CHEMICAL MODIFICATION OF WOOD TO IMPROVE DECAY AND THERMAL RESISTANCE

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ABSTRACT

Wood reacted with phosphoramides produced *in situ* by reacting phosphorus pentoxide with amines resisted fungal and thermal degradation. Moisture sorption study at 90% relative humidity for 4 weeks showed that wood reacted with phosphoramides absorbed moisture similar to or higher than untreated wood. This indicated that the decay protection of the modified wood was not based on hydrophobicity but was attributed to the release of fungicidal groups from the reacted wood.

Thermal analysis by DSC in nitrogen of wood reacted with phosphoramides showed that the mechanism of fire retardancy was attributed to dehydration.

Keywords: Chemical modification, wood, phosphoramides, fungal and thermal resistance

INTRODUCTION

The degradation of wood by decay, fire and UV constitutes the three major losses of wood products in use. Commercial wood preservatives including chromated copper arsenate(CCA) and pentachlorophenol (penta) were developed to only protect wood from decay. Dual protections of wood against decay and fire are desirable. Many phosphorus and boron compounds possess fire retardant and decay resistant properties (Grassie, 1990). The aim of this research was to investigate the possibility of dual protections of wood by reacting wood with phosphoramides. Phosphoramides have been shown to have good fire retardant properties (Hendrix et al., 1970a, 1970b, 1972a, 1972b; Langley et al. 1980; Kaur et al. 1986). In our preliminary study, phosphoramides produced *in situ* by reacting phosphorus pentoxide with butylamine were able to react with wood and the resultant modified wood has fire and decay protecting properties. Another aim of this research was to investigate the influence of functional groups of phosphoramides including alkyl, aryl and halogens on fire retardancy and decay resistance.

MATERIALS AND METHODS

Characterization: Bond formation between wood and phosphoramides was identified by FTIR using KBr on a Wattson Model 5000 FTIR spectrophotometer. The distribution of chemicals in cell walls of wood was determined by energy dispersive X-ray analysis using a Tracor Northern 5500 energy dispersive spectrometer. The distribution of chemicals in wood cells was detected by X-ray maps. Elemental analysis was performed by the Galbraith Laboratories.

Fungal Decay Evaluation: Eighteen loblolly pine or sweetgum blocks (1.9 cubic cm in radial, tangential and longitudinal directions) in a reaction flask were vacuumed at 2.1-3.3 kPa for 30 min in a desiccator and then impregnated with DMF(N,N-dimetylformamide)(900 ml)(dried over molecular sieve 4A more than 1 day). Phosphorus pentoxide:amine:wood (calculated as 1,4-anhydroglucopyranose equivalent) in a molar ratio of 1: 3: 1 were added to the flask. The amines used in the reaction with wood were listed in Table 1. The solution was maintained at 115°C. During the reaction, six blocks were withdrawn at 7,8 and 10 h intervals for the pine blocks and 1,2 and 4 h intervals for the sweetgum blocks. The blocks from each treatment were extracted with acetone (900 ml) in a Soxhlet extractor for 12 h, air dried for 1 day and then leached in distilled water(300 ml)daily for 2 weeks. After leaching, the blocks were heated in an oven at 60°C for 1 day. The blocks were conditioned at 26.7°c and 30% relative humidity for 3 weeks before decay test.

Soil-block fungal decay tests were conducted according to ASTM standard D1413 (ASTM 1990). *Gloeophyllum trabeum* (Pers.:Fr.) Murr.,MAD-617, a brown rot fungus, was used with loblolly pine blocks, and *Coriolus versicolor* (L.:Fr.) Quel.,MAD-697, a white rot fungus, was used with sweetgum blocks. Five replicate blocks from each treatment, five control, and five blocks treated with solvent alone were tested for decay resistance over a period of 12 weeks. The extent of decay was evaluated by the weight loss. Chemical retention that resulted in £ 2% weight loss by decay was generally considered the threshold retention.

Thermal Properties Evaluations: 30 Loblolly pine samples (6.4 x 3.2 x 25.4 mm in radial, tangential and longitudinal directions) were dried in an oven at 60°C for 1 day. The samples in a reaction flask were vacuumed at 2.1-3.3 kPa for 30 min. and then impregnated with N,N-dimethyl formamide (DMF)(20 ml, dried Over molecular sieve 4A for more than 1 day). Phosphorus pentoxide, amine and wood (calculated as 1,4 anhydroglucopyranose equivalent) in a molar ratio of 1:3:1 were added to the flask (Table 1). The solution was maintained at 115°C for 24 h. During reaction, six samples were withdrawn at 2, 4, 8 and 12 h intervals. The samples in each treatment were extracted with acetone (600 ml) in a Soxhlet extractor and then leached in distilled water (600 ml) daily for 14 days. After leaching, the samples were used for DSC and TGA analysis.

