Assessment of Termite and Decay Damage to Mass Timber Elements in AWPA Ground Proximity and Above Ground Field Tests in Southern Mississippi

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ABSTRACT

The ability of soil insecticidal drenches or spray-on insecticide/fungicide treatments to protect mass timber elements was assessed using two modified AWPA ground proximity tests established in 2017 and 2019. The 2017 test evaluated 3-ply Douglas-fir cross-laminated timber using a modified AWPA Standard E26 while the 2019 test used a modified AWPA E21 protocol to evaluate 3-ply Douglas-fir or southern pine cross-laminated timber as well as Douglas-fir mass plywood panels. Both tests were installed at the Harrison Experimental Forest (Saucier, Mississippi) and will be assessed for five years. Treatments include an initial soil termiticide drench, spray-on borate at initiation, borate rods at initiation, remedial boron spray treatment two years after installation, and untreated controls. Samples were left undisturbed for one or two years and then rated for degree of termite and fungal damage. Moisture content of the test materials increased greatly over the non-disturbance period. Untreated control samples were attacked by both decay fungi and termites within the first year after test initiation. Soil termiticide treated plots showed no sign of termite attack, but decay was evident on some samples compared to non-soil termiticide treated plots. Samples treated with borates at test initiation showed limited decay or termite attack. The tests will continue to be evaluated for a period of at least 5 years or longer and serve as critical baseline data for field evaluation methods of mass timber in areas of high subterranean termite and decay pressure.

INTRODUCTION

The use of mass timber for mid-level and high-rise construction has risen due to increasing interest in using 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). Architects and engineers are excited about this relatively new product in wood construction for applications where steel and concrete predominate (Mallo and Espinoza, 2014; Mallo and Espinoza, 2015).

Mass timber is sometimes a preferred building material over concrete and steel due to its unique set of properties (Robertson et al., 2012). Wood has excellent thermal (Pei et al., 2012) and seismic properties (Popovski et al., 2012). Parts of structures can be prefabricated with mass timber decreasing building completion time. Mass timber also provides increased carbon storage compared to alternative building materials like steel and concrete (Brandner et al., 2016).

For all of its benefits, wood in mass timber elements can degrade, particularly when exposed to elevated moisture levels. The hazard level for decay and insect attack is very high in many regions where use of these products is contemplated (Wang et al., 2018). Recent laboratory and field tests exposing CLT to subterranean termites showed that termites readily attacked CLT material (Stokes et al., 2017; Franca et al., 2018; Mankowski et al., 2018; 2020).

Although mass timber is generally used in above-ground protected situations where biological risks are lower, structures built in high biological hazard zones will need protection either via soil pesticide treatments, post layup treatments, pretreatment of the mass timber elements with chemical wood protection systems, or a combination of these.

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., 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 spray-on solutions or solid boron rods that readily dissolve at wood moisture contents (MCs) above 30% (Morrell and Schneider, 1995). These rods have been shown to readily diffuse when applied to utility poles or timbers in service (Morrell and Schneider, 1995). Other studies examining moisture ingress in mass timber showed that moisture contents can increase greatly along non-edge sealed sides of CLT as well as in field tests with non-edged sealed CLT (Mankowski et al., 2018; 2020; Morrell et al., 2018). The high moisture contents suggest that boron rods could be used to protect CLT exposed to extremely harsh conditions or water ingress-related situations.

In this paper, we discuss two modified AWPA standard field methodologies for mass timber samples in covered ground proximity and above-ground tests after four and two years, respectively. We examined protection of mass timber elements using a soil termiticide drench below test samples and boron rods as well as spray on borate treatments at test initiation and as a remedial treatment after control samples were attacked.

MATERIALS AND METHODS

Ground Proximity Test

The ground proximity test utilized 3-ply cross laminated timber (CLT) fabricated from Douglas-fir obtained from D.R. Johnson, Riddle, Oregon. The material varied in width and height with a constant thickness of 105 mm. Forty samples were cut into approximately 305 x 355 x 105 mm (L x H x W) pieces for testing. Samples were conditioned at 23°C and 70% relative humidity for approximately 60 days and weighed before initiation of the field test. Two moisture measurements were made with a Wagner MMC 220 pinless electronic moisture meter (Wagner Meters, Rogue River, OR) on the face of each sample after the 60-day equilibration period.

