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Korean Lignocellulosics and Portland Cement as a Structural Material[1]

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건축재로 국산목질과 포틀랜드 시멘트[1]

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要 約

한국식목질과 포틀랜드 시멘트(Type I)로 건축재개발가능성을 구명하기 위하여 소나무, 리기다 소나무, 잣나무, 일본잎갈나무, 현사시나무 목질과 왕겨 및 볏짚과 포틀랜드 시멘트 그리고 물과 혼합하여 24시간동안 수화열을 측정하고 수화억제지수를 산출한 바 리기다 소나무와 소나무가 한정된 조건하에서 목질-시멘트 복합체에 적절한 수종이며, 열수추출 수행하면 경화억제지수가 개선되어 왕겨, 잣나무, 일본잎갈나무는 한정된 조건하에 적절한 수종이고 열수추출과 경화촉진제와 염화칼슘이나 염화마그네슘을 겸용하면 현사시나무 일본 잎갈나무도 리기다 소나무와 아울러 우수한 수종으로 판명되었다.

Summary

In order to investigate the inhibitory index (I) and the effects of hot water extraction treatments and addition of accelerators on the index in hardening of Korean lignocellulosics, portland cement (Type I) and water system, hydration tests were carried out on 8 Korean lignocellulosics, namely, *Pinus densiflora, Pinus rigida, Pinus koraiensis, Abies holophylla, Larix leptolepis, Populus alba-glandulosa,* rice husk and rice stalk with or without hot water extraction or chemical additives. The inhibitory index of *Pinus densiflora* and *Pinus rigida* found to be suitable under limited conditions for composite without any treatment. With hot water treatment rice husk, *Pinus koraiensis, Larix leptolepis,* and *Abies holophylla* were reclassified from not suitable to suitable under limited conditions. Combining hot water extraction with chemical addition of accelerator, calcium chloride or magnesium chloride, *Populus alba-glandulosa, Larix leptolepis,* and *Pinus rigida* became highly suitable.

Introduction

The Korean forest products industry is a major factor in the overall economic activities in the Republic of Korea. The annual sales for this in-

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[1] Received for publication on August 16, 1984. This document is intended as the report of the cooperative project between the Seoul National University and the University of Idaho. The project was supported by the Korea Science and Engineering Foundation (KOSEF) and the National Science and Foundation (NSF, U.S.). This report presents the results of this cooperative study delineating the potential of using a variety of Korean lignocellulosics for cement-bonded strucural materials. The original research data were collected in the laboratories of the Department of Forest Products and Technology at the Seoul National University, Suwon, Korea.

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dustry exceeded $4 billion in 1983. The industry, however, heavily depends on the import of its raw material. In 1982, over 80 percent of the total raw material requirement was imported primarily from southeast Asia, United States, and New Zealand.*

Korean domestic forest resources are limited. These forests are divided into subtropical, temperate and subarctic forests. These resources in Korea include such species as Japanese larch (*Larix leptolepis*), fir (*Abies holophylla*), and several species of pine (*Pinus densiflora, Pinus koraiensis* and *Pinus rigida*) (see Figure 1 for a general forest type map of the Korean peninsula).[3] A significant portion of these coniferous forests in Korea are composed of small diameter trees in plantations. In addition to the species indicated, there are many plantations of poplar (*Populus alba · glandulosa*) which generally grow very rapidly. Other biomass sources of potential consideration in Korea are rice husk and rice straw. However, the major question centers around whether or not these resources can effectively be incorporated into a panel product which could be utilized in Korea and have the potential of being exported to other nations.

The cement-bonded structural material using such biomass possesses a number of advantages for low-cost housing in Korea and elsewhere. They would be highly fire-resistant, could easily be applied to structural applications, are easily machineable with common wood-working tools, are highly resistant to insect and rot attack and can stand the rigor of outdoor exposure.

The primary concern will be whether or not the lignocellulosic species would be compatible with the cement binder. This is due to the fact that cement is discriminatory to lignocellulosic species, bonding well with some while it is not compatible with others based on prior research.[9,13,16] Therefore, the focus of this cooperative research has involved the determination of compatibility of the particular Korean biomass with cement based on hydration experiments. The resolution of this compatibility question constitutes a major factor in the further development of this technology.

