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Field Performance of Thermally Modified Wood in a Severe Test Site

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ABSTRACT

Thermally modified wood (TMW) is a growing trend in North America in areas of low decay and insect pressure. Thermal modification improves dimensional stability, decreases moisture uptake, and results in a darkened color that resembles tropical hardwoods. More testing is needed in severe decay situations and in areas of high termite pressure to fully understand the boundaries of its material performance. Within the AWPA, the P9 subcommittee (non-biocidal wood protectants) has been working to develop test methodologies and appropriate use category designations for TMW materials. The Forest Products Laboratory has been conducting field tests at a severe decay hazard site (Saucier, Mississippi) since 2013 to evaluate the performance of several wood species with varying degrees of thermal modification and additional surface coatings aimed to increase product longevity. Results to date show that in instances of close ground proximity, almost all the thermally modified samples have failed unless they were subject to a supplementary coating or treatment. In accelerated field testing of these materials, it has been observed that sample size has shown to be an important parameter and careful attention needs to be paid when preparing future field tests to properly evaluate TMW. Five- and ten-year results of separate ongoing field tests are reported along with a preliminary discussion of findings and steps forward.

Keywords: thermally modified wood, durability, field testing, severe field site

INTRODUCTION

Thermally modified wood has gained significant attention in recent years as an alternative to traditional chemically treated wood products, especially for cladding and above ground decking. Thermal modification is typically produced by subjecting wood to high temperatures in an oxygen starved environment. The advent of TMW came about as a wood drying accident; Tiemann [1] dried air-dry wood in the presence of superheated steam and noted a reduction in moisture sorption as a result. The earliest commercialization attempt was by Stamm et al. [2], but was largely unsuccessful. In the mid-1990s, VTT in Finland successfully registered Thermowood® as the first commercial wood thermal modification [3]. There are now several methods for production of TMW, and have been reviewed quite extensively [4]. There is a wide range of research data pertaining to TMW in a growing range of wood species, but overall, TMW is generally shown to improve material decay resistance, improve dimensional stability, and provide enhanced aesthetics more closely resembling that of tropical hardwoods. Some documented drawbacks to TMW are reductions in mechanical strength, limited availability, unknown environmental impact, and conflicting data on long-term field performance, especially in relation to decay fungi and termites. A more thorough understanding of long-term field performance of thermally modified wood is critical to realizing its full potential as a chemical free building material for non-structural applications.

Thermally modified wood in AWPA

Thermally modified wood has been a topic of discussion within the American Wood Protection Association (AWPA) since 2009. An instruction was issued at the creation of the P9 subcommittee to discuss establishing guidelines for inclusion of TMW into the AWPA Book of Standards. A task force was formed that year which remains active today. The task force drafted guidance Document N in 2019 and was incorporated into the 2020 Book of Standards [5]. This was a preliminary step to establishing a pathway to standardization for TMW by an interested producer wishing to bring a process forward. As more producers begin to manufacture TMW, there is an increased need for broader code acceptance, which typically relies on wood protection standards writing bodies, such as the AWPA, to develop guidelines to properly assess and characterize material performance.

Overall research goals

This paper details the results of several interconnected studies designed to test the durability of TMW in a severe hazard test site. Materials were exposed in either laboratory, ground proximity or above ground conditions with very little separation from ground and decking materials to simulate "worst case" situations for material exposure. The results presented herein are grouped into three tests and discussed in detail.

RESULTS AND DISCUSSION

Test 1: 2014 Field Tests with Natural Resources Research Institute (NRRI)

The goal of the first test was to evaluate several species of wood (aspen, birch, black ash) after thermal modification at 170ºC as well as with supplemental treatments (water repellent or brush on copper-based preservative). These test units were installed as E25 decking units very close to the ground, with very little air flow, thus providing significant convection originating from the soil surface. These test units were rated annually for a period of five years and again at the eight-year mark. Decay ratings for each test group are shown in Figure 1. Aspen and white birch controls failed between 4 and 5 years, and black ash failed between 5 and 8 years. Thermal modification had additive effects on the performance of aspen and white birch, but little or no improvement in durability of black ash. The combined water repellent and copper biocide faired the "best" in these tests but had a mean rating of 6 after 8 years of exposure.