The CLT samples were installed at the Harrison Experimental Forest (HEF) in Saucier, Mississippi in 2017 according to a modified AWPA E26 (AWPA, 2017) ground proximity protected field test. The method was modified to use a large specimen size, and no plywood under the samples as the standard describes plywood is optional for areas with *Reticulitermes*. The test area consisted of a large plot measuring 7.3 m x 7.6 m with 25 subplots measuring 0.76 m x 0.76 m. A total of 20 subplots were used for four treatment sets of the study. Five subplots were not used. The 20 subplots were tilled by hand to a 50 mm depth with a pickaxe and any roots or stones were removed. Two CLT samples set on four bricks on the 0.76 m x 0.76 m cleared square were placed in each subplot.

The treatments were:

1. Soil termiticide only: A 0.61 m x 0.61 m area of the 0.76 m x 0.76 m subplot was drenched with a 0.125% fipronil [5-amino-3-cyano-1-(2, 6-dichloro-4-trifluoromethylphenyl)-4-fluoromethylsulfinyl pyrazole] solution (applied as one gallon mixed with water per subplot). Bricks and mass timber samples were placed on the treated area with as little soil disturbance as possible (Figure 1).
2. Preventative borate spray: (Nisus, Knoxville, TN); 23% disodium octaborate tetrahydrate (DOT) in glycol was applied to one of the two CLT samples; the other was left untreated. A plastic shield was placed over the adjacent sample on the bricks before spraying to minimize excessive borate application to the adjacent untreated sample (Figure 2, top).
3. Remedial treatment: The two samples in a subplot treated as controls and exposed for one year with no initial treatment to allow decay and termite attack to occur prior to application of spray-on remedial treatment (23% disodium octaborate tetrahydrate (DOT)). As with the preventative treatment, one sample was treated and the other left untreated.
4. Untreated controls.

After placement and treatment, the samples were covered with pre-constructed ventilated plywood covers. The covers measured 559 mm x 495 mm at their base and were 737 mm high in front and 686 mm high in back creating a sloped roof for rain runoff (Figure 1, top far right). The covers were constructed from treated plywood and painted white to minimize heating. The front and back of each cover had three 25 mm diameter ventilation holes covered with mesh. Samples remained undisturbed for one year except to check moisture in six samples in three of the soil termiticide plots after six months. After one year and subsequently each year thereafter, two moisture readings were taken on the face of each sample using the Wagner meter, then the four moisture readings per sample were averaged and compared to readings taken before the test was initiated.

The test samples were rated using the AWPA E26 rating system for termites and the AWPA E21 rating system for decay. Samples were assessed for degree of decay and termite damage after 12, 24, 36, and 48 months. Since the samples were large, the ratings only reflected the bottom 25 mm of the sample in contact with the brick.

Above-ground Test

Mass timber samples consisting of three types were tested in an AWPA E21-18 above-ground test (AWPA, 2019). The test materials were: 3-ply southern pine cross-laminated timber (CLT) produced at Clemson University and shipped to FPL Starkville, MS, 3-ply Douglas-fir CLT provided by D.R. Johnson (Riddle, OR), and mass panel plywood (MPP) made from Douglas-fir which was supplied by Freres lumber (Lyons, OR). The 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 (H x L x W). Samples were conditioned and moisture contents were taken as described in the ground proximity test.

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 9.14 m x 9.14 m 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. The 30 subplots were tilled by hand to a 50 mm depth with a pickaxe 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 1).

The treatments were:

1. Soil termiticide only: A 0.61 m x 0.61 m area of the 0.76 m x 0.76 m subplot was drenched with a 0.125% fipronil [5-amino-3-cyano-1-(2, 6-dichloro-4-trifluoromethylphenyl)-4-fluoromethylsulfinyl pyrazole] solution (applied as one gallon mixed with water per subplot). Cinder blocks and mass timber samples were placed on the treated area with as little soil disturbance as possible (Figure 1).
2. Preventative borate spray: (Nisus, Knoxville, TN); 23% disodium octaborate tetrahydrate (DOT) in glycol 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 2, bottom).
3. Boron rods: Rods (WoodCare Systems, Kirkland, WA) 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. In the lower face bore holes we placed a 25 mm long rod along with wire for later extraction. All rod holes were plugged with plastic (black, polyethylene) plugs (Figure 3).
4. Remedial treatment: Assemblies were exposed for 2 years with no initial treatment to allow decay and termite attack to occur prior to application of 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). 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. The covers were painted white to minimize heating. The front and back of each cover had four 25 mm 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 using the AWPA E21 rating scale after 24 months. Since the samples were large, the ratings only reflect conditions near the bottom 25 mm of the sample in contact with the cinder block.

