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Advancing Timber for the Future Built Environment

STRUCTURAL PROPERTIES OF LUMBER FROM SMALL LOGS GENERATED IN FOREST THINNING OPERATIONS

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ABSTRACT: Restoration forest thinning is an important strategy for mitigating risks of catastrophic wildfires in forestlands of the Western US. This process is costly and yields significant volumes of younger, smaller trees containing substantial proportions of juvenile wood. Currently, most sawmills consider processing small diameter logs unprofitable and large proportions of the resulting lumber less qualified for structural uses than lumber from commercial harvests. Utilization of lumber from small diameter logs in mass timber products would add market value to this material. However, a recent study, based on elastic moduli measured on a limited sample suggested that the lumber from small diameter logs may not meet the National Design Specifications (NDS) benchmarks for the corresponding visual grades. The objective of this project is to verify the outcomes of that study with elastic and strength properties measured on a representative sample and compare with reference NDS design values for the same size, grade, and species. The procedures follow standard test methods for mechanical properties of structural lumber as well as small clear specimens. The resulting properties will be used to obtain estimates of design values compatible with NDS. If the obtained values fail to meet the benchmarks, they will be proposed as design values for lumber obtained from restoration thinnings targeting small logs.

KEYWORDS: restoration thinning, juvenile wood, small diameter logs, design values, lumber grading

1 – INTRODUCTION

Effectively controlling the spread of wildfires in the dry, densely overgrown, fuel-charged forests in large regions of the western US is a challenging task. One commonly employed strategy is known as selective restoration thinning. This process is costly and yields a high percentage of younger, smaller diameter trees, often from low value species. The US Forest service is seeking value-added uses for this material. Utilization of lumber from small diameter logs in structural applications, including cross laminated timber (CLT) panels, is commonly expected to add market value to the material generated as a byproduct of the thinning operations.

There is an especially close intersection between the growing range of ponderosa pine and regions which are considered high risk for wildfires, requiring major thinning operations (Figure 1). Therefore, increasing the market value associated with this species is of particular interest.

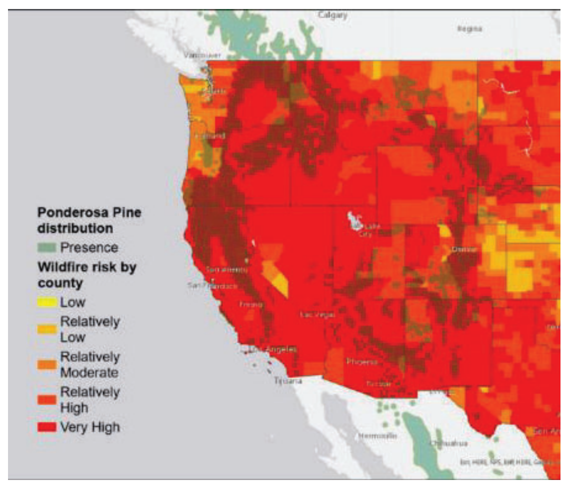

Figure 1. Overlap between ponderosa pine growing range and wildfire risk regions [1]

While in principle small logs can be processed with viable profit margins into thin and narrow lumber, most North American sawmills targeting the domestic dimension

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lumber market compliant with *National Design Specification for Wood Construction (NDS) [2]* , consider processing small logs unprofitable and the resulting lumber less qualified for structural uses.

The National Design Specifications (NDS) standard contains mechanical property requirements for lumber to be usd in structural applications. Reference design values for visually graded dimension lumber (between 2 and 4 inches, or 50 to 100 mm in nominal thickness) , are listed in the NDS supplement. These benchmark values, which consist of 5th percentile limits (for strength properties) and mean values (for elastic modulus), are categorized per lumber cross section sizes, grades, and species. Ponderosa pine is included within the *Western Woods* species category in the NDS table of design values (Figure 2) . This implies that visually graded dimension lumber sawn from ponderosa pine may be used in structural applications.