TGA of reacted wood was carried out on an Omnitherm TGA-1000. Derivative thermal gravimetric analysis provided a derivative form (rate of mass loss) as function of temperature or time. Char residue, max. temperature of pyrolysis and rate of weight loss were obtained from TGA and DTG.

Wood reacted with phosphoramides was analyzed by a DuPont 910 DSC cell interface to a PL Thermal Science Analyzer and Plotter. Five mg of reacted wood with chemical retention of 50 mmoles per 100 g wood were heated from 40 to 600°C under a nitrogen or air with flow rate of 20 ml/min and heating rate of 10°C/min.

RESULTS AND DISCUSSION

Charactérization (bond formation and chemical distribution): Bond formation between wood and phosphoramides was evidenced by the IR absorptions of P-OH, P=O and P-N groups which were able to detect at chemical weight gain of 52% (Fig. 1). The absorptions at 2,480, 1,240 and 926 cm^{-1} were attributed to P-OH stretching vibration, P=O vibration and asymmetric stretching vibration of P-N groups, respectively (Colthup et al., 1964).

The distribution of bromine and phosphorus in the cell walls of monobromophenyl phosphoramide reacted wood (Fig. 2) indicated that phosphoramides were able to bond to wood. At chemical weight gain of 12.8% (50 mmoles/100 g wood), the distribution of bromine in the middle lamella was higher than phosphorus. This indicated that other reactive chemicals containing bromine were also presented. These reactive chemicals were able to react preferably with lignin in wood. The distribution of bromine and phosphorus were the same in the S2 layer of cell walls.

Another evidence of bond formation between wood and butyl phosphoramide was provided by the high content of phosphorus(10%) and nitrogen(3.5%) of the reacted wood(52 % weight gain of chemical in wood)by the elemental analysis.

Fungal Decay Evaluation: Brown rot fungus: Threshold retentions with *G. trabeum* of wood reacted with alkyl phosphoramides including octyl, hexyl, butyl and propyl derivatives were 13, 13.3, 18.7 and 20.4 mmoles per 100 g wood(Table 2). This indicated that increased hydrophobicity of the modified wood increased decay resistance.

For wood reacted with halophenyl phosphoramides, threshold retentions with *G. trabeum* were 11.3, 12.7 , 17.0 and 8.1 mmoles for fluoro, chloro and bromo and tribromo derivatives, respectively(Tab1e 2). The results indicated that tribromo derivative was the most effective followed by fluoro, chloro and bromo derivatives. It indicated that the increase bromine substitution on the phenyl ring increased the efficacy of decay protection.

For wood reacted with phenyl phosphoramides , threshold retentions with *G. trabeum* were 9.3, 19.2 mmoles for nitro and 4-methyl derivatives, respectively, while anilino and anisole derivatives were ineffective (Table 2). The increase in hydrophobicity on the aromatic ring may play a role in decay resistance.

White-rot fungus: Decay test of wood reacted with alkyl phosphoramides showed that threshold retentions with *C. versicolor* were 4.7, 5.9, 11.2 and 13.3 mmoles for octyl, hexyl, butyl and propyl derivatives, respectively (Table 3). The incease in hydrophobicity of the modified wood may contribute to decay resistance.

For wood reacted with monohalophenyl phosphoramides, threshold retentions with *C. versicolor* were 4.5, 5.6 and 6.3 mmoles for chloro, fluoro and bromo derivatives, respectively (Table 3). It was difficult to access that chloro was more effective than the fluoro derivative because only one concentration was used to determine the threshold value. For bromine derivatives, increased bromine substitution increased fungitoxicity. Threshold value for tribromo derivative was 3.5 mmoles while monobromo derivative was 6.3 mmoles.

For wood reacted with phenyl phosphoramides, threshold retentions with *C. versicolor* were 2.9. 5.0. 5.2 and 9.9 mmoles for nitro, anilino, 4-methyl and 4-methoxy derivatives, respectively (Table 3). The nitro derivative was the most effective, followed by anilino and methoxy derivatives while 4-methyl derivative was the least effective.

The results of decay tests indicated that wood reacted with phosphoramides was more effective to a white rot fungus than a brown-rot fungus. Threshold values were lower with a white rot fungus,&. versicolor (ranging from 2.9 to 13.3 mmoles) while higher with a brown-rot fungus, *G. trabeum* (ranging from 8.1 to 20.4 mmoles). The decay resistantce of wood reacted with phosphoramides was comparable to that of wood impregnated with known fungicides including pentachlorophenol and boric acid (Chen, 1994). The modified woods decayed by *G. trabeum* with threshold retentions ranging from 8.1 to 20.4 mmoles after leaching were slightly less effective than that of leached penta (3.2 mmoles) but were as effective as that of unleached boric acid (14 mmoles). The modified woods decayed by *C.* versicolor with threshold retentions ranging from 2.9 to 13.3 mmoles after leaching remained effective while that of leached penta was ineffective(9.8 mmoles of retention had 48% weight loss).

