejo (1988), Oyagade (1994)
16	<i>Terminalia ivorensis</i>	≥ 540	Oyagade (1994), Sadiku & Sanusi (2014)
17	<i>Triplochiton scleroxylon</i>	370 – 450	Badejo (1987), Badejo (1988), Oyagade (1994), Sadiku & Sanusi (2014)

However, the sugar contents of only three of the Nigerian-grown tropical hardwood species tested for cement-bonded particleboard production were found during literature search. Badejo and Simatupang (1989) reported the presence of only two reducing sugars, i.e., 0.55% glucose and 0.45% fructose in *Antiaris Africana*, and four reducing sugars, i.e., glucose (0.35%), fructose (0.70%), xylose (0.10%) and sucrose (0.09%) in *Terminalia*

*superba*. Azzez *et al.* (2016) reported the presence of 51.35% glucose, 10.16% xylose, 0.33% arabinose, 0.64% galactose, and 2.01% mannose in *Gmelina arborea*, and hot water extract of 1.78%. These results are indicative of the cement hydration inhibition potentials of the three species since a glucose concentration of 0.25% or more retards cement hydration, while sucrose or xylose concentration of 0.125% and more is also inhibitory (Simatupang 1979). The relatively low hot water extracts in *Gmelina arborea* suggests that pre-treatment by hot water extraction alone may not completely ameliorate its inhibitory effects such as delay of setting and hardening times as well as reduction in maximum hydration temperature and strength properties of composite boards.

## **INHIBITORY INDICES OF THE HARDWOOD SPECIES TESTED**

Available data on the inhibitory indices of un-treated Nigerian hardwoods, calculated using equation 1 developed by Weatherwax and Tarkow (1964), are presented in Table 2. *Gmelina arborea* came first in terms of cement inhibition, while *Nesogordonia papaverifera* appeared to be the least inhibitory. These results confirm the inhibitory potentials of *Antiaris Africana*, *Terminalia superba* and *Gmelina arborea* as indicated by their glucose contents. There were, however, conflicting reports on the inhibitory indices of *Antiaris africana*, *Terminalia ivorensis*, and *Triplochiton scleroxylon* as reported by Oyagade (1994) and Sadiku and Sanusi (2014) respectively. The values reported by Sadiku and Sanusi (2014) for the three species were consistently lower than those reported by Oyagade (1994), though both reports indicated that the wood samples were collected from sawmills in the same geographical location, i.e., Akure, Ondo State, located in the south-western rainforest region of Nigeria. These inconsistencies again bring to the fore the need for researchers to always indicate the following parameters of the test material: ages, part(s) of the wood, as well as the degree of decay and/or fungus infestation. The type of Portland cement tested is another important parameter omitted in the two reports. Nevertheless, the findings are indicative of the inhibitory effects of Nigerian hardwoods on cement.

## **PRE-TREATMENT METHODS**

The pre-treatment methods reportedly used for various Nigerian-grown hardwoods and their effects include the following:

### **Air-Drying Coupled with the Use of Calcium Chloride**

Badejo (1987) reported the use of air-drying under a shed for a period of 8 weeks coupled with the addition of calcium chloride (CaCl<sub>2</sub>) to the cement-wood mixing water for *Ceiba pentandra*, *Mitragyna ciliata*, *Terminalia superba*, and *Triplochiton scleroxylon*. However, Badejo (1989) combined the use of air-drying for 8 weeks with either hot water extraction (at 50 °C and 75 °C) or CaCl<sub>2</sub> addition (at 1.5% and 3.0% by weight of Portland cement) for the pre-treatment of *Gmelina arborea*, *Melia composita*, and *Tectona grandis*. Experimental boards were then produced at a target density 1200 Kg/m<sup>3</sup> and tested. The modulus of rupture (MOR) ranged from 4.7 to 8.2 N/mm<sup>2</sup> for boards made from *Mitragyna ciliata*, 5.0 to 8.0 N/mm<sup>2</sup> for boards made from *Triplochiton scleroxylon*, 4.4 to 6.1 N/mm<sup>2</sup> for boards made with *Terminalia superba*, and 3.7 to 6.0 N/mm<sup>2</sup> for boards made with *Ceiba pentandra*. These values are less than the minimum MOR of 9 N/mm<sup>2</sup> stipulated in ISO 8335 (1987) for cement-bonded particleboard, and is an indication that the pre-treatment method might not have been sufficiently effective for improved bond strength between cement and the wood particles. The mean thickness swelling (TS) following 72 h of soaking in cold water ranged from 1.0 to 4.5% for boards made from *Mitragyna ciliata*, 1.6 to 5.5% for boards made from *Triplochiton scleroxylon*, 0.5 to 3.6% for boards made with *Terminalia superba*, and 3.3 to 5.7% for boards made with *Ceiba pentandra*.