The North American Standard for Performance Rated Cross Laminated Timber (PRG 320, [3]) specifying criteria for raw materials for CLT products requires that laminations used for CLT fabrication must be produced from lumber for which design values are *published in the National Design Specification for Wood Construction (NDS)*.

Species and commercial grade	Size classification	Design Values (psi)			
		Bending F_b	Tension parallel to grain F_t	Modulus of Elasticity E	E_{min}
WESTERN WOODS					
Select Structural	2" & wider	900	400	1,200,000	440,000
No. 1		675	300	1,100,000	400,000
No. 2		675	300	1,000,000	370,000
No. 3		375	175	900,000	330,000
Stud	2" & wider	525	225	900,000	330,000
Construction	2" - 4" wide	775	350	1,000,000	370,000
Standard		425	200	900,000	330,000
Utility		200	100	800,000	290,000

Figure 2. Example section of NDS [2]

In a prior study by Jahedi et al. [4], focused on utilization of lumber from small diameter ponderosa pine logs generated through restoration thinning operations in CLT [4] dynamic modulus measured on a relatively small sample of visually graded dimension ponderosa pine lumber was compared with the corresponding elastic modulus values listed in NDS for Western Woods. The results of this testing indicated that the visually graded #2 lumber did not meet the corresponding NDS benchmarks (Figure 3).

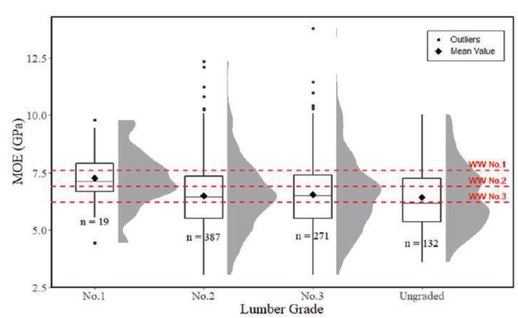

Figure 3. Experimental dynamic modulus of elasticity (MOE) values compared with NDS requirements [4]

The authors suggested that the observed difference was “likely a result of the presence of higher proportion of juvenile wood in the restoration program material compared with lumber generated in commercial harvesting” [4] . Juvenile wood is found near the center (pith) of the tree and generally located within the first 10-20 growth rings (Figure 4).

The juvenile wood zone can be described as "the zone of rapid wood property change prior to greater uniformity in the mature wood nearer the bark" [5] Juvenile wood differs from mature wood in terms of multiple key properties (Figure 4). Such properties include wood specific gravity as well as mechanical strength and stiffness [6] .

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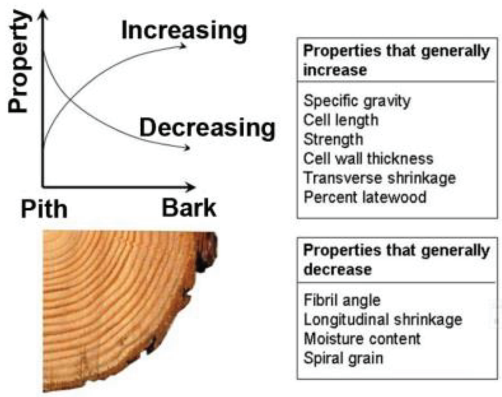

Figure 4. General trends in wood property variation from pith to bark [6]

The current NDS values as well as correlations between properties measured on small clear specimens and bending and tensile properties of dimension lumber were derived from lumber sawn from logs harvested in commercial operations, where small logs constituted a small portion of the total harvest. Therefore the NDS design values may not accurately represent the mechanical performance of lumber from selective restoration thinning operations targeting predominantly small diameter logs as this requires accounting for higher proportions of juvenile wood.

Since the earlier study was limited in scope and the conclusions were based only on the dynamic modulus, additional data is necessary to verify these observations.

The objective of the current study is to evaluate the mechanical performance of lumber from small diameter ponderosa pine logs representing the parts of the growing regions where restoration thinning occurs and including all mechanical properties listed in NDS, in order to either confirm or disprove the conclusion from the prior study.

