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Testing and Enhancing The Compatibility of Five Saudi Wood Species for Cement-Bonded Particleboard Industry

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ABSTRACT

Cement-bonded particleboard (CBP) panels have excellent sound insulation, highly resistant to water and termites and are excellent for outdoor uses. However not all wood species react favorably with cement. Therefore, the present study was undertaken to test the suitability of some wood species that available in Saudi Arabia for CBP manufacturing. After testing, the study was designed to enhance the compatibility of these wood species with cement using different pretreatments and chemical additives. Buttonwood (*Conocarpus erectus*), lebbeck (*Albizia lebbeck*), Council tree (*Ficus altissima*), leucaena (*Leucaena leucocephala*), and Madras thorn (*Pithecellobium dolce*) were collected from Experiment Station near Dirab, Riyadh, Saudi Arabia. The results of this work were compared with the data were obtained from Scots pine (*Pinus sylvestris*). Portland cement (Type I) is manufactured by Al Yammama Cement Company was used as a binder. The hydration procedure was carried out using Dewar flask. Inhibitory index (I), hydration rate (R), and compatibility factor (C_A) were calculated from the hydration data. The results showed that under untreated condition, Scots pine and Buttonwood gave the highest maximum temperature (T_{max}), and the lowest time to reach maximum temperature (t_{max}), and they were compatible with cement and classified as "suitable under limited conditions" for making CBP, while the lowest T_{max} and the highest t_{max} were obtained for the rest wood species and they were classified as "unsuitable" and they require special treatments to reduce their inhibitory characteristics when mixed with cement. Using cold or hot water extraction for the six wood species resulted in an enhancement in their compatibility with cement. Under these pretreatments and with some expansions, all wood species used could be reclassified to “suitable under limited condition” for manufacturing CBP. Council tree and leucaena are still unsuitable for cement mixture since T_{max} is below 50 ^oC. Addition of either $CaCl_2$ or $MgCl_2$ to the mixture of cement and untreated wood improved the parameters and indices of hydration. All wood species used were reclassified from unsuitable or suitable under limited conditions to suitable for making CBP after treating by different treatments used in this work. Correlation coefficients of the hydration parameters are highly significant, therefore the three indices (C_A, R and I) can be used as suitable estimates for the compatibility of the wood-cement mixtures in the current study.

Key Words: Hydration, wood species, Portland cement, Inhibitory index, Cement-bonded particleboard.

INTRODUCTION

Growing demand of wood in the forest industries due to their rapid development has led to decline of wood supply. Many regions in the world have an acute shortage of wood and it has been very scarce (Vermass, 1981). Saudi Arabia as like many developing countries does not posses adequate forest reserves to cover their needs for fuel wood, industrial wood, sawn wood, and wood composite panels. In wood-based composite panels industry (including wood-cement particleboard) efforts are being intensified to find other suitable substitutes for wood. Apart from the utilization of tree thinning, fast growing trees and agricultural residues have been tried (Almeida *et al*, 2002, Mohamed, 2004, C?pür *et al*, 2007, Al-Mefarrej and Nasser, 2008).

Cement-bonded particleboard (CBP) as one type of mineral-bonded products has evolved as high density smooth surfaced boards with promising characteristics for exterior use or where fire resistance is needed. These panels contain 30-70% (by weight) wood particle and 30-60% mineral binder (Vaickelioniene and Vaickelionis, 2006). Wood wool slabs using magnisite as a binder were first produced but later Portland cement was introduced. The most important one of the binders is cement because of its high quality and availability virtually all over the world (Malony, 1987).

In wood industries and to avoid hitch free production, wood-cement particleboards are generally made from wood species which have been tested and proved suitable (Ajayi and Badejo, 2005). So that wood species from different countries have been screened, tested and classified according to their suitability for CBP production using varying methods and techniques

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(Hofstrand *et al*, 1984, Gnanaharan and Dhamodaran, 1985, Yasin and Qurashi, 1990, Semple *et al.*, 2002 and Al-Mefarrej and Nasser, 2008).

CBP panels have excellent sound insulation, highly resistant to water and termites, and excellent for outdoor uses which lead to their wider potential applications for replacing traditional building materials and conventional wood composites (Wei and Tomita, 2001) as roofing, wall, flooring parts, and noise absorbing partitions.

The ability of wood to combine with Portland cement (compatibility) can be measured by testing the exothermic behavior during the hydration process (Hachmi *et al*, 1990, and Semple *et al.*, 2002) or by measuring some strength properties of wood–cement mixtures (Miller and Moslemi, 1991, and Papadopoulos, 2008). However, hydration characteristics have been commonly used to assess the compatibility with cement of potential wood species. Suitability of these species was classified based on the extent to which they retarted cement hydration using maximum temperature (T_{max}), compatibility factor (C_A) and inhibitory index (I) according to Sandermann and Kohler (1964), Hachmi and Moslemi (1989), and Okino *et al.* (2004).

