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FINAL REPORT

BONDING OF PORTLAND CEMENT WITH HONDURAN WOOD BIOMASS FOR STRUCTURAL APPLICATIONS

Project No. AID/SCI 2E-17

A Cooperative Project Between

Escuela Nacional de Ciencias Forestales
Corporacion Hondureña de Desarrollo Forestal
Siguatepeque, Honduras

and

Department of Forest Products
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, Idaho, USA

March 15, 1986

cc: BOSTID
CDIE

Rec'D 3/24/86

EXECUTIVE SUMMARY

The field of wood-cement technology has a significant potential to impact the field of construction and housing to a substantial extent. Wood-cement panels are practically fire-proof, will not rot, can be exposed to the rigors of outdoor exposure, and are easy to cut, nail, glue. The raw material, namely wood waste, cement and water, is available in Honduras requiring no imports of expensive adhesives. Chemical additives are inorganic (i.e., calcium chloride) and inexpensive and only small quantities are needed.

The wood-cement panels can easily be used for building applications requiring little time to build houses, storage facilities and other types of construction. The construction technology with wood-cement panels is already available and can readily be adapted to Honduran conditions, including rural areas.

This technology, however, is very sensitive to wood species. Some species bond well with cement while others fail or produce very weak panels. This project set out to seek desirable wood species growing in Honduras and determine the important properties of the resulting panel. In a 2-phase effort, we found that the four Honduran pine species hold promise as a raw material for this technology. Cement made in Honduras, bonds well with these four pine species producing panels that can attain high strength when wood particles with appropriate geometry are utilized. The Honduras wood-cement panels are dimensionally stable upon submersion in water. This indicates that these panels can hold their integrity well under exposed outdoor conditions.

Although the technical aspects have been addressed and statistically analyzed in this project, data is lacking as to the economic viability of this

technology. A proposal for an economic feasibility study has been developed and is enclosed with this report. Funding is needed to carry out this economic feasibility study so that economic/market information is generated for a successful industrial development which would not only affect the building technology in Honduras but possibly even expand at a later date for export opportunities.

ACKNOWLEDGMENT

On behalf of project personnel we wish to express our gratitude to the Office of Science Advisor, Agency for International Development of the United States for funding this cooperative project. Our thanks to the principal cooperating agencies, namely COHDEFOR (ESNACIFOR), (Honduras) and the University of Idaho (United States of America) for their full cooperation in facilitating all aspects of this effort. Special thanks is due to the Agency for International Development, Honduras Mission in Tegucigalpa for their administration, support and encouragement in successfully carrying out this project.

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BONDING OF PORTLAND CEMENT WITH HONDURAN WOOD BIOMASS FOR STRUCTURAL MATERIALS

The Objective of This Report:

The objective of this document is to present information obtained from the second phase of a cooperative project between Escuela Nacional de Ciencias Forestales (ESNACIFOR) in Honduras and the University of Idaho in the United States. The results of the first phase of this 2-phase project was presented in a report dated March 15, 1984, a copy of which is enclosed with this document.

The first phase of this project dealt with assessing the compatibility of a number of Honduran wood species with portland cement. This was accomplished by a series of hydration experiments originally developed at the University of Idaho. For further details on that phase of the project, the reader is referred to the report noted above. The second phase of the project involved panelmaking and testing. Much of this task was carried out in Honduras, particularly with an objective of training scientists and technicians in this technology. Although much progress has been made in equipment acquisition during the life of this project, the lack of proper wood flaking equipment and a hydraulic press still remains a deficiency. Nevertheless, attempts were made to make up for these deficiencies. To generate some base data, a small quantity of wood was air-shipped to the University of Idaho from which panels were made and later tested for mechanical strength properties.

The Objective of the Total Project:

For the statement regarding the objectives of the overall project, the reader is referred to page 7 of the attached progress report dated March 15, 1984. It is important to note that the objective has been two-fold. (a)

to evaluate the wood-cement composite technology with regard to Honduran wood species and (b) to help develop a capability for research at ESNACIFOR which will extend far beyond this particular cooperative project.

Background:

As pointed out in an earlier report (see enclosures), Honduras is a country of substantial pine resources (Figure 1). These resources occupy some 3 million hectares. During the first phase of this project it was determined that all four pine species were compatible to varying degrees with the portland cement binder (6). Thus, the second phase of the project involved panelmaking (boardmaking) and testing using the four pine species. Considerable amounts of residue (Figure 2) and thinnings are available which could readily be utilized for the wood-cement structural panel technology. Under current utilization practices, up to 50% of the useable log is reduced to residue, much of which is currently treated as waste. These wastes, through the wood-cement technology, can be put to effective use in producing materials that can substantially upgrade housing which is very inadequate particularly in the poor sections of the country (Figures 3 and 4).

Experimental Procedure:

The process of panelmaking and testing involved essentially two components: (a) determining the basic mechanical properties of the panel made with *Pinus oocarpa* which is the most prevalent pine species in Honduras. This segment was carried out at the University of Idaho with material air-shipped from Honduras and (b) carrying out extensive experiments with all four pine species (*P. oocarpa*, *P. maximinoii*, *P. caribaea* and *P. tucumumanii*) in panelmaking and testing including both

mechanical tests as well as dimensional stability trials. The objective of part (a) was to establish values using well-developed laboratory equipment and high quality wood particles. Part (b) was to develop a native capability in Honduras in wood-cement technology which would continue well beyond the termination of this cooperative effort, as noted earlier.

(a) Experiments Carried Out at the University of Idaho:

Small quantities of the wood of *Pinus oocarpa* and Honduran cement was shipped to the University of Idaho for panelmaking and testing. Once this material arrived, the wood was converted into flakes approximately ½-inch wide, 1-inch long and had an average thickness of 0.022 inches. Upon flaking, the wood had a moisture content of 9.4%. The flakes thus made were stored in plastic bags for several days prior to use. All fines were screened out. The ratio of cement to wood, by weight, was 3:1 for all boards made in these experiments. In addition, chemical accelerators $AlCl_3$ or $CaCl_2$ were used at the rate of 5% (based on cement weight). The objective here was to assess the differences which may be attributable to either aluminum chloride or calcium chloride. The amount of water added to the mix was determined using the following relationship (15, 17):

$$\text{water (liters)} = 0.35C + (0.30 - MC)\ Wod$$

in which:

C = cement weight (kg)

MC = moisture content of wood (in fractional unit)

Wod = oven-dry wood weight (kg)

The cement used was made by Piedras Azules Company in Comayagua, Honduras. Its composition is described on page 9 of the attached report dated March 15, 1984.

The process of mixing furnish and mat formation was essentially the same as that used in Honduras (see the following three pages of this report). However, a computerized press was utilized in compressing the mats into boards. Pressure was maintained at 250 psi (1.7 MPa) to reduce the mat thickness into the ½-inch target. The mat was kept in the compressed state for 24 hours to allow cement to set and permit board handling. The size of each panel made was 28 inches x 28 inches. Immediately following the 24-hour setting period, specimens measuring 14 inches x 3 inches were sawn from each panel and stored for further curing. To minimize rapid drying, specimens were misted with distilled water, then wrapped in cellophane before storing at ambient room conditions. All specimens were cured for 30 days prior to testing.

It should be pointed out that boards were also made with P. oocarpa wood particles but utilizing cement made in the United States. The objective here was to determine if the source of cement would have an impact on the mechanical properties of the wood-cement specimens (12, 18, 19).

(b) Experiments Carried Out in Honduras:

In this segment of the study, logs were obtained from the four pine species noted earlier. These logs were debarked manually. Since no wood flaking equipment was available in Honduras, particles produced by a planer (planer shavings) were used. Once these particles were generated, they were dried to a moisture content of about 8%. Further reduction of these particles took place in a Wiley mill. Particle size separation followed with a screen classifier with particles measuring, on average, ¼-inch wide, 3/4-inch long and 0.020 inches in thickness.

Type I portland cement produced in Piedras Azules in Comayagua, Honduras, was utilized. Because cement hydration characteristics vary with age and from batch to batch (18), the cement was fresh and purchased directly from the producer. A cement-wood ratio of 2.7:1 (by weight) was used in boardmaking (Figures 5 and 6). Specifically, in panels in which no chemical accelerators were used, the amounts utilized were 3727 grams of cement, 1377 grams of wood and 1543 ml of water to reach a panel target density (dry weight/volume) of about 1.18 gr/cm^3. In panels with chemical accelerators, the amount of such chemicals consisted of 3% (by weight) of cement. Panel dimensions were 22 x 24 x ½ inches. Figures 7-16 illustrate, in sequence, the boardmaking process, as this was done, in the laboratories of ESNACIFOR in Honduras. In all cases, the measured amount of water was first incorporated into the wood particles. Cement addition then followed and was thoroughly mixed with the moist (but not wet) wood particles. Chemical additives (if appropriate) were added. These additives included calcium chloride or aluminum chloride. Once these materials were thoroughly mixed (see Figure 9), it was poured on a wire forming deckle frame (see Figure 12) on a previously greased metal caul plate (see Figure 10) with an additional caul plate placed on top. The mat (see Figure 14) was placed into a manual press (see Figures 15, 16 and 17) and pressed for 24 hours. After this period, the boards were taken out of the press (Figure 18) and cured at room temperature (24°C ± 3°C) for either 30 or 45 days, prior to testing (Figure 19). As shown in Table 1, a total of 12 panels from each of the four species were made. From each panel, static bending and thickness swelling test specimens were sawn. A total of 2 bending test specimens (measuring 3 x 14 x 12 inches) were cut at 30 days of cure and another 2 specimens were sawn at 45 days of cure. Table 1

shows that some 192 bending test specimens were involved. For thickness swelling, the species in size was 6 x 6 inches. Here again, 192 test specimens were included in order to examine the effects of chemical additives and boiling wood particles on thickness swelling (see Figures 20, 21).

After curing, boards were tested for bending strength, density and dimensional stability. Strength tests consisted of static bending (to determine modulus of rupture, R, and elasticity, E, values) performed on a 1137 Instron Universal testing machine (Figure 19). Dimensional stability tests consisted of water absorption and thickness swelling under 2- and 24-hours of water soak (Figure 22). The specifications of the American Standard for Testing and Materials (ASTM-1037) (2) were used for this project. The number of panels and test specimens prepared for this phase of the project are presented in Table 1.

Table 1. Number of panels and specimens utilized in testing for mechanical and physical properties.

A. Panelmaking

4 species (*P. oocarpa*, *P. maximinoii*, *P. tucumunanii*, *P. caribaea*)
4 treatments (control, 15-minute boil, 3% $CaCl_2$, 3% $AlCl_3$)
3 replications

Total number of panels: 48

B. Test Specimens for Physical and Mechanical Properties

(a) Moduli of rupture and elasticity in static bending (3"x14"x½")
2 specimens at 30-day cure
2 specimens at 45-day cure
48 panels

Total number of specimens: 192

(b) Thickness swelling and water absorption (6" x 6")
4 treatments (see part A above)
48 panels

Total number of specimens: 192

Results and Discussion:

This section describes the results of the experiments carried out at the University of Idaho in Moscow, Idaho, USA, and at the laboratories of the Escuela Nacional Ciencias Forestales (ESNACIFOR) at Siguatepeque, Honduras. The major portion of this effort was carried out at ESNACIFOR because a primary objective of this cooperative project was to establish a capability in research on wood science and technology in Honduras. The work done at the University of Idaho involved two objectives: (a) to train Honduran personnel in all aspects of panelmaking, testing, data analyses and reporting and (b) to provide a small amount of base data on achievable strength properties using Honduran pine (Pinus oocarpa) and compare this data with values obtained at ESNACIFOR. The experience, the facilities and equipment at the University of Idaho have been established over a number of years and are well suited for wood-cement composite technology research and development. On the other hand, the facilities and equipment at ESNACIFOR, although substantially strengthened during the life of this cooperative project, still lack wood flaking equipment and utilizes a less developed process. Personnel at ESNACIFOR, however, have become very well trained and are fully capable of carrying on further research in the many opportunities this technology presents.

(a) Results Obtained at the University of Idaho:

Experiments carried out at the University of Idaho (involving Pinus oocarpa) are shown in Table 2. This table displays the results of the experiment using flakes with relatively large length to width and length to thickness ratios. For comparison purposes, Table 2 further shows data obtained on one of the most cement compatible species we know: lodgepole pine (Pinus contorta) (9). Each value presented for lodgepole pine is the

mean value of 4 test specimens. Data which has been statistically analyzed, show values for boards made with both type I and type II cement produced in the United States. It is noted that panels made with Pinus oocarpa bonded together with Honduran cement performed nearly as well as those made with lodgepole pine held together by U.S. made cement, particularly in regard to modulus of elasticity (E).

Table 2. A comparison of the mechanical properties of wood-cement panels made with Pinus oocarpa and Pinus contorta (10) (lodgepole pine).

	Pinus oocarpa[1]			Pinus contorta [2]		
Test No.	Density (gr/cm^3)	Modulus of Rupture, R (psi)	Modulus of Elasticity, E (1000 psi)	Density gr/cm	Modulus of Rupture, R (psi)	Modulus of Elasticity, E (1000 psi)
Test 1	1.4	2208[x]	960[x]	1.3	2296*	797*
Test 2	1.3	1848[x]	750[x]	1.3	2241[+]	836[+]

(1) 5% addition of $AlCl_3$ and cured for 30 days
(2) 1.5% addition of $CaCl_2$ cured for 28 days
(x) Type I Honduran cement
(*) Type I U.S. cement
(+) Type III U.S. cement

Table 2a. Mechanical properties of resin-bonded commercial particleboard (ANSI A208.1-79) (1)

Grade	Modulus of Rupture, R (psi)	Modulus of Elasticity, E (1000 psi)
1-H-1[a]	2400	350
1-H-2[a]	3000	350
1-H-3[a]	3400	400
2-H-1[b]	2400	350
2-H-2[b]	3400	400

(a) Urea-formaldehyde bonded panels
(b) Phenol-formaldehyde bonded panels

The values for modulus of rupture (R), however, fell somewhat below that of lodgepole pine. For further comparison, Table 2a shows standard values for R and E for commercial particleboard in the United States (ANSI A208.1-79) (1). Comparing values in this table with those of wood-cement panels, readily show that although wood-cement boards are not as strong as those of resin-bonded particleboard, they are considerably superior in the stiffness (modulus of elasticity) property. This is a logical outcome because cement imparts rigidity to the wood-cement system thereby increasing the E values (4, 5, 8, 11).

Further experiments at the University of Idaho involved particles that were hammermilled to a -7 + 16-mesh size. Table 3 shows that substantial reductions in both R and E values resulted. This series of tests point to the importance of particle geometry in relation to the mechanical properties of the final board. The Honduran cement did not appear to perform as well as cement obtained in the United States in this series of tests. However, some of the reduction in quality, may have occurred as the result of the age of the Honduran cement.

(b) Results Obtained at ESNACIFOR:

The data obtained in this series of experiments have been presented in Tables 4 through 7 which show mean values obtained for each of the four pine species. Both mechanical and dimensional stability data are presented in these tables. The dimensional stability data involve thickness swelling and water absorption. Linear expansion data was not collected because it is well established (13, 16, 20) that linear dimensional change using standard tests are less than 0.1% for wood-cement panels, a significantly desirable characteristic for such materials.

Table 3. Mechanical properties of wood-cement panels made with small particles of Pinus oocarpa at the University of Idaho (*).

Test	Additive	Cement Source-Type	Density (g/cm^3)	Moisture Content %	R (psi)	E (1000 psi)
1A	5% Al_2Cl_3	Hond.-Type 1	1.3	9.8	1008	460
1B	"	"	1.3	9.9	1176	580
2A	5% Al_2Cl_3	US-Type 1	1.3	9.8	1513	700
2B	"	"	1.3	9.8	1416	640
4A	"	"	1.4	10.4	1392	830
4B	"	"	1.3	10.5	1248	500
5A	5% $CaCl_2$	US-Type I	1.4	9.9	1536	620
5B	"	"	1.3	9.6	1176	590

(*) Particle size was -7 + 16-mesh in all cases

Table 4 presents mechanical and thickness swelling properties for Pinus oocarpa. Analysis of variance was used to statistically examine the differences in the mean values. All differences observed due to species and chemical additives were significant at the 1% level. The statistical analyses of the effect of curing the panels for 30 and 45 days, however, revealed no significant differences. Also, the influence of boiling the wood particles and removing the extractives were not significant.

Comparison of mechanical properties data in this table with those shown in Table 2 point out that both R and E values are considerably below those obtained at the University of Idaho. The primary reason for such lower values is attributable to the geometry of particles used at ESNACIFOR. Planer shavings reduced in size by a Wiley mill were used as noted earlier. Particles so produced do not have proper geometry for best results (irregular shape, torn flake fibers, cuts across the grain, etc.). Prior studies indicate considerably lower R and E values result with planer shavings compared with flakes (14).

Table 4. Mean values for physical and mechanical properties of wood-cement panels made with *Pinus oocarpa.*

Curing Time (days)	Treatment	Density* (g/cm^3)	Modulus* of Rupture, R (psi)	Modulus* of Elasticity, E (1000 psi)	Thickness Swelling (%)		Water Absorption (%)	
					2-hr soak	24-hr soak	2-hr soak	24-hr soak
30	Control	1.18	368.35	132.83	1.21	2.42	14.67	20.21
	15-minute boil	1.23	476.08	239.05	0.81	2.28	8.84	15.62
	3% $CaCl_2$	1.34	967.12	354.36	1.64	2.42	9.30	13.91
	3% $AlCl_3$	1.34	716.68	350.65	1.15	1.57	10.53	15.57
45	Control	1.18	325.08	175.24	2.22	3.39	18.58	21.38
	15-minute boil	1.23	451.44	232.86	2.15	3.61	15.86	20.69
	3% $CaCl_2$	1.37	895.84	392.14	0.84	3.30	11.10	15.96
	3% $AlCl_3$	1.25	689.04	372.82	1.63	2.46	11.06	15.00

(*) mean of 6 specimens
(+) mean of 3 specimens

Table 5. Mean values for physical and mechanical properties of wood-cement panels made with *Pinus tecumumanii.*

Curing Time (days)	Treatment	Density* (g/cm^3)	Modulus of Rupture, R* (psi)	Modulus of Elasticity, E* (1000 psi)	Thickness Swelling+ (%)		Water Absorption+ (%)	
					2-hr soak	24-hr soak	2-hr soak	24-hr soak
30	Control	1.09	622.16	333.36	1.58	2.05	11.15	17.10
	15-minute boil	1.10	716.32	334.25	0.06	0.51	8.28	13.99
	3% $CaCl_2$	1.16	1120.08	511.76	0.41	1.57	9.38	14.74
	3% $AlCl_3$	1.04	739.52	358.53	3.03	4.16	14.40	19.54
45	Control	1.09	587.84	325.57	2.87	3.26	13.64	18.66
	15-minute boil	1.08	750.64	321.43	1.66	3.25	10.44	15.74
	3% $CaCl_2$	1.16	1119.36	399.36	1.71	1.76	9.66	14.55
	3% $AlCl_3$	1.11	839.52	347.57	5.57	6.01	14.64	18.96

(*) mean of 6 specimens
(+) mean of 3 specimens

Table 6. Mean values for physical and mechanical properties of wood-cement panels made with *Pinus maximinoii.*

Curing Time (days)	Treatment	Density* (g/cm^3)	Modulus of Rupture, R* (psi)	Modulus of Elasticity, E* (1000 psi)	Thickness Swelling+ (%)		Water Absorption+ (%)	
					2-hr soak	24-hr soak	2-hr soak	24-hr soak
30	Control	1.08	471.16	252.04	0.54	1.37	12.69	18.46
	15-minute boil	1.12	630.08	329.09	0.51	2.13	12.36	19.03
	3% $CaCl_2$	1.16	880.88	354.22	0.05	0.89	11.68	15.81
	3% $AlCl_3$	1.11	701.36	394.87	2.09	3.40	14.84	19.37
45	Control	1.13	514.80	270.95	0.96	2.73	15.48	20.57
	15-minute boil	1.09	544.56	285.13	4.07	4.51	17.33	22.76
	3% $CaCl_2$	1.17	920.48	378.77	1.70	1.74	13.70	17.28
	3% $AlCl_3$	1.14	643.28	346.14	3.20	3.26	17.95	21.71

(*) mean of 6 specimens
(+) mean of 3 specimens

Table 7. Mean values for physical and mechanical properties of wood-cement panels made with *Pinus caribaea*.

Curing Time (days)	Treatment	Density* (g/cm^3)	Modulus of Rupture, R* (psi)	Modulus of Elasticity, E* (1000 psi)	Thickness Swelling+ (%)		Water Absorption+ (%)	
					2-hr soak	24-hr soak	2-hr soak	24-hr soak
30	Control	1.13	887.92	454.57	2.35	2.83	19.45	24.68
	15-minute boil	1.09	438.24	234.13	0.09	0.83	11.34	18.65
	3% $CaCl_2$	1.20	826.32	385.51	2.37	2.51	11.93	17.27
	3% $AlCl_3$	1.10	587.84	328.78	2.04	2.88	17.04	22.26
45	Control	1.10	629.20	321.81	2.48	4.54	16.78	24.53
	15-minute boil	1.07	512.16	304.13	1.59	3.05	15.09	20.96
	3% $CaCl_2$	1.21	856.24	417.54	0.49	0.94	12.21	16.63
	3% $AlCl_3$	1.05	491.04	294.36	3.34	3.72	22.38	26.91

(*) mean of 6 specimens
(+) mean of 3 specimens

Furthermore, the use of the manual press, the only press available at ESNACIFOR, probably resulted in some reduction in values. The extra cure time between 30 and 45 days did not increase either R or E values. This is consistent with prior research with lodgepole pine (10). The latter study comparing R and E values at 14 and 28 days of cure time shows that 95% to 98% of R values are reached at 14 days of cure. In E values, 84% to nearly 100% of value is attained at 14 days of cure. The addition of $AlCl_3$, although helpful in increasing R and E values, was not as advantageous as $CaCl_2$.

The panels generally exhibited good thickness stability with swelling limited to about 2% or less. This is supported by other studies which show that wood-cement boards exhibit excellent dimensional stability when submerged in water (5, 7, 10, 15). Water absorption values, however, are high which is probably the result of the porous nature of the panels brought about by the geometry of the planer shavings utilized.

Similar observations can be made on data obtained for the other three pines used in this study. However, for these three pines, R values are generally higher than that for Pinus oocarpa when no treatments are employed.

Figure 23 makes a comparison among the R values for the species and the treatments used. The difference observed is attributable to the differences among the species and the influence of the treatments used. It is clear that the addition of 3% $CaCl_2$ had a decided impact in increasing the R values for all the four pine species. The addition of $AlCl_3$, although beneficial, was not as effective as $CaCl_2$. Boiling the wood particles in water and draining out the water soluble extractives so removed was not advantageous, as pointed out earlier.

The E values shown in Figure 24 also illustrate the enhancement of these values by the addition of $CaCl_2$. In particular, substantial increases in E are noted for P. oocarpa, P. tucumumanii and P. maximinoii when $CaCl_2$ is added at the rate of 3% based on cement weight. Increases in E are also observed with $AlCl_3$ addition, although not to the extent shown by the addition of $CaCl_2$.

Thickness expansion (swelling) is a critically important property in many applications when the material is exposed to water. Figure 25 illustrates that thickness expansion under 2-hour and 24-hour soak is relatively small. Removal of extractives by hot water (15-minute boil) enhances thickness stability. On the contrary, boards containing $AlCl_3$ exhibited the least stability in thickness when submerged in water. Figure 26 illustrates the extent of water absorption in the boards. Specimens containing $CaCl_2$ permitted the least amount of water into the board while the control boards (no treatment) absorbed a higher percentage of water. Figure 26 indicates that most of the water enters the board during the first two hours of submersion in water.

Figure 27 illustrates some interesting comparisons, as these relate to the R values. This bar diagram depicts the values obtained for boards for which data are available, either through this project or obtained from previous work (1, 10). Comparisons are made among wood-cement boards made at ESNACIFOR and at the University of Idaho with Pinus oocarpa. These comparisons also include wood-cement boards made with small (low length to thickness ratio) and those made with long, slender flakes (high length to thickness ratio) again using Pinus oocarpa and Honduran cement. Figure 27 shows that the boards made at ESNACIFOR produced low R values. Wood-cement boards made at the University of Idaho yielded higher

R values, largely due to more desirable particle geometry used compared to those made at ESNACIFOR. Boards made with flakes had three times the R value of those made at ESNACIFOR at similar densities. These boards had about twice the R value compared to boards made with short particles produced and tested at the University of Idaho.

A comparison between flakeboards made with P. oocarpa (Honduran cement, type I) and Pinus contorta (U.S. cement, type I) shows nearly similar values. This is significant because lodgepole pine (P. contorta) is among the most compatible species with cement as noted earlier (9). Comparisons with conventional urea-bonded or phenol-bonded particleboard (1) shows that R values for flake-type wood-cement boards fall somewhat below those of conventional particleboard in R values. However, the E values for wood-cement boards generally are well above those of conventional particleboard as Figure 28 illustrates.

CONCLUSIONS AND RECOMMENDATIONS

The primary conclusion is that the Honduran pine species are suited for the manufacture of wood-cement technology. This conclusion was reached through a 2-phase cooperative project involving substantial training and participation of the Honduran personnel at Escuela Nacional Ciencias Forestales at Siguatepeque, Honduras. The first phase of the project involved wood species suitability experiments through extensive hydration trials. This phase was fully reported in a progress report enclosed in the back of this document. In that phase, it was noted that the four pine species exhibited good compatibility with cement and had the potential of providing the raw material for a successful wood-cement technology. Several other biomass sources included did not prove useful. For more details on the conclusions reached during the first phase of the project, the reader is referred to pages 40-41 of the progress report dated March 15, 1984 (a copy is attached).

During the second phase of this project, actual panelmaking and testing took place. The major portion of all experiments took place at ESNACIFOR and were carried out and statistically analyzed by Honduran personnel under the supervision of the University of Idaho scientists. In this portion of the research, it was determined that the four pine species can produce technically viable cement-bonded panels. For good strength development, flake-like particles produced boards that are readily acceptable for structural purposes at densities reported in this document. For example, comparing the strength development of wood-cement boards using P. oocarpa with that reported for one of the most suitable species reported, namely Pinus contorta, shows that both moduli of elasticity and rupture are relatively close in value. Other Honduran pines, namely P. caribaea, P.

maximinoii and P. tucumumanii, are expected to produce relatively good strength characteristics with flake-like particles.

The thickness stability after submersion in water is excellent for wood-cement panels. Honduran pines have shown that they are stable when submerged in water. This implies that wood-cement panels thus made are expected to be dimensionally stable in outdoor environments.

During the 1985 period, when initial data showed technical promise for Honduran pine-cement production, some work was devoted to the development of a proposal for an economic feasibility study for wood-cement technology in Honduras. For this technology to be successful, both technical and economic requirements must be met. In the just concluded 2-phase project, the technical viability has been addressed. The University of Idaho in association with ESNACIFOR, is now seeking funds from the Agency for International Development to carry out the economic feasibility study. A draft copy of the economic feasibility study is also attached with this document. It is recommended that the work on the economic feasibility begin immediately so that the information base is generated for the industrial development in this technology which can substantially impact housing opportunities in Honduras.

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Progress Reports

Since this project was initiated, some 11 progress reports have been filed. Three of the eleven progress reports were major documents. Specifically, the following lists the dates of the reports.