Thermal Properties Evaluations: DSC analysis: Pyrolysis of wood components and wood in nitrogen (Fig.3) showed that active pyrolysis took place after 150°C. Xylan pyrolyzed at lower temperature(150°C) and gradually increased exothermic reaction (peak at 190°C) followed by steep increase in exothermic reaction

(peak at 250°C) which was attributed to flamming combustion of volatiles and tars, the char oxidation was decreased gradually from 300°C to 500°C (Hirata et al., 1991; LeVan, 1984; Shafiizadeh, 1984). For cellulose, active pyrolysis started at 300°C with large endothermic reaction (peak at 344°C) which was attributed to depolymerization and volatilization, followed by two large exothermic reactions (peaks at 380°C and 425°C) attributed to flamming combustion and char oxidation (Hirata et al., 1991; LeVan, 1984; Shafiizadeh, 1984). Lignin pyrolyzed slowly between 200- 350°C, and active pyrolysis due to char oxidation begin at 350°C with exothermic reaction (peak at 400°C) (Hiram et al., 1991; LeVan. 1984; Shafiizadeh, 1984). Pyrolysis of wood reflected the pyrolysis of wood components. Pyrolysis started with early decomposition of hemicelluloses, slow pyrolysis of lignin and then depolymerization of cellulose followed by active flaming combustion and char oxidation.

Pyrolysis of wood reacted with phosphoramides can be explained by the dehydration and depolymerization mechanisms (Kaur et al., 1986). Pyrolysis of wood reacted with alkyl, halophenyl phosphoramides including monosubstituted flouro, bromo and chloro derivatives were dominant by dehydration reaction (Fig. 4-7, Table 4,5). The mechanism was similar to that of wood impregnated with diammonium phosphate. However, the pyrolysis of iodo and nitro derivatives were dominant by depolymerization reaction. The advantages of pyrolysis proceeded by dehydration reaction were to decrease volatiles and increase char formation (Hirata et al., 1991; LeVan, 1984; Shafiizadeh, 1984). The rate of char oxidation was also decreased.

Thermal decomposition in air of wood reacted with phosphoramides showed that active combustion took place at 200°C and ended at 520°C with two major peaks (Table 5). The first peak at 339°C was attributed largely to flamming combustion of the volatiles and the second peak at 496°C was attributed to char oxidation (Sekiguchi et al., 1984). For alkyl derivatives, increased alkyl chain increase flamming combustion. Among the halophenyl derivatives, bromine derivatives reduced the flamming combustion the most, and the tribromo derivative reduced flamming combustion and char oxidation even further. The anisole derivative also reduced flamming and char oxidation.

Heat of combustion obtained from DSC thermograms of wood reacted with phosphoramides in air showed that heat release from first exothermic peak attributed to flamming combustion was reduced significantly (489.5-674.8 mcal/mg) compared to that of wood (693.5 mcal/mg) (Table 6). In particular, the halophenyl derivatives have smaller heat release (ranging from 489.5 to 579.9 mcal/mg). Trapping radicals by bromine compounds in the gas phase may be attributed to these reductions. The 2nd exothermic peak attributed to char oxidation was smaller for alkyl derivatives but halogen and phenyl derivatives were larger. The reasons for this difference were not clear. The char formed by alkyl derivatives may be more oxygenated resulting in low heat content while that of halophenyl and phenyl derivatives are less oxygenated.

TGA analysis: TGA in nitrogen at 600°C of phosphoramide reacted wood showed that most of them have higher char yields (ranging from 40.4 to 44.7%) than that of wood impregnated with diammonium phosphate (40.4%) while wood has only 20.1% char (Table 7). The iodo and phenylene diamine derivatives have low char yields 33.9% and 32.0%, respectively. TGA in air at 600°C of wood reacted with phosphoramieds also showed that most of them (ranging from 11.1% to 17.7%) have higher char than that of wood impregnated with diammonium phosphate while wood has only 2.7% char yield (Table 8). Char yields of iodo and phenylene diamine derivatives were low, 7.7% and 8.5%, respectively.

CONCLUSION

Phosphoramides prepared in situ by reacting phosphorus pentoxide with amines were able to react with wood. Evidences of bond formation between wood and phosphoramides were provided by FTIR, energy disperse x-ray and elemental analysis.