Previous studies revealed that not all wood species react favorably with cement due to adverse effects of certain extractives on cement setting. These species are not suitable for the manufacture of CBP (Miller and Moslemi, 1991, and Al-Mefarrej and Nasser, 2008). To overcome this problem, many investigators carried out series of tests to enhance the compatibility of wood and cement by using some pretreatments and chemical additives. Cold and hot water extraction are among the common pretreatments used to extract the inhibitory substances in wood (Mohamed, 2004, and Olorunnisola, 2008). Some researchers carried out a series of tests designed to improve the compatibility of wood-cement mixtures by addition of some chemicals such as calcium chloride, sodium hydroxide… etc. Calcium chloride is one of the chemical additions widely used as accelerator of cement setting (Zhengtian and Moslemi, 1985, Fernandez and Taja-on, 2000, and Okino *et al*, 2007). These treatments are relatively cheap and easy to use.

For CBP industry, the first step in assessing the suitability of different wood species for use in CBP panels involves testing whether the wood significantly inhibits the hydration reaction of Portland cement or not. Therefore, the present study was undertaken to test the suitability of some wood species that available in Saudi Arabia for CBP manufacturing. Thereafter, the study was designed to enhance the compatibility of these wood species with cement using different pretreatments and chemical additives to remove or equalize the effect of extractives and water-soluble substances of wood.

MATERIALS AND METHODS

The raw materials of wood-cement particleboard for the present work were wood, Portland cement (as a binder) and water. Five locally grown wood species were used including lebbeck (*Albizia lebbeck* L.), buttonwood (*Conocarpus erectus* L.), Council tree (*Ficus altissima*), leucaena (*Leucaena leucocephala*), and Madras thorn (*Pithecellobium dolce*). Trees were randomly selected from a previous plantation trees planted in October 2002 at the Agricultural Experimental Station near Derab, 35 km south Riyadh, Saudi Arabia. In order to facilitate grinding into meal, wood were air-dried then reduced to small pieces, then hammer milled using prototype hammer mill and then particles were screened. Wood meal (20-40 mesh screens) was used for hydration test, while that meal (40-60 mesh screen) was used for wood chemical analysis. Commercial ordinary Portland cement (Type I), meeting ASTM C150-84 specification (1984), and is manufactured by Al-Yammama Cement Company was used.

Two chemical addition were used in the present work, namely calcium chloride dehydrate ($CaCl_2$. $2H_2O$) and magnesium chloride ($MgCl_2$) at 3% of cement weight. Additions were dissolved in distilled water at least 15 minutes before added to wood-cement mixture.

Cold and hot water treatments

To enhance the compatibility of wood species with cement, cold and hot water extraction were used according to Moslemi *et al.* (1983) with some modification for removing extractives and soluble water substances (for more details see Al-Mefarrej and Nasser, 2008). Cold and hot water solubilities were calculated and the pH of their extracts was measured using pH meter.

Chemical analysis of wood

Percentage contents of Cellulose, hemicellulose, lignin, total extractives and ash were determined for each wood species according to the standard methods (ASTM D-1037, 1989).

Hydration procedure

The hydration procedure was carried out according to Hofstrand *et al.* (1984) using a two litter Dewar flask (for more details see Al-Mefarrej and Nasser, 2008). All experiments were carried out at an ambient room temperature between 20-23 ^oC. Three replications for each mixture were prepared. Exothermic hydration curve was obtained by plotting the time and temperature readings. Hydration data were recorded for each curve to calculate three indices, namely compatibility factor (C_A, %), inhibitory index (I, %), and hydration rate (R, $C.h^{-1}$) according to Hachmi *et al*. (1990), Hofstrand *et al*. (1984), and Semple *et al* (2002), respectively. Wood/cement ratio by weight was 1/13.3 (Weatherwax and Tarkow, 1967). The 24-h limit was chosen for practical reasons in order to limit the hydration test duration (Okino *et al.*, 2004).

Results of this work were compared with the data obtained from the mixture of cement and Scots pine (*Pinus sylvestris*), a species that is suitable for the manufacture of wood-cement composites (Nasser, 1996).

The results of the current study were analyzed using Statistical Analyses System. Least significant differences at 95% level of confidence ($LSD_{0.05}$) were used to test the differences among wood species and treatments means as well as the interaction among them (Steel and Torrie, 1989).

RESULTS AND DISCUSSION

Suitability of the wood species for CBP industry

Mean values of hydration data (t_{max}, T_{max}, ΔT, R, I, and C_A) for wood-cement mixtures made of the six wood species under untreated conditions are presented in Table 1. Analysis of variance revealed that various hydration data of the wood-cement mixtures differed from species to species. Fig. 1 illustrates the effects of various wood species on the hydration exothermic curves of Portland cement. This figure indicated that each species reacted differently when mixed with cement.

Table 1. Hydration data* for wood-cement mixtures studied

Wood Species	Symbol	t_{max} (hrs)	T_{max} (°C)	ΔT (°C)	R (°C.h^{-1})	C_A (%)	I (%)
Lebbeck	**AL**	24.0	31.03	8.37	0.35	17.67	118.49
Buttonwood	**CE**	15.06	50.57	24.80	1.65	51.95	44.39
Council tree	**FA**	24.0	35.40	13.13	0.55	22.70	109.98
Leucaena	**LL**	24.0	35.43	12.70	0.53	19.05	109.83
Madras thorn	**PD**	24.0	32.73	10.97	0.46	19.87	119.56
Scots pine	**PS**	9.93	52.50	32.32	3.25	58.98	13.23
Cement	**C**	**6.28**	**84.30**	**59.20**	**9.43**	**100**	**0**

*Each value represents the average of three replications.

