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Section 4 **Applications and Performance**

Evaluation of mass timber materials for military and commercial trailer decking

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ABSTRACT

In this study, CLT trailer decking was manufactured to current military trailer decking specifications, verified using PRG320 performance criteria, and treated with either waterborne or oil borne wood preservatives. Preliminary results show adequate uptake of preservative solution and subsequent testing shows minimal effect due to treatment. Field durability tests are also being conducted of treated and untreated materials in tropical sites in Suriname and 8-month data is presented herein. Presence of gaps in the CLT layup have proven problematic as it presents a pocket for collection of soil and moisture that could promote fungal decay, or provide an ingress point for termite attack. In follow-up studies, additional panels will be fabricated, treated and coated with a randomized assortment of protective coatings and subject to weathering. The results of these studies will be used by the U.S. military to aid in the selection of durable materials to replace threatened tropical hardwoods.

Keywords: Cross laminated timber, biodeterioration, southern pine, red oak, utility trailer decking, non-destructive testing.

1. INTRODUCTION

Cross laminated timber (CLT) is becoming increasingly popular in North America. Design standards require a protective envelope for mass timber construction but there is growing demand for using cross laminated timber in exterior exposure, which will necessitate some form of additional protection from biodeterioration agents and UV weathering. Aside from its use in constructing tall timber buildings, CLT is also an attractive option for modular construction in sectors such as transportation, recreational trails, and infrastructure.

The USDA Forest Service Forest Products Laboratory (FPL) has been investigating durability and biodeterioration risks for mass timber since 2015, with most recent projects focused on modular engineered wood for military trailer decking (Fig. 1). This material is being evaluated as an alternative to the tropical hardwoods currently being used by the U.S. Army and other branches of the military for this purpose. Apitong (*Dipterocarpus* spp.) in particular is a hardwood that has been used exclusively for fabrication of Army trailer decking because of its strength, high density and durability against biodegradation. However, this wood material is becoming increasingly rare due to overharvesting and is currently recognized as being critically endangered. Thus, finding

sustainable alternative materials for tactical trailer decking has become a critical need to meet U.S. Army transportation demands.

Figure 1: M871A2 trailer with bulkhead removed. Timber panels are recessed and currently decked with Apitong (*Dipterocarpus* spp.). Engineered wood CLT panels are being proposed as a modular option to reduce demand on tropical hardwood species.

Among currently available options, various domestic hardwood species from within the U.S. may offer the greatest potential as sustainable and cost-effective alternatives to tropical hardwoods. They have been shown to perform well in a wide range of environmental conditions and several species have outstanding strength properties (Ross 2021). In addition, the volume of U.S. hardwoods growing on sustainably managed forest lands has increased 130% since the early 1950s, so there is currently ample supply of these materials for sustainable use.

2. CURRENT METHODS FOR CLT RESEARCH PROJECTS

2.1 Pressure Treatments for Post Layup CLT Trailer Decking

CLT panels were treated using wood preservatives per AWPA treating recommendations in an attempt to achieve UC4 (ground contact retentions) using a 24-hour, 1% copper naphthenate soak (CuNap-WA) or pressure treatment with a 1% solution of oil borne copper naphthenate (CuNap-OP) to target a 0.6 pcf retention of Cu (expressed as CuO). In addition to copper naphthenate, samples were also treated commercially using a UC4 retention of 4,5-dichloro-2n-octyl-4-isothiazolin-3-one (DCOI). Both the southern pine samples and the hybrid southern pine – red oak panels were treated. In accordance with PRG320, strength tests were performed to determine any strength reductions due to treatments.

2.2 Non-Destructive Evaluation of Pressure Treated CLT Trailer Decking

Two non-destructive evaluation (NDE) methods were used to evaluate the specimens: stress wave time of flight (TOF) according to ASTM D6874 (ASTM 2021) and computerized tomography X-ray scanning (CT). Time of flight is the inverse of the stress wave velocity and is used to determine

dynamic modulus of elasticity (MOE_D) (Ross and Pellerin 1994). MOE_D is proportional to the product of the material density and the square of the stress wave velocity (Graff 1991). Using a Fakopp Microsecond Timer (Fakopp Enterprise Bt. Hungary), the TOF parallel to the grain for each board in the outer laminae of the CLT was measured before and after treatment to quantify changes in the panels associated with the treatment process. Since the individual board masses were not known, published specific gravity (SG) values from the Wood Handbook (Senalik and Farber 2021) were used to calculate the approximate MOE_D for each species. Specimens treated with DCOI were not available for TOF measurements prior to treatment.

