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Post-layup protection of mass timber elements in above ground protected exposures: 2-year results

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ABSTRACT

Mass timber has seen increased use as a building material for low and mid-rise construction in recent decades. The durability of mass timber elements has not been fully examined and the effects of wood destroying organisms on this these materials merits attention. The effectiveness of currently labeled soil termiticides and passively applied biocides at post-construction or as remedial agents needs to be evaluated for mass timber used in structures, particularly in areas with elevated risk of termite attack. The ability of soil insecticidal drenches or spray-on insecticide/fungicide treatments for protecting mass timber in service was assessed with a modified AWPA Standard E21 above-ground test using three ply Douglas-fir or southern pine cross-laminated timber as well as Douglas-fir mass plywood panels. Samples of each material (305 x 102 x 102 mm) were installed in an above ground protected test at the Harrison Experimental Forest (HEF) (Saucier, Mississippi) in September, 2019. Six replicates of five treatments including soil termiticide, no treatment, spray-on borate at initiation, borate rods and remedial treatment, using spray on borate of attacked material after two years, were tested. Samples were left undisturbed for two years and then examined and rated. Near surface moisture content increased to levels approaching the fiber saturation point over the two-year non-disturbance period. Untreated control samples were attacked by both decay fungi and termites. Samples treated with borates at test initiation showed limited decay or termite attack. Soil termiticide treated plots showed no sign of termite attack, but some samples had heavy decay compared to non-soil termiticide treated plots.

Keywords: Cross laminated timber, mass panel plywood, AWPA Standard E21, above-ground testing, soil termiticide, borate, field test, durability, decay, termite.

1. INTRODUCTION

Despite the use of steel and concrete in the construction of low and high rise structures, wood remains a preferred construction material in many low to mid-rise applications due to its many positive attributes (Robertson *et al.* 2012). The use of mass timber for midlevel and high rise construction has also increased substantially in recent years due to a general desire to use more environmentally sustainable materials coupled with changes to building codes (Karacabeyli and Lum 2014, Pei *et al.* 2016, Singh and Page 2016, Stokes *et al*. 2017, Wang *et al*. 2018). Mass timber has excellent seismic (Popovski *et al.* 2012) and thermal properties (Pei *et al.* 2012). It also allows parts of structures to be prefabricated, reducing erection time, and provides increased carbon sequestration compared to alternative building materials like steel and concrete (Brandner et al. 2016). This success has changed global perceptions about wood construction with architects and engineers reevaluating the use of mass timber (Mallo and Espinoza 2014, 2015).

All wood is susceptible to biodeterioration under the proper temperature and moisture conditions, including mass timber (Wang *et al.* 2018). While most mass timber will be used in interior applications where wetting is not a major issue, some elements will invariably be wetted or termites will move up and into a structure, bringing in additional moisture. However, most mass timber used in construction is not chemically treated to prevent decay or insect attack, despite preliminary laboratory assays indicating that the material is wholly susceptible to termite attack (Wang *et al.* 2018, Franca *et al.* 2018). Many mass timber structures being built or in planning stages are in areas with potentially high decay and termite activity and thus prone to biological attack (Wang *et al.* 2018). Recent laboratory of cross-laminated timber observed termite tunneling along glue lines and consumption of untreated test samples (Stokes *et al.* 2017, Franca *et al.* 2018).

Identifying the conditions required to render mass timber elements susceptible to biological attack and methods for preventing this damage is essential for expanded use of these materials. While mass timber is currently not used in ground contact, moisture conditions in structures built in high decay and termite areas without adequate moisture controls may ultimately reach conditions suitable for degradation. Soil barrier treatments remain an important tool for limiting the risk of termite attack and have a long successful record, but there are few data on the ability of these products to protect mass timber elements (Mankowski *et al.* 2018, 2020, Shelton *et al.* 2015, 2021). Borates are also potentially useful for protecting mass timber against both fungal and insect attack as well as remediating existing attack. Some remedial borate treatments use concentrated boron rods that readily dissolve at wood moisture contents (MCs) above 30% (Morrell and Schneider 1995, DeGroot *et al.* 2000, Cabrera and Morrell 2009). These rods have been shown to readily diffuse when applied to utility poles or timbers in service (Morrell and Schneider 1995, DeGroot *et al.* 2000). Our earlier CLT field tests showed that moisture contents after six to twelve months were above 25% and approached 30% in the outer 15mm of the wood (Mankowski *et al.* 2018, 2020). The high moisture contents imply that boron rods could be used to protect CLT exposed to extremely harsh conditions or water ingress-related situations. In this paper, we discuss the methodology and two-year results of a five-year field study examining the ability of soil termiticides and passive borate treatments to protect mass timber materials in a ground proximity protected test.

