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Evaluation of Using Midribs of Date Palm Fronds as a Raw Material for Wood-Cement Composite Panels Industry in Saudi Arabia

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Abstract: This study was carried out in 2010 to investigate the suitability of date palm midribs (*Phoenix dactelifera* L.) as a lignocellulosic material for the production of wood-cement composite panels, in addition to enhancement their compatibility with cement using various pretreatments and chemical additives. Materials used for this study were midribs of fronds of different date palm varieties available in Saudi Arabia and Portland cement (Type I) manufactured by Yammama Cement Company. To achieve this aim, hydration tests of net cement and date palm-cement mixture were carried out using a 2-litter Dewar flask. The suitability of date palm for this industry was made according to inhibitory index (I) and compatibility factor (C_A) which were calculated from the hydration data. The results showed that under untreated condition, date palm particles are incompatible with cement and were classified as "unsuitable" for making wood-cement boards. Using of cold or hot water extraction for date palm materials resulted in an enhancement in their compatibility with cement. However, date palm can be reclassified as suitable under limited conditions for making wood-cement boards only by using hot water extraction. Addition of 3% $CaCl_2$ to untreated date palm particles resulted in reclassified it to suitable under limited conditions (T_{max} value was 54.23°C and C_A value was 75.73%). These results suggested that date palm midribs can be used to produce wood-cement panels either after extraction by hot water or addition of 3% $CaCl_2$ as an accelerator to date palm-cement mixture.

Key words: Date palm · Wood-cement panels · Portland cement · Hydration · Compatibility

INTRODUCTION

Saudi Arabia does not posses adequate forest resources to meet their needs for fuel wood, industrial wood and wood composition panels. However, it has relatively large quantities of other lignocellulosic materials available in the form of agricultural residues. The number of date palm trees exceeds 20 million [1]. A large quantity of this date palm population sheds huge quantity of plant biomass annually from seasonal pruning as an essentially agricultural practice. According to El-Juhany [2], 35-kg on average of palm residues are obtained per tree annually and about one million metric tons of date palm biomass are wasted annually from seasonal trimming of the palm tree population in Saudi Arabia. In developing countries most of these residues are burnt. However, in developed countries these residues are used to produce wood composites such as particleboard and medium density fiberboard.

The date palm (*Phoenix dactylifera* L.) is an important element of the flora in the whole Arab countries. It plays a pivotal role in the economic, social and cultural life in the Arab region [3]. Horticultural experts believe that the cultivation of the date palm tree started around 6000 BC with many uses of the trees. The wood and leaves provide timber and fabric for houses and fences. The leaves are used for making ropes, cord, baskets, crates and furniture. The base of the leaves and the fruit stalks are used as fuel.

In Egypt, the date palm midribs were successfully used in'Mashrabia handicrafts as a substitute for the imported beech wood, *Fagus sylvestris* [3], in the core layer of the blockboard as a substitute for the imported spruce wood (*Picea abies*) without sacrifice of the

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utilization properties of the product. Three layer particleboards were made of palm midrib as a substitute for casuarina wood, *Casuarina* spp. [3, 4]. The Center for Development of Small Scale Industries and Local Technologies in Egypt has demonstrated the successful use of date palm fronds for the manufacture of lumber-like product having physical and mechanical properties similar to those for imported wood [3].

Wood-cement particleboards (WCP) are referred to particles or fibers of wood or non-wood materials, which are used as reinforcement materials, bonded and held together by an inorganic binder such as ordinary Portland cement. Using various methods and techniques, lignocellulosic materials from different countries have been screened, tested and classified according to their suitability for wood-cement panel production [5-10] Based on these results wood-cement particleboards are generally made from wood species which have been tested and proved suitable.

Unlike resin-bonded particleboard, WCP shows excellent sound insulation, high resistant to water and termites and excellent long-term weatherability and outdoor conditions. These advantages lead to its wider potential applications for replacing traditional building materials and conventional wood composites as siding, roofing, wall, flooring parts, support tables and noise absorbing partitions [11]. This interest in cement-bonded particleboard (CBP) can be attributed to the high cost of resin and machinery necessary for production of resin-bonded boards, which are an attractive to WCP [12].