These values could not be compared directly with the maximum TS values of 1.8% and 2.0% specified by ISO 8335 (1987) and BS 5669 (1989) respectively for cement-bonded since the duration of soaking was more than the 24 h specified in both standards. However, it is apparent from the lower bounds of the TS values reported for all the boards that they apparently met the standard requirements. Since thickness swelling is more an indication of the level of compaction achieved than the level of bonding between cement and wood particles, it could not be used to measure the effect of the pre-treatment measure adopted.

**Table 2: Inhibitory Indices of Selected Nigerian Hardwoods Tested for Cement-Bonded Composite Manufacture**

S/No	Species	Inhibitory Index	References
1	<i>Antiaris africana</i>	<sup>a</sup> 31.25, <sup>b</sup> 123.53	<sup>a</sup> Sadiku and Sanusi (2014) <sup>b</sup> Oyagade (1994)
2	<i>Alstonia congensis</i>	52.94	Oyagade (1994)
3	<i>Cordia millenni</i>	88.24	Oyagade (1994)
4	<i>Gmelina arborea</i> Roxb.	135.29	Oyagade (1994)
5	<i>Terminalia ivorensis</i>	<sup>a</sup> 25.00, <sup>b</sup> 64.71	<sup>a</sup> Sadiku and Sanusi (2014) <sup>b</sup> Oyagade (1994),
6	<i>Terminalia superba</i>	49.18	Oyagade (1994)
7	<i>Triplochiton scleroxylon</i>	<sup>a</sup> 68.75, <sup>b</sup> 94.12	<sup>a</sup> Sadiku and Sanusi (2014) <sup>b</sup> Oyagade (1994)
8	<i>Nesogordonia papaverifera</i>	5.8	Oyagade (1994)

#### Air-drying coupled with the use of dilute sodium hydroxide

Sadiku and Sanusi (2014) investigated the possibility of using sodium hydroxide (NaOH) for extraction of inhibitory substances in Nigerian grown *Terminalia ivorensis*, *Triplochiton scleroxylon* and *Antiaris africana*. The wood particles were dried to about 12% moisture content and soaked in 5% sodium hydroxide solution for 24 h. This procedure reduced the inhibitory effects of the three species with Portland cement in the following order: *Terminalia ivorensis* > *Triplochiton scleroxylon* > *Antiaris africana*.