2. MATERIALS AND METHODS

Three types of mass timber panels were tested using an AWPA E21-18 above-ground test (AWPA 2019). Three-ply cross-laminated timber (CLT) made from southern pine was produced at Clemson University and shipped to FPL Starkville. Three-ply Douglas-fir CLT was provided by D.R. Johnson (Riddle, OR USA) and Douglas-fir mass panel plywood (MPP) was supplied from Freres lumber, (Lyons, OR USA). Mass plywood and southern pine CLT samples measured 305 x 305 x 105 mm (H x L x W), while Douglas-fir CLT samples measured approximately 305 x 355 x 105 mm. Samples were conditioned for 60 days at 24 °C and 12% relative humidity and weighed before field exposure. Two moisture measurements were made with a Wagner MMC 220 pinless electronic moisture meter (Wagner Meters, Rogue River, Oregon) on the upper and lower part of the two broad faces of each sample after the 60 day equilibration period.

Samples were installed at the Harrison Experimental Forest (HEF) in Saucier, Mississippi in an AWPA E21-18 (AWPA 2019) above-ground protected field test. The HEF has an average annual precipitation of 1600 mm. Mean annual minimum and maximum temperatures (Jackson, MS data) are 12°C and 24°C, with no mean monthly temperature below 10°C. The topography is relatively flat with a slope of 5 to 12 percent. The soil is Poarch fine sandy loam with a pH of 4.9. The site has a Scheffer Index value of 70 (Morris and Wang 2008). Ground cover is predominately yaupon holly, wiregrass, broom sage with loblolly and long leaf pine. The HEF has a well-documented occurrence of Eastern subterranean termites, *Reticulitermes flavipes* Kollar. The test was set up as a randomized block design where each column of replicates had a different treatment. The plot containing the test blocks measured 9.14m x 9.14m and contained 0.76 m x 0.76 m sublots which were 1.52 m apart. A total of 36 subplots were used for the five treatments and six replicates of each treatment. Six subplots were not used (Figure 1). The 30 subplots were tilled by hand to a 50-100mm depth with a pick axe and any roots or stones were removed. Each subplot contained three mass timber samples of each type set on cinder blocks that measured 194 x 397 x 92 mm (Figure 2).

The treatments were:

1. Soil termiticide only: A 0.61m x 0.61m area of the 0.76m x 0.76m subplot was drenched with a 0.125% fipronil [5-amino-3-cyano-1-(2, 6-dichloro-4-trifluoromethylphenyl)-4-fluoromethylsulfinyl pyrazole] solution (per gallon of water). Bricks and mass timber samples were placed on the treated area with as little soil disturbance as possible (Figure 2).
2. Preventative borate spray: (Nisus, Knoxville, TN USA); 23% disodium octaborate tetrahydrate (DOT)) was applied to each mass timber sample of the six subplots. A plastic shield was placed over the adjacent sample on the cinder block before spraying to minimize excessive borate application to already sprayed samples (Figure 3).
3. Boron rods: Rods (WoodCare Systems, Kirkland, WA USA) were placed in bore holes at the top and on one face of each of the three mass plywood samples in each sub-plot. Top bore holes (19 mm in diameter by 114 mm deep) were drilled in the top center ply of each sample. Side bore holes were drilled at a 40° angle in the lower face of one side of the sample 105 mm from the bottom edge. Side face rod holes were drilled 60 mm deep. A 50 mm long solid boron rod was placed into each top bore hole along with a copper wire to help extract the rod for later weighing. The lower face bore holes received a 25 mm long rod along with wire for later extraction. All rod holes were plugged with plastic plugs (Figure 4).
4. Remedial treatment: Assemblies were exposed for 2 years with no initial treatment to allow decay and termite attack to occur prior to application spray-on remedial treatment (23% disodium octaborate tetrahydrate (DOT)).
5. Untreated controls