With all the advantages of WCP, however, the compatibility of some lignocellulosic materials with cement is limited, which may inhibit cement setting to some extent and limit WCP development [7, 13-14]. The water-soluble materials in wood have the greatest inhibitory effect [8, 15-18]. Extraction of wood by hot or cold water and/or addition of chemical additives to wood-cement mixtures are extremely important in improving their compatibility [18, 19].

The method developed by Sandermann and Kohler [15] is commonly used to measure the compatibility of wood-cement mixture because it is reliable and very simple to be carried out. In this method, the heat of hydration produced during the setting of wood-cement mixture is measured. This compatibility was classified based on the extent to which they retarded cement hydration using compatibility factor (C_A) and inhibitory index (I) according to Sandermann and Kohler [15], Hachmi and Moslemi [20] and Okino *et al*. [21].

The studies conducted in Saudi Arabia to produce wood-cement particleboard and to evaluate the compatibility of agricultural residues for CBP manufacturing are limited. Therefore, the objective of the current study was to evaluate the suitability of the midribs of date palm fronds as a lignocellulosic raw material for manufacturing wood-cement products that have high economical value.

MATERIALS AND METHODS

Raw Material: The lignocellulosic material used for the current study was pruning residues of date palm (*Phoenix dactelifera* L.) which are midribs of fronds collected from the seasonal pruning process in 2010 of date palm trees planted at the Agricultural Experimental Station near Derab, 50 km south Riyadh, Saudi Arabia. On the other hand and for comparison purpose, wastes from European redwood (*Pinus sylvestris* L.) were collected from wood stores in Riyadh city. Theses materials were air-dried then reduced to small pieces in order to facilitate grinding into meal. These were later put in hammer mill using prototype hammer mill and screened. Wood meal passing through a 20-mesh screen and retained on a 40-mesh screen was used for hydration test, while those meals that pass through a 40-mesh screen and retained on a 60-mesh screen were used for chemical analysis.

Commercial ordinary Portland cement (Type I), meeting ASTM C150-84 specification [22] and manufactured by Al-Yammama Cement Company was used as a binder.

Chemical Additives: Two chemical additives were used in this study, namely calcium chloride dehydrate ($CaCl_2$. $2H_2O$) and magnesium chloride ($MgCl_2$) at 1 and 3% of cement weight. Additives were dissolved in distilled water at least 15 minute before adding to the untreated wood-cement mixture.

Cold and Hot Water Treatments: About 30 grams of oven-dried wood meal (20-40 mesh) were soaked in cold distilled water (cold water treatment) or were extracted in boiling distilled water (hot water treatment) for 48- hours or 3 hours, respectively according to Moslemi *et al*. [17] with some modification. The pH of the extracts was measured with Accunet pH meter. Later, the extracted materials were used for hydration test to determine their compatibility with cement. The seven treatments were used in this study, namely wood+cement (untreated, UNTRT), wood extracted by cold water+cement (CWE), wood extracted by hot water+ cement (HWE), UNTRT+1%$CaCl_2$, UNTRT+3%$CaCl_2$, UNTRT+1%$MgCl_2$ and UNTRT+ 3%$MgCl_2$.

Chemical Analysis of Date Palm Midribs and European Redwood: The contents of cellulose, hemicellulose, total extractives and ash were determined for date palm midribs and European redwood according to the standard methods as follows:

Extractives Content Determination: The extractive content of wood was determined according to the ASTM, D1105-84 [23]. Samples of air-dry wood were chipped and ground to pass through 40-mesh screen and retained on a 60-mesh screen. Air-dried wood meal was extracted in a Soxhlet apparatus with ethanol-benzene mixture (in the ratio of 1:2 by volume, respectively) for four hours, followed by extraction with 95% ethanol for four hours and finally extracted with hot distilled water for four hours with chancing water every one hour. The percentage of extractives was calculated based on the oven-dry weight of wood samples.

Cellulose Content Determination: Cellulose content was determined by the treatment of extractive-free wood meal with nitric acid and sodium hydroxide: one gram of extractive-free wood meal was treated with 20 ml of a solution of nitric acid 3% in flask and boiled for 30 min. The solution was filtered in a crucible. The residue was treated with 25 ml of a solution of sodium hydroxide 3% and boiled for 30 min. The residue was filtered, washed with warm water to neutral filtrate, dried and weighed. The cellulose content was calculated as percentage of residues based on oven dry wood meal weight [24].

