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Production and Design Value Assessment of Sweetgum LVL for Temporary Infrastructure Bridging

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Abstract

The utilization of low-grade hardwood to produce temporary bridges and mats is crucial due to economic benefits and positive environmental impact. This paper investigates the potential use of laminated veneer lumber (LVL) made from grade D and better sweetgum (Liquidambar styraciflua L.) for temporary bridges. The veneers were parallel laminated with butt joints at six-inch intervals. The lamina was hot-pressed with phenol formaldehyde-impregnated paper under laboratory conditions. After cooling, three-point bending tests were conducted on the specimens. Moisture content and density of the tested specimens were measured. Parametric and nonparametric bending strength design values were calculated based on fifth percentiles reduced by a factor of uncertainty and 10-year load duration. The results showed that the laminated veneer lumber provided favorable design properties compared to alternative materials.

Keywords: Laminated veneer lumber; Parametric and non-parametric design values; Sweetgum engineered lumber; Underutilized hardwoods; Structural hardwood lumber

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Introduction

Wood, as a biological material, optimizes itself for survival, leading to natural defects like grain slopes and knots in lumber. Clear wood, free of defects, has well-oriented cells with helically wound cellulose microfibrils, offering the highest strength-to-weight ratio in tension. To harness this property, eliminating or dispersing defects through glue lamination is essential. Laminated veneer lumber (LVL), a high-yield, efficient product, achieves this and is recognized as an engineered material with reliable strength and stiffness. Developed in the 1940s for high-strength aircraft components, veneers were sometimes impregnated with phenolic resin for added stability and strength. Appreciated by the furniture industry for its machinability and uniform mechanical properties, LVL became crucial as high-quality sawlogs dwindled, offering higher yield potential. Since the 1970s, LVL has been used as reliable structural members, such as tension chords in I-joists, trusses, and laminated beams, due to its engineered strength and adaptability [1].

LVL is produced similarly to plywood but with parallel lamination using rotary-cut veneers, significantly influencing yield. One of the most promising features of LVL is its ability to ensure structural performance by grading veneer based on quality and optimizing veneer placement. The plywood industry widely uses visual veneer grading. Advanced lathes now peel veneers to a 50mm core diameter, increasing LVL yield by 47% compared to sawn lumber [2]. Veneer is dried to approximately 5%-7% moisture content using energy-efficient methods. Veneer can be treated with preservatives or fire retardants. Thinner veneers dry more economically but require more adhesive, necessitating a balance between veneer thickness and adhesive usage for optimal LVL properties.

Various types of resins are used to bond LVL layers together depending on the application. Phenolic-based resins (phenol-resorcinol-formaldehyde and phenol-formaldehyde resin), with over a century of history [3] are used for structural applications, while urea resins (urea-formaldehyde and melamine-urea-formaldehyde) are typically employed for non-structural applications [4]. Once resin is applied to the veneer layers, the veneer lay-up is subjected to both pressure and elevated temperature. This process is usually accomplished with a long single-opening press or a caterpillar type press. Heat may be supplied via steam, hot oil, electric resistance, or radio frequency.

LVL has less variation in strength as compared to solid lumber sourced from the same logs. Strength becomes more reliable with an increase in the number of laminations, particularly noticeable when the quality of logs is lower. This trend also applies to stiffness properties in both LVL and solid lumber. The allowable design stress (F_a) in LVL can be estimated using a formula: $F_a=(F_m-n_\sigma)/2.1$, where F_m represents the average strength, σ is the standard deviation and n is a coefficient dependent on the shape of the strength distribution. The denominator 2.1 accounts for the effect of long-term loading as a safety factor. Typically, the 5% exclusion limit (F_5) is utilized, where stress values below (F_m-n_σ) are considered. If the distribution follows Gaussian norms and the sample size is sufficiently large, n assumes a value of 1.645. Empirical investigations into LVL suggest that a value of 2.0 should be used for n, considering safety factors in use [5,6]. Alternatively, nonparametric analysis can also be used as it is distribution independent. When the sample size is known, ASTM D2915 [7] provides guidance regarding which factor or order statistic should be used when assigning parametric or nonparametric Fa values, respectively.

