COMPATIBILITY OF SOME TROPICAL HARDWOOD SPECIES WITH PORTLAND CEMENT

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OYAGADE, A. O. 1994. Compatibility of some tropical hardwood species with Portland cement. The compatibility of eight tropical hardwood species with ordinary Portland cement was investigated using the cement hydration reaction method. The hydration characteristics (maximum hydration temperature and time to reach maximum hydration temperature) observed for the wood-cement-water mixtures of various species under investigation showed considerable differences in their effect on the hydration reaction of Portland cement. Among the eight species examined, danta was observed to be the least inhibitory while gmelina was the most potent in its effect on cement setting. Hot water extraction had no significant effect on the compatibility of danta with Portland cement. All other species including ahun, idigbo, afara, obeche, antiaris, omo and gmelina showed considerable improvement in their compatibility with Portland cement following hot water extraction. Gmelina, however, appeared to require more than hot water treatment to make it sufficiently compatible with Portland cement.

Key words: Tropical hardwoods - cement - hydration - cement/wood composite - inhibitory index - water extraction

OYAGADE, A. O. 1994. Kesesuaian beberapa spesies kayu keras tropika dengan simen Portland. Kesesuaian lapan spesies kayu keras tropika dengan simen biasa Portland dikaji dengan menggunakan kaedah reaksi penghidratan simen. Ciri-ciri penghidratan (suhu penghidratan maksimum dan masa maksimum untuk mencapai suhu penghidratan maksimum) yang diperhatikan untuk campuran kayu-simen-air bagi pelbagai spesies dalam kajian menunjukkan perbezaan yang besar pada kesannya terhadap reaksi penghidratan simen Portland. Antara lapan spesies yang dikaji, diperhatikan bahawa danta yang paling kurang terencat manakala gmelina memberikan kesan yang paling kuat sekali pada proses pemejalan simen. Ekstraksi air panas tidak memberikan kesan ketara pada kesesuaian danta dengan simen Portland. Selepas ekstraksi dengan air panas, kesesuaian kesemua spesies yang lain termasuk ahun, idigbo, afara, obeche, antiaris, omo dan gmelina dengan simen Portland bertambah baik. Bagaimanapun, gmelina kelihatan memerlukan rawatan air panas yang lebih untuk menjadikannya cukup sesuai dengan simen Portland.

Introduction

The development of the particleboard industry has provided a very efficient means of optimizing the timber resources of many nations. In the developing nations, one of the problems against the development of the industry is the high cost of resin binder. Resin adhesive is usually imported by these nations and thus constitutes a major portion of the production cost of the board. In the case of

Nigeria, for example, the resin binder has been noted to account for about 65% of the raw material imput costs for particleboard production (Omoluabi 1982).

An interesting development which is an advantage to the developing nations in providing a partial solution to the problem of high cost of synthetic resin is the use of cement as a binder for particleboard manufacture. Cement has an advantage of being locally available in most of these nations. In addition, the production method for wood particleboards bonded using cement can easily be adapted to a low level of technology, making it suitable for the developing nations. However, before embarking upon the development of cement-bonded particleboard industry, there is a need to investigate the compatibility of the locally available wood species for the board manufacture.

It has been widely observed that certain species of wood react unfavourably with cement (Sandermann *et al.* 1960, Weatherwax & Tarkow 1964, Davis 1966), thus making such species naturally unsuitable for cement-wood composite board manufacture. The degree of inhibition of wood on cement setting varies from species to species, with some completely preventing cement setting. Softwoods are known to be more compatible with cement than hardwoods. Thus, the former are mostly considered for use in the manufacture of wood-cement composite board than the latter. Even when hardwood species from the tropical and the temperate regions of the world are compared, the tropical hardwoods are noted to show a higher inhibition to cement setting than the temperate hardwoods (Simatupang *et al.* 1978).

The compatibility of wood species with cement have been associated primarily with water-soluble chemical substances present in wood (Biblis & Lo 1968). The results of studies by Biblis and Lo (1968) and Moslemi *et al.* (1983) show that hot water and/or alkali extraction of some wood species known to cause serious inhibition to cement setting is effective in overcoming the inhibitory effect.

The objective of this study was to assess the compatibility of eight tropical hardwood species with Portland cement and to evaluate the effects of hot water extraction of the wood species on their compatibility with the cement using the hydration method.