Hemicelluloses Content Determination: Hemicellulose content of buttonwood samples was determined by the treatment of extractive-free wood meal (about 1.5 g) with 100 ml sulfuric acid (2%) and boiled for 1 hour under a reflex condenser and filtrated in a crucible. After that the residue was washed with 500 ml of hot distilled water to free of acid and contents were dried in an oven at 105± 2°C, cooled in a desiccator and weighed [25]. Then, the hemicellulose content was calculated based on the oven-dry weight of the spacemen.

Ash Content Determination: Ash content of wood was determined according to the Chemical Analysis and Testing Task Laboratory Analytical Procedure “NREL” [26]. Approximately one gram of oven-dry sample was placed into the crucible. The sample in an uncovered crucible was heated gradually, then ignited at 575±25°C in muffle furnace for a minimum of three hours, or until all the carbon is eliminated. Ash content was calculated as a percentage of residues based on the oven-dry wood meal weight.

Hydration Procedure: The hydration of net cement and wood-cement mixtures was carried out according to Hofstrand *et al*. [5]. 200 grams of cement and 15- grams of oven-dried milled wood (20-40 mesh) were mixed and kneaded with 90.5 ml of distilled water for about two minutes. The mixture was then placed into a two litter Dewar flask. The thermocouple wire (Type T) was connected to a data-logger where the temperature was measured at 15-minute intervals for 24 h. The time and temperature readings were plotted to obtain the exothermic hydration curve. The hydration data were used to calculate compatibility factor, C_A, [27] and inhibitory index, I, [5]. The 24-h limit was chosen for practical reasons in order to limit the hydration test duration [24].

The used experimental design was the split-plot design [28]. The main plot was lignocellulosic materials, while treatments (pretreatments and chemical additives) were used as sub-plot, with three replicates. The results were analyzed using Statistical Analyses System [29]. The Least significant differences at 95% level of confidence ($LSD_{0.05}$) were used to detect the differences between means.

RESULTS AND DISCUSSION

The obtained results (T_{max} and t_{max}) and calculated (C_A and I) from the hydration test of date palm-cement and European redwood-cement mixtures are presented in Table (1). Since the main objective of this study was to evaluate the suitability of midribs date palm midrib fronds as a raw material for manufacturing wood-cement particleboard, in addition to improve their compatibility with cement, the obtained results will be discussed as follow:

Suitability of the Untreated Date Palm Midribs for WCP Industry: The statistical analysis of the current data revealed that all various hydration parameters of wood-cement mixtures differed between date palm and European redwood. Figure (1) shows the exothermic hydration curves of the untreated lignocellulosic materials with cement. It can be seen from this figure that each material

Table 1: Hydration data for the mixture of untreated date palm-cement mixture in comparison with European redwood-cement mixture and net cement

Mixture	T_{max} (°C)	t_{max} (hrs)	ΔT (°C)	R (°C/hr)	C_A (%)	I (%)
Date palm-cement	38.17^B	24.00^A	13.90^B	0.58^B	29.54^B	119.67^A
European redwood-cement	52.50^A	9.93^B	27.80^A	2.80^A	78.49^A	13.24^A
Net cement	83.60	6.28	59.20	9.43	100.0	0

Means with the same letters in the same column are not significantly differences at 5% level of probability according to LSD test

T_{max} : Maximum temperature. t_{max} : time to reach T_{max}.
ΔT : Rise in temperature above the ambient. R : Hydration rate.
C_A : Compatibility factor. I : Inhibitory index.

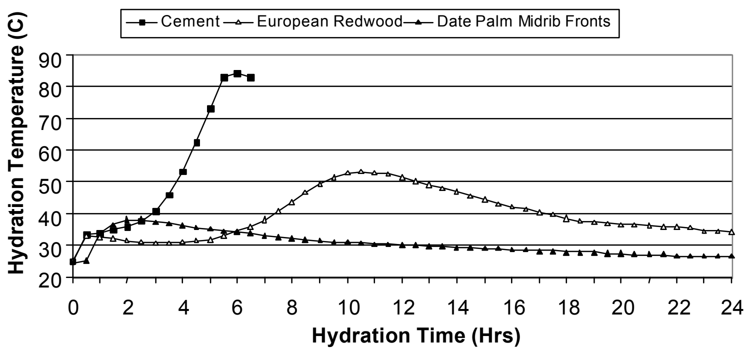

Fig. 1: Exothermic hydration curves of untreated date palm-cement and European redwood-cement mixtures without chemical additives comparing with net cement

reacted differently when mixed with cement. The extents to suppression temperature and t_{max} took place were measured for the retarding effect of the wood and non-woody lignocellulosic materials on cement setting. Wood which caused greater temperature depression is likely to be less suitable for WCP manufacture [30].

