Thermally Modified Wood Performance Test Report

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Products: Thermally modified Yellow Poplar, Ash, and Red Maple

Project Summary

Faculty in the Department of Sustainable Biomaterials at Virginia Tech are researching thermally modified (TM) lumber with the collaboration of three U.S producers of thermally modified hardwoods. One objective is to evaluate the mechanical properties of thermally modified wood. This research is part of a larger project funded by the U.S. Forest Service, Wood Innovations Grant program. The mechanical properties studied were; hardness, bending, the equilibrium of moisture content, and volumetric shrinkage. The product description, test procedure, and test results are reported herein.

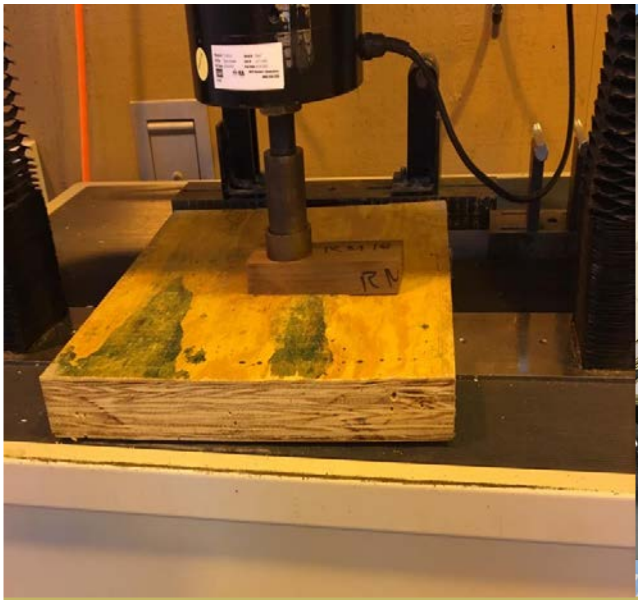
Test Method

The test specimens were evaluated in general accordance with ASTM D143 Standard Test Methods for Small Clear Specimens of Timber, ASTM D4442 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials, and AWPA E10 Laboratory Method for Evaluating the Decay Resistance of Wood-Based Materials Against Pure Basidiomycete Cultures: Soil/Block Test.

Product Description

The products tested were provided by three producers of TM hardwood products. The material had to be milled and conditioned at 23°C and 65% relative humidity until it reached an equilibrium to proceed with the mechanical testing.

Test Procedures



ASTM D143 Static Bending

Testing was conducted on an MTS test machine using a 3,000-pound load cell operating at a speed of 0.05in. (2.5 mm)/min. The span length was 14 in. (360mm) and each sample was subjected to a center point compressive load until failure occurred.

ASTM D143 Hardness

Testing was conducted on an MTS Test Machine using a 3,000-pound load cell operating at a speed of 0.25 in. (6 mm)/min. There were two penetrations made on the tangential surface.

ASTM D143 Radial and Tangential Shrinkage

The sample's length was measured, and testing was conducted in an oven and was dried at 103± 2°C until an approximate constant mass was attained. Measurements of were made of the oven-dry specimens. The shrinkage is expressed as the percentage of the volumetric changes that it had through the oven-dried process.

ASTM D4442 Equilibrium of Moisture Content (EMC)

After conditioning the specimens to a uniform weight at 23°C and 65% they were oven dried at 103± 2°C. The moisture content, EMC, was determined for the original conditions, which is approximately 12% for un-modified wood.

AWPA E10 Decay Resistance

The decay test was conducted using *Gloeophyllum trabeum (brown rot)* and *Trametes versicolor (white rot)* with sterilized materials and equipment. Test bottles with soil and a feeder strip were inoculated with fungi for three weeks. After the mycelium spread on the feeder strip, the test blocks were added. After twelve weeks, the samples with the mycelium were removed from the test blocks and then oven-dried for one day. The final step was storing the samples in the conditioning room until the equilibrium of moisture content was achieved to weigh the samples.

