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Bending Properties from Laboratory and Field Exposures of FRT Plywood

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ABSTRACT

The impact of the variables was evaluated by measuring bending strength properties and comparing matched laboratory and field exposure samples. The physical test data show the positive effects of adding a buffering system to model FR compounds and the negative effects of increasing the moisture in the environment during exposure.

Keywords: fire retardants, strength, buffer, moisture

INTRODUCTION

Our understanding of the laboratory induced degradation with fire retardant systems is currently limited since we are unable to correlate laboratory steady-state experiments with actual in-service field degradation. Current model studies have generally been limited to isothermal rate studies with selected model FR chemicals. Other factors also play a major role in the degradation of FR-treated wood. These factors, which have not been studied in any detail, include relative humidity/moisture content cycles and thermally-induced evolution of ammonia from ammonium phosphates to give phosphoric acid. The objective of this study was to determine the relationship between laboratory and field results based on strength-temperature-relative humidity (moisture content)-FR chemical interactions.

METHODS AND MATERIALS

Twenty sheets of 5/8-in (16 mm) thick, 4-ply southern pine plywood made with defect-free N-grade veneers were used to reduce variability in mechanical properties resulting from random placement of defects in interior veneers. From each sheet, 48 samples measuring 4- x 22-in (102- x 559-mm) parallel to face grain were cut. One sample from each sheet was randomly assigned to 48 experimental groups resulting in a blocked experimental design. Laboratory tests were conducted in accordance with ASTM D 5516 (ASTM 1991). Samples were treated with monoammonium phosphate (MAP) alone or in combination with phosphoric acid (PA) or disodiumoctaborate tetrahydrate (DOT). Field exposures were conducted in simulated attics maintained at ambient or high humidity conditions. Two structures are designated as the DRY-DRY buildings to show that the plywood was kiln dried after treatment (KDAT) and installed in a dry structure. These two structures represent the assumed typical exposure for roof sheathing where the panels are installed dry and kept dry. These two structures had no ingress or egress of ambient air so that the DRY building would match the WET buildings discussed below.

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Two additional structures provided humidified air periodically to maintain a high relative humidity (rh) (>85%) environment. Relative humidity within each structure was monitored on a periodic basis to develop a temperature/relative humidity profile for each structure. It was not possible to ventilate these structures and maintain the humidity. One humidified chamber was used to test samples which were KDAT and rewetted by immersion before exposure (DRY-WET structure). The other was used to expose treated samples which were not dried before exposure (i.e. installed wet from treating) and this structure was referred to as the WET-WET. The untreated panels for the WET-WET condition were treated with water only and installed wet. The groups that were not dried at all after treatment and were exposed wet were meant to ascertain problems associated with rewetting in service. This latter exposure was intended to provide a worst-case scenario. The experimental design is summarized in Table 1. Retention averaged 54.2 kg/m^3 across all treatments.

Table 1. Experimental design showing months of exposure in each environment.[1]

Treatment	Steady State Lab Exposure (66 ºC, 75% relative humidity)	Field Exposures		
		KDAT Unvented DRY-DRY (DD)	KDAT >85% rh DRY-WET (DW)	No KDAT >85% rh WET-WET (WW)
100% MAP	0[2], 60, 180 d	1, 3.6 yr	1, 3.6 yr	1, 3.6 yr
75% MAP + 25% PA				
50% MAP + 30% PA + 20% DOT				
Untreated				

[1]One experimental group of 20 or 40 samples was tested for each time period indicated; [2]Represents the unexposed control.

Temperature loadings in the attic structures are seen in Figure 1 for the two exposure periods. Testing of all samples was done in accordance with ASTM D 3043 (2008).