The Test Site – Harrison Experimental Forest

Samples were installed at the Harrison Experimental Forest (HEF) in an AWPA E21-18 (AWPA, 2019) above-ground protected field test. The HEF has an average annual precipitation of 1,600 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, and broom sage with loblolly and long leaf pine. The HEF has a well-documented occurrence of *Reticulitermes* spp. dominated by Eastern subterranean termites, *Reticulitermes flavipes* (Kollar), *R. virginicus* (Banks), and *R. hageni* (Banks) (Shelton et al., 2014).

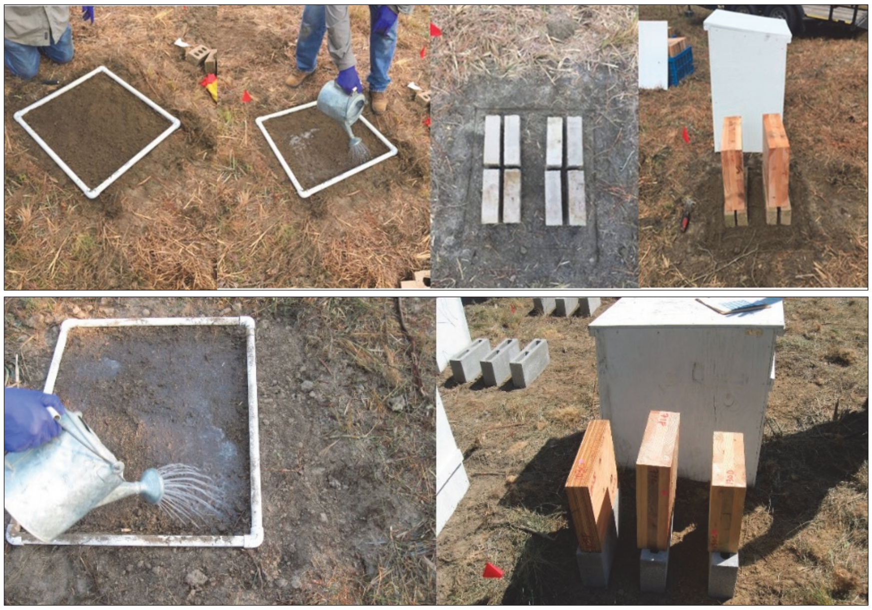

Figure 1. Treatment with fipronil soil termiticide showing arrangement of ground bricks or cinder blocks and CLT in soil termiticide subplots. Ground proximity test (top), above-ground test (bottom).

Figure 2. Photographs showing arrangement of ground bricks or cinder blocks and mass timber in subplots. Treatment with spray-on borate (23% DOT; arrow shows tip of spray nozzle) in the preventative and remedial treatments. Ground proximity test (top), above-ground test (bottom).

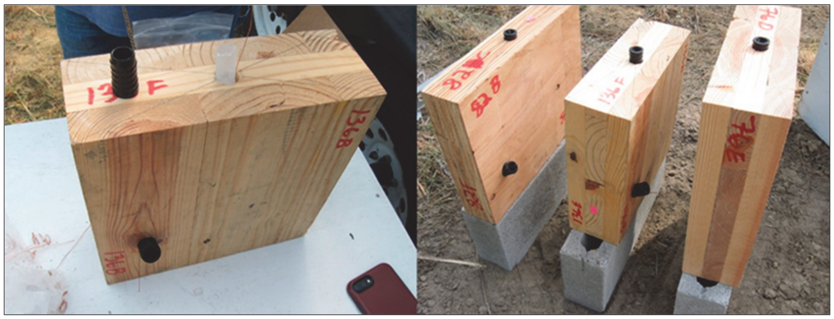

Figure 3. Arrangement of blocks and samples for boron rod treatment. Two rods placed in each sample; one at the top and one at the bottom face (left). Samples with rods capped, placed on blocks, and covered (right).

RESULTS AND DISCUSSION

Ground Proximity Test

Surface moisture contents of the CLT samples were 11.4% initially, which would be close to the 12% moisture content of the samples at the time of production. Figure 4 shows the average moisture content of the samples after 6, 12, 24, 36, and 48 months compared to the initial moisture content. Average moisture content increased to nearly 23.7% at the end of the first six months of exposure suggesting that the humidity inside the cover boxes was high. High average sample moisture contents were also recorded at the other annual check points indicating that the CLT samples readily absorbed moisture, despite being covered and out of direct soil contact. The surface moisture levels reached levels where biodeterioration would become a concern. This may be attributed to condensation forming inside the boxes as was observed at every moisture check.

