Research Journal of Recent Sciences _____ ISSN 2277-2502
Vol. **2(2),** 59-65, February **(2013)** *Res.J.Recent Sci.*

The Most Suitable species of six West African Hardwood Species for Wood – Cement Composites

Tchéhouali D.A.[1]*, Aïna M.P.[1], Houanou K.A.[1], Foudjet A.[2] and Thimus J.F.[3]
[1]Laboratoire d'Energétique et de Mécanique Appliquée–Ecole Polytechnique d'Abomey Calavi, Université d'Abomey Calavi (LEMA/EPAC/UAC), 01 BP 2009 Cotonou, BENIN
[2]CRESA Forêt – Bois Université de Dschang, CAMEROUN
[3]Génie civil et environnemental, Ecole Polytechnique de Louvain, Université catholique de Louvain, Belgique, BELGIUM

Available online at: www.isca.in
Received 27th November 2012, revised 18th December 2012, accepted 30th December 2012

Abstract

Some tropical wood species are currently used in wood work in Benin and generating very important quantities of wood waste. To recycle these wastes through building material, the suitability of wood species for wood - cement composites is evaluated. Wood - cement compatibility is studied based on measurements of cement heat hydration and compatibility indices. The potential for the sawdust species to be used in wood - cement composites was investigated by determining the mechanical strengths of the composites. Six hardwood species namely Afzelia africana, Diospyros mespiliformis, Khaya grandifoliola, Tectona grandis, Pterocarpus erinaceus, and Isoberlina doka are tested. In general, the woody residues inhibit the hydration reaction of cement but the hydration tests identified Isoberlina doka and Diospyros mespiliformis as compatible with cement. Tectona grandis, Khaya grandifoliola and Pterocarpus erinaceus was compatible with cement after hot water treatment. Afzelia africana was incompatible with cement. Mechanical tests showed that Tectona grandis, Pterocarpus erinaceus and Isoberlina doka provided the highest mechanical strengths.

Keywords: Wood-cement compatibility, tropical wood, hydration, cement, mechanical strengths.

Introduction

Many wood species are identified to be hard wood, available in the West African region, especially in Benin to generate significant volumes of wood with the commercial potential. Consequently, large quantities of wood waste will be generated in this region in the future and will constitute a major environmental problem.

The reuse of wood waste as building materials is one way of tackling the problem. Wood – cement composites have been widely investigated[1,2,3]. The dimensional variations have been studied[4]. The major well known problem occurring about this topic is the aptitude of wood species to be used as wood – cement composites. Such problem is widely discussed[5,6]. Many studies have been undertaken to assess the compatibility of wood with cement[7,8,9].

Today, although a large number of wood species have been investigated such as *pin wood*, *Western Australian malle Eucalyptus*, *Acacia Mangium and Eucalyptus Pellita*, *Amblygonocarpus andongensis, Brachystegia speciformis, Pterocarpus angolensis, Kaya nyasica, Erythrophleum suaveoleuns, Albizia adianthifolia, Sterculia appendiculata, Millettia stuhlmannii, Julbernadia globiflora, Afzelia quanzenzis*, few information related to the compatibility of West African wood species with cement is available[10,11,12,13]. Moreover, it was found that the nature of wood species influences considerably the hardening of the cement depending on the origin of the tree[13].

The aim of this research was to determine the most suitable of six West African hardwood species to be used as wood –cement composite in Benin. The first step in assessing the suitability of different wood species for their use in cement composite involves testing whether the wood significantly inhibits the hydration reaction of Portland cement. Compatibility with cement of six West African wood species based on the measurement of cement hydration temperature and compatibility indices was studied. In the second step, mechanical tests have been carried out on moulded blocks to confirm hydration tests[14]. In the third step, the suitability of wood species for wood – cement composites were evaluated by determining tensile and compressive strengths on the samples of wood cement - composite.

Material and Methods

Material: Sawdust deducted in sawmills from six wood species available in Benin were used in this study: *Afzelia africana*, *Diospyros mespiliformis, Khaya grandifoliola, Tectona grandis, Pterocarpus erinaceus, and Isoberlina doka*.