Materials and method

Material procurement and treatment

The eight tropical hardwood species employed in this study consisted of the following:

i) *Nesogordonia papaverifera* (Danta)
ii) *Alstonia congensis* (Ahun)
iii) *Terminalia ivorensis* (Idigbo)
iv) *Terminalia superba* (Afara)
v) *Triplochiton scleroxylon* (Obeche)
vi) *Antiaris africana* (Antiaris)

vii) *Cordia millenii* (Omo)
viii) *Gmelina arborea* (Gmelina)

The choice of the wood species (i) to (vii) was based on the fact that they are among those species which are commonly available for mechanical processing by the wood-based industry in Ondo State of Nigeria where the study was conducted. The wood material of each of the seven species was collected in the form of sawdusts from sawmills in the Akure local government area immediately after sawmilling of the logs of the individual species. Following collection, the saw-dusts were dried to about 12% moisture content and stored in polythene bags. Gmelina was included in the study because it is the most widely grown plantation species in Nigeria. The gmelina wood, obtained from a seven-year-old plantation, was debarked and converted to sawdust on a circular saw. The saw-dust was dried to 12% moisture content before storing in polythene bag.

The dry sawdust of each species was sieved using 0.3 *mm* and 0.8 *mm* mesh screens. The particles which passed through the 0.8 *mm* mesh screen but remained on the 0.3 *mm* mesh screen were collected for use. A part of the sawdust of each species was extracted by boiling 35-*g* portion in 500 *ml* of distilled water in a beaker for 2 *h*. This was followed by washing with 1 *l* of hot distilled water. The boiling and washing procedure was repeated two more times, making the total period of heating the sawdust in boiling water to be 6 *h*. Following extraction, the sawdust was dried to a moisture content of 12 %. Both the unextracted and hot water extracted sawdusts were stored in polythene bags prior to use.

Ordinary Portland cement manufactured in Nigeria under the trade name "Elephant cement" was used. The cement had physical characteristics and chemical composition complying with BS 12:Part 2 1971. It was purchased in standard bags of 50*kg* weight from fresh consignment. Immediately after purchase, the cement was stored in sealed polythene bags.

Hydration test

The experiments to evaluate the hydration characteristics of neat cement and cement paste in the presence of unextracted and hot water extracted wood samples of each species were carried out using a wide mouth thermos flask. The proportions of cement to wood, cement to water and water to wood were based on the initial studies by Weatherwax and Tarkow (1964, 1967). In these studies, 2.7 *ml* of water per gram of wood (oven dry weight basis) and 0.25 *ml* of water per gram of cement were employed in mixing 15*g* of wood particles with 200*g* of cement.

In the present study, three replicate samples, each weighing 15*g* were taken from unextracted and extracted particles of each species. Each of the 15 *g* sample was dry mixed with 200 *g* of cement in a polythene bag. After thorough mixing, the required amount of distilled water was kneaded into the mixture until it appeared homogeneous. A thermometer which has been protected with aluminium tubing and foil was inserted into the mix. A rubber band was used to secure the polythene bag around the stem of the thermometer. After placing the bag with its content in the flask, additional insulation using glass fiber was provided around the polythene bag. The flask was convered using stryrofoam stopper that had been bored at the centre to accommodate the stem of the thermometer. The temperature of the system was monitored at 1 *h* interval during the first five hours, and subsequently at 30 *m* interval until after the maximum temperature was attained. This procedure was also performed for cement-water mixtures. Two-hundred grams of cement were mixed with 50 *ml* of water. The experiments were conducted at an ambient temperature ranging from 26° to 29°*C*.

Quantitative evaluation of degree of inhibition

Some research workers (Weatherwax & Tarkow 1964, 1967, Hofstrand *et al.* 1984, Moslemi & Lim 1984), in their studies relating to wood-cement compatibility have used some mathematical expressions derived from the hydration parameters as a quantitative measure of the compatibility of any given wood material with cement. With such equations, the termed inhibitory index gives a comparison between one or more of the hydration characteristics such as the maximum hydration temperature, time to reach the maximum temperature and maximum hydration temperature/time slope of neat cement and wood-cement-water system. One equation developed by Weatherwax and Tarkow (1964) is:

$$\text{Inhibitory index (I)} = \frac{(t_o - t_s)\ 100}{t_s}$$

Where

t_o = time required for inhibited cement to attain its maximum hydration temperature;

t_s = time required for the uninhibited cement to reach its maximum hydration temperature.

The above mathematical expression was used to calculate the inhibitory indices for the eight hardwood species under investigation.

Results and discussion

Effects of wood species

It is evident that the degree of interference with the hydration reaction of Portland cement varies with species (Table 1, Figure 1). Generally, with the exception of gmelina, all the species, after the initial period of a slight rise in temperature followed by a period in which there was little or no temperature change, showed an increase in temperature with time until a maximum temperature was reached.

