Proceedings IRG Annual Meeting (ISSN 2000-8953)

IRG/WP 24-41010

THE INTERNATIONAL RESEARCH GROUP ON WOOD PROTECTION

Section 4 **Applications and Performance**

Performance of Douglas-fir cross laminated timber (CLT) subjected to elevated humidity in a ground proximity field test for 6 years

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Paper prepared for the IRG55 Scientific Conference on Wood Protection
Knoxville, Tennessee, USA
19 - 23 May 2024

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Performance of Douglas-fir cross laminated timber (CLT) subjected to elevated humidity in a ground proximity field test for 6 years

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ABSTRACT

The ability of insecticidal soil drenches or spray-on insecticide/fungicide treatments to protect mass timber elements exposed in a high moisture environment but out of direct soil contact was assessed using a modified AWPA ground proximity test established in 2017. Three-ply Douglas-fir CLT pieces measuring 305 x 355 x 105 mm (L x H x W) were installed at the Harrison Experimental Forest (HEF) (Saucier, Mississippi) in 2017. Test samples were placed in sets of two on bricks approximately 150 mm apart, 75 mm above the soil and covered with ventilated waterproof covers. A total of 20 test sets (40 total samples) of four different treatments were installed. Treatments were a soil termiticide (fipronil), a spray-on borate (23% DOT) preventative treatment at test initiation, a remedial borate treatment after one year and an untreated control treatment. To mimic an in-service structural component, borate treated samples were sprayed on all sides except the bottom of the sample where it sat on the bricks near soil. This was to mimic a worst-case scenario where an in-service member could not be fully treated after building construction. Samples were monitored for moisture and biological attack annually for the next six years. Moisture contents of the samples were high throughout the duration of the test. Sample mass losses after six years were elevated in the control and untreated sister sample pairs. Samples treated with borates at test initiation and remedially after one year of exposure showed limited decay or termite attack and low mass loss compared to other treatments or untreated paired samples. Borate treated samples were also cut and indicator stained at the end of the test to examine boron diffusion. Soil termiticide treated plots showed no sign of termite attack, but some of the samples incurred heavy fungal decay resulting in substantial mass loss compared to non-soil termiticide treated plots. The results provide critical baseline data for field evaluation methods of mass timber in areas with high subterranean termite and decay pressure.

Keywords: Mass timber, AWPA Standard E26, soil termiticide, borate, durability, decay, termite.

1. INTRODUCTION

Wood has many qualities that make it a preferred construction material over steel or concrete (Robertson *et al.* 2012). The development of mass timber products has allowed wood to be used in much taller buildings, formerly restricted to steel and concrete. The use of mass timber for multi-level construction has increased 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), can allow parts of structures to be prefabricated, and provides increased carbon sequestration making it an attractive construction material (Brandner *et al.* 2016). Architects and engineers are starting to shift their attention to this new product in wood construction for applications where steel and concrete predominate (Mallo and Espinoza 2014, Mallo and Espinoza 2015).

Despite 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 being considered (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, França *et al.* 2018, Mankowski *et al.* 2018, 2020, 2022a, 2022b). Although mass timber is 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 or pretreatment of the mass timber elements with chemical wood protection systems or some combination of these. Understanding the conditions that are conducive to deterioration of mass timber elements and identifying methods for preventing this damage will be essential for expanded use of these materials. Even though mass timber will be used out of ground contact where the risk of damage is lower, buildings will still be constructed in areas prone to subterranean termite attack and termites can penetrate barriers to move upward into a structure.

Identifying the conditions required to render mass timber elements susceptible to biological attack and methods for preventing this damage are essential for expanded use of these materials. While most 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 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. Other studies examining moisture ingress in mass timber showed that moisture contents can increase greatly along non-edge sealed sides of CLT (Mankowski *et al.* 2018, 2020, 2022a, 2022b, Morrell *et al.* 2018). The high moisture contents that develop suggest that boron should diffuse readily into a large piece of mass timber like CLT and protect it in extremely harsh conditions or water ingress-related situations. In this study, we exposed CLT to a potentially worst-case biological deterioration scenario where in-service structural members could not be entirely treated. In this paper, we discuss the methodology and six-year results of a 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

The 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 50% relative humidity (RH) for approximately 60 days and weighed before initiation of the field test. Two moisture measurements were made with a Wagner MMC 220 pin less electronic moisture meter (Wagner Meters, Rogue River, Oregon) 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. A modified AWPA E26-15 (AWPA 2017a) ground proximity protected field test was employed for long term exposure. The method was modified to use a large specimen size, with no plywood under the samples, as the standard describes plywood is optional for areas with

Reticulitermes sp. We did not use in-ground feeder stakes as the E26-15 standard suggests because one of the test treatments was a soil chemical barrier treatment and the use of in-ground feeder stakes would breach the chemical barrier. The test area consisted of a large plot measuring 7.6 x 7.6 m with twenty-five subplots measuring 0.76 x 0.76 m that were 1.5 m apart (Fig. 1). A total of twenty 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 were set on four bricks on the 0.76 x 0.76 m cleared square in each subplot. The samples were approximately 75 mm from the ground and approximately 200 mm apart (Fig. 2).