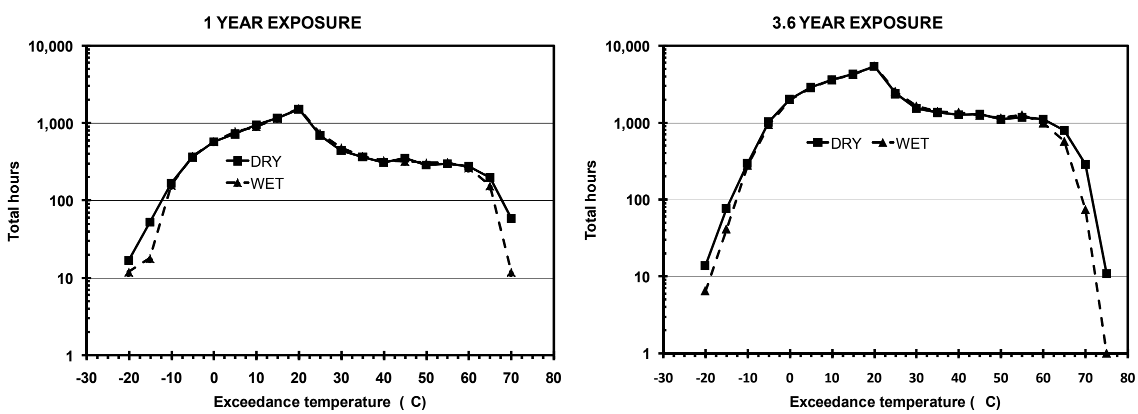

Figure 1. Temperature loads during exposure periods

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RESULTS AND DISCUSSION

For ease of comparison, it was decided to express the data as the ratio of the treated material to the untreated, unexposed material at the same exposure time. These data are shown in Figure 2 for the laboratory data.

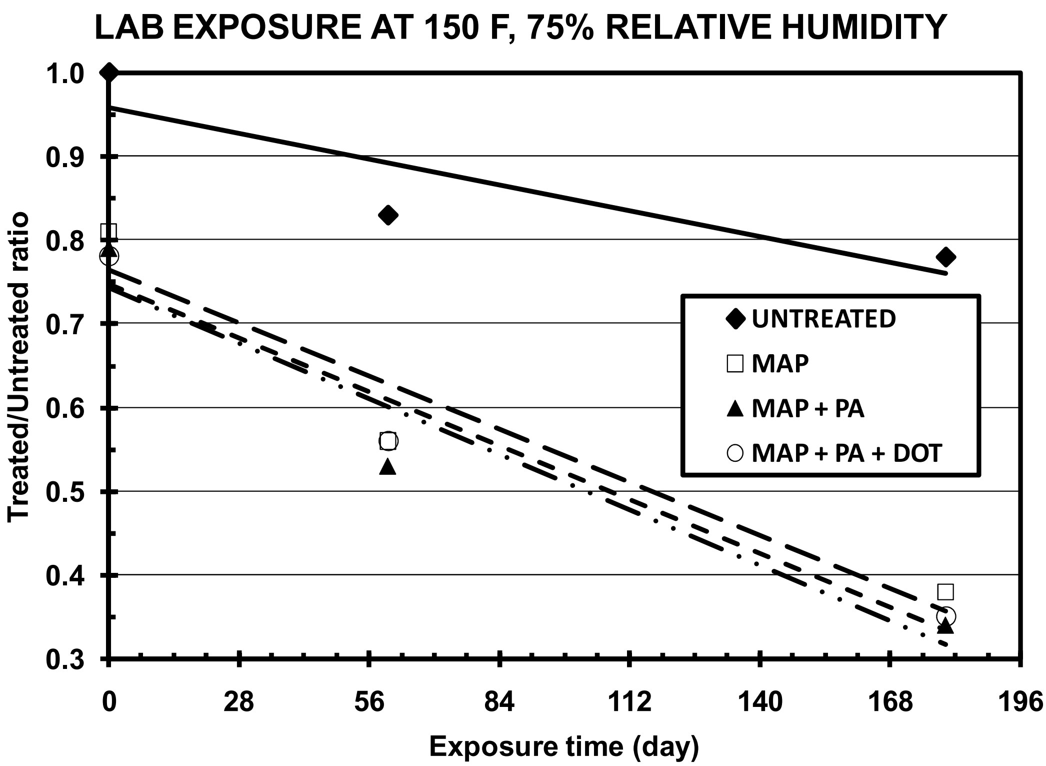

Figure 2. Comparison of treated/untreated, unexposed MOR ratios in the laboratory study.