#### Aqueous Extraction Only

Aqueous extraction involves removal or partial removal of soluble inhibitory wood components with cold, warm or hot water. Soaking wood particles in cold water tends to dissolve tannins, gums, sugars, and colouring matter, while warm or hot water tends to dissolve starches in addition to the afore-mentioned materials (Sutigno 2002). Cold water extraction for 24 h was reported by Sadiku and Sanusi (2014) for *Antiaris africana*, *Terminalia ivorensis* and *Triplochiton scleroxylon*. The water temperature was not specified. Air-seasoning for 8 weeks coupled with warm water extraction at 35 °C for 1 h was reported by Olorunnisola (2007) for *Azelia africana*, *Ceiba pentandra*, *Melicia excelsa* and *Pterygota macroparva*; air-seasoning for 8 weeks coupled with hot water extraction at 50 °C and 75 °C (soaking time unspecified) was reported by Badejo (1989). Oyagade (1994) reported hot water extraction for 6 h (water temperature unspecified) of *Alstonia congensis*, *Antiaris africana*, *Cordia mellenni*, *Gmelina arborea*, *Nesogordonia papaverifera*, *Terminalia ivorensis*, *Terminalia superba*, and *Triplochiton scleroxylon*; while Sadiku and Sanusi (2014) reported hot water extraction at 80 °C for 1 h for *Antiaris africana*, *Terminalia ivorensis* and *Triplochiton scleroxylon*. The findings of Oyagade (1994) presented in Table 3 showed that hot water extraction was effective to varying degrees in reducing setting times and increasing the maximum hydration temperatures of wood-cement composites containing *Antiaris africana*, *Cordia mellenni*, *Gmelina arborea* *Terminalia superba*, and *Triplochiton scleroxylon*. Only Sadiku and Sanusi (2014) compared the efficacy of cold and hot water extractions on the same sets of species. Their findings showed that cold water extraction was mildly effective for *Antiaris Africana* and *Terminalia ivorensis* resulting in an increase of about 6 °C in maximum hydration temperature of the wood-cement composites, while hot water extraction was very effective for *Triplochiton scleroxylon* - increasing the maximum hydration temperature of the wood-cement mixture by 4 °C and reducing the setting time by 2.5 h from 13.5 to 11 h. Alberto *et al* (2000) also observed that cold water treatment improved the compatibility of two Mozambican hardwoods while other species required hot water pre-treatment. However, since the aqueous extracts were not chemically analysed, it

was not possible to determine soluble inhibitory wood components removed from each species at the different water temperatures.

**Table 3: Hydration test data for eight tropical hardwood species tested for cement-bonded composite manufacture**

Species	Untreated Samples			Treated Samples		
	Max. Hydration Temp. (°C)	Setting Time (h)	Inhibitory Index	Max. Hydration Temp. (°C)	Setting Time (h)	Inhibitory Index
<i>Antiaris africana</i>	50.8	19.0	123.53	59.8	10.5	23.53
<i>Alstonia congensis</i>	60.7	13.0	52.94	64.6	9.0	5.88
<i>Cordia millenni</i>	49.0	16	88.24	62.3	9.5	11.76
<i>Gmelina arborea</i> <i>Roxb.</i>	31.5	20	135.29	52.3	13.5	58.82
<i>Nesogordonia</i> <i>papaverifera</i>	62.3	9.0	5.88	63.0	9.0	5.88
<i>Terminalia superba</i>	59.2	12.0	41.18	61.0	9.0	5.88
<i>Terminalia</i> <i>ivorensis</i>	60.0	14.0	64.71	60.7	9.5	11.76
<i>Triplochiton</i> <i>scleroxylon</i>	51.7	16.5	94.12	60.9	9.0	5.88
Neat Cement	66.7	8.5				

Source: Oyagade (1994)

### Hot Water Extraction Coupled with the Use of Chemical Additives

As noted by Blankenhorn *et al.* (1994), cement hydration process is sensitive to water quality, temperature, and alkalinity. To further enhance wood compatibility with cement after water extraction, chemical additives and accelerators including sodium silicate, magnesium chloride, aluminium sulphate, and dilute sodium hydroxide are often added to mineralize the mixing water and/or coat the wood material against interference with cement hydration (Schmidt *et al.* 1994). The amount of accelerator, usually Calcium Chloride, to be used depends on the kind of wood (Johansson 1994). Some Nigerian hardwoods have been pre-treated with a combination of hot water extraction and chemical accelerator to enhance their compatibility with Portland cement. For example, Badejo (1988) used a combination of hot water extraction at 50 °C coupled with calcium chloride addition at 3.0% levels of concentration (by weight of cement) for a mixture of *Khaya ivorensis*, *Terminalia superba* and *Triplochiton scleroxylon*. Experimental boards were then produced with the mixed particles of the three species at target densities of 1050, 1125 and 1200 Kg/m<sup>3</sup> and cement - wood ratio 2.5:1.0. The results obtained showed that the MOR ranged from 5.22 to 11.15 N/mm<sup>2</sup>, while the MOE ranged from 2420 to 4820 N/mm<sup>2</sup>. The fact that the MOR and MOE values of some of the pre-treated boards exceeded 9.0 N/mm<sup>2</sup> and 3000 N/mm<sup>2</sup>, respectively, is an indication that the pre-treatment method was effective for the mixed species tested.