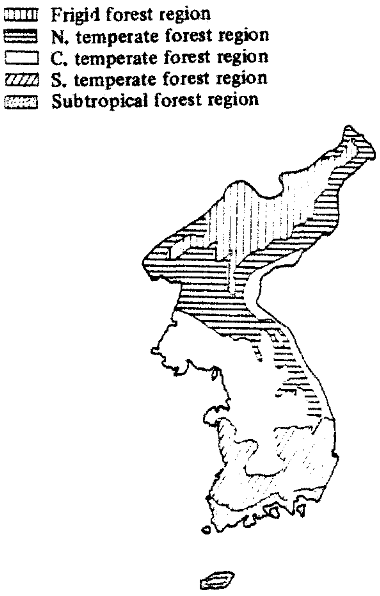

Fig. 1. Distribution of forest types in the Korean peninsula.

Sandermann *et al.*[17] concluded that the adverse impact of wood on cement is governed by a variety of factors including geographic location, felling season, tree species and a variety of wood components. Weatherwax and Tarkow[19,20] have shown that the presence of bark, decayed wood and certain wood carbohydrates are particularly detrimental to the setting of cement. Other recent studies show that water soluble extractions have a major impact on hydration characteristics of wood-cement mixtures.[11] In some cases, the lignocellulosic influence on the setting of portland cement has been substantial[11] while other species appear to have minimal impact on cement hardening.[15] Pinon[14], for example, studied a number of European softwood and hardwood species and found that the inhibitory influence varied in accordance with the species. He found that a number

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* Of the total 6,591,114 m^3 used in 1982, some 5,615,000 m^3 was imported.

of British-grown softwood species were suitable for the manufacture of wood-cement panels. He further found that freedom from fungal decay was important in the wood raw material. Studies carried out in India[7,8)] using a number of lignocellulosics grown locally showed adequate strength developing in the resulting panel. Work on 27 tropical species by Nilela and Pasquier[18)] found different results: cement hardening characteristics varied considerably among the 27 species used.

The influence of water-soluble extractives and sugars have been blamed as detrimental to cement setting by a number of researchers.[4,5,11)] These studies conclude that the presence of such extractives and sugars tend to prolong the setting time of portland cement, as measured by the heat of hydration given off during the cement hardening. Broeker and Simatupang[6)] showed that, with European species, removal of extractives and sugars with dilute NaOH solution (0.1 – 1.0%) prior to mixing with cement did reduce cement setting time. Postulations are made that such lignocellulosic particle pretreatment either removed the offending extractives and sugars or made them insoluble in water. Other additives have also been tried in various experiments.[10)] Calcium chloride has been reported by several studies as having improved lignocellulosic-cement hardening.[5,8,12)] Ahn and Moslemi[1)] contend that wood and cement appear to adhere together by a system of mechanical interlockings, based on an electron microscopic study. Crystallites developed in portland cement after the addition of water interlock with each other and with wood to develop the bond in the wood-portland cement mix. Calcium chloride was shown to improve crystal formation(Fig. 2), thereby increasing bond strength. In the same study, addition of glucose and sucrose significantly impaired crystalline formation. Other additives such as magnesium chloride and calcium hydroxide have been reported as lowering the inhibitory effect of wood on setting of portland cement. Liu and Moslemi[10)] examined some 30 additives and found five having a positive effect on wood-cement hardening.

Fig. 2. Electron micrograph of crystal formation in portland cement with the addition of 5 percent calcium chloride (Ahn and Moslemi).

Materials and procedures

The lignocellulosic Materials

The lignocellulosic material selected for this research included the species listed in Table 1. The selection of these materials is based on earlier discussion. Specifically, three pines, larch and fir were included in addition to rice husk and rice straw. This table also shows the amount of extract obtained using water and three other solvents. It is noted that fir (*Abies holophylla*) and Japanese larch (*Larix leptolepis*), among the wood species, produced the largest amounts of extracts, particularly using NaOH at 1 percent concentration. Ethyl ether, extracted the nonpolar wood components and brought out relatively uniform amounts of the wood extractives from the wood species included. The rice residue also produced a comparable amount of extract to the wood species used utilizing the type of solvents employed. This type of raw material, however, contains much larger amounts of ash, primarily due to high silica levels in rice residue.