In order to assess the influence on the compatibility indices of the treatment method applied on the wood species, the sawdust was pre treated firstly with cold water and secondly with hot

water. Treatment in cold water has consisted in drenching during 48 h and washing thoroughly sawdust in water at ambient temperature. Treatment in hot water has consisted in drenching during 48 h and washing sawdust in water at 80°C because of their great degree of inhibition assumed[7,15].

After washing, the sawdust were dried in a kiln at 105°C within 48 h then separated by sieving in three size classes. Class retained for the tests was 0, 1 - 4 mm.

The type of cement used was CPJ-CEMII 35 manufactured in SCB Lafage Company and locally available in Benin.

Measurement of cement hydration temperature and compatibility indices: Wood: cement: water mass ratio of 15 g: 200 g: 90.5 g was used and 200 g of cement were mixed with 80 ml of water in case of cement control samples (containing no wood)[16].

The samples were thoroughly mixed with water in a sealable polyethylene bag during 2 min.

Immediately after mixing, the tip of a temperature thermocouple (type K) was taped to the outside of sample bag and enclosed within the body of the wood – cement mix by folding the bag and contents around it and securing the folded bag with adhesive tape. The bag was then placed in a polystyrene cup and sealed inside a flask. This process was carried out for three samples per test. All experiments were undertaken in a controlled temperature room maintained at 20 ± 1 °C. A cement hydration temperature logging apparatus was used to measure the heat of hydration of the three wood-cement samples over 24 h. Temperatures were recorded at 5 min intervals and the curves were smoothed by plotting the progressive averages of every three successive readings. Maximum heat of hydration temperature (T_{max}) and time (t) to reach T_{max} were recorded and two wood - cement compatibility indices, C_A – factor and hydration rate $R = (T_{max} - T_{min})/t$ were calculated[8]. The C_A – factor is the ratio of the areas under the wood-cement sample and control (cement only) hydration curves, expressed as percentage. The T_{min} component of hydration rate is the temperature attained during the time when no more than three repeated values are recorded. Then, wood species were classified as compatible, moderately compatible or incompatible with cement based on the extent to which they retarded cement hydration[8].

Mechanical tests on moulded blocks: The evaluation of the aptitude of wood species to wood works by measuring cement hydration temperature and compatibility indices has been completed by mechanical tests on moulded blocks. Thus, sawdust treated in hot water, cement and water were mixed respecting the following ratio:

Wood: cement: water mass ratio of 75 g: 1000 g: 452.5 g[14].

For each batch of mix, twelve cubes (50 mm x 50 mm x 50 mm) were used to conduct compressive test after 28 days of curing in water in room at 20°C -25°C.

Mechanical tests on wood – cement composites: The sawdust, cement and water were mixed according to the most convenient ratio for wood species as indicated in table 1.

Table-1
Most convenient ratios for wood species

Wood species	Wood: Cement: Water ratio
Afzelia africana	0.8 : 1 : 1.09
Diospyros mespiliformis	0.8 : 1 : 0.85
Khaya grandifoliola	0.8 : 1 : 0.87
Tectona grandis	0.8 : 1 : 0.61
Pterocarpus erinaceus	0.8 : 1 : 0.84
Isoberlina doka	0.8 : 1 : 1.09

The mixture was placed in steel mould and compacted. For each batch of mixture, twelve cubes (50 mm x 50 mm x 50 mm) and twelve cylinders (diameter: 50 mm and height: 100 mm) were used to conduct compressive and indirect tensile (split tensile) tests. After 24 h, the boards were de-clamped and conditioned for 28 days at 20°C and 65% RH to allow the cement to cure and gain strength.

Tensile and compressive tests were carried out on some samples directly while others were tested after they were soaked in water at laboratory room temperature (20°C) for 24 h. After soaking, the samples were drained on paper towels for 20 mn to remove excess water.

Results and Discussion

Compatibility of wood species with cement based on measurements of cement hydration temperature and compatibility indices.