CT scans produce cross sectional images of the CLT in which the pixel brightness is proportional to density (Bucur 2003). Images were recorded every 2.5 mm using a General Electric Discovery RT Gen 2, 16 slice scanner with power settings of 120 kV and 150 mA. Three groups of specimens were scanned: untreated, treated with waterborne copper naphthenate applied at atmospheric pressure (CuNap WA), and oil borne copper naphthenate applied under pressure (CuNap OP). Specimens treated with DCOI were not available for CT scanning. To calibrate the images, a collection of 24 wood cubes with edge lengths of approximately 25 mm and with varying SG values were placed alongside the specimens during scanning. The values for SG ranged from 0.081 (*Heliocarpus appendiculatus (*Turcz.) to 1.121 (*Chrysophyllum oliviforme* L.), which was measured independently for each cube; no published values were used. A linear relationship between pixel brightness and SG was established. The relationship matched previous research using the same technique (Senalik *et al.* 2019). Once the pixel brightness was converted to density, the average density through the depth and across the width of each lamina of the specimens was calculated.

Treated and untreated CLT panels were subjected to stress wave measurements to determine dynamic MOE both pre- and post-treatment. Additional measurements using ground penetrating radar were taken to scan for interior defects or significant internal cracks. Finally, treated and untreated samples were subjected to CT scanning at UW-Madison Veterinary clinic in order to verify preservative penetration using a non-destructive approach. The resulting scans were compared to cross sections stained with chrome azurol indictor dye to validate CT results.

2.3 Shear and Delamination

Cyclic delamination was performed on 7.62 x 7.62 cm x 4.76 cm (= 3” x 3” x 1-7/8”) specimens according to methods described in ANSI/APA PRG 320. The two tests required for PRG 320 are the ASTM D905 sheer block test (ASTM 2021) and the cyclic delamination (AITC 110). The sheer block test measures the continuity of adhesive bond lines by applying force in opposing directions. The maximum force to failure (in psi) is measured as well as the amount of fiber tear out on the failed block. Fiber tear indicates a wood failure and not an adhesive failure. The cyclic delamination test subjects test materials to fluctuating environmental conditions that cause rapid shrinking and swelling of the wood components to stress the bond lines. A feeler gauge is used to measure delamination and the total amount of delaminated glue line is recorded in inches.

2.4 Field Tests in Suriname

Small CLT blocks with dimensions of 7.62 x 7.62 x 4.76 cm (= 3” x 3” x 1.875”) were exposed in a ground proximity durability test following the AWPA (AWPA 2018) E-18 standard test method. Six-foot panels were also installed in ground proximity to observe termite and fungal attack. These panels were also assessed for abrasion resistance and will undergo a truck trailer manufacturing association (TTMA) cyclic loading test (TTMA 37-07).

Figure 2: Test setup of the AWPA E-18 ground proximity test (left) and full-size platform tests (middle & right) at the Afobaka field test site in Suriname. Tests being performed on exposed panels using a modified version of the truck trailer manufacturing association (TTMA) standard method for rating of van, trailer, and container floors for lift truck loading (TTMA 37-07).

3. RESULTS AND DISCUSSION

3.1 Treatment Data

Treatment data are reported here as average chemical retention (ACR) in pounds per cubic foot (pcf) Cu (expressed as CuO) (Fig. 3). 24-hour soaks for RO and SYP in CuNap WA resulted in an average chemical retention of 0.06 and 0.03, respectively. Both values are less than the AWPA recommended 0.075 pcf specified for ground contact. Some additional research will be needed to ensure higher chemical retentions through modifications to our soak method (higher initial concentration, longer soak times). Ultimately, a pressure applied waterborne copper naphthenate would provide much more uniform and effective results. Oil-borne pressure treatments yielded similar results, albeit higher than the soaks. The average chemical retention for RO and SYP in CuNap OP were 0.05 and 0.07 pcf, respectively. As above, some additional research will be needed to ensure higher chemical retentions through modifications to treatment parameters (i.e., time, pressure, vacuum) for this material.