Among the wood species listed in Table 1, *Pinus densiflora* is the most abundant native species generally growing in natural stands and in plantations in various parts of Korea. *Pinus rigida*, an imported species, grows in plantations in the various

Table 1. The ash and extractive yield for the lignocellulosic material used in this study using a variety of solvent

Species	Ash (%)	Cold water extract (%)	Hot water extract (%)	1% NaOH extract (%)	Alcohol-benzene extract (%)	Ethyl ether extract (%)
Pinus densiflora	0.38	0.62	2.88	19.15	3.22	4.88
Pinus rigida	0.30	0.46	2.68	18.24	3.50	4.49
Abies holophylla	0.29	1.11	3.56	19.45	4.38	4.96
Larix leptolepis	0.36	1.83	10.50	24.45	4.12	4.19
Rice stalk	9.56	0.97	7.00	22.356	3.812	3.244
Rice husk	13.00	0.51	2.76	18.82	2.75	2.38
Pinus koraiensis	0.33	1.8	4.5	20.9	3.0	4.50

parts of the country including the northern reaches of the Korean peninsula. Some 80 years of experience has developed in growing and managing this pine, now the most abundant species after the native *P. densiflora*. The native *Pinus koraiensis* is available in natural stands above 600 m of elevation with extensive growth ranges into North Korea, eastern Manchuria and southeast Siberia. Extensive plantations of this pine have also been established in Korea and China. Large acreages of fir (*Abies holophylla*) and Japanese larch (*Larix leptolepis*) are scattered throughout the country. Among these two species, fir is a native species growing on elevations of over 800 m while Japanese larch is not native, found in plantations and was originally brought from Japan some 80 years ago.

In addition to the conifers noted, hybrid popular (*Populus alba·gladulosa*) was included in this study due to Korea's extensive plantations in moist bottomlands. This particular hybrid was developed by forest genetics professor, Hyun, Shin-Kyu of Seoul National University. It is a fast biomass producer reaching diameters of 20 cm or more in 10 years.

Substantial quantities of rice husk and rice stalk available in Korea could also conceivably be used as a raw material in a lignocellulosic cement material technology. It is estimated that nearly one million tons of rice husk are available in the country needing more effective use. The quantities of rice stalk exceed that of rice husk comprising substantial resources.

Portland cement

The portland cement utilized for this study is manufactured in Korea in large quantities. In fact, cement is a major export item in Korea. Large quantities are also used domestically to support its growing economy and construction industry. The chemical and physical composition of Type 1 cement, which was utilized for this study, is shown in Table 2.

Experimental procedure

For each coniferous wood species, a tree was selected in the Experimental Forest of the Korean Forest Research Institute at Kwang Neung, approximately 30 km northeast of Seoul. All trees were from plantations with ages ranging from 25 to 30 years old. Poplar samples were obtained from the same area. The rice residue material was made available from a rice processing plant 4 km west

Table 2. The chemical composition and physical properties of Korean Type I cement

A. Chemical composition

Item	ASTM C 150	Test results (%)
SiO_2	–	20.8
Al_2O_3	–	5.8
Fe_2O_3	–	3.9
CaO	–	62.4
MgO	Max. 6.0	3.4
SO_3		
when C_3A=8%	Max. 3.0	–
when C_3A=8%	Max. 3.5	1.6
Loss on ignition	Max. 3.0	0.9
Insoluble residue	Max. 0.75	0.21
C_3S	–	47
C_2S	–	24
C_3A	–	8.8
$C_4AF + 2C_3A$	–	–

B. Physical properties

Fineness, specific surface, air permeability	Min. 2800 (cm^2/g)	3,250 (cm^2/g)
Autoclave expansion %	Max. 0.8	0.8
Time of setting		
Gillmore test		
Initial set min.	Min. 60	180
Final set hr.	Max. 10	5:40
Compression strength kg/cm^2 (psi)		
3 days	Min. 127(1800)	186(2645)
7 days	Min. 197(2800)	262(3730)
28 days	–	341(4850)

of Suwon, Korea.