The test was set up in a randomized block design with five blocks containing one treatment per block in the total plot (Fig. 1). For the remedial treatment, five plots were left undisturbed for one year 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. To mimic an in-service structural component that could not be treated on all surfaces, borate treated samples were sprayed on all sides except the bottom of the sample where it rested on the bricks near soil. This is not necessarily how an in-service component would be treated in the real world, but we did this as an example of a worst-case scenario. In situations where an in-service component cannot be treated on all surfaces it is recommended that wood surfaces that can be treated are done so with two applications 30 minutes apart when using a 23% boron solution.

Test Treatments:

1. Soil termiticide only: A 0.61 x 0.61 m area of the 0.76 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 CLT samples were placed on the treated area with as little soil disturbance as possible (Fig. 2).
2. Preventative borate spray: (Nisus, Knoxville, TN USA); 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 (Fig. 3). All sides of the treated samples were sprayed except the bottom of the sample. Treated samples were sprayed twice with applications 30 minutes apart.
3. Remedial treatment: The two samples in a subplot were treated as controls and exposed for one year with no initial treatment to allow decay and termite attack to occur prior to application spray-on of the remedial treatment (23% disodium octaborate tetrahydrate (DOT)). As with the preventative treatments, one sample was treated and the other left untreated.
4. Untreated controls.

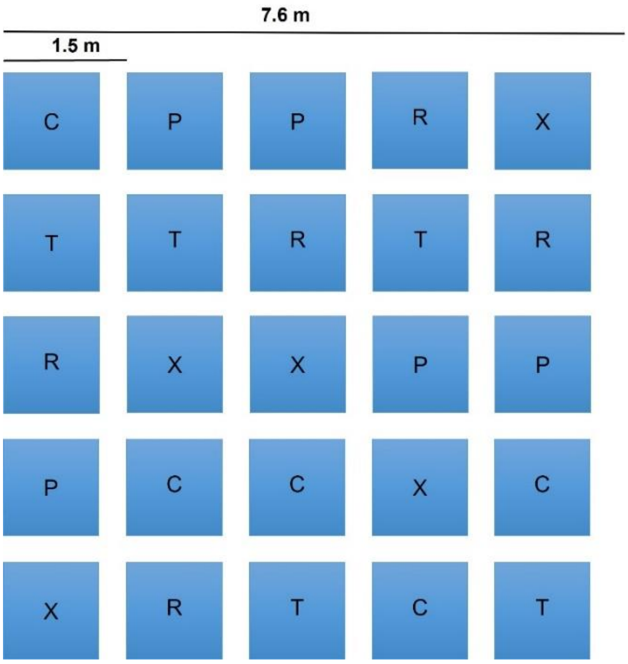

Figure 1: Layout of randomized block design for the modified AWPA E26 ground proximity field test. Treatment designations are as follows: P = Protective treatment with borate (DOT at 23%), T = Treatment with fipronil soil termiticide (0.125%), C = Control, R = Remedial borate spray treatment (23% DOT) after one-year check, X = Subplot not used.

After placement and treatment, the samples were covered with pre-constructed ventilated plywood covers. The covers measured 559 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 (Fig. 4). 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 six years except for annual moisture readings and damage ratings. A total of four moisture readings were taken by taking two moisture readings 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 rated using the AWPA E26 rating system for termites and the AWPA E18-15 rating system for decay (AWPA 2017 a, b). Samples were assessed for degree of decay and termite damage on a scale from 10 (sound) to 0 (failure) after 12, 24, 36, 48, 60 and 72 months. Since the samples were large, the ratings only reflected the bottom 25 mm of the sample in contact with the brick.

After six years, the test samples were removed from the field site and taken to Starkville, MS where they were allowed to dry at 23 °C and 50% RH until sample masses equilibrated. Final moisture content and mass values for each sample were recorded. The DOT-treated samples were longitudinally cross sectioned and stained for the presence of boron according to the AWPA A68-22, *Standard method for determining penetration of boron-containing preservatives and fire retardants* (AWPA 2022).