The E25 decks were essentially in ground contact, which likely accelerated decay due to limited air flow and convective soil moisture. Ring shake and cathedral grain was also noted in the TM birch and ash, this is likely due to their growth ring characteristics. Termite attack was noted for several samples, but our rating scale for E25 did not include termite damage, which will need to be considered for future ratings. Finally, all samples in the test showed significant graying as early as 6 months outdoor exposure. These tests will continue for at least 10 years.

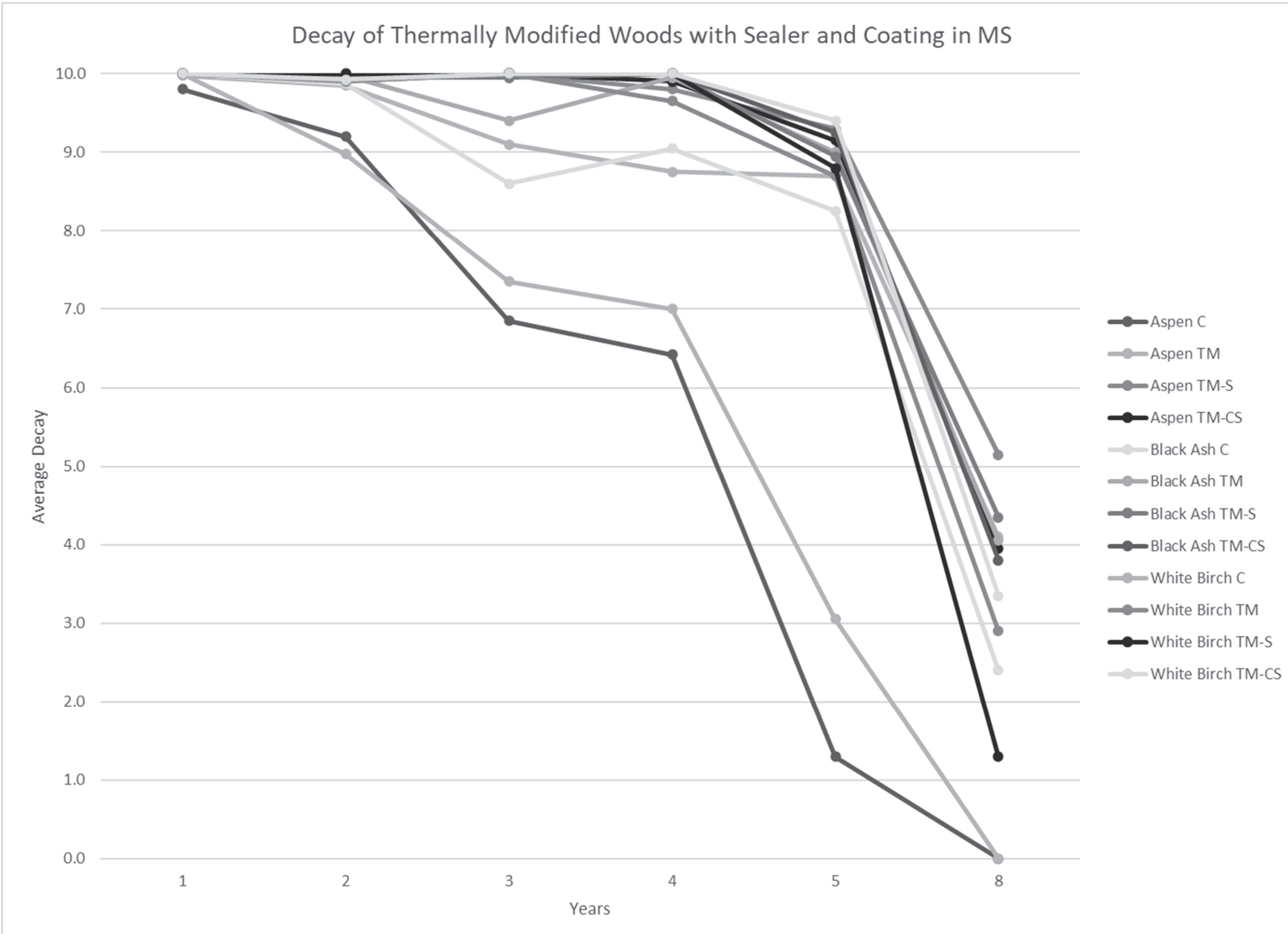

Figure 1: Mean decay ratings of aspen, yellow birch and black ash both unmodified (C) and subject to thermal modification (TM) with and without a sealant (S) and a supplemental coating (CS).