From each tree species, approximately a one-meter section was taken above the diameter breast height (DBH). This material was then brought to the laboratories at Seoul National University in Suwon for processing. This processing included first debarking followed by quartering the logs into manageable portions. A circular saw was used to generate sawdust particles which were subsequently milled by a Wiley Mill to produce particle sizes that would pass through a 20-mesh screen but be retained on a 40-mesh screen. After screening, the particles were air-dried in the laboratory at approximately 30°C during August 1981.

Early in the experimentation process, a series of tests were carried out to determine the extractive and ash content of the selected lignocellulosics. The results were reported earlier in this document in Table 1. This information was to serve as a reference source, as the hydration data for the various lignocellulosic sources were examined.

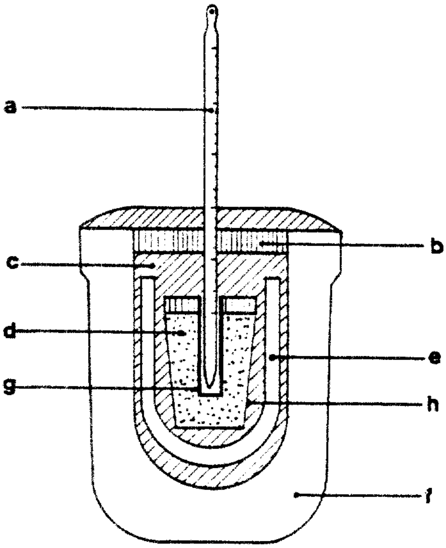
Hydration tests

The wood-cement and rice residue-cement compatibility tests were performed in Dewar flasks, as shown in Figure 3. These flasks were obtained in the United States and have proven to be effective in prior tests carried out at the University of Idaho. The experimental setup shown in Figure 3 was composed of the flask, a thermometer, a paper cup and associated material.

For each experiment, 15 grams of wood (oven-dry basis), 200 grams of cement and 90.5 ml of distilled water was used. In each case, wood was mixed with cement followed by water addition. The material was placed into the paper cup, thoroughly stirred prior to placing the mixture (with the cup) into the Dewar flask. A thermometer equipped with a copper sleeve was inserted 7 cm into the cup containing the mixture. Afterwards, fiberglass insulation was added in accordance with Figure 3 and thermometer readings began. To avoid temperature variations encountered in the ambient surroundings in the laboratory, the Dewar flasks were placed in an incubator with temperature variations limited to 21-23°C.

Upon start of the hydration experiments, temperature of the mixture was read at one-hour intervals with readings taking place every half hour near the peak of the temperature rise. Four replicates were used for each species. Therefore, a total of 32 experiments were carried out for the six lignocellulosic sources and the two types of rice residue.

For each experiment, the maximum temperature



a) thermometer
b) insulation stopper
c) fiberglass
d) wood-cement mixture
e) filler
f) Dewar flask
g) copper pipe sleeve at stopper
h) paper cup

Fig. 3. The Dewar flask used in the hydration experiment.

and the time to reach maximum temperature were measured. In addition, a number of data points (time and temperature) were obtained to enable the plotting of the exothermic curve from which inhibitory calculations were made.

Treatments and additives

In addition to taking measurements on untreated raw material, a series of experiments were conducted on material which had previously been extracted using hot water. The primary purpose of this treatment was to determine whether removal of extractives by hot water affected hydration data. In these tests, 200 grams of each species were boiled in a beaker for 3 hours, after which the material was drained on a 60-mesh screen to retain the extracted wood material. Hot water was used to rinse the material. The lignocellulosic material, so treated, was dried in an oven at 90-100°C prior to hydration experiments. The hydration experiments were carried out in an identical fashion to that already described for untreated material.

In this study, chemical additives were also utilized to determine their impact on wood-cement compatibility. The additives, however, were used in connection with only two species, selected based on earlier data. These were *Pinus densiflora* and *Populus alba-gladulosa* to determine whether wood-cement compatibility could be enhanced. The amount of each chemical additive was based on 1 percent of the amount of cement used utilizing 5 percent aqueous solutions. This material was added to the wood-cement-water mixture just prior to the start of the hydration tests. Chemical additives were used with both hot water treated and untreated lignocellulosic material to observe any differences in cement compatibility which may exist.