Table 1 shows the average decay and termite ratings of the samples for the various treatments. Samples in the remedial no boron spray and remedial boron spray were controls at initiation and controls at one year when they were treated. Control samples were being attacked by termites in four out of five of the subplots after one and two years. After three years, all control plot samples had been attacked by termites. Control plots incurred ratings of 8.0 and 7.3 for decay and termites after 4 years of exposure, respectively (Table 1; Figure 5, right). Although the soil termiticide treatment (fipronil) limited termite attack, we noticed heavy decay in the fipronil treatments (Figure 5, left). This suggests that decay fungi either may be flourishing in the soil on components of the soil termiticide, or the lack of termites encouraged fungal growth from the soil to the samples. Another study, not described here, is examining this. The boron spray preventative treatments appeared to be controlling both termites and decay compared to samples not treated initially with boron. Remedial treatment with boron spray after one year also appeared to be limiting decay and termite attack. Active termite infestation was not observed on samples in the remedial treatment after one year (two years in test, but one year after treatment).

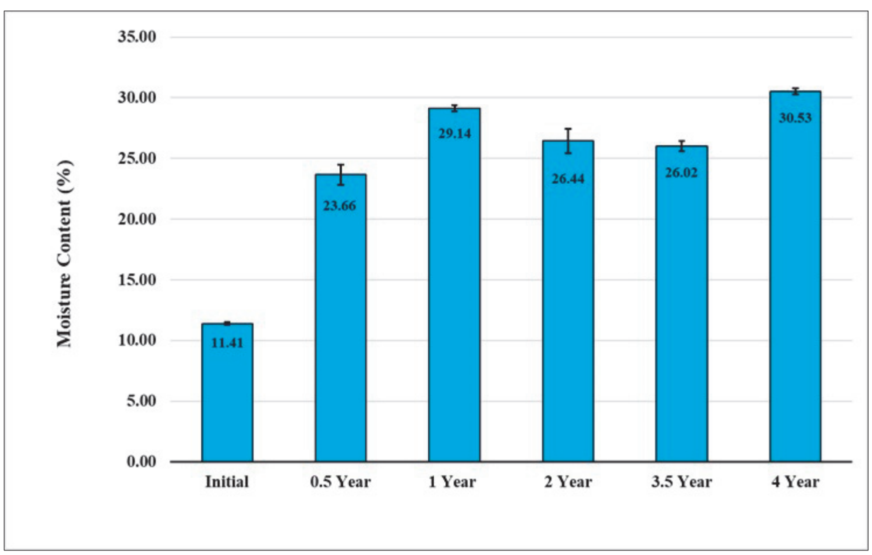

Figure 4. Average surface moisture content of Douglas-fir CLT samples at test initiation, after six months, and at annual intervals for four years of exposure in a ground proximity protected field test in Saucier, Mississippi.

Table 1. Average decay and termite ratings for 3-ply Douglas-fir CLT placed in the field in a ground proximity test after four years.

Treatment	1 Year		2 Year		3.5 Year		4 Year	
	Decay	Termite	Decay	Termite	Decay	Termite	Decay	Termite
Control – No Treatment	9.4	9.1	9.2	8.9	8.0	7.3	8.0	7.3
Remedial at 1 Year Boron (23% DOT) Spray	9.6	8.8	9.4	9.2	9.4	8.8	9.4	9.0
Preventative Boron (23% DOT) Spray	9.8	10.0	9.6	9.8	9.4	9.8	9.8	9.8
Soil Treatment – Fipronil (0.125%)	9.5	10.0	8.8	10.0	8.1	10.0	7.3	10.0

Figure 5. Examples of fungal decay (left) and termite damage (right) to 3-ply Douglas-fir CLT in a covered ground proximity test after four years.

Above-ground Test

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. As in the ground proximity test, the results indicate that the covered mass timber samples were absorbing high levels of moisture increasing the risk of biodeterioration. As in the ground proximity test, condensation was often observed on the samples inside the boxes. 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 or where contact with liquid water raises moisture content. This could come from condensation, leaks, or moisture barrier failure.