Comparing with net cement, the untreated lignocellulosic materials used in this study depressed the temperature rise and increased the time to reach maximum temperature during the setting process of cement (Table 1 and Fig. 1). European redwood (*Pinus sylvestris*) gave the higher T_{max} (52.50°C) and the lower t_{max} (9.93 hrs), while the lower T_{max} (38.17°C) and the higher t_{max} (24 hrs) were obtained from date palm midribs. According to these values, the former gave the higher C_A value (78.49%) and the lower I value (13.24%), while the latter gave the lower C_A and the higher I values (29.54 and 119.67 %, respectively). The values of the inhibitory index of untreated date palm was very high (119.67%) due to long t_{max} and low T_{max} of hydration.

Accordingly and based on the obtained results as well as the classifications of Sandermann and Kohler [15] and Hofstrand *et al*. [5] the midrib of date palm fronds are extremely inhibitory and can be classified as "unsuitable" and require special pretreatments to reduce their inhibitory characteristics with cement whereas European redwood could be grouped as least inhibitory and was classified as "suitable under limited conditions" for making WCP panels.

The differences in the compatibility between date palm and European redwood under untreated conditions can be attributed to the differences in cold and hot water soluble substances of wood, which is determined as solubility and the pH of their extracts as well as to the differences in the type and quantity of hemicelluloses. It can be said that *Pinus sylvestris* as softwood species with the xylans in its polyoses are different from the date palm as monocotyledons type of polyoses in its chemical structure. The obtained results for solubility and pH of the extracts (Table 2) are consistent with the hydration characteristics results of the untreated materials. Date palm particles contain the higher hot and cold water substances and the lower pH vales, whereas European redwood reacted differently (Table 2). Gnanaharan and Dhamodaran [7] reported that species with low acidic extract along with low cold water solubility will be suitable for wood-cement-wool board manufacture. These results are in agreement with the results of research carried out in other parts of the world [16, 30-31].

Effect of Some Treatments on the Compatibility of the Date Palm with Cement: The results of the analysis of variance revealed that the treatments used in the present investigation affected significantly all hydration parameters of wood-cement mixtures. In addition, the interaction of kind X treatments is significant. This means that under different treatment used, each lignocellulosic material reacted differently when mixed with cement.

Table 2: Chemical analysis of date palm midribs and European redwood used for wood-cement mixtures

Lignocellulosic Materials	% of total material weight				Hot water		Cold water	
	Total extractives	Cellulose	Hem-celllulose	Ash	Solubility (%)	pH	Solubility (%)	pH
Date palm	15.45^{A}	46.41^{B}	25.89^{A}	7.91^{A}	21.65^{A}	4.85^{B}	15.28^{A}	4.33^{B}
European redwood	6.65^{B}	53.47^{A}	16.99^{B}	0.30^{B}	6.03^{B}	5.70^{A}	3.13^{B}	5.87^{A}

Means with the same letters in the same column are not significantly differences at 5% level of probability according to LSD test