Data analysis

The primary parameters in a hydration test involve the maximum temperature of the wood-water-cement mixture and the time needed to reach that maximum temperature. The data obtained is plotted in the manner shown schematically in Figure 4. This figure illustrates that after cement, wood and water are mixed, no significant response in the exothermic behavior is exhibited for a period of time, shown in Figure 4 to be $(t_1 - t_0)$ (hrs). The initial temperature, T_0 (°C) remains essentially constant. However, at time t_1, the exothermic response begins at an accelerated pace, reaching a constant slope and finally tapers off at time t_2, reaching its maximum at time t_2. The information on maximum temperature, T_2 (°C), time to reach that maximum, t_2 (hrs) and the slope of the curve, as shown in Figure 4 (in °C/hr) were used to calculate an inhibitory index, I, as follows:

$$I = 100 \left[\left(\frac{T_1 - T_2}{T_2}\right) \left(\frac{t_2 - t_1}{t_1}\right) \left(\frac{S_{max_1} - S_{max_2}}{S_{max_1}}\right) \right]$$

The subscript 1 in this equation denotes the parameter for cement-water mixture and subscript 2 for wood-cement-water mixture. The I value is high for lignocellulosic species which have low

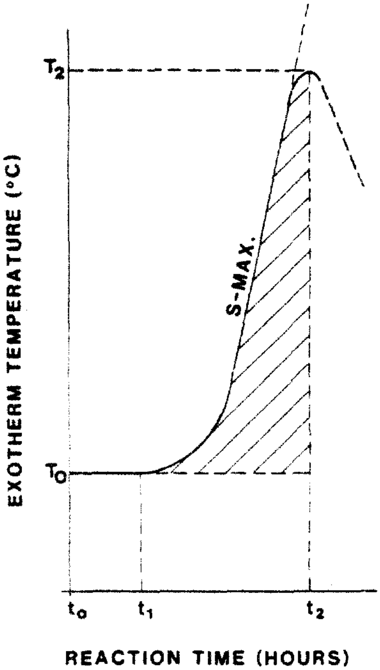


Fig. 4. A schematic representation of the typical behavior of wood-cement-water mixture during hydration tests.

compatibility with cement while the I value is low when the degree of compatibility is high. In the above equation, T_2 refers to the maximum temperature, (°C), while t_2 is the time, in hours, needed to reach the maximum temperature. Smax denotes the maximum slope for the time-temperature curve

Results and discussion

To establish the hydration characteristics of the Korean cement without wood addition, experiments were carried out to determine the time-temperature curve for the cement-water mix. The data obtained here along with those carried out for the eight lignocellulosics used in this study is shown in Figure 5. These data show that *P. rigida* and *P. densiflora* performed better than the other six sources of raw material. Poplar illustrates severe inhibitory effect on cement hydration (setting). In actual laboratory observations, poplar-cement mixtures did not set for long periods of observation amounting to a week or more. The same problem was encountered with *P. koraiensis* and rice stalk. *Larix leptolepis* and *Abies holophylla* also produced low hydration temperatures. However, rice husk, *P. densiflora* and *P. rigida* visibly produced strong setting characteristics in the laboratory.

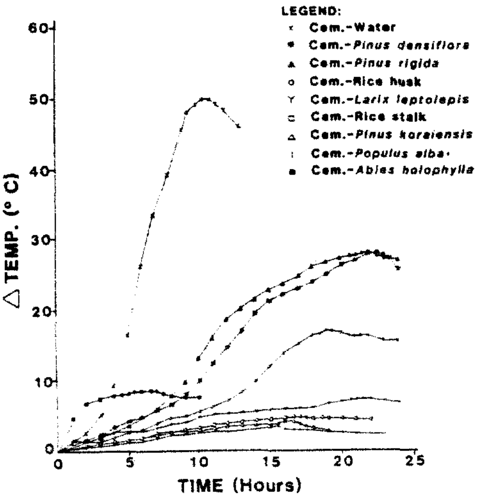


Fig. 5. The hydration curves for Korean cement and wood-cement mixtures for the lignocellulosics selected for this study.

