In: Wang, X.; Sauter, U.H.; Ross, R.J., eds. 2019. Proceedings: 21st International Nondestructive Testing and Evaluation of Wood Symposium. General Technical Report FPL-GTR-272. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. pp 643-649.

Utility of Image Software in Quantification of Termite Damage on Cross-Laminated Timber (CLT)

Tamara S.F.A. França*
Department of Sustainable Bioproducts, Mississippi state University, Mississippi State University, Mississippi, USA, tsf97@msstate.edu

C. Elizabeth Stokes
Department of Sustainable Bioproducts, Mississippi state University, Mississippi State University, Mississippi, USA, ces8@msstate.edu

Juliet D. Tang
USDA Forest Service, Forest Products Laboratory, Starkville, Mississippi, USA, juliet.d.tang@usda.gov

Rachel A. Arango
USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA, rrachel.arango@usda.gov

* Corresponding author

Abstract

Cross Laminated Timber (CLT) is part of a new generation of engineered wood products that are now widespread across Europe, Australia, and Canada. As this trend is now growing in the United States, manufacturers are looking to expand the use of CLT into the North American market, which includes states located in the southeastern U.S. As this region is known to have an increased risk of termite attack, standards should be developed to evaluate termite damage on CLT products prior to extensive use of the product in this region. However, existing standard test methods cannot be applied directly to CLT specimens as current standard test sample sizes are too small to adequately represent CLT constructed materials. Therefore, larger sample sizes were examined to determine resistance of CLT products against termite attack. Large sample size made it difficult to evaluate termite damage using weight loss as a variable as termite damaged specimens showed relatively low weight loss values. The objective of this work was to examine the use of the image analysis software, ImageJ, in determining the extent of termite damage on CLT blocks. Results showed that evaluation of void volume percent could be used in conjunction with weight loss and visual rating to obtain a more accurate measurement of overall termite damage in CLT.

Keywords: mass timber products, subterranean termites, image measurements, mass loss.

Introduction

Cross-laminated timber or CLT is a mass timber product that was first developed in Austria in the 1990s and has since expanded through the European construction market. As CLT is manufactured with wood, which is a renewable material, it is seen as highly desirable in the 'green' building movement (Singh and Page, 2016). The volume of lumber used in the material allows for a high level of carbon sequestration within a structure, a highly desirable characteristic in today's sustainable-focused construction market. Additionally, CLT provides all the excellent characteristics associated with wood products including a high strength to weight ratio, an exceptional sound insulator, and a significantly lower carbon footprint than steel and concrete (Smyth, 2018). These panels can compete with pre-cast concrete, as they can be handled on-site, and are lower in weight compared to concrete which makes CLT ideal for rapid construction of modular buildings, including apartment/condominium structures (Van de Kuilen et al., 2011).

Due to the strong establishment of CLT in Europe, investors are searching for new markets and growth opportunities (Grasser, 2015). Recently, it has become common to find CLT buildings proposed in the mid-rise and tall building construction market in Canada and northwestern parts of the U.S (CLT Handbook, 2013).

As the adoption of CLT construction expands, so does the need for research focused on specific regional hazards or conditions. To date, studies conducted with CLT panels are mainly focused on seismic design factors, elastic properties, responses to fire, structural properties, and strength properties (Steiger et al., 2008; Frangi et al., 2009; Gulzow et al., 2009; Ceccotti et al., 2010; Popvski and Karacabeyli, 2012; Pei et al., 2012; Gavric et al., 2013; Shen et al., 2013; Cao et al., 2019). However, limited studies have evaluated the resistance of CLT to termite attack in laboratory assays (França et al., 2018a; França et al., 2018b). Because CLT is a new product in the market and is a mass timber product, there is a need to not only determine specific vulnerabilities of the product to termite damage, but also develop new methods to measure termite damage. The goal of this study was to modify existing test small sample size methods to be used for evaluating the resistance of CLT to termite feeding and to assess the use of image analysis for prediction of product resistance to termite attack.

Material and Methods

AWPA Standard E1-17 (AWPA, 2019) was selected as the basis for the test design. However, this protocol uses a smaller specimen size that would not be representative of a CLT panel, so it was determined that the product should be tested using its full thickness. An assay was developed specifically for testing mass timber products. Modifications included sample size, size of test container, amount of sand and water added to the test containers, number of termites, and the test duration (Table 1).