T_{max}: Maximum temperature; t_{max}: time to reach T_{max}; ΔT: rise in temp. above ambient
R: hydration rate; C_A: compatibility factor; I: inhibitory index

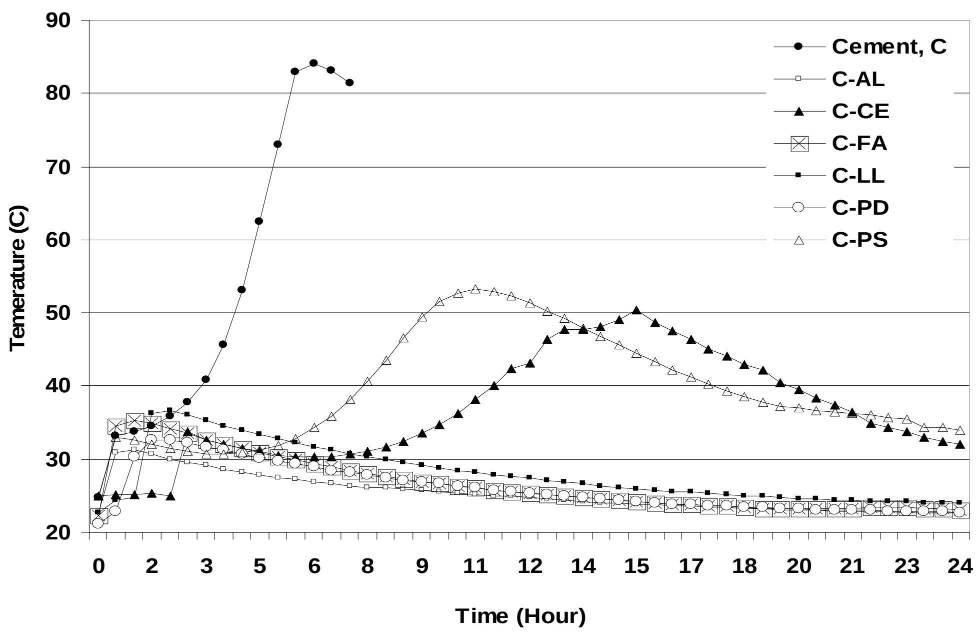


Fig. 1. Effects of wood species on exothermic hydration reaction of Portland cement

(Fore legend see Table 1)

It can be noted from Table (1) and Fig. (1) that the addition of untreated wood to cement severely reduced all various hydration parameters. This means that all wood species used in the present work inhibit the setting of cement by decreasing maximum temperature, hydration rate, and compatibility factor and increasing time to reach maximum temperature and inhibitory index. The extent to which the wood retarded the hydration of Portland cement varied with wood species. These results indicated that the wood in the mixture exerted a certain inhibitory influence on the cement setting. These results are in agreement with Almeida *et al* (2002), Semple *et al* (2002), and Al-Mefarrej and Nasser (2008).

Scots pine and buttonwood have the highest T_{max} values (52.50 and 50.57 ^oC, respectively) and the lowest t_{max} values (9.93 and 15.06 hrs, respectively), while the remaining four wood species were similar and have the lowest T_{max} and the highest t_{max} (24 hrs). According to these values, Scots pine and buttonwood gave the highest C_A (58.98 and 51.95%, respectively) and the lowest I values (13.23 and 44.39%, respectively). The values of the inhibitory index (I) of untreated lebbeck and Madras thorn were very high (118.49 and 119.56%, respectively) due to long t_{max} and low T_{max} of hydration. The same I value was obtained for Council tree and leucaena (109.98 and 109.83%, respectively). Comparing with Scots pine, it can be said that the compatibility indices were higher than those of all wood species used (Table 1).

According to the above results as well as the results of Hofstrand *et al.* (1984) and Sandermann and Kohler (1964) Scots pine and buttonwood are the least inhibitory on cement setting and was classified as "suitable under limited conditions" for making CBP, whereas the other four wood species (Madras thorn, lebbeck, leucaena, and Council tree) are extremely inhibitory and can be classified as "unsuitable", so using these species for CBP will require special treatments to reduce their inhibitory characteristics with cement.

The above-mentioned differences in the compatibility of various wood species under untreated condition can be attributed to the differences in one or more of the following chemical constituents: 1) cold and hot water soluble substances of wood. Since buttonwood and Scots pine contain the lowest cold and hot water-soluble substances (Table 2). Their compatibility was higher than those of the rest wood species that posses higher water soluble substances. These results are in agreement with the results carried out in parts of the world (Hachmi and Moslemi 1989, Nasser 1996, Semple *et al* 2002 and Al-Mefarrej and Nasser 2008). 2) the pH values of the cold and hot water extracts can be also used to explain differences among compatibility of wood species with cement. The obtained results for solubility and pH of the extracts (Table 2) are consistent with the hydration characteristics results of the untreated materials. Species with higher solubility (cold or hot water) and acidic extract i.e., lebbeck and Madras thorn, gave lower compatibility with cement than those species with lower solubility contents and higher pH values i.e., Scots pine and buttonwood. Gnanaharan and Dhamodaran (1985) 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 Jai and Chen (1977), Zhengatian and Moslemi (1989) and Mohamed (2004).

