

# Effects of a new GUP-B fire retardant on mechanical properties of Korean pine when exposed to elevated temperature

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## Abstract

The bending properties of Korean pine (*Pinus koraiensis*) treated with a newly formulated guanylurea phosphate (GUP) fire retardant were evaluated. The chemical processing method used to formulate this fire retardant (called FRW) results in an organic phosphate fire-retardant system with less acidic pH and fewer impurities. The fire-retardant chemical studied consisted of high purity GUP, boric acid (B), and a minor amount of additives. The clear specimens of pine treated with FRW were either air-dried after treatment or kiln-dried at 70°C and were then subjected to various durations of a steady-state exposure at 66°C and 75 percent relative humidity. No significant differences in thermal degradation between the untreated controls and the FRW-treated pine were found regardless of whether it was air-dried or kiln-dried after treatment. However, for other tested fire retardants with much lower pH values, kiln-redrying induced significantly more degradation compared with air-redried material. On exposure to elevated temperature, the strength and stiffness of FRW-treated Korean pine experienced deterioration, but the extent was less than that previously reported for other GUP-B formulations produced using different manufacturing processes. Because of its milder acidity which results from the modified manufacturing process, enhanced stability related to thermal degradation was noted for this enhanced GUP-B (FRW).

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Researchers have long recognized that fire-retardant treatment and post-treatment redrying reduce the initial strength properties of wood. Furthermore, in-service reductions in strength may occur when some fire-retardant-treated (FRT) products are exposed to elevated temperatures such as those induced by solar loads on roof systems (LeVan and Collet 1989). Research has defined how much, when, and why fire retardants affect the properties of treated wood (LeVan et al. 1990; Winandy 1995, 1997, 2001). Models have been developed for predicting loss in bending strength of lumber and sheathing material (Pasek and McIntyre 1990, Lebow and Winandy 1999). Only one study has focused on in-service thermal degrade as affected by fire-retardants and post-treatment drying methods (Winandy 1997) and that study did not look at organic phosphate fire retardants. Thus, it is not known if or how much mild or intense drying conditions might affect thermal degradation of organic-phosphate-treated wood and its mechanical properties.

Recently, an organic phosphate phosphorus-nitrogen-boron multiplex fire retardant called FRW, which stands for fire-retardant wood, was synthesized at Northeast Forestry University, Harbin, China (Wang et al. 1999). The formulation of FRW is similar to that of FR-1 fire retardant, which has a pH range of 2.5 to 4.5 in American Wood-Preservers' Association (AWPA) Standard P17 (AWPA 2003a). Both are mainly com-

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posed of guanidurea phosphate (GUP), boric acid (B), and a minor amount of additives. However, the GUP in FRW was synthesized by a new processing method with higher yields, lower processing costs, and a milder final acidity (pH range 3.8 to 4.5) (Wang et al. 1999, Wang 2000). While both FRW and FR-1 might use the same pH treating solution to effectively treat a refractory species, an FRW treating solution for a highly absorbent species such as loblolly pine, or in this case Korean pine, would be much milder than that needed for FR-1.

In this new method, GUP is synthesized by the complete reaction of dicyandiamide, phosphoric acid, and water at a reaction temperature between about 90°C and 120°C, whereas prior to reaction, the mole ratio of dicyandiamide to phosphoric acid is 1.0 to 1.0. To obtain solid GUP with a purity of no less than 99.0 percent, the mixture was cooled after the reaction and the crystallized GUP was collected by filtration and then dried. The filtrate can be used as solvent in the next synthesis process, which in turn eliminated wastes formed in the production of GUP. New GUP formulating methods (Wang et al. 1999, Pasek and Thomason 2003) differ from the previous method of Oberley (1983) in which GUP was formed from the partial reaction product of dicyandiamide, phosphoric acid, and water at a reaction temperature between about 70°C and 90°C. The Oberley (1983) process is the formulating method on which FR-1 fire retardant in AWWA Standard P17 is based (AWPA 2003a). Because of the presence of residual (unreacted) phosphoric acid in Oberley's method, FR-1 fire retardant is more acidic and its pH range is wider than that of the new GUP process (Wang et al. 1999). The objective of this study was to look at the effect of the post-treatment drying method on bending strength of the wood treated with FRW solution when exposed to elevated in-service temperature. The benefits of the milder pH of the FRW treatment might result in less thermal degrade and hence could result in enhanced service life for FRW-treated wood products when used at elevated temperatures.