Test 2: 2016 Lab & Field Tests with TM Red Oak and Ash

In 2016, laboratory and field tests were conducted on TM red oak and ash. Modified (TM) and unmodified (kiln dried, kd) versions of each wood species were evaluated as well as each species with a supplemental penetrating oil/ extractive blend (Figure 2). First, an E1 termite test was conducted using *Reticulitermes flavipes* (Kollar) collected from field sites around Starkville, Mississippi. Untreated southern pine was used as a non-durable control and resulted in 35% mass loss and 34% mortality at the end of the 4-week test. Thermal modification had little impact on mass loss and no effect on mortality for ash and increased mass loss (albeit lower mortality) in red oak. Treated reference materials (MCA-C) exhibited less than 1% mass loss and 100% mortality in these tests.

Wood ID	Mass Loss %	Mortality %
1-kd ash	2.94	100.00
2-tm ash	1.96	100.00
3-kd oak	1.24	100.00
4-tm oak	7.47	39.13
5-tm oak + penefin oil	5.72	51.05
6-tm ash + penefin oil	0.63	86.60
7-MCA-C (treated controls)	0.90	100.00
8-untreated pine	35.19	34.10

Figure 2: Mean mass loss and termite mortality of thermally modified (TM) red oak and ash compared to kiln dried (kd) of same, untreated pine, and a chemically treated reference (MCA-C, UC3B retention).

The second test conducted was an AWPA E18 ground proximity test (Figure 3). This test is currently at 4 years and results are shown below (Figure 3). Briefly, thermally modified red oak and ash are performing similarly, or worse in the case of red oak, to untreated pine under this type of exposure. The addition of a penetrating oil showed variable protective value after 4 years (positive for red oak, negative for ash). These tests will continue to be evaluated for at least 5 years.

	One year 6/26/19		Two year 8/12/2020		Three year 8/04/2021		Four year 9/13/2022	
	Termite	Decay	Termite	Decay	Termite	Decay	Termite	Decay
1-kd ash	8.9	8.8	6.4	8.0	6.2	6.4	6.0	5.8
2-tm ash	9.6	9.4	9.0	8.6	8.6	7.6	8.4	7.4
3-kd oak	9.0	9.0	8.4	8.4	8.4	7.6	7.8	7.4
4-tm oak	7.6	8.4	6.6	7.8	6.6	6.0	3.2	4.0
5-tm oak + penefin oil	7.6	9.0	7.0	8.6	6.8	7.8	6.8	6.8
6-tm ash + penefin oil	8.2	9.2	6.2	8.0	5.8	5.8	4.8	5.0
7-MCA-C (treated controls)	9.8	9.0	9.8	9.0	9.8	8.8	9.8	9.4
8-untreated pine	8.4	8.6	7.4	8.2	7.4	7.4	6.2	7.0

Figure 3: Results of E18 tests of TM ash and oak, KD ash and oak, penetrating oil ash and oak after 4 years of ground proximity exposure in Saucier, Mississippi (AWPA hazard class 3, severe). MCA-C and untreated pine served as positive and negative controls respectively.

An E26 ground proximity test (Figure 4) was also conducted using the same treatments as E18. Results after 4 years of exposure are presented below. Briefly, all untreated pine failed by year 4 due to termite and decay damage while specimens treated with the chemical reference remained sound. Thermally modified red oak is close to failing due to both termites and decay fungi (termites 3.8 and decay 2.8), but the thermally modified ash is performing slightly better (termites 8.6 and decay 7.6). The kiln dried oak is performing slightly better than the RM red oak and again, the addition of penetrating oil yielded variable results (improved performance in red oak, decreased in ash).