Enhancing the compatibility of wood-cement mixtures using pretreatments

To enhance the compatibility of some wood species which appeared as highly inhibitory to cement setting, some pretreatments and chemical additions were used. 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. Using cold or hot water extraction for the various wood species resulted in an enhancement in their compatibility with cement depending on the types of wood under considered. This enhancement can be noted by changes in the hydration curves, 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).

Table 2. Chemical analysis of wood species used for wood-cement mixtures

Wood Species	% of				Hot water		Cold water	
	Cellulose	Hemcel	Lignin	Ash	Solubility	pH	Solubility	pH
Lebbeck	48.65^C	25.80^A	24.42^E	2.65^B	15.91^A	4.77^B	9.49^C	5.10^C
Buttonwood	47.41^D	20.90^B	27.81^D	2.63^B	11.07^D	4.93^B	6.25^E	5.36^B
Council tree	49.77^B	11.27^D	36.55^A	3.37^A	14.12^B	5.06^B	7.10^D	5.09^C
Leucaena	49.34^B	20.79^B	27.49^D	2.12^C	15.37^A	4.81^B	10.53^B	5.04^C
Madras thorn	44.38^E	19.70^B	33.53^B	3.49^A	13.94^C	4.71^B	11.16^A	4.16^D
Scots pine	53.47^A	16.99^C	28.55^C	0.30^D	6.05^E	5.70^A	3.13^F	5.87^A

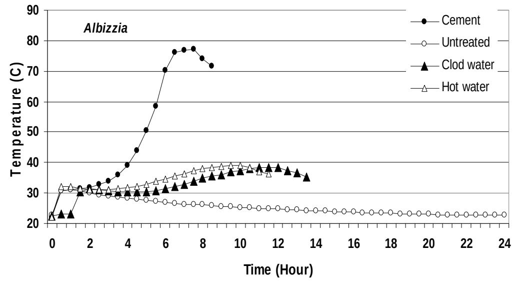
*Each value represents the average of five replications.

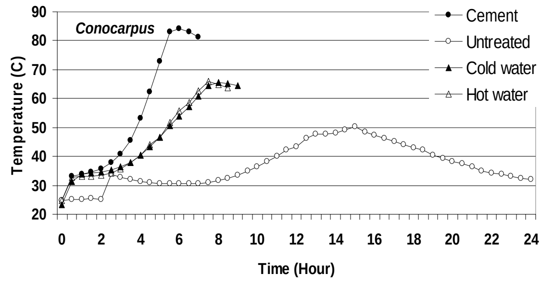
Means with the same letters in the same column are not significantly differences at 5% level of probability.

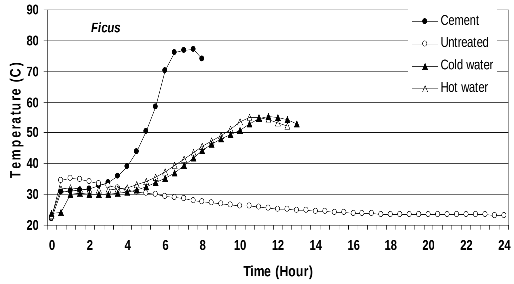
Table 3. Hydration data of wood-cement mixtures as affected by pretreatment of wood

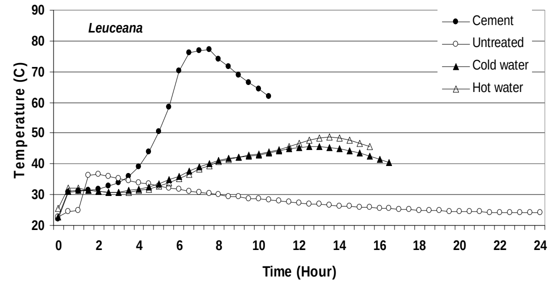
Wood Species	Treatments	t_{max} (hrs)	T_{max} (^oC)	ΔT (^oC)	R ($^oC.h^{-1}$)	C_A (%)	I (%)
Lebbeck	Untreated	**24.0**	**31.03**	**8.37**	**0.35**	**17.17**	**118.49**
	Cold water	15.06	37.30	15.80	1.05	42.45	48.21
	Hot water	12.63	39.00	16.83	1.33	47.96	30.94
Buttonwood	Untreated	**15.06**	**50.57**	**24.80**	**1.65**	**51.95**	**44.39**
	Cold water	8.17	64.87	41.83	5.12	77.84	4.21
	Hot water	7.33	69.40	46.57	6.36	82.60	1.41
Council tree	Untreated	**24.0**	**35.40**	**13.13**	**0.55**	**22.70**	**109.98**
	Cold water	12.11	55.97	32.10	2.65	65.11	13.19
	Hot water	11.11	53.70	30.67	2.77	62.87	11.61
Leucaena	Untreated	**24.0**	**35.43**	**12.70**	**0.53**	**19.05**	**109.83**
	Cold water	12.21	44.17	21.13	1.73	69.93	25.05
	Hot water	13.33	47.20	23.50	1.77	61.27	27.69
Madras thorn	Untreated	**24.0**	**32.73**	**10.97**	**0.46**	**19.87**	**119.56**
	Cold water	14.56	58.03	35.43	2.44	62.39	14.44
	Hot water	11.28	51.17	28.40	2.52	60.72	13.66
Scots pine	Untreated	**9.93**	**52.50**	**27.32**	**2.80**	**58.98**	**13.23**
	Cold water	7.99	59.83	35.27	4.42	81.74	4.34
	Hot water	8.23	62.67	37.97	4.61	86.43	4.40
Cement		**6.28**	**84.30**	**59.20**	**9.43**	**100**	**0**