Moisture sorption study at high humidity (90% relative humidity for 4 weeks) showed that wood reacted with phosphoramides absorbed moisture similar to or higher than untreated wood. This indicated that the decay resistant of the modified wood was not based on hydrophobicity but attributed to the release of fungicidal groups from the reacted wood. The efficay of decay resistant of wood reacted with phosphoramides was comparable to that of wood impregnated with penta or boric acid. Threshold retentions ranged from 8 to 19 mmoles for *G. trabeum* and 2.9 to 13 mmoles for *C. versicolor.*

Thermal analysis by DSC in nitrogen of wood reacted with phosphoramides showed that the mechanism Of fire retardancy was attributed to dehydration Pyrolysis of the modified wood by dehydration reaction leads to decrease in production of volatiles and increase char formation. The rate of char oxidation was also decreased.

TGA in nitrogen or air showed that the modified woods have higher char yields than that of wood impregnated with diammonium phosphate, Heat of combustion of wood reacted with phosphoramides in air showed that heat release from halophenyl derivatives were less compared to the unreacted wood. The decrease in heat release may be attributed to the trapping of free radicals by halogen compounds in the gas phase. Heat release from 2nd peak attributed to char oxidation was more for halophenyl and phenyl derivatives but was less for alkyl

derivatives. Chars formed from alkyl derivatives may be more oxygenated which was low in heat content while char formed from halopheny and phenyl derivatives may be less oxygenated.

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Table 1. Chemicals reacted with wood through phosphorus pentoxide and amines system

Chemical	Structure	Molecular Weight	Symbol
Phosphorus pentoxide	P_2O_5	141.94	P
Diammionium phosphate	$(NH_4)_2HPO_4$	132.06	DAP
Propylamine	$C_3H_7NH_2$	59.1I	PAM
Butylamine	$C_4H_9NH_2$	73.14	BAM
Hexylamine	$C_6H_{13}NH_2$	101.19	HAM
Octylamine	$C_8H_{17}NH_2$	129.25	OAM
4-Fluoroaniline	$C_6H_4FNH_2$	111.12	FAN
4-Chloroaniline	$C_6H_4ClNH_2$	127.57	CAN
4-Bromoaniline	$C_6H_4BrNH_2$	172.03	BAN
4-lodoaniline	$C_6H_4INH_2$	219.03	IAN
2,4-Dibromoaniline	$C_6H_3Br_2NH_2$	250.93	DBAN
2,4,6-Tribromoaniline	$C_6H_2Br_3NH_2$	329.83	TBAN
Aniline	$C_6H_5NH_2$	93.13	AN
p-Anisidine	$C_6H_4OCH_3NH_2$	123.16	ASD
p-Toludine	$C_6H_4CH_3NH_2$	107.16	TLD
4-Nitroaniline	$C_6H_4NO_2NH_2$	138.13	NAN
N,N,Dimethyl	$C_6H_4NC_2H_6NH_2$	136.20	DMPDA
1,4-Phenylene diamine	$C_6H_4N_2H_4$	108.14	PDAM

Table 2. Soil-block decay test (12 weeks) of southern pine reacted with phosphoramides and inoculated with *Gloeophyllum trabeum* [a]

Treatment	Weight retention [b] (%)	Weight loss [c] (%)
Control		46.8 ± 2.0
DMF		30.3 ± 5.2
PPAM	9.7 (20.4)	12.0 ± 1.0
PBAM	10.0 (18.7)	2.6 ± 0.5
PHAM	8.4 (13.3)	1.2 ± 0.3
POAM	9.9 (13.0)	0.6 ± 0.1
PFAN	7.2 (11.3)	1.7 ± 0.5
PCAN	8.7 (12.7)	1.2 ± 0.2
PBAN	14.5 (17.0)	1.7 ± 0.1
PTBAN	11.5 (8.1)	1.7 ± 0.8
PAN	12.2 (22.5)	3.0 ± 0.2
PASD	16.9 (24.8)	5.9 ± 1.5
PTLD	11.8 (19.3)	1.7 ± 0.1
PNAN	6.8 (9.3)	1.4 ± 0.5

a Specimens leached with acetone in Soxhlet extractor for 12 hours and then leached for 14 days with distilled water before subjected to decay test Values are means of five specimens

b Values in parentheses are mmol/100g wood

c Values are means of five specimens ± standard error

Table 3 Soil-block decay test (12 weeks) of sweetgum reacted with phosphoramides and inoculated with *Coriolus versicolor* [a]

Treatment (%)	Weight retention [b] (%)	Weight loss [c]
Control		37.5 ± 3.5
DMF		32.0 ± 11.7
PPAM	6.3 (13.3)	2.4 ± 0.7
PBAM	6.0 (11.2)	2.0 ± 0.1
PHAM	3.8 (5.9)	2.0 ± 0.1
POAM	3.5 (4.7)	2.1 ± 0.l
PFAN	3.6 (5.6)	2.1 ± 0.5
PCAN	3.1 (4.5)	1.9 ± 0.5
PBAN	5.2 (6.3)	2.1 ± 0.5
PTBAN	4.8 (3.5)	2.0 ± 0.4
PAN	2.8 (5.0)	2.1 ± 0.6.
PASD	6.6 (9.9)	0.4 ± 0.1
PTLD	3.3 (5.2)	2.0 ± 0.4
PNAN	2.1 (2.9)	1.9 ± 0.5

a Specimens leached with acetone in Soxhlet extractor for 12 hours and then leached for 14 days with distilled water before subjected to decay test Values are means of five specimens

b Values in parentheses are mmol/100g wood

c Values are means of five specimens ± standard error

Table 4 Analysis of DSC responses of reacted wood with 50 m mole per 100g wood retention of fire retardants under flowing nitrogen