From figure 1, when the sawdust of wood species were treated with cold water, the curves indicate that in the mixture of *Isoberlina doka* and *Diospyros melsiformis* species, hydration reactions started very earlier (about 3 h after adding water) than in other mixtures. In the mixtures of neat cement, *Tectona grandis* and *khaya grandifoliola* species hydration reactions started about 2 h, 7 h and 5 h respectively. The curve corresponding to *Tectona grandis* presented a great and favourable tendency in developing heat hydration even over 30 h. From table 2, *Isoberlina doka* and *Diospyros melsiformis* species have yielded the highest compatibility indices with C_A factor equal to 61% and 64% respectively. *Khaya grandifolila* and *Tectona grandis* species had C_A-factors equal to 55% and 48% respectively. Data are not present in columns corresponding to *Pterocapus erinaceus* and *Afzelia africana* species because of their great inhibitory effect on the cement hydration.

Table-2
Compatibility indices of tropical wood species treated with cold water

Mix	T_{max} (°C)	T_{min} (°C)	TIME (H)	RATE (°C/H)	C_A. FACTOR (%)
CEM II	47.9	31.6	9	1.81	100
CEMII + D*iospyros mespiliformis sawdust*	46.9	34	7.75	1.66	64
CEM II + *Isoberlina doca sawdust*	43.2	33.2	10.41	1	61
CEM II + K*haya grandifoliola* sawdust	47.1	34.9	7.10	1.74	55
CEM II + Tectona grandis sawdust	41.9	33.6	5.33	1.56	48
CEM II + P*terocarpus erinaceus* sawdust	00	00	00	00	00
CEM II + *Afzelia africana* sawdust	00	00	00	00	00

