ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 10 N° 2 2014
pp. 3-10

WOOD PRE-TREATMENT INFLUENCE ON THE HYDRATION OF PORTLAND CEMENT IN COMBINATION WITH SOME TROPICAL WOOD SPECIES

Nusirat Aderinsola SADIKU*
Department of Forest Resources Management, University of Ilorin, Nigeria
E-mail: tundesalih@yahoo.com

Ahmad SANUSI
Department of Civil Engineering, Federal University of Technology, Akure, Nigeria
E-mail: mrsan13@yahoo.com

Abstract:
The influence of three pre-treatment methods on the hydration characteristics of Portland cement in combination with three tropical hardwood species was investigated. The maximum hydration temperature and time to reach maximum hydration temperature were analysed for the wood-cement-water mixtures of the three species after removing inhibitory extractives of wood samples by extraction with 5% Sodium hydroxide (NaOH), cold and hot water after removing inhibitory extractives of wood samples. There were differences in the hydration reaction of the wood species with Portland cement using the different pre-treatment methods. The compatibility of the wood species with Portland cement improved following pre-treatment. Sodium hydroxide pre-treatment had the most significant effect followed by hot water. Terminalia ivorensis (Idigbo), and Antiaris africana (Oriro) species showed considerable improvement in their compatibility with Portland cement at 5% Sodium hydroxide pre-treatment with maximum hydration temperature of 65^{o}C where Arere had 60.5^{o}C where both cold and hot water were unable to raise the hydration temperature beyond 55.5^{o}C . This study shows that the wood species requires more than cold and hot water extraction to make them suitable for wood cement composite materials as extraction with sodium hydroxide (1% solution) was found to be the most effective treatment for the wood species under investigation.

Key words: *cement/wood composite; hydration; inhibitory index; pre-treatment; tropical hardwood.*

INTRODUCTION

Hydration characteristics of wood-cement mixtures have been commonly used to assess the compatibility of lignocellulosic materials with cement for cement/wood composite production (Sandermann and Kohler 1964, Jain *et al*. 1989, Shittu 1990, Iddi *et al*. 1992, Hawks and Cox 1992, Oyagade 1994, Abdalla and Ashraf 1998, Badejo 1999, Abdelgadir and Ibrahim 2002 and 2003). The compatibility of wood with cement can be enhanced by the extraction of the inhibitory substances found in wood or by the addition of chemical additives (Abdalla and Ashraf 1998, Abdelgadir and Ibrahim 2002 and 2003). Hot water and weak alkali extractions are among the common treatments used to extract the inhibitory substances found in wood and to improve the degree of compatibility of wood with cement. Weathermax and Tarkov (1964 and 1967) developed the technique for assessing the inhibitory index of wood species taken into consideration the hydration temperature test method. The maximal hydration temperature of wood and cement is reduced by these inhibitory substances and the maximal hydration temperature attained is used as an indicator for the compatibility of wood and cement (Oyagade 1990, Frybort *et al*. 2008).

Different parameters have been used, such as measuring the hydration characteristics (Sandermann and Kohler 1964, Weatherwax and Tarkow 1964, Sandermann *et al*. 1960, Schubert and Wienhaus 1984, Hachmi and Moslemi 1990, Hachmi *et al*. 1990, Sauvat *et al*. 1999, Wei *et al*. 2000a, Wei *et al*. 2000b, Alberto *et al*. 2000, Brandstetr *et al*. 2001, Karade *et al*. 2003), the peak of the hydration temperature, as well as the time to reach maximum temperature to give information on the suitability of a particular species to be bonded with cement (Frybort *et al*. 2008). This level of suitability is expressed by the “inhibitory index”. According to Sandermann and Kohler (1964) and Sandermann *et al*. (1960) and Hofstrand *et al*. (1984), wood species are classified into suitable, moderately suitable and unsuitable based on the maximum hydration temperature attained. Species attaining maximum hydration temperature above 60^{o}C are classified as suitable, those reaching temperatures ranging from 50°C to 60°C as moderately suitable and those attaining temperatures below 50°C as unsuitable.