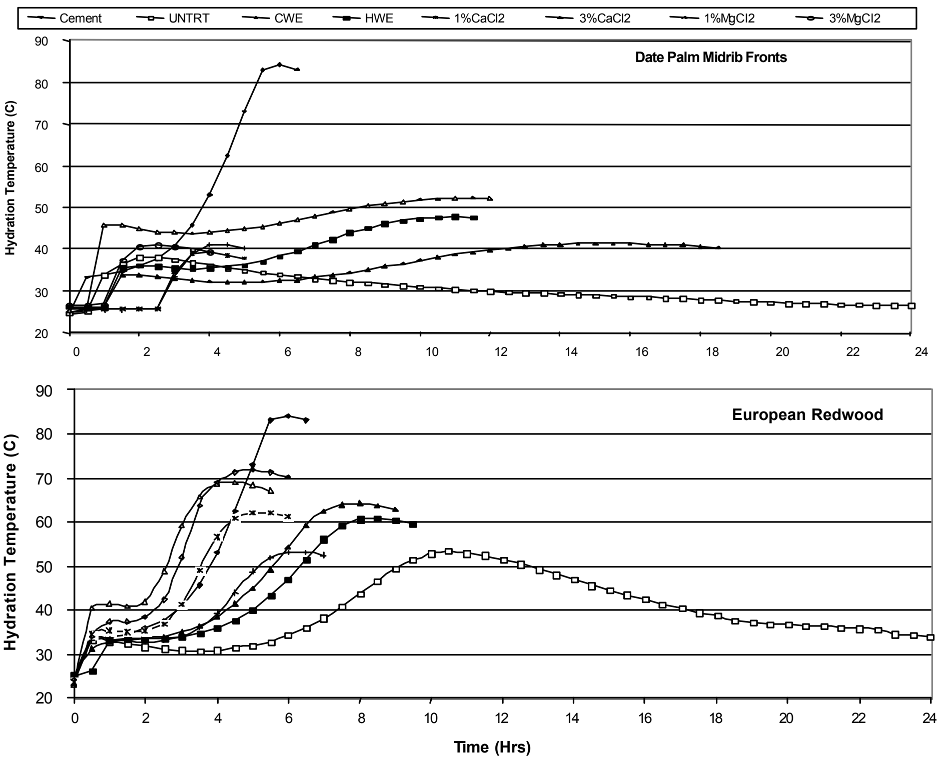

Fig. 2: Exothermic hydration curves of the mixtures of midribs date palm fronds and European redwood with cement under different treatments as compared to net cement. For legend see section of materials and methods

Figure (2) shows the effect of different treatments on hydration characteristics of the date palm and European redwood materials.

For each lignocellulosic material there was a certain combination among the seven treatments used in this study that produced the best result. Using of cold or hot water extraction for the two materials used resulted in an enhancement in their compatibility with cement depending on the types of materials under consideration. This enhancement can be noted by changes in the hydration curves (Fig. 2), increase in T_{max} and C_A values and decrease in t_{max} and I values of wood-cement mixtures (Table 3 and Fig. 2). There were very large variations in improvements which were obtained using cold or hot water extraction among the date palm and European redwood. Generally, enhancement obtained by hot water extraction was higher than in cold water extraction.

Effect of Pretreatments on the Compatibility: Under cold or hot water extraction and based on the classification of Sandermann and Kohler [15] and Okino *et al*. [21, 32], date palm particles were suitable under limited conditions only if they were treated with hot water since T_{max} is between 50 and 60°C (50.25°C) and C_A value is increased to reach 68.73%. No enhancement was obtained after extracted date palm particles by cold water. On the other hand, European redwood reclassified from suitable under limited conditions to suitable for making wood-cement board by using either cold or hot water extraction (Table 3). This improvement can be attributed to removal of sugars and other water-soluble substances from woody and non woody materials used, especially for date palm, which appear to be highly inhibitory to setting of cement in their natural state. These results are conformed in this study by the addition of cold or hot water extracts of

Table 3: Maximum temperature (T_{max}), time to reach maximum hydration temperature (t_{max}), inhibitory index (I) and compatibility factor (C_A) for the mixtures of date palm-cement and European redwood-cement as affected by some treatments

	Treatments						
Species	Wood	Additives	T_{max} (°C)	t_{max} (h)	I (%)	C_A (%)	Suitability*
Date palm	Untreated	None	38.17	24.00	119.67	27.85	Unsuitable
	CWE	None	41.10	13.57	54.30	27.75	Unsuitable
	HWE	None	50.25	11.43	28.78	68.73	SU
	Untreated	1%$CaCl_2$	39.83	24.00	77.79	30.48	Unsuitable
	Untreated	3%$CaCl_2$	54.23	11.89	28.28	75.83	SU
	Untreated	1%$MgCl_2$	42.27	24.00	66.95	41.45	Unsuitable
	Untreated	3%$MgCl_2$	40.93	24.00	75.82	28.29	Unsuitable
European	Untreated	None	52.50	9.93	13.24	78.49	SU
Redwood	CWE	None	59.83	7.99	4.34	81.74	Suitable
	HWE	None	62.67	8.23	4.41	86.44	Suitable
	Untreated	1%$CaCl_2$	63.67	5.04	-1.02	82.01	Suitable
	Untreated	3%$CaCl_2$	69.73	4.58	-0.56	90.52	Suitable
	Untreated	1%$MgCl_2$	55.37	6.23	-0.77	89.96	Suitable
	Untreated	3%$MgCl_2$	69.53	4.98	-0.39	92.94	Suitable
LSD0.05 for species*Treatments			2.13	3.64	11.88	5.93	
Net cement			83.60	6.28	0.00	100.00	

Each value represents the mean of three replications.