Badejo (1989) again used hot water extraction at 50 °C and 75 °C coupled with calcium chloride addition at 1.5% and 3.0% levels of concentration (by weight of cement) for *Gmelina arborea*, *Melia composita* and *Tectona grandis*. Experimental boards were then produced with the particles of each species at a target density 1200 kg/m<sup>3</sup> and cement - wood ratio 2.5:1.0. The results obtained, reproduced in Table 4, showed that the MOR values of some of the pre-treated boards exceeded 9.0 N/mm<sup>2</sup>, an indication that the pre-treatment method was effective for the three species tested. The highest MOR values were obtained in boards pre-treated with hot water at 75 °C coupled with calcium chloride addition at 3% level of concentration. In the case of *Gmelina arborea*,

the hydration test results obtained by Oyagade (1994) also confirmed the efficacy of hot water extraction in reducing its inhibitory effects on Portland cement.

**Table 4: Modulus of Rupture of Cement-Bonded Particleboards Made from *Tectona grandis*, *Melia composita* and *Gmelina arborea***

Water Temperature (°C)	Calcium Chloride Concentration (%)	Modulus of Rupture (N/mm <sup>2</sup> )		
		<i>Tectona grandis</i>	<i>Melia composita</i>	<i>Gmelina arborea</i>
50	0	6.21	6.77	9.42
50	1.5	7.27	7.27	10.92
50	3.0	9.20	7.77	11.50
75	0	8.93	7.46	11.20
75	1.5	9.04	7.93	12.50
75	3.0	9.65	11.32	14.75

Source: Badejo 1989

Olorunnisola (2007) used hot water extraction at 35 °C and 50 °C coupled with aluminium sulphate (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>) addition at 1.5% and 3.0% levels of concentration (by weight of cement) for pre-treating a mixture of wood particles of *Azelia africana*, *Ceiba pentandra*, *Melicia excelsa*, and *Pterygota macrocarpa*. The hydration test results showed that hot water (50 °C) extraction coupled with aluminium sulphate, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> at 3% level of concentration reduced the setting time of the wood-cement mixture significantly from 14 h to 1 h but had no effect on the maximum hydration temperature. While this is another evidence of the conflicting results obtainable from hydration tests, it is, nevertheless, a clear indication of the positive effect of the pre-treatment measure.