Table 3 tabulates the hydration results along with a statistical analysis of the data. The calculation of the inhibitory index, I, was not possible for *A. holophylla* due to highly irregular shape of the hydration curve making slope determinations not feasible. The I calculation for other species were made and the values for untreated lignocellulosics are shown in Figure 6. Caution should be exercized in examining this data for poplar, *P. koraiensis*, rice stalk and larch. Due to the highly inhibitory nature of these species, I calculations are somewhat approximate due to the difficulty of determining S_{max} accurately.

Table 3. Hydration data for the eight Korean lignocellulosic and Korean cement. The data represent average of four replications for untreated material

Species	T_2 (°C)	LSD*	t_2 (hrs)	LSD
P. rigida	28.25	a**	21.00	b
Rice husk	17.45	b	19.75	c
P. densiflora	27.70	a	22.25	a
Populus alba-gladulosa	3.48	f	24.00**	a
P. koraiensis	4.15	ef	16.38	a
Rice straw	5.03	e	24.00***	d
L. leptolepis	7.25	d	21.13	b
A. holophylla	8.58	c	6.38	e

* Significant at the .05 level.

** Same letters are not significantly different.

*** No curing of mixtures occurred after 24 hours.

Hot water treatment

Removal of extractives with hot water, as previously described, significantly improved compatibility as shown in Figure 7. This figure indicates significant increases in maximum hydration temperature, especially for *P. koraiensis*, larch, rice stalk and fir. Additional improvements in compatibility were also noted for *P. rigida* and *P. densiflora*. Actual laboratory observations confirmed the increased setting capability of the hot water extracted test samples. Table 4 records the data for the extracted Korean lignocellulosics. It is clear that poplar and rice stalk did not respond positively

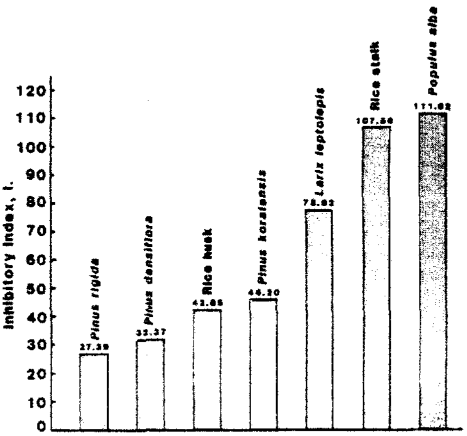


Fig. 6. Inhibitory index values for untreated Korean lignocellulosics used in this study.

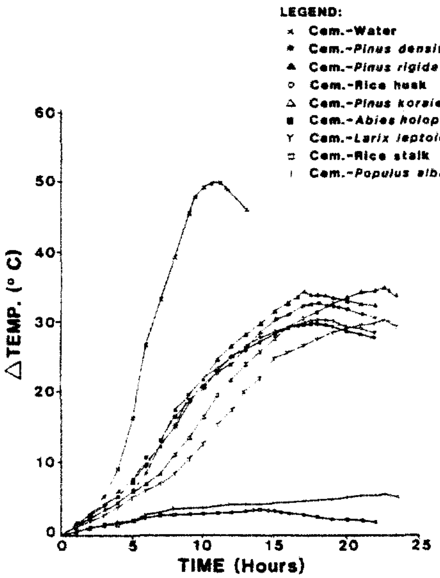


Fig. 7. The hydration characteristics of portland cement mixed with Korean lignocellulosics after removal of extractives with hot water.

to the removal of extractives with hot water. The alkaline-soluble hemicelluloses may account for the inhibitory effect on cement. The inhibitory index calculations for this set of data is shown in Figure 8 showing reduction in I values (as compared to untreated samples) for all lignocellulosics utilizedin this study.

Table 4. Hydration data for the eight Korean lignocellulosics and Korean cement for hot water extracted material. Data represent an average of four replications

Species	T_2 (°C)	LSD*	t_2 (hrs)	LSD
P. rigida	34.30	a**	17.75	bc
P. densiflora	33.08	ad	18.13	bc
P. koraiensis	35.05	a	22.25	a
Rice husk	30.43	bd	18.38	b
Abies holophylla	30.33	b	17.63	c
Rice straw	3.63	c	24.00***	d
Larix leptolepis	30.40	bd	22.50	a
Populus alba-gladulosa	5.70	c	22.50	a
Cement	50.40		10.63	

* Significant at the .05 level.