Several methods have been used such as hot or cold water extraction and soaking (Moslemi and Lim 1984, Schwarz and Simatupang 1984, Eusebio *et al*. 2000, Sutigno 2000, Okino *et al*. 2005), long-time storing of the raw material (Badejo 1999, Cabangon *et al*. 2002), many chemical extraction methods (Schwarz and Simatupang 1984, Moslemi *et al*. 1983, Kavvouras 1987, Alberto *et al*. 2000), fungi treatment (Thygesen *et al*. 2005), as well as addition of small amounts of cement setting accelerators, such as NaOH,

* Corresponding author

CaCl2, MgCl2, Na2CO3, and NH4Cl, have been tested to shorten the setting and curing time as well as improving the specific properties of CBCs (Hofstrand *et al*. 1984, Moslemi *et al*. 1983, Kavvouras 1987, Badejo 1988, Hermawan *et al*. 2002, Semple and Evans 2004, Bejó *et al*. 2005, Papadopoulos *et al*. 2006).

Few reports have been published on the influence of different pre-treatment methods on the hydration temperature of cement mixed with tropical hardwood species. Chemical and extractive contents are species dependent hence the pre-treatment method will differ from species to species. The objective of this study was to investigated the influence of three pre-treatment methods which are: cold water, hot water and sodium hydroxide treatment on the hydration characteristics of cement in mixture with tropical wood species.

MATERIALS AND METHOD

Material procurement and treatment

Three tropical hardwood species were used for this study: *Terminalia ivorensis* (Idigbo), *Triplochiton scleroxylon* (Arere) and *Antiaris africana* (Oriro). These wood species 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 choice of the wood species was also based on the earlier study by Oyagade (1990) which demonstrated the behaviour improvement of the wood samples used by hot water pre-treatment and which was able to make the species moderately suitable. This study was performed using three pre-treatment methods and the untreated samples served as the control. The wood samples were collected from the wood industry in form of particles and were dried to about 12% moisture content and stored in polythene bags. The dried particles of each species were sieved using 0.3mm mesh screen to remove any unwanted particles and to obtain a homogenous particle size. The wood particles of the three wood species each were divided into four parts. Three parts for pre-treatment and one part serving as control. A part of each of the wood species were extracted by soaking in hot water at 80^{o}C for 30 minutes, this was followed by washing with hot distilled water. Hot water soaking and washing procedure was done twice. The second part were extracted by soaking in cold water for 24 hours, followed by washing the soluble extractives from wood with distilled water and the third part were extracted by soaking in 5% sodium hydroxide solution for 24 hours after which the NaOH solution was thoroughly washed off the wood to remove any traces of NaOH while the fourth part served as the control. Following extraction, the wood particles were dried to 12% moisture content. Both the untreated and treated wood particles were stored in polythene bags prior to use. Ordinary Portland cement manufactured in Nigeria was used, the cement was stored in sealed polythene bags.

Hydration test

The hydration test was carried out using a wide mouth thermos-flask where the mixture wood cement was placed. The mixture included the following proportions: 2.7ml of water per gram of wood (oven dry weight basis) and 0.25ml of water per gram of cement were employed in mixing I5g of wood particles with 200g of cement similar to Weatherwax and Tarkow (1964 and 1967), Oyagade (1990) and Badejo (1999) studies. Three replicate samples, each weighing 15g were taken from untreated, NaOH, cold and hot water treated samples of each species. Each of the 15g sample was dry mixed with 200g 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 mixture. 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 insulation of bag with mixture was performed by a rubber band around the thermometer and the flask was covered 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 hour (h) interval during the first five hours, and subsequently at 30 minutes interval for fourteen hours until after the maximum temperature was reached. This procedure was also performed only for cement-water mixtures where two hundred grams of cement were mixed with 50ml of water. The experiments were conducted at an ambient temperature ranging from 30°C to 32°C.