Specimen	Peak of temperature (°C)	
	Endo	Exo
Control	362	
DAP	193,216	272
PPAM	190,239	376
PBAM	197,240	433
PHAM	191,238	263,370
POAM	195,238	263,380
PFAN	190,233	265,369
PCAN	156,219	270,393
PBAN	200,241	306,413
PIAN	173,230	313,377
PDBAN	214	27 1,368
PTBAN	119,180,227	248,363
PAN	193,239	280,407
PNAN	177	275
PASD	200,240	267,379
PTLD	192,238	269,371
PDMPDA	198,238	283,382
PPDAM	177,245	320,410

Table 5 DSC results of reacted wood with 50 mmole/100 g wood retention of fire retardants in air

Specimen	Onset temp ("C)	Peak temp (°C)		Heat flow at peak (mcal/sec)	
		1st	2nd	1st	2nd
Control	200	339	496	5.7	5.5
DAP	207	333	500	3.5	3.2
PPAM	170	333	500	3.6	3.2
PBAM	169	340	496	4.0	3.2
PHAM	169	335	505	3.7	3.4
POAM	170	336	505	3.8	3.3
PFAN	167	331	505	3.2	3.6
PCAN	175	334	503	3.3	3.9
PBAN	169	339	498	3.8	4.1
PIAN	169	338	493	3.7	3.7
PDBAN	176	333	500	3.4	3.9
PTBAN	170	322	507	3.0	3.2
PAN	176	341	500	3.9	4.0
PNAN	174	333	497	3.7	4.1
PASD	173	345	499	3.6	3.8
PTLD	167	341	500	3.9	3.9
PDMPDA	162	339	495	4.1	3.8
PPDAM	161	336	491	4.7	3.7

Table 6 Heat of combustion (mcal/mg) from DSC of reacted wood with 50mmole/100g wood retention of fire retardants in air

Specimen	Total	1 st area (%)	2nd area (%)
Control	1152	693.5 (60.2)	458.5 (39.8)
DAP	1059	626.9 (59.2)	432.1 (40.8)
PPAM	1079	638.8 (60.0)	440.1 (40.0)
PBAM	1102	666.7 (60.5)	435.3 (39.5)
PHAM	1090	648.6 (59.5)	441.4 (40.5)
POAM	1087	652.2 (60.0)	434.8 (40.0)
PFAN	1092	560.2 (51.3)	531.8 (48.7)
PCAN	1050	514.5 (49.0)	535.5 (51.0)
PBAN	I064	551.2 (51.8)	512.8 (48.2)
PIAN	1092	579.9 (53.1)	512.1 (46.9)
PDBAN	993	497.5 (50.9)	495.5 (49.1)
PTBAN	927	489.5 (52.8)	437.5 (47.2)
PAN	1159	625.9 (54.0)	533.1 (46.0)
PNAN	1127	556.7 (49.4)	570.3 (50.6)
PASD	1129	581.4 (51.5)	547.6 (48.5)
PTLD	1259	674.8 (53.6)	584.2 (46.4)
PDMPDA	1222	672.1 (55.0)	549.9 (45.0)
PPDAM	1154	733.9 (63.6)	420.1 (36.4)

Table 7 Thermal and flammability data from TGA and DTG curves of reacted wood with 50 mmole/100 g wood retention of fire retardants in nitrogen

Specimen	Ti (°C)	Tmax (°C)	Max. Weight loss rate (%)	Weight loss (°C)		Char yields at 600 °C
				5%	50%	
Control	266	377	0.97	266	365	20.1
DAP	206	281	0.65	210	409	40.4
PPAM	217	266	0.56	215	430	42.4
PBAM	218	280	0.58	217	413	41.4
PHAM	211	268	0.57	210	417	41.2
POAM	214	268	0.58	205	388	40.4
PFAN	210	272	0.52	209	443	42.7
PCAN	208	275	0.52	207	434	41.6
PBAN	21I	282	0.63	210	425	41.2
PIAN	215	295	0.62	213	346	33.9
PDBAN	201	273	0.44	207	453	43.5
PTBAN	201	257	0.49	129	426	42.3
PAN	211	284	0.56	218	422	41.4
PNAN	209	281	0.37	214	519	44.7
PASD	212	277	0.57	217	457	43.8
PTLD	210	279	0.58	216	436	42.7
PDMPDA	222	290	0.57	229	466	44.3
PPDAM	231	304	0.64	239	384	32.0