The initial losses for all formulations was in the order of 20%, a value which agrees with the long-standing recommendation to reduce plywood design values by 16.7% if the plywood is treated with fire retardants (APA 1966). In our work, the untreated samples sustained a 22% loss after six months of steady-state laboratory exposure at 150 F and 75% relative humidity while all of the treatments showed about 65% loss (Fig 2). That is, there was little to no difference between the various treatments: increasing the acid content or adding a buffer showed no effect compared to the MAP alone. There was little difference in the losses after two months of exposure also. This finding suggests that the laboratory exposure essentially overwhelms any effects due to the various treatments. The laboratory exposed samples have considerably higher strength losses compared to the field exposed samples discussed below. This was expected because Kim and LeVan (1990) showed that continuous exposure such as the laboratory test seemingly gave much higher strength loss than cyclic exposures. However, when Kim and Levan (1990) compared the strength data on the basis of the amount of time at the same temperature, the strength losses for the cyclic and continuous exposures are the same for the same amount of time at a given temperature.

Data for the field exposures are shown in Figure 3. Untreated plywood showed a 7% total loss when exposed in the DRY-DRY condition and 8% total loss when exposed in the DRY-WET condition for 3.6 years. The total losses in the WET-WET condition at 16% after 3.6 years were about twice the above. This demonstrates that continual moisture is the worst condition for plywood.

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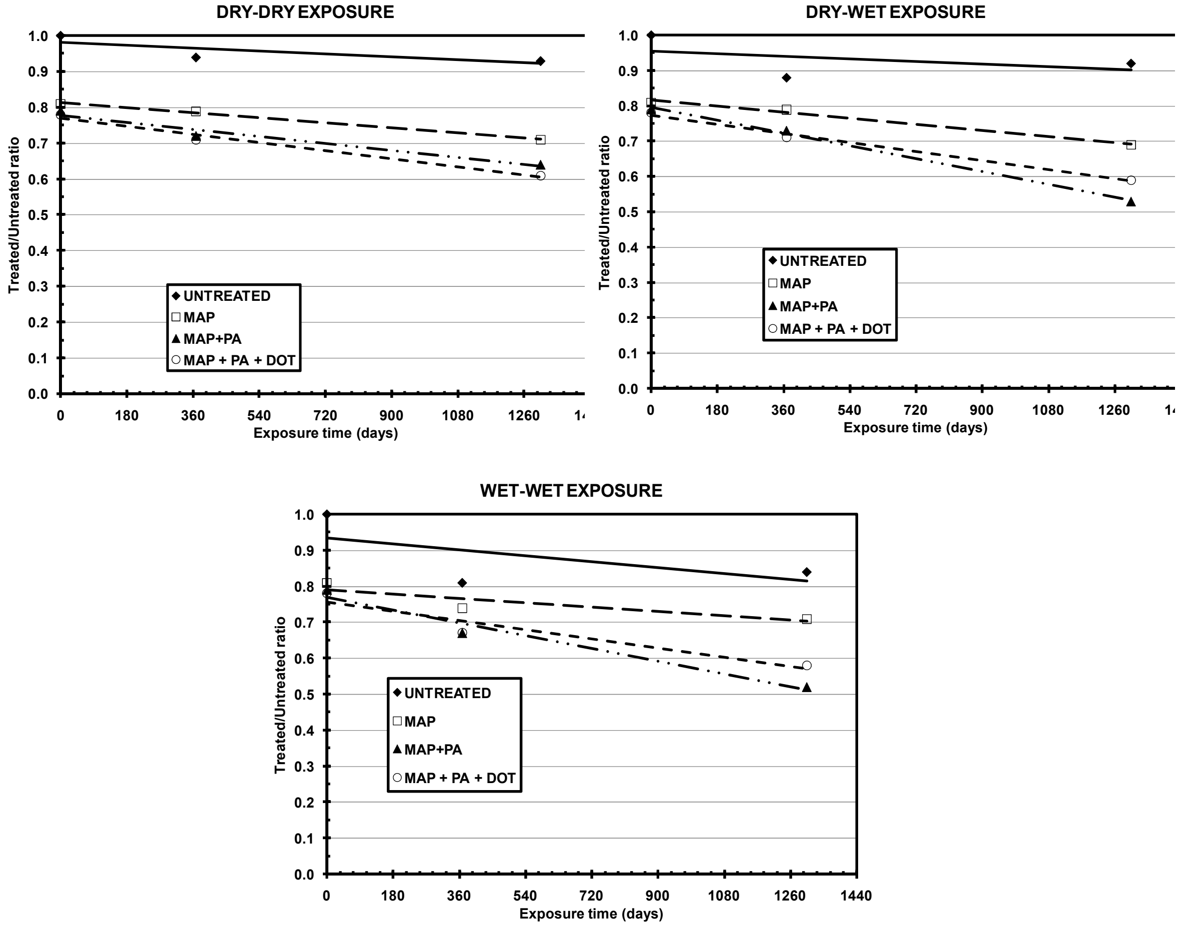

Figure 3. Strength ratios for samples exposed in simulated attics.