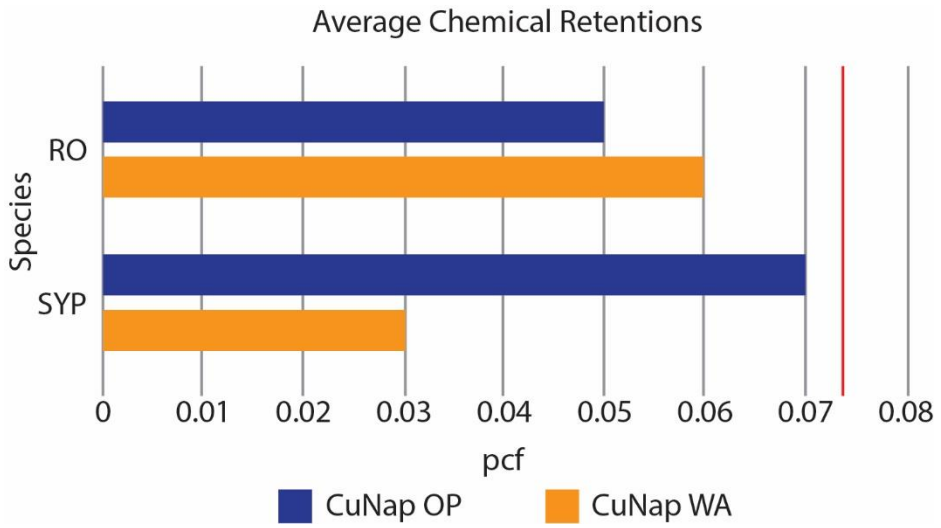


Figure 3: Average chemical retention (pcf) of red oak (RO) and southern pine (SYP) CLT. Waterborne copper naphthenate (CuNap WA) was applied as a 24-hour soak and oil borne copper naphthenate (CuNap OP) was pressure applied with an initial vacuum of 28 mm Hg for 30 min and 150 psi of pressure for 1 hour. Red line represents the recommended AWPA retention level for ground contact.

3.2 Non-Destructive Evaluations

The MOE_D before and after treatment for several specimens is shown in Fig. 4. An overall dynamic modulus for the CLT was approximated as an area weighted sum of the individual board MOE_D. Fig. 5 shows the average MOE_D and range of values for each species and treatment. For untreated specimens, white oak had similar MOE_D to red oak; SYP had lower MOE_D than both oaks. Treatment with CuNap-WA did not cause an apparent consistent change for red oak specimens. A limited number of specimens prevented conclusions being drawn for SYP treated with CuNap WA. Treatment with CuNap OP reduced the MOE_D for red oak for all specimens; SYP did not have a consistent change in MOE_D after CuNap OP treatment.