Determination of degree of inhibition

The most appropriate quantitative measure for determining suitability of wood with cement is inhibitory index (Oyagade 1990, Badejo 1999). Though hardwood are inhibitory to cement setting (Sandermann 1970, Simatupang *et al*. 1978), the use of maximum hydration temperature as well as time to reach maximum temperature by a wood-cement-water system alone cannot determine the suitability of the wood species with cement (Oyagade 1990) because maximum hydration temperature attainable depends largely on the chemical composition of cement which vary from country to country and from manufacturer to the other and chemical/extractive content of wood which also vary within species as well as from species to species. Researchers (Weatherwax & Tarkow 1964 and 1967, Hofstrand *et al*. 1984, Moslemi and Lim 1984) have used some mathematical expressions derived from the hydration parameters as a quantitative measure of the compatibility of any given wood material with cement. This is termed inhibitory index which compares the maximum hydration temperature, time to reach the maximum temperature and maximum hydration temperature/time slope of neat cement and wood-cement-water system.

Degree of hydration is measured by inhibitory index which indicate wood-cement compartibility. This inhibitory index can be calculated by:

$$Inhibitory index\,(I) = \frac{t_o - t_s}{t_o} \times 100 \quad \% \qquad (1)$$

where:
t_o = time required for inhibited cement to attain its maximum hydration temperature (minutes);
t_s = time required for the uninhibited cement to reach its maximum hydration temperature (minutes).

RESULTS AND DISCUSSION

Effects of wood species

The average maximum temperature attained by each species is presented in Table 1. Their were no significant difference in the maximum temperature attained and the time to reach the maximum temperature for control samples. The wood species under investigation were able to attain maximum hydration temperature of 50^{o}C, 49.5^{o}C and 49.5^{o}C and time to reach maximum hydration temperature of 13.5h, 10h and 10.5h for *Triplochiton scleroxylon* (Arere), *Terminalia ivorensis* (Idigbo), and *Antiaris africana* (Oriro) respectively. In accordance to the classification of Sandermann and Kohler (1964) and Hofstrand *el al*. (1984), the wood species are classified as moderately suitable, unsuitable and unsuitable respectively in their untreated state.

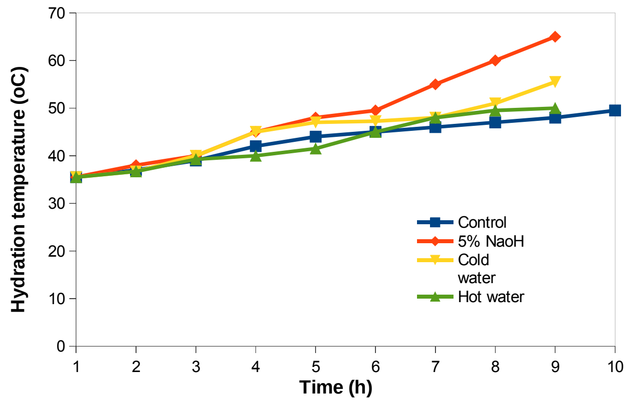

Fig. 1.
Effect of pre-treatment method on hydration temperature of Terminalia ivorensis wood and cement mixture.

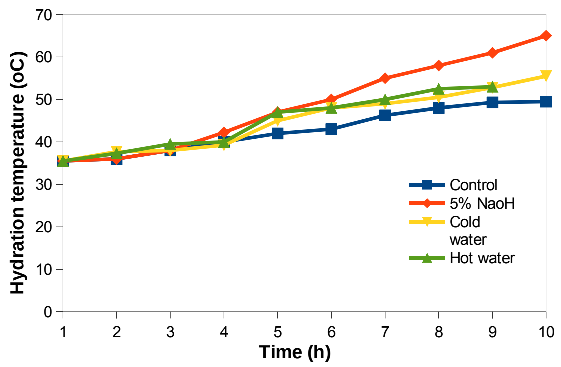

Fig. 2.
Effect of pre-treatment method on hydration temperature of Antiaris africana wood and cement mixture.

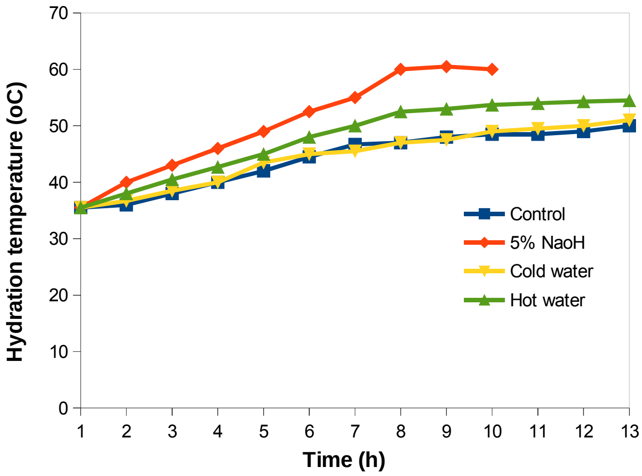

Fig. 3.
Effect of pre-treatment method on hydration temperature of Triplochiton scleroxylon wood and cement mixture.