Table 2 shows the average decay and termite ratings of the samples for the various treatments after two years. Samples in the remedial boron spray treatment were considered as controls at two years, but were grouped separately to minimize confusion with actual controls. Termites and decay fungi were attacking the control samples in all subplots after two years (Figure 7). Untreated Douglas-fir CLT 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 similar to the ground proximity test and earlier observations (Mankowski et al., 2020). The preventative boron spray treatments appeared to be limiting attack by both termite and decay. Although the boron rod treatment ratings were slightly better or equal to the controls, termite attack was observed on these 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 and could not be removed from the treatment hole. In the Starkville, MS subset (to be reported in a subsequent publication), the boron rods 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.

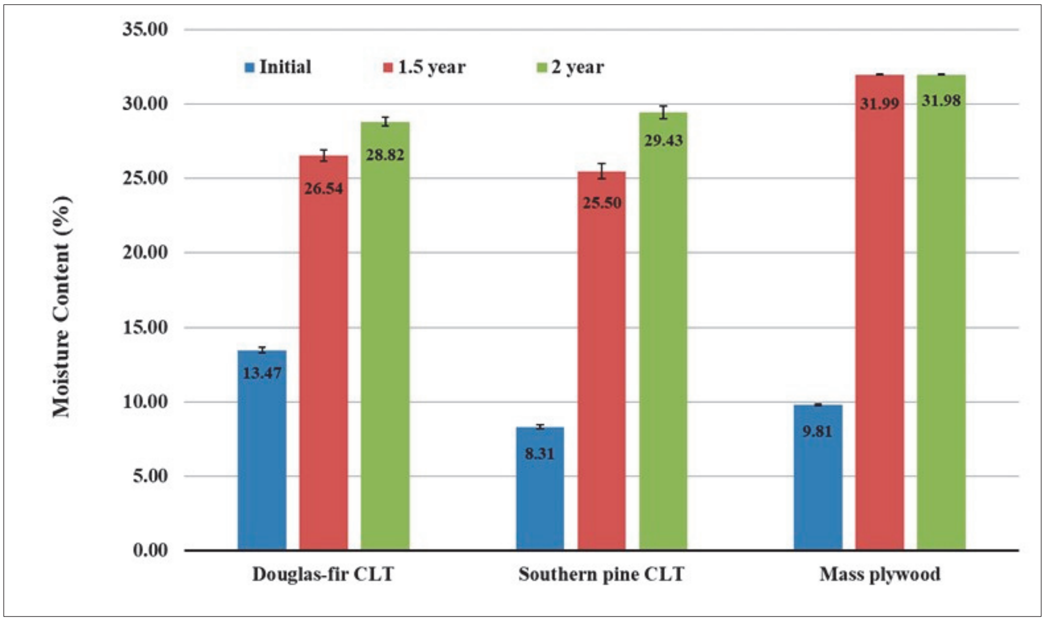

Figure 6. Average sub-surface moisture content of three types of mass timber samples at test initiation, as well as at 1.5- and two-years exposure in an above-ground protected field test in Saucier, Mississippi.

Table 2. Average decay and termite ratings for three mass timber types placed in the field in an above-ground test after two years.

	Treatment	Decay	Termite
Douglas-fir CLT	Control – No Treatment	9.2	7.8
	Remedial Before Boron (23% DOT)	8.7	7.8
	Boron Rod	9.2	8.0
	Preventative Boron (23% DOT)	9.7	9.0
	Soil Treatment – Fipronil (0.125%)	9.2	10.0
Southern Pine CLT	Control – No Treatment	9.0	8.9
	Remedial Before Boron (23% DOT)	9.0	8.3
	Boron Rod	9.2	8.8
	Preventative Boron (23% DOT)	9.6	9.8
	Soil Treatment – Fipronil (0.125%)	8.7	10.0
Mass Plywood	Control – No Treatment	9.0	8.0
	Remedial Before Boron (23% DOT)	9.0	7.8
	Boron Rod	9.3	8.7
	Preventative Boron (23% DOT)	9.8	8.7
	Soil Treatment – Fipronil (0.125%)	9.8	10.0

Figure 7. Example of termite attack and damage to 3-ply Douglas-fir CLT in a covered above-ground test after two years.

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.
- Surface 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 were at an increased risk of biodeterioration from termite and fungal attack.
- Termite attack was observed in almost all untreated samples after two years.
- A preventative (applied at initiation) boron treatment remained effective against termite attack, as did the soil termiticide treatment for termites, after four years in test.
- 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.

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