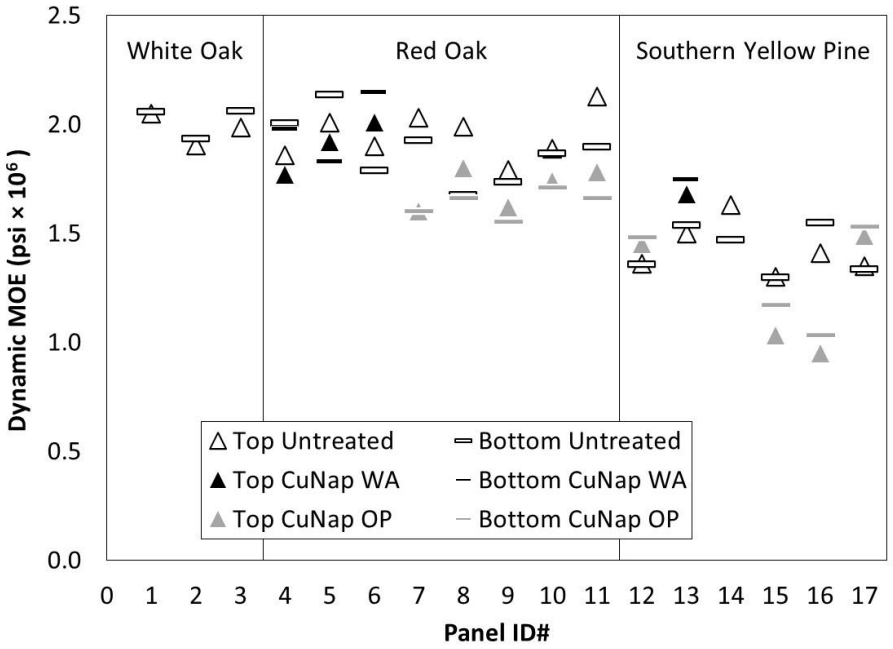
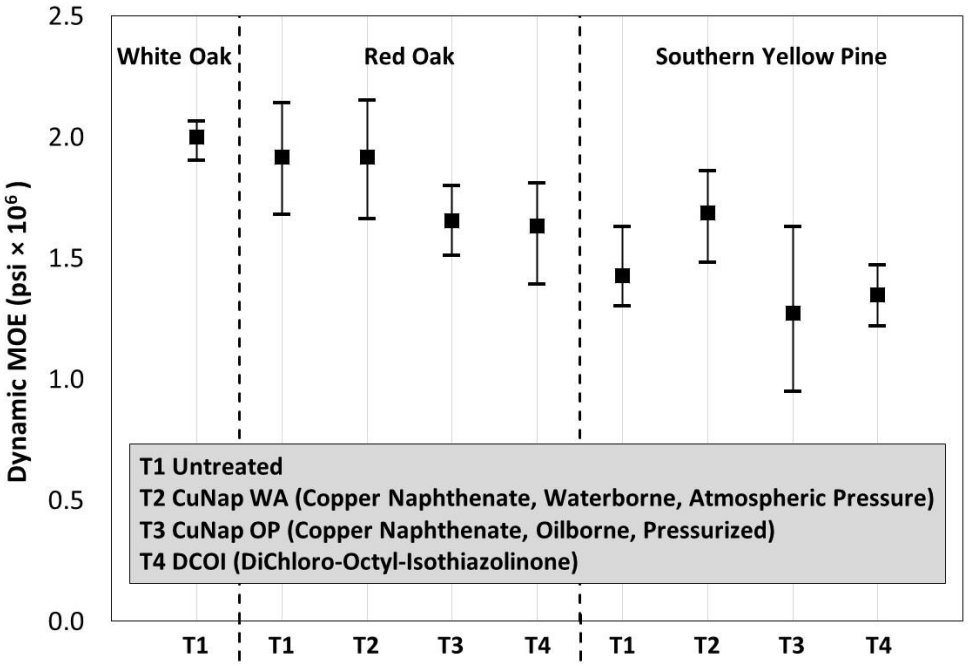


Figure 4: Top and bottom dynamic modulus of elasticity (MOE_D) for the CLT panels. The triangles represent the MOE_D of the top lamina; the horizontal line represents the bottom lamina. Post treatment values are shown as black for waterborne copper naphthenate (CuNap WA) applied at atmospheric pressure and gray for oil-borne copper naphthenate (CuNap OP) applied under pressure.



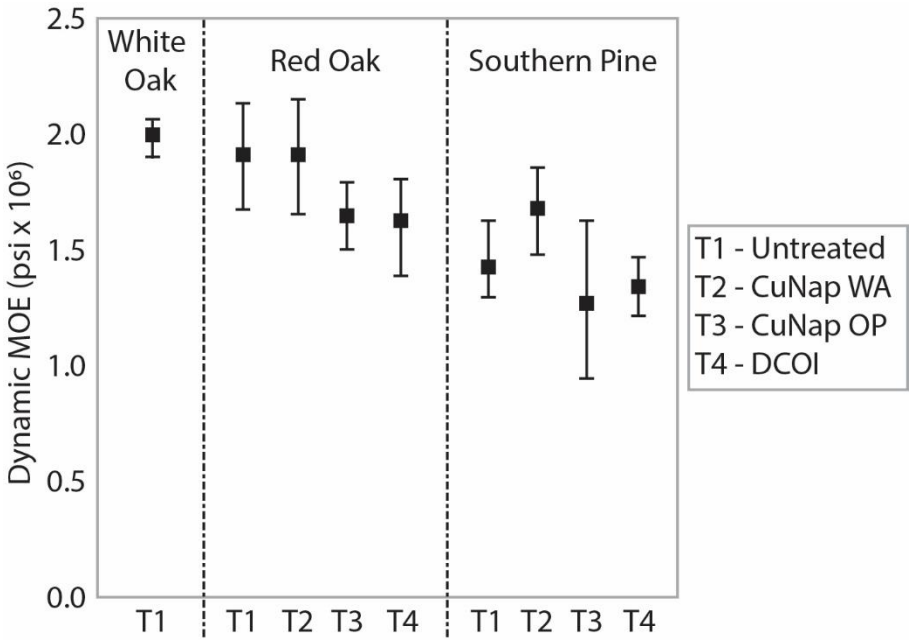


Figure 5: Average MOE_D for each species and treatment. The square is the average; the upper and lower bars represent the range of values.