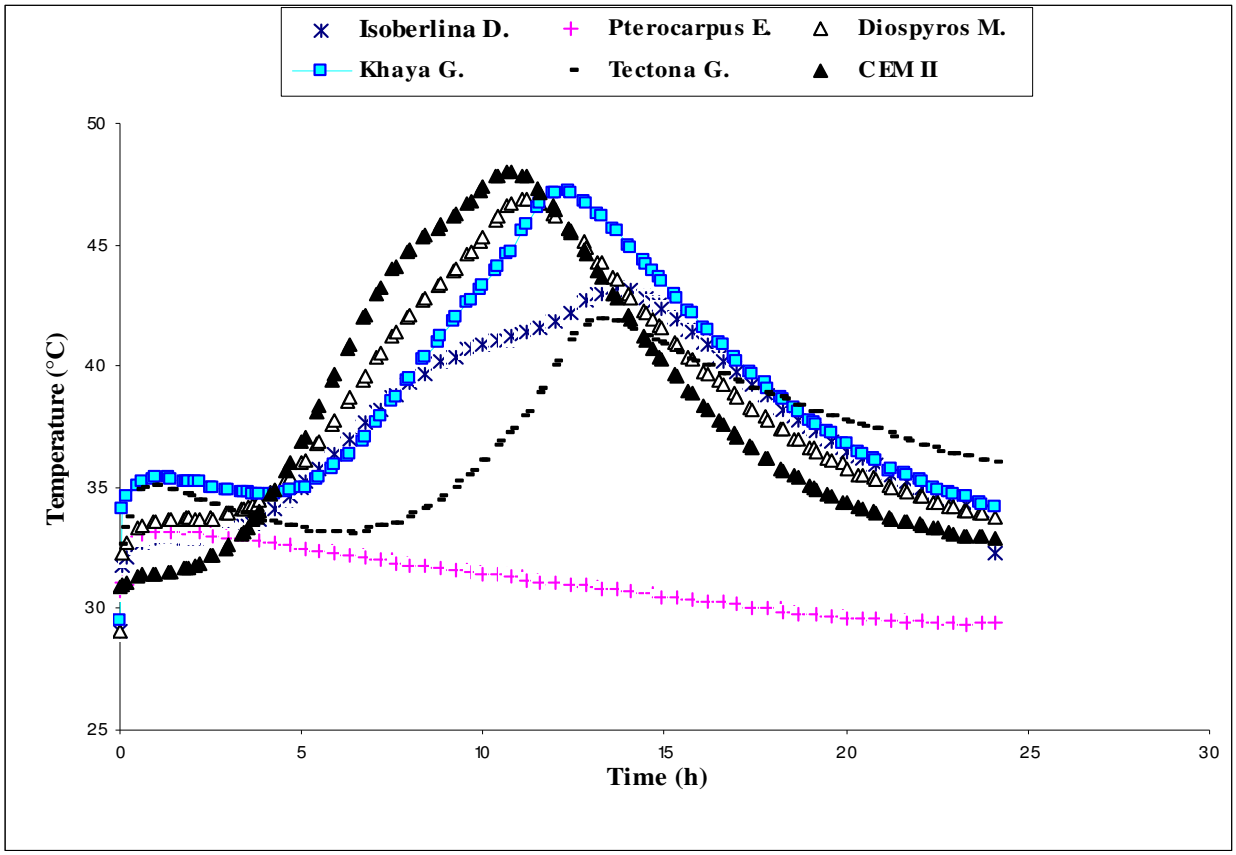

Figure-1
Hydration exotherms (temperature v time) for neat cement1 and cement containing tropical wood treated with cold water

From figure 2, in case of hot water treatment, the curves of the mixture of *Isoberlina doka* and *Pterocarpus erinaceus* species show earliest hydration reactions starting about 2 h and 2.5 h respectively after mixing with water. The mixtures of K*haya grandifoliola*, *Diospyros melsiforis and Tectona* grandis species started their hydration reactions about 3.33 h, 3.67 h and 4.17 h respectively after mixing with water. In despite of a long delay in starting hydration reactions, *Tectona grandis* specie had good compatibility indices as indicated in table 3. *Isoberlina doka*, *Tectona grandis*, *Pterocarpus erinaceus* species and *Diospyros mespiliformis* had average C_A -factors equal to 80%, 78%, 74% and 70% respectively. The lowest compatibility indices were provided by *Khaya grandifolila* (C_A – factor equal to 66%). *Afzelia africana* specie appeared to be totally incompatible with cement.

The results indicate that treatment of sawdust in hot water enhance notably the compatibility indices of all species as found in previous work[13].

With simple treatment in cold water, *Isoberlina doka* and *Diospyros melsiformis* species had good compatibility indices while compatibility indices of *Tectona grandis* and *Pterocarpus erinaceus* species were negatively affected. *Afzelia africana* specie was totally incompatible with cement.

Table-3
Compatibility indices of tropical wood species treated with hot water

Mix	T_{max} (°C)	T_{min} (°C)	TIME (H)	RATE (°C/H)	C_A. FACTOR (%)
CEM II	45.6	31.5	9	1.57	100
CEMII + D*iospyros mespiliformis sawdust*	41.4	31.8	6.67	1.51	70
CEM II + *Isoberlina doca sawdust*	42.9	32.1	6.92	1.56	80
CEM II + K*haya grandifoliola* sawdust	41.4	31.8	6.75	1.42	66
CEM II + P*terocarpus erinaceus* sawdust	42.7	31.5	7.26	1.54	74
CEM II +T*ectona grandis* sawdust	42.3	31.3	8.17	1.55	78
CEM II + Afzelia africana sawdust	00	00	00	00	00