Table 8 Thermal and flammability data from TGA and DTG curves of reacted wood with 50 mmole/100 g wood retention of fire retardants in air

Specimen	Ti (°C)	Tmax (°C)		Max. weight loss rate (%)		Weight loss at (°C)		Char yields at 600 °C
		1st	2nd	1st	2nd	5%	50%	
Control	255	326	507	1.24	0.21	255	331	2.7
DAP	200	272	527	0.62	0.22	206	373	11.1
PPAM	213	279	531	0.60	0.22	221	368	12.2
PBAM	214	281	524	0.65	0.23	228	366	11.2
PHAM	210	261	530	0.57	0.23	211	378	12.9
POAM	205	266	530	0.58	0.23	211	368	12.4
PFAN	205	267	529	0.52	0.26	211	396	12.9
PCAN	204	268	530	0.54	0.26	211	394	12.2
PBAN	205	277	521	0.62	0.25	213	387	12.3
PIAN	210	287	519	0.66	0.24	210	343	7.7
PDBAN	197	266	523	0.49	0.25	212	407	4.8
PTBAN	199	253	530	0.51	0.21	130	393	7.7
PAN	204	281	525	0.55	0.25	214	386	2.0
PNAN	200	273	516	0.42	0.25	215	416	6.6
PASD	204	267	525	0.55	0.24	214	395	3.9
PTLD	206	272	526	0.56	0.25	218	386	1.5
PDMPDA	220	282	521	0.59	0.26	231	415	13.8
PPDAM	228	293	520	0.70	0.24	237	363	8.5

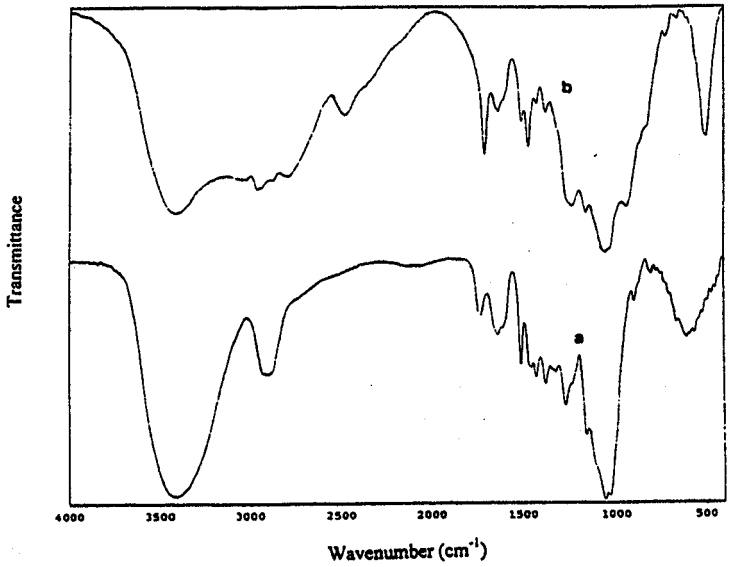

Figure 1 FTIR spectra of control wood fiber and wood fiber reacted with PBAM at 52% weight gain: (a) control; (b) reacted fiber