Images of untreated and treated red oak from X-ray CT scanning are shown in Fig. 6. For ease of interpretation, the images were converted to an inverted grayscale. Darker pixels represented denser areas than lighter pixels. In Fig. 6 (bottom), the specimens on the left were treated with CuNap WA; the specimens on the right were treated with CuNap OP. The images of the treated specimens had darker coloration than then images of the untreated specimens. The darker coloration indicated that the treated specimens had greater density than the untreated specimens. The additional mass of the treated specimens is from the treatment process.

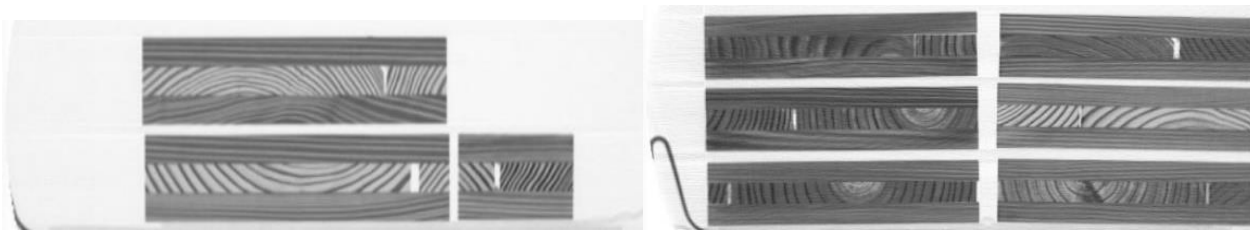


Figure 6: X-ray computer (CT) tomography images of untreated red oak CLT (top) and treated red oak CLT (bottom): left side is treated with CuNap WA; right side treated with CuNap OP. The darker cross sections of the treated specimens indicate higher density. The higher density is caused by the additional mass from the treatment.

To aid in visualization, the average density of lamina for each species and for each treatment was calculated across the width and depth of each lamina. The density profiles for SYP and red oak are shown in Figs. 7 and 8, respectively. Results show the density profiles of the treated specimens to be consistently higher than the untreated specimens which is indicative of good penetration by the preservative across the depth and width of each lamina.

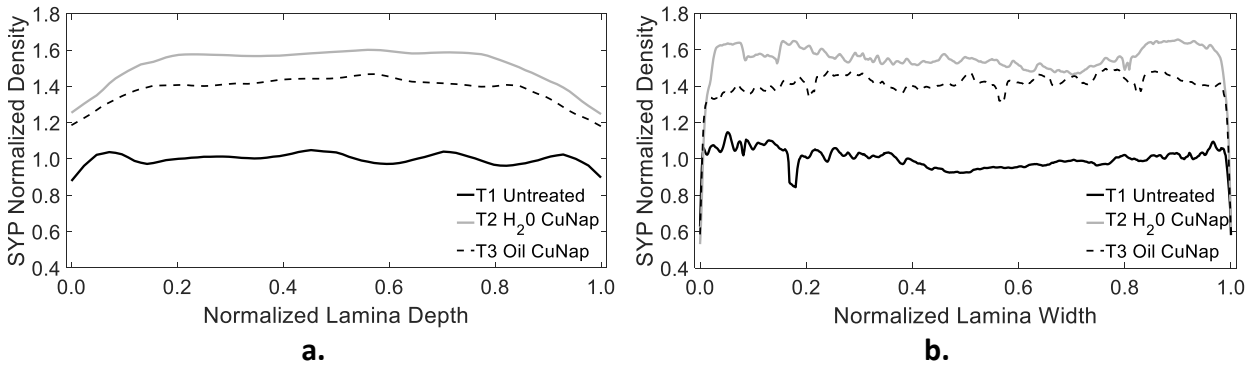


Figure 7: Density comparisons from CT scans between untreated southern yellow pine (SYP) and SYP treated with either CuNap WA or CuNap OP. Density is normalized against the untreated specimens. Both treatments have penetrated through the depth of each lamina for SYP. a) across laminae depth b) across laminae width.