Effect of cold water pre-treatment

There were significant differences in the hydration temperature between cold water treated samples and untreated samples of Oriro and Idigbo and no significant difference in case of Arere wood samples. The hydration temperature was improved by 1°C – 5.5°C following cold water extraction. It took Idigbo and Oriro 7hours to attain maximum temperature while it took Arere 8 hours, both cold and hot water extraction appears not sufficient to make the species fully compatible with Portland cement considering the hydration characteristics of NaOH treated wood samples which improved tremendously making all the wood species to be fully compatible with Portland cement.

Effect of hot water pre-treatment

The changes in the maximum temperature, time to reach maximum temperature, and the value of inhibitory index for hot water extraction are shown in Table 1. The hydration temperature of all the samples differs, the hydration temperature was improved following hot water extraction which was seen through increase in the maximum hydration temperatures of wood-cement-water mixtures of the various species but it appears that hot water extraction alone is not sufficient to make the species fully compatible with Portland cement judging from the hydration characteristics of NaOH treated wood samples which improved tremendously making all the wood species to be fully compatible with Portland cement.

Effect of NaOH pre-treatment

There was an improvement in compatibility following NaOH extraction (Fig. 1 and Table 1). NaOH alone was sufficient to make the species fully compatible with Portland cement. NaOH extraction varied among the three species. It seems that NaOH has a positive influence on the hydration behaviour of Idigbo and Oriro, the two species exhibited maximum temperature of 65°C but the time to reach maximum hydration differs. Idigbo species attained maximum temperature in 8.5 hours while Oriro attained in 9 hours. These two species differs significant from Arere which reached a maximum temperature of 60.5°C in 10 hours. Although, both cold and hot water were able to improve the hydration characteristics of the wood species but they are not sufficient to make the species fully compatible with Portland cement, only NaOH treatment was able to make all the wood species to be fully compatible with Portland cement. Although NaOH treatment reduced considerably the inhibitory effect. On the other hand, NaOH treatment may result in decrease in the properties of the wood-cement composites which might be explained by erosions on the fiber surface when compared to other treatments (Ferraz *et al*. 2011).

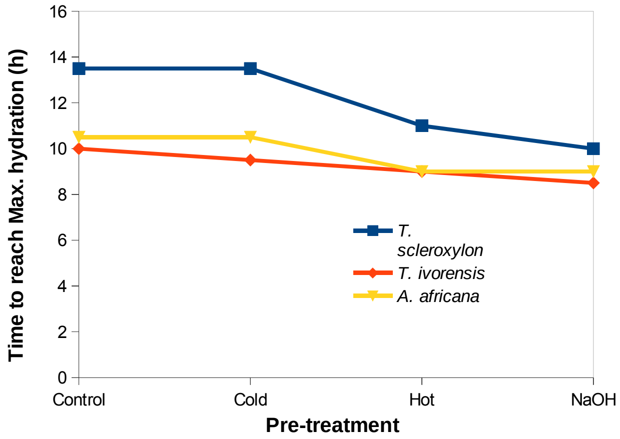

Fig. 4.
Effect of pre-treatment on time to reach maximum hydration temperature of the wood species.

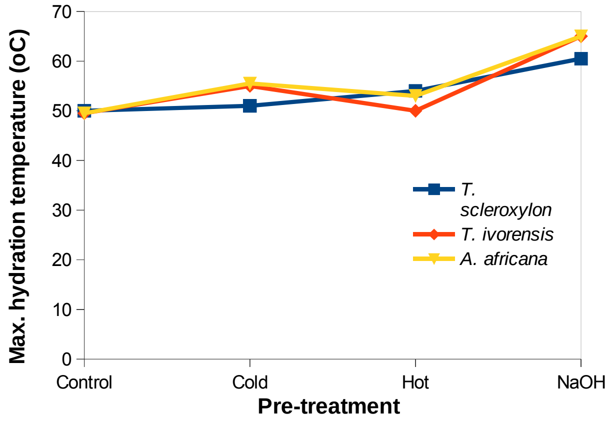

Fig. 5.
Effect of pre-treatment on the maximum hydration temperature of the wood species.