	One year 6/26/19		Two year 8/12/2020		Three year 8/04/2021		Four year 9/13/2022	
	Termite	Decay	Termite	Decay	Termite	Decay	Termite	Decay
1-kd ash	**9.0**	**9.2**	**8.0**	**8.8**	**4.0**	**5.0**	**4.0**	**0.0**
2-tm ash	**10**	**9**	**9.2**	**9**	**8.8**	**8.2**	**8.6**	**7.6**
3-kd oak	**10**	**9.2**	**9.2**	**8.8**	**8.8**	**8.4**	**8.4**	**7.6**
4-tm oak	**10**	**9.4**	**8.2**	**8.8**	**3.8**	**7**	**3.8**	**2.8**
5-tm oak + penefin oil	**9.2**	**9.6**	**8.6**	**9.2**	**6.6**	**8.4**	**5**	**5.4**
6-tm ash + penefin oil	**9.6**	**9.6**	**8.6**	**9.2**	**6.6**	**8.8**	**6.4**	**6.6**
7-MCA-C (treated controls)	**9.8**	**9**	**9.8**	**9**	**9.4**	**9**	**9.5**	**9.8**
8-untreated pine	**9**	**9.2**	**7.6**	**8.6**	**5.6**	**7.4**	**2**	**2.4**

Figure 4: Results of E26 tests of TM ash and oak, KD ash and oak, penetrating oil ash and oak after 4 years of ground proximity exposure in Saucier, Mississippi (AWPA hazard class 3, severe). MCA-C and untreated pine served as positive and negative controls respectively.

High mortality was noted in the E1 forced feeding tests, therefore, choice tests might yield different results and should be considered for future evaluations. TM red oak had only 40% mortality in tests compared to 100% with other TM species. The penetrating oils showed some protective effects in the E1 tests, but results were variable in later field tests. Leaching was not evaluated in this test but should be considered for future evaluations. The ground proximity tests showed thermal modification of red oak and ash resulted in only marginal improvements in TM red oak and TM ash and the addition of a penetrating oil were inconclusive. These tests will continue to be evaluated for at least 5 years.

Test 3: TM Black Locust, Lodgepole and SYP with NRRI - Strength Tests

Strength tests were conducted at NRRI (Duluth, Minnesota) to assess possible strength changes due to varying degrees of thermal modification. For black locust, a slight decrease in modulus of elasticity (MOE) was noted along with a more drastic decrease in modulus of rupture (MOR) (Figure 5). The highest level of TM for black locust (180ºC) resulted in significant decreases in MOR. Lodgepole pine was variable but was not significantly different from unmodified wood. Southern yellow pine also exhibited variable results with even higher standard error.

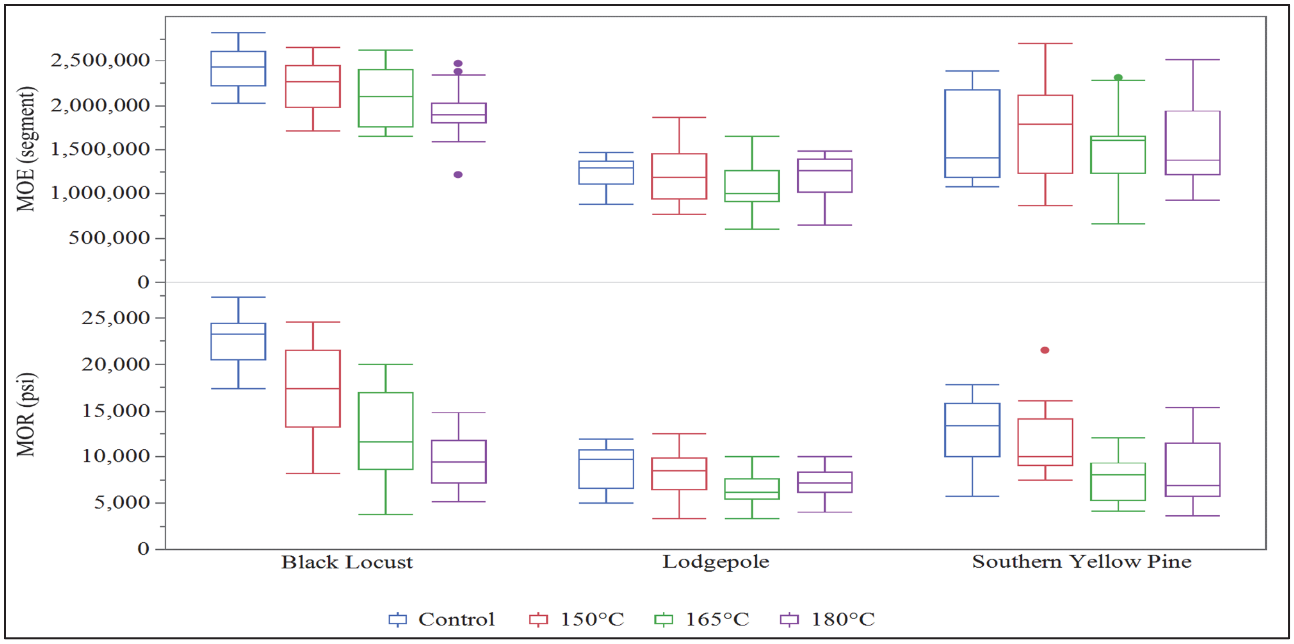

Figure 5: Modulus of elasticity (MOE) and modulus of rupture (MOR) values for black locust, lodgepole and southern yellow pine thermally modified at 150º, 165º and 180ºC and un-modified controls of same.