Samples were installed at the Harrison Experimental Forest (HEF; Saucier, MS). The HEF has an average annual precipitation of 1600 mm. Mean annual minimum and maximum air temperatures (Jackson, MS data) are 12 °C and 24 °C, with no mean monthly temperature below 10 °C. The topography is flat with a slope of 5 to 12 percent. The soil is Poarch fine sandy loam and 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 *Reticulitermes* spp., dominated by Eastern subterranean termites, *Reticulitermes flavipes* (Kollar), *R. virginicus* (Banks) and *R. hageni* (Banks) (Shelton *et al.* 2014).

Figure 2: Treatment with fipronil soil termiticide showing arrangement of ground bricks or cinder blocks and CLT in soil termiticide subplots.

Figure 3: Photographs showing the arrangement of ground bricks and mass timber samples in subplots. Treatment with spray-on borate (23% DOT; arrow shows tip of spray nozzle) in the preventative and remedial treatments.

Figure 4: Photograph of all test assemblies at the experimental plot after covers were applied.

3. RESULTS AND DISCUSSION

Initial surface moisture contents of the CLT samples averaged 11.4%, which would be close to the 12% moisture content of the samples at the time of production and returned to that same level at the end of the field trial (Fig. 5). Average moisture content increased to 23.7% at the end of the first six months of exposure, suggesting that the humidity inside the cover boxes was high and that the ventilation in the cover boxes may have been inadequate (Fig. 5). 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. These surface moisture contents 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.

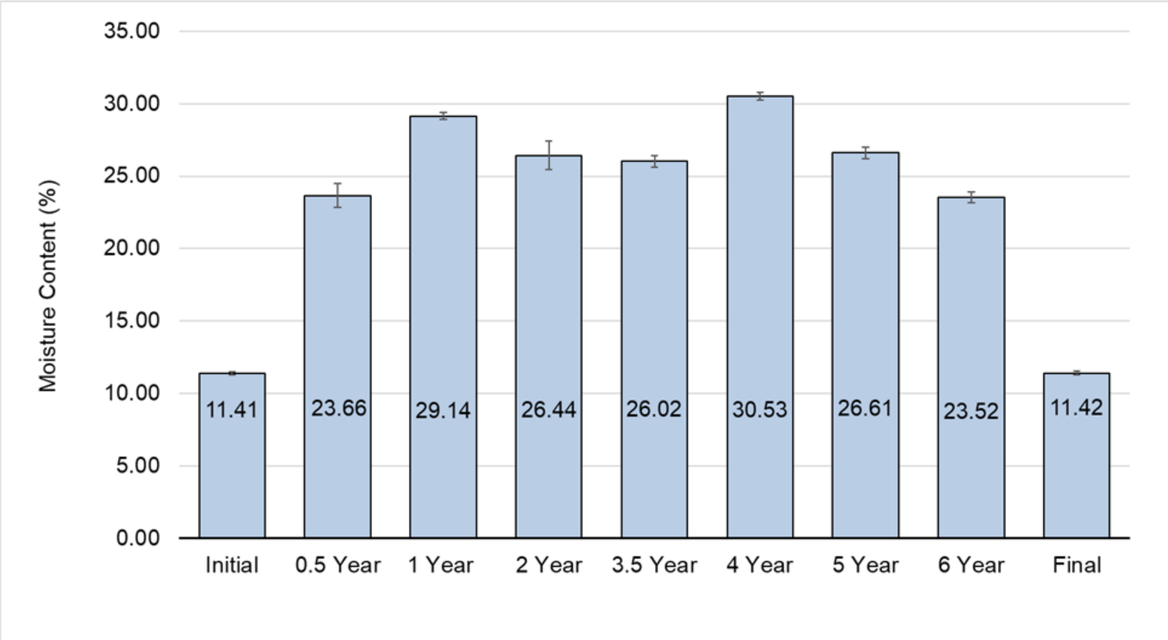

Figure 5: Average surface moisture content of Douglas-fir CLT samples at test initiation, after six months, at annual intervals for six years of above ground, covered exposure in Saucier, MS and a final dry moisture content after exposure. Numbers in bars represent the average moisture content.