Degree of inhibition

The inhibitory index calculated for the hardwood species are given in Table 1. The inhibitory indices ranged from 6.25% to 68.75%. NaOH treatment gave the lowest inhibitory indices of 25%, 6.25% and 12.5% for Arere, Idigbo and Oriro respectively, followed by hot water which gave inhibitory indices of 37.50%, 12.50% and 12.50% for Arere, Idigbo and Oriro respectively (Fig. 6.). These values were lower compared to that of Oyagade where he got 94.12%, 64.71% and 123.53% for Arere, Idigbo and Oriro respectively. According to Garcia (1981) ranking system, inhibitory index lower than 50% is moderately suitable while those above are not suitable. Hot water and NaOH treatments made all the wood species studied to be suitable for wood cement composites production (Table 1).

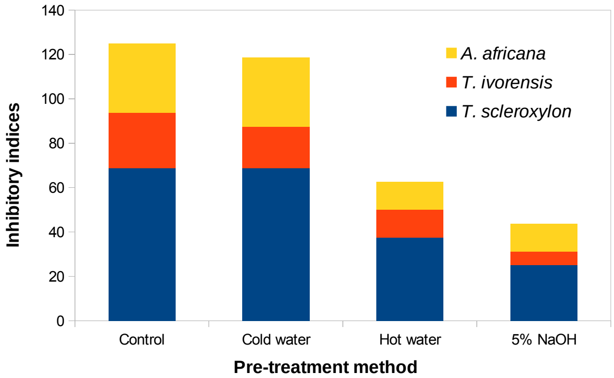

Fig 6.
Effect of pre-treatment methods on the inhibitory indices of wood and cement mixture of the three wood species.

Table 1
Mean hydration data for three tropical hardwood from untreated, NaOH, cold and hot water treated wood samples (Number of observation = 3)

Treatment	Species	Max. hydration Temp. (°C)	Time to reach Max. Temp. (hour)	Inhibitory index (%)	Suitability rating
Untreated	Arere	50.0	13.5	68.75	MS
	Idigbo	49.5	10.0	25.00	NS
	Oriro	49.5	10.5	31.25	NS
Cold water	Arere	51.0	13.5	68.75	MS
	Idigbo	55.0	9.5	18.75	MS
	Oriro	55.5	10.5	31.25	MS
Hot water	Arere	54.0	11.0	37.50	MS
	Idigbo	50.0	9.0	12.50	MS
	Oriro	53.0	9.0	12.50	MS
NaOH	Arere	60.5	10.0	25.00	S
	Idigbo	65.0	8.5	6.25	S
	Oriro	65.0	9.0	12.50	S
Neat cement		69.0	8.0	-	

NS = Not Suitable; MS = Moderately Suitable and S = Suitable

CONCLUSION

Based on the findings and results of this study, all the wood species can not combine well with cement without treatment. The wood species extractives can be minimized by soaking in hot water. There were differences in the hydration temperature among the three pre-treatment methods used. The hydration temperature was improved by hot water and NaOH extraction. Considering the maximum temperature attained (65°C), NaOH treatment was able to make all the wood species tested to be fully compatible with Portland cement. Although both cold and hot water were able to improve the hydration characteristics of the wood species as well with maximum hydration temperature of 55.5°C and 54°C respectively. Considering the inhibitory index, the inhibitory indices calculated for the wood species showed that only NaOH was effective in enhancing the compatibility of wood species with cement for wood-cement-composite production.

REFERENCES

Abdalla Ashraf MA (1998) Effect of Pre-treatment, Particle Size, Pressure and Cement – Wood ratio on Properties of Cement Bonded Products From Acacia nilotica (sunt wood). M.Sc. Thesis, University of Khartoum.