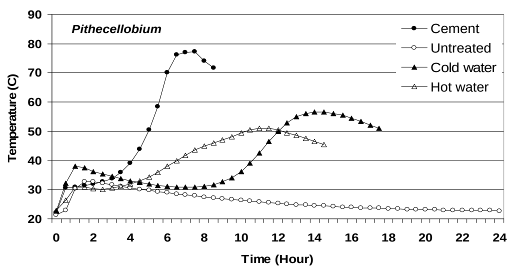
*Each value represents the average of five replications. For legend see Table 1.











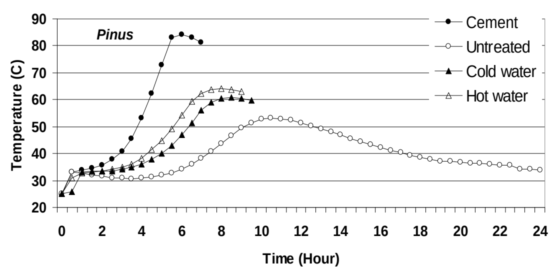


Fig. 2. Exothermic reaction of Portland cement as affected by cold and hot water extraction

There were very high variations in improvements which were obtained using cold or hot water extraction among the four materials. Generally, enhancement was obtained by hot water extraction was higher than that of cold water extraction. Based on the classification of Sandermann and Kohler (1964) and Okino *et al.* (2004), Scots pine and buttonwood were reclassified from suitable under limited conditions to suitable for making wood-cement boards under cold or hot water extraction (T_{max} values were above 60 ^oC), whereas Council tree and Madras thorn were reclassified from unsuitable to suitable under limited conditions (T_{max} values were between 50 and 60 ^oC). Lebbeck and leucaena are still unsuitable under these conditions (Table 3).

According to T_{max}, C_A and I values of wood-cement mixture, the lowest enhancements were obtained from treated lebbeck with either cold or hot water extraction (Table 2). It can be said that this species is still unsuitable for cement mixtures after treating by either cold or hot water extraction, where T_{max} is still below 50 ^oC (37.50 and 39.00 ^oC, respectively). The improvement in the compatibility after cold or hot water extraction can be attributed to removal of sugars and other water-soluble substances from woody materials used. These results are conformed in this study by the higher water-soluble substances content of lebbeck and leucaena as compared to that of buttonwood and Scots pine (Table 2). These results are in agreement with the results reported by many investigators (Moslemi *et al*., 1983, Gnanaharan and Dhamodaran, 1985, Nasser, 1996, Mohamed, 2004 and Al Mefarraj and Nasser, 2008). With exception to lebbeck and leucaena, cement-bonded particleboard can be made from the wood species used after either cold or hot extraction. It can be seen that the large variations in hydration parameters among the five wood species used and Scots pine were reduced when wood was treated by either cold or hot water extraction (Table 3).

Enhancing the compatibility of wood-cement mixtures using chemical additions

Chemical additions are widely used in CBP as accelerators to accelerate the cement setting. Two common additions, 3% by weight of $CaCl_2$ or $MgCl_2$ were added to the mixture of cement and untreated wood. It is obvious from Table (4) that each wood species reacted differently with cement when chemical additive was added to the mixtures. The highest T_{max} values were obtained for buttonwood-cement mixture after adding either $CaCl_2$ or $MgCl_2$ (75.80 and 79.07 ^oC, respectively), while the lowest values were obtained after adding $CaCl_2$ for wood-cement mixtures in the case of lebbeck, leucaena and Madras thorn.

Based on the classification of Sandermann and Kohler (1964) and Okino *et al.* (2004) all wood species used were reclassified from unsuitable or suitable under limited conditions to suitable for making CBP by addition $MgCl_2$ to wood-cement mixtures. The same results were obtained after adding 3% of $CaCl_2$ to wood-cement mixtures containing either buttonwood or Council tree (T_{max} values were above 60 ^oC) and these species were reclassified from unsuitable to suitable, however the rest three wood species were reclassified from unsuitable to suitable under limited condition (T_{max} values were between 50 to 60 ^oC) as shown in Table (4) and Fig. (3).

It can be seen from the above results that chemical additions used in the present study act as accelerators. 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 species or to provide a more suitable pH for setting the wood-cement mixtures (Moslemi *et al*., 1983). These results are in agreement with Zhengtian and Moslemi (1989), Mohamed (2004), Olorunnisola (2007) and Al Mefarraj and Nasser (2008). It can be concluded that regarding Scots pine, there were very large variations in hydration parameters among the studied wood species, however, these variations were reduced when chemical additions were added to the mixture.