The test was set up in a randomized block design with six blocks containing one treatment per block in the total plot (Figure 1). For the remedial treatment, six plots were left undisturbed for two years to allow for biological attack, after which each sample (in this treatment) was remedially treated with the spray-on borate solution following the same method described for the borate preventative treatment at test initiation. A subset of 15 southern pine CLT samples (to be reported on in a later paper) was set out in a similar manner in Starkville, MS for annual boron assessment since samples in the HEF field test could not be sacrificed until the end of the five year test.

After placement and treatment, the samples were covered with pre-constructed ventilated plywood cover boxes with sloping roofs to help shed rain runoff (Figure 5). The covers were painted white to minimize heating. The front and back of each cover had four 25mm diameter mesh-covered ventilation holes. Samples remained undisturbed for two years except to check moisture in samples after 1.5 years. After 1.5 and 2 years, two moisture readings were taken on the top and bottom of the two broad faces of each sample using the Wagner meter, then the four moisture readings per sample were averaged and compared to pre-test initial (dry) moisture readings.

The test samples were installed in September 2019 and were rated and assessed for degree of decay and termite damage after 24 months. After 24 months, six non-treated control sample plots with termite attack were treated with boron spray as described above as a remedial treatment. Since the samples were large, the ratings reflect the bottom 75mm depth of the sample in contact with the cinder block.

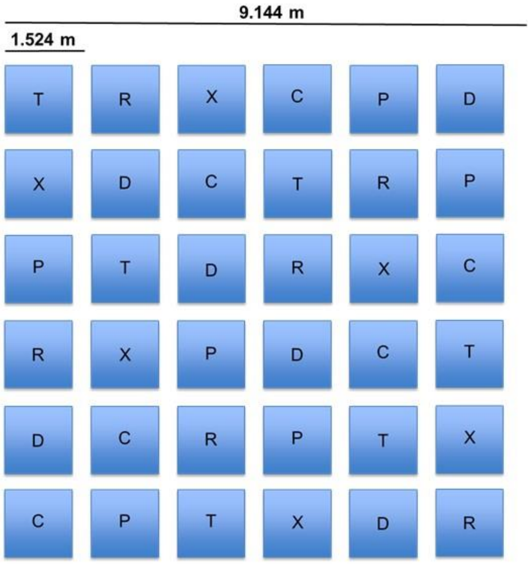

Figure 1: Layout of randomized block design for the modified AWPA E21 ground proximity field test. P = Protective treatment with borate (DOT at 23%). T = Treatment with fipronil soil termiticide (0.125%). C = Control. R = Remedial borate spray treatment (23% DOT) after two year check. D = boron rods in samples at initiation. X = Subplot not used.

Figure 2: Drench treatment with fipronil soil termiticide and arrangement of ground bricks and CLT in soil termiticide subplots before covering. Note the hand tilled soil. PVC frame used as guide for insecticide application.

Figure 3: Arrangement of blocks and samples in subplots for preventive and remedial treatments sprayed with borate solution (23% DOT) before cover was placed over samples (note plastic barrier to minimize drift on adjacent samples).

Figure 4: Arrangement of blocks and samples for boron rod treatment. Two rods placed in each sample at top and one face (left). Samples with rods capped, placed on blocks and covered (right).

Figure 5: Photograph of all test assemblies at the experimental plot after covers were applied.

The degree of fungal and termite attack was assessed visually on a scale from 10 (no attack) to 0 (complete failure) as described in AWPA Standard E21-18. The primary evaluation point for termite attack was the area of each sample in contact with the concrete block. The results were averaged for each treatment group.