Table 1. Modifications made to the AWPA Standard E1-17 test method for evaluating termite damage to CLT materials.

	AWPA Standard	Modifications for evaluation of CLT
Wood sample size	2.5 cm x 2.5 cm x 0.6 cm (1 in x 1 in x ¼ in)	10 cm x 10 cm x 2.5 cm (4 in x 4 in x 1 in)
Test container	80 x 100 mm glass screw-top jars	4 L food-safe container
Amount of sand/water	150g/27mL	1000g/180 mL
Number of termites	400	1000
Test duration	4 weeks	4 weeks

A total of five replicates were cut from 3-ply pine/spruce/fir CLT panels obtained from a commercial manufacturer. Samples were placed in test containers and exposed to feeding by the eastern subterranean termites, *Reticulitermes* sp. for 4 weeks. For this test, food-safe containers (4 L capacity) were used. All test specimens were oven dried at 60°C until constant weight was reached and weighed both before and after the exposure period to determine mass loss.

At the end of each test, percent mass loss was determined for the CLT block, and each block was examined and visually rated using the AWPA E1 visual ratings (Table 2). Additionally, the CLT block face in contact with sand substrate of each specimen was photographed and the digital images were analyzed using ImageJ software (Version 1.32j, US National Institutes of Health, Bethesda, Maryland; Rasband 2004). On each image, areas of termite feeding, and outer boundaries were manually outlined on the digital image and used to calculate percentage of the block face damaged by termites.

Table 2. Visual rating system according to AWPA Standard E1-17 (AWPA, 2019)

Visual rating classification	Rating
Sound	10
Trace, surface nibbles permitted	9.5
Slight attack, up to 3% of cross-sectional area affected	9
Moderate attack 3–10 % of cross-sectional area affected	8
Moderate/severe attack, penetration, 10–30%, of cross-sectional area affected	7
Severe attack, 30–50% of cross-sectional area affected	6
Very severe attack, 50–75% of cross-sectional area affected	4
Failure	0

Results and Discussion

The AWPA E1 Standard is used to evaluate the resistance of wood materials to subterranean termites. This standard uses small sized samples (2.5 cm x 2.5 cm x 0.6 cm), and mass loss calculations are easy to determine. Figure 1 shows a comparison between the size of the CLT test sample used in this study and the test sample used in the AWPA E1-17 Standard (AWPA, 2019).

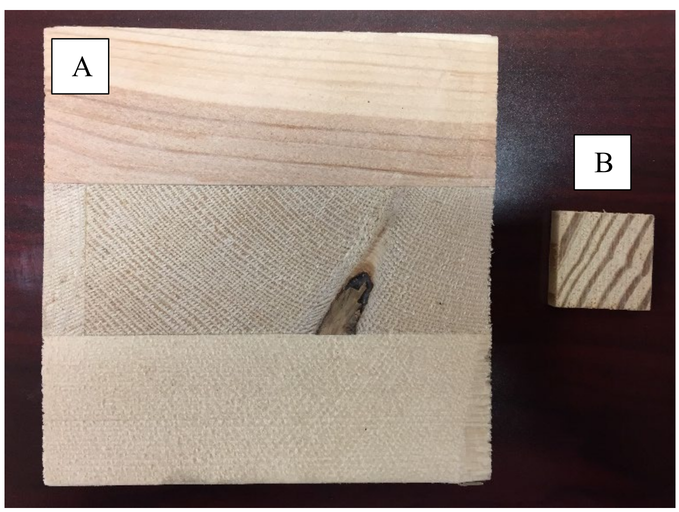

Figure 1. Comparison between samples: (a) CLT test block face with dimensions of 10 cm x 10 cm x 2.5 cm; (b) AWPA E1-17 cross-section with sample size of 2.5 cm x 2.5 cm x 0.6 cm

Table 3 shows visual ratings, percent mass loss and percentage of termite damage to the CLT block face as measured by ImageJ analysis. Studies evaluating the resistance of pine, spruce and fir alone using AWPA E1-17 (2019) sample dimensions showed mass loss percentages around 40%, 23%, and 25%, respectively (Arango et al., 2006; Kose and Tylor, 2012; França et al., 2016). However, the mass loss on CLT is harder to detect since the sample size is so large relative to the amount of wood consumed by termites and scaling up the termites would require adding more termites than was feasible to collect. The average mass loss of CLT samples in this study was 1.7% (Table 3). These results are in accordance with other studies that evaluated the resistance of CLT to termites, which showed a mass loss percentage of approximately 1.5% (França et al., 2018a; França et al., 2018b).