Abdelgadir AY, Ibrahim MF (2002) A note on compatibility of five-home grown species with Portland cement. University of Khartoum, Journal of Agricultural Science 10:150-155.

Abdelgadir AY, Ibrahim MFS (2003) Effect of pretreatments and cement/wood ratio on compatibility of wood with Portland cement. Sudan Silva 9(2):77-85.

Alberto MM, Mougel E, Zoulalian A (2000) "Compatibility of some tropical hardwood species with Portland cement using isothermal calorimetry," Forest Prod. J. 50:83-88.

Badejo SOO (1999) Influence of Process Variables on Properties of Cement-Bonded Particleboards from Mixed Tropical Hardwood. Ph.D. Thesis, Fed. Uni. Of Tech., Dept. of For. And Wood Tech. Akure, Nigeria.

Badejo SOJ (1988) "Effect of flake geometry on properties of cement-bonded particleboard from mixed tropical hardwoods," Wood Sci. Technol. 22:357-370.

Bejó L, Takáts P, Vass N (2005) "Development of cement bonded composite beams," Acta Silv. Lign. Hung. 1:111-119.

Brandstetr J, Polcer J, Krátký J, Holesinský R, Havlica J (2001) "Possibilities of the use of isoperibolic calorimetry for assessing the hydration behaviour of cementitious systems," Cement Concrete Res. 31:941-947.

Cabangon RJ, Cunningham RB, Evans PD (2002) "Manual strand orientation as a means of improving the flexural properties of wood-wool cement boards in the Philippines," Forest Prod. J. 52(4):53-59.

Eusebio DA, Soriano FP, Cabangon RJ, Evans PD (2000) "Manufacture of low-cost wood-cement composites in the Philippines using plantation-grown Australian species: I. Eucalyptus," Wood-Cement Composites in the Asia-Pacific Region, Canberra, Australia, 105-114.

Frybort S, Mauritz R, Teischinger A, Müllera U (2008) “Cement bonded composites review,” BioResources 3(2):602-626.

Garcia JF (1981) An Evaluation of the Rate of Heat Evolution of Portland Cement, Northern Rocky Mountain Species, M.Sc. Thesis. Univ. of Idaho, Moscow, Idaho.

Hachmi M, Moslemi AA (1990) "Effect of wood pH and buffering capacity on wood-cement compatibility," Holzforschung 44:425-430.

Hachmi M, Moslemi AA, Campbell AG (1990) "A new technique to classify the compatibility of wood with cement," Wood Sci. Technol. 24:345-354.

Hermawan D, Hata T, Kawai S, Nagadomi W, Kuroki Y (2002) "Manufacturing oil palm fronds cement-bonded board cured by gaseous or supercritical carbon dioxide," J. Wood Sci. 48:20-24.

Hofstrand AD, Moslemi AA, Garcia JF (1984) Curing characteristics of wood pa rticles from nine northern Rocky Mountain species mixed with Portland cement. Forest Products Journal 34(2):57-61.

Hawks AJ,Cox DRS (1992) A Small Scale Processing for Manufacturing Wood-Wool Cement Slabs in Developing Countries, Bulletin 49, Natural Resources Institutte pp. 38.

Iddi S, Hamza KS, Ringo WN, Ishengoma RC (1992) The Suitability of Some Tanzania Hardwood for the Manufacture of Cement particleboards. Holz als. Roh-und Werkstoff. 50(7-8):280-281.

Jain VK, Shukla KS, Kumar S (1989) Heat of Hydration Studies on Cellulosic Materials and Cement System. Journal of the Imber Dev. Assoc. of India. 35(2):19-32.

Ferraz JM, Cláudio HS, Del Menezzi, Divino E, Teixeira DE, Sabrina A Martins (2011) “Effects Of Treatment Of Coir Fiber And Cement/Fiber Ratio On Properties Of Cement-Bonded Composites” BioResources 6(3):3481-3492.

Karade SR, Irle M, Maher K (2003) "Assessment of wood-cement compatibility: A new approach," Holzforschung 57:672-680.

Kavvouras PK (1987) "Suitability of Quercus conferta wood for the manufacture of cement-bonded flakeboards," Holzforschung 41:159-163.