CWE : Wood extracted by cold water. HWE: Wood extracted by hot water

SU : Suitable under limited conditions. * According to Sandermann and Kohler [15]

For neat Portland cement: T_{max} (83.6°C), t_{max} (6.28 h), I (0) and C_A (100%)

(-) Negative I values due to lower t_{max} of neat cement than t_{max} of wood-ceme

these materials to cement. The inhibitory effect of these extracts on cement setting can be noted by the increase in t_{max} and I values and decrease in T_{max} (Fig. 3), ΔT and C_A values.

Effect of Chemical Additives on the Compatibility: With regard to the addition of either $CaCl_2$ or $MgCl_2$ (1 or 3% based on cement weight) to the mixture of cement and untreated date palm midribs and European redwood, it is obvious from Table (4) and Fig. 2 that each materials reacted differently with cement when added chemical additives to the mixtures. The highest T_{max} values were obtained for untreated European redwood-cement mixture after adding either 3% $CaCl_2$ or 3% $MgCl_2$ (69.73 and 69.53°C, respectively). Based on the classification of Sandermann and Kohler [15] and Okino *et al*. [21], date palm midribs were reclassified from unsuitable to suitable under limited conditions only if added $CaCl_2$, whereas European redwood was reclassified from suitable under limited conditions to suitable for making WCP by addition either $CaCl_2$ or $MgCl_2$ to untreated wood-cement mixtures. No improvements were achieved by adding 1% $CaCl_2$ or $MgCl_2$ (1 or 3% by cement weight).

Although, addition of chemical additives to wood-cement mixtures in the current study improved the compatibility with cement, these additives did not appear to have neutralized the detrimental effect of high inhibitory date palm midribs on exothermic reactions of cement. This statement is in agreement with Moslemi *et al*. [17] and Mohamed [30] who found that the addition of 3% $CaCl_2$ to the mixture slightly improved the maximum hydration temperature for the untreated cotton stalks and bagasse particles by 17.6% and 18.49%, respectively but in contradiction with Naser [33] who reported that among different types of chemical additives ($CaCl_2$, $FeCl_3$, $MgCl_2$ and NaOH), the addition of 3% $CaCl_2$ to untreated cotton stalks-cement mixture gave the lowest decrease in I values.

When chemical additives act as accelerators in the case of European redwood, the improvements in various hydration parameters obtained in the current study can be attributed to speed up the rate of hydration of plain cement without reacting with the wood substances when combined with low inhibitory materials or to provide a more suitable pH for setting the wood-cement mixtures [17]. These results are in agreement with those of

Zhengtian and Moslemi [31], Nasser [18], Mohamed [30] and Olorunnisola [34].

There is a certain combination among the seven treatments used in this study that produced the best result for each material used. In the case of European redwood, all treatments used in this study gave almost high improvements, but addition of either 3% $CaCl_2$ or 3% $MgCl_2$ to the untreated wood-cement mixtures gave the best results. However, out of the seven treatments used, the addition of 3% $CaCl_2$ to the untreated wood-cement mixtures showed the best results for date palm. Under this treatment, only date palm can be used for making wood-cement particleboard. Finally, it can be said that date palm midrib front particles were suitable to produce wood-cement particleboard only if particles were treated either with hot water extraction or with added 3% $CaCl_2$ to the mixture.

CONCLUSION

According to the obtained results from the current study, the following conclusions may be drawn:

- Date palm midrib fronds are extremely inhibitory and can be classified as "unsuitable" and require special treatments to reduce their inhibitory characteristics with cement, however European redwood was least inhibitory and classified as "suitable under limited conditions" for making WCP.
- The best treatments which proved effective for enhancing the compatibility of date palm midribs were either extraction with hot water or addition of 3% $CaCl_2$ as accelerator but we suggest the addition of 3% $CaCl_2$ to treated wood by hot water extraction which gave the best result.

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