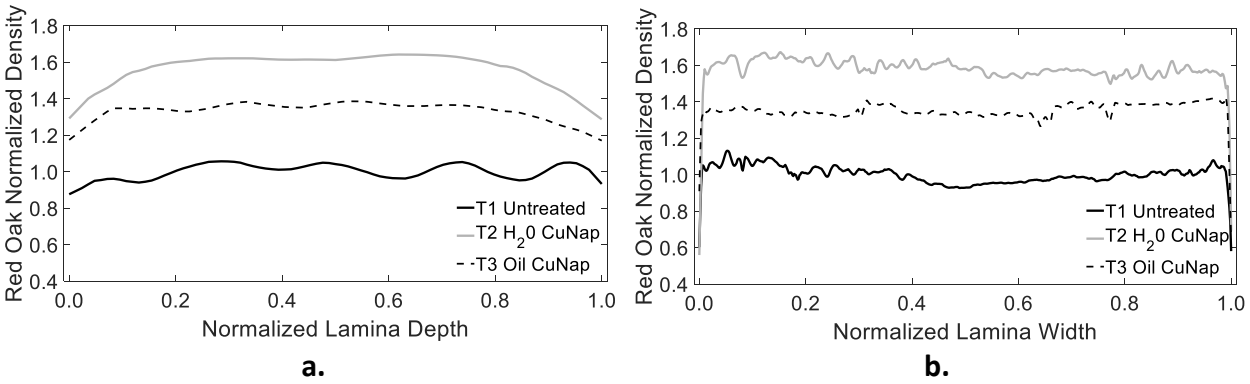


Figure 8: Density comparison from CT scan between untreated red oak and treated with either CuNap WA or CuNap OP. Density is normalized against the untreated specimen. The results show that both treatments have penetrated across the width of each lamina for red oak. a) across laminae depth b) across laminae width.

3.3 Shear and Delamination Data

Block shear and fiber tear out was estimated using ASTM D905 methods (Fig. 9). All chemical treatments still had average values that surpassed the 450-psi minimum specified in the standard. White oak averaged 406.3 psi, indicating that some additional work might be needed for proper fabrication of white oak hybrid panels. Data presented below are average psi separated by treatment and wood species. AITC 110 cyclic delamination data (not shown) showed 100% delamination of hybrid southern pine – red oak specimens pressure treated with DCOI and will warrant further examination. Additionally, most of remaining hybrid panels exhibited notable delamination. The southern pine only specimens, treated and untreated, showed minimal delamination.

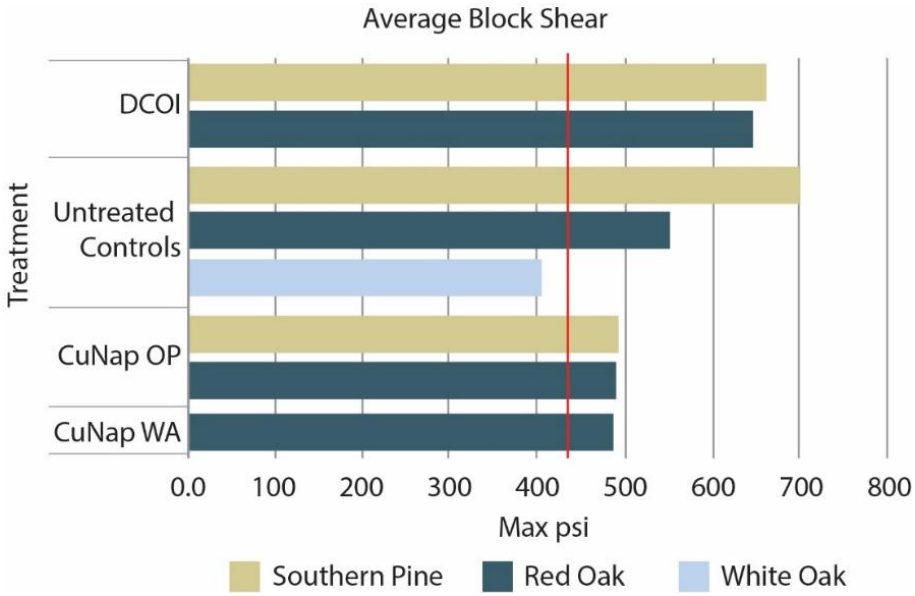


Figure 9: Shear block data for all treatments and species. Excluding white oak, all species combinations exceeded the minimum shear block thresholds specified in PRG 320. Slight reductions were noted in oil borne pressure treatments but were still above the threshold value (represented by the red line).