### Materials and methods

Korean pine (*Pinus koraiensis*) lumber was sawn from four trees grown in the same forested area near Harbin, China. The lumber was initially kiln-dried at 70°C until the moisture content (MC) was between 8 percent and 10 percent, and it was then processed into 350 clear, straight-grained samples that were 305 (longitudinal) by 36 (radial) by 16 mm (tangential). This specimen size was selected to correspond to the size used by LeVan et al. (1990), Winandy (1995), and Winandy and Lebow (1996). This specimen size is different than the flexure specimen size specified in the American Society for Testing and Materials (ASTM) D 5664 method (ASTM 2003) (584 by 38 by 38 mm), but it is not suspected that such small size differences would in any way alter the results compared with it if the D 5664 size had been used. From the 350 samples, 125 pieces were randomly selected and used as untreated controls, 75 others were treated with 10 percent phosphoric acid (PA), and the remaining 150 samples were treated with FRW.

A full-cell pressure process with final vacuum was used to impregnate the equilibrated specimens with the appropriate fire-retardant chemicals. In both the PA and FRW treatments, the concentration of the chemical solution was 10 percent by weight and the treating process and conditions were the same. Both treatments were conducted at 18° to 20°C. The full-cell process started with a vacuum of 0.095 MPa (gauge) for 15 minutes. After using the vacuum to introduce the treating solu-

tion into the retort tank, a pressure of 1.40 MPa was applied for 25 minutes. After discharging the treating solution, a final vacuum of 0.095 MPa was applied for 15 minutes.

Samples were weighed before and after impregnating with a FRW or PA solution. From these data, all of the 16-mm-thick PA- or FRW-treated specimens seemed fully penetrated. The resultant average retention was 55 kg/m<sup>3</sup>, and the range was 50 to 58 kg/m<sup>3</sup>. The retention was selected to achieve a fire performance level of better than China's National Standard GB8624 Class B1 and to evaluate the effects of high retention FRW on the bending properties of wood. To achieve a fire performance of GB8624 Class B1 standard, the required retention of FRW in Korean pine wood is 35 to 40 kg/m<sup>3</sup>. Acidity was defined as pH value of the fire-retardant treating solution both before and after treatment and was determined by a Sartorius AG (Goettingen, Germany) PB-20 pH meter. The pH values of the FRW solution before and after treatment were 4.0, and for the PA solution, the corresponding pH values were both 1.0. While PA is not used as a sole ingredient in commercial fire retardant formulations, it is an effective fire retardant and was selected as a worst control case for its high potential to accelerate the degradation of wood (LeVan et al. 1990).

After treating, some pieces were air-dried while others were kiln-dried. For the 75 pieces treated with 10 percent PA solution, 25 were air-dried for 25 days while the remaining 50 were kiln-dried at 70°C. For the 150 pieces that were treated with 10 percent FRW solution, 25 were air-dried while the other 125 were kiln-dried at 70°C. Air-drying required 25 days, while kiln-drying was performed at 70°C dry-bulb and 51° to 56°C wet-bulb temperatures in 60 hours. Kiln- or air-drying was considered finished when the average moisture content (MC) of treated samples decreased to 12 to 18 percent. All of the test specimens were again weighed after redrying and were then packaged in a moisture-resistant container and shipped from China to the United States where they were equilibrated to constant weight at 23°C and 65 percent relative humidity (RH).

After equilibration, the specimens in each of the five groups were then sorted randomly into five additional subgroups and each subgroup was exposed at 66°C and 75 percent RH for either 0, 21, 70, 125, or 200 days. The number of specimens assigned to each subgroup is shown in **Table 1**.

At the end of each exposure, specimens were once again equilibrated to constant weight at 23°C and 65 percent RH and were then tested to failure in bending. The center-point bending test was evaluated across a 224-mm span with the rate of loading set to induce failure in 30 to 90 seconds. The exposure methods and mechanical test methods used in this study were similar to those used by Winandy (1995) to test and calculate the modulus of elasticity (MOE) and the modulus of rupture (MOR). The MOR and MOE for the five groups were compared using t-test at  $\alpha = 0.05$  with Microsoft (Redmond, WA) Excel software. MC and density were determined for each specimen. Chemical component contents, including lignin, glucan, and other sugars, were also measured during the exposure time using procedures developed by Davis (1998).