Among the five treatments used in this study there was a certain combination that produced the best result for each wood species. For all wood species, any treatment used gave almost high improvements but addition 3% of either $CaCl_2$ or $MgCl_2$ to the untreated wood-cement mixtures gave the best results. Cement-bonded particleboard can be made from the wood species used after either cold or hot extraction which gave high enhancement. Out of the five treatments used in this study, the addition of chemical substances to the untreated wood-cement mixtures showed better results for all the wood species used and the addition of $MgCl_2$ gave the best enhancement.

Relationship between hydration parameters of wood-cement mixtures

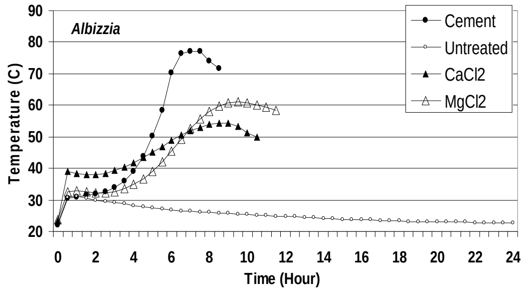
Table (5) shows the correlation coefficients matrix of hydration parameters of wood-cement mixtures made of the six wood species under different conditions. It can be seen from the table that all correlation coefficients were highly significant except the relation between inhibitory index (I) and hydration rate (R) which was significant. The correlations among the three indexes

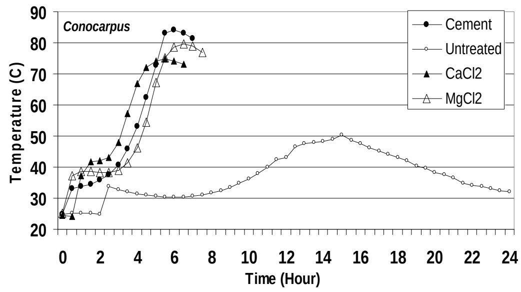
Table 4. The effects of chemical additions on hydration data of wood-cement mixtures

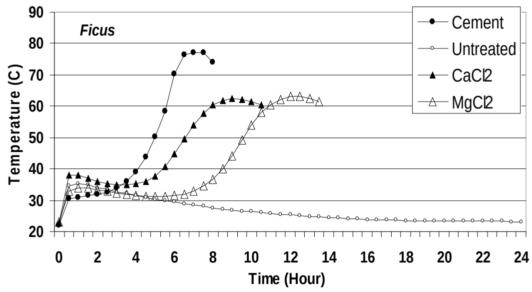
Wood Species	Treatments*	t_{max} (hrs)	T_{max} (^oC)	ΔT (^oC)	R ($^oC.h^{-1}$)	C_A (%)	I (%)
Lebbeck	Untreated	**24.0**	**31.03**	**8.37**	**0.35**	**17.67**	**118.49**
	3% $CaCl_2$	8.50	53.90	30.83	3.63	73.89	3.28
	3% $MgCl_2$	9.71	60.23	36.70	3.78	81.27	4.32
Buttonwood	Untreated	**15.06**	**50.57**	**24.80**	**1.65**	**51.95**	**44.39**
	3% $CaCl_2$	5.39	75.80	51.10	9.49	87.42	-0.01
	3% $MgCl_2$	6.22	79.07	54.63	8.79	90.69	-0.01
Council tree	Untreated	**24.0**	**35.40**	**13.13**	**0.55**	**22.70**	**109.98**
	3% $CaCl_2$	11.33	61.10	38.90	3.43	77.66	5.85
	3% $MgCl_2$	12.22	62.63	39.53	3.23	76.44	6.09
Leucaena	Untreated	**24.0**	**35.43**	**12.70**	**0.53**	**19.05**	**109.83**
	3% $CaCl_2$	8.23	57.27	35.167	4.28	70.39	1.710
	3% $MgCl_2$	5.67	70.80	48.07	8.49	67.00	-0.79
Madras thorn	Untreated	**24.0**	**32.73**	**10.97**	**0.46**	**19.87**	**119.56**
	3% $CaCl_2$	13.43	57.50	34.83	2.59	70.40	12.98
	3% $MgCl_2$	16.12	60.83	38.00	2.36	67.00	13.29
Scots pine	Untreated	**9.93**	**52.50**	**27.32**	**2.80**	**58.98**	**13.23**
	3% $CaCl_2$	4.58	69.73	45.57	9.95	90.52	-0.56
	3% $MgCl_2$	4.98	69.53	45.83	9,21	92.42	-0.39
Cement		**6.28**	**84.30**	**59.20**	**9.43**	**100**	**0**

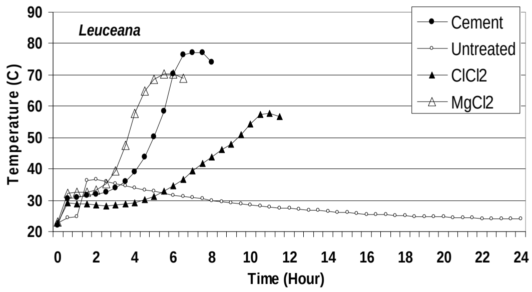
Each value represents the mean of three replications.