2 – MATERIALS & METHODS

2.1 SCOPE

Tests are performed on visually graded dimension lumber (2x4 and 2x6; Grades No. 2 and No. 3) and on small clear specimens. Standard tests methods outlined in ASTM D198 [7] and D4761 [8] (full-size) along with D143 [9] (small clear), are supplemented with alternative methods to enable more meaningful correlations between properties (Figure 5). Particularly, the longitudinal and rolling shear will be tested on dimension lumber specimens to verify practice used in the CLT design by shear analogy method [10] . Note that L indicates full sized lumber, while SC stands for small clear specimens.

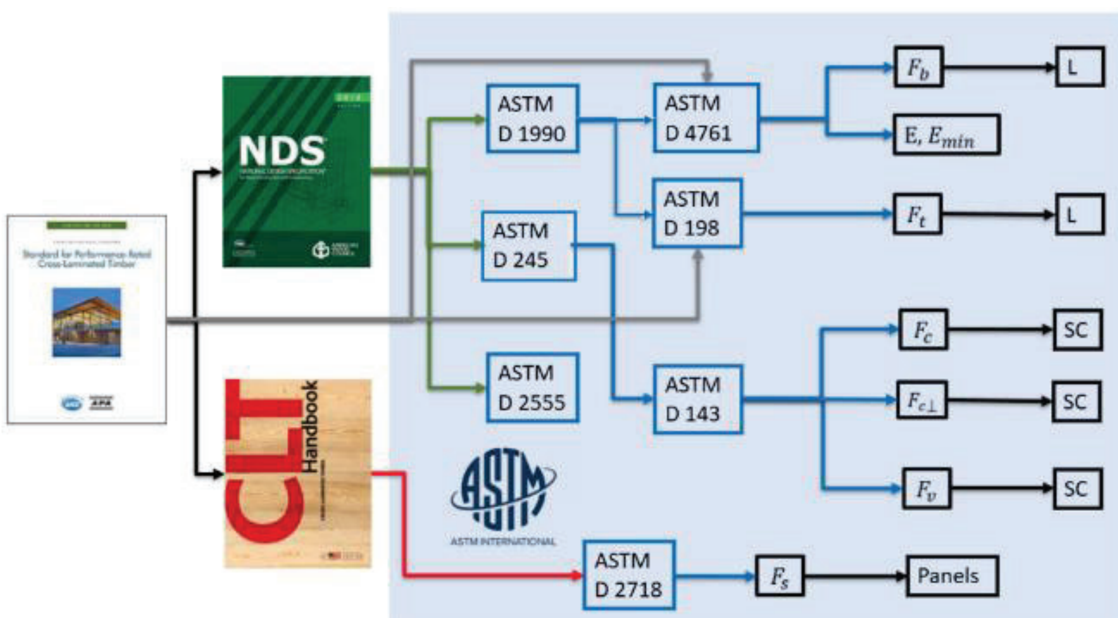

Figure 5. Diagram of references between relevant standards used to select test procedures for each mechanical property [11]

2.2 MATERIALS

Provenience

The sampling scheme is shown in Figure 6. This sampling plan has been designed with the objective of obtaining a sample that adequately represents the Ponderosa Pine growing range within the western US. The specific regions included were chosen as advised by consultants from the Pacific Lumber Inspection Bureau (PLIB) as well as Forest Products Laboratory (FPL).