### Results and discussion

The average MOE and MOR values for all groups, along with the coefficients of variation (COV) are given in **Table 1**. The results of the bending tests are shown in **Figures 1 to 4**. For untreated specimens (the control group), no change was found

Table 1. — Average modulus of elasticity (MOE) and modulus of rupture (MOR) of each group and significance of differences (coefficient of variation (COV)).<sup>a</sup>

Treatment-drying group <sup>b</sup>	Exposure (days)	No. of specimens	MOE (GPa)	MOR (MPa)	Work to max. load <sup>b</sup> (kJ/m <sup>3</sup> )	COV		
						MOE	MOR	Work to max. load
FRW-AD	0	5	8.00	77.7	42.7	0.09	0.41	0.37
FRW-AD	21	5	7.66	68.1	34.1	0.11	0.42	0.45
FRW-AD	70	5	8.03	71.6	31.9	0.10	0.41	0.36
FRW-AD	125	5	7.86	67.8	29.2	0.17	0.43	0.42
FRW-AD	200	5	7.55	55.6*	22.8*	0.17	0.50	0.70
FRW-KD	0	24	8.56	79.8	40.1	0.18	0.24	0.26
FRW-KD	21	24	8.02	69.7*	35.6*	0.17	0.25	0.34
FRW-KD	70	24	7.88*	64.6*	27.6*	0.19	0.24	0.46
FRW-KD	125	24	7.72	62.8*	25.9*	0.16	0.25	0.36
FRW-KD	200	24	7.52	58.1*	23.6*	0.15	0.26	0.53
PA-AD	0	7	8.18	47.2*	18.4*	0.20	0.39	0.40
PA-AD	21	6	7.33	47.1*	24.1*	0.16	0.44	0.32
PA-AD	70	6	5.81*	31.6*	13.0*	0.25	0.47	0.42
PA-AD	200	6	5.22*	24.5*	5.7*	0.19	0.42	0.35
PA-KD	0	13	6.87*	46.4*	17.8*	0.21	0.31	0.30
PA-KD	21	13	6.44*	37.3*	13.9*	0.17	0.40	0.42
PA-KD	70	12	5.75*	34.5*	12.0*	0.19	0.35	0.39
PA-KD	200	12	5.20*	23.1*	5.0*	0.23	0.38	0.40
Untreated	0	25	8.67	79.8	48.5	0.17	0.23	0.28
Untreated	21	25	8.01	75.5	44.2	0.17	0.23	0.28
Untreated	70	25	8.71	75.2	43.6	0.18	0.23	0.31
Untreated	125	25	8.06	73.9	40.5	0.19	0.24	0.33
Untreated	200	25	8.20	70.3	39.9	0.17	0.23	0.29

<sup>a</sup> \* signifies value as significantly different ( $p \leq 0.05$ ) compared with the untreated group at the same exposure time.

<sup>b</sup> FRW = new guanlyurea phosphate-boron based fire-retardant treatment; AD = air-dried; KD = kiln-dried; PA = phosphoric acid.

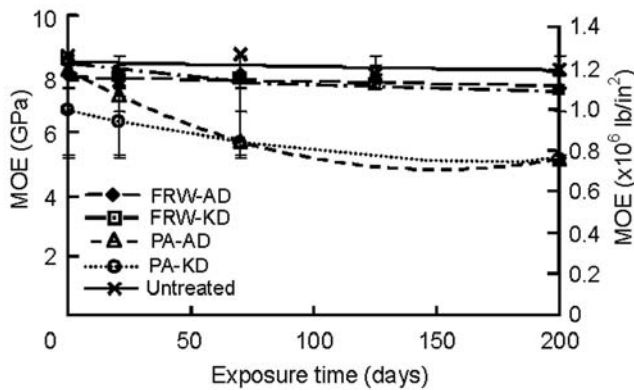


Figure 1. — Comparison of MOE for different treatments and drying methods (FRW = new guanlyurea phosphate-boron based fire-retardant treatment; PA = phosphoric acid; AD = air-dried; KD = kiln-dried).