Previously researchers have investigated limited aspects of hardwood LVL. Brashaw and Ross [8] reported on sorting hardwood veneer via ultrasonics as a means of controlling and upgrading veneer-based structural products. That research focused mainly on red maple. Wang et al. [9] reported on mechanical properties of hardwood based LVL. That research also focused on red maple. It demonstrated feasibility but did not have a sufficient sample size to calculate a nonparametric F_a value. Nationally, there is a current and pressing need for greater markets for underutilized hardwood species and a particular emphasis toward developing commercially viable structural applications and markets [10].

Currently, there is a national effort to enhance the utilization of undervalued hardwoods. Developing markets for low-value and underutilized species, as well as lesser grades, and finding structural applications are crucial. Sweetgum (*Liquidambar styraciflua L.*) is one such species. Lumber from these trees often exhibits mineral stains or other streaking. Helical and interlocked grain frequently lead to a high incidence of warp. Additionally, smaller diameter trees and stems with multiple branches often produce narrow, knotty, and lower-grade lumber and veneer. Thus, usually very little high-grade lumber can be recovered sweetgum trees.

The access mat industry requires temporary bridges for infrastructure projects like powerlines, wind turbines, oil fields and pipelines, where small streams, creeks and ditches must be crossed. Air bridges are also needed to protect existing utility lines during construction. Heavy equipment operating on mats creates high loads over short durations. Often bridges need to be 30 to 50 feet in length. Multi-piece laminated veneer lumber (LVL) stringers are an engineered solution for these temporary bridges due to their known and predictable strength and stiffness. However, LVL can be expensive and supply-constrained, as it is typically made from high-grade, ultrasonically tested veneer from high-quality logs. A viable option may be to produce LVL from low-grade hardwood veneer. It is technically feasible to manufacture LVL from hardwood veneer. If the design values of the LVL are favorable, then it could be economically viable for commercial production. The aim of this study is to manufacture and then determine the design values of sweetgum LVL.

Material and Methods

Material

Wood

Sweetgum, grade D and better, 0.10-in.-thick veneer (PS1, [11]) was procured from a regional producer. Sweetgum is classified in PS1 [11] as Group 2. Included in this group are other species such as true firs, western hemlock, and western pines among others. As received, veneer was approximately 6% moisture content. The 0.10-in.-thick veneer sheets were approximately 25 x 84 in.

Adhesive

Phenol formaldehyde impregnated paper was used. This adhesive is structural and waterproof. Its cure temperature was on the order of 260-270 F.

Methods

LVL production process

Target thickness was 3.6 - 3.8 in. In support thereof, billets were laid up with 36 layers. For layup, butt joints were located at 6-in. intervals in each successive layer. As such, starting from the bottom, layer 1, there was a joint at 0 (no joint), layer two 6-in., layer three 12-in. etc. (Figure 1). Figure 1 is not to scale. Once the staggered joint end of the panel, the pattern was repeated. In this manner, during subsequent testing, the structural design values for the engineered composite, with staggered butt joints could be investigated.

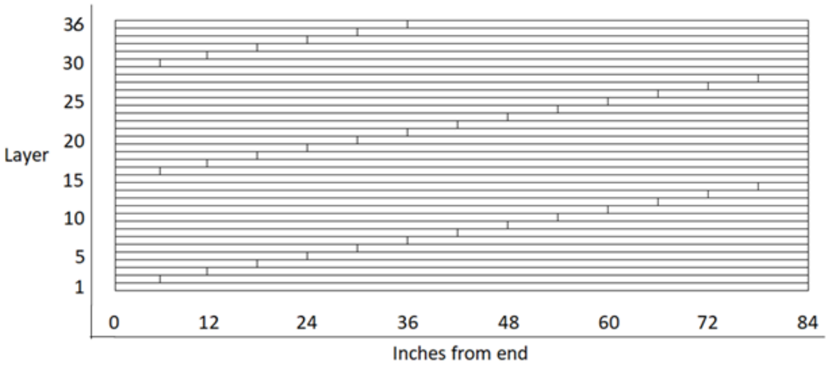

Figure 1: Not-to-scale schematic of the staggered butt-joint layup pattern in each 84-inch-long billet.