January 1983*

June 1983

July 1983

August 1983

September 1983

March 1984*

July 1984

August 1984

April 1985 (two reports)

April 1985*

The reports without an asterisk were minor reports exchanged between cooperators (ESNACIFOR and University of Idaho). Those with an asterisk were forwarded to a number of individuals and organizations as follows:

Mr. Felipe Monteiga/Mr. Ramon Alvarez/Mr. Marc Scott
Agency for International Development
United States Embassy
Tegucigalpa, Honduras

Dr. Irv Asher/Dr. Miloslav Reccigl
Office of Science Advisor
Agency for International Development
Washington, D.C. 20523

Mr. James Hester
Environmental Office
Agency for International Development
LAC-DR Room 2252, New State
Washington, D.C. 20523

Dean John Ehrenreich
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, Idaho 83843

Dr. Carl Gallegos
Forestry
Forestry, Environment and Natural Resources
Agency for International Development
Washington, D.C. 20523

Dr. Ruben Guevara M., Director
ESNACIFOR
Apartado Postal No. 2
Siguatepeque, Honduras

Director General
COHDEFOR
Tegucigalpa, Honduras

Dr. John D. Sullivan, Director
Forestry, Environment and Natural Resources
Office of Science and Technology
Room 509
Agency for International Development
Washington, D.C. 20523

Manuscripts Prepared

One manuscript, based on the results of the first phase of the study, was prepared and submitted to the IX World Forestry Congress in Mexico City. This congress was held in June/July 1985. The title of the paper was "Compatabilidad de la madera de pinos Hondureños y el cemento portland" authored by Ing. Jose F. Garcia, Dr. A.A. Moslemi and Das. Astor U. Urbina.

Visitations by Project Personnel

During the course of this cooperative project, investigators from both ESNACIFOR and the University of Idaho visited each other for the purpose of scientific exchange and training in carrying out this project. In addition, presentations were given during these visits to other colleagues and students. Specifically, Professor A.A. Moslemi visited ESNACIFOR on May 16-25, 1983, December 5-17, 1983, August 14-18, 1984, February 24-March 3, 1985, and July 12-17, 1985. Ing. Jose Francisco Garcia spent the period of February 20-March 10, 1984, at the University of Idaho. In

addition, Das. Astor U. Urbina was extensively trained at the University of Idaho in boardmaking and testing during the period April 6-18, 1985. Ing. Jose Francisco Garcia in cooperation with Dr. A.A. Moslemi prepared a major report during his February 20-March 10, 1985 visit to the University of Idaho. Also, Dr. Ruben Guevara, the Director of ESNACIFOR, visited the University of Idaho during late May, 1985, and traveled with Dr. Moslemi to Washington, D.C. in order to confer with USAID officials and make a presentation to AID scientists and staff on this project.

During his five visits to Honduras, Dr. A.A. Moslemi spent time not only with project personnel at ESNACIFOR, he also visited the officials of COHDEFOR in Tegucigalpa, Honduras, updating them on the progress of this project. He also has lectured to the faculty and students at ESNACIFOR during these visits. In addition to Professor A.A. Moslemi, Dr. Alton Campbell and Dr. Peter Steinhagen each traveled once to Honduras to provide specialized expertise in the advancement of this project. A special display at ESNACIFOR portrays the findings for faculty and students.

News Releases

The innovative approaches used by this project generated a variety of news releases in both written media and radio/television. A number of examples of news releases pertaining to this project in written media is attached to this report.

Personnel Involved

A. University of Idaho
   - Dr. A.A. Moslemi - Project Director
   - Dr. A.G. Campbell - Wood Chemist
   - Dr. Peter S. Steinhagen - Wood Technologist
   - Mr. Stephen Pfister - Research Assistant
   - Mr. David Ritter, Research Assistant

B. ESNACIFOR

Ing. Jose Francisco Garcia - Project Leader
Das. Astor Uriel Urbina - Project Sub-leader
Dr. Ruben Guevara - ESNACIFOR Director
Das. Mauricio Cubas - Project Collaborator
Sr. Antonio Zavalla - Laboratory Assistant
Sr. Orlando Cuestas - Laboratory Technician
Sr. Gabriel Alvarado - Laboratory Assistant
Sr. Olman Rodriguez - Laboratory Assistant

C. Agency for International Development (Tegucigalpa)

Mr. Anthony J. Cauterucci, Mission Director
Mr. Marc Scott
Mr. Russell Hawkins
Mr. Felipe Mantaiga
Mr. Ramon Alvarez

BEST AVAILABLE DOCUMENT

A new structural material suitable for housing has been developed in a cooperative project between the University of Idaho and Escuela Nacional Ciencias Forestales (ESNACIFOR) in Honduras. The development of the material, which is a composite of wood waste and cement, has been supported by the AID Office of the Science Advisor.

Professor A. A. Moslemi of the University of Idaho and Professor Jose Francisco Garcia of ESNACIFOR have worked on the project for more than a year, and are now making test panels of the material.

The panels are composed of wood particles held together by a cement binder using water and inexpensive inorganic additives. The ratio of cement to wood varies from two or three parts of cement to one part of wood by weight. The ratio would be reversed if measured by volume.

The panels are suitable for use in all climates, especially in tropical areas where wood structures are vulnerable to rot and insect attack. The cement bonding makes the material inedible to insects, while providing excellent resistance to wood-destroying fungi.

Tests on the panels show that they do not burn easily. They give off virtually no hazardous fumes if burned. For example, no organic adhesives are used in the material so the panels do not emit formaldehyde fumes when burned, as do particleboard or plywood. The material is also superior to particleboard because of its better dimensional stability under test conditions.

The density of the material can be varied over a range that is generally heavier than particleboard and lighter than concrete. The material can be lightened by increasing the ratio of wood to cement; however, there is a point beyond which altering the ratio will unacceptably weaken it.

For the last year, researchers have been examining a number of wood sources for use in the material. Four Honduran pines, a hardwood, and a bagasse (sugar cane residue) have been examined. Initial hydration tests examined the compatibility of the various species with cement. The four Honduran pines tested were promising, forming strong bonds with the cement and producing structurally strong panels. Current tests at ESNACIFOR laboratories in Siguatepeque, Honduras are determining the level of strength and dimensional properties achievable at the current level of the technology.

Ruben Guevara, director of ESNACIFOR, believes the new building material has great potential for use in housing construction both in Honduras and around the world. The raw materials needed for this technology are available virtually anywhere, and little capital is needed to construct a plant capable of producing the panels. Procedures already exist for rapidly constructing housing out of the new material, which is suitable for both interior and exterior use. And folded panels could replace solid wood as studs.

The material is easily machinable with standard woodworking tools. It can be nailed, glued, painted and machined similar to solid wood or resin-bonded particleboard.

The technology creates new uses for residue from sawmills, thinnings from forestry improvements and residue retrievable from the forest floor. According to Professor Guevara, some 75-80% of the tree biomass is wasted in logging and milling operations. A great deal of this lost biomass can be retrieved by this type of technology.

The new technology is likely to have spinoff effects in the United States as well. Lodgepole pine, a species in large supply throughout much of the United States, has been successfully tested as an excellent wood base for the material. The little-used species bonds excellently with cement.

Researchers are already receiving weekly inquiries about the economic feasibility of manufacturing the new building material, according to Moslemi. "So far, we have concentrated on technology development; in the near future we need to examine economic feasibility under Honduran conditions, and eventually, in the United States as well," he says.

Manufacturing the new material should be relatively easy, researchers say, because the plant design is a relatively simple one. No wood drying is necessary, they say, and no hot pressing is required.

Project directors plan to present a paper on their findings at the ninth World Forestry Congress scheduled in Mexico City, July 1-12, 1985.

—Miloslav Rechcigl

Scientists examine the results of tests on the new building material showing the material's strength and resistance to fire.

Honduran takes home ideas to fix housing woes

5/13/85 IDAHONIAN

A 28-year-old Honduran hopes the technology he learned at the University of Idaho's forest product's department will ease the severe housing shortage his people face.

Astor U. Urbina is learning the technology, testing and manufacturing techniques to create an experimental cement-and-wood particle board that his country hopes to use as a low-cost building material to improve its housing.

Urbina is part of an intensive two-week course that is part of a cooperative two-year project between the UI and the Honduran National Forestry School in Siguatepeque. Project scientists are experimenting with the technology that can create structural building materials from sawdust, waste wood and Honduran native pine.

"In a country where 80 percent of the population is in inadequate housing, this technology would allow them to use their own timber resources to solve the housing shortage," said Al Moslemi, head of the UI forest products department and team leader of the university's portion of the project.

The project is funded by a $174,000 grant from the U.S. Agency for International Developement to determine whether a structurally strong cement-and-wood particle board can be manufactured using four species of Honduran pine.

"We are trying to help bring a cheaper board to the people. Now it is too expensive for most of them to use," Urbina said.

If the cement-board project is successful, Urbina said his government wants to build a cement-board factory at Comayagua in central Honduras where wood is plentiful and there is a local cement factory.

The project, called the "Bonding of Portland Cement with Honduran Wood Biomass for Structural Materials," involves making, curing and testing boards of native wood and training Hondurans to use the techniques in their country. The boards can be used for boxes, building materials, walls and building partitions.

"Until now, more than half of the Honduran timber resources have been wasted as trees have been chopped down for fuel or to make way for grazing," Moslemi said. "Half of their wood ends up as sawdust, slabs or waste, but this technology will allow them to use much more of their timber resources to solve their problems."

Moslemi is a pioneer in the development of the process to use cement to bond waste-wood and forest residues to create a strong, insect-resistant wood.

Urbina said he wished all countries were thinking of projects like this to help their people and save their timber resources.

"Life in my country is very expensive, so I wish all governments were considering projects like this for their cities and countries."

Urbina will begin the next stage of testing the product in Honduras when he returns home.

UI TECHNOLOGY should help Honduras. Here, Astor U. Urbina, left, inspects a cement-bonded particle board created in a process developed by Al Moslemi, right, of the UI Forest Products Department.

UI photo

BEST AVAILABLE DOCUMENT

Plan developed to ease housing in Honduras

Associated Press

MOSCOW — A University of Idaho researcher has developed a plan to help Honduras solve its housing problem using waste wood.

Instead of allowing wood left on forest floors and at sawmills to be burned, A.A. Moslemi, head of the UI forest products department, proposes to shape the residues into building panels.

His plan calls for grinding the waste into sawdust, mixing it with cement and water and then making boards or bricks.

The resulting material would be non-combustible and impervious to rot and insects, Moslemi said.

Commercial logging and sawmill operations in Honduras produce millions of tons of waste wood each year, more than enough to make enough panels to solve the nation's housing problem.

"There might even be boards left for export," he said. "Forestry in Honduras utilizes only 40 to 45 percent of the log.

"A lot of wood is left to rot."

Forest residues include treetops, branches and other pieces less than 10 inches long. Sawmills also waste more than half the logs they receive, Moslemi said.

the test project was financed by a $174,000 grant from the U.S. Agency for International Development.

One question, however, remains: whether the pine trees grown in Honduras are suitable for cement binding.

"The very large pine resource in Honduras appears to be excellent for this type of technology," he said in an interim report.

"The building panels we are testing could be used for walls, roofs, and both the interior and exterior of houses."

Another year of research remains before a final decision is made on whether the process should be tried commercially.

Lewiston Trib 2/26/84

UI planning project to aid Honduras in manufacturing timber materials

MOSCOW — A joint research project by the University of Idaho Department of Forest Products and the government of Honduras will, if successful, enable citizens of that country to manufacture building materials using logging residues available in their own area.

According to A.A. Moslemi, Forest Products Department head and leader of the UI part of the project, such residue use would help alleviate the Honduran housing shortage as well as increase the economic value of the country's forest resources.

"Under current utilization standards," Moslemi said, "up to 50 percent of the usable wood is left as waste." Logging residues are considered anything less than 10 inches long and include treetops, branches and other pieces.

These residues are used with Portland cement to create structural panels. The cement replaces the more expensive petroleum binders commonly used in panel manufacture.

Cement-bonded panels are ideally suited for Honduras' tropical climate because they are impervious to rot and insect attacks, Moslemi said. Researchers are determining whether the pine resources available in Honduras are suitable for cement binding.

Moslemi has received a $174,000 grant from the U.S. Agency for International Development and is working in cooperation with the Honduran National Forestry School testing the experimental panels. Interim results of the project, now at its halfway point, show a "good to excellent" possibility of successfully using the pine logging residues, Moslemi said.

Honduras Project Promises Cheaper Housing

A joint research project by the University of Idaho Department of Forest Products and the government of Honduras will, if successful, enable Honduran citizens to manufacture building materials using locally available logging residue.

Use of residue would help alleviate the Honduran housing shortage as well as increase the economic value of the country's forest resources, said A.A. Moslemi, Forest Products Department head and leader of the university's part of the project.

Researchers hope the residues can be used with Portland cement to create structural panels. The cement replaces the more expensive petroleum binders commonly used in panel manufacture. Cement-bond panels are ideally suited for Honduras's tropical climate because they are impervious to rot and insect attacks, Moslemi said.

Moslemi has received a $174,000 grant from the U.S. Agency for International Development and is working in cooperation with the Honduran National Forestry School testing the experimental panels, in order to determine whether the pine resources available in Honduras are suitable for cement binding. The interim results of the project, now at its halfway point, show that the pine logging residues are indeed suitable, Moslemi said.

Water Quality and Fish Populations Studied At Adirondack Lakes

The Adirondack Lakes Survey Corporation, established by the New York State Department of Environmental Conservation and the Empire State Electric Energy Research Corporation to study water quality and fish populations in some 1,200 Adirondack lakes, has reported that staffing for the project is complete and work on the study has begun. The first phase of the project involves selection of lakes to be studied.

The three-year study, which was announced last year by Gov. Mario M. Cuomo, will cost an estimated $4.2 million.

A semi-permanent mobile laboratory containing state-of-the-art analytical instrumentation was installed at study headquarters in Ray Brook at the end of April. That is when actual survey work and field studies began. Walt Kretser of the state's Bureau of Fisheries has been designated project manager and heads a staff of about 25.

Initially, fishery efforts will focus on finding and determining the presence of species, relative abundance, and other selected population characteristics. Coinciding with the fishery investigations will be the collection of water samples for analysis.

According to Environmental Conservation Commissioner Henry G. Williams, this cooperative effort will help "fill gaps in our knowledge of the water chemistry and its effects on fish life in the Adirondacks. Not since the 1920s and '30s has a study of this magnitude been undertaken in the Adirondacks. This new study will provide extensive baseline data for assessing environmental changes long into the future."

News Briefs

□ Smokey Bear, the symbol of forest fire prevention, will celebrate his 40th birthday this year.

□ A new color resource map, which covers the state of Oregon at a scale of about 1 inch=14 miles, is available from the USDI Bureau of Land Management. The map is a revision and replacement of the BLM Recreation Guide printed about five years ago. The new map shows the location of BLM public lands and developed recreation sites, major whitewater rivers and hiking trails, and other points of interest. The reverse side describes the various resource activities available on the agency's land. Copies are $1 at all BLM offices in Oregon.

□ Recreation opportunities on public lands in Montana will be expanded as a result of land exchanges recently completed by the USDI Bureau of Land Management. Last year BLM acquired land near its Holter Lake recreation site north of Helena, and an easement along the upper Missouri River. As a result of the exchanges, the public now has access to nearly 6,000 acres of prime shorefront along Holter Lake. This area is part of the historic Lewis and Clark trail.

□ President Reagan has signed legislation making the scenic Bear Trap Canyon area in southwestern Montana the first wilderness area to be managed by the USDI Bureau of Land Management. The 6,000-acre Bear Trap Canyon, about 29 miles southwest of Bozeman, is now part of the newly created Lee Metcalf Wilderness Area, named after the late U.S. senator from Montana who championed wilderness causes.

□ America's paper industry, which presently exports over $275 million in products to the People's Republic of China annually, expects to more than double that figure in the next five years, according to the American Paper Institute.

□ Research projects are under way in the University of Montana Forestry Center, located at the university's Lubrecht Experimental Forest, east of Missoula. The 7,000-square-foot center, which was dedicated in February, houses year-round dry and wet laboratories, computer systems, offices, seminar rooms, and public exhibition rooms.

□ At the Secretary of Agriculture's Challenge Forum, held January 16 at the National Academy of Science, scientists from government, industry, and academia warned that the country's agricultural enterprise could be seriously threatened if colleges are not able to attract more highly qualified students who will pursue careers in agricultural research.

BEST AVAILABLE DOCUMENT

35

Lewiston Morning Tribune 2/26/84

... begin development of a ... Videotex is a two-way, interac...

Lewis trib 2-26-84

UI planning project to aid Honduras in manufacturing timber materials

MOSCOW — A joint research project by the University of Idaho Department of Forest Products and the government of Honduras will, if successful, enable citizens of that country to manufacture building materials using logging residues available in their own area.

According to A.A. Moslemi, Forest Products Department head and leader of the UI part of the project, such residue use would help alleviate the Honduran housing shortage as well as increase the economic value of the country's forest resources.

"Under current utilization standards," Moslemi said, "up to 50 percent of the usable wood is left as waste." Logging residues are considered anything less than 10 inches long and include treetops, branches and other pieces.

These residues are used with Portland cement to create structural panels. The cement replaces the more expensive petroleum binders commonly used in panel manufacture.

Cement-bonded panels are ideally suited for Honduras' tropical climate because they are impervious to rot and insect attacks, Moslemi said. Researchers are determining whether the pine resources available in Honduras are suitable for cement binding.

Moslemi has received a $174,000 grant from the U.S. Agency for International Development and is working in cooperation with the Honduran National Forestry School testing the experimental panels. Interim results of the project, now at its halfway point, show a "good to excellent" possibility of successfully using the pine logging residues, Moslemi said.

of war debts and reparations."

short- and long-term conse-

885-0719.

Idahonian 2-28-84

UI-Honduran research

New uses for waste wood products

A joint research project by the University of Idaho Department of Forest Products and the government of Honduras will, if successful, enable citizens of that country to manufacture building materials using locally available logging residues.

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Cement-bonded panels are ideally suited for Honduras' tropical climate because they are impervious to rot and insect attacks, said Moslemi. Researchers are determining whether the pine resources available in Honduras are suitable for cement binding.

Moslemi has received a $174,000 grant from the U.S. Agency for International Development and is working in cooperation with the Honduran National Forestry School testing the experimental panels. He said the interim results of the project, now at its halfway point, show "a good to excellent" suitability of successfully using the pine logging residues.

University of Idaho
Forest Products

FOREST PRODUCTS SEMINAR

(ForPr 496/501 - Harry Lee)

GUEST SPEAKER

JOSE FRANCISCO GARCIA

PROFESSOR

NATIONAL SCHOOL OF FOREST SCIENCES

SIGUATEPEQUE, HONDURAS

PAST, PRESENT AND FUTURE OF FORESTRY IN HONDURAS

Tuesday
February 28, 1985

FWR Room 102
12:30 p.m.

Figures for this Report

CAPTIONS FOR PHOTOGRAPHS

Figure 1. A photo of the pine resources of Honduras. These include primarily four species; the most prevalent is Pinus oocarpa.

Figure 2. Sawmill residue including slabs, trims and sawdust are potential raw material for wood-cement technology.

Figure 3. An example of poor housing conditions especially in rural areas of Honduras.

Figure 4. An example of a house made with wood-cement panels (photo from Bisonwerke, Germany) (3).

Figure 5. Laboratory assistant Antonio Zavalla weighs wood particles for panelmaking.

Figure 6. Das. Astor Uriel Urbina and Antonio Zavalla carefully measure the amount of water to be used in panelmaking.

Figure 7. The measured amount of water is being incorporated into the wood particles.

Figure 8. Wood particles are being thoroughly mixed with water.

Figure 9. Cement, wood, water and chemicals are being incorporated into a furnish for panelmaking.

Figure 10. Gabriel Alvarado greases a caul plate in preparation for panelmaking.

Figure 11. A deckle frame is placed on the press for mat formation.

Figure 12. Wood-cement furnish is being formed with a mat.

Figure 13. A uniform layer of furnish has been formed into a mat.

Figure 14. The deckle frame has been removed upon mat formation. A ½-inch metal stop is positioned into place.

Figure 15. The manual press is being assembled to compress the mat.

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Figure 1

Figure 2

Figure 3

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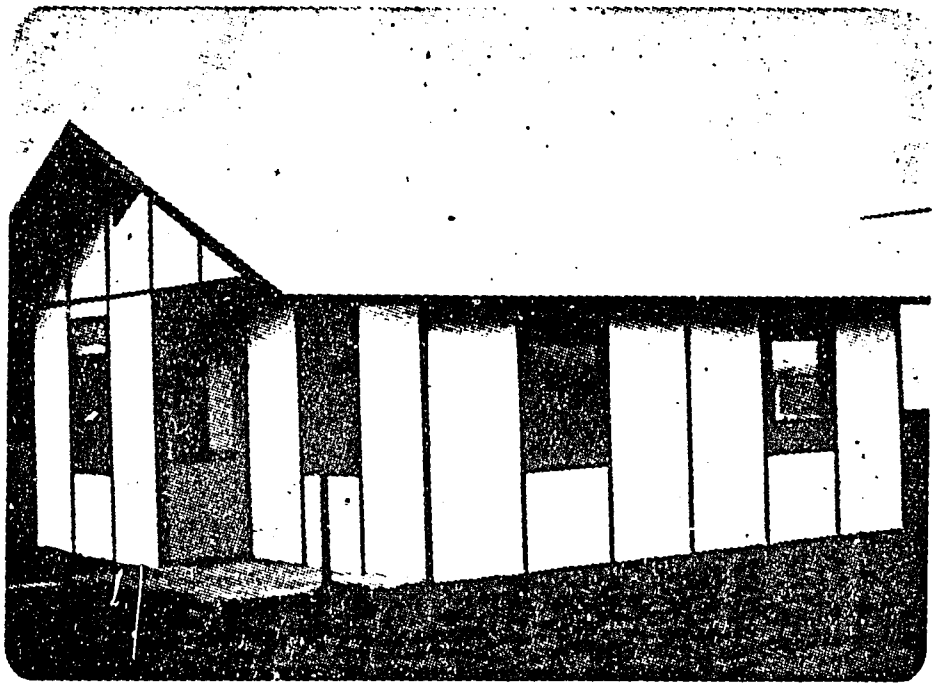
Figure 4



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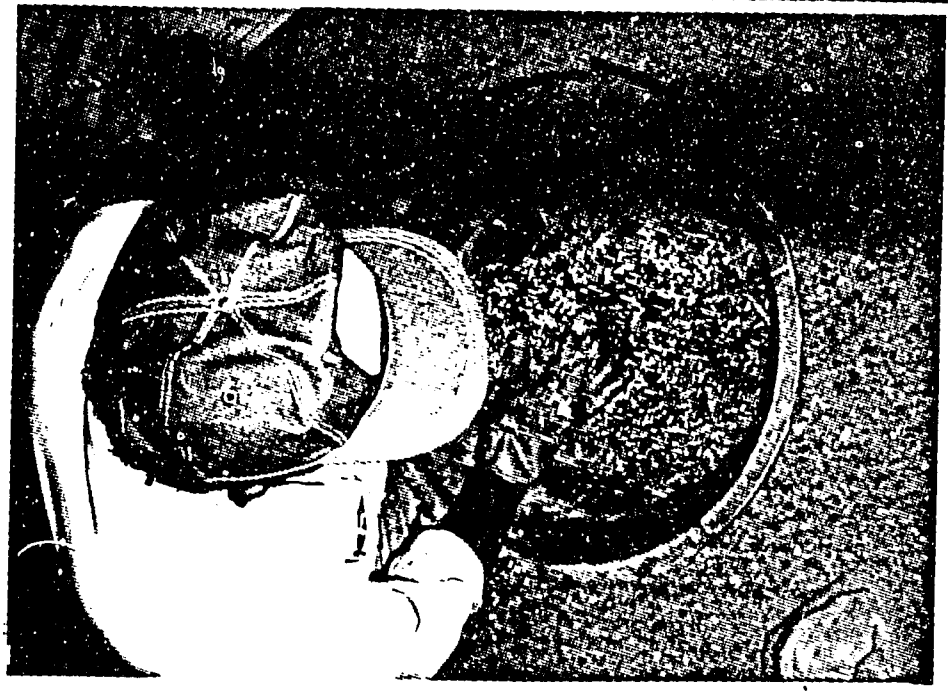

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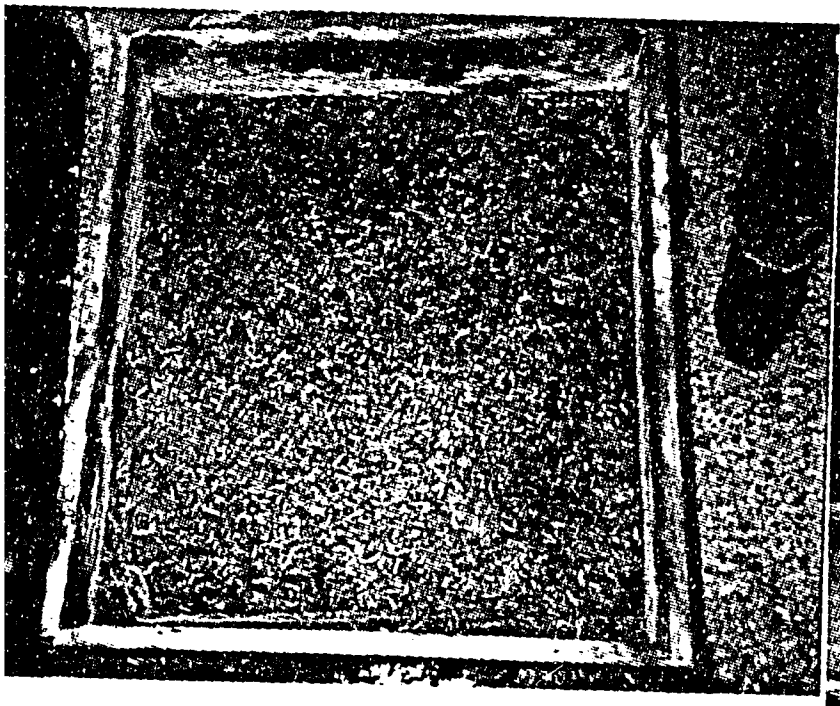

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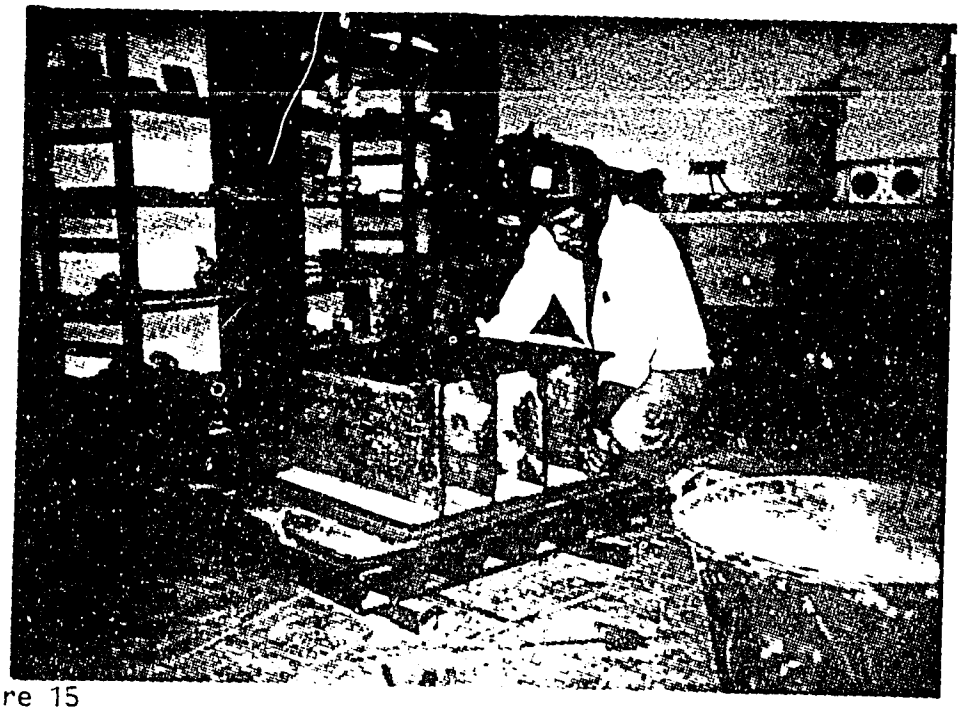