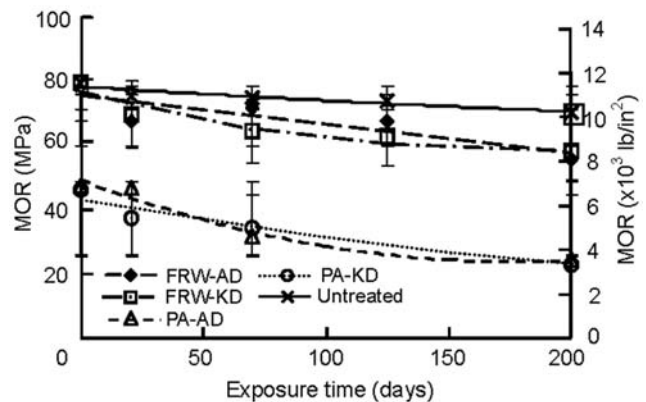


Figure 2. — Comparison of MOR for different treatments and drying methods (FRW = new guanlyurea phosphate-boron based fire-retardant treatment; PA = phosphoric acid; AD = air-dried; KD = kiln-dried).

in MOE after 200 days for all exposures (Table 1, Fig. 1). However, MOR showed statistically significant ( $p \leq 0.05$ ) reductions after 125 or 200 days of exposure compared with unexposed specimens (Fig. 2). The combination of high temperatures and moist conditions resulted in decreased strength, even

though the material was untreated and no acidic-type fire-retardant treatments were involved. Previous work has noted similar trends and attributed them to the acetyl breakdown, which generated sufficient acetic acid to promote acid hydrolysis (LeVan et al. 1990).

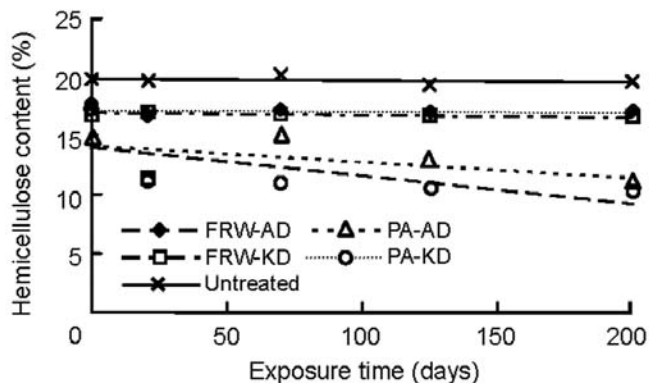


Figure 3. — Comparison of hemicellulose contents for different treatments and drying methods (FRW = new guanylurea phosphate-boron based fire-retardant treatment; PA = phosphoric acid; AD = air-dried; KD = kiln-dried).

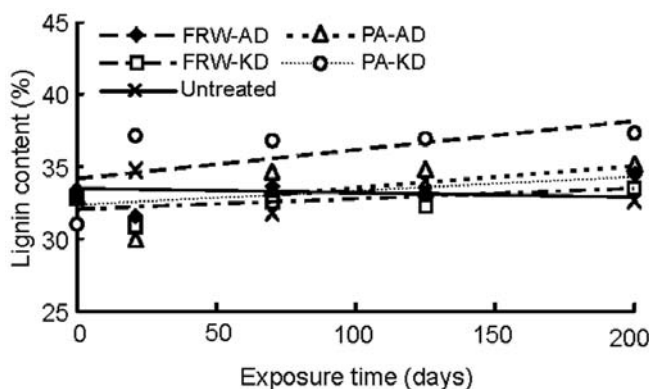


Figure 4. — Comparison of lignin contents for different treatments and drying methods (FRW = new guanylurea phosphate-boron based fire-retardant treatment; PA = phosphoric acid; AD = air-dried; KD = kiln-dried).

### PA treatment effects

For specimens air-dried after treatment, no significant initial effect on MOE occurred between untreated and PA-treated pine before exposure to 66°C (Table 1, Fig. 1). However, after 70 days of exposure, there was a significant decrease in MOE of 33 percent compared with that of untreated, unexposed control specimens, but with more exposure, the MOE remained stable. A significant initial decrease occurred in MOR of 41 percent, and a progressive trend of strength decrease continued as exposure progressed (Table 1, Fig. 2). At the end of the exposure, MOE and MOR had decreased 39 percent and 69 percent, respectively.