** Same letters are not significantly different.

*** Did not set after 24 hours.

Chemical additives

In this series of experiments, chemical additives were used as cement hardening accelerators. Two separate series of hydration tests were carried out: one with unextracted and the other with hot water extracted wood material. This series of tests, as noted earlier, involved primarily two species: *P. densiflora* (a generally compatible species) and poplar (a highly inhibitory species). The purpose of these experiments was to determine the impact of the chemical accelerators used on the hydration (and thereby compatibility) parameters of the selected species. Table 5 records the hydration time and temperature data for four different additives. It is clear that calcium chloride beneficially impacted the hydration parameters by increasing the maximum temperature achieved and shortening the time required to reach that temperature. For poplar, the influence of $CaCl_2$ was substantial. $MgCl_2$ was also beneficial, although this chemical was not as effective as $CaCl_2$. The other two chemicals, NaOH and $Ca(OH)_2$ were not effective. In more specific terms for *P. densiflora,* the time to reach maximum hydration temperature (t_1) was reduced from 22.3 hours to 11.3 hours for $CaCl_2$ and to 12.0 hours for $MgCl_2$. NaOH also reduced the time to 13.5 hours. $Ca(OH)_2$ did not have an influence on the time required to reach

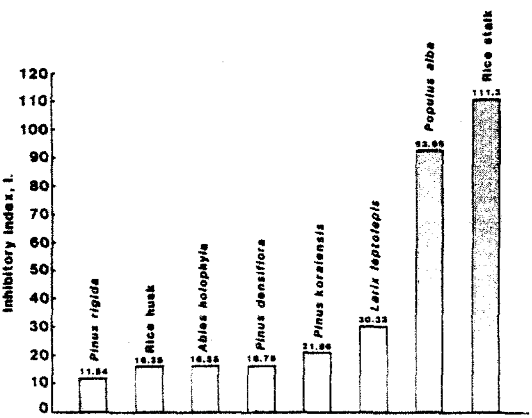


Fig. 8. The inhibitory index values for hot water extracted Korean lignocellulosics.

Table 5. Effect of chemical additives on the maximum hydration time and temperature for two Korean wood species when mixed with portland cement and water

Species	Chemical additives	t (hr)	T (°C)
Pinus densiflora	$Ca(Cl)_2$	11.3	35.5
	$Mg(Cl)_2$	12.0	33.3
	NaOH	13.5	13.7
	$Ca(OH)_2$	22.5	27.6
	None	22.3	27.7
Populus alba-gladulosa	$Ca(Cl)_2$	17.0	38.4
	$Mg(Cl)_2$	17.0	34.3
	NaOH	19.0	4.9
	$Ca(OH)_2$	20.5	2.4
	None	15.7	3.5

Table 6. Hydration data for two selected Korean species when chemical additives are incorporated with hot water extracted and unextracted wood material

	Unextracted wood					Hot water extracted wood			
Species	Chemical additives	T_2 (°C)	LSD* (T_2)	t_2 (hrs)	LSD* (t_2)	T_2 (°C)	LSD* (T_2)	t_2 (hrs)	LSD* (t_2)
Pinus rigida	$MgCl_2$	34.58	c	14.63	b	36.93	b	9.25	b
	$CaCl_2$	27.53	bc	14.63	b	35.50	ab	8.75	a
Larix leptolepis	$MgCl_2$	39.08	b	10.00	a	32.25	a	10.13	c
	$CaCl_2$	35.28	a	9.13	a	33.60	ab	9.00	ab

*Significant at 0.05 level. The same letters are not significantly different.

maximum temperature (T_2) for this pine species. For poplar, $CaCl_2$ was the most effective additive among those employed in this study.

In order to determine the combined effect of hot water extraction with chemical additives, hydration tests were carried out on two additional species: *L. leptolepis* and *P. rigida*. The data for this series are presented in Figure 9. Table 6 presents the numerical data for this experiment. An examination of the data indicates that, for *P. rigida*, the time to reach maximum temperature was reduced from 17.75 hours to 14.63 hours when $MgCl_2$ was added. However, this chemical did not have any influence on maximum temperature. For larch, however, the maximum temperature was increased significantly (from 30.4°C to 39.1°C for $MgCl_2$ and to 35.3 for $CaCl_2$). The time to reach the maximum temperature was reduced substantially from 22.5 hours to 10 hours (see Table 6).