Table 1 shows the average decay and termite ratings of the samples for the various treatments. Samples in the remedial boron spray were controls at initiation and controls at one year when they were treated. At least one of the control samples in the two sample sets was heavily attacked by termites in four of five subplots after six years. One control subplot was not attacked until the third year and then was only slightly attacked by year six. Control plots incurred ratings of 3.5 and 3.2 for decay and termites after 6 years of exposure, respectively (Table 1, Fig. 6, right). Although the soil termiticide treatment (fipronil) prevented termite attack, heavy decay was noted in some of the fipronil treatments (Fig. 6, 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. This premise is being investigated in a separate study. 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). Five years after the remedial treatment, these samples remained close to their one-year attack ratings.

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

Treatment	1 Year		2 Year		3.5 Year		4 Year		5 Year		6 Year	
	Decay	Termite	Decay	Termite	Decay	Termite	Decay	Termite	Decay	Termite	Decay	Termite
No Treatment	9.4	9.1	9.2	8.9	8.0	7.3	8.0	7.3	5.0	5.0	3.5	3.2
Soil Treatment Fipronil (0.125%)	9.5	10.0	8.8	10.0	8.1	10.0	7.3	10.0	5.9	10.0	4.9	10.0
Preventative Boron (23% DOT)	9.8	10.0	9.6	9.8	9.4	9.8	9.8	9.8	9.9	9.7	10.0	9.7
Remedial at 1 Year Boron (23% DOT)	9.6	8.8	9.4	9.2	9.4	8.8	9.4	9.0	9.4	8.8	9.40	8.50

Figure 6: Examples of fungal decay (left) and termite damage (right) to 3-ply Douglas-fir CLT in a covered ground proximity test after six years (picture taken at year 4).

Fig. 7 shows the average mass losses for all samples in the control and soil termiticide treatments (n = 10) as well as the mass loss averages for the borate treatments (n = 5). Mass losses of untreated samples averaged 19.39% while those incurred by samples in the fipronil plots were also relatively high (10.53%). There was no termite attack in the fipronil, and the mass loss was only attributed to decay. The borate treatment appeared to have worked well at limiting biological attack.

Interestingly, one of the two samples in each subplot in the untreated control and fipronil treatment generally had higher mass losses. Fig. 8 shows the high and low mass losses for each treatment including mass losses in the preventative and remedial borate treatments. These were the paired samples that were never treated and left next to the treated sample in each subplot. It is uncertain why one sample was more heavily attacked in the subplots but may have to do with resource concentration regarding termite attack or possibly the limited length of the test.

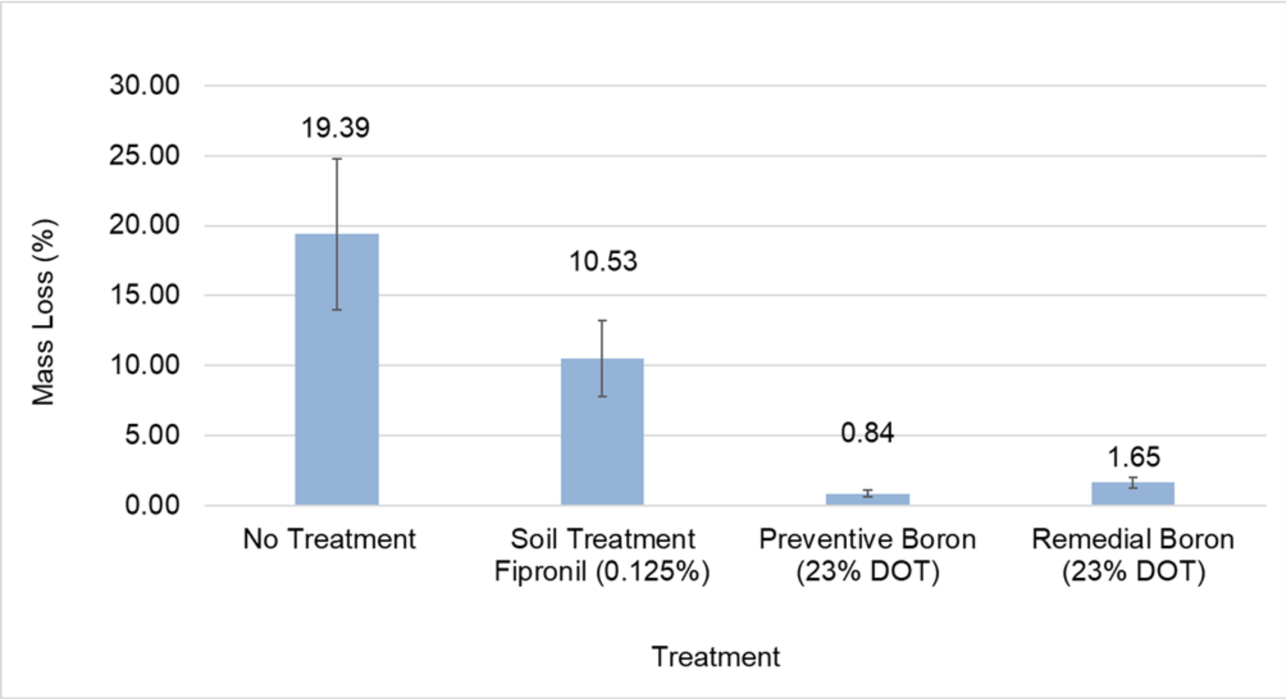

Figure 7: Average mass losses for all samples by treatment after six years. Numbers in bars represent average mass loss.