Side hardness data is presented in Figure 6. A linear decrease was noted on all faces for black locust and the highest level had significantly lower values compared to un-modified wood. Lodgepole pine exhibited little change in side hardness at all levels with slightly higher values on end grain. Southern yellow pine yielded similar results to lodgepole pine with slightly more variability.

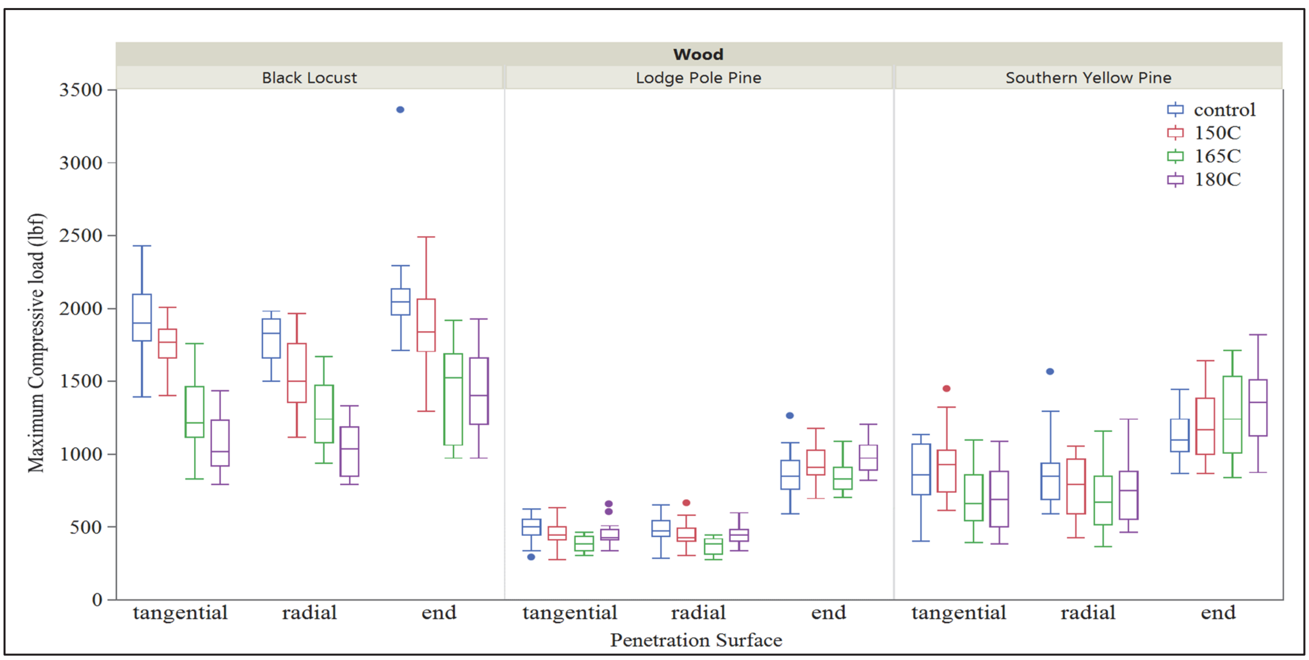

Figure 6: Side hardness data (maximum compressive load (lbf)) on tangential, radial and end grain surfaces of black locust, lodgepole and southern yellow pine thermally modified at 150º, 165º and 180ºC and un-modified controls of same.

Split resistance (Figure 7) results were largely inconclusive but overall black locust showed a decrease in split resistance that followed a linear trend (Figure 7). Additionally, noticeable checking was apparent with the TM black locust that increased in severity to increasing degree of thermal modification. Lodgepole and southern yellow pine had lower starting values but resulted in negligible decreases.