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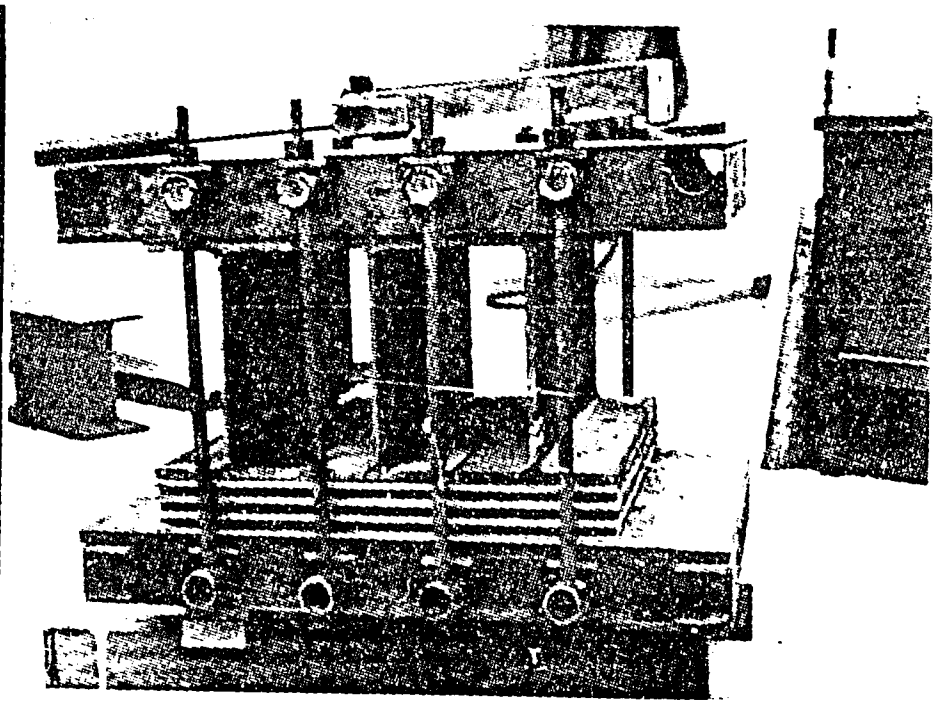

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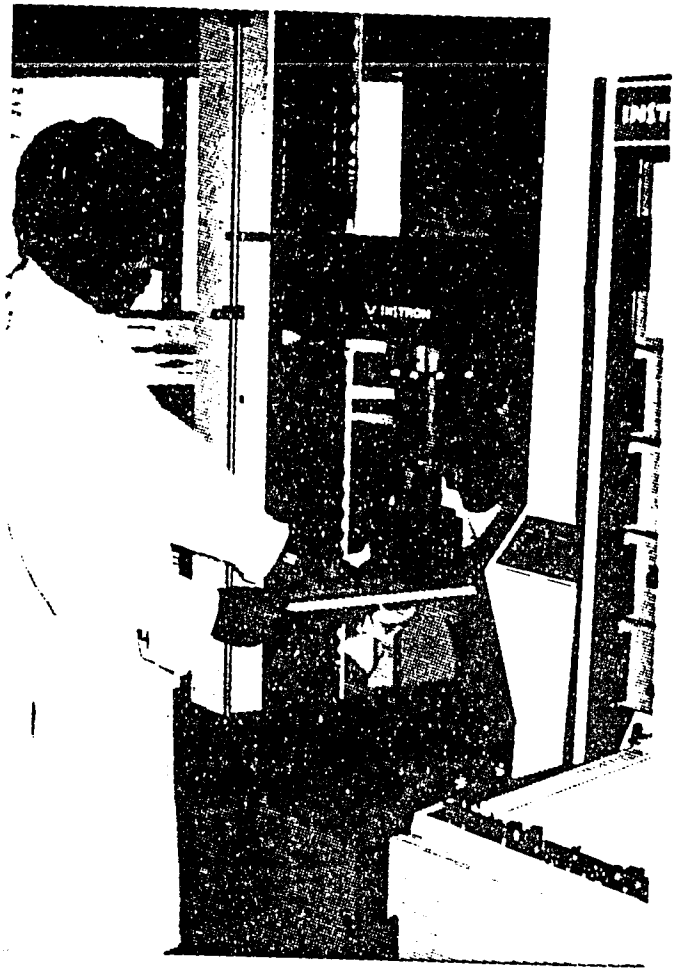

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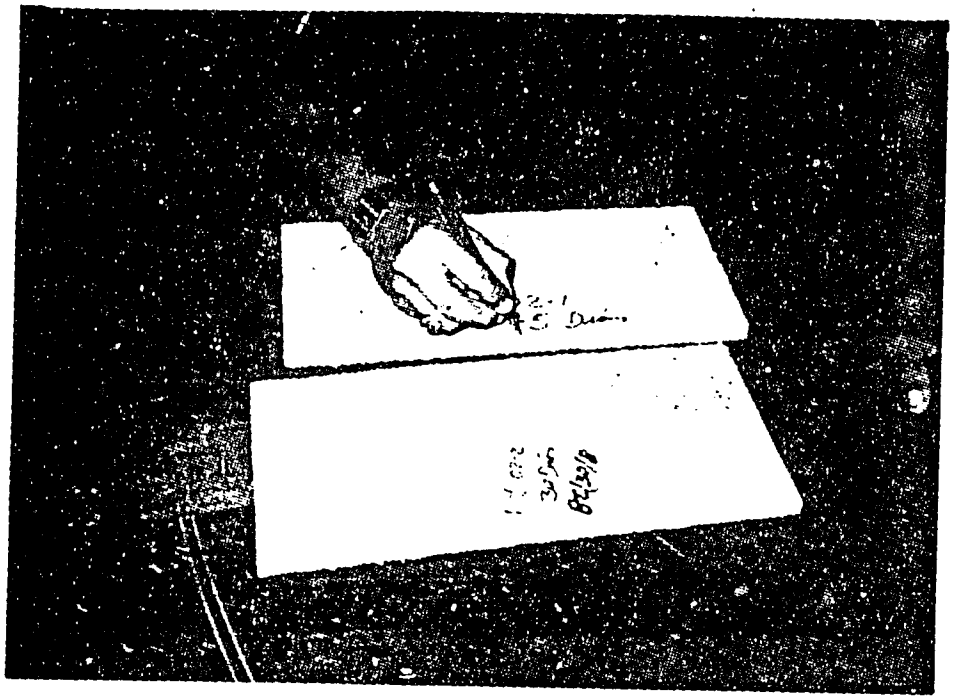

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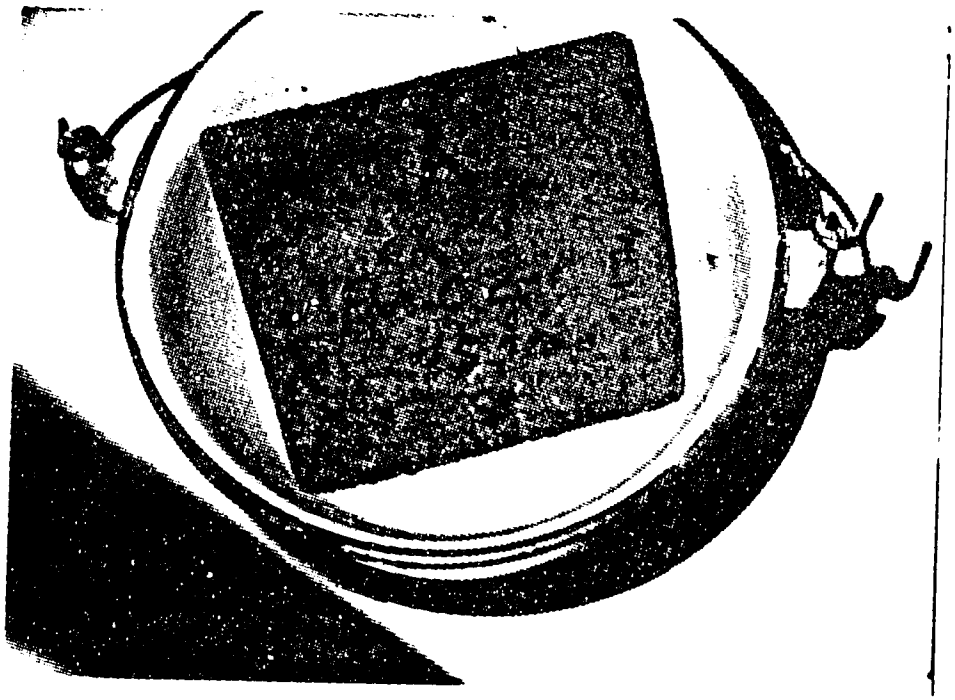

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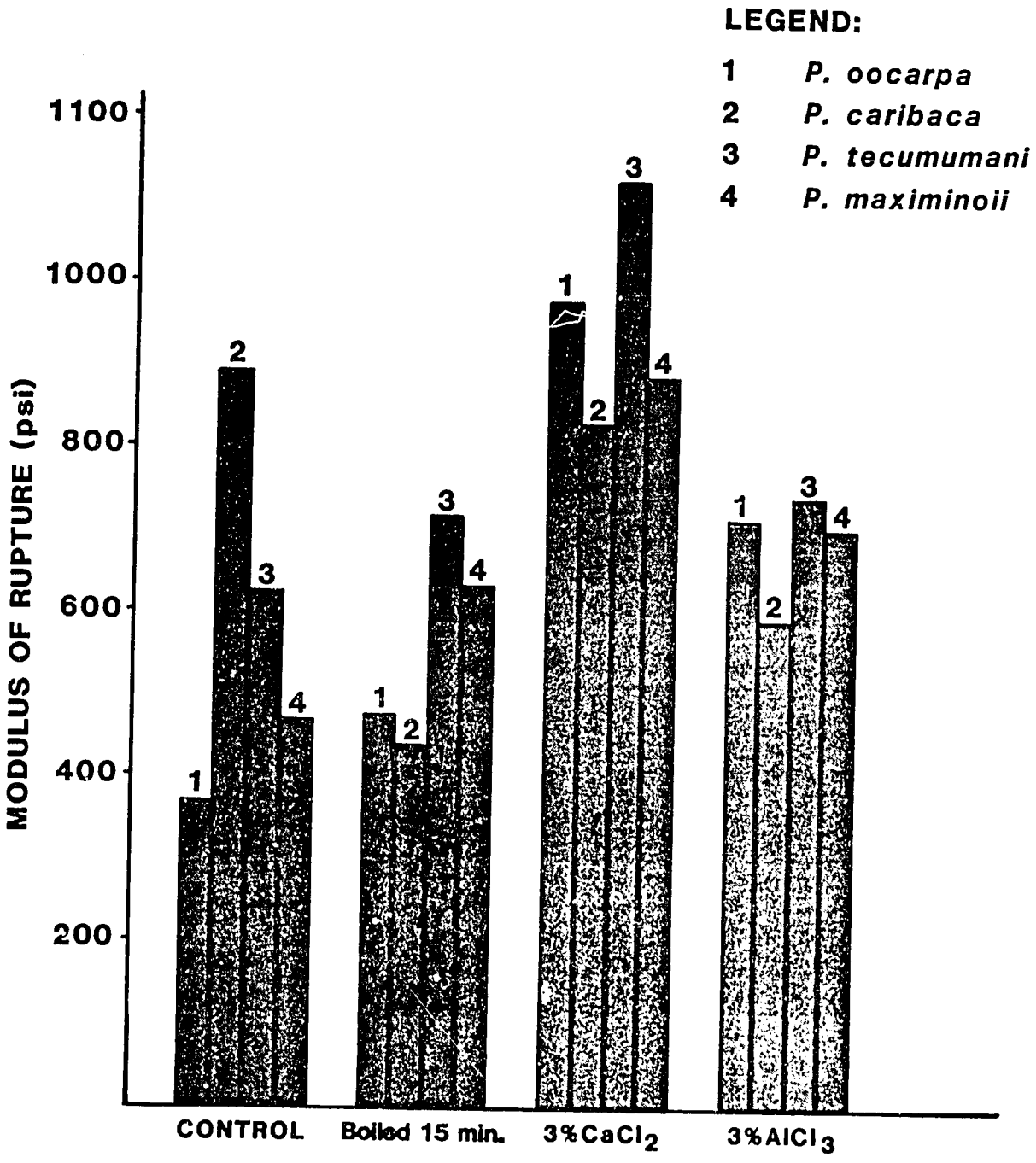


Figure 23. Modulus of rupture for the four Honduran pine species and the various treatments used in this project.

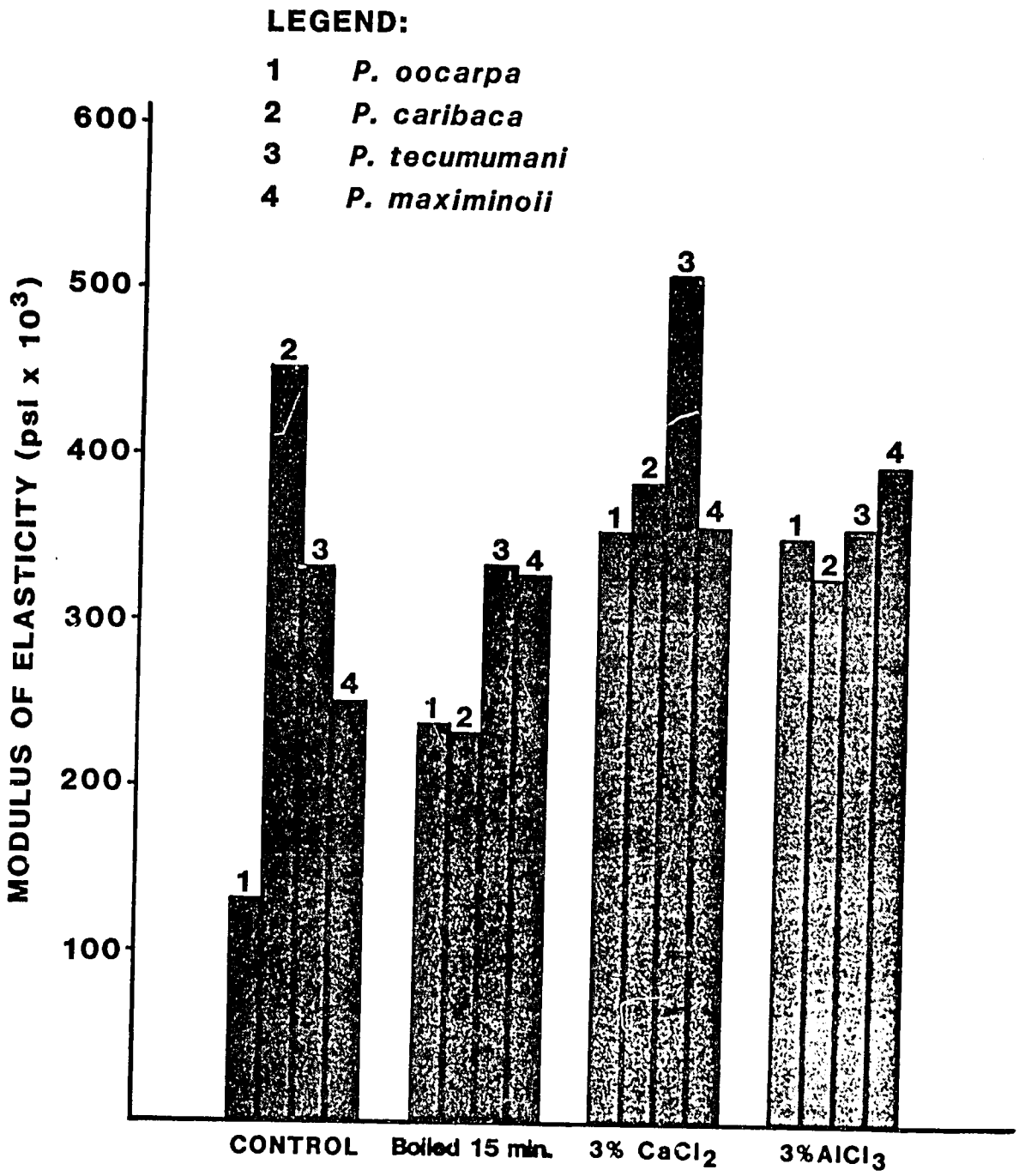
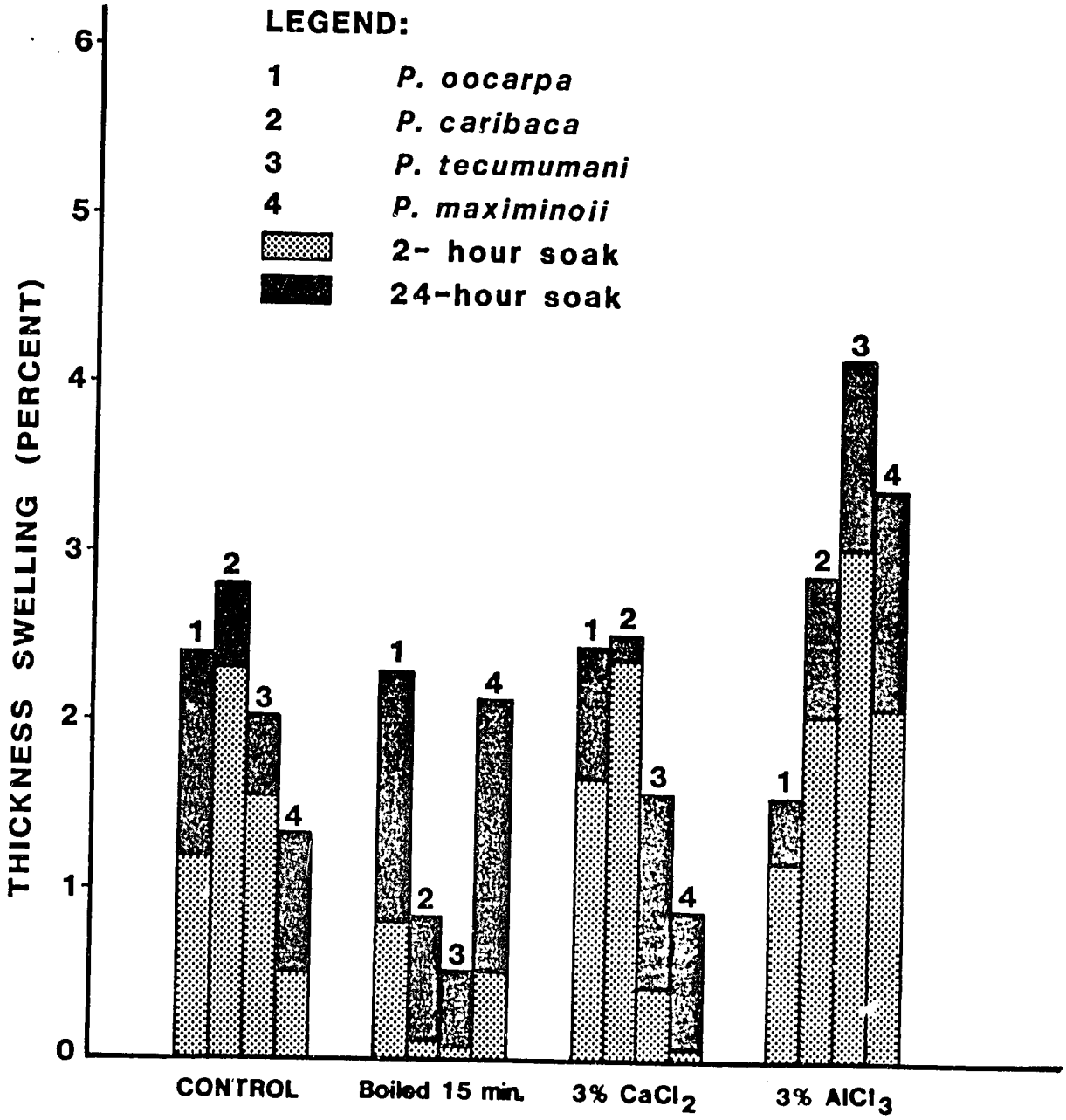


Figure 24. Modulus of elasticity for the four Honduran pine species and the various treatments used in this project.



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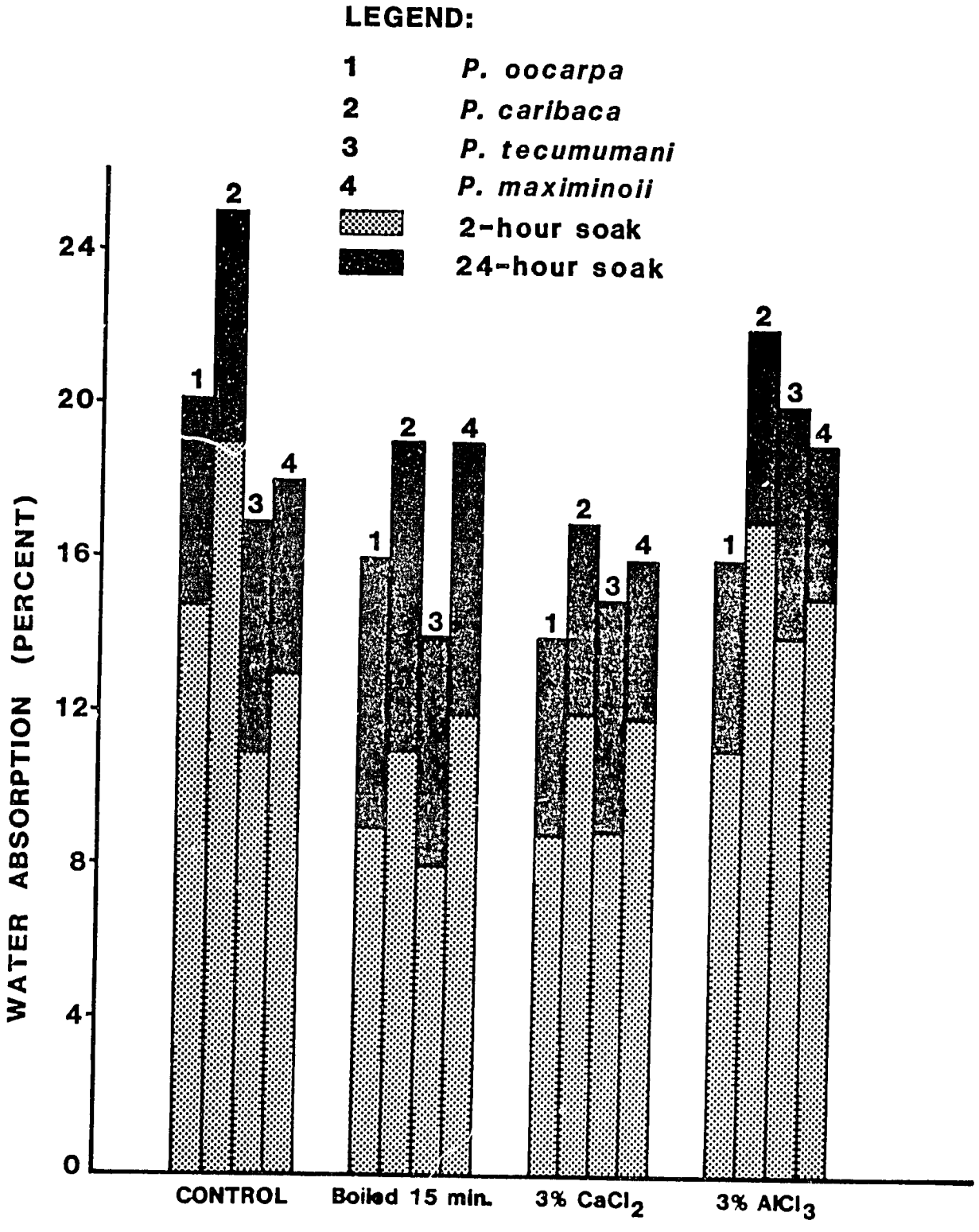

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LEGEND:

A *P. oocarpa* 3% $AlCl_3$ small particles (ESNACIFOR)
B *P. oocarpa* 5% $AlCl_3$ small particles (University of Idaho)
C *P. oocarpa* 5% $AlCl_3$ large particles (Flakes)
D *P. contorta* 1.5% $CaCl_2$ large particles (Flakes)
E Conventional particleboard (grade 1-H-1 or 2-H-1) ANSI A208.1-79

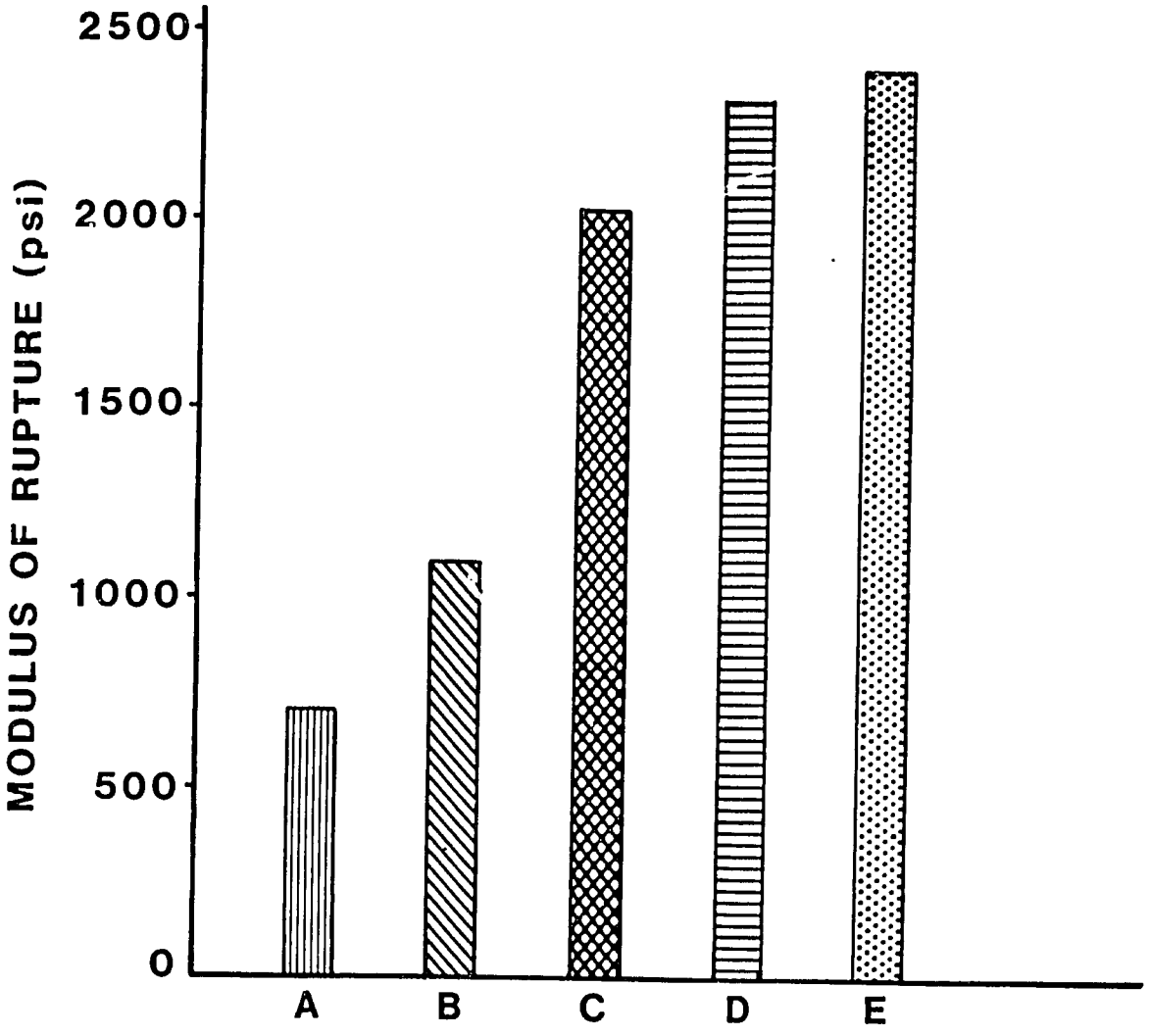

Figure 27. A comparison of the modulus of rupture,

LEGEND:

A *P. oocarpa* 3% $AlCl_3$ small particles (ESNACIFOR)
B *P. oocarpa* 5% $AlCl_3$ small particles (University of Idaho)
C *P. oocarpa* 5% $AlCl_3$ large particles (Flakes)
D *P. contorta* 1.5% $CaCl_2$ large particles (Flakes)
E Conventional particleboard (grade 1-H-1 or 2-H-1) ANSI A208.1-79

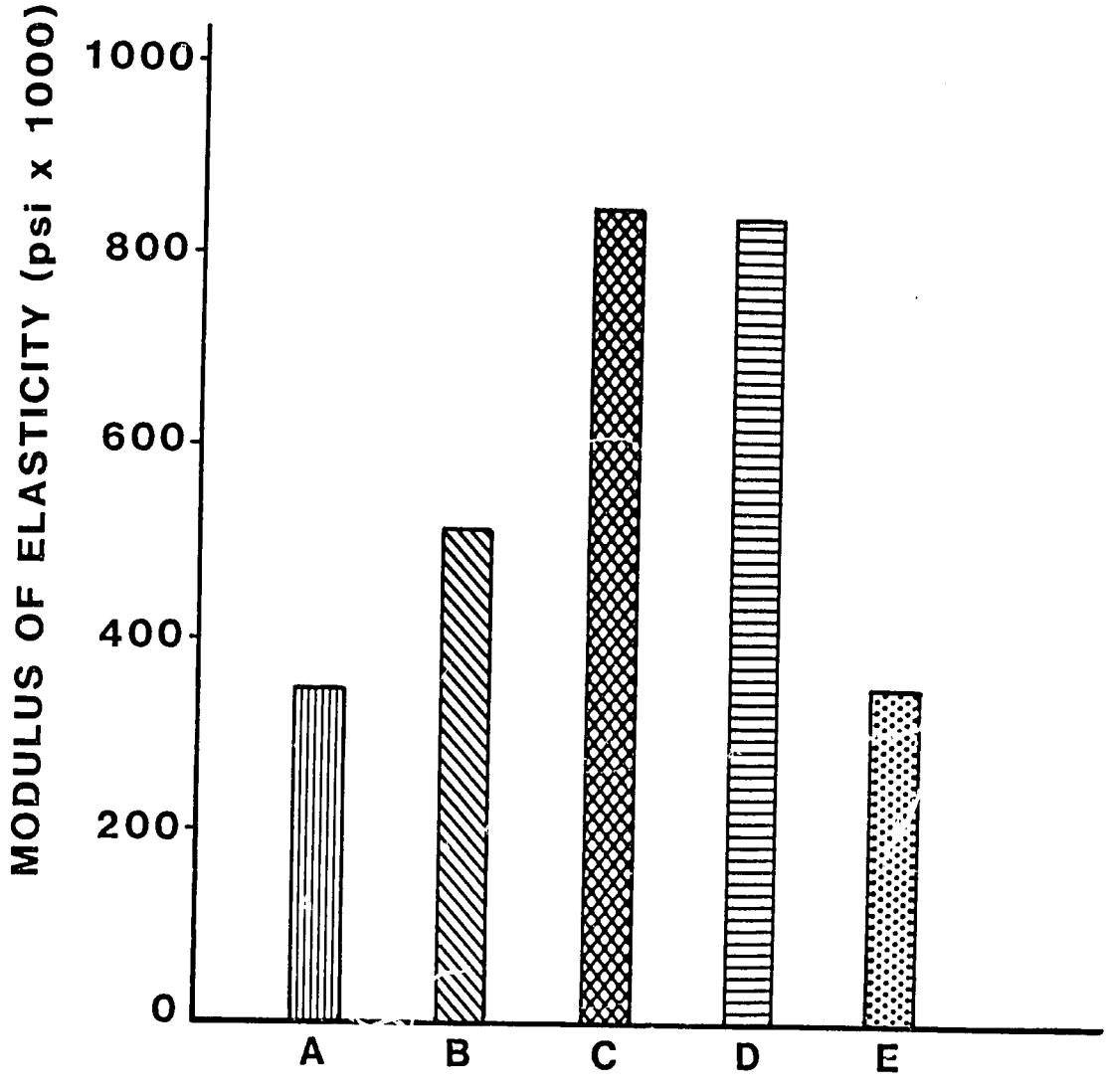

Figure 28. A comparison of the modulus of elasticity.

REPORTE FINAL

ADHESION DEL CEMENTO PORTLAND CON RESIDUOS DE MADERAS HONDUREÑAS PARA ELABORACION DE MATERIALES ESTRUCTURALES

Projecto No. AID/SCI 2E-17

Proyecto Cooperativo
entre

Escuela Nacional de Ciencias Forestales
Corporacion Hondureña de Desarollo Forestal
Siguatepeque, Honduras

y

El Departamento de Productos Forestales
Facultad Forestal, Vida Silvestre y Pastoreo
Universidad de Idaho
Moscow, Idaho, USA

Marzo 15, 1986

RESUMEN EJECUTIVO

El campo de aplicación de los tableros de cemento y madera presenta un impacto potencial en el desarrollo de los areas de la construcción habitacional. Los tableros de cemento y madera sobresalen entre otros productos por su resistencia al fuego, al ataque de hongos y otros enemigos naturales, asi como por su resistencia a condiciones de uso en exteriores y su excelente trabajabilidad (fáciles de cortar, clavar,pegar, pintar, etc). La materia prima requerida para su elaboración consiste en residuos de madera, cemento y agua, estos elementos estan disponibles en suficientes cantidades en Honduras y por lo tanto no implican la importación de resinas sintéticas que por su elevado precio son prohibitivas para un pais en desarrollo como Honduras. Los aditivos químicos usados ademas de ser requeridos en pequeñas cantidades son de naturaleza inorgánica (i.e. cloruro de calcio) y como asi mismo de bajo costo.

Los tableros de cemento y madera pueden ser utilizados con facilidad en el campo de construcción, requiriendose poco tiempo para el ensamblaje de casas, bodegas de almacenaje y otro tipo de construcciones. La tecnología de construcción usando tableros de cemento y madera esta actualmente disponible y con facilidad puede ser transferida a las condiciones de Honduras, especialmente en construcciones de areas rurales.

No obstante las ventajas mencionadas esta tecnología es muy

sensible a las características químicas de las especies utilizadas. Algunas especies son excelentes para la elaboración de tableros, mientras otras producen tableros muy débiles o no son adecuadas.. Este proyecto fue diseñado para encontrar las especies maderables de Honduras que mejor resultados presenten al ser utilizadas en combinación com cemento. Los resultados de las dos fases del proyecto indican que las cuatro especies de pinos de Honduras estudiadas presentarón muy buenas características para la elaboración de tableros de cemento y madera. El cemento producido en Honduras demostro,ademas buenas condiciones de fraguado al ser utilizado con partículas de adecuada geometría de estas especies, produciendose en consecuencia tableros con buenas propiedades físicas y mecánicas. Adicionalmente, los tableros de cemento y madera Hondureños exhiben excelente estabilidad dimensional al ser expuestos al agua. Esto indica que estos tableros pueden mantener su integridad al ser expuestos a la interperie, es decir al ser utilizados en exteriores.

No obstante, que los aspectos técnicos han sido abordados en este estudio, el estudio de pre-factibilidad económica se hace necesario como prerequisito a cualquier intento de implementación de la industria en Honduras. De esta manera un anteproyecto (propuesta) para el estudio de factibilidad económica ha sido preparado y el mismo se adjunta en este reporte de terminacion del proyecto. Para el cumplimiento de esta tercera y última fase del proyecto, se requiere el financiamiento necesario con el propósito de realizar el estudio de factibilidad a fin de generar la información básica económica y de mercado que asegure un exitoso desarrollo de esta industria, que no

solo podría impactar en el area de la construcción habitacional, si no que tambien podria en un futuro representar un producto de exportación para beneficio de la economía y pueblo Hondureño.

AGRADECIMIENTOS

En nombre del personal del proyecto queremos expresar nuestra gratitud a la Oficina de Asesoría Científica de la Agencia para el Desarrollo Internacional de los Estados Unidos de América por el financiamiento de este proyecto cooperativo. El agradecimiento se hace extensivo a los organismos responsables de este proyecto La Corporación Hondureña de Desarrollo Forestal (COHDEFOR) y la Universidad de Idaho en Estados Unidos de América por su amplia y decidida cooperación en todos los aspectos de este proyecto. Finalmente, en forma especial el agradecimiento para la Agencia de Desarrollo Internacional de los Estados Unidos con sede en Tegucigalpa D.C. Honduras por la administración del proyecto y su constante apoyo que hizo posible el término exitoso de este estudio.

A. A. Moslemi

Jose F. Garcia

Ruben Guevara

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ADHESION DEL CEMENTO PORTLAND CON RESIDUOS DE MADERAS HONDUREÑAS PARA ELABORACION DE MATERIALES ESTRUCTURALES

Objetivo de este reporte:

El objetivo de este documento es presentar los resultados obtenidos durante la segunda fase del proyecto de cooperación entre la Escuela Nacional de Ciencias Forestales (ESNACIFOR) en Honduras y la Universidad de Idaho en Estados Unidos de América. Los resultados de la primera fase de este proyecto fueron presentados en el reporte del 15 de Marzo de 1984, y del cual se adjunta copia en este documento.

La primera fase de este proyecto trata sobre la determinación del grado de compatibilidad entre un número de especies maderables de Honduras y el cemento Portland. Los objectivos fueron logrados mediante la realización de una serie de ensayos de hidratación diseñados originalmente en los laboratorios de la Universidad de Idaho. Para obtener información detallada sobre esta primera fase se aconseja al lector consultar el reporte de 1984 referido anteriormente. La segunda fase de este proyecto consistió en la elaboración de tableros de cemento y madera y en la determinación de las propiedades físicas y mecánicas de los mismos. La mayor parte de las actividades se realizaron en Honduras, con el objetivo en particular de entrenar científicos y personal de apoyo en la implementación de esta tecnología. No obstante que muchos logros se obtuvieron en la adquisición de equipo durante el desarrollo de este proyecto, se evidenció la falta de una Astilladora (chipper) y un molino para la fabricación de partículas de madera (flakes), así como de una prensa hidráulica para la fabricación apropiada de los tableros. Estas deficiencias y limitaciones de equipo aunque con dificultades fueron superadas durante el desarrollo del proyecto. En adición y a fin de generar un banco de información básica una pequeña cantidad de material fue transportado vía aérea de Honduras a la Universidad

de Idaho usandosepara la elaboracion de tableros y determinación las propiedades mecánicas (esfuerzos).

Objetivos Globales del Proyecto:

El enunciado de los objetivos de todo el proyecto está tipificado en la página 7 del reporte adjunto del 15 de Marzo, 1984. Sin embargo, es importante apuntar que en resumem, los principales objetivos fueron dos: (a) evaluar la factibilidad técnica de elaborar tableros de cemento usando materia prima Hondureña y (b) desarrollar en ESNACIFOR una capacidad de investigación en esta tecnología que pueda ser extrapolable más allá de este proyecto cooperativo entre las dos intituciones.

Antecedentes:

Tal y como se ha indicado en reportes anteriores Honduras es un país con un gran potencial forestal y particularmente con substancial abundancia de especies del género Pinus (Fig. 1). Estos recursos coníferos ocupan un área de alrededor de tres (3) millones de hectáreas. Durante la primera fase de este proyecto se determinó que las cuatro especies de pino estudiadas podrían ser utilizadas favorablemente en la elaboración de tableros en donde el cemento actua como adhesivo. En consecuencia la segunda fase de este proyecto consistió en la elaboración de tableros y la determinación de las principales propiedades físicas y mecánicas de las cuatro especies de pino estudiadas en la primera fase. Como puede observarse en la Figura 2, existen considerables cantidades de residuos disponibles que pueden ser utilizados en la elaboración de paneles estructurales de cemento y madera. Se estima que bajo las prácticas actuales de utilización los aserraderos obtienen un rendimiento de aproximadamiente 50%, convirtiendose en desperdicios el remanente. Estos residuos, a traves de la tecnologia de cemento madera, pueden ser incorporados en la elaboración de tableros estructurales, los cuales aumentarian substancialmente la calidad habitacional, en los sectores de menores ingresos de las áreas rurales del país.

Procedimiento experimental:

El proceso de elaboración de tableros y determinación de sus propiedades consistió basicamente en dos partes: (a) determinación de las propiedades mecánicas básicas de los tableros de cemento y madera elaborados en la Universidad de Idaho con *Pinus oocarpa* de Honduras y (b) determinación de las principales propiedades físicas y mecánicas en ESNACIFOR, Honduras, de tableros elaborados con cuatro diferentes especies de pinos Hondureños (*P. oocarpa*, *P. maximinoii*, *P. caribaea* y *P. tecumumanii*). Los objetivos de la parte (a) fueron los de establecer valores de comparación usando el más apropiado equipo tanto para la producción de partículas como para el prensado del tablero. Los objetivos de la parte (b) fueron los de desarrollar una capacidad adaptada a las condiciones reales de Honduras en este campo tecnológico y el cual pueda ser continuado después de la terminación de este proyecto.

(a) Experimentos realizados en la Universidad de Idaho:

Pequeñas cantidades de madera de *P. oocarpa* y cemento Hondureño fueron transportados a la Universidad de Idaho para la elaboración de tableros y determinación de sus propiedades. La madera de *P. oocarpa* una vez en Idaho fue convertida en partículas (flakes) de aproximadamente 1/2 pulgada de ancho y 1 pulgada de longitud y un espesor promedio de 0.022 pulgadas. El contenido de humedad promedio de las partículas fue de 9.4% habiendo sido almacenadas en bolsas plásticas por varios días previo a su utilización. Todas las partículas finas fueron extraidas. La proporción de cemento en relacion a la madera en base a peso fue de 3:1 para todos los tableros elaborados en Idaho. Además, aceleradores químicos tales como $AlCl_3$ y $CaCl_2$ fueron usados en proporción de un 5%

(basado en el peso del cemento). Los objetivos específicos fueron identificar las diferencias que puedan ser atribuibles ya sea al efecto del cloruro de aluminio o al cloruro de calcio. La cantidad de agua usada para cada tablero fue calculada en base a la siguiente fórmula (15, 17):

$$\text{Agua (litros)} = 0.35\ C + (0.30 - CH)\ Ps$$

Donde:

C = peso del cemento (kgs)

CH = contenido de humedad de la madera (en fracciones de unidad)

Ps = peso seco de la madera (kg)

El cemento utilizado fue, cemento portland tipo I producido por la Compania Piedras Azules en Comayagua, Honduras. La composición química del cemento se describió en la página 9 del reporte adjunto de 1984.

El proceso de mezclado y formación del tablero fue esencialmente similar al utilizado en Honduras (ver las tres proximas páginas de este reporte). Sin embargo, en el proceso de prensado, una prensa computarizada fue utilizada. La presión aplicada fue de 250 PSI (1.7 MPa) hasta alcanzar un espesor del tablero de 1/2 - pulgada. El tablero fue mantenido bajo presión por un período de 24 horas para permitir el fraguado del cemento y su facil manipulacion. Las dimensiones de los tableros elaborados fueron de 28 x 28 x 1/2 pulgadas. Inmediatamente después de las 24 horas del prensado se prepararon las muestras de 14 x 3 pulgadas y las mismas fueron almacenadas para su respectivo curado. A fin de minimizar un secado excesivamente rápido, las muestras fueron rociadas con agua destilada

y envueltas en papel celofan antes de su almacenamiento a una temperatura ambiente. Todas las muestras fueron curadas por 30 días antes de practicar las pruebas mecánicas.

Es importante notar que algunos tableros fueron hechos utilizando partículas de P. oocarpa pero con cemento portland tipo I producido en Estados Unidos de América. El objetivo en este último ensayo fue el de identificar si la fuente de cemento podría tener un impacto en las propiedades mecánicas de los tableros elaborados (12,18,19).

(b) Experimento realizado en Honduras:

Para esta parte del estudio pequenõs trozos de madera fueron obtenidos de las cuatro (4) especies de pino estudiadas, estos trozos fueron decortezados manualmente. La falta de una astilladora y molinos especiales para producir las partículas (flakes) obligó a la utilización de un cepillador eléctrico. Estas partículas así generadas fueron secadas en horno eléctrico hasta obtener un contenido de humedad promedio del 8%. La reducción final de estas partículas fue realizada mediante el uso de un molino adquirido con fondos del proyecto del tipo willey-mill. La clasificación por tamaño de las partículas se llevó a cabo mediante el uso de tamices clasificadores para producir partículas que en promedio fueran de: 1/4 - pulgada de ancho, 3/4 pulgada de largo y 0.02 pulgadas de espesor.

Cemento portland tipo I producido en Comayagua, Honduras fue utilizado. En vista que las características de hidratación del cemento varian con el tiempo de adquisición (18), el cemento utilizado fue siempre fresco y comprado directamente de la fábrica.

Una proporción de cemento/madera de 2.7 : 1 (en base a peso) fue usada en la elaboración de los tableros (Figuras 5 y 6). El material utilizado para elaborar los tableros sin aceleradores quimicos fue de 3727 gramos de cemento, 1377 gramos de madera y 1543 mililitros de agua a fin de alcanzar una densidad deseada de alrededor del 1.18 gr/cm3 (peso seco/volume seco). Para los tableros con aceleradores químicos la cantidad de químicos utilizada fue de un 3% en base al peso del cemento. Las dimensiones de los tableros elaborados fue de 22 x 24 x 1/2 pulgada. Las Figuras 7 - 16 ilustran, secuencialmente, el proceso de elaboración de tableros tal y como fueron hechos en los laboratorios de ESNACIFOR en Honduras. En todo caso la cantidad debidamente pesada de agua fue incorporada en las partículas de madera, para despues agregar el cemento y proceder al mezclado completo y uniforme de agua, partículas de madera y cemento. En el caso de tableros con aceleradores químicos (3% $CaCl_2$ ó 3% $AlCl_3$) éstos fueron incorporados uniformemente a la mezcla, previamente a la formacion del tablero. El material asi preparado (ver Figura9) fue pesado en una zaranda metálica de 1/4 de pulgada (Figura 12) y depositado en un molde o caja de formación el cual fue colocado sobre el plato inferior de la prensa manual sobre el cual se habia colocado a la vez un separador metálico previamente engrasado (Figura 10). Un separador metálico engrasado fue utilizado adicionalmente sobre el tablero en formación para el respectivo pre-prensado y prensado subsiguiente; el tablero así formado fue colocado en la prensa manual (Figuras 15,16 y 17) y prensado por un período de 24 horas. Inmediatamente después del prensado el tablero fue sacado de la

prensa (Figura 18) y curado a temperatura ambiente (24 C +- 3 C) por un período de 30 y 45 días antes de la determinación de las pruebas físicas y mecánicas (Figura 19). Tal y como se muestra en el Cuadro 1 un total de 12 tableros por cada especie fueron elaborados. De cada tablero se prepararon los especímenes necesarios para flexión estática y estabilidad dimensional. Un total de 2 muestras por tablero para el ensayo de flexión estática (3 x 14 x 12 pulgadas) fueron preparados para 30 días de curado y otras 2 muestras similares para tableros con 45 días de curado. El Cuadro 1 indica que 192 muestras y/o especímenes fueron necesarios para las pruebas de flexión estática. Para las pruebas de estabilidad dimensional (expansión en espesor y absorción de agua) el tamano de las muestras fue de 6 x 6 x 1/2 pulgadas. Para estas pruebas 192 muestras fueron requeridas a fin de poder examinar el efecto de los aceleradores químicos y el hervido de particulas de madera en la estabilidad dimensional del tablero (Figuras 20,21). Después del curado de los tableros básicamente se determinaron los esfuerzos en flexión, la densidad del tablero y la estabilidad dimensional. Los esfuerzos de flexión consistieron en la prueba de flexión estática a fin de determinar los valores de ruptura (R) y elasticidad (E) estos ensayos fueron realizados mediante el uso de la máquina universal para prueba de materiales INSTRON 1137 que posee ESNACIFOR (Figura19). Las pruebas de estabilidad dimensional consistieron en la determinación de la expansión en espesor (thickness swelling) y absorción de agua para 2 y 24 horas de inmersión en agua del tablero (Figura 23). Las especificaciones de las Normas Americanas para las Pruebas de

Materiales (ASTM 1037) (2) fueron usados en este proyecto. El número total de tableros y muestras preparadas y probadas en esta segunda fase del proyecto se presentan a continuación en el Cuadro # 1:

Cuadro 1. Número de parcelas y muestras utilizadas en la determinación de las pruebas físicas y mecánicas.

A. ELABORACIÓN DE TABLEROS

4 especies (*P. oocarpa*, *P. maximinoii*, *P. tecumumanii*, *P. caribaea*)

4 tratamientos (control, 15 minutos hervido, 3% $CaCl_2$, 3% AlCl)

3 repeticiones

Número total de tableros: 48

B. MUESTRAS PARA LAS PROPIEDADES FÍSICAS Y MECÁNICAS

(a) Módulos de ruptura y elasticidad para flexión estática (3''x 14''x 1/2'')

2 muestras para 30 días de curado

2 muestras para 45 días de curado

48 tableros

Número total de tableros: 192

(b) Expansión en espesor y absorción de agua (6''x 6'')

4 tratamientos (ver parte (a) arriba)

48 tableros

Número total de muestras: 192

Resultados y discusión:

Esta sección describe los resultados de los experimentos realizados en la Universidad de Idaho en Moscow, Idaho USA y aquellos realizados en los laboratorios de la Escuela Nacional de Ciencias Forestales (ESNACIFOR) en Siguatepeque, Honduras. La mayor parte de las actividades del proyecto se realizaron en ESNACIFOR, ésto a fin de alcanzar el objetivo principal que fue el de establecer una capacidad de investigación en esta área de la tecnología de la madera en Honduras. El trabajo desarrollado en la Universidad de Idaho implicó dos objetivos: (a) entrenar a personal Hondureño en todos aquellos aspectos relacionados con la elaboración de tableros, determinación de propiedades, y análisis y presentación de datos y (b) obtener una pequeña cantidad de datos base sobre las propiedades físicas y mecánicas del Pinus oocarpa de Honduras a fin de comparar estos valores con aquellos obtenidos en ESNACIFOR. Es oportuno indicar que la experiencia, las facilidades y el equipo que posee la Universidad de Idaho ha sido establecida a través de varias décadas y son apropiadas para la investigación y desarrollo de la tecnología de tableros de cemento y madera. Por otro lado las facilidades y equipo de ESNACIFOR, no obstante que fueron substancialmente mejoradas durante el transcurso de este proyecto cooperativo aún son limitadas, evidenciándose la falta de una astilladora y molinos para la producción de partículas apropiadas y una prensa hidráulica de suficiente potencia. Sin embargo, el personal de ESNACIFOR, ha sido bien entrenado y está en completa capacidad de continuar con proyecto de esta categoría en las diversas oportunidades que esta tecnología

demanda.

(a) Resultados obtenidos en la Universidad de Idaho:

Los resultados de los experimentos realizados en la Universidad de Idaho (involucrando P. oocarpa) se presentan en el Cuadro 2. Este cuadro muestra los resultados obtenidos al utilizar partículas (flakes) con longitud relativamente grande en relación al ancho y espesor de la misma. Con fines comparativos el Cuadro 2, muestra además los datos obtenidos para una de las mejores especies compatibles para la fabricación de tableros de cemento: Pinus contorta (lodgepole pine) (9). Cada valor presentado para Pinus contorta representa el valor promedio de 4 observaciones (muestras ensayadas). La información presentada, que ha sido estadisticamente analizada, consiste de datos obtenidos con cemento tipo I y tipo II producido en los Estados Unidos. Es importante destacar que los tableros hechos con Pinus oocarpa y cemento Hondureño generan resultados tan buenos como aquellos de Pinus contorta hechos con cemento producido en USA, ésto quedó más evidenciado en el caso del módulo de elasticidad (E), los valores para el módulo de ruptura (R) sin embargo resultaron un poco mas bajos que los de Pinus contorta. Otras comparaciones, presentadas en el Cuadro 2 (A), muestran valores de R y E para tableros de partículas tipo comercial hechos en Estados Unidos (ANSI A208.1 - 79) (1). Comparando los valores de este cuadro con los generados por los tableros de cemento y madera, se puede fácilmente colegir que no obstante los tableros de cemento y madera no son tan fuertes como aquellos de tableros de partículas, son sin embargo, considerablemente superiores en lo que respecta al módulo de

elasticidad. Este resultado obtenido es más que lógico ya que el cemento imparte rigidez al sistema de cemento madera aumentando el valor E (4,5,8,11).

Experimentos adicionales realizados en la Universidad de Idaho consistieron en la fabricación y prueba de tableros usando partículas finas (-7 +16 mesh size) producidas mediante el uso de un molino de martillos (hammermill). El Cuadro 3, muestra la reducción substancial en ambos R y E generada por el efecto de las partículas finas. Esta serie de ensayos evidencian la importancia de la geometría y tamaño de la partícula en relación a las propiedades finales de los tableros elaborados. El cemento Hondureño no dio resultados tan satisfactorios como el cemento obtenido en los Estados Unidos. Sin embargo, es muy posible que la reducción qualitativa en las propiedades experimentada se deba a efectos de deterioro natural con el tiempo del cemento Hondureño utilizado en dichos experimentos.

Cuadro 2. COMPARACIÓN DE LAS PROPIEDADES MECÁNICAS DE TABLEROS DE CEMENTO Y MADERA DE PINUS OOCARPA Y TABLEROS DE PINUS CONTORTA (LODGEPOLE PINE). (10)

	Pinus oocarpa(1)				Pinus contorta (2)		
Prueba No.	Densidad gr/cm3	Módulo Ruptura R (PSI) PSI)	Módulo Elastic. E (1000 PSI)	:	Densidad gr/cm3	Módulo Ruptura R (PSI)	Módulo Elastic. E (1000)
Prueba 1	1.4	2208*	960*	:	1.3	2296-	797-
Prueba 2	1.3	1848*	750*	:	1.3	2241-	836+

(1) 5% AlCl3 30 días de curado (2) 1.5%CaCl2 28 días de curado
(*) Cemento Tipo I de Honduras (-) Cemento Tipo I de USA
(+) Cemento Tipo III de USA

Cuadro 2(A). PROPIEDADES MECÁNICAS DE TABLEROS DE PARTÍCULAS COMERCIALES (ANSI A208.1 -79) (1)

Grado	Módulo de Ruptura R (PSI)	Módulo de Elasticidad E (1000 PSI)
1 - H - 1*	2400	350
1 - H - 2*	3000	350
1 - H - 3*	3400	400
2 - H - 1+	2400	350
2 - H - 2+	3400	400

(*) Tableros de partículas hechos con Urea-formaldehido
(+) Tableros de partículas hechos con Fenol-formaldehido

(b) Resultados obtenidos en ESNACIFOR:

Los resultados obtenidos en esta serie de experimentos se presentan en los Cuadros 4 al 7, los cuales muestran valores promedios obtenidos para cada una de las cuatro especies ensayadas. Tanto las propiedades mecánicas como la estabilidad dimensional se presentan en estos cuadros. La estabilidad dimensional abarca en este estudio la expansión en espesor y la absorción de agua. La expansión lineal no fue incluida ya que ha sido bien establecido en otros estudios (13,16,20) que los cambios dimensionales y longitudinales usando pruebas estandarizadas son menores al 0.1% y por lo tanto sin mayor importancia en el caso de tableros de cemento y madera.