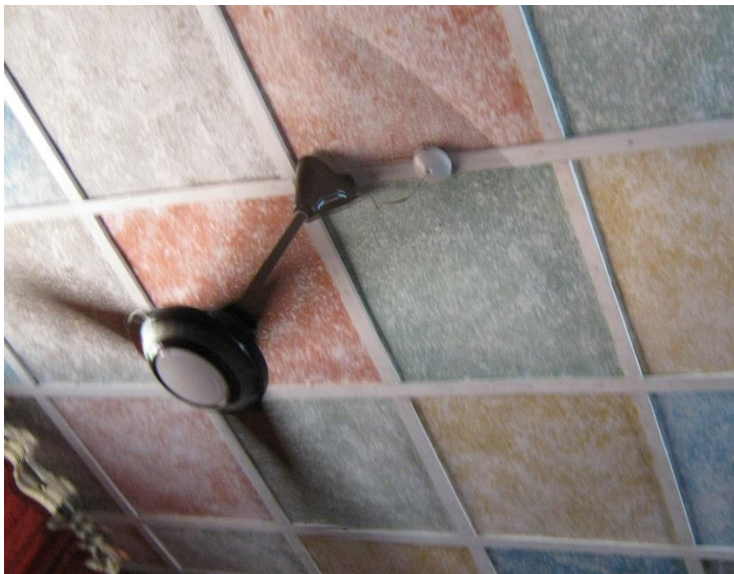
## PROSPECTS AND CHALLENGES OF WOOD CEMENT COMPOSITE MANUFACTURE IN NIGERIA

The prospects of wood cement composite manufacture in Nigeria can be assessed based on several parameters. The production technology for wood-cement panels, in terms of manufacturing equipment and production process, is rather very simple and adaptable to the prevailing climatic and economic conditions in Nigeria. All the necessary production equipment can be manufactured, using available local materials. Hence, a number of small scale enterprises have been established already, particularly in the western parts of the country. Wood procurement is also not a problem. Wood wastes being generated in Nigerian sawmills in form of bark, sawdust, trimming, split wood, planer shavings, and sanderdust exceed 1,000,000 m<sup>3</sup> and the bulk of these wood residues presently attracts little or no significant commercial value (Ogunwusi 2014). It is possible, therefore, to manufacture wood-cement panels in areas where large volumes of wood residues are generated. However, a number of Nigerian hardwoods have obnoxious/offensive odour which precludes them from industrial processing and utilization.

Portland cement is quite expensive in Nigeria. One of the possible ways of enhancing sustainable production of wood-cement composite panels in the country (including the challenge of CO<sub>2</sub> emission by cement), therefore, is the use of supplementary cementitious materials derived from industrial and agricultural waste materials, such as fly ash, sugar cane bagasse, corncob, and rice husk ash (RHA) in particular, as partial replacement for cement. Rice husk, a waste product of rice milling has one of the greatest potentials because rice is cultivated in virtually all the agro-ecological zones in Nigeria in paddies or on upland fields, depending on the requirements of the particular variety. The annual local rice production in Nigeria has been estimated at about 15 million metric tonnes (Mohammad 2017). As the ash content by weight is about 20% (Olorunnisola 2012), there are potentially

3,000,000 metric tonnes of RHA available as a pozzolana. Incidentally, while accumulation of unmanaged wastes is major source of environmental hazards in many parts of the country, wood-cement composite panels are noted for their unique capability to utilize large quantities of these supplementary cementitious materials.

As noted by Owonubi and Badejo (2000) and Ogunwusi (2014), a relatively small local market already exists for wood-cement panel product in Nigeria. The products are gradually being employed as construction materials for interior/exterior wall cladding, roofing, ceiling and shuttering, (as shown in Figure 1) but they are yet to become widely acceptable for regular building construction. Though a number of product characterization studies have been reported (Table 5), a primary concern is their compliance with local building codes. There is a need to specify design loads, wind resistance, and fire rating, among others. Regulation of product standards relating also needs to be addressed.



**Figure 1: Wood-Cement Composite Ceiling Boards installed in a Reception Hall of the Forestry Research Institute of Nigeria**

**Table 5: A Comparison of Hardwood Sawdust-Cement Tiles Manufactured in Nigeria with Ceramic Tiles**

Product	Thickness (mm)	Weight/unit area (g/cm <sup>2</sup> )	Density (g/cm <sup>3</sup> )	Water absorption after 144 h (%)	Thickness swelling after 144 h (%)
Sawdust-Cement Wall Tiles	6	1.02 – 1.23	1.57 – 1.82	6.3 – 13.1	0.36 – 0.46
Ceramic Wall Tiles	6	0.94 – 1.04	1.64 – 1.71	13.25 – 16.20	0.47 – 0.73
Sawdust-Cement Floor Tiles	12	1.92 – 2.18	1.59 – 2.06	11.7 – 14.3	0.16 – 0.25
Ceramic Floor Tiles	9	1.54 – 2.01	1.86 – 2.03	6.20 – 16.88	0.33 – 0.72

Source: Owonubi and Badejo (2000)