Moslemi AA, Garcia JF, Hofstrand AD (1983) Effect of various treatments and additives on wood-Portland cement-water systems. Wood, and Fiber Science 15(2):164-176.

Moslemi AA, Lim YT (1984) Compatibility of southern hardwood with Portland cement. Forest Products Journal. 34(7/8):22-26.

Okino EYA, Souza MR, Santana MAE, Alves MV, Sousa ME, Teixeira DE (2005) "Physico-mechanical properties and decay resistance of Cupressus spp. cement-bonded particleboards. "Cement Concrete Comp. 27:333-338.

Oyagade AO (1990) Effect of cement/wood ratio on the relationship between cement-bonded particleboard deasily and bending properties. Journal of Tropical Forest Science 2(2):211-219.

Oyagade AO (1994) Compatibility of some Tropical hardwood species with Portland cement. Journal of Tropical Forest Science 6 (4):387-396.

Papadopoulos AN, Ntalos GA, Kakaras I (2006) "Mechanical and physical properties of cement-bonded OSB." Holz Roh Werkst. 64:517-518.

Sandermann W, Preusser H, Schweers W (1960) "Studien über mineralgebundene Holzwerkstoffe: Über die Wirkung von Holzinhaltsstoffen auf den Abbindevorgang bei zementgebundenen Holzwerkstoffen," Holzforschung 14:70-77 (In German).

Sandermann W, Kohler R (1964) Investigations on mineral bound wood materials. A short test of the aptitudes of woods for cement-bonded materials. Holzforschung 18(12):53-59.

Sandermann W (1970) Technical Processes for the Production of Wood-Wool Cement Boards and their Adaptation for the Utilization of Agricultural Residues UNIDO.ID/WG.83/4,1970.

Sauvat N, Sell R, Mougel E, Zoulalian A (1999) "A study of ordinary Portland cement hydration with wood by isothermal calorimetry," Holzforschung 53:104-108.

Schubert B, Wienhaus O (1984) "Die Messung des Temperaturverlaufes der Zementhydratation als Prüfmethode für die Herstellung von Holz-Zement-Wekstoffen," Holztechnologie 25(3):118-122 (In German).

Schwarz HG, Simatupang MH (1984) "Eignung des Buchenholzes zur Herstellung zementgebundener Holzwerkstoffe," Holz Roh Werkst. 42:265-270 (In German).

Semple KE, Evans PD (2004) "Wood-cement composites - Suitability of Western Australian mallee eucalypt, blue gum and melaleucas ," RIRDC/Land & Water Australia/FWPRDC/MDBC.

Simatupang MH, Schwarz GH, Broker FW (1978) Small-scale plants for the manufacture of mineral-bonded wood composites. 8th World Forestry Congress FID-11/ 21 - 30, Jakarta,Indonesia. October 16-28. Special paper.

Shittu KA (1990) Assessment of Hydration Temperature Test Behaviour of Thirty Nigerian Hardwood Species for Board Formation with cement. M.Sc. Thesis, Dept. of Forest Resources Management, University of Ibadan, Ibadan.

Sutigno P (2000) "Effect of aqueous extraction of wood-wool on the properties of wood-wool cement board manufactured from teak (Tectona grandis)," Wood-Cement Composites in the Asia-Pacific Region, Canberra, Australia, 24-28, 2000.

Thygesen A, Daniel G, Lilholt H, Thomsen AB (2005) "Hemp fiber microstructure and use of fungal defibration to obtain fibres for composite materials," J. Natural Fibers 2:19-37.

Weatherwax RC, Tarkow H (1964) Effect of wood on the setting of Portland cement. Forest Products Journal 14(12):567-570.

Weatherwax RC, Tarkow H (1967) Effect of wood on the selling of Portland Cement. Decay wood as an inhibitor. Forest Products Journal 17(7):30-32.

Wei YM, Zhou YG, Tomita B (2000a). "Study of hydration behavior of wood cement-based composite II: Effect of chemical additives on the hydration characteristics and strengths of wood-cement composites," J. Wood Sci. 46:444-451.

Wei YM, Zhou YG, Tomita B (2000b). "Hydration behavior of wood cement-based composite I: Evaluation of wood species effects on compatibility and strength with ordinary Portland cement," J. Wood Sci. 46:296-302.