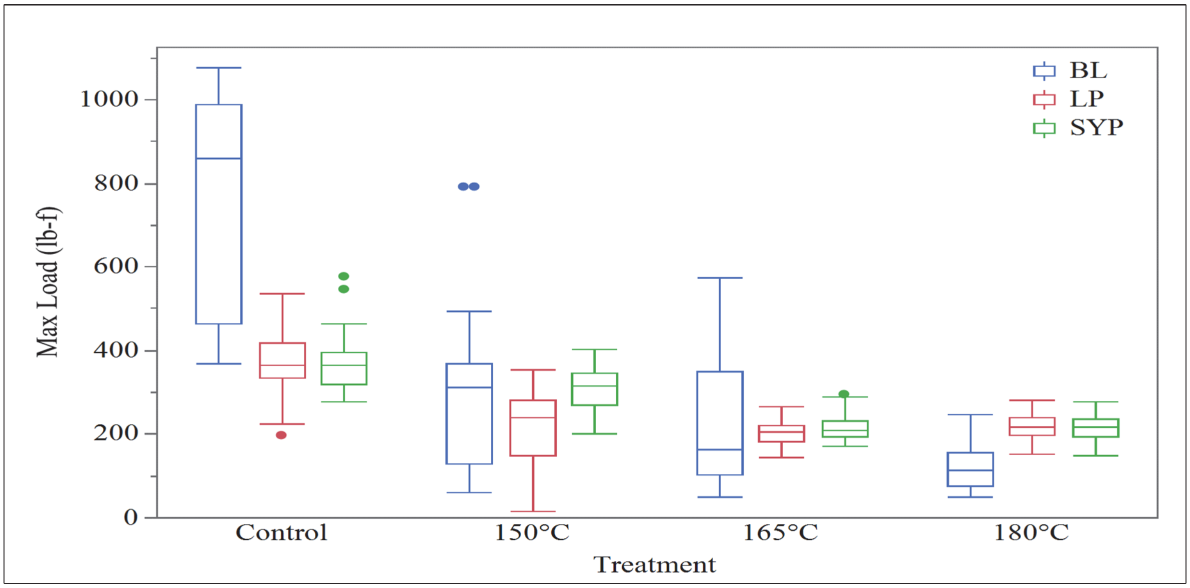

Figure 7: Split resistance (max load to failure in lb./ft) of black locust (BL), lodgepole (LP) and southern yellow pine (SYP) thermally modified at 150º, 165º and 180ºC and un-modified controls of same.

SUMMARY

Test 1: 2014 Field Tests with NRRI

- Based on preliminary results, TM aspen, birch, and black ash have a service-life expectancy of 5-6 years in severe above ground exposure; supplemental preservatives and sealants had little additive effect. Continued evaluations will be used to provide more realistic service life estimates in a severe decay hazard.
- Extreme proximity to ground and sample dimension likely had a negative impact on results.
    - Sample geometry had a negative impact on ratings, thin samples experienced more cupping than would be expected in full size commodity material.

Test 2: 2016 Laboratory & Field Tests with TM Red Oak and Ash

- TM red oak and ash exhibited durability improvements compared to untreated controls, but still exhibited high rates of decay after four years.
- Penetrating oil had inconclusive improvements to thermal modification treatments.
- Sample size effects in these tests were also apparent.

Test 3: TM Black Locust, Lodgepole and SYP with NRRI - Strength Tests

- Strength reductions were found with increasing degrees of thermal modification, especially in black locust.
- Softwood species exhibited less strength reductions than hardwoods, but based on limited comparisons, more replication would be needed to properly address these reductions.

Overall

It should be noted that biological durability of these wood species showed negligible improvement compared to un-modified materials, but it is possible that these levels are not high enough to significantly improve decay and insect resistance based on European literature of thermal modification [6]. However, as with most thermally modified wood, the decreases in strength values must be considered in order to balance material stability with material durability.

FUTURE WORK

Field tests of thermally modified black locust (BL), lodgepole pine (LP) and southern pine (SP)

- Assess above ground and ground contact durability
- Examine effects of UV weathering and leaching
- Explore more coating and supplemental treatment options

Re-evaluate test methods

- Determine if adaptations needed to existing standards
- Revisit Guidance Document N
- Analytical and QA/QC standards are needed

Postmortem assessments

- Characterize decay fungi on TMW
- Explore antifungal mechanisms vs. moisture exclusion

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