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









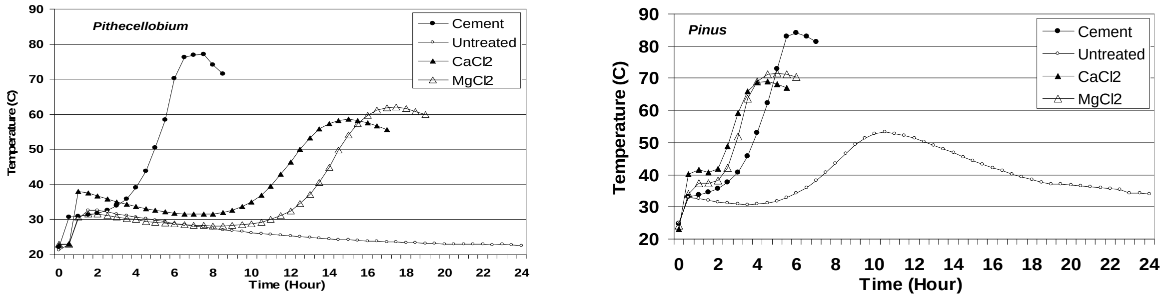


Fig. 3. Hydration curves of wood-cement mixtures as affected by chemical additions

were highly significant. This means that the three indices can be used as suitable estimates for the compatibility of the wood-cement mixtures. Figures 4 to 7 indicated that there were relatively strong positive correlation between

C_A and T_{max} (r= 0.89), however the strong negative correlations were found between C_A and each of t_{max}, and I (r= -0.92 and -0.94, respectively). These results are in agreement with those of Nasser (1996), and Olorunnisola (2008).

CONCLUSIONS

Based on the results of the current study on the compatibility of some wood species with cement and its enhancing, the following conclusions are drawn:

1- Under untreated conditions, buttonwood and Scots pine showed the same behavior in hydration characteristics, while other wood species behaved differently.
2- Scots pine and buttonwood were the least inhibitory and classified as "suitable under limited conditions" for making CBP.
3- Council tree, lebbeck, leucaena and Madras thorn are extremely inhibitory and can be classified as "unsuitable"and require special treatments to reduce their inhibitory characteristics with cement.
4- Treating wood by hot water extraction and/or adding 3% of MgCl2 based on cement weight are the best treatments for improving the compatibility with cement.
5- Large variations in improvements were obtained by using cold or hot water extraction among the six wood species used.
6- Variations in hydration parameters among the wood species were reduced when chemical additions were added to the mixture of wood, cement and water.
7- All wood species used were reclassified from unsuitable or suitable under limited conditions to suitable for making cement-bonded panels (CBP) after treating by different treatments used in this work.
8- All correlation coefficients of hydration parameters are highly significant therefore the three indices (C_A, R and I) can be used as suitable estimates for the compatibility of the wood-cement mixtures.

Table 5. Correlation coefficients matrix among hydration parameters

	$.t_{max}$	**C_A**	R	I
T_{max}	-0.85**	0.89**	0.88**	-0.83**
$.t_{max}$		-0.92**	-0.82**	0.92**
C_A			0.75**	-0.94**
R				-0.64*

*Correlation coefficients are significant at 0.05 level of probability.
**Correlation coefficients are significant at 0.01 level of probability.
For legend see Table 2.

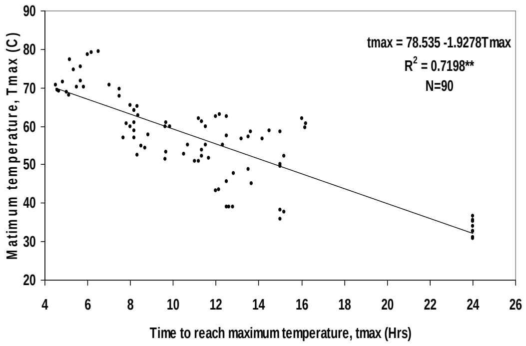


Fig. 4. Correlation between T_{max} and t_{max}.

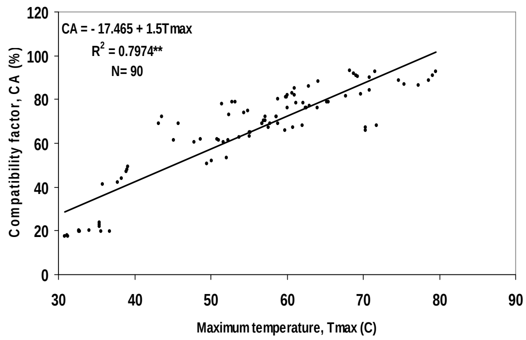


Fig. 5. Correlation between C_A and T_{max}.

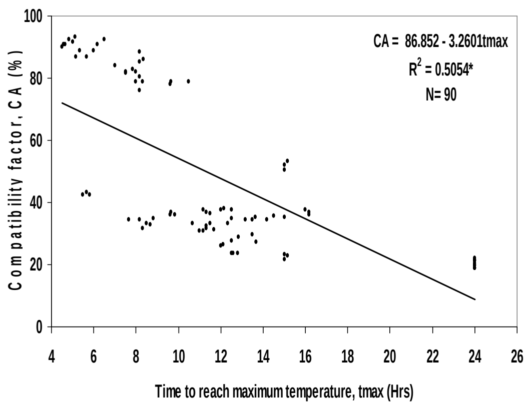


Fig. 6. Correlation between C_A and t_{max}.