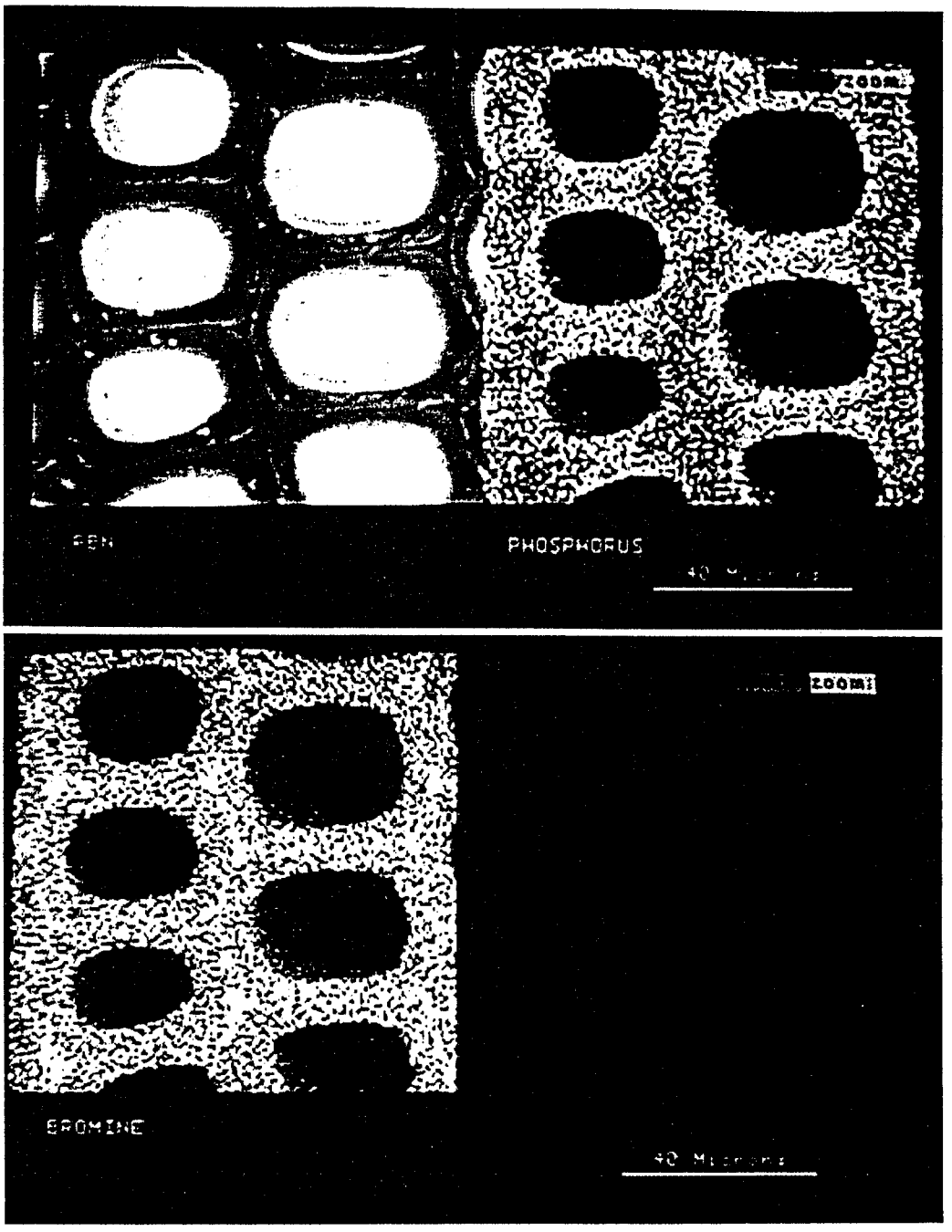

Figure 2 EDXA distribution map of pine wood reacted with PBAN at 50 mmole/100g wood retention, leached (1000X)

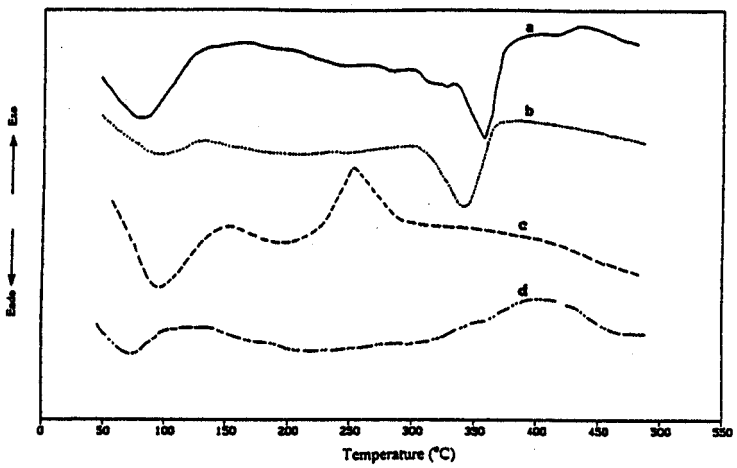

Figure 3 DSC curves in nitrogen of wood components: (a) southern pine; (b) cellulose; (c) xylan; (d) lignin.

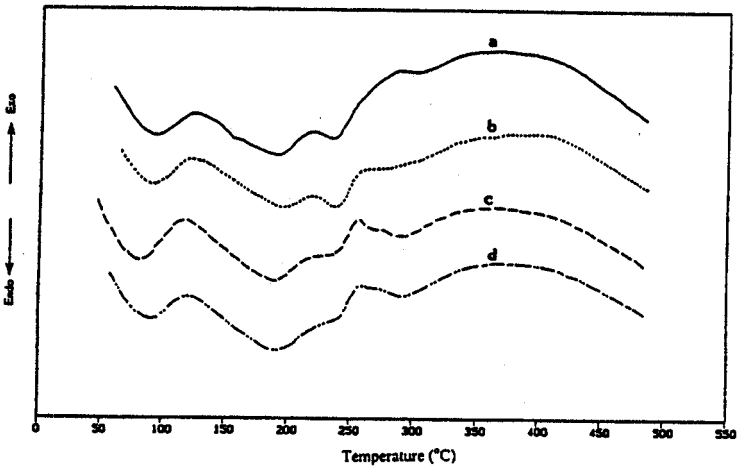

Figure 4 DSC curves in nitrogen of reacted wood with 50 mmole/100 g wood retention of (a) PPAM; (b) PBAM; (c) PHAM; (d) POAM.