3.4 Suriname Exposure Field Data

Ground proximity (AWPA E18) tests showed slight levels of termite and decay damage after only 8 months exposure at the Suriname test site for the 3" x 3" samples (Table 1). Hardwoods (red and white oak) showed slightly higher decay and termite damage compared to the pine. This suggests that white-rot fungi may be most active at this site compared to a more temperate-forest environment. Both CuNap treatments as well as the DCOI treatment show some initial susceptibility to decay and termites but do seem to be performing better than controls, at least at this early stage. The large gaps present in these panels were of particular concern as they serve as a soil and moisture catch and additional open spaces for termite ingress. These concerns have been communicated to the manufacturer and these gaps will be corrected in the phase 2 panel layup using side compression during gluing.

Table 1: Average ratings for specimens exposed in an AWPA E18 test at the WPG Afobaka field test site in Suriname.

3x3 Blocks				Sept. 2023 (3 months)			Feb. 2024 (8 months)		
Type	**Substrate/ Face spp.**	**Treatment Group**	**Series**	**Decay**	**Termite**	**Delam. (%)[a]**	**Decay**	**Termite**	**Delam. (%)[a]**
1	Southern Pine	Untreated Controls	CLT	10	10	-	8.7	9.9	-
2	Red Oak			9.3	9.9	40	8.5	9.8	60
3	White Oak			9.5	9.8	30	8.6	9.3	50
4	Southern Pine	CuNap WA	CLT	9.9	10	-	9.6	10	-
5	Red Oak			9.8	10	50	8.9	10	80
6	Southern Pine	CuNap OP	CLT	10	10	-	9.8	10	-
7	Red Oak			9.9	9.8	70	9.0	9.9	80
8	Southern Pine	DCOI	CLT	9.9	10	10	9.9	10	10
9	Red Oak			10	10	70	9.6	10	90
10	White Oak	Solid Untreated	-	9.5	10	n/a	8.4	9.6	n/a
11	Apitong			9.3	10	n/a	8.5	9.7	n/a
12	Southern Pine		-	10	10	n/a	9.0	9.9	n/a

[a] Delamination (%) is the percentage of total samples of a type that show separation of substrates at a glueline.

Full size CLT panel platforms (6’ x 2’) were evaluated according to the same rating scales used in the E18 tests above with an added measure of material cupping (AWPA 2021). Untreated RO and WO panels were susceptible to termite attack as early as 3 months exposure (Table 2). After 8 months exposure all untreated panels showed susceptibility to decay and termites. Both CuNap treatments offered protection against termite activity and fungal decay through 3 months compared to the untreated panels; however, initial instances of decay susceptibility are present at 8 months exposure in the treated panels. The RO panels regardless of treatment are showing increased cupping at 8 months exposure.

Table 2: Average ratings of 6’ CLT panels exposed at the WPG Afobaka field test site in Suriname.

6’ x 2’ Panels			Sept. 2023 (3 months)			Feb. 2024 (8 months)		
Type	**Face spp.**	**Treatment Group**	**Decay**	**Termite**	**Cup (ave. mm)**	**Decay**	**Termite**	**Cup (ave. mm)**
1	Southern Pine	Untreated Controls	10	10	0.0	7.0	9.0	0.0
2	Red Oak		10	8.0	3.3	8.0	7.3	10
3	White Oak		10	9.0	1.7	8.3	8.0	0.0
4	Southern Pine	CuNap WA	10	10	0.0	9.3	10	0.0
5	Red Oak		10	10	10.0	9.0	10	16.7
6	Southern Pine	CuNap OP	10	10	0.0	9.3	10	0.0
7	Red Oak		10	10	7.3	9.8	10	9.3
8	Southern Pine	DCOI	10	10	0.0	9.0	10	0.0
9	Red Oak		10	10	7.3	9.0	10	7.0