For specimens kiln-dried after treatment, PA treatment without any exposure (0 days) at 66°C resulted in a significant initial decrease in MOE of almost 21 percent and in MOR of 42 percent, compared with the untreated, unexposed control group. In all of the exposure durations, specimens that were kiln-dried after treatment appeared to undergo a consistent trend in property decrease. The degradation of kiln-redried specimens was so severe that the decrease in MOE and MOR reached 40 percent and

71 percent, respectively, at the end of the exposure (200 days at 66°C).

Kiln-drying after treatment resulted in greater initial decrease in strength for PA-treated pine than did air-drying. However, no practical differences related to post-treatment drying regime existed in either MOE or MOR at the end of the 200-day exposure at 66°C. The effects of the two redrying methods on bending strength were the same in the long run. Both kiln-redried and air-redried specimens showed that MOR was affected to a greater degree than was MOE. As previously noted by LeVan et al. (1990) and Winandy (1995), PA has more significant negative effects on viscoelastic properties than on the elastic properties of treated wood, as do other more acidic fire retardants.

### FRW treatment effects

The FRW-treated specimens that were air-dried after treatment showed no significant decrease in either MOE or MOR compared with control values for all exposure durations, except that MOR decreased by 21 percent in samples exposed for 200 days (Table 1).

Kiln-redried specimens exhibited no significant initial decrease in bending strength. A significant decrease in MOE, compared with the control group, did not occur until 70 days of exposure. The samples may have experienced a brief period of resistance to thermal degrade, but when exposed for 21 days, MOR had decreased by 8 percent. At the end of exposure, MOE had decreased, but not significantly, while MOR had significantly decreased by 17 percent or 27 percent compared with untreated but similarly exposed controls or untreated, unexposed controls, respectively. The MOE stabilized during the exposure time, and the MOR decrease showed a slight on-going downward trend with time of high-temperature exposure. This trend was similar to those previously reported for standardized GUP-B systems (Winandy 1995).

### Effects of redrying method on treated specimens

As previously noted, MOR was usually more sensitive to the redrying method than was MOE; this was especially obvious in PA-treated specimens (Table 1). As expected because of its highly acidic characteristics, samples with PA treatment experienced a larger initial negative effect on MOR than did the FRW-treated samples (Figs. 1 and 2). The PA-treated pine also experienced negative thermal-induced effects on both MOE and MOR. This severe degradation in bending strength is related to the stronger acidity of PA compared with other model compounds or existing commercial fire-retardant formulations.

For FRW-treated pine, there was no significant difference in effects on properties between air-drying and kiln-drying after treatment (Figs. 1 and 2). This comparison indicates that redrying methods did not affect the subsequent resistance of FRW-treated pine to thermal degradation. This may be attributed to the mild acidity of FRW and its inherent stability to thermal degradation because of its pH-buffered nature when exposed to elevated temperatures while in service.

In summary, the two post-treatment redrying methods showed few measurable differences in effects on MOE (Fig. 1) or MOR (Fig. 2) compared with matched untreated controls. While treated specimens that were kiln-dried after treatment experienced somewhat more rapid degrade than comparable air-redried specimens, this trend eventually stabilized and few

practically important differences were eventually noted between the two post-treatment redrying methods.

### Comparison with standardized GUP-B fire retardant

The GUP used in the FRW formulation was synthesized by a new method that results in higher GUP yield with fewer impurities and a more neutral pH (Wang et al. 1999). The FRW data were compared with the standardized GUP-B formulation studied and reported in previous research (Winandy 1995). Both experiments were performed using different wood species but similar experimental designs, treatment processes, and exposure conditions. When the results with the FRW formulation were compared with previously reported results for the standardized GUP-B formulation, the newly synthesized FRW exhibited no practical difference in effect on MOE compared with the standardized GUP-B, but FRW experienced noticeably fewer negative effects upon bending strength with time at high-temperature exposure than did the standardized GUP-B formulation (Table 2). The newly synthesized FRW formulation for GUP-B seems to be equal or superior to the GUP-B formulation currently standardized as FR-1 (AWPA 2003a) in that it causes similar or in some cases even less property degradation. Recently, data were presented to substantiate that after more than 20 years of service, roof plywood treated with the standardized formulations of GUP-B has had no known field-related problems with in-service thermal degrade (Hoffman 2004). Accordingly, the slower property degradation noted for the new GUP-B formulation (FRW) may in turn result in even longer service lives for FRW-treated materials exposed to elevated temperatures while in service (Lebow and Winandy 1999).