El Cuadro 4 muestra los resultados de las propiedades mecánicas y el espesor de hinchamiento para *Pinus oocarpa*. Una comparación entre los resultados del Cuadro 4 y los datos reportados previamente en el Cuadro 2 indican que tanto el valor de R y E obtenido en ESNACIFOR son considerablemente menores a los obtenidos para la misma especie en la Universidad de Idaho. La razón principal se atribuye al tamaño y geometría de las partículas producidas en ESNACIFOR. En estudios anteriores realizados en Idaho ha quedado claramente evidenciado que partículas producidas con equipos inadecuados producen malos resultados (forma irregular, corte a través del grano, etc), es más se comprobó recientemente (14) que los valores de R y E son menores cuando se usan mas partículas pequeñas (shavings) que largas (flakes). Otro factor de considerable peso que influyó en los valores bajos de R y E obtenidos en ESNACIFOR fue sin lugar a dudas el uso de la prensa manual para el prensado de los tableros. El tiempo extra de curado entre 30 y 45 días no tuvo ningún efecto significativo en los valores de R y E. Estos

resultados en particular son consistentes con estudios anteriores realizados en Idaho con lodgepole pine (10). En el estudio recién apuntado se comprobo que comparando los valores de R y E alcanzados a 14 y a 28 días de curado no existen diferencias significativas ya que los valores de R en un 95 a 98% son alcanzados en los primeros 14 dias de curados. En igual forma en dicho estudio quedó comprobado que un 84 a 100% del valor de E es alcanzado a los 14 días de curado de los tableros. La adición de Al_2Cl_3, sin duda mejoro los valores de R y E alcanzados, pero no mostro ser tan efectivo como al usar $CaCl_2$.

Cuadro 3. PROPIEDADES MECÁNICAS DE TABLEROS DE CEMENTO Y MADERA ELABORADOS CON PARTÍCULAS PEQUEÑAS DE *PINUS OOCARPA* EN LA UNIVERSIDAD DE IDAHO*.

Prueba	Aditivo	Fuente y tipo de cemento	Densidad	Contenido humedad(%)	R (PSI)	E (1000PSI)
1A	5% AlCl3	Honduras Tipo I	1.3	9.8	1008	460
1B	5% AlCl3	Honduras Tipo I	1.3	9.9	1176	580
2A	5% AlCl3	USA - Tipo I	1.3	9.8	1513	700
2B	5% AlCl3	USA - Tipo I	1.3	9.8	1416	640
4A	5% AlCl3	USA - Tipo I	1.4	10.4	1392	830
4B	5% AlCl3	USA - Tipo I	1.3	10.5	1248	500
5A	5% CaCl2	USA - Tipo I	1.4	9.9	1536	620
5B	5% CaCl2	USA - Tipo I	1.3	9.6	1176	590

(*) El tamaño de la partícula en todos los casos fue de malla -7 +16.

Los tableros elaborados en general exhibieron excelente estabilidad dimensional en lo que concierne a expansión en espesor, la cual fue en todos los casos inferior al 2%. Los resultados así obtenidos son similares a los de varios estudios en donde ha quedado evidenciado que los tableros de cemento y madera muestran excelente estabilidad dimensional al ser sumergidos en agua (5,7,10,15). Los valores de absorción de agua fueron relativamente altos, ésto probablemente como una consecuencia de la naturaleza porosa de los tableros, producto de la geometría de las partículas (shavings) utilizadas.

Observaciones similares pueden ser colegidas al analizar los resultados obtenidos con los otros tres pinos estudiados, sin embargo los valores de estos pinos tanto para R como para E son por lo general más altos que los reportados para Pinus oocarpa sin ningun tratamiento (Cuadros 5,6 y 7).

La Figura 23 establece una comparación entre los valores de R para las diferentes especies estudiadas y los respectivos tratamientos usados. Las diferencias observadas son atribuibles al efecto de las especies y de los tratamientos usados. Los datos claramente indican que la adicion del 3%$CaCl_2$ aumentan substancialmente los valores de R para las cuatro especies de pino. La adición de Al_2Cl_2 también tiene un efecto positivo pero menos efectivo que el $CaCl_2$. El tratamiento consistente en hervir la madera para extraer las substancias solubles en agua no resultó ser de mucho beneficio en el aumento del módulo de ruptura de las especies ensayadas.

Los valores de E, presentados en la Figura 24, también revelan la importancia de la adición del $CaCl_2$. Un efecto bastante significativo se obtuvo con las especies P. oocarpa, P. tecumumanii y P. maximinoii cuando se agregó un 3% de $CaCl_2$ en base al peso del cemento. Los valores de E también fueron aumentados con la adición de Al_2Cl_3, sin embargo no mostraron la efectividad agregada por el $CaCl_2$.

Cuadro 4. VALORES PROMEDIOS DE LAS PROPIEDADES MECÁNICAS DE TABLEROS DE CEMENTO Y MADERA PARA *PINUS OOCARPA*.

Tiempo curado (dias)	Tratamiento	Densid. gr/cm3	R* (PSI)	E* (1000PSI)	Expansión en+ espesor (%) 2 hrs.	24 hrs.	Absorción+ de agua(%) 2 hrs.	24hrs.
30	control	1.18	368.35	132.83	1.21	2.42	14.67	20.21
	15 minutos hervido	1.23	476.08	239.05	0.81	2.28	8.84	15.62
	3% $CaCl_2$	1.34	967.12	354.36	1.64	2.42	9.30	13.91
	3% Al_2Cl_3	1.34	716.68	350.65	1.15	1.57	10.53	15.57
45	control	1.18	325.08	175.24	2.22	3.39	18.58	21.38
	15 minutos hervido	1.23	451.44	232.86	2.15	3.61	15.86	20.69
	3%$CaCl_2$	1.37	895.84	392.14	0.84	3.30	11.10	15.96
	3%Al_2Cl_3	1.25	684.04	372.82	1.63	2.46	11.06	15.00

(*) valor promedio de 6 muestras
(+) valor promedio de 3 muestras

Cuadro 5. VALORES PROMEDIOS DE LAS PROPIEDADES MECÁNICAS DE TABLEROS DE DE CEMENTO Y MADERA PARA PINUS TECUMUMANII.

Tiempo curado (dias)	Tratamiento	Densid. gr/cm3	R* (PSI)	E* (1000PSI)	Expansión en+ espesor (%) 2 hrs.	24 hrs.	Absorción+ de agua (%) 2 hrs.	24hrs.
	control	1.09	622.16	333.36	1.58	2.05	11.15	17.10
30	15 minutos hervido	1.10	716.32	334.25	0.06	0.51	8.28	13.99
	3% CaCl2	1.16	1120.08	511.76	0.41	1.57	9.38	14.74
	3% Al2Cl3	1.04	739.52	358.53	3.03	4.16	14.40	19.54
	control	1.09	587.84	325.57	2.87	3.26	13.64	18.66
45	15 minutos hervido	1.08	750.64	321.43	1.66	3.25	10.44	15.74
	3%CaCl2	1.16	1119.36	399.36	1.76	1.71	9.66	14.55
	3% Al2Cl3	1.11	839.52	347.57	5.57	6.01	14.64	18.96

(*) valor promedio de 6 muestras
(+) valor promedio de 3 muestras

Cuadro 6. VALORES PROMEDIO DE LAS PROPIEDADES MECÁNICAS DE TABLEROS DE CEMENTO Y MADERA PARA *PINUS MAXIMINOII*.

Tiempo curado (dias)	Tratamiento	Densid. gr/cm3	R* (PSI)	E* (1000PSI)	Expansión en+ espesor (%) 2 hrs.	24 hrs.	Absorción+ de agua(%) 2 hrs.	24hrs.
	control	1.08	471.16	252.04	0.54	1.37	12.69	18.46
30	15 minutos hervido	1.12	630.08	329.09	0.51	2.13	12.36	19.03
	3% CaCl2	1.16	880.88	354.22	0.05	0.89	11.68	15.81
	3% Al2Cl3	1.11	701.36	394.87	2.09	3.40	14.84	19.37
	control	1.13	514.80	270.95	0.96	2.73	15.48	20.57
60	15 minutos hervido	1.09	544.56	285.13	4.07	4.51	17.33	22.76
	3% CaCl2	1.17	920.48	378.77	1.70	1.74	13.70	17.28
	3% Al2Cl3	1.14	643.28	346.14	3.20	3.26	17.95	21.71

(*) valores promedios de 6 muestras
(+) valores promedios de 3 muestras

Cuadro 7. VALORES PROMEDIOS DE LAS PROPIEDADES MECÁNICAS DE TABLEROS DE CEMENTO Y MADERA PARA *PINUS CARIBAEA*.

Tiempo curado (dias)	Tratamiento	Densid. gr/cm3	R* (PSI)	E* (1000PSI)	Expansión en+ espesor (%) 2 hrs.	24 hrs.	Absorción+ de agua(%) 2 hrs.	24hrs.
	control	1.13	887.92	454.57	2.35	2.83	19.45	24.68
30	15 minutos hervido	1.09	438.24	234.13	0.09	0.83	11.34	18.65
	3% CaCl2	1.20	826.32	385.51	2.37	2.51	11.93	19.27
	3%As2Cl3	1.10	587.84	328.78	2.04	2.88	17.04	22.26
	control	1.10	629.20	321.81	2.48	4.54	16.78	24.53
45	15 minutos hervido	1.07	512.16	304.13	1.59	3.05	15.09	20.96
	3% CaCl2	1.21	856.24	417.54	0.49	0.94	12.21	16.63
	3% Al2Cl3	1.05	491.04	294.36	3.34	3.72	22.38	26.91

(*) valores promedios de 6 muestras
(+) valores promedios de 3 muestras

Los análisis de varianza realizados para detectar diferencias entre especies y tratamientos, resultaron con valores de F significativos al 99% en todos los casos. Los datos claramente indican que la adición del 3% $CaCl_2$ aumentan sustancialmente los valores de R para las cuatro especies de pino. La adición de $AlCl_3$ también tiene un efecto positivo pero menos efectivo que el $ClCl_2$. El tratamiento consistente en hervir la madera para extraer las sustancias solubles en agua no resultó ser de mucho beneficio en el aumento del módulo de ruptura de las especies ensayadas.

Los valores de E presentados en la Figura 24 revelan la importancia de la adición del $CaCl_2$. Un efecto estadísticamente significativo al 99% de probabilidad, se obtuvo con las especies P. oocarpa, P. tecumumanii y P. maximinoi, cuando se agregó un 3% de $CaCl_2$ en base al peso del cemento. La remoción de extractivos solubles en agua mediante la aplicación de hervido durante 15 minutos no mostró efectos significativos en los valores correspondientes al módulo de elasticidad.

La expansión en espesor (thickness swelling) es una crítica e importante propiedad para muchas aplicaciones, principalmente cuando el material estructural es sometido al contacto con el agua. La Figura 25 ilustra que la expansión durante 2 y 24 horas es relativamente poca y prácticamente insignificante.

La remoción de extractivos con agua hervida (15 minutos) mejora la expansión en espesor. Contrariamente, los tableros bajo la adición de Al_2Cl_3 exhibieron menor grado de estabilidad dimensional al ser sumergidos en agua. La Figura 26 ilustra el comportamiento de los

tableros en lo que respecta a absorción de agua. Las muestras con $CaCl_2$ permitieron la menor cantidad de agua mientras que las muestras sin ningún tratamiento (control) permitieron un porcentaje mayor de agua. La Figura 26 claramente muestra que el mayor percentaje de agua absorbida por el tablero toma lugar en las primeras dos horas de inmersión.

La Figura 27 ilustra relaciones de mucho interés conrespceto a los valores del módulo de ruptura. Estos gráficos de barra compara datos obtenidos en estudios previos (1,10) con los datos obtenidos en ESNACIFOR y aquellos obtenidos con Pinus oocarpa en la Universidad de Idaho. Estas comparaciones también incluyen valores para tableros hechos con pequeñas partículas y particulas con el tamaño y geometría apropiados para la elaboración de este tipo de tableros. La Figura 27 muestra que los tableros elaborados en ESNACIFOR generaron valores de R más bajos. Los tableros hechos en Idaho generaron valores más altos para el módulo de ruptura, principalmente en el tipo de partícula que fue posible producir con el equipo disponible en la Universidad de Idaho. Los tableros hechos con partículas grandes (flakes) generaron valores 3 veces más altos que los producidos en ESNACIFOR con similares densidades. Estos tableros de particulas grandes (flakes) poseen valores de R el doble que aquellos hechos con la misma tecnología en la Universidad de Idaho pero utilizando partículas más pequeñas (shavings).

Al comparar los tableros hechos con Pinus oocarpa y cemento tipo I de Honduras con tableros hechos con Pinus contorta (USA cemento-tipo I) no se encuentran diferencias significativas. Estos resultados son

halagadores si se considera que Pinus contorta es una de las especies de mayor futuro para la fabricación de tableros de cemento y madera reportada en los Estados Unidos (9). Comparando estos tableros con tableros de partículas convencionales usando adhesivos en base a urea y fenol formaldehido (1) se puede observar que los valores de los tableros de cemento y madera son menores para R. Sin embargo, los valores de E para los tableros de cemento y madera son superiores a los de tableros de partículas tal y como se evidencia de la Figura 28.

CONCLUSIONES Y RECOMENDACIONES

La primera conclusión que genera este estudio es que las especies de pino hondureño son apropiadas para la fabricación de tableros de cemento y madera. Esta conclusión ha sido posible a través de la ejecución de las dos fases de este proyecto cooperativo el cual ha involucrado entrenamiento substancial y participación activa de personal técnico de la Escuela Nacional de Ciencias Forestales en Siguatepeque, Honduras. La primera fase de este proyecto consistió en la determinación del índice de inhibición de especies Hondureñas a través de una serie intensiva de ensayos de hidratación. Esta fase fue completamente reportada en el informe de progreso de marzo de 1984 y el cual se adjunta al final de este documento. En esa fase se concluyó en forma parcial que las cuatro especies de pino ensayadas exhibían buena compatibilidad con el cemento y que por lo tanto tenían un gran potencial como materia prima para la implementación de esta tecnología en Honduras. Sin embargo es importante destacar que varias otras substancias biomásicas fueron totalmente descartadas. Para detalles completos sobre esta primera fase el lector es referido a las páginas 40 y 41 del informe previamente mencionado.

Durante la segunda fase de este proyecto, la elaboración de tableros y determinación de las propiedades físicas y mecánicas representaron el principal quehacer del proyecto. La mayor parte de los experimentos se realizaron en ESNACIFOR y los resultados fueron obtenidos y estadísticamente analizados por personal técnico de Honduras bajo la supervision de personal técnico y científico de la

Universidad de Idaho. En esta fase del proyecto se determinó que las cuatro especies pueden producir técnicamente buenos tableros de cemento y madera. Sin lugar a duda se concluye que al refinar esta tecnología principalmente mediante la producción de partículas con buen coeficiente de esbeltéz (buena geometría) se pueden producir tableros con adecuada densidad y excelentes propiedades mecánicas para el uso estructural de los mismos. Por ejemplo, comparando los valores de flexión estática (R y E) obtenidos usando P. oocarpa con los valores obtenidos con una de las mejores especies para tableros como es el Pinus contorta se concluye que no existen diferencias significatívas entre ambas especies. Las otras especies de pinos Hondureños tales como P. caribaea, P. maximinoii y P. tecumumanii también son candidatos prometedores para producir tableros de cemento y madera con excelentes propiedades, siempre y cuando se generen las partículas adecuadas para la elaboración de los tableros.

La expansión en espesor (thickness swelling) al sumergir los tableros en agua también resultó ser excelente. Los tableros hondureños han demostrado poseer muy buena estabilidad dimensional al sumergirse en agua. Esto indica categóricamente que estos tableros así elaborados exhiben buena estabilidad dimensional y por ende son apropiados para su uso en exteriores.

Durante 1985, cuando los resultados preliminares comenzaron a ser prometedores para la posible elaboración de tableros de cemento y madera en Honduras, se dedicó cierta porción de tiempo para el desarrollo de un anteproyecto (propuesta) de estudio de factibilidad económica para la instalación de esta industria en Honduras. Para que

esta tecnología pueda ser implementada en Honduras con buen exito, tanto la factibilidad técnica como la económica deben ser realizadas. Con la terminación de este proyecto la factilidad técnica ha sido concluida. La Universidad de Idaho en conjunto con ESNACIFOR, está actualmente buscando financiamiento por parte de la Agencia Internacional de Desarollo de los Estado Unidos a fin de poder realizar el estudio de factibilidad económica. Una copia borrador de la factibilidad economica tambien se adjunta a este informe de terminación del proyecto. Finalmente, se recomienda que el estudio de factibilidad económica sea continuado de inmediato a fin de que la información básica sea generada para la implementación industrial de esta tecnología, la cual sin lugar a equivocaciones es de capital importancia par el desarrollo habitacional de Honduras.

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REPORTES DE PROGRESO

Desde la iniciación de este proyecto, alrededor de 11 reportes de progreso han sido producidos. Tres de estos reportes fueron detallados y completos. A continuación se presenta una lista de los fechas en que los reportes fueron preparados:

Enero 1983*	Marzo 1984*
Junio 1983	Julio 1984
Julio 1983	Agosto 1984
Agosto 1983	Abril 1985 (2 reportes)
Septiembre 1983	Abril 1985

Los reportes sin asterisco fueron documentos menores intercambiados entre colaboradores (ESNACIFOR y la Universidad de Idaho). Los reportes con asteriscos fueron reportes completos y enviados a un número de personas y organizaciones tal y como se indica a continuación:

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MANUSCRITOS PREPARADOS

Un manuscrito basado en los resultados de la primera fase de este estudio fue preparado y submitido al IX Congreso Mundial Forestal celebrado en Junio/Julio de 1985 en la Ciudad de México. El título del documento fue "Compatibilidad entre la Madera de Pinos Hondureño y el Cemento Portland", escrito por Ing. José F. García, Dr. A. A. Moslemi y Das. Astor U. Urbina.

VISITAS REALIZADAS POR EL PERSONAL DEL PROYECTO

Durante el desarrollo de este proyecto cooperativo, investigadores tanto de ESNACIFOR como de la Universidad de Idaho realizaron visitas recíprocas con el propósito de intercambio científico o de entrenamiento en servicio. En adición, una serie de presentaciones fueron dadas durante estas visitas ya sea a colegas o estudiantes específicamente; el Professor A. A. Moslemi visitó ESNACIFOR en Mayo 16-25, 1983; Diciembre, 5-7, 1983; Agosto 14-18, 1984; Febrero 24 - Marzo 3, 1985 y Julio, 12-17, 1985. El Ing. José F. García permaneció durante el período Febrero 20 a Marzo 10, 1984 en la Universidad de Idaho. También el Dasonomo Astor U. Urbina recibió un entrenamiento intensivo en elaboración de tableros y determinación de propiedades físicas y mecánicas en la Universidad de Idaho durante el período de Abril, 6-18, 1985. El Ing. García en conjunto con el Dr. A. A. Moslemi preparó el reporte correspondiente a la primera fase del proyecto durante el viaje de Febrero 1985. Adicionalmente, Dr. Ruben Guevara, Director de ESNACIFOR, visitó la

Universidad de Idaho en Mayo de 1985 y viajo en compania del Dr. A. A. Moslemi a Washington D.C. a fin de entrevistarse con personal del US AID y a la vez dar una presentación a los cientificos del AID en Washington sobre el proyecto. Durante las cinco visitas a Honduras del Dr. A. A. Moslemi además de la asesoria tecnica y presentaciones en ESNACIFOR también visito al personal ejecutivo (tecnico y administrativo) de COHDEFOR en Tegucigalpa, Honduras. Finalmente se mencionan las visitas del Dr. Alton Campbell y Dr. Peter Steinhagen, científicos de la Universidad de Idaho quienes dieron asesoramiento tecnico durante sus respectivas viajes. Un tablero especial para divulgar los logros de este proyecto se exhibe en la entrada principal del Centro Nacional de Investigación Forestal Aplicada (CENIFA) en ESNACIFOR.

PERSONAL INVOLUCRADO EN EL PROYECTO

A) UNIVERSIDAD DE IDAHO

Dr. A. A. Moslemi - Director del Proyecto
Dr. A. G. Campbell - Wood Chemist
Dr. Peter S. Steinhagen - Tecnologo de la Madera
Mr. Stephen C. Pfister - Investigador Assistente
Mr. David Ritter - Investigador Assistente

B) ESNACIFOR

Ing. José Francisco García - Lider del Proyecto
Das. Astor Uriel Urbina - Sub-Lider del Proyecto
Dr. Rubén Guevara - Director ESNACIFOR
Das. Mauricio Cubas - Colaborador
Sr. Antonio Zavala - Asistente de Laboratorio
Sr. Orlando Cuestas - Tecnico de Laboratorio
Sr. Gabriel Alvarego - Asistente de Laboratorio
Sr. Olman Rodriguez - Asistente de Laboratorio
Sec. Edith Castañeda - Secretaria del Proyecto

C) Agencia para el Desarrollo Internacional (Tegucigalpa)

Mr. Anthony J. Canterucci, Director
Mr. Marc Scott
Mr. Felipe Manteiga
Mr. Ramón Alvarez
Mr. Julio Zepeda

Progress Report

Bonding of portland cement with Honduran Wood Biomass for structural materials

Project Number

AID/SCI 2E - 17

A Cooperative Project
Between

Escuela National de Ciencias Forestales
Corporation Hondurena de Desarrollo Forestal
Siguatepeque, Honduras

and

Department of Forest Products
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, Idaho, USA

March 15, 1984

Funds for this project are provided by the Agency for International Development (US AID) and Corporacion Hondurena de Dessarollo Forestal (COHDEFOR) under Cooperative project agreement AID/SCI 2E - 17 signed 22 December 1982.

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BONDING OF PORTLAND CEMENT WITH HONDURAN WOOD BIOMASS FOR STRUCTURAL MATERIALS

The Objective of this Report: The primary objective of this document is to report on the first phase of this cooperative research. This phase involves determining the compatibility of wood with cement using several Honduran wood species and sugar cane as potential raw material for cement-bonded structural panels. The compatibility determination was performed by hydration experiments monitoring such hydration data as maximum temperature of the cement-wood-water mixture, time required to maximum temperature and the slope of the time-temperature curve. Prior experience with other species points to these data as important parameters when determining wood-cement compatibility and eventual strength development in the resultant cement-bonded panel. This report presents a preliminary analysis of the hydration data obtained over the last 10 months. It delineates the potential of the selected Honduran species for possible technological development in the field of cement-bonded structural panel manufacture in Honduras.

Background: Honduras is a country of substantial forest resources. Large areas of the land is covered by both softwood and hardwood forests. Some 63% of the country is forested with several pine species and a large number of hardwoods. Specifically four pine species* cover some 3 million hectares (See Figure 1). Hardwoods, on the other hand, cover even a larger area amounting to some 4 million hectares. Although the pines involve a smaller area than hardwoods, much of the Honduran forest products industry is concentrated in the pine regions. Sawmilling is the primary form of utilization with two plywood plants also using peeler pine logs to produce structural plywood.

*The four species in order of abundance are: *Pinus oocarpa, Pinus maximinoii, Pinus caribaea* and *Pinus tecumumanii.*

Under current utilization standards, up to 50% of the useable wood is left as waste either as logging or sawmill residue(12). The logging waste is composed of useable tree portions which are left behind in the woods upon completion of the harvesting process. The minimum diameter specified for tree removal is 30 cm. Material smaller than this size and larger material of low quality are left in the woods. The sawmilling industry considers the removal of this material uneconomical. Economic uses for this material is, therefore, needed to improve resource use and generate economic activity and employment in Honduras.

The sawmills also dispose much of their manufacturing residue as useless waste. This residue includes planer shavings, sawdust, trimmings, bark and edgings. The uses of this substantial resource need urgent attention to strengthen the economic posture of the country and possibly even generate hard currency through the export of the products made from this resource. In addition to the logging and mill waste, there is also need to utilize thinnings which are produced periodically to improve the silvicultural practice and enhance sawlog production in the pine lands.

A logical course of action involves production of particleboard. This product is composed of wood particles held together by a resin binder (adhesive). It is a well-established industry in many parts of the world using wood waste and such binders as urea formaldehyde or phenol formaldehyde. However, both urea formaldehyde and phenol formaldehyde are natural gas based and would have to be imported by Honduras at a substantial cost. In fact, preliminary estimates point to the possibility of some 40-50 percent of the panel costs being the cost of the binder. On the other hand, the cement-bonded particleboard panels have several distinct advantages for the Honduran setting: all required raw material is available locally, the product is well suited for the tropical climates and the capital costs are lower than resin-bonded particleboard. A major question is whether Honduran wood waste is suitable for cement-bonded panels. Prior research with other species (5, 6) show that cement setting (hardening) is highly species sensitive. Research at

the University of Idaho and elsewhere clearly shows that a relatively high degree of compatibility exists between wood and cement for some species such as lodgepole pine (*Pinus contorta*) while other species, such as larch (*Larix occidentalis*) are highly inhibitory to cement hardening (7). It is, therefore, essential to establish the degree of compatibility which may exist between Honduran wood species and cement made locally.

Objectives of the Total Project: The basic objectives of this project are simply to shed light on: (a) the viability of several carefully selected raw material sources for a mineral-bonded structural panel industry, (b) why the various species react with to the cement binder in the way they do, (c) what bonding mechanisms may be involved and what affects those mechanisms and (d) building a scientific research capability in the field of wood science and technology at the Honduran national forestry school (Escuela Nacional de Ciencias Forestales) at Siguatepeque, Honduras

The Raw Material: Since much of the wood waste (logging, mill residue and forest thinnings) are concentrated in several locations in the pine region, it became clear that the wood of the four pine species noted on page 1 need to be examined. Among the four pines, *P. oocarpa* is the most important raw material being logged and brought into the mills. This pine grows usually at 600-1600 meters in elevation. It is a "hard" pine with a wood density of about 0.52. To the unfamiliar eye, its wood resembles that of southern pines in the United States. Other pines, namely *P. maximinoii* (elevation: 1100-1800 m.), *P. caribaea* (elevation 20-700 m.), and *P. tecumumanii* (elevation 1700-2400 m.), have a wood density range of 0.42-0.52. Wood properties are similar among these pines with all used for lumber production. The wood from these pines as well as their bark were included in hydration experiments carried out over the first phase of this project. Bark levels at 50% and 100% (all bark) were tested to determine their inhibitory characteristics on portland cement. Table 1 illustrates the location where the pine raw material was gathered. In addition, the series

Table 1: The location, altitude, age and specific gravity of the raw material selected for this study.