Conclusions

It is clear that Korean lignocellulosics included in this study react quite differently when mixed with portland cement and water. In fact in their natural state, most of the material considered would be problematic if mixed with portland cement for the purpose of manufacturing panels. This is based on the fact that hydration data, particularly the maximum hydration temperature, T_2, is highly correlated to final panel properties in cement-bonded wood composites based on prior studies completed at the Unversity of Idaho[15)] and elsewhere.[16)] This particular study confirms an earlier European investigation when Sandermann[16,17)]

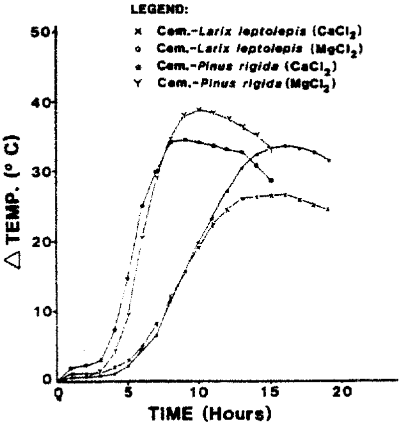


Fig. 9a. Hydration curves for *P. rigida* and *L. leptolepis* with chemical additives. Both unextracted wood and hot water extracted wood are illustrated. Hydration curves for unextracted wood.

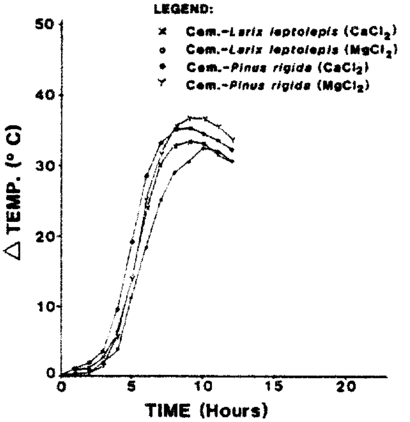


Fig. 9b. Hydration curves for *P. rigida* and *L. leptolepis* with chemical additives. Both unextracted wood and hot water extracted wood are illustrated. Hydration curves for extracted wood.

concluded that species with a maximum temperature of less than 50°C (temperature rise plus embient temperature) were not found to make acceptable panels with portland cement as a binder. When that maximum temperature reached between 50 to 60°C, the species was considered suitable under limited conditions. If the temperature reached or exceeded 60°C, the species was considered highly suitable. Under this scenario, six of the eight lignocellulosic sources considered reached a maximum temperature of less than 50°C. These included rice husk, poplar, *P. koraiensis*, rice straw, larch and fir. Only *P. rigida* and *P. densiflora* were found "suitable under limited conditions." None could be classified as "highly suitable." The hot water treatment (and subsequent removal of water soluble additives), makes a significant impact on the maximum temperature reached. With this treatment, rice husk, *P. koraiensis*, Japanese larch and fir were reclassified from "not suitable" to "suitable under limited conditions." When extractive removal is combined with chemical accelerators ($CaCl_2$ and $MgCl_2$), poplar, larch and *P. rigida* become "highly suitable." It should be noted that only four of the eight lignocellulosic sources were considered for the test series combining the effect of hot water and chemical accelerators. If all eight sources were included, additional species or rice residue (especially rice husk) may have become classified as "highly suitable" under that classificatidn system.

An additional important parameter, namely the time required to reach the maximum hydration temperature, generally was shortened with the removal of extractives in wood. Further reduction of time to maximum temperature was achieved when extraction removal was combined with chemical accelerators. For example, for *P. rigida* this time was reduced from about 21 hours for untreated material to 18 hours for hot water treated material. Calcium chloride addition reduced the time further to 15 hours. The combined effect of extractive removal and chemical accelerators had a substantial influence on time reduction (to only 9 hours). Similar reductions in time were observed for larch. The results of this study show clearly that the production of wood-cement panels with Korean raw material would need to incorporate some type of treatment which would minimize the deleterious effect of extractives on cement setting.

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