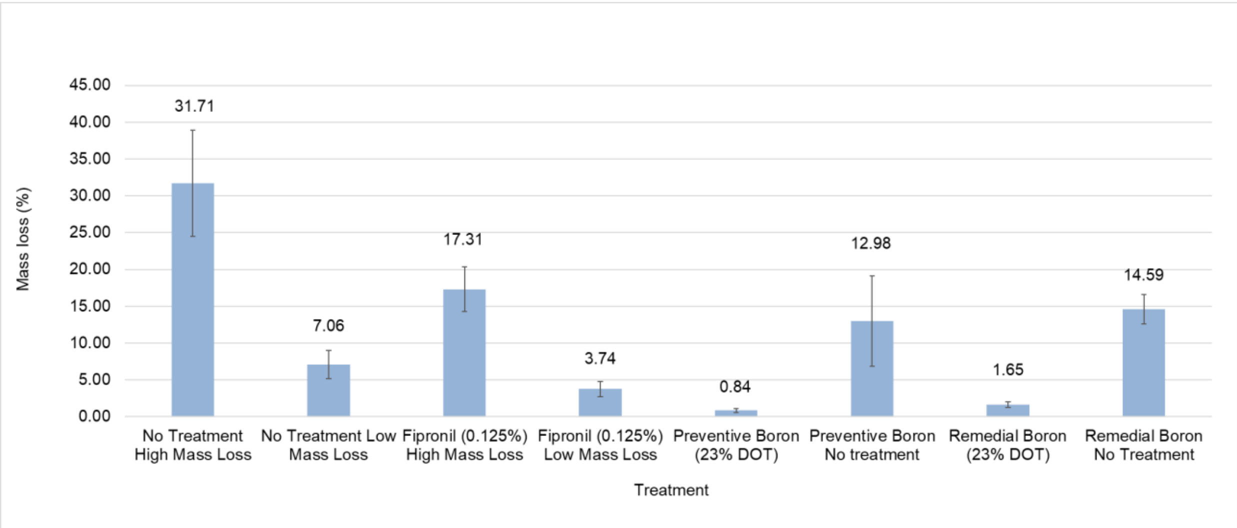

Figure 8: High and low mass losses of samples in treatments after six years. Numbers in bars represent average mass loss.

Dark red colour indicates that boron was present across the entire CLT sections (Fig. 9). It must be stressed that the samples were treated on the outer surfaces only and that the observed presence of boron was from diffusion. The excellent diffusion of boron into the center ply of the CLT is indicative of the high moisture levels in the covered boxes and suggests that using this preservative in high moisture, worst-case scenario, water ingress situations may be advantageous. The preventive borate treatment showed excellent boron diffusion at six years (Fig. 9, left). The remedially treated CLT samples also showed good boron diffusion. The termite attack shown in the center ply of these samples occurred in the first year of exposure before the treatment (Fig. 9, right). No activity was observed in this subplot after the remedial treatment.

Figure 9: Cross-cut curcumin-stained samples treated with borates at test initiation (preventative) (left) after six years and remedial treatment (right) after five years showing boron diffusion (red) surrounding dormant termite galleries.

4. CONCLUSIONS

- Near surface moisture contents in mass timber samples exposed in a ground proximity test approached the fiber saturation point after one in the field.
- 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 three years.
- A preventive (applied at initiation) boron treatment remained effective against termite attack as did the soil termiticide treatment.
- A remedial (applied after 1 year) boron treatment arrested attack and remained effective against biological attack.
- Boron diffusion from the surface to the center ply of 3-ply of refractory species CLT was excellent.
- Some of the soil termiticide treatment subplots showed decay and associated mass loss.

5. ACKNOWLEDGEMENT

The authors would like to acknowledge the following individuals: Craig Bell and Shawn Cooper at FPL Starkville who helped with installation and ratings at the HEF, Patti Lebow at FPL Madison (retired) who advised regarding the experimental design.

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