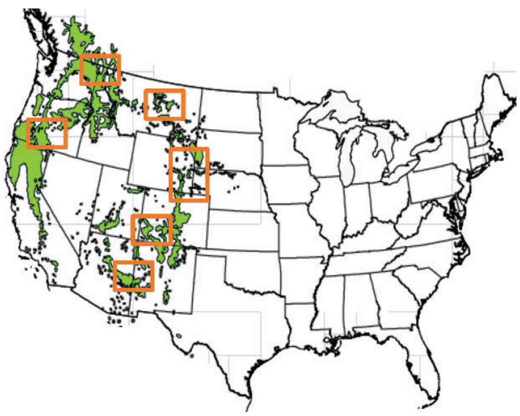

Figure 6. Areas marked in orange correspond to targeted sampling regions (label states). The Ponderosa Pine growing range is marked in green [12]

Test cells

Table 1 shows the specific test cells (size/grade combinations) selected for this study along with the number of pieces of lumber (n) per cell (and per test). Note that n must be multiplied by the number of test cells (4) then by the number of types of tests on full-sized lumber (2) followed by the number of sampling locations (6) to determine the total amount of dimension lumber required. In addition, multiple types of tests will be performed on small clear specimens taken from the full-sized lumber that has been tested in either bending or tension. The lumber units obtained from each site will be divided between bending and tensile tests according to a randomization procedure conducted using Excel.

Table 1. Structure of test cells

Sizes		Grades	
mm	(in)	#2	#3
51x102	(2x4)	n=40	n=40
51x152	(2x6)	n=40	n=40

Selection criteria

Obtaining lumber sawn exclusively from small diameter Ponderosa Pine logs has proven to be a challenge. An alternative approach used in this study is to select lumber which either contains the pith or is estimated to be sawn from within a certain radius from the pith (the equivalent of a small diameter log). This selection is performed based on the lumber cross sections as follows:

Step 1: Identify cross sections which contain the pith (partially or completely)

Step 2: Use the circle template as shown in Figure 7 to identify cross sections which have 75% or more rings that fit within the curve of the circle (outer = 8 in diameter, inner = 5 in diameter)

Figure 7. Circle template used to select lumber based on ring curvature in the cross sections [11]

Regrading

Lumber units with grades assigned at the mill were regraded by PLIB grading expert, who marked grade limiting defects as shown in Figure 8. In addition, 2x4 lumber regraded as #2 (roughly an amount equivalent to a sampling cell) was scanned by Microtec to obtain additional data that can be correlated with the visual grades as well as mechanical test results.

Figure 8. Examples of grade limiting defects [11]

Specimen fabrication

Small clear specimens were fabricated to the specifications indicated in Table 2, from sound sections harvested from dimension lumber pieces after destructive bending tests and appear as shown in Figure 9.

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Table 2. Dimensions of small clear specimens

Test type	Dimensions [mm (in)]
Static bending	25.4 x 25.4 x 406 (1 x 1 x 16)
Shear block	50.8 x 50.8 x 63.5 (2 x 2 x 2.5)
Compression perpendicular to grain (standard method)	50.8 x 50.8 x 152 (2 x 2 x 6)
Compression perpendicular to grain (modified method)	50.8 x 50.8 x 50.8 (2 x 2 x 2)
Compression parallel to grain	25.4 x 25.4 x 102 (1 x 1 x 4)

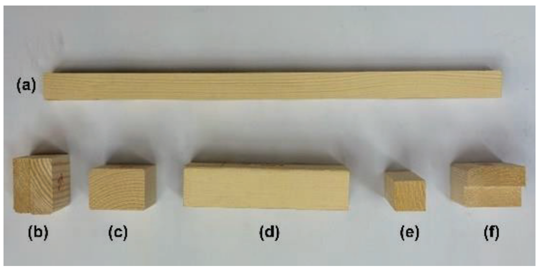

Figure 9. Small clear specimens from top view: (a) static bending; (b) block shear; (c) compression perpendicular (standard); (d) compression perpendicular (modified); (e) compression parallel; (f) block shear (rotated) [13]

3 – EXPERIMENTAL SETUP

3.1 DIMENSION LUMBER

Dynamic Modulus

The dynamic modulus of elasticity (based on vibration frequency) is measured using the Metriguard set-up shown in Figure 10. This non-destructive method is conducted prior to the destructive testing described in the following sections.