Results

Figure 1. Modulus of Elasticity

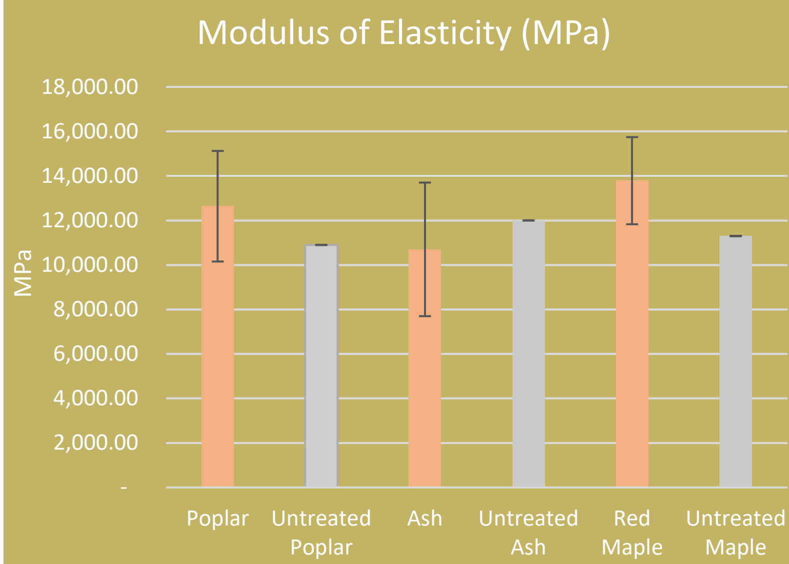


Figure 1 shows the graph with the Modulus of Elasticity (MOE), where the MOE value for poplar and red maple increased 15% and 20%, respectively, and the result showed that both had a high standard deviation. In the case of ash, the MOE tends to decrease by 8% compared to untreated wood from published values.

Figure 2. Hardness

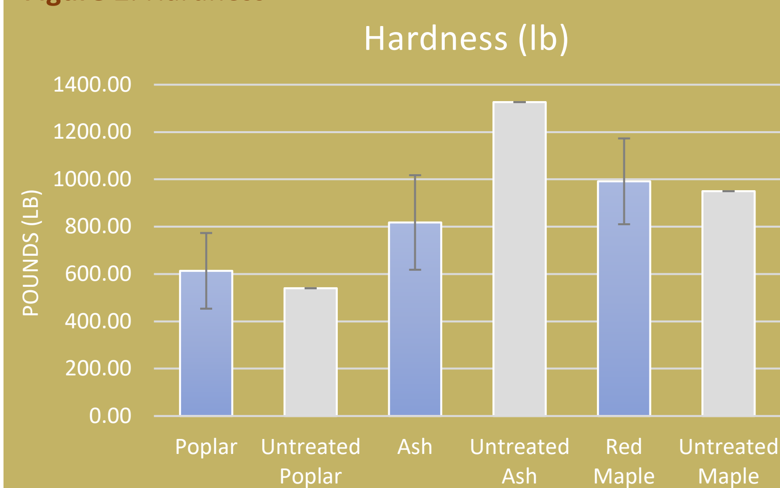


Figure 2 presents the hardness values, where TM poplar and red maple hardness increased by 13% and 4%, respectively, where the case of ash the hardness value decreased by 47%. Hardness performance is essential for flooring applications.

Figure 3. Modulus of Rupture

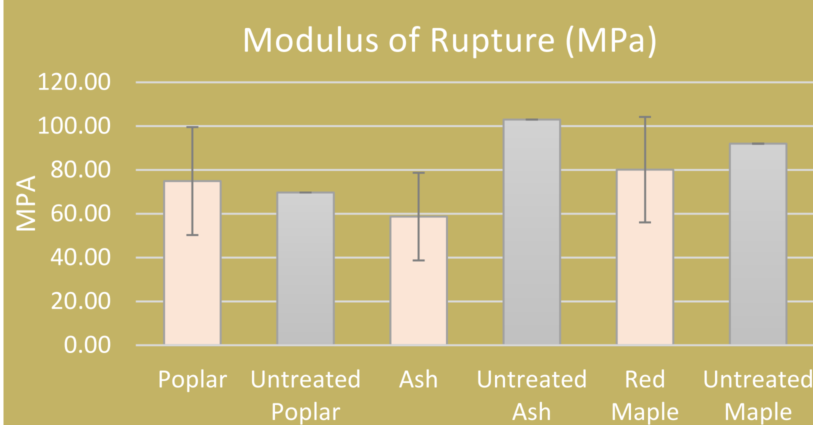
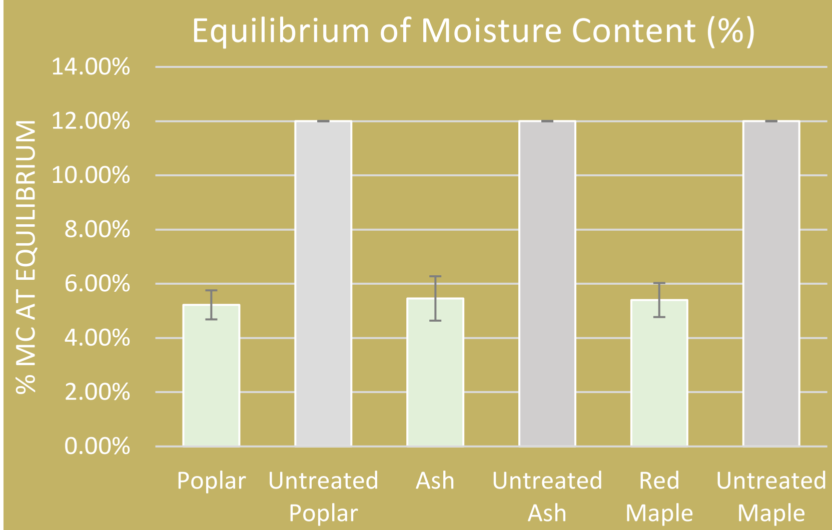