4. CONCLUSIONS

Cross laminated timber panels were commercially fabricated with red oak, white oak and southern pine. Middle lamellae were all southern pine. Test blocks were assessed with PRG320 performance criteria to ensure initial CLT quality. Three preservative treatments were applied to southern pine and red oak while white oak was left untreated to serve as a durable species comparison. Following treatment, panels were assessed again using PRG320 criteria to evaluate adhesive performance post treatment and additional MOE determination to assess possible strength reductions due to treatment. Minimal effects on MOE due to treatment were seen in the pine and red oak panels and in general hardwood combinations exhibited greater MOE. X-ray CT scans showed increased density (due to treatment) in both waterborne and oil borne treatments, demonstrating that this method could be a potential novel means to assay preservative penetration. Post treatment, shear block data was still above the threshold designated by PRG320 but delamination was noted in red oak when commercially treated with DCOI. Additional work will be conducted to discern causality of these failures. Additional optimization of material layup methodologies is likely needed to account for the use of hardwoods in modular CLT products. Preliminary field data show some signs of biodeterioration and termite activity, but delamination is apparent in red oak as soon as 3 months and material cupping is notable for red oak, both treated and untreated. Additional work is underway to improve material stability to survive in these harsh environments and include optimization of treatments and some adjustment of manufacturing parameters.

5. FUTURE WORK

Further optimization of CLT layups will be initiated to improve downstream exterior performance through augmentation of adhesives, press time, and other factors. The research team will be working with CLT manufacturers to further validate these designs. Additional work will also be conducted to ensure that suitable chemical treatment options are fully vetted that will ensure appropriate and realistic service life predictions. Finally, surface coatings and remedial treatments will also be explored to provide the military the full spectrum of maintenance options to ensure adequate performance of these materials. All of this work is on-going as part of a U.S. Army Small Business Innovation Research (SBIR) Phase II project.

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7. REFERENCES

AITC 110 (2001): Standard appearance grades for structural glue laminated timber. American Institute of Timber Construction: Englewood, CO, USA.

ANSI/APA PRG 320 (2011): Standard for Performance-Rated Cross-Laminated Timber. APA-The Engineered Wood Association: Tacoma, WA, USA.

ASTM D6874 (2021): Standard test methods for non-destructive evaluation of the stiffness of wood and wood-based materials using transverse vibration or stress wave propagation. ASTM International: West Conshohocken, PA, USA.

ASTM D905 (2021): Standard test method for strength properties of adhesive bonds in shear by compression loading. ASTM International: West Conshohocken, PA, USA.

AWPA E18 (2018): Standard field test for evaluation of wood preservatives to be used above ground (UC3B); Ground proximity decay test. American Wood Protection Association: Birmingham, AL, USA.

Bucur, V (2003): *Non-destructive characterization and imaging of wood*. Springer Science & Business Media.

Graff, K F (1991): *Wave motion in elastic solids*. Dover Publications, Inc. New York.

Ross, R J (2021): *Wood Handbook: Wood as an Engineering Material*. Forest Products Laboratory, Madison, WI.

Ross, R J, Pellerin, R F (1994): Non-destructive testing for assessing wood members in structures: a review. (General technical report FPL; GTR-70):39 p. : ill. ; 28 cm.

Senalik, C A, Wacker, J, Wang, X, Wu, Xi (2019): Identifying incipient decay in Douglas-fir bridge components using x-ray computerized tomography. *In*: Wang, X.; Sauter, U.H.; Ross, R.J. (eds.). Proceedings: 21st International Non-destructive Testing and Evaluation of Wood Symposium. General Technical Report FPL-GTR-272. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 62-70.

Senalik, C A, Farber, B (2021): Chapter 5: Mechanical Properties of Wood. *In*: Ross, R.J. and Anderson, J.R. (Eds.), Wood Handbook, Wood as an Engineering Material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 5-1 – 5-46 p.

Taylor, A, Denavit, M, Lloyd, J, Kim, J-W, Kirker, G, Mankowski, M (2023): Borate Treatment of CLT Panels Using Vacuum: A Proof of Concept. *Forest Products Journal*, **73**(1), 24-30.

TMMA RP-37-2007 (2007): Rating of Van Trailer and Container Floors for Lift Truck Loading. Truck Trailer Manufactures Association: Gainsville, VA, USA.