Once layed up, each billet was hot pressed. Hot press conditions were 30-seconds to closure and then hold at 200 psi until the center most glue-line reached 267 F. This center glue-line temperature was sought to cure the adhesive throughout the billet. Two billets were pressed, side by side, between the 54 by 102-inch press platens. Platen temperature was maintained at 365 to 370 F during pressing. Actual centreline glue temperature was read throughout by virtue of a thermocouple inserted into the billet during layup. Press times ranged from approximately 3 hr 23 min to 3 hr 46 min. Once the target temperature was reached, pressure was released over a 20-second period and then the press was opened. Next, the two billets were removed and cooled. Once cooled, each billet was edge trimmed. Once edge-trimmed, each billet was ripped into five test specimens. Each test specimen was approximately 3.6 x 4 inches in cross section (Figure 2).

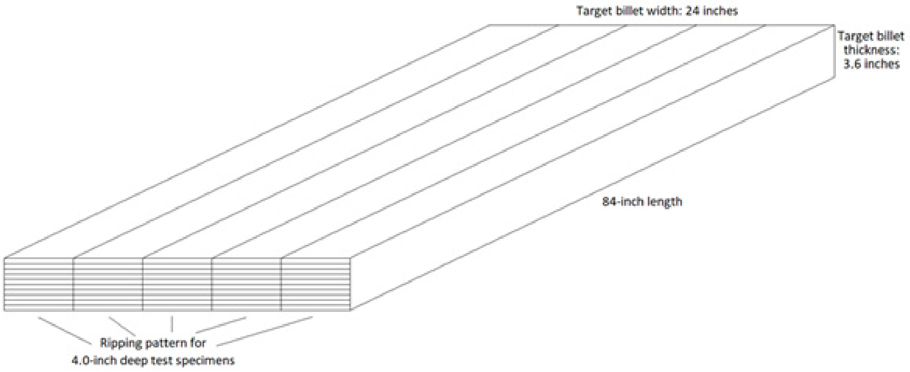

Figure 2: Ripping pattern that yielded 5-edgewise bending test specimens from each 3.6 x 24 x 84 in. billet.

Final billet thickness was approximately 3.6 inches. Because six billets were produced and each billet yielded 5-test specimens, a total of 28-test specimens were developed. In this manner, both parametric and non-parametric bending design values (Fa and MOE) could be computed.

Mechanical testing of LVL

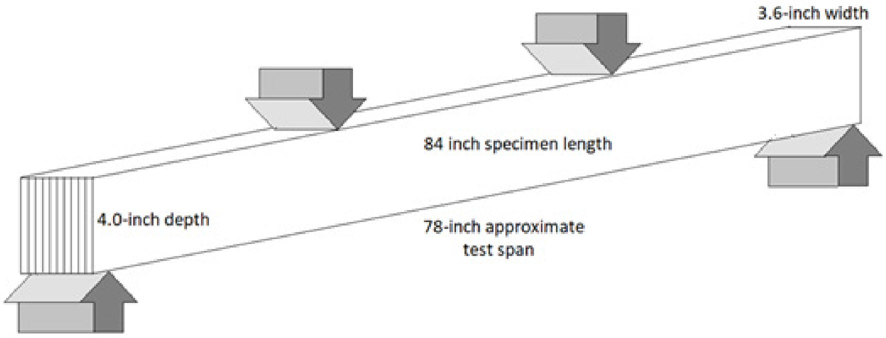

Figure 3: Schematic of test configuration.