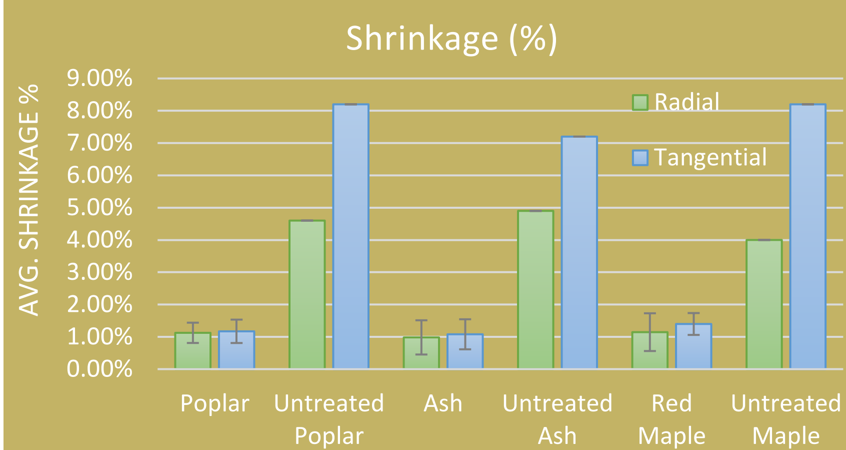
Figure 3 shows the Modulus of Rupture (MOR), where poplar tends to increase by 7%, but for red maple and ash, the values decreased by 14% and 66%, respectively.

Figure 4. Equilibrium of Moisture Content



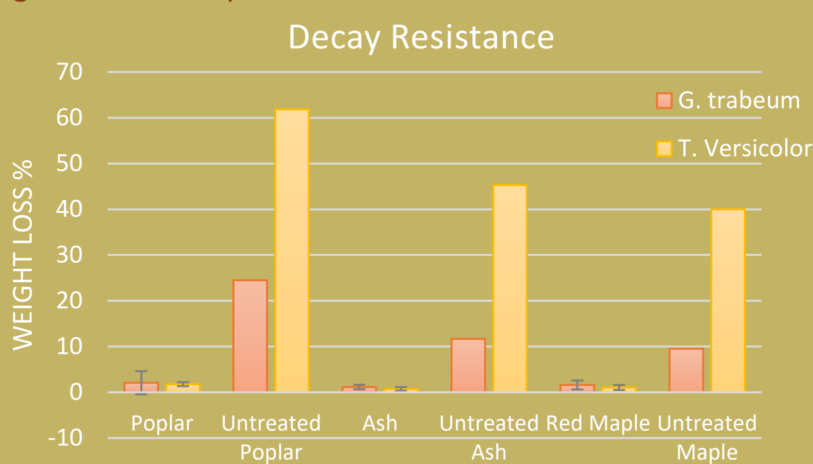
The Equilibrium of Moisture Content (EMC) is shown in Figure 4. The results show that there was a significant decreased in the EMC at the same temperature and relative humidity when the compared to untreated wood.

Figure 5. Shrinkage



The shrinkage values for the tangential surface tends to decrease by 85%, 83%, and 82%, respectively. The same goes for the shrinkage values on the radial surface, decreasing the value by 76%, 80% and 72%, respectively.

Figure 6. Durability



The weight loss observed in Figure 6 shows the improvement that thermally modified wood species have compared to untreated values. This is due to the lower levels of moisture content and sugars left in lumber.

Additional Information

The data displayed on the tables and figures provide the values of untreated wood for the three species studied, which was came from published literature rather than comparison testing [Ross (2010), Larose (2014), Schirp et al., (2007), Sivrikaya et al., (2015)].

The average MOE measured for all three companies was higher than the average MOE of untreated wood as measured by Hill (2007). This was not expected, since most literature described a decrease in mechanical performance (Esteves et al., 2008). Also, most of the work done by Esteves did not specify the technology used to thermally modify the wood, only the schedule utilized, which may be crucial. For example, Candelier (2014) mentioned that commercial technologies utilizing a vacuum in their systems did not see a considerable reduction of the mechanical properties of wood after the modification, due to improved drying of the wood in the chamber.