SPECIES	COMMON NAME	SPECIFIC GRAVITY	AGE (YEARS)	ALTITUDE	LOCATION
Pinus oocarpa	Pino ocote	0.52	20	1000	ESNACIFOR Forest Siguatepeque
Pinus maximinoii	Pino triste	0.42	16	1200	La Danta, Siguatepeque
Pinus caribaea	Pino costanero	0.50	24	710	Lago de Yojoa Siguatepeque
Pinus tecumumanii	Pino rojo	–	15	1200	La Danta, Siguatepeque
Vochysia hondurensis	San Juan	–	19	100	Lancetilla, Tela
Saccharum officinarum	Cana				Taulabe, Siguatepeque

Table 2: The composition of Piedrasugules cement used in the experiment.

COMPONENT	PERCENTAGE
Silicon	21.3
Aluminum	5.0
Iron	3.1
Calcium	65.2
Magnesium	2.1
Sulfur trioxide	3.0
Residue of steel	1.8
Free calcium	1.5
Tricalcium silicate	65.3
Dicalcium silicate	11.9
Tricalcium aluminate	8.9
Tricalcium aluminoferrite	9.4

of tests included one hardwood (*Vochysia hondurensis*) to assess the response of this species to cement setting. Also, sugar cane residue (bagasse) from *Saccharum officinarum* were included due to ready availability of this raw material for potential utilization in cement-bonded panel technology.

Experimental Procedure: For this series of experiments, trees were selected from the species indicated earlier and in locations noted in Table 1. These trees were felled and the logs were debarked. Wood of each species was converted into particles using a chain saw specially set aside for this project. Wood and bark particles were separately and temporarily stored for later drying. To avoid stain development, all particles were dried in an oven at 104°C for approximately 24 hours prior to storage until needed for further processing. Dry particles were later ground into smaller particles using a hand-turned grinder. These particles were screened using U.S. standard sieves to obtain particles of 20-25 mesh which were used in the hydration experiments. The sieved particles were stored in polyethylene bags at room temperature (24-30° C) until use.

The cement used in these experiments was type I produced by the Piedras azules plant in Comayagua, Honduras. The chemical composition of the cement is shown in Table 2. Once the cement was obtained, batches of 200 grams each were stored in plastic bags to diminish cement hydration before experimental use.

A variety of chemical additives were used in these experiments to determine whether such additives could improve cement setting when mixed with Honduran wood species. These additives included $CaCl_2$, $AlCl_3$, $FeCl_3$, $MgCl_2$, NaOH, $SnCl_2$ and K_2HPO_4. Chemical additives were added at concentrations of 3% or 5% based on the water, before the water was mixed with the cement. Distilled water was used in all experiments; however, preliminary experiments indicated no significant differences when tap water was used. For this research, seventy ml of water was mixed with 200 gm of cement and 15 gm of the lignocellulosic material (wood or sugar cane) was mixed into the wood-cement paste for the

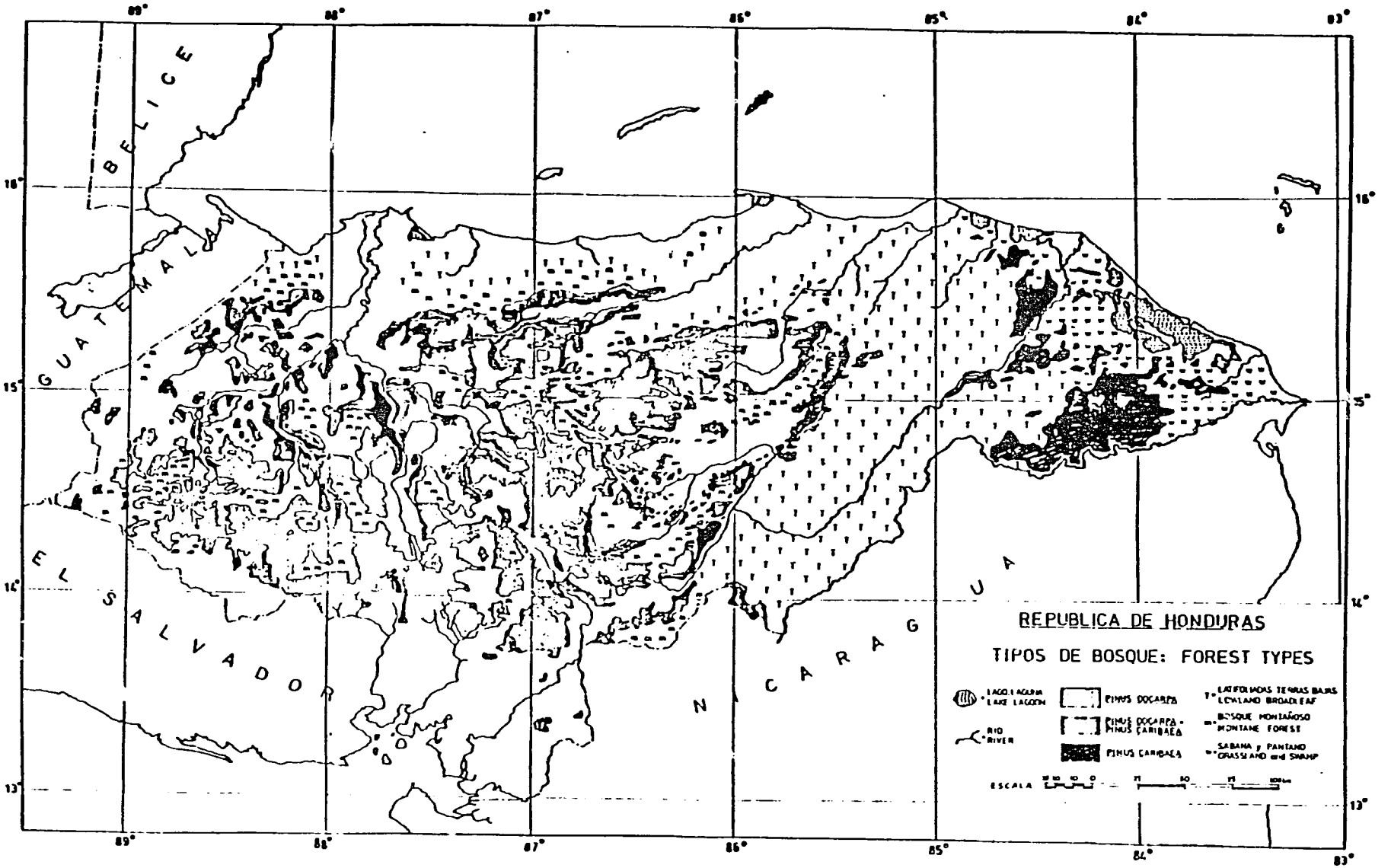

Figure 1. The distribution of the pine species in Honduras. The area covered by pines comprise some 3 million hectares.

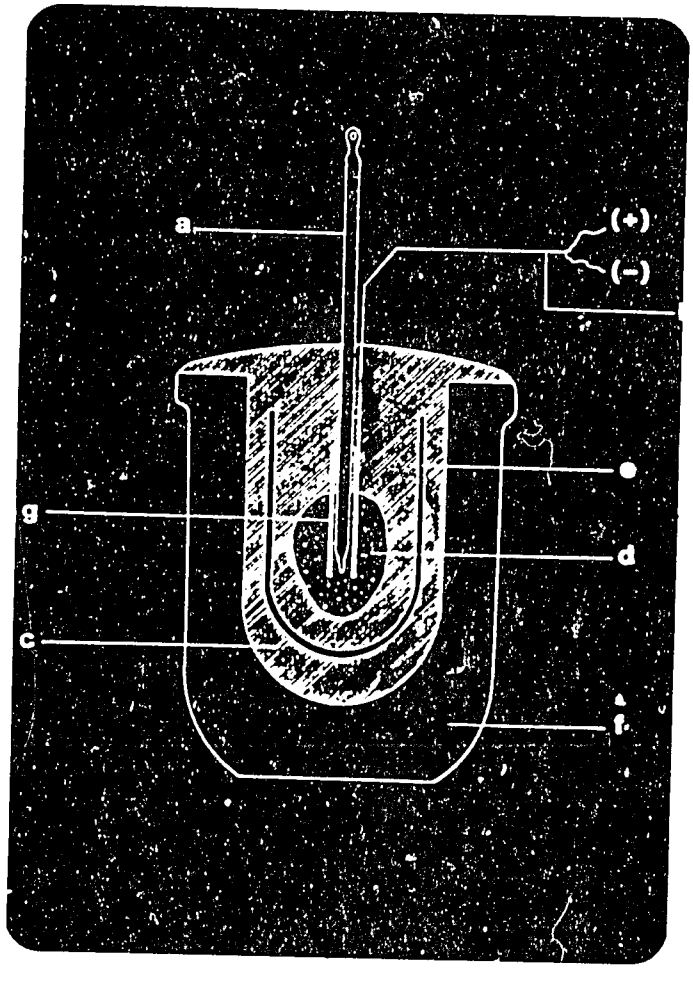

Figure 2. Schematic diagram of the equipment used in the hydration experiments: (a) thermometer, (b) thermocouple wire, (c) fiberglass, (d) wood-cement mixture, (e) thermo-replacement filter, (f) dewar flask y(g) copper pipe sleeve.

hydration experiment. This combination of water-wood-cement proportions provided an easy-to-handle mixture and has been used in the past by several investigators (4,11).

The equipment used to carry out the hydration experiments is schematically shown in Figure 2. This figure illustrates a cut-away view of a Dewar flask with a thermometer, (for monitoring temperature by recording devices), fiberglass insulation, copper pipe sleeve and the wood-cement mixture. In addition, fiberglass insulation was placed on the top of the flask to provide additional insulation as shown in Figure 3. This figure shows three actual Dewar flasks in the process of being readied for use. Figure 4 illustrates the placement of a thermometer into the wood-cement-water mixture prior to placing the whole assemblage into the flask. Figure 5 shows the hydration experiment in process with time-temperature data being recorded. In this study, a dozen of such experiments were conducted simultaneously with experiments running from early morning until midnight.

Time-temperature data were recorded at 5-minute intervals for the required time for the wood-cement-water mixture to reach maximum temperature. Four replicates were run for each sample in order to assure statistical meaning to the results. The four replicates were averaged in calculating the maximum temperature, Tmax, and the average time in hours needed to reach that maximum temperature.

The Hydration Data: 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 as noted earlier. The data obtained is basically plotted in the manner shown schematically in Figure 6. The information on maximum temperature Tmax (° C), time needed to reach that maximum t^2 (in hours) and the slope of the curve as shown in Figure 6 (in ° C/hr) are the data important in the hydration experiment. From this data, an inhibitory index I was calculated as follows:

$$I = 100 \cdot \left[\left(\frac{Tmax_1 - Tmax_2}{Tmax_1} \right) \left(\frac{t_2 - t_1}{t_1} \right) \left(\frac{Smax_1 - Smax_2}{Smax_1} \right) \right]$$

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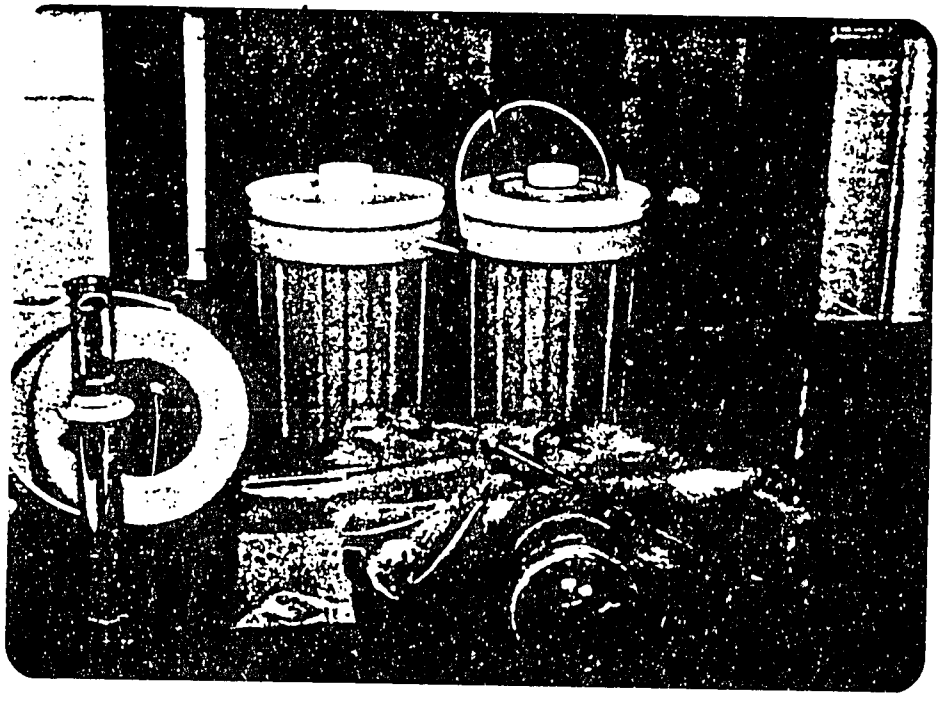

Figure 3. Actual Dewar flasks utilized for the hydration experiment. This photo shows three Dewar flasks, a thermometer, samples of wood and cement in plastic bags (pre-weighted), water and insulation material used to provide added insulation.

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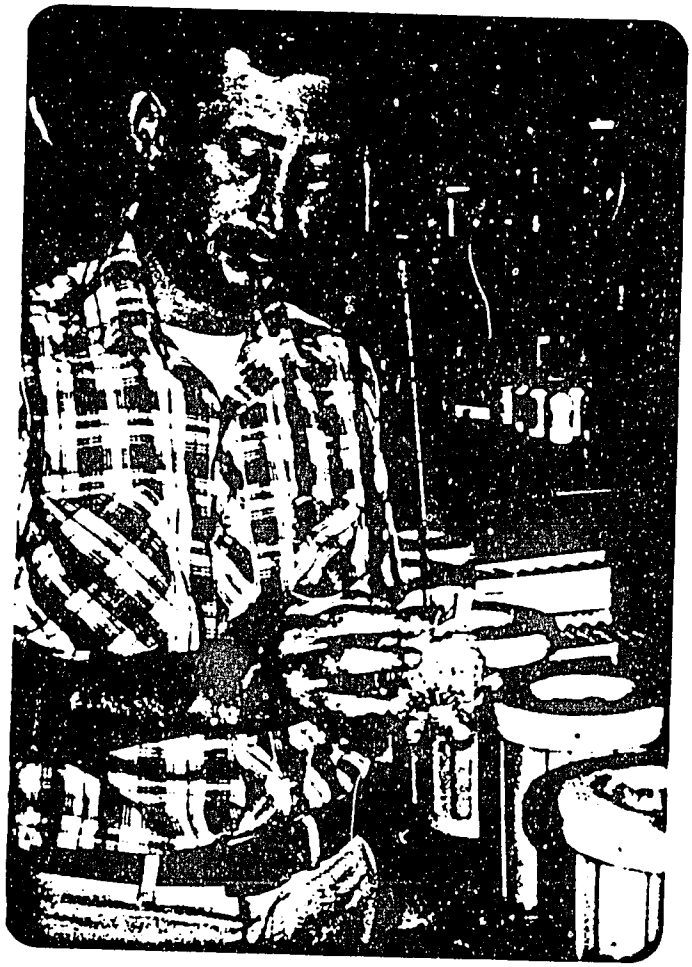

Figure 4. Placing thermometer into the wood-cement-water mixture prior to lowering the assemblage into the Dewar flask.

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Figure 5. A hydration experiment in progress with time-temperature data being recorded.

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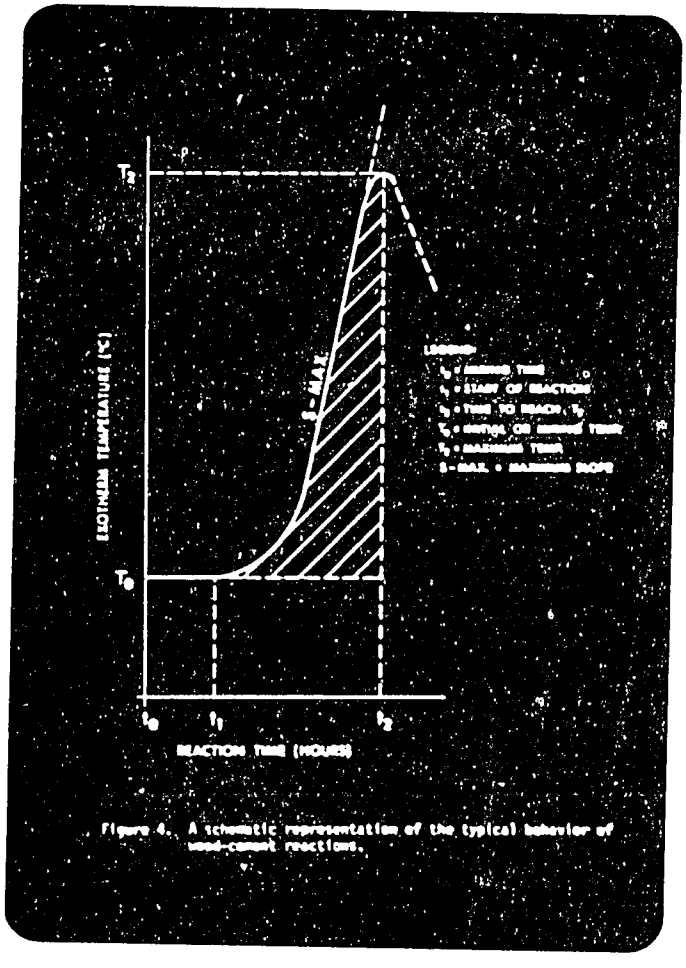

Figure 6. A schematic representation of the typical behavior of wood-cement-water mixture during hydration tests.

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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 with wood species which have low compatibility with cement while it is low when the degree of compatibility is high. In the above equation Tmax refers to the maximum temperature (in degrees C) while *t* is the time (in hours) needed to reach the maximum temperature. Smax denotes the maximum slope for the time-temperature curve.

RESULTS

The primary focus of this section can be traced back to an earlier section of this report where the objectives of this study were noted. Specifically, this section will focus on hydration data dealing with (a)wood species, (b)effect of pre-treatment on hydration data, (c)the influence of chemical additives and (d)the impact of bark at two different levels.

Honduran Wood Species and Cement Setting: The six wood sources used in this study reacted differently when mixed with cement and water as shown in Figure 7. It is clear that bagasse and the broadleaf species included (*Vochysia hondurensis*) have a strong negative impact on cement setting. For these sources of biomass, no exothermic reaction occurs. It is believed that sugar in bagasse serves to strongly inhibit cement hardening. This is in line with prior experience with other species when sugars are involved: a variety of sugars have proven to interfere with cement setting (2). With *Vochysia*, it is not clear what the elements are which affect cement setting. The chemical composition of this species is not known. However, it is anticipated that extractives and saccharides present in this wood may inhibit the cement hardening and bond development.

The situation of the pines is different since all four pines appear to cause only a relatively small degree of inhibition when mixed with cement (Figure 7). All four pines exhibit an exothermic reaction when mixed with cement and water. Table 3 tabulates the hydration data for the four pines. It is noted that *Pinus maximinoii* generates the highest

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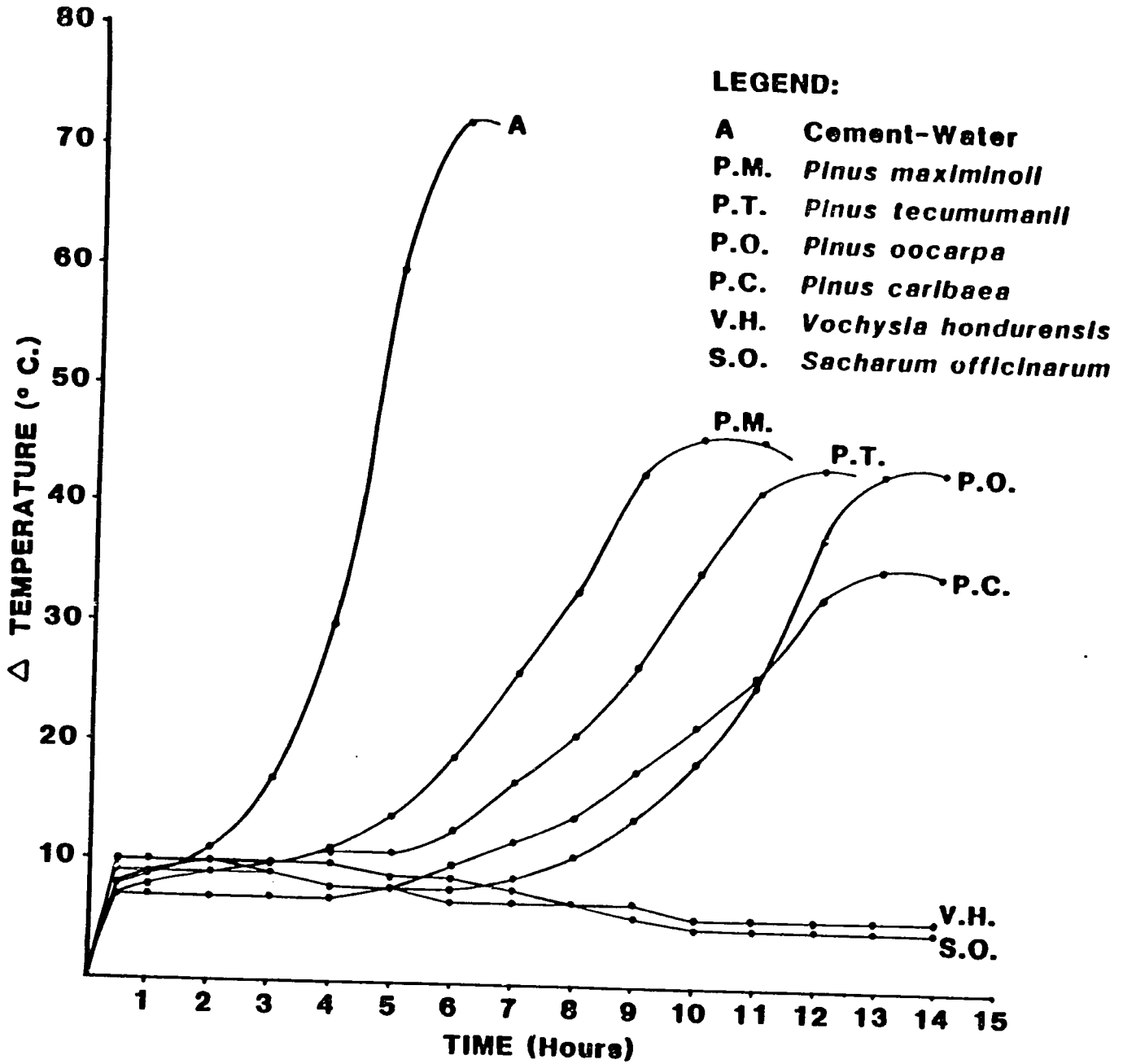

Figure 7. The hydration characteristics of the Honduran biomass (4 pines, one broadleaf species and sugar cane) when mixed with cement and water.

Table 3: Maximum hydration temperature, time to maximum temperature, temp/time slope and inhibitory index for the four Honduran pine species.

SPECIES	Tmax(°C)	t_2(hrs)	Smax(°C/hr)	I
Pinus maximinoii	70.3	10.3	1.9	15
Pinus oocarpa	68.6	12.6	1.8	24
Pinus tecumumanii	68.4	11.5	1.3	23
Pinus caribaea	58.5	13.3	0.8	44
Cement	96.9	5.8	6.0	00

temperature (70.3° C) developing over 10.3 hours. In contrast, *P. Caribaea*, generated only 58.5° C requiring a longer period of time (13.3 hours). The other two pines, namely *P. oocarpa* and *P. tecumumanii* fell between the two already mentioned. The inhibitory index I ranges from a low of 15 for *P. maximinoii* to a high of 44 for *P. caribaea* (Table 3).

The hydration data on these pines suggest that all four pines would very likely make acceptable cement-bonded particleboard panels due to high correlation existing between these data and final board properties, as noted earlier. For example, earlier research carried out by Sandermann and Kohler (9) suggests that highly suitable woods attain hydration temperatures of greater than 60°C when mixed with cement and water. Less suitable species do not exceed 50°C. If we were to compare the pine data with this prior research, we would conclude that all four pines would be suitable for cement-bonded boards. These results imply that cement would be able to develop acceptably strong bonds with wood particles thereby developing panels of relatively good strength. The time to reach maximum temperature for all four pines was less than 15 hours which is an acceptable length of time for this type of technology. Table 4 shows a statistical analysis of the hydration data showing that there was practically no difference among the pines with the exception of *P. Caribaea* when maximum temperature is considered.

Effect of bark: The reason for inclusion of bark results from the fact that mill and forest residues contain varying amounts of bark in an industrial setting. Therefore, bark from all four pines was individually examined and compared with data obtained from wood alone. Figure 8 shows the results obtained for *P. oocarpa*. This figure also compares the data for wood (without bark) and cement-water data. The curve labeled C shows the data for a 50-50 mixture of wood and bark of *P. oocarpa* with curve D showing the same set of data for 100% bark. These data suggest that bark from this species does not appear to significantly impact the hydration data in either a negative or positive way when compared with the wood of the same species. The situation for *P. maximinoii*, however, is dramatically

Table 4: Statistical analysis of the hydration data for the four pine species.

SPECIES	Tmax(°C)	n	Duncan's Test on Tmax[1]	t_2(hrs)	n	Duncan's Test on T_2
P. maximinoii	70.3	4	a[2]	10.3	4	a
P. oocarpa	68.6	4	a	12.6	4	b
P. tecumumanii	68.4	4	a	11.5	4	b
P. caribaea	58.5	4	b	13.3	4	c

(1) New Multiple Range Duncan's Test a 0.05 significant level

(2) Means with the same letter are not statistically different

different: the bark from this species decidedly inhibited cement hydration at both 50% and 100% bark levels (Figure 9). It is conjectured that extractives from this bark adversely affect cement setting. Figure 10 illustrates the data obtained with *P. caribaea* showing bark having little impact on the hydration data (and cement setting) compared with the wood of the same species. Figure 11 presents the results for *P. tecumumanii.* Table 5 records the maximum hydration temperature for all four pines and the time needed to reach those maxima for 0%, 50%, and 100% bark included with the mixture. Again, it is readily apparent that *P. maximinoii* is the decided exception when the influence of bark on cement setting is examined.

Effect of Wood Extraction: Based on prior research we have suspected that a major inhibitory effect on cement setting involve water-soluble wood extractives (1,2,10,11,12). In a study using larch (*Larix occidentalis*), for example, dramatic improvements in cement setting was experienced at the University of Idaho when wood particles were boiled in water and drained (4). To determine whether a similar improvement can be experienced with Honduran pines, a series of hydration experiments were carried out with wood particles which were boiled for varying periods of time ranging from 15 minutes to 120 minutes. The water extract was removed in all cases prior to carrying out the hydration experiment. Figures 12 through 15 show the results of these experiments for the four pines. Figure 12 illustrates that boiling the wood particles for 15 minutes improved cement setting by removing some of the inhibitory, water-soluble substances which normally exist in *P. oocarpa*. This was not the case for *P. maximinoii*, as no improvements over control are being detected (Figure 13). For *P. caribaea*, a 15-minute boil substantially improved cement setting (Figure 14). For *P. tucumumanii*, boiling did not appear to affect results in a consistent manner: boiling the wood particles for as long as 30 or 60 minutes only somewhat shortened setting time without any increase in the maximum temperature of hydration.