Table 3. Data summary for visual rating, percent mass loss, and percent cross section damaged measured with ImageJ software for CLT samples exposed to *Reticulitermes* sp.

Sample ID	Mass Loss (%)	Visual Rating	Cross sectional area damaged* (%)
1	1.6	6	24.3
2	1.3	6	30.2
3	2.0	6	30.2
4	2.0	6	36.2
5	1.6	6	32.2

*Calculated using ImageJ software.

The visual rating system described in the AWPA E1-17 (2019) Standard is based on small sample size dimensions. When CLT samples were evaluated using this system, it required a level of consideration and experience to accurately determine the degree of termite damage on larger specimens. After testing, specimens exposed to termites were classified according to the visual rating system described in AWPA E1-17 (2019). All CLT specimens exposed to termites received a score of 6, which is considered severe attack with 30 to 50% of cross-sectional area affected (Table 3). However, when samples were analyzed with ImageJ software, it showed that specimen 1 would have been graded as 7 with moderate/severe attack and penetration, having 10 to 30% of sectional area affected.

A contrast based on mass loss percentages was also found after evaluation of the images. Samples 3 and 4 showed the highest mass loss (2.0% for both samples). ImageJ analysis, however, showed that samples 4 (36.2%) and 5 (32.2%) had substantial damaged area percentages, while sample 3 showed a 30.2% damaged area, similar to sample 2. Figure 2 shows the five CLT block faces that were in contact with sand substrate during the test. By a simple visual comparison of these images, it is not visually apparent that samples 3 and 4 were the samples with highest mass loss percentage.