3. RESULTS AND DISCUSSION

Average initial surface moisture contents of the samples were 13.5, 8.3, and 9.8% for Douglas-fir CLT, southern pine CLT and mass plywood, respectively (Figure 6). Sample moisture contents increased to 26.5, 25.5 and 32.0% for same materials 1.5 years after installation. Moisture contents were similar 2 years after installation suggesting that the materials had reached an equilibrium. The large initial moisture content increase reflects the high humidity inside the cover boxes resulting from elevated temperatures and seasonal rainfall. These results indicate that the mass timber samples were absorbing moisture despite the lack of an external liquid moisture source or direct soil contact and were reaching moisture levels where biodeterioration would become a concern. It is important to note that these readings were for moisture near the wood surface (approximately 10-15 mm) only, but they do indicate that mass timber elements will be at risk wherever air-handling mechanical equipment fails to control relative humidity.

Table 1 shows the average decay and termite ratings of the samples for the various treatments. Remedial boron spray treatment samples were still considered as controls at two years, but were grouped separately to minimize confusion with actual controls. Control samples were being attacked by termites and decay fungi in all subplots after two years. For Douglas-fir CLT, controls had termite and decay ratings of 7.8 and 9.2, respectively. Southern pine CLT performed slightly better, but heavy mold growth was observed on the southern pine CLT samples which may have inhibited termite and decay attack. Although the soil termiticide treatment (fipronil) prevented termite attack (rating 10), some samples were already experiencing extensive decay. This suggests that decay fungi were either stimulated by the soil termiticide or the lack of termites encouraged more fungal growth from the soil to the samples and was observed in an earlier study with similar treatments (Mankowski *et al.* 2020). The boron spray preventive treatments appeared to be limiting both termite attack and fungal decay. Although the boron rod treatment ratings were slightly better or the same as the controls, termite attack was observed on the boron rod treated samples. This would be expected as it would take a substantial amount of time for the boron rod to dissolve and diffuse from the application point to be effective. Boron rods were starting to dissolve as the rods could not be removed from the treatment hole. Boron rods in the Starkville samples had changed little after two years and were still removable from the rod holes. Samples in Starkville also had much lower moisture contents after two years compared to the HEF test site illustrating climatic differences as well as the higher biodeterioration hazard presented at the HEF site.

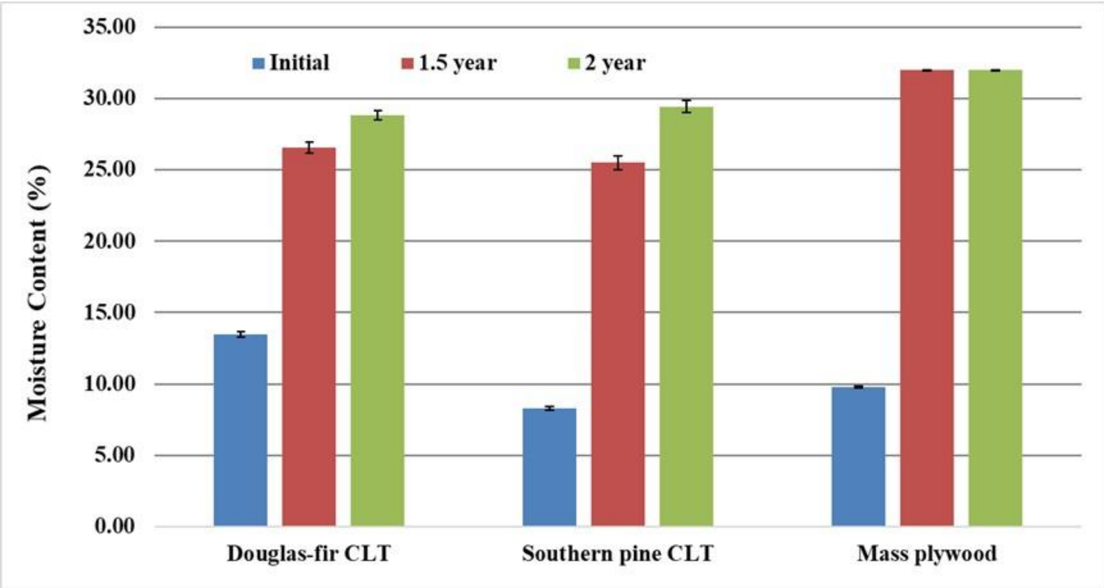

Figure 6: Average surface moisture content of mass timber samples (n = 120) at test initiation, then after 1.5, and 2 years of exposure in an above-ground protected field test in Saucier, Mississippi USA.