Table 6 records the maximum hydration temperature, Tmax and the time t_2 needed to reach Tmax for various hot water extraction periods. This table also lists the effect of

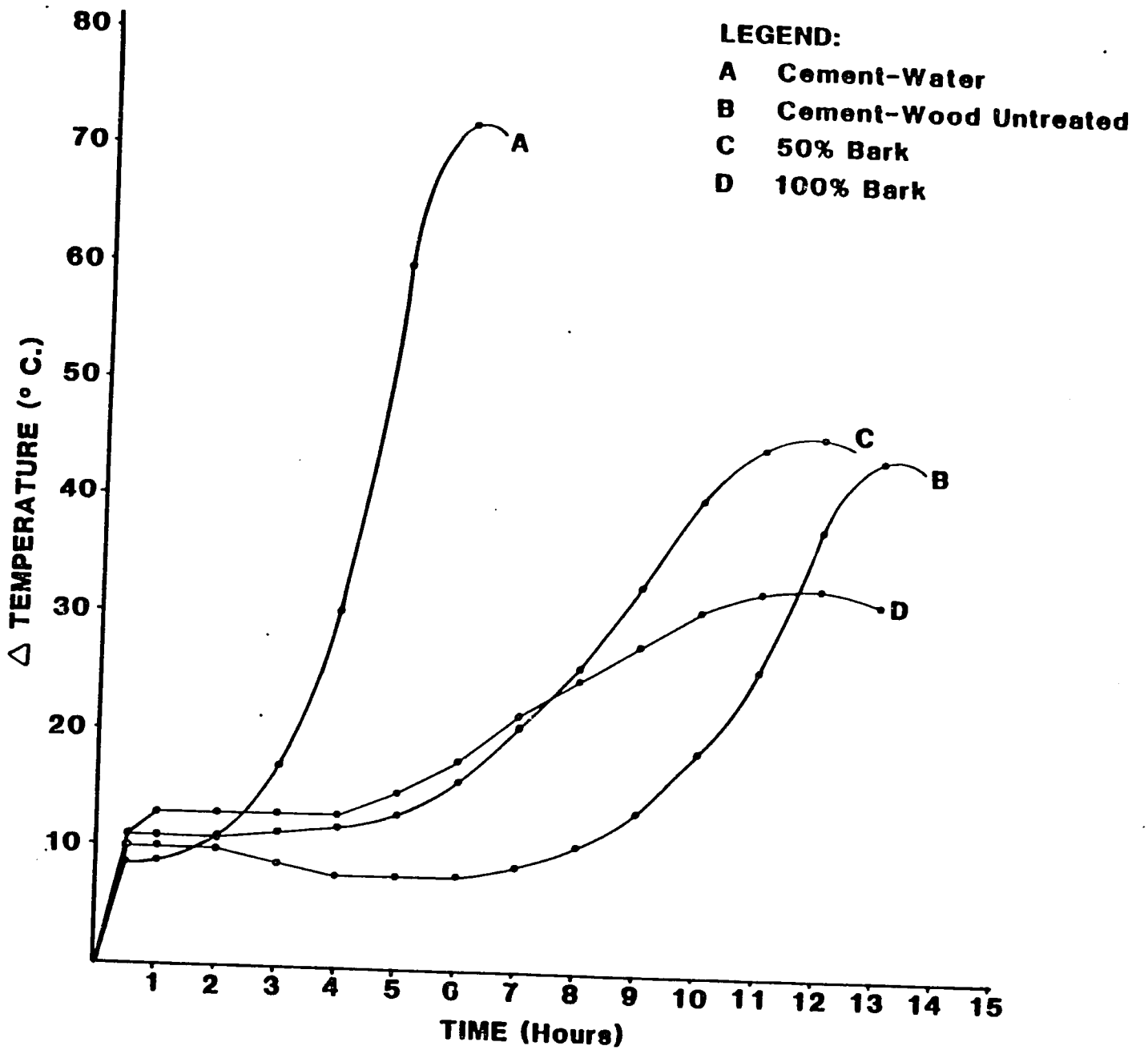

Figure 8. The hydration data for *P. oocarpa* providing comparisons on the effect of 0%, 50%, and 100% bark with cement-water data.

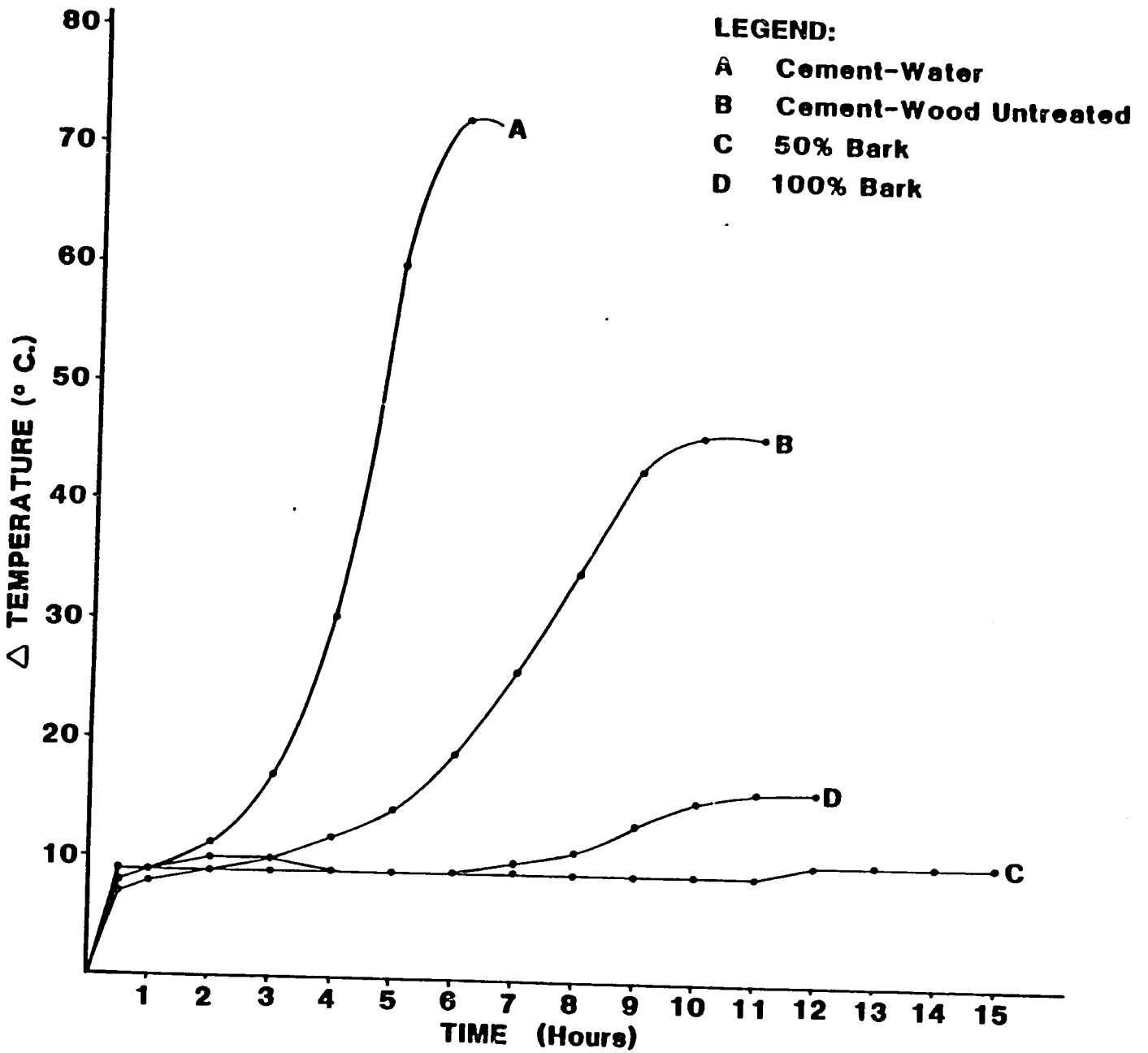

Figure 9. The hydration data for *P. maximinoii* providing comparisons on the effect of 0%, 50%, and 100% bark with cement-water data.

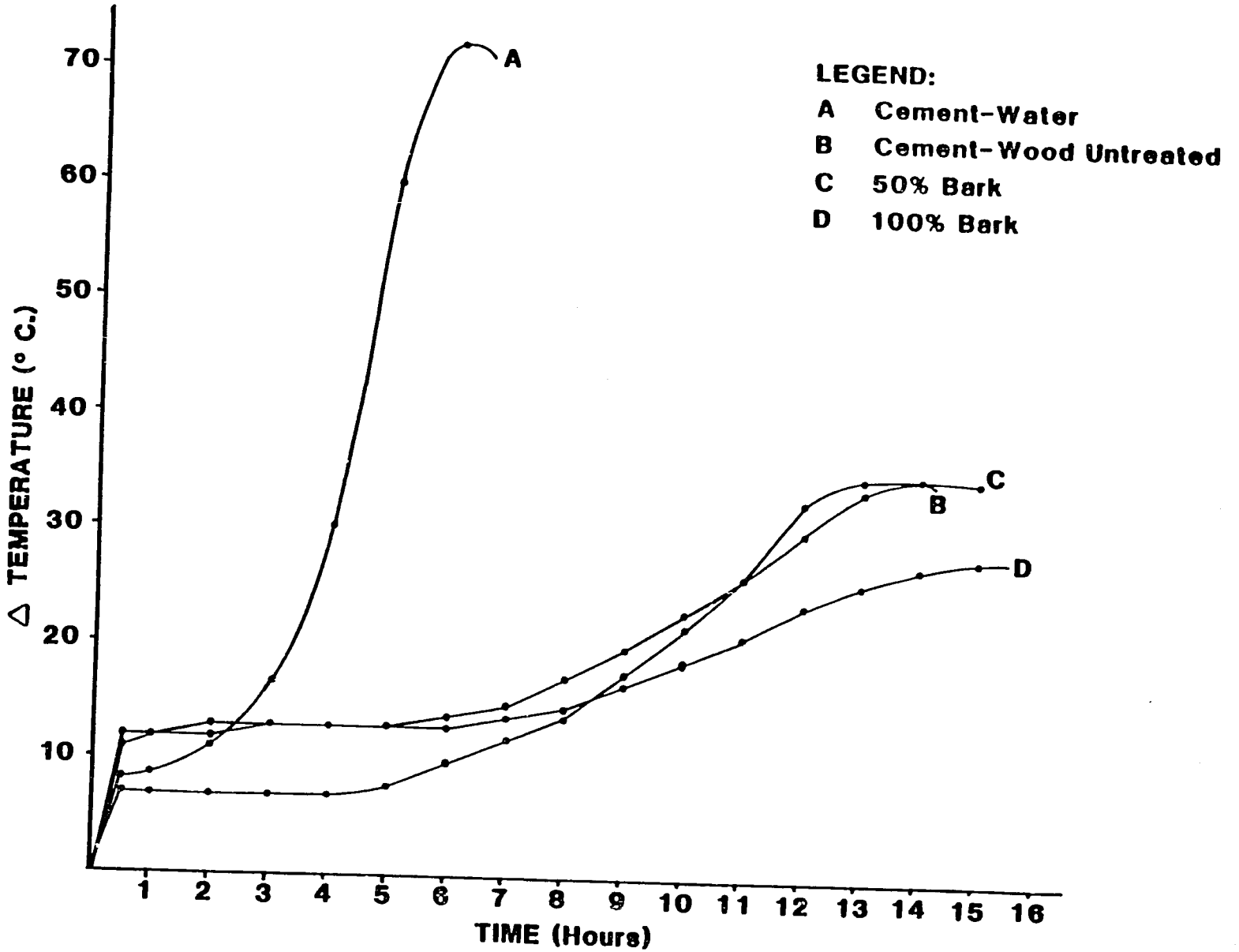

Figure 10. The hydration data for *P. caribaea* providing comparisons on the effect of 0%, 50%, and 100% bark with cement-water data.

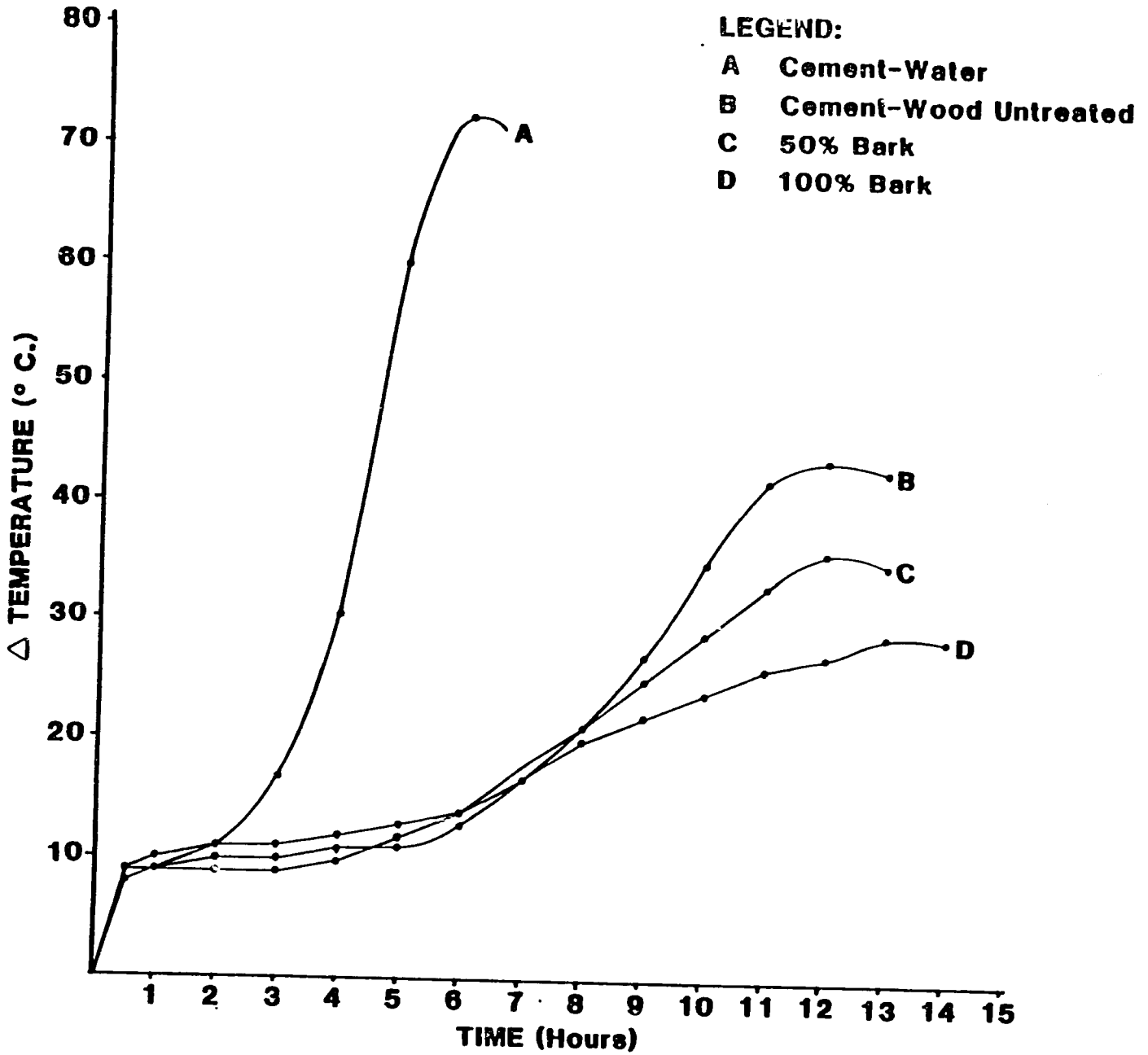

Figure 11. The hydration data for *P. tecumumanii* providing comparisons on the effect of 0%, 50%, and 100% bark with cement-water data.

Table 5: The effect of 0% (all wood), 50% and 100% (all bark) bark on hydration data.

BARK(%)	P. OOCARPA		P. MAXIMINOII		P. CARIBAEA		P.TUCUMUMANII	
	Tmax(°C)	t_2(hrs)	Tmax °C	t_2(hrs)	Tmax °C	t_2(hrs)	Tmax °C	t_2(hrs)
0	68.6	12.6	70.3	10.3	58.5	13.3	68.4	11.5
50	69.0	11.2	32.7	15*	59.2	14.1	59.5	12.2
100	55.8	11.9	36.0	13*	54.4	14.2	54.5	12.9

*The mixture did not react and times noted represent the last readings taken.

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cold water extraction on the data. It is noted that cold water soaking of wood particles for one hour somewhat improved the data (higher maximum temperature and shorter t_2) on *P. oocarpa*, but appear to influence *P. maximinoii* and *P. tucumumanii* somewhat negatively for unknown reasons.

It should be noted that hot water extraction of wood particles can be an expensive process in an industrial setting. The cost/benefit of adding such a step must be carefully assessed before a water extraction step can be added to the process of manufacturing cement-bonded panels. In their natural state, the four Honduran pines appear to be suitable for boardmaking. The additional "quality" obtained through the extraction process must be economically and technically justified before it is to be implemented.

The Effect of Chemical Accelerators: To accelerate and enhance cement setting, a variety of chemicals were used. Some of these chemicals are well known while others are experimental at the University of Idaho. These chemical accelerators when added to the wood-water-cement mixture, increase the maximum hydration temperature and shorten the time needed to reach the maximum temperature.

The chemicals used for this research were $CaCl_2$, $AlCl_3$, $FeCl_3$, $MgCl_3$, $SnCl_2$, K_2HPO_4, and NaOH. The selection of these chemicals were carefully made based on our prior experience at the University of Idaho working with North American species. Two concentration levels were used for each chemical: 3% and 5% based on the water added to the wood-cement mixture. Figures 16 through 19 illustrate the results on the four pine species for the more effective chemicals selected at the 3% concentration level. Table 7 records the max-imum temperature and the time to maximum temperature for the two concentration levels of all chemicals used in this research.

For *P. oocarpa* all chlorides except $FeCl_3$ influenced cement setting in a positive manner, they increased the hydration temperature and shortened the time needed to reach maximum temperature (Figure 16). Aluminum chloride at 3% concentration level was

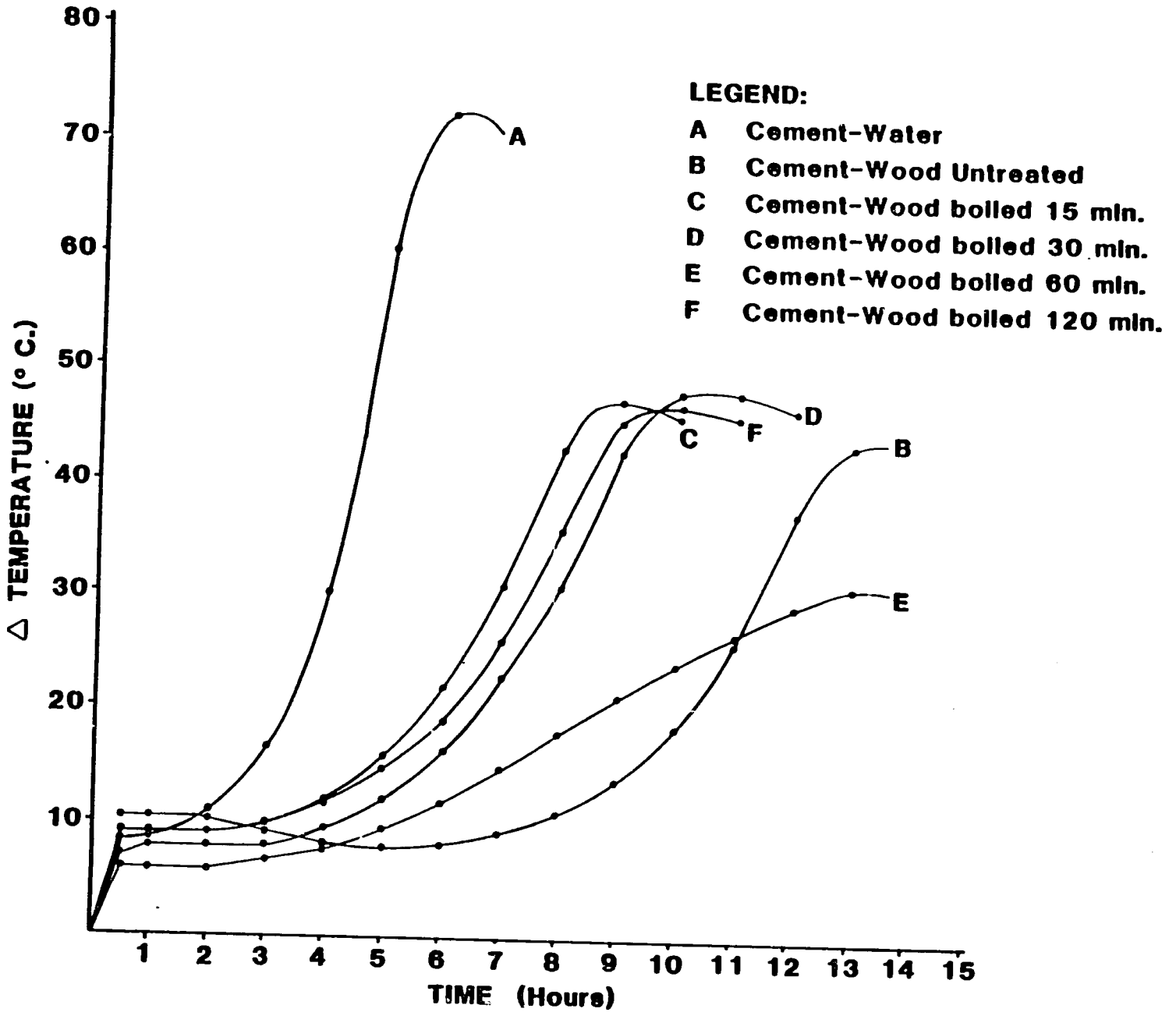

Figure 12. The effect of hot water extraction on hydration data for *P. oocarpa*.

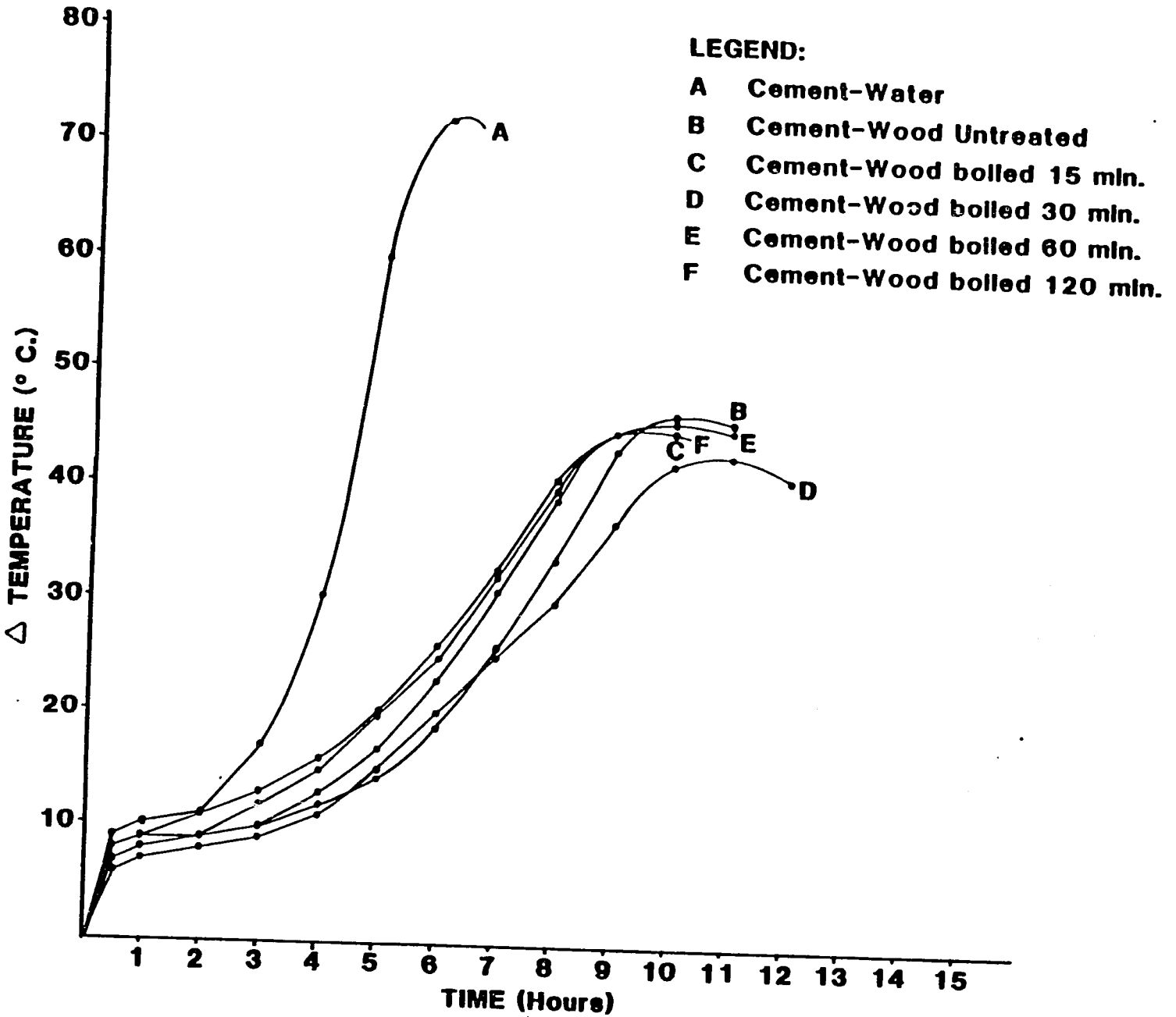

Figure 13. The effect of hot water extraction on hydration data for *P. maximinoii*.

Table 6: The effect of wood extraction by water on maximum hydration temperature, Tmax and the time using several extraction times by hot water and a one-hour extraction with cold water.

Water Pre-treatment	*P.OOCARPA*		*P. MAXIMINOII*		*P. CARIBAEA*		*P. TUCUMUMANII*	
Of Wood	Tmax(°C)	t_2(hrs)	Tmax(°C)	t_2(hrs)	Tmax(°C)	t_2(hrs)	Tmax(°C)	t_2(hrs)
Unextracted (control)	68.6	12.6	70.3	10.3	58.5	13.3	68.4	11.5
Cold Water Extraction (60 min.)	72.1	9.7	69.0	10.0	•	•	62.8	11.5
15-min. boil	72.0	8.8	69.5	9.6	78.4	9.6	62.8	9.6
30-min. boil	71.4	9.1	67.9	9.8	64.8	10.6	66.2	9.3
60-min. boil	55.2	12.5	69.1	9.5	70.2	12.3	67.8	8.9
120-min. boil	72.1	9.6	69.4	9.2	68.5	10.2	70.2	8.8
Cement	Tmax = 96.9°C		t_2 = 5.8 hrs.					

• Mixture did not react.