Plywood treated with MAP alone decreased by 10, 12, and 10% for the DRY-DRY, DRY-WET and WET-WET conditions, respectively, after the initial treatment losses. This shows that MAP alone is relatively insensitive to moisture since essentially the same degree of loss is shown for all conditions. Addition of PA to MAP showed a 21% initial loss which is similar to the initial loss for MAP alone. However, 3.6-years of field exposure greatly increased the total losses. Under the DRY-DRY conditions, the loss increased by 15% at 3.6 years to a total of 36%. This formulation had further decreases in strength due to moisture with the DRY-WET samples losing 47% total and the WET-WET conditions losing 48% total. The two wet conditions increased losses by 11-12% from the DRY-DRY. This indicates that moisture aggravates the attack of the acid-containing formulation. The buffered FR-model compound MAP/PA/DOT had an initial loss of 22% which is essentially the same as the other treatments. Interestingly, the buffer showed the same loss regardless of the moisture conditions with the three year losses increasing 17%, 19% and 20% for the DRY-DRY, DRY-WET and WET-WET conditions, respectively. When compared to the losses for the MAP/PA, these are 3% worse for the DRY-DRY but 6% better for both moisture conditions. This shows the MAP/PA/DOT to be intermediate in effect on long-term field exposure when compared to MAP or MAP/PA. It would also appear that the buffer required some moisture to be effective.

It should be reemphasized that the formulations selected for this work were chosen to simulate possible scenarios and are not representative of actual commercial formulations. To the authors' knowledge, there are no commercial formulations that are purely MAP but rather formulations based on MAP always have incorporated borate buffers. Obviously, there are no commercial formulations that purposely incorporate PA and its inclusion in this work was to simulate the possible *in-situ* formation of PA during extended exposure periods. As noted, the formulations in this work were chosen to help elucidate possible mechanisms of strength loss during exposure and accelerate such losses into a reasonable time frame. Statistical comparisons within an exposure group were done by comparing the strength losses for a formulation to those of the untreated wood at the same exposure time. An analysis of variance (SAS 2001) showed that the data could be separated into different groupings as shown in Table 2. Tukey's test was used to separate means.

Table 2. Strength ratios relative to untreated controls exposed for the same duration.

Exposure	Time	Treatment		
		MAP	MAP+PA	MAP+PA+DOT
Wet-Wet	1 yr	0.91	0.82	0.83
	3.6 yrs	0.80	0.58	0.65
Dry-Dry	1 yr	0.84	0.76	0.75
	3.6 yrs	0.77	0.68	0.65
Dry-Wet	1 yr	0.89	0.83	0.81
	3.6 yrs	0.75	0.57	0.64
Lab	0 days	0.80	0.79	0.78
	60 days	0.67	0.63	0.68
	120 days	0.49	0.44	0.45
$LSD_{a=0.05}$ = 0.18; means separated by a value of $\geq$ 0.18 are significantly different one from another at α = 0.05.				

However, when free acid is added to the formulation and the moisture increased, then additional strength loss over and above the initial loss occurs. Buffering the formulation with borate helps resist some of the acid degradation.

SUMMARY AND CONCLUSIONS

A series of laboratory and field tests were designed to investigate the impact of exposure conditions on the strength of southern pine plywood treated with model fire retardant compounds. In this initial report it was shown that steady-state laboratory conditions were much more severe than those found in field. Future papers on modeling should help us correlate lab and field exposure data. While strength loss rates were essentially equal for both untreated and treated specimens exposed under dry, ambient conditions in the field, increasing the moisture loading increased the strength loss for systems containing free phosphoric acid. MAP alone has little impact on the degradation rate compared to untreated wood. Buffering the system with borates helps resist some of the acid degradation

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