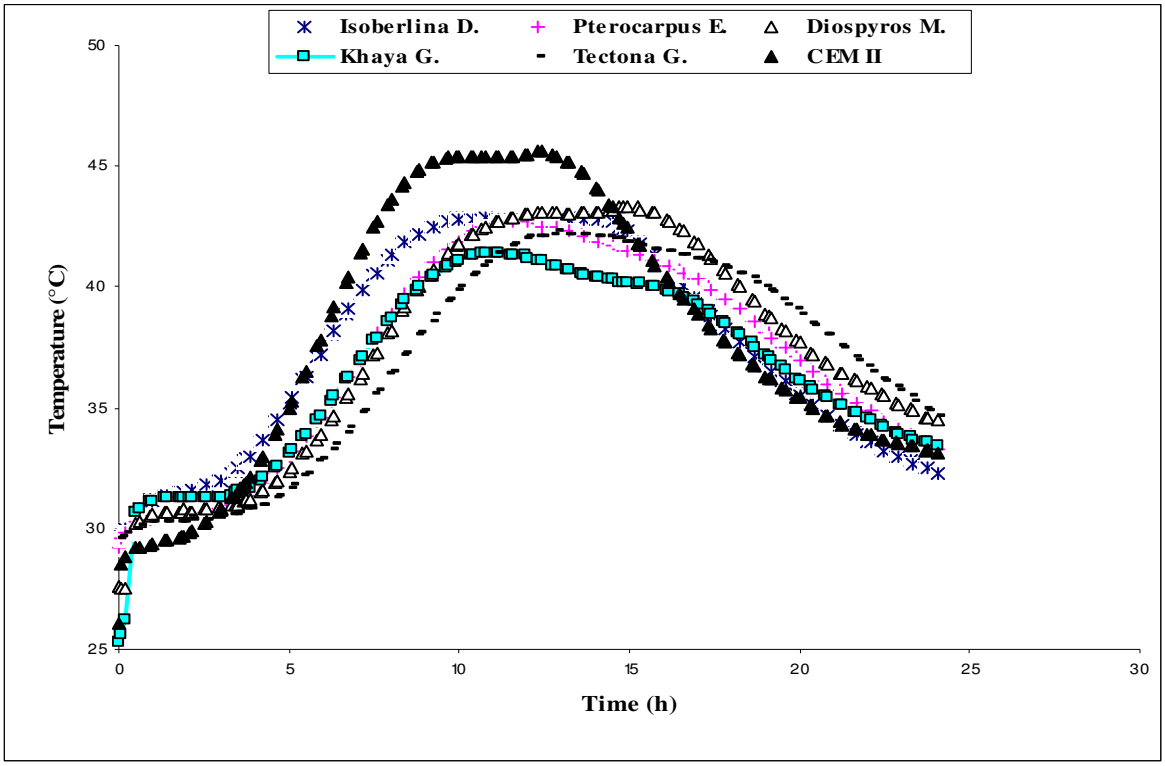

Figure-2
Hydration exotherms (temperature v time) for neat cement and cement containing tropical wood treated with hot water

Pterocarpus angolensis and *Khaya nyasica* species were previously identified as species compatible with cement after simple cold or hot water treatment in a previous work[13]. This contrast could be explained by the fact that the properties of these species which grow in Mozambique (Central Africa) could be different from those of the same species growing in Benin (West Africa) depending on the difference in climatic condition. Such observation has been done on five Western Australian malle eucalypt species[11]. Moreover, during the hydration process, the accumulated enthalpies constitute a factor of compatibility between cement and wood and the incompatibility of wood with cement may be due to many factors such as the chemical composition of wood in relation with the extractives components[5]. Then, with the same wood specie, different behaviour of wood -cement composite can be observed depending on the location of the tree.

Characteristics of moulded blocks: The blocks have presented an average density about 1550 Kg/m^3. They couldn't be classified as lightweight concretes[4]. The very slight variation of the densities (minimum value 1531 Kg/m^3 corresponding to T*ectona grandis* specie and maximum value 1600 Kg/m^3 corresponding to *Isoberlina doka* specie) tallies with the slight variation of the characteristics of the blocks as shown in figure 3 whereby compressive strengths vary from 23.5 MPa for *Pterocarpus eurinaceus* specie to 26.5 MPa for *Isoberlina doka* specie. Moreover, from figure 3, compressive strengths values were linearly proportional to C_A – factors and such results lead to the conclusion that physical test could be a real indicator of wood-cement compatibility as found previously[14].

Mechanical strengths of wood – cement composites: In case of cold water treatment, the highest mechanical strengths of wood

– cement composite were obtained with *Isoberlina doka* and *Diospyros mespiliformis* species both in dry and in wet conditions as shown in figure 4. *Tectona grandis* specie provided the lowest mechanical strengths and *Pterocarpus eurinaceus* specie didn't allow cement setting.

In case of hot water treatment, *Tectona grandis* and *Pterocarpus erinaceus* species showed, in figure 5, the highest strengths. Samples made from *Isoberlina doka and Diospyros mespiliformis* species presented good strengths both in dry and wet conditions. *Khaya senegalensis* specie provided the lowest mechanical strengths.