### Effects on chemical composition of wood

Fire-retardant treatment and thermal exposure resulted in a chemical component change in the treated wood, especially in the hemicellulose content (Table 3, Fig. 3). For the control group, the chemical components in the wood remained constant during the exposure time.

After PA treatment, the percentage of hemicellulose was initially decreased compared with the untreated specimens. Thereafter, the individual and the total hemicellulose content continued to decrease during the course of high-temperature exposure time (Table 3, Fig. 3). Conversely, lignin residues increased during exposure duration, especially for PA-treated specimens that were kiln-dried after treatment (Table 3, Fig. 4). We feel this apparent increase in lignin might simply be a remnant of the fact that the relative content of total weight of lignin rises as sizable losses occur in polysaccharide content from acid degradation. Comparing the relative rate of increase in lignin (Fig. 4) to the relative rate of loss in hemicellulose (Fig. 3) seems to confirm our suspicion. The trends in both hemicellulose and lignin also seem to show that kiln-redrying of PA-treated specimens caused more changes in wood components than air-redrying during subsequent high-temperature exposure.

For FRW specimens, hemicellulose content initially decreased compared with the untreated control group, but the individual and the total hemicellulose contents generally remained stable during the high-temperature exposure (Table 3, Fig. 3). Lignin content also showed a slight increasing trend for PA-treated specimens but not for FRW-treated pine. These re-

Table 2. — Change in MOE and MOR of treated wood specimens during exposure at 66°C.<sup>a</sup>

Exposure time (days)	FRW-KD		Standardized GUP-B formulation <sup>b</sup>	
	MOE (GPa)	MOR (MPa)	MOE (GPa)	MOR (MPa)
0	8.56	79.8		
7			14.1	105.9
21	8.02	69.7	13.3	104.9
60			13.3	98.8
70	7.88	64.6		
125	7.72	62.8		
160			12.2	78.3
200	7.53	58.1		
290			13.3	69.8
Slope ( $dx/dt$ )	-0.004	-0.092	-0.002	-0.136
$r^2$	0.791	0.809	0.186	0.953

<sup>a</sup> FRW = new guanylurea phosphate-boron based fire-retardant treatment; KD = kiln-dried; GUP = guanylurea phosphate; B = boric acid.

<sup>b</sup> Data compiled from Winandy (1995).

sults are similar to previously reported results for the standardized formulation of GUP-B exposed to similar temperatures for their initial 200 days of exposure (Winandy 1995). There seemed to be no significant differences in the effect on chemical composition between kiln-drying and air-drying after treatment (Fig. 3). Few differences were noted between the three treatments (untreated, FRW, or PA) in glucan analysis.

Previous work has shown that the hemicellulose content is normally significantly decreased during the course of high-temperature exposure and is also related to the acidity of fire-retardant chemicals (LeVan et al. 1990, Winandy 1995, Winandy and Lebow 1996). As expected, the highly acidic PA-treated specimens showed the most changes in various wood components. The PA treatment caused more severe degradation in hemicelluloses than did FRW (Fig. 3) because of the much lower pH value in PA, which accordingly created a greater proportion of lignin in total components. Neither PA nor FRW caused any obvious decrease in cellulose, which made it seem that cellulose content was largely unaffected by high-temperature exposure at 66°C.

The physical and mechanical properties of wood are a complex function of cellular and polymeric structure and chemistry (Winandy and Rowell 1984). It was observed that changes in the chemical composition of wood directly corresponded to a loss of strength. The critical component seems to be the hemicellulose. Any significant decrease in hemicellulose content resulted in decreased bending strength. As shown previously, MOR is more sensitive to this change than MOE. The results observed in this study were consistent with others (Davis and Thompson 1964, Kollman and Fengel 1965, LeVan et al. 1990, Reinprecht et al. 1999). It is thought that early strength loss in wood might be closely related to the initial degradation of the branched units of hemicelluloses, while later more advanced strength loss is related to further degradation of residual hemicellulose main chains and initial degradation of cellulose and lignin.