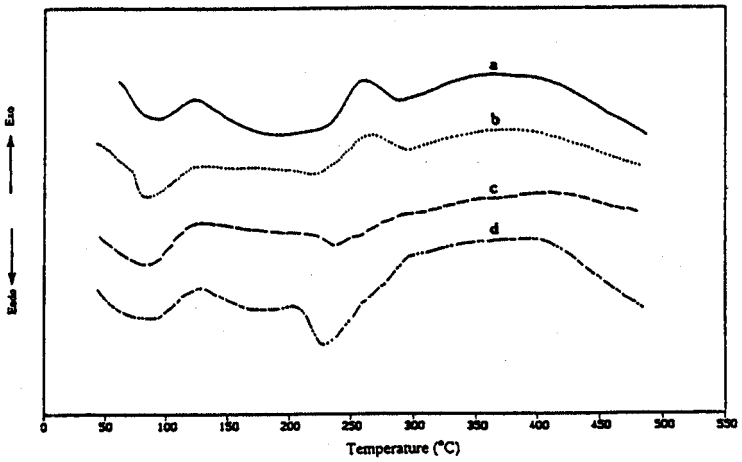

Figure 5 DSC curves in nitrogen of reacted wood with 50 mmole/100 g wood retention of (a) PFAN; (b) PCAN; (c) PBAN; (d) PIAN.

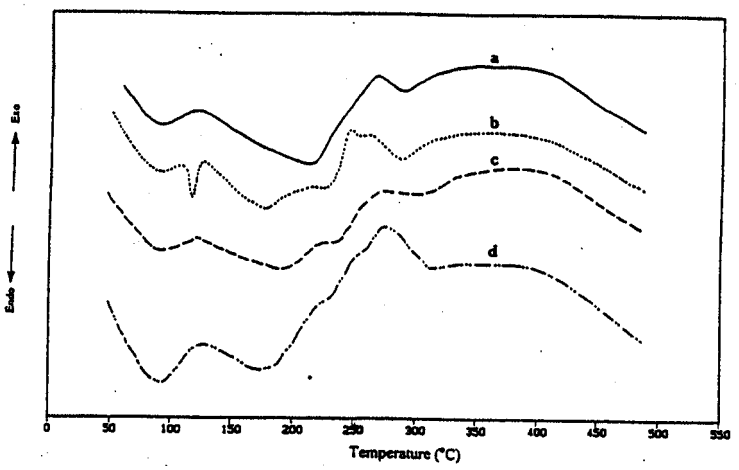

Figure 6 DSC curves in nitrogen of reacted wood with 50 mmole/100g wood retention of (a) PDBAN; (b) PTBAN; (c) PAN; (d) PNAN

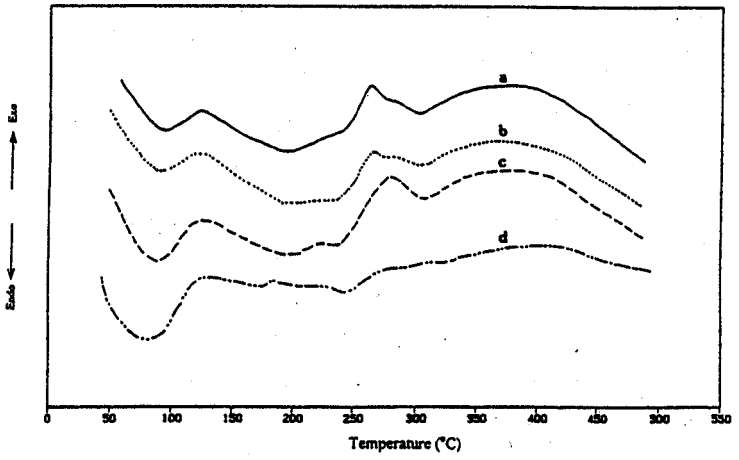

Figure 7 DSC curves in nitrogen of reacted wood with 50 mmole/100 g wood retention of (a) PASD; (b) PTLD; (c) PDMPDA (d) PPDAM.

Problem 2 **Chemical and structural modifications of wood-basedmaterials are required to improve properties and to maximize end use performance of bio-basedcomposite materials.**

FY2001 ResearchAttainments

Publications
Research Unit

Lee, Hong-lin;Chen, George C.; Rowell, Roger M. 2000. Chemical modification of wood to improve decay and thermal resistance. In: Proceedings of the 5th Pacific Rim bio-basedcomposites symposium; 2000 December 10-13; Canberra, Australia. Canberra, Australia: Department of Forestry, The Australian National University: 179-189.