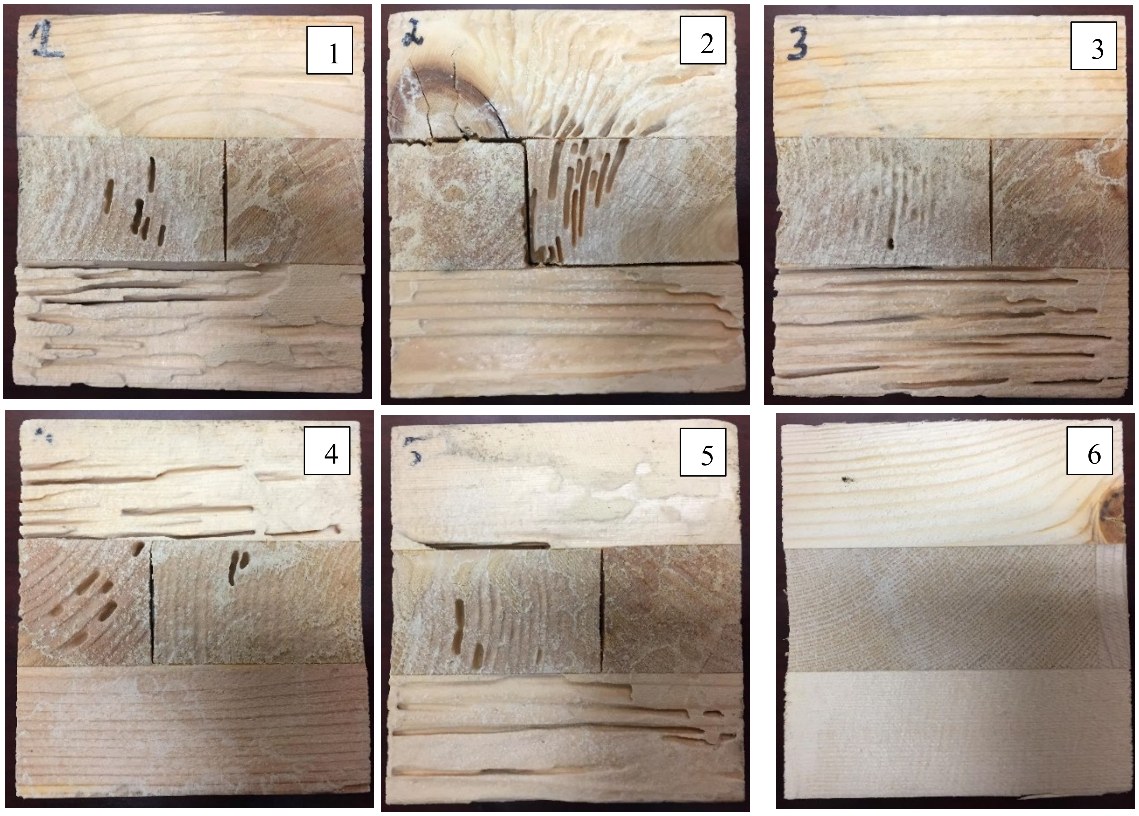

Figure 2. CLT samples exposed for four weeks: 1 to 5 = specimens exposed to *Reticulitermes* sp.; 6 = control sample.

Previous studies show that image software analyses can be useful to determine termite and decay damage, influence of treatments on wood, and other tests where mass loss does not fully describe the amount of damage. Lebow et al. (2010a, 2013b) used ImageJ to determine preservative formulation, wood moisture content, and diffusion time after treatment of borate penetration in framing lumber of southern pine species. Arango et al. (2016) used image software to evaluate if laser marking on dip-treatment blocks increased susceptibility to termite feeding. The authors evaluated termite damage by percent of surface attack using ImageJ software rather than weight loss due to the large size of specimens. Kim and Lloyd (2017) also used ImageJ to determine diffusion of borate inside bridge ties.

Conclusions

Cross-laminated timber is a new generation of engineered wood product, and it has attracted the attention of investors to expand its use throughout the southeastern U.S. wood market. CLT is gaining prominence in the wood industry and provides the same benefits that other wood products do including thermal insulation properties, cost effectiveness, environmental advantages, and less waste than other building materials including steel and concrete. Most studies conducted on CLT panels are focused on evaluation of mechanical properties. However, as a wood material, CLT panels are susceptible to biological degradation, and it is extremely important to understand the resistance of this product to biological agents such as termites.

To better evaluate the performance of CLT products against termite attack, modifications to the AWPA E1-17 (AWPA, 2019) standard are needed, and new methods should be created to better predict the natural resistance of this new product. Since larger specimens are needed to properly simulate mass timber product materials, mass loss data alone does not appear to be the most accurate way to describe damage throughout the product.

CLT test blocks can be evaluated using the visual rating system used by the AWPA E1-17 Standard, but evaluation requires more experience from the grader due to the non-standard sample size. Surface excavations from termites can be visualized easily, but it is more difficult to quantify internal tunneling to the mass of wood. The use of other techniques such as image software analysis combined with weight loss and visual evaluation, appear to be a better combination than mass loss data or visual rating only. Future research will be conducted to create technologies to facilitate the examination of termite activity on CLT products in-use.

References

American Wood Protection Association (AWPA). 2019. Laboratory methods for evaluating the termite resistance of wood-based materials. Standard E1-17. AWPA book of standards. American Wood Protection Association, Birmingham, AL.

Arango, R.A.; Green, F.; Hintz, K.; Lebow P.K.; Miller R.B. 2006. Natural durability of tropical and native woods against termite damage by *Reticulitermes flavipes* (Kollar). International Biodeterioration & Biodegradation, 57:46–150.

Arango, R.A.; Woodward, B.M.; Lebow, S.T. 2016. Evaluating the effects of post dip-treatment laser marking on resistance to feeding by subterranean termites. In: Proceedings IRG Annual Meeting (ISSN 2000-8953) 2016 The International Research Group on Wood Protection; IRG/WP 16-10854 The International Research Group on Wood Protection; Section 1 Biology.

Cao, Y.; Street, J.; Li, Minghao, L.; Hyungsuk, L. 2019. Evaluation of the effect of knots on rolling shear strength of cross laminated timber (CLT). Construction and Building Materials, 222(20):579–587.

Ceccotti, A.; Sandhaas, C.; and Yasumura, M. 2009. Seismic behavior of multistory cross-laminated timber buildings. In: International Convention of Society of Wood Science and Technology, Geneva, Switzerland CSA S-16. (2009). Design of Steel Structures. Ottawa: Canadian Standards Association. 2010.