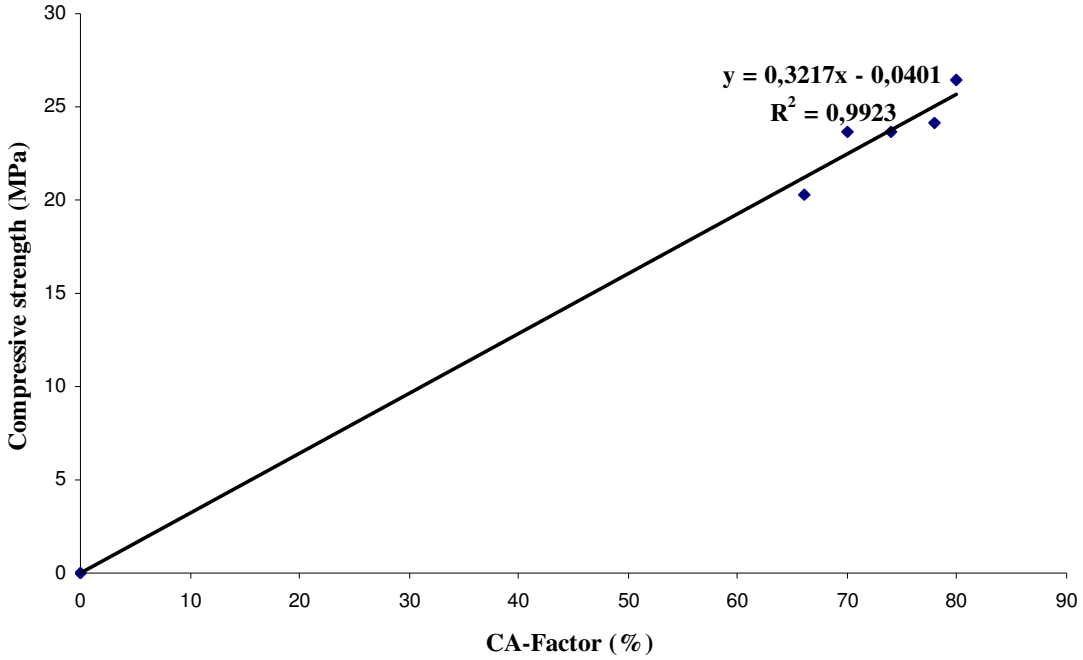

Figure-3
Evolution of compressive strengths of moulded blocks with C_A-factor

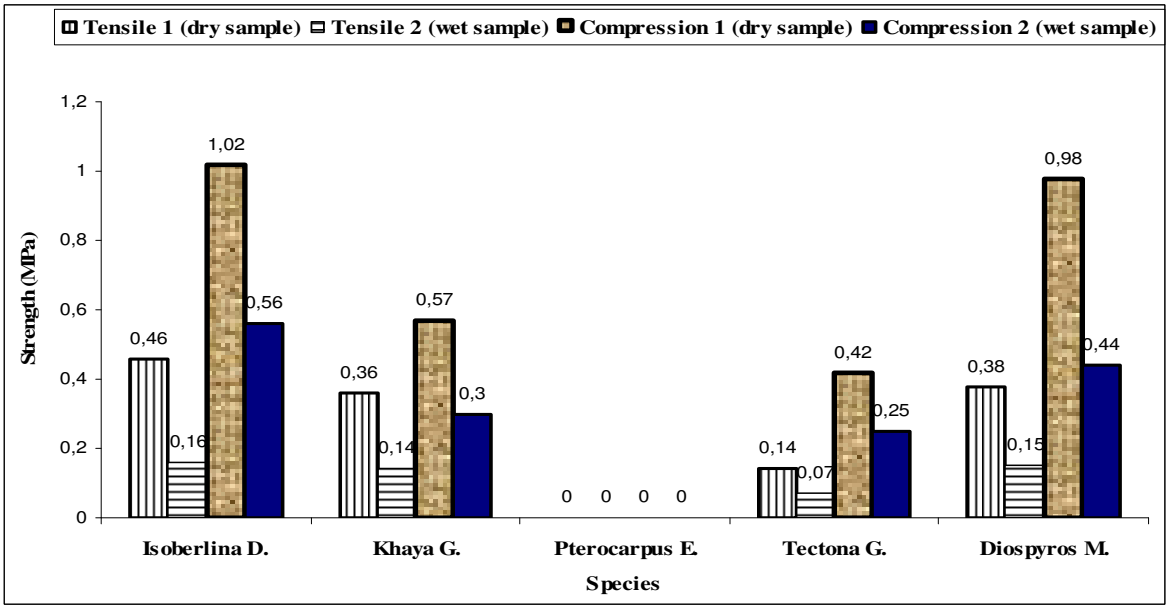

Figure-4
Tensile and compressive strengths of wood cement composites (treatment in cold water)