Testing was conducted per a modified version of ASDM D5456 [12]. The modification was that 28 specimens were used to compute the non-parametric design values. Specimens were tested edgewise over a 78-inch span in third point bending (Figure 3). Loads were applied at 26-inches from each end and 26-inches apart. Test-specimen depths were approximately 4.0 inches. Thus, the approximate span to depth ratio was approximately 20:1. Test specimen widths were equal to the billet thickness, approximately 3.6 inches. Actual width and thickness for each specimen was measured at the time of testing. The rate of loading was adjusted in attempt to reach an approximate time to failure of 2 minutes, consistent with ASTM D4761 [12].

Physical properties of tested LVL

Following testing, moisture content and specific gravity sections were crosscut from one end of each test specimen. To that end, approximately 10 inches was crosscut and removed from the end of each test specimen. Then an approximately 1.5-inch-long section was crosscut. The sections were weighed and dimensionally measured. From the measurements, specific gravity based on volume at the time of testing and oven dry mass was calculated. Moisture content was calculated as per ASTM D4442 [13,14].

Parametric and non-parametric of design value

By obtaining the average values of modulus of rupture (MOR) from bending tests, the parametric 5th percentile was calculated using the mean (μ) and standard deviation (σ) of MOR, with a K-value of 1.88 (ASTM D2915 [7]):

$$5^{th}\ \text{percentile} = \mu - \text{K-value} \times \sigma \qquad (1)$$

Subsequently, a parametric F_a value (F_a, para) was determined by dividing the fifth percentile by a combined uncertainty and 10-year load duration factor (2.1) based on Practice D245:

$$F_{a\ para} = 5^{th}\ \text{percentile} / 2.1 \qquad (2)$$

Additionally, the non-parametric F_a value (Fa, nonpar) was calculated from the lowest MOR value (MOR _min, first order statistic and adjusted by the same combined safety and load duration factor:

$$F_{a\ nonpar} = MOR_{min} / 2.1 \qquad (3)$$

Where MOR min equals the appropriate order statistic.

Results and Discussion

To visualize the cumulative distribution of values across the dataset of modulus of elasticity (MOE) and modulus of rupture (MOR) for the LVL is presented: Figure 4. The data in Figures 4a & 4b follow a consistent trend, increasing from minimum to maximum values. This uniform trend for both MOE and MOR indicates a similar distribution pattern across the dataset in LVL.