The average maximum temperature attained by each species is presented in Table 1. It is evident from the table that the maximum temperature attained and the time to reach the maximum temperature varied considerably with wood species. With gmelina, apart from the initial rise in temperature which occurred within the first one hour after mixing, the cement paste failed to exhibit exothermic reaction over the 20-*h* period in which the hydration reaction was monitored. This species gave a maximum hydration temperature of 31.5°*C*.

The maximum hydration temperature and time to attain the maximum temperature by wood-cement-water systems have been used to assess the suitability of wood species for cement-wood composite board manufacture (Sandermann & Kohler 1964, Hofstrand *et al.* 1984). According to Sandermann and Kohler (1964), species attaining maximum hydration temperature above 60°*C* are classified as suitable, those reaching temperatures ranging from 50° to 60°*C* as suitable under limited condition (*i.e.*, moderately suitable) and those attaining temperatures below 50°*C* as unsuitable.

Table 1. Hydration data for eight tropical hardwoods with untreated and hot water extracted wood sample (n = 3)

Species	Untreated samples			Hot water treated samples		
	Maximum hydration temp. (°*C*)	Time to reach max. temp. (*h*)	Inhibitory index	Maximum hydration temp. (°*C*)	Time to reach max. temp. (*h*)	Inhibitory index
Danta	62.3	9.0	5.88	63.0	9.0	5.88
Ahun	60.7	13.0	52.94	64.6	9.0	5.88
Idigbo	60.0	14.0	64.71	60.7	9.5	11.76
Afara	59.2	12.0	41.18	61.0	9.0	5.88
Obeche	51.7	16.5	94.12	60.9	9.0	5.88
Antiaris	50.8	19.0	123.53	59.8	10.5	23.53
Omo	49.0	16.0	88.24	62.3	9.5	11.76
Gmelina	31.5	20.0	135.29	52.3	13.5	58.82
Neat cement	66.7	8.5	-	-	-	-

The maximum hydration temperature attainable depends largely on the chemical composition of cement which may vary from country to country and from one manufacturer to the other. Consequently, the maximum hydration temperature by a wood-cement-water system alone cannot determine the suitability of the wood species with cement. For the same reason, a valid comparison cannot be made by directly comparing the maximum temperature data obtained in the present study with that observed by Sandermann and Kohler (1964) and Hofstrand *et al.* (1984). From their study, Hofstrand *et al.* (1984) noted that wood species which attained maximum temperature in less than 15 *h* could be considered as suitable. It should also be pointed out that the use of time to judge suitability of wood species for cement composite board manufacture without reference to the degree of exothermic reaction attainable by the wood-cement-water system may be misleading. It is not impossible to have some species in a mixture with cement exhibiting time to reach maximum temperature that is comparable with that of neat cement but having significantly lower maximum hydration temperature. Apparently, the most appropriate quantitative measure for determining suitablility of wood with cement is inhibitory index.