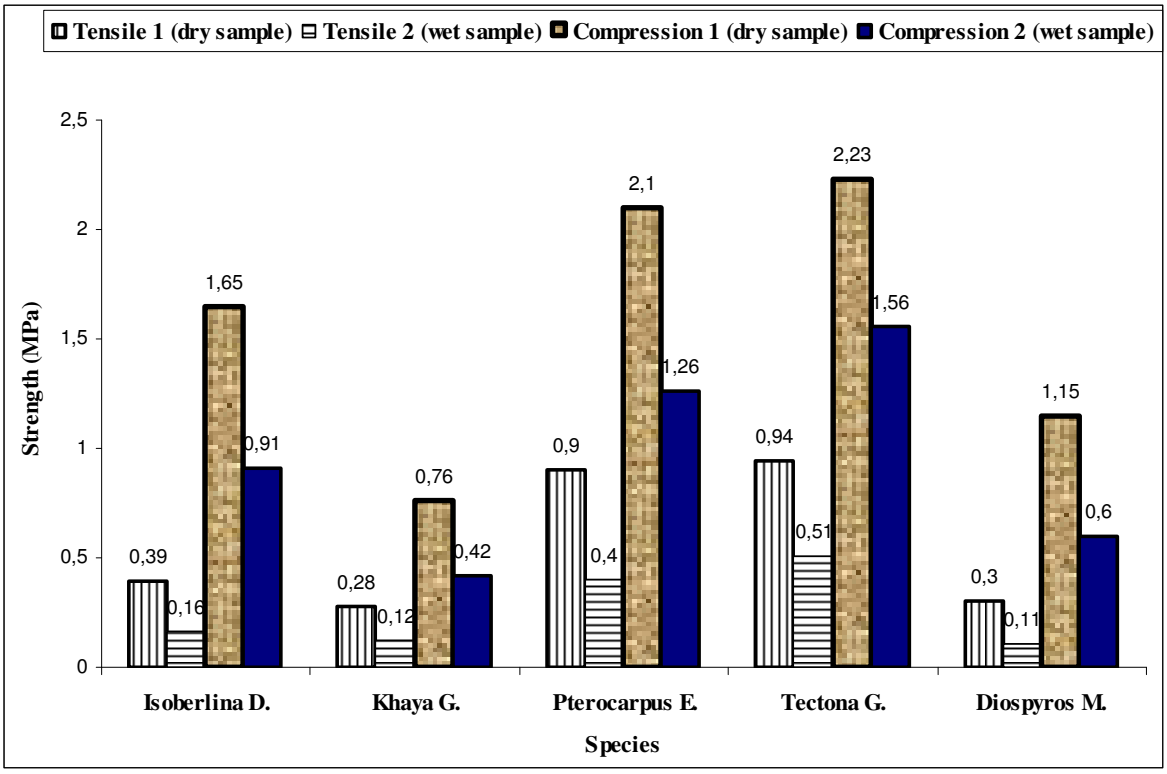

Figure-5
Tensile and compressive strengths of wood - cement composites (treatment in hot water)

The mechanical strengths of wood-cement composites were very low and decreased drastically in wet conditions (about 40% in compression and 60% in tensile) especially with *Isoberlina doka* and *Diospyros mespiliformis* species.

Conclusion

Among the six West African wood species tested in this study, only *Afzelia Africana* specie which grows in Benin (West Africa) appeared to be incompatible with cement CEM II – CPJ 35 even after treatment with hot water. *Isoberlina doka*, *Diospyros mespiliformis, Tectona grandis Pterocarpus erinaceus and Khaya grandifoliola* species had moderate to good compatibility with cement after treatment with hot water. *Tectona grandis* and *Pterocarpus erinaceus* species were greatly affected with cold water treatment.