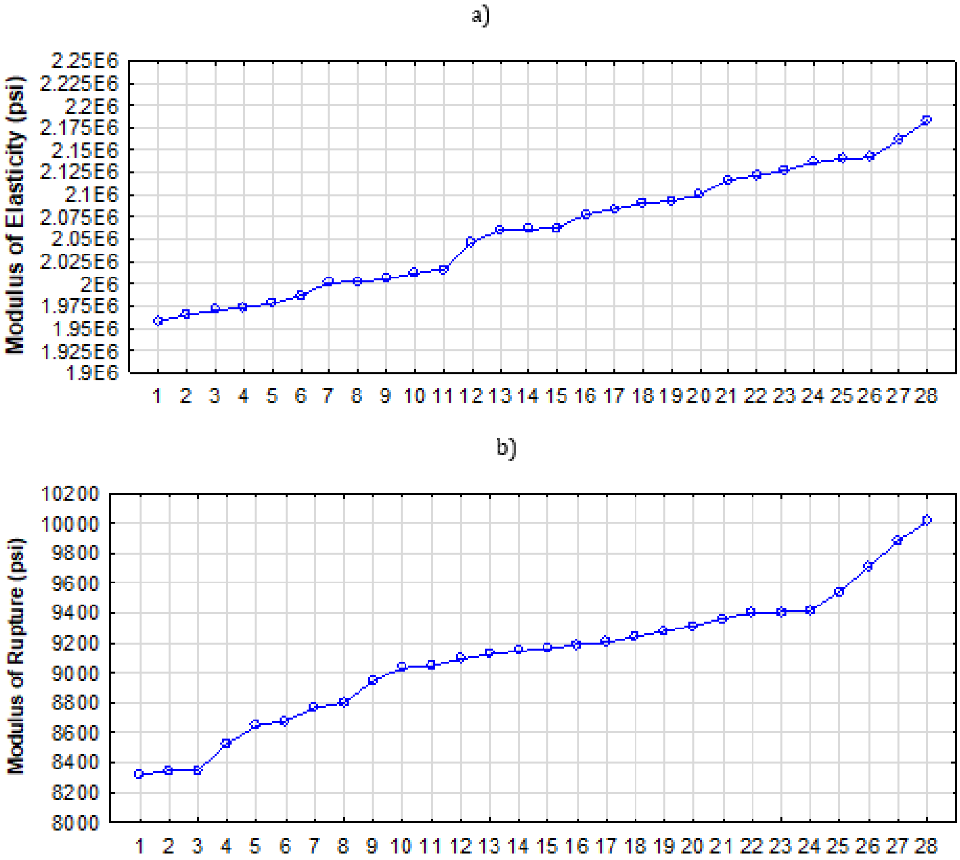

Figure 4: Cumulative frequency of a) modulus of rupture and b) modulus of elasticity.

The plot of MOR vs MOE is shown in Figure 5. The data in Figure 5 illustrate how MOE and MOR are correlated. The result of R^2, 0.340 a moderate relationship between MOE and MOR. Approximately 34% of the variability in MOR can be explained by the variability in MOE. While there is a relationship between MOE and MOR, 66% of the variability in MOR is not explained by MOE. This suggests that other factors might also significantly influence MOR. In practical terms, while MOE is a useful predictor of MOR, it is not the only factor. This moderate R^2 suggests that while there is a connection, it may not be strong enough to rely on MOE alone for predicting MOR with high accuracy. Likely this moderate correlation would be increased if veneer were sorted by acoustic velocity, dynamic MOE, or some other factor prior to lay up.

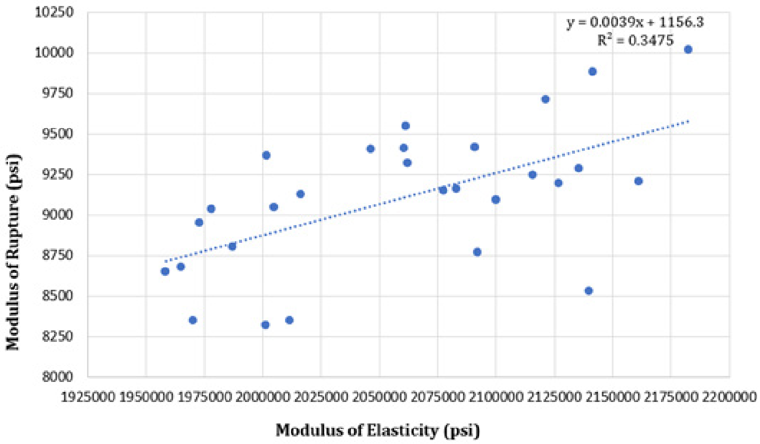

Figure 5: Regression analysis between modulus of rupture and modulus of elasticity.

Summary statistics for bending strength, (MOR), and stiffness (MOE) were calculated (Table 1). The average values of MOE and MOR for 28 specimens were 2,060,000 psi and 9106 psi, respectively. To determine the potential allowable design properties of the LVL, the parametric and non-parametric 5% tolerance limits were calculated. This is a statistical measure indicating that 95% of the material samples will have a strength at or above 8281 psi, with 75% confidence. When the parametric (8281 psi) and non-parametric (8315 psi) 5% tolerance limits are nearly identical, it means that both analytical methods agree which suggests that the distribution is not likely skewed. The

parametric and non-parametric F_a values were similar, 3943 psi and 3960 psi (Table 1). The approximate similarity between parametric and non-parametric design values Fa suggests that the data is not skewed.

Table 1: Mechanical properties of 36-ply sweetgum-based LVL made from grade D and better veneer.