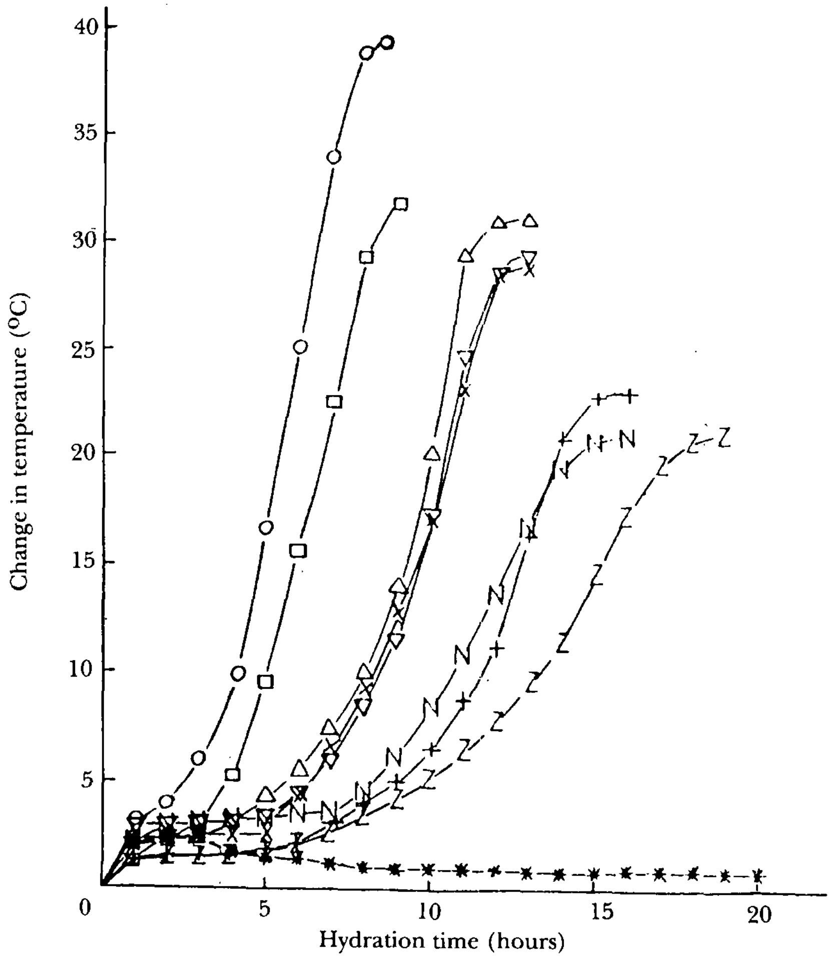

Figure 1. Comparison of the effects of eight tropical hardwood species on the exothermic reaction of Portland cement

Legend :

O	Neat cement	+	Obeche
N	Omo	Z	Antiaris
*	Gmelina	▢	Danta
Δ	Ahun	∇	Idigbo
X	Afara		

The inhibitory indices calculated for the eight hardwood species under investigation are given in Table 1. The inhibitory indices ranged from 5.88 to 135.29. If the values obtained here are compared with the results of work by Hofstrand *et al.* 1984, of the eight hardwood species investigated, danta, afara, ahun and idigbo which gave inhibitory indices of 5.88, 41.18, 52.94 and 64.71 respectively, can probably be employed in the manufacture of wood-cement composite without pre-treatment. It seems that the others would require some kind of treatment such as extraction with hot water to remove water soluble wood extractives and /or addition of cement setting accelerators such as calcium chloride and magnesium chloride to make them compatible with Portland cement.

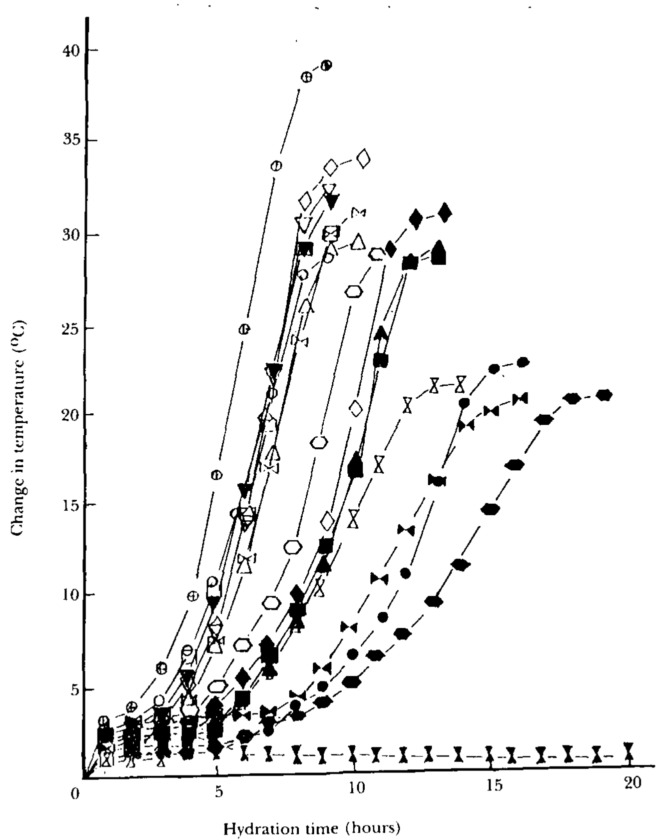

Figure 2. Effects of hot water extraction of eight tropical hardwood species on the hydration reaction of Portland cement

Legend: Neat cement

Wood species	Untreated Wood	Hot water extracted wood
Danta	▼	▽
Ahun	♦	◊
Idigbo	▲	△
Afara	■	□
Obeche	●	○
Omo	⧓	⋈
Antiaris	⬣	⬡
Gmelina	⧗	⧖