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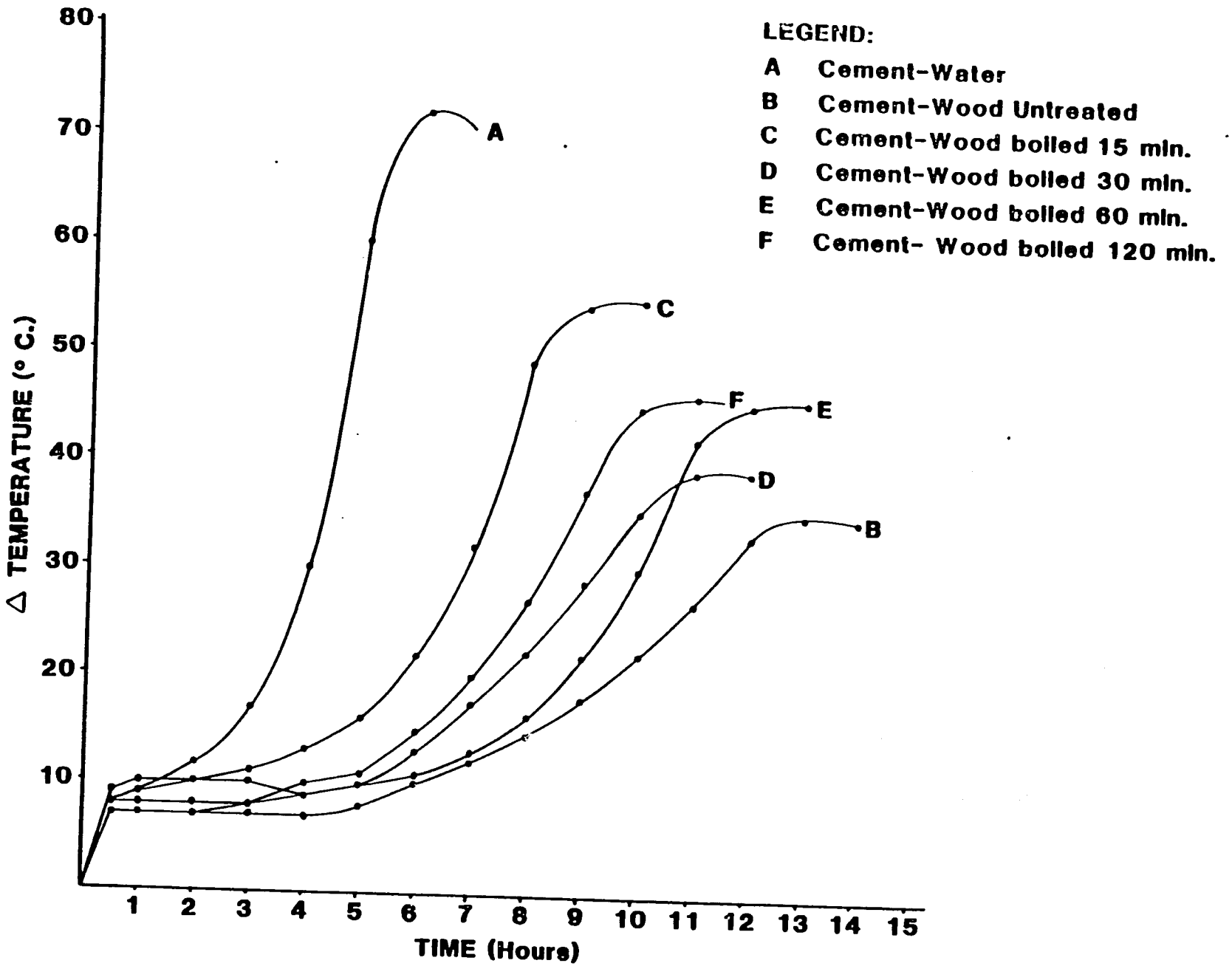

Figure 14. The effect of hot water extraction on hydration data for *P. caribaea*.

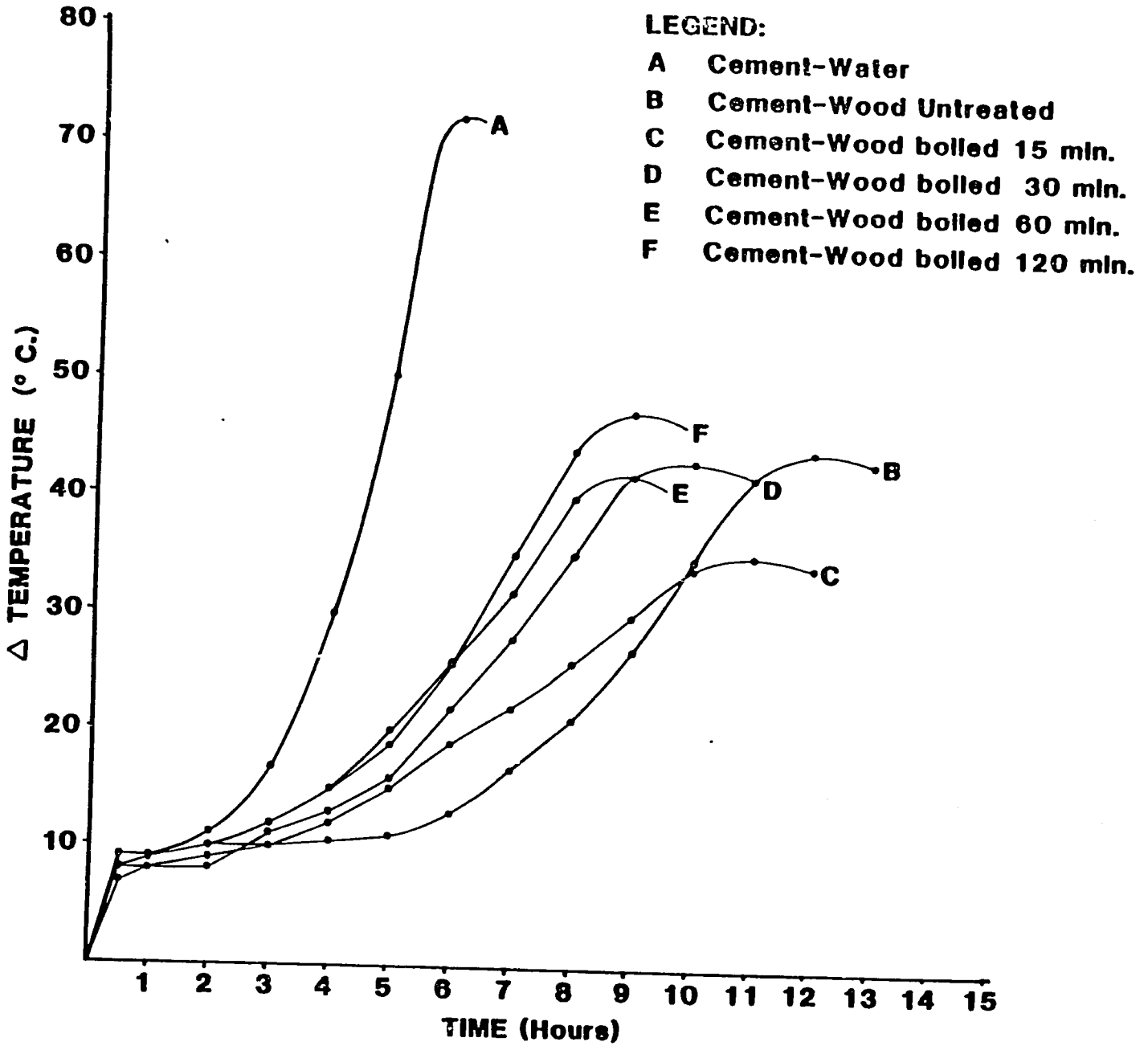

Figure 15. The effect of hot water extraction on hydration data for *P. tucumumanii*.

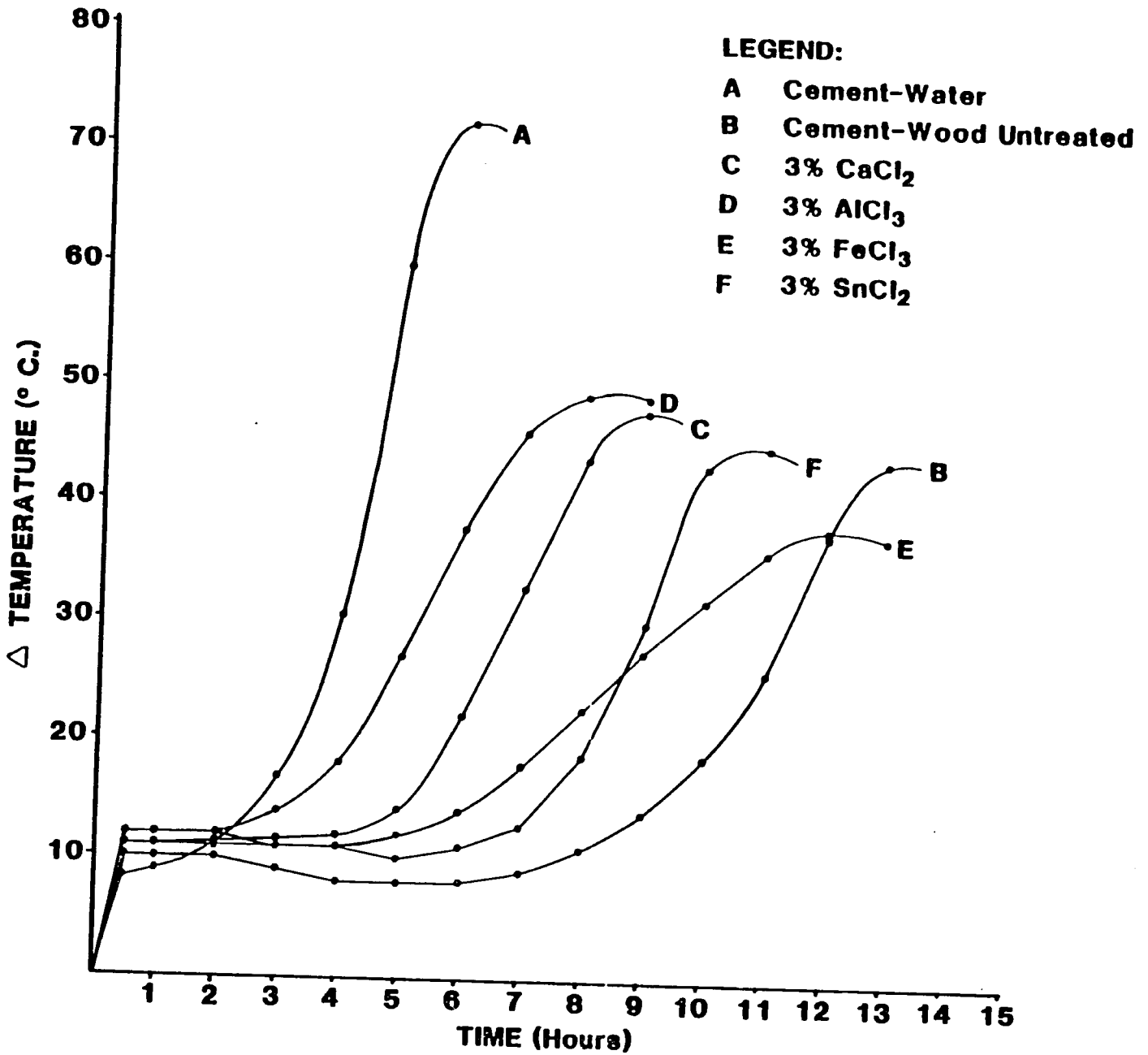

Figure 16. The influence of four chemical accelerators on the hydration data for *P. oocarpa*.

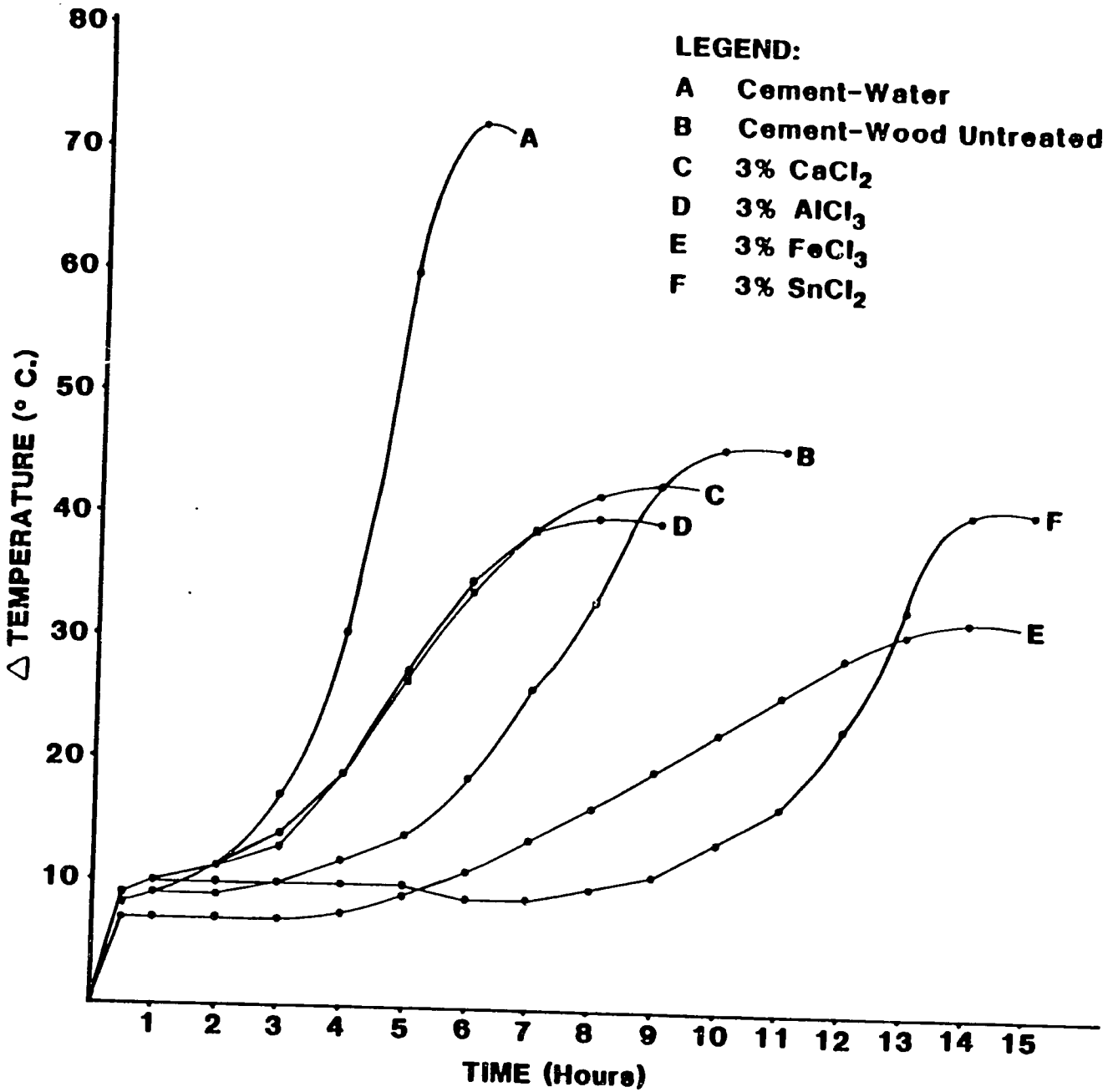

Figure 17. The influence of four chemical accelerators on the hydration data for *P. maximinoii*.

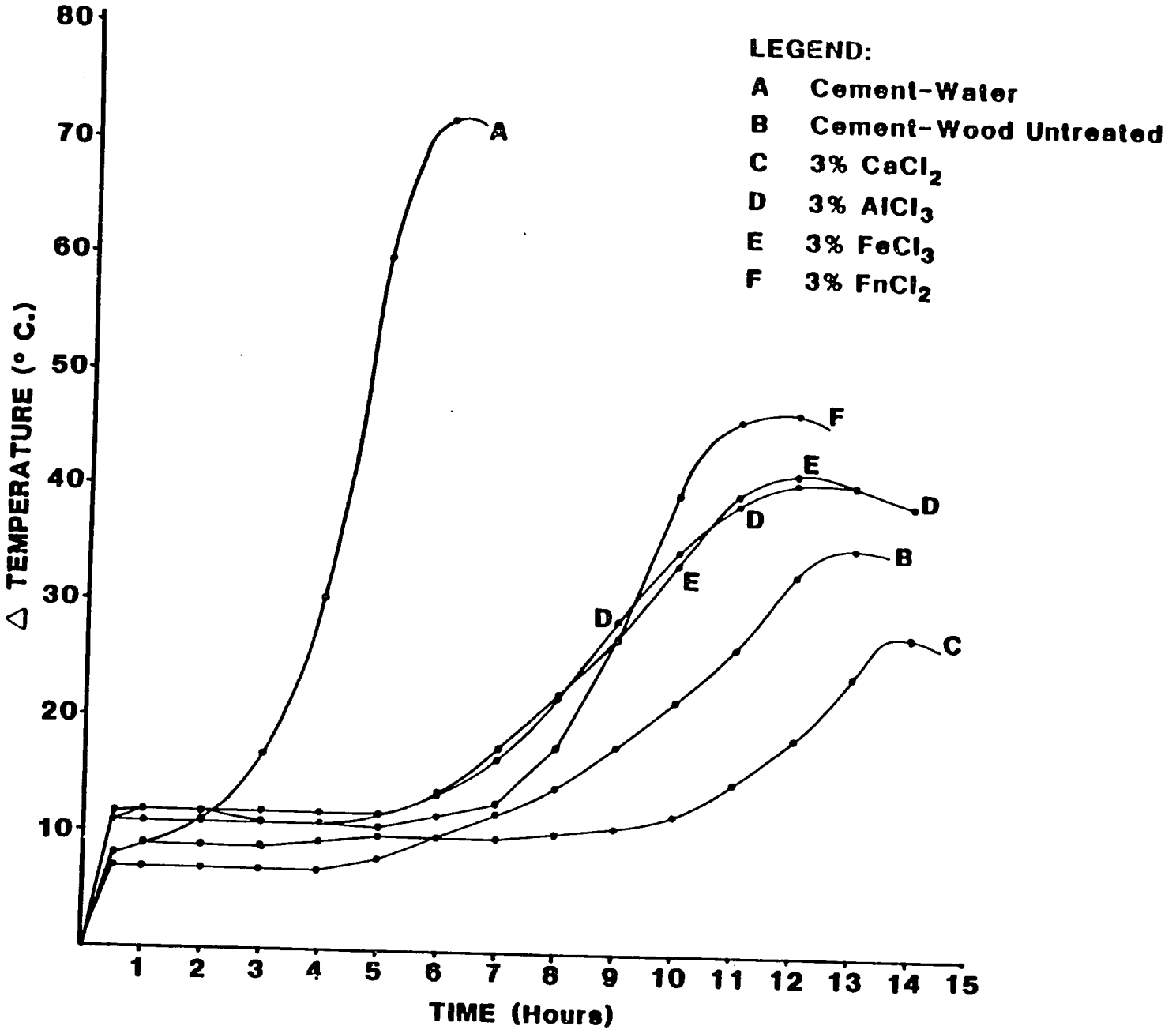

Figure 18. The influence of four chemical accelerators on the hydration data for *P. caribaea.*

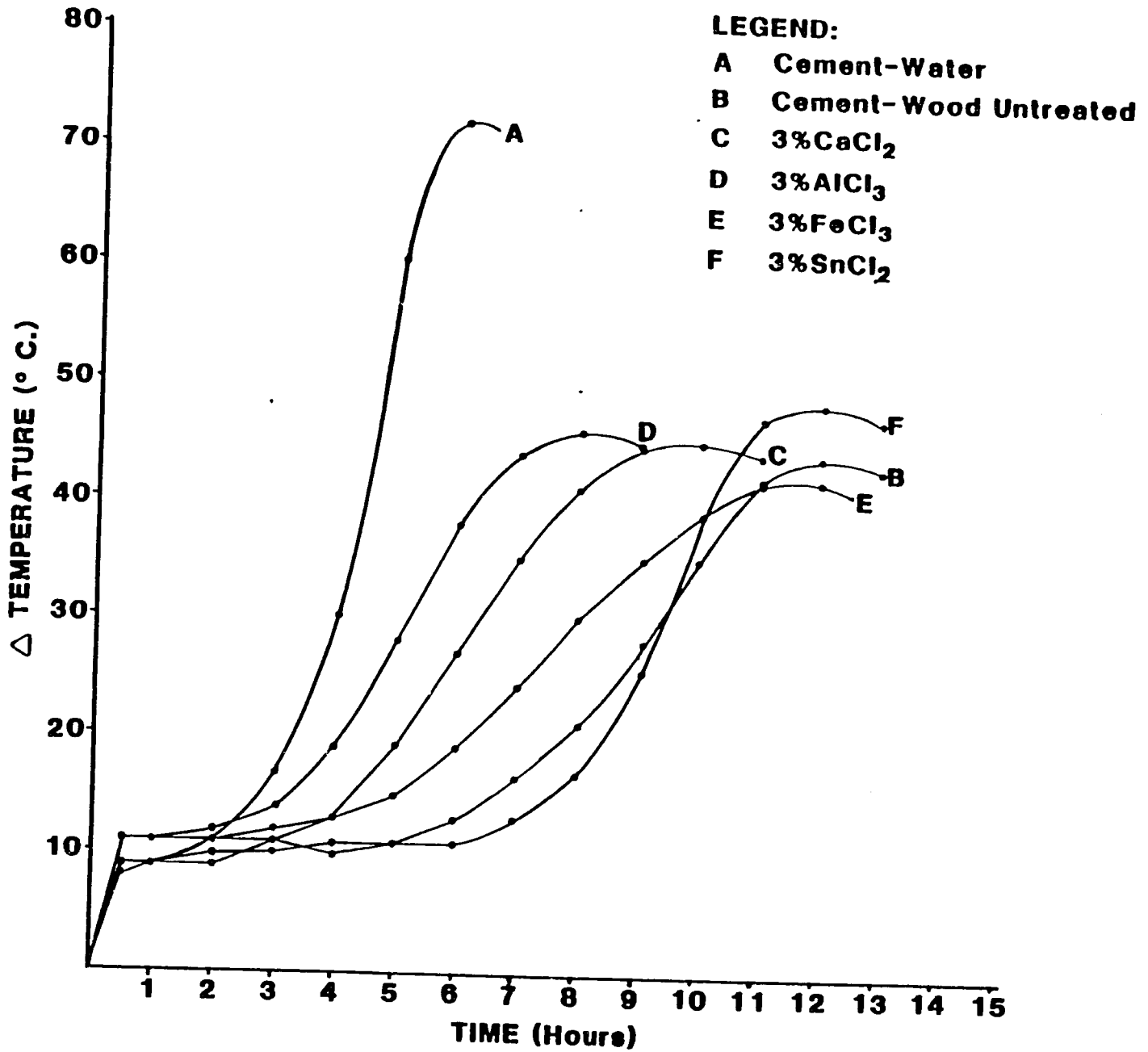

Figure 19. The influence of four chemical accelerators on the hydration data for *P. tucumumanii.*

Table 7: The effect of chemical accelerators on Tmax and time for the four pine species.

CHEMICAL ACCELERATOR		*P. OOCARPA*		*P. MAXIMINOII* P.M.		*P. TUCUMUMANII* P.T.		*P. CARIBAEA* P.T.	
		Tmax	Time	Tmax	Time	Tmax	Time	Tmax	Time
$Ca\ Cl_2$	(3%)	72.3	8.8	66.7	7.8	70.4	8.8	56.4	13.9
$Ca\ Cl_2$	(5%)	77.1	7.2	67.0	6.2	68.5	6.3	64.9	10.2
$Al\ Cl_3$	(3%)	71.6	8.3	63.6	7.8	70.4	7.5	65.3	12.6
$Al\ Cl_3$	(5%)	71.6	6.8	64.1	6.0	67.7	5.9	68.3	8.8
$Fe\ Cl_3$	(3%)	62.5	11.5	56.1	13.3	68.1	10.9	67.3	12.6
$Fe\ Cl_3$	(5%)	63.0	10.5	57.1	12.1	62.3	10.8	62.7	12.4
$Mg\ Cl_2$	(3%)	57.0	14.1	62.5	11.0	66.8	10.9	62.6	10.5
$Mg\ Cl_2$	(5%)	56.2	11.7	61.4	10.0	69.2	9.6	65.5	9.0
$Sn\ Cl_2$	(3%)	70.4	10.8	61.5	13.6	70.9	11.8	68.8	11.9
$Sn\ Cl_2$	(5%)	72.2	10.0	62.9	13.1	72.6	10.3	68.5	11.0
Na OH	(3%)	58.1	12.4	68.0	8.1	71.8	9.6	69.4	8.1
Na OH	(5%)	55.9	10.6	66.8	7.3	68.3	8.2	66.9	7.5
K_2HPO_4	(3%)	–	–	56.5	14.1	62.4	14.4	62.5	14.9
K_2HPO_4	(5%)	––	–	53.4	13.8	62.8	13.7	63.3	14.0
Control w/o accelerator		68.6	12.6	70.3	10.3	68.4	11.5	58.5	13.3

especially useful. Calcium chloride came very close in its influence on cement setting to that of aluminum chloride. For *P. maximinoii*, the influence of chemical additives was not as positive as that shown for *P. oocarpa* (Figure 17). Although $CaCl_2$ and $AlCl_3$ shorten the time needed to reach maximum temperature, they did not increase the maximum temperature monitored in the hydration process. *P. caribaea*, when mixed with cement and water, showed improvement in setting with $AlCl_3$, $FeCl_3$ and $SnCl_2$, but not with $CaCl_2$. For this pine, stannous chloride gave the best results showing a substantial increase in the maximum temperature and somewhat shortening the time needed to reach maximum temperature. Stannous chloride, calcium chloride and aluminum chloride all triggered enhanced hydration characteristics with *P. tucumumanii* (Figure 19). Aluminum chloride shortened the time needed to reach maximum temperature while stannous chloride improved the maximum temperature reached in the hydration process with wood-cement-water mixtures using *P. tucumumanii*.

The data shown in Table 7 notes that increasing the level of chemical additives from 3% to 5% of the water used (water concentration of 3 to 5%) did not significantly yield improved results in the hydration process. Furthermore, additional chemicals, namely NaOH and K_2HPO_4 did not prove useful in influencing the hydration process.

CONCLUSIONS

The results of the first phase of this research suggest that *P. oocarpa*, *P. maximinoii* and *P. tucumumanii* appear to be excellent candidates for making cement-bonded structural panels. Although *P. caribaea* does not appear to be as suitable as other pines, it is not highly inhibitory to cement. This pine, in moderate mixtures with the previous three pine species, could conceivably be used in an industrial process making such structural panels. This study made it clear that sugar cane residue (bagasse) and the hardwood

Vochysia hondurensis would very likely need substantial pre-treatment (by hot water and chemical additives) to become suitable as raw material. For this reason and the fact that much of the available residue is pine residue, further experimentation with sugar cane and *Vochysia* are not recommended.

Chemical accelerators, such as $AlCl_3$, $SnCl_2$ and $CaCl_2$, can enhance board properties based on observations made in the hydration process. Bark contents of up to 50% appear to be acceptable when mixed with the wood of the pines grown in Honduras. This should make it specially attractive to use all pine raw material without the need to segregate bark prior to use in a manufacturing process.

As noted earlier, hydration data are strongly correlated with the board strength properties based on prior research carried out at the University of Idaho (8). However, to be sure in making recommendation for technological development based on this research, boards should be made and tested. The results obtained, so far, will be carefully considered in boardmaking due to the relatively large amount of material needed in the boardmaking phase of this research. It is clear that the next phase should concentrate on the pine resource in Honduras since its residue is available in large quantities in terms of logging and mill waste and forest thinnings. Certainly what is found, so far, is highly encouraging in terms of possible development of a cement-bonded structural panel industry in Honduras. The final judgement would have to await the results of the boardmaking and testing process which is planned for the next phase of this effort.

Present Status of the Project: Professors A. A. Moslemi and Alton Campbell of the University of Idaho spent the period of December 5-17, 1983, in Siguatepeque, Honduras, to begin the preparation of this report in cooperation with Professor J. Francisco Garcia of ESNACIFOR. Professor Garcia plans to spend the month of March 1984 at the University of Idaho in order to lay the ground for the next phase of this project. Specifically, Professor Garcia will work with a boardmaking press to become familar with cement-bonded board

manufacture for research use. He also will cure several experimental boards and make preliminary mechanical tests so that he can become thoroughly acquainted with the procedural matters required for the next phase of this effort. Other get-togethers among cooperating scientists will be arranged as necessary.

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