	Strength (MOR)	Stiffness (MOE)
Number	28	28
Average (psi)	9106	2,060,000
Median (psi)	9154	2,061,919
Maximum (psi)	10,014	2,180,000
Minimum (psi)	8,315	1,960,000
Standard deviation (psi)	439	67,000
Coefficient of variation (%)	4.82	3.25
Parametric 5% tolerance limit (95% content, 75% confidence)	8281	Not applicable
Non-parametric 5% tolerance limit (95% content, 75% confidence)	8315	
F_a parametric (psi)	3943	
F_a nonparametric (psi)	3960	

Moisture content and specific gravity values of 28 LVL specimens are shown in Table 2. The average specific gravity was 0.651. The average moisture content was 2%. Initially, the moisture content of the veneer was approximately 6%, indicating that hot pressing during production reduced the moisture content of the LVL to 4%. Further optimization of the hot-press parameters, such as reducing cure temperature and minimizing press time would better moisture content of LVL.

Table 2: Physical properties of LVL.

	Moisture Content %	Specific Gravity
Number	28	28
Average	2.0	0.651
Median	2.0	0.650
Minimum	1.6	0.631
Maximum	2.5	0.674
Standard deviation	0.23	0.012
Coefficient of variation		

Table 3 demonstrates that LVL exhibits the highest design value (F_a) among all the matting materials listed, signifying its superior resistance to bending forces. The 5.5-in. Deep Glued Mixed Hardwood Billets, with the second-highest F_a value, demonstrate significant strength; however, the LVL's F_a value remains superior, offering even better bending resistance. Additionally, Sweetgum LVL's design value is more than three times higher than that of the 3-ply cross laminated bamboo composite, Number 2 Grade southern pine 3-ply CLT, and 3-ply waffle type matting from southern oak. This superior bending resistance of LVL provides significant advantages in terms of durability and structural integrity compared to other mating materials. In contrast, the 3-ply bolt-laminated pine represents the lowest F_a value among all products, being approximately 83% lower than the LVL value.

Table 3: Reported design values for various matting materials.

Material	Source	Depth (in.)	Fa (psi)	MOE (psi x 10^6)
36-ply sweetgum LVL	Reported herein	4.0	3943	2.06
Number 2 grade, southern pine, 3-ply CLT	Spinelli Correa et al. [15]	4.5	1354	1.18
3-ply cross laminated bamboo composite	Shmulsky et al. [16]	2.6	1174	0.28
3-ply, solid, southern oak	Snow [17]	4.5	2208	0.23
3-ply, waffle, southern oak		4.5	1387	0.18
3-ply, solid, Midwest hardwoods (oak, hickory, pecan, beech, ash, honeylocust, & sycamore)		4.5	1758	0.19
3-ply, waffle, Midwest hardwoods (oak, hickory, pecan, beech, ash, honeylocust, & sycamore)		4.5	1418	0.17
3-ply, bolt laminated pine	Khademibami et al. [18]	4.5	659	0.17
8-in. deep oak timber	Shmulsky et al. [19]	8	2415	1.43
8-in. deep mixed hardwood timber	Owens et al. [20]	8	2319	1.11
12-in. deep oak timber	Shmulsky et al. [19]	12	2200	1.33
5.5-in. deep glued mixed hardwood billets	Shmulsky & Shi [21].	5.5	3075	1.55

Conclusion

This study aimed to produce and test LVL made of grade D or better to measure the design value F_a and MOE under bending tests. The LVL was successfully produced, and the F_a value, both non-parametric and parametric, as well as MOE was calculated and compared with other matting materials. The main conclusion is as follows:

A. The F_a value, parametric and non-parametric, of LVL specimens obtained roughly the same, indicates that the MOR distribution of this material is not likely skewed.

B. The F_a values of LVL showed the highest values compared to a series of other matting products.

This exceptional strength makes LVL highly suitable for structural applications requiring high performance, such as temporary matting bridges, load-bearing structures, and other high-stress environments.

Future research could focus on the long-term durability of sweetgum LVL under various environmental conditions. Investigating innovative applications of LVL in modular building systems and large-scale temporary structures, assessing the environmental impact of its production and use and exploring reinforcing techniques to increase its load-bearing capacity and resilience are also promising areas for further study.