While the test is still in the early phases of evaluation, the results illustrate the high risk posed by prolonged exposure to elevated humidity conditions. While soil drenches have limited termite attack, decay fungi have begun to degrade many of the panels. Surface application of boron has reduced but not prevented this attack. Interestingly, decay appeared to be slightly worse on Douglas-fir than southern pine CLT. Douglas-fir timber has a relatively high proportion of heartwood is which classified as moderately durable. Southern pine timber tends to contain higher percentages of more decay susceptible sapwood. The improved performance of mass plywood could reflect the combination of the moderately durable heartwood and the preponderance of glue lines that may limit moisture ingress. Previous studies have shown that moisture moves readily along the non-edge-glued sides of CLT (Morrell *et al.* 2018), while these pathways are lacking in the mass plywood. However, the high percentage of exposed grain in the mass plywood also resulted in the moisture content quickly reaching 32% after 1.5 years. Future moisture assessments will include the use of pin-type resistance measurements to gain a better perspective on interior moisture levels as they relate to decay development and termite attack.

Table 1: Average (n = 6) percent moisture content, decay and termite ratings for 3-ply Douglas-fir or southern pine CLT and mass panel plywood (MPP) after two years in an above-ground field test. Remedial treatment group are considered controls at this point as they have not been treated until two years after initiation. They are shown here as a separate treatment to discern between the control group for future ratings.

	Treatment	Decay	Termite	% MC
Douglas-fir CLT	Control - No Treatment	9.2	7.8	27.6
	Remedial Before Boron (23% DOT) Spray	8.7	7.8	29.3
	Boron Rod	9.2	8.0	28.2
	Preventive Boron (23% DOT) Spray	9.7	9.0	29.8
	Soil Treatment - Fipronil (0.125%)	9.2	10.0	29.2
Southern Pine CLT	Control - No Treatment	9.0	8.9	30.2
	Remedial Before Boron (23% DOT) Spray	9.0	8.3	28.6
	Boron Rod	9.2	8.8	29.0
	Preventive Boron (23% DOT) Spray	9.6	9.8	31.5
	Soil Treatment - Fipronil (0.125%)	8.7	10.0	27.9
Mass Plywood	Control - No Treatment	9.0	8.0	32.0
	Remedial at Before Boron (23% DOT) Spray	9.0	7.8	32.0
	Boron Rod	9.3	8.7	32.0
	Preventive Boron (23% DOT) Spray	9.8	8.7	32.0
	Soil Treatment - Fipronil (0.125%)	9.8	10.0	32.0

Figure 7: Examples of termite attack showing extensive mud tubes on a Douglas-fir CLT sample (left) and termite tunnelling and excavation underneath the sample at the two-year rating (right).

4. CONCLUSIONS

- Near surface moisture contents in mass timber samples exposed in an above-ground test approached the fiber saturation point after two years in the field.
- Moisture content remained above 25% for Douglas-fir and southern pine CLT after two years. Moisture content for mass panel plywood remained at 32% after two years.
- Increased moisture levels suggested that the materials are at an increased risk of biodeterioration from termite and fungal attack.
- Termite attack was observed in almost all untreated samples after two years.
- A preventive (applied at initiation) boron treatment remained effective against termite attack as did the soil termiticide treatment for termites.
- Some of the soil termiticide treatment subplots showed decay at two years.

- Boron rods appeared to be dissolving as a result of the high moisture content of the samples or high humidity conditions at the exposure site.
- Panels will continue to be monitored.

5. ACKNOWLEDGEMENT

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