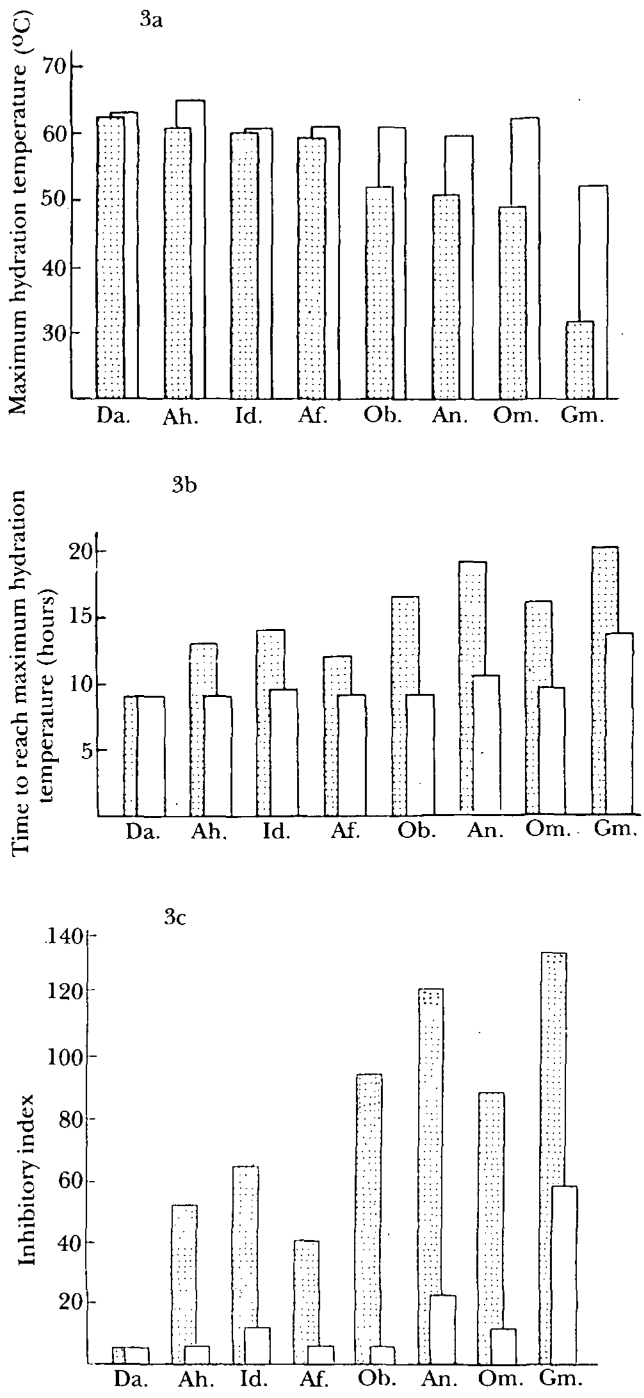

Figure 3. Effects of hot water extraction on maximum hydration temperature (3a), time to reach maximum temperature (3b), and inhibitory index (3c) of wood-cement-water mixture from eight tropical hardwoods

Legend:	Da.	Danta	Af.	Afara	Om.	Omo
	Ah.	Ahun	Ob.	Obeche	Gm.	Gmelina
	Id.	Idigbo	An.	Antiaris	Ce.	Neat Cement

Unextracted wood   Extracted wood

Effect of hot water extraction

The results of hot water extraction on the exothermic reaction of the individual hardwood species investigated in this study are presented on Table 1. The results are also illustrated in Figure 2. It is evident that the effect of hot water extraction varied with species. Danta did not show any significant difference between untreated and hot water treated samples.

While there appears to be no considerable variation in the maximum hydration temperature between treated and untreated samples of idigbo and afara, the two species showed considerable difference between treated and untreated samples with respect to time to reach maximum hydration temperature. All other species showed considerable differences between the treated and untreated samples with respect to both hydration characteristics. Generally, the maximum hydration temperatures of wood-cement-water mixtures of the various species were increased by hot water extraction. Also, all the species, with the exception of danta exhibited reduction in the time to reach maximum temperature. With gmelina, even though there was an improvement in compatibility following hot water extraction, it appears that hot water extraction alone is not sufficient to make this species fully compatible with Portland cement. The changes in the maximum temperature, time to reach maximum temperature, and in the value of inhibitory index resulting from hot water extraction are illustrated using bar diagrams in Figure 3.

Conclusion

The eight tropical hardwood species studied vary considerably in their effect on the hydration reaction with ordinary Portland cement. While danta does not require hot water extraction to enhance its compatibility with Portland cement, other wood species including ahun, idigbo, afara, obeche, antiaris, omo and gmelina need to be extracted with hot water to improve their compatibility with the cement. Gmelina, particularly, requires more than hot water extraction to make it adequate for cement-wood composite board manufacture.

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