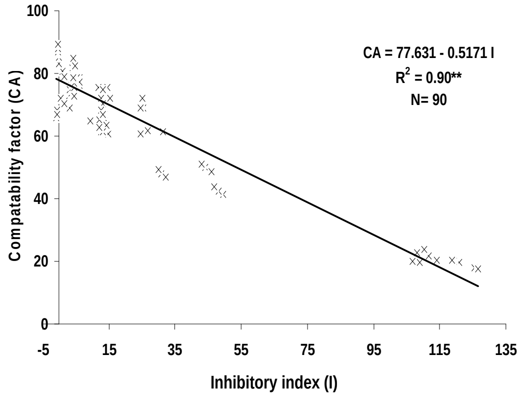


Fig. 7. Correlation between C_A and I.

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الملخص العربي

اختبار وتحسين توافق خمسة أنواع من الأخشاب السعودية لصناعة الخشب الحبيبي الأسمنتي

حمد بن عبد المحسن المفرج

تمتاز الواح الخشب الحبيبي الأسمنتي بالعزل الصوتي، ومقاومتها العالية للرطوبة والنمل الأبيض كما أنها تستخدم في الاستعمالات الخارجية بصورة ممتازة. ومع ذلك لا تتفاعل كل الأنواع الخشبية بصورة جيدة مع الأسمنت. لذا أجريت تلك الدراسة على اختبار مدى توافق بعض الأنواع الخشبية المتاحة في المملكة العربية السعودية لصناعة الخشب الحبيبي الأسمنتي. وبعد اختبار تلك الأنواع استخدمت بعض المعاملات والإضافات الكيميائية لتحسين توافق تلك الأنواع مع الأسمنت. استخدمت في تلك الدراسة خمسة أنواع خشبية هي اللبخ (*Albizia lebbeck*)، الكونوكاربس (*Conocarpus erectus*)، الفيكس التسيما (*Ficus altissima*)، الليوسينا (*Leucaena leucocephala*) واللوز الهندي (*Pithecellobium dolce*) والتي جمعت من محطة الابحاث الزراعية بديراب-كلية علوم الأغذية والزراعة-جامعة الملك سعود، الرياض واستخدمت أخشاب السويد (*Pinus sylvestris*) لاغراض المقارنة. استخدم الأسمنت البورتلاندي العادي (Type I) كمادة لاصقة من إنتاج شركة أسمنت اليمامة بالمملكة العربية السعودية. واجريت تجربة تشرب للأسمنت فقط وخليطه مع أخشاب تلك الأنواع باستخدام الـــ Dewar flask تم تسجيل بيانات التشرب للأسمنت وخليطه مع الخشب ومن تلك البيانات تم حساب معامل التثبيط (I)، معدل التشرب (R) ومعامل التوافق (C_A). اوضحت النتائج أنه تحت ظروف الكنترول (بدون معاملات أو إضافات كيميائية)، يعطي خليط الخشب والاسمنت الناتج من الكونوكاربس أو السويد أعلى درجة حرارة (T_{max}) واقل زمن (t_{max}) ويعتبرا من الأنواع المتوافقة تحت ظروف محددة لصناعة الخشب الأسمنتي وعلى العكس تماماً من ذلك كانت باقي الأنواع الخشبية المستخدمة غير متوافقة لتلك الصناعة وتحتاج إلى بعض المعاملات أو الإضافات لتقليل التأثير التثبيطي لها عند خلطها بالأسمنت. عملية الاستخلاص بالماء البارد أو الساخن نتج عنها تحسين توافق تلك الأنواع مع الأسمنت باستثناء اللبخ والليوسينا إذ ما زالا غير متوافقين تحت تلك المعاملة. وتحت تلك المعاملات أصبح الكونوكاربس "متوافقاً" بينما الفيكس واللوز الهندي أنواع "متوافقة تحت ظروف محددة". حدث تغير في مقاييس التشرب ومعاملي التثبيط والتوافق نتيجة إضافة أي من كلوريد الكالسيوم أو كلوريد المغناسيوم بنسبة ٣% من وزن الأسمنت لخليط الخشب والأسمنت تبعاً للنوع الخشبي المستخدم وادى إضافة كلوريد المغناسيوم إلى نتائج أفضل. أصبحت جميع الأنواع الخشبية متوافقة مع إضافة اي من الإضافات الكيميائية إلى خليط الخشب والأسمنت مع جميع الأنواع الخشبية المستخدمة. أوضحت معاملات الارتباط (R) ان هناك ارتباط معنوي بين الدلائل الثلاثة للتشرب (الـــ C_A، الـــ R و الـــ I) والمستخدمة في تلك الدراسة لتحديد درجة توافق الأنواع الخشبية مع الأسمنت مما يشير إلى أنه يمكن استخدام أي منها لتحديد توافق تلك الأنواع مع الأسمنت.