The study confirms that physical tests on wood - cement composites could provide quick and satisfactory results to assess the aptitude of tropical hardwood species for wood work.

In wet conditions, the mechanical strengths of wood-cement composites decrease drastically (about 40%), especially *Isoberlina doka* and *Diospyros mespiliformis* species. Such important result must be taken into account when using the composite in a humid environment. Finally, one can suggest the most suitable species of the six West African hardwood species for wood - cement composite in the following order *Tectona grandis, Pterocarpus erinaceus, Isoberlina doka*, *Diospyros mespiliformis* and *Khaya grandifoliola* species.

References

1. Dinwoodie J.M. and Paxton B.H., Wood - cement particle board: a technical assessment, *Journal of Applied Polymer Science*, **40,** 217- 227 **(1984)**
2. Hachmi M. and Sesbou A., Les composites bois - ciment: une nouvelle filière pour la valorisation des produits lignocellulosiques marocains, Annales de la Recherche Forestière au Maroc, **(1990)**
3. Hofstrand A.D., Moslemi A.A. and Garga J.F., Curing characteristics of wood particles from nine northern Rocky Mountain species mixed with Portland cement, *Forest Prod. J.*, **34(2),** 57-61 **(1984)**
4. Mougel E., Mise au point d'un composite ciment – bois dont les variations dimensionnelles vis-à-vis des variations d'humidité sont contrôlées, Thèse de Doctorat de l'Université de Nancy I, **(1992)**
5. Pereira C., Caldeira Jorge F., Ferreira J.M., Wood-cement composites: A review, *Holz Roh- Werkst*, **62,** 370-377 **(2004)**

6. Badejo S., Influences of pre treatment temperature and additives concentration on the properties of cement - bonded particleboard from plantation grown tropical hardwoods, *Tropical Science*, **29**, 285- 296 **(1989)**

7. Hachmi M. and Moslemi A.A., Correlation between wood - cement compatibility and wood extractives, *Forest Prod. J*., **39,** 55-58 **(1989)**

8. Hachmi M., Moslemi A.A., Campell A.G., A new technique to classify the compatibility of wood with cement, *Wood Science and Technology*, **24,** 345-354 **(1990)**

9. Sandermann W. and Kohler R., Studies on mineral bonded wood materials VI: A short test of aptitudes of wood for cement – bonded materials, *Holzforschung*, **18,** 53-59 **(1964)**

10. Semple K.E. and Evans P.D., Adverse effects of heartwood on the mechanical properties of wood-wool cement boards manufactured from radiata pin wood, *Wood fibre Science*, **32(1),** 37-43 **(2000)**

11. Semple K.E., Cunningham R.B. and Evans P.D., Suitability of five western Australian mallee eucalypt species for wood – cement composites, *Industrial Crops and Products*, **16,** 89-100 **(2002)**

12. Semple K.E., Cunningham R.B. and Evans P.D., Cement hydration tests using wood flour may not predict the suitability of Acacia Mangium and Eucalyptus Pellita for the manufacture of wood- wool cement boards, *Holzforschung*, **53(3)**, 327-332 **(1999)**

13. Alberto M.M, Mougel E., Zoulalian A., Compatibility of some tropical hardwood species with Portland cement using isothermal calorimetry, *Forest Prod J*., **50(9),** 83-88 **(2000)**

14. Andy W.C.L. and Zhongli H., Compressive strength of cylindrical samples as an indicator of wood-cement compatibility, *Forest Prod. J.*, **36 (11/12),** 87-90 **(1986)**

15. Pereira C., Caldeira Jorge F., Irle M.A., Ferreira J.M., Extractive contents of two woods and cork of Portuguese origin and the interaction of these substrates with cement suspensions, *Forest Prod. J*., **53(10),** 39-43 **(2003)**

16. Weatherwax R.C., Tarkow H., Effect of wood on setting of Portland cement, *Forest Prod. J*., **14**, 567-570 **(1964)**