With different schedules and technologies used to produce TM wood, it makes sense to have different values such as an incremental increase in MOE, MOR, and hardness performance, depending on the species. The results from the dimensional stability, equilibrium of moisture content, and durability against fungus showed significant improvement for the three-wood species studied, and most of the test values obtained from each company were statistically the same or if statistical differences existed, they were not practical differences in regards to product use. For example, the practical difference between a final EMC of 4.4% compared to 5.7%

Overall, the results obtained from the physical tests, showed improved values of 5% to 1%, for the radial section for yellow poplar with treated and untreated values, and for the tangential section the red maple samples showed untreated and treated values from 8% to 1%. In the case of EMC, the values improved approximately from 12% to 5%. There were differences in the values between the companies, as shown in the previous section, but each showed larger reductions, relative to untreated values. While there were statistical differences between the values of some of the companies, the overall improvements, compared to untreated wood, were quite large, from 12% to 5%. This demonstrated that, relative to untreated wood, the different commercial processes were a significant improvement.

The average values of the three companies showed an improvement in the decay resistance of TM wood, when compared to untreated wood. TM yellow poplar treated by Shi (2007), showed improvements from untreated values of 69% of weight loss to 18%. Literature indicated that thermal modification increased the performance against brown-rot more than white-rot (Esteves, 2009; Sandberg et al., 2015), and the obtained results in this study demonstrated it. Most importantly, the results showed that different commercial processes and schedules resulted in the same decay resistance for all three species tested.

Table 1. Mechanical and Physical Test Results

Test/Specie	Bending								Shrinkage			
	MOE		MOR		Hardness		EMC		Radial		Tangential	
	Mean (MPa)	Std Dev	Mean (MPa)	Std Dev	Mean (lbs.)	Std Dev	Mean (%)	Std Dev	Mean (%)	Std Dev	Mean (%)	Std Dev
TM Yellow Poplar	12,640.07	(2,485.46)	74.92	(24.64)	613.45	(159.84)	5.22	(0.54)	1.12	(0.31)	1.17	(0.36)
Untreated Poplar	10,900.00	--	69.70	--	540.00	--	--	--	4.6	--	8.2	--
TM Ash	11,114.08	(3,124.72)	51.99	(21.81)	817.84	(199.73)	5.48	(0.83)	1.03	(0.60)	1.03	(0.53)
Untreated Ash	12,000.00	--	103.00	--	1326.38	--	--	--	4.9	--	7.2	--
TM Red Maple	13,787.89	(1,958.14)	80.13	(24.07)	991.69	(181.31)	5.40	(0.63)	1.15	(0.58)	1.40	(0.34)
Untreated Maple	11,300.00	--	92.00	--	950.00	--	--	--	4.0	--	8.2	--

Table 2. Durability mass loss percentage of treated and untreated wood species.

Test/Specie	G. trabeum Average Mass Loss (%)	T. versicolor Average Mass Loss (%)
TM Yellow Poplar	2.08	1.77
Untreated Poplar	26.49*	61.85**
TM Ash	1.14	0.78
Untreated Ash	11.68*	45.3***
TM Red Maple	1.59	1.06
Untreated Maple	9.54*	40.0****

References

American Wood Protection Association. (2012). AWPA E10-12 standard method of testing wood preservatives by laboratory soil-block cultures. AWPA Book of standards.

****Anagnost, S. E., & Smith, W. B. (1997). COMPARATIVE DECAY OF HEARTWOOD AND SAPWOOD 01; RED MAPLE.

ASTM D143-14 Standard Test Methods for Small Clear Specimens of Timber, ASTM International, West Conshohocken, PA, 2014.

ASTM D4442-16 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials, ASTM International, West Conshohocken, PA, 2016.

Donahue, P., Aro, M., French-Coda, S., & Chen, W. (2011). Thermally-modified Eastern hardwoods as high-tech fenestration and exterior shuttering. USDA Wood Education and Resource Center Project, (09-DG), 090.

Candelier, K., Dumarcay, S., Petrissans, A., Gerardin, P., & Pétrissans, M. (2014). Advantage of vacuum versus nitrogen to achieve inert atmosphere during softwood thermal modification. Pro Ligno, 10(4), 10-17.

*Larose, M. (2014). Determination of the properties of thermally modified red oak, white ash, and yellow poplar (pp. 42-44). Wood Design & Building.

Ross, R. J. (2010). Wood handbook: Wood as an engineering material. USDA Forest Service, Forest Products Laboratory, General Technical Report FPL-GTR-190, 2010: 509 p. 1 v., 190

***Sivrikaya, H., Can, A., de Troya, T., & Conde, M. (2015). Comparative biological resistance of differently thermal modified wood species against decay fungi, Reticulitermes grassei, and Hylotrupes bajulus. Maderas. Ciencia y tecnología, 17(3), 559-570.

**Schirp, A., & Wolcott, M. P. (2007). Influence of fungal decay and moisture absorption on mechanical properties of extruded wood-plastic composites. Wood and Fiber Science, 37(4), 643-652

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