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References

1. Schniewind AP (1989) Wood & wood-based materials. Pergamon Press, Oxford.
2. Guo F, Altaner CM (2018) Properties of rotary peeled veneer and laminated veneer lumber (LVL) from New Zealand grown Eucalyptus globoidea. New Zealand Journal of Forestry Science 48(3): 1-10.
3. Kong I (2021) Wood-Based phenolic composites. In: Jawaid M, Asim M (Eds.), Phenolic Polymers Based Composite Materials, Composites Science and Technology. Springer, Singapore, pp. 39-64.
4. Shukla SR, Kamdem DP (2008) Properties of laminated veneer lumber (LVL) made with low density hardwood species: effect of the pressure duration. European Journal of wood and wood products 66(2): 119-127.
5. Koch P (1973) Structural lumber laminated from 1/4-inch rotary-peeled Southern Pine veneer. Forest Product Journal 23(7): 17-25.
6. Bodig J, Jayne BA (1982) Mechanics of wood and wood composites. Van Nostrand Reinhold Co, New York, USA.
7. ASTM D2915 (2010) Standard practice for evaluating allowable properties for grades of structural lumber. ASTM International West Conshohocken, Pennsylvania, USA.
8. Brashaw BK, Ross RJ (2020) Ultrasonic grading of hardwood veneer. Chapter In: Ross RJ, Erickson JR (Eds.), Undervalued hardwoods for engineered materials and components: second edition. General Technical Report FPL-GTR-276. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA, p. 108.
9. Wang X, Ross RJ, Brashaw BK, Verhey SA, Forsman JW, et al. (2020) Properties of hardwood laminated veneer lumber. Chapter In: Ross RJ, Erickson JR (Eds.), Undervalued hardwoods for engineered materials and components: second edition. General Technical Report FPL-GTR-276. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA, p. 108.
10. Spinelli Correa LM, Shmulsky R, Ross RJ (2024) Proceedings, structural and engineered hardwood materials and applications workshop. General Technical Report FPL-GTR-301. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA, p. 64.
11. National Institute OF Standards and Technology (2019) Voluntary wood products PS 1-19: structural plywood. Department of Commerce, USA.
12. ASTM D5456–21 (2021) Standard specification for evaluation of structural composite lumber products. American Society for Testing and Materials, West Conshohocken.
13. ASTM International, Subcommittee, A.S.T.M. & ASTM Committee D07 on Wood (2013) Standard test methods for mechanical properties of lumber and wood-base structural material. ASTM International.
14. ASTM D4442-20 (2020) Test methods for direct moisture content measurement of wood and wood-based materials. ASTM International.
15. Correa LS, Shmulsky R, França FJN (2023) Case study of 3-ply commercial southern pine CLT mechanical properties and design values. Wood and Fiber Science 55(1): 94-99.
16. Shmulsky R, Correa LMS, Quin F (2021) Strength and stiffness of 3-Ply industrial bamboo matting. Bio Resources 16(3): 6392-6400.
17. Snow RD (2022) Wood properties and utilization of assorted hardwoods. Mississippi State University ProQuest Dissertations and Theses, pp. 1-58.
18. Khademibami L, Ward KB, Seale RD, Shmulsky R, Ratcliff JT (2023) Flexural properties of three-ply bolt-laminated pine mats. Forest Products Journal 73(2): 171-174.
19. Shmulsky R, Lopes DV, Rodrigues BP, Bobadilha GDS (2021) Strength and stiffness of 8-inch and 12-inch deep mixed oak bolt-laminated timber mats. BioResources 16(2): 3298-3303.
20. Owens FC, Seale RD, Shmulsky R (2020) Strength and stiffness of 8-inch deep mixed hardwood composite timber mats. BioResources 15(2): 2495-2500.
21. Shmulsky R, Shi S (2008) Development of novel industrial laminated planks from sweetgum lumber. Journal of Bridge Engineering 13(1): 64-66.