Table 3. — Percentage of total chemical composition of PA-treated or FRW-treated Korean pine specimens during exposure at 66°C.

Treatment <sup>a</sup>	Days of exposure at 66°C and 67% RH	Total weight (%)							Total carbohydrate	Total yield
		Klason lignin	Arabinan	Galactan	Rhamnan	Glucan	Xylan	Mannan		
									----- (%) -----	
PA-KD	0	31.0	0.8	3.8	0.07	35.7	3.2	9.2	52.9	84.0
	21	37.1	0.4	1.9	0.03	34.9	1.8	6.6	45.6	82.9
	70	36.8	0.4	2.4	0.05	34.6	1.8	6.7	46.0	82.9
	200	37.2	0.3	2.1	0.05	35.6	1.6	6.3	45.9	83.1
PA-AD	0	32.9	0.7	3.2	0.07	35.9	2.8	8.1	50.7	83.8
	21	29.9	0.6	2.6	0.06	38.1	2.6	9.3	53.3	83.3
	70	34.6	0.4	1.7	0.05	35.2	2.0	7.2	46.6	81.5
	200	34.2	0.3	1.6	0.05	37.9	1.6	7.1	48.5	82.7
FRW-KD	0	33.1	0.8	3.9	0.08	35.2	3.2	8.9	52.0	85.3
	21	31.0	0.7	3.0	0.07	37.2	3.0	10.2	54.2	85.5
	70	32.8	0.4	4.5	0.10	35.5	3.3	8.7	52.5	85.3
	125	32.6	0.4	4.0	0.09	35.5	3.3	8.8	52.1	84.8
	200	33.8	0.3	4.4	0.10	34.7	3.3	8.4	51.3	85.1
FRW-AD	0	33.2	1.0	4.5	0.09	33.9	3.0	9.0	51.4	84.9
	21	31.5	0.8	4.3	0.08	35.8	3.1	9.2	53.2	84.8
	70	33.6	0.5	3.5	0.08	36.5	3.1	9.4	53.2	86.8
	125	33.3	0.4	4.0	0.10	36.1	3.1	9.2	52.9	86.2
	200	34.3	0.3	4.7	0.11	34.7	3.4	8.4	51.6	86.0
Untreated control	0	32.9	1.0	4.2	0.09	40.6	3.6	10.9	60.4	93.2
	21	34.7	1.0	5.7	0.12	38.9	3.9	9.5	59.1	93.8
	70	31.8	0.8	4.0	0.08	41.8	3.6	11.2	61.5	93.2
	125	34.0	0.9	4.5	0.10	39.9	3.7	10.4	59.5	93.6
	200	32.7	0.8	3.9	0.10	40.7	3.6	10.9	60.0	92.7

<sup>a</sup> FRW = new guanlyurea phosphate-boron based fire-retardant treatment; KD = kiln-dried; AD = air-dried.

## Conclusions

The post-treatment drying method causes varying effects on the strength of FRT wood depending on the type of fire retardant. For FRW treatment, it was found that there were no significant differences in bending strength between air-redrying and kiln-redrying. For those fire retardants with very low pH values, such as PA, kiln-redrying seemed to induce more severe degradation compared with air-redrying. Based on the field experience of currently standardized GUP-B systems, we believe that our findings indicate that kiln-redrying at  $\leq 70^{\circ}\text{C}$ , as specified in AWWA C20 (AWPA 2003b), will be acceptable for FRW.

In this study, the bending strength of FRW-treated pine was compared with that of PA-treated pine. The resulting data further corroborates previous findings that when wood is later exposed in-service to high temperatures for extended periods, the cumulative strength loss is related to both the initial pH of the wood and the buffering capacity of the fire-retardant system (Winandy 1997). When FRW fire retardant was used, less degradation in bending strength was noted compared with results from currently used and previously reported organic-phosphate

GUP-B formulations (Winandy 1995). This was attributed to the more neutral pH, fewer impurities, and higher yield of the FRW formulation resulting from less unreacted phosphoric acid during the manufacturing process.

Finally, based on these results, any decrease in field performance of FRW-treated products related to deterioration in mechanical properties compared with currently standardized GUP-B systems is not expected.

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