Another germane issue is that consumer concerns about tropical deforestation have become a major factor that shapes the demand for tropical hardwood products in the international market. Negative consumer attitudes to the non-sustainable manner in which tropical forests are being exploited have weakened the demand for tropical hardwood products in many developed countries in the last 25 years. As noted by Duery and Vlosky (2005), "the concept of forest and wood products certification originated in order to slow down the rate of deforestation in tropical countries". Since then, many developed countries have adopted quantitative restrictions to limit the import



of "unsustainably produced" forest products or to impose countervailing duties on imported products that benefit from an "environmental" export subsidy. Some countries have also adopted the use of *ecolabelling* and *green certification* to distinguish sustainably produced forest products or to ensure that forest product imports conform to domestic environmental standards and regulations. Regrettably, Nigeria currently has one of the highest annual rates of forest loss or deforestation in the world. Between 2000 and 2005, 55.7 % of the country's primary forests were lost to logging, subsistence agriculture and collection of fuelwood (Anon., 2009), though harvesting of at least twenty-six hardwood species, including some of those already tested for cement-bonded particleboard production (Table 6) have been banned in different states across the country as far back as 1999 due to their endangered status and concern over their extinction (Olorunnisola 2013). The good news, though, is that other non-forest timber products such as rattan, coconut husk, oil palm, etc are available as substitute materials for particleboard production. The core challenge, nevertheless, is that Nigeria, like many other African countries, is yet to fully embrace forest and wood products certification. Hence, a variety of environmental and trade restrictions may impact negatively on the production and exportation of cement-bonded particleboards produced with tropical hardwoods in the country.

**Table 6: Tree Species Banned from Harvest in different States of the Federal Republic of Nigeria**

S/No	Species	State(s) where Harvesting has been Banned
1	<i>Afzelia africana</i>	Imo
2	<i>Aformosia elata</i>	Cross River
3	<i>Canarium schweinfurthii</i>	Plateau
4	<i>Diospyros mespiliformis</i>	Ondo, Imo
5	<i>Erythrophleum ivorense</i>	Rivers
6	<i>Erythrophleum spp</i>	Ekiti
7	<i>Funtumia spp.</i>	Cross River
8	<i>Gossweilerodendron balsamiferum</i>	Ekiti
9	<i>Guarea spp.</i>	Ogun
10	<i>Holoptelea grandis</i>	Ekiti
11	<i>Irvingia spp.</i>	Cross River
12	<i>Isobertinia doka</i>	Niger
13	<i>Khaya grandifoliola</i>	Enugu, Kaduna, Kwara
14	<i>Khaya ivorensis</i>	Rivers
15	<i>Khaya senegalensis</i>	Kaduna, Kebbi, Kwara, Plateau
16	<i>Lophira alata</i>	Ondo, Imo
17	<i>Mansonia altissima</i>	Ekiti, Imo, Ogun, Osu
18	<i>Melicia excelsa</i>	Abia, Osun, Akwa-Ibom, Anambra, Benue, Ebonyi, Ekiti, Enugu, Kwara, Niger, Ogun, Plateau, Rivers
19	<i>Mitragyna stipulosa</i>	Ekiti, Ogun
20	<i>Nauclea diderrichii</i>	Ekiti, Enugu
21	<i>Nauclea latifolia</i>	Niger
22	<i>Nesogordonia papaverifera</i>	Ekiti
23	<i>Pterocarpus erinaceus</i>	Kano
24	<i>Pterocarpus osun</i>	Kaduna
25	<i>Triplochiton scleroxylon</i>	Abia
26	<i>Uapaca spp.</i>	Ebonyi, Imo

Source: Olorunnisola (2013)

## CONCLUSION

A review of seventeen tropical hardwoods that have been tested for cement-bonded particleboard production in Nigeria, the various pre-treatment measures applied, and their effects, has been presented. The review indicated that a majority of the hardwoods were inhibitory when untreated, but responded positively to different forms of pre-treatment as indicated by the performance of *Gmelina arborea*, the most inhibitory species that was successfully treated to produce boards of acceptable quality. While there are prospects for cement-bonded composite manufacture, the challenges of deforestation and attendant imposition of a ban on the harvesting of numerous hardwoods, lack of product specification for local building codes and the non-compliance with *green certification* requirements in line with current global requirements have to be tackled.

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