CLT Handbook: cross-laminated timber (US Edition). 2013. E. Karacebeyli and B. Douglas ed. Special Publication SP-529E. 572 pp.

França, T.S.F.A.; França, F.J.N.; Arango, R.A.; Woodward, B.M.; Arantes, M.D.C. 2016. Natural resistance of plantation grown African mahogany (*Khaya ivorensis* and *Khaya senegalensis*) from Brazil to wood-rot fungi and subterranean termites. International Biodeterioration & Biodegradation, 107:88–91.

França, T.S.F.A.; Stokes, C.E.; Tang, J.D. 2018a. Durability of cross laminated timber against termite damage. In: Proceedings, 61st international convention of society of wood science and technology and Japan wood research society. Monona, WI: Society for Wood Science and Technology. 10 p.

França, T.S.F.A.; Stokes, C.E.; Tang, J.D. 2018b. Evaluation of cross-laminated timber resistance to termite attack. In: Proceedings of the American Wood Protection Association Annual Meeting. 114:266–271.

Frangi, A.; Fontana M.; Hugi, E.; and Jübstl R. 2009. Experimental analysis of cross-laminated timber panels in fire. Fire Safety Journal 44(8):078–1087.

Gavric, I.; Fragiacomo M.; Popovski M.; and Ceccotti, A. 2014. Behaviour of cross-laminated timber panels under cyclic loads. In: Materials and Joints in Timber Structures, pp. 689-702. Springer Netherlands.

Grasser, K.K. 2015. Development of Cross Laminated Timber in the United States of America. Knoxville, TN: University of Tennessee. 115 p. M.S. thesis.

Gülzow, Arne, Klaus Richter, and René Steiger. 2011. Influence of wood moisture content on bending and shear stiffness of cross laminated timber panels. European Journal of Wood and Wood Products 69(2): 193-197.

Kim, J.W.; and Lloyd, J.D. 2017. Borate and Copper Naphthenate Dual Treatment of Bridge Timbers-Borate movement over time. In: Proceedings IRG Annual Meeting (ISSN 2000-8953) 2017 The International Research Group on Wood Protection; IRG/WP 17-40795 The International Research Group on Wood Protection; Section 4 Processes and properties…

Kose, C.; Tylor, A.M. 2012. Evaluation of mold and termite resistance of included sapwood in eastern redcedar. Wood and Fiber Science, 44(3):319–324.

Lebow, S.T.; Lebow, P.K.; Halverson, S.A. 2010a. Penetration of boron from topically applied borate solutions. Forest Products Journal, 60(1):13–22.

Lebow, S.T.; Lebow, P.K.; Halverson, S.A. 2012b. Boron diffusion in surface-treated framing lumber. Forest Products Journal, 63(7/8):275–282.

Pei, S.; Van de Lindt J.W.; and Popovski M. 2012. Approximate R-factor for cross-laminated timber walls in multistory buildings. Journal of Architectural Engineering 19(4):245–255.

Popovski, M.; and Karacabeyli E. 2012. Seismic behavior of cross-laminated timber structures. In Proceedings of the World Conference on Timber Engineering, Auckland, New Zealand.

Rasband, W. S. 2004. ImageJ. US National Institutes of Health, Bethesda, Maryland. http://rsb.info.nih.gov/ij.

Singh, T.; Page, D. 2016. The durability of manufactured structural building materials. Proceedings IRG-WP Annual Meeting. ISSN 2000-8953.

Shen, Y.; Schneider, L.; Tesfamariam, S.; Stiemer, S.F.; and Mu, Z. 2013. Hysteresis behavior of bracket connection in cross-laminated-timber shear walls. Construction and Building Materials 48:980–991.

Steiger, R.; Gülzow, A.; and Gsell, D. 2008.Non-destructive evaluation of elastic material properties of cross-laminated timber (CLT). In: Conference COST E, 53:29-30.

Smyth, M. 2018. Cross laminated timber for residential construction. Stockholm, Sweden: KTH Royal Institute of Technology. 95 p. M.S. thesis.

Van de Kuilen, J.W.G.; Ceccotti, A.; Zhouyan X.; Minjuan H. 2011. Very tall wooden buildings with cross laminated timber. Procedia Engineering 14:1621–1628.