Bending

The procedures followed Section 6 of ASTM D4761 ("Bending Edge-Wise – Third-Point Loading") [8] . An MTS (Materials Test Systems) experimental set-up is used for these tests. Figure 11 shows the loading configuration for the third-point bending test. The deflection is measured using a yoke (Figure 12) with an LVDT (Linear Variable Differential Transformer) attached.

Figure 10. Metriguard set up for dynamic modulus measurement [11]

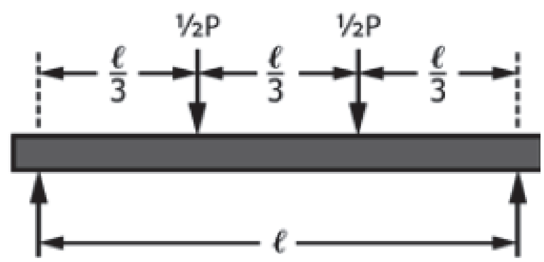

Figure 11. Third-point loading diagram [7]

Figure 12. Yoke for measuring deflection in third-point bending [11]

Tension

Procedures follow Sections 29-36 of ASTM D198 ("Tension Parallel to Grain") [7] . The basic experimental set-up is shown in Figure 13. A pressure gauge measures the force applied, while an extensometer will be used to measure the displacement.

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Figure 13. Tension test set-up (top) [14] and close view of example failure (bottom) [11]

3.2 SMALL CLEAR SPECIMENS

Procedures for small clear specimen tests are outlined in Sections 9, 12, and 14 of ASTM D143 ("compression parallel and perpendicular, and shear test") [9] . These tests are performed using the Instron. Figure 14 shows the experimental set up used for the shear test as well as the compression perpendicular to grain test.

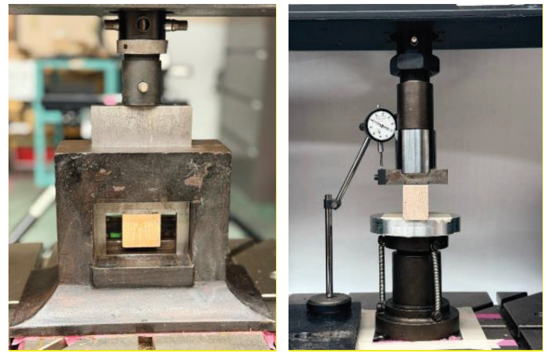

Figure 14. Experimental set up for block shear test (left) and compression perpendicular to grain test (right) [13]

3.3 MOISTURE CONTENT MEASUREMENT

Moisture content (MC) of the specimens is determined following ASTM D143 oven-dry procedures [9] . After mechanical testing, samples are oven-dried at 103 ± 2°C until a constant weight is achieved.

4 – RESULTS

4.1 ANALYSIS

Test data will be converted to NDS design values in accordance with procedures outlined in ASTM D1990 [15] and D245 [16] . These values will be statistically compared with the current benchmarks listed in NDS for Western Woods (for the sizes and grades tested).

Mechanical values were adjusted to a reference moisture content of 15%. This conversion is performed using formulas from ASTM D1990 (Appendix A1) [15] . Equation (1) is used for adjustment of elastic modulus (E) values, while Equations (2) and (3) are applied to modulus of rupture (MOR), ultimate tensile strength parallel to the grain (UTS) and ultimate compression strength parallel to the grain (UCS).

$$S_2 = S_1 \frac{(B_1 - (B_2 \times M_2))}{(B_1 - (B_2 \times M_1))} \tag{1}$$

For MOR, UTS, AND UCS values below a specified limit:

$$S_2 = S_1 \tag{2}$$

For MOR, UTS, AND UCS values above a specified limit:

$$S_2 = S_1 + \left(\frac{S_1 - B_1}{B_2 - M_1}\right)(M_1 - M_2) \tag{3}$$

In all equations, the variables are defined as follows:

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S_1 = property at moisture content 1 (psi)
S_2 = property at moisture content 2 (psi)
M_1 = moisture content 1 (%)
M_2 = moisture content 2 (%)
B_1 and B_2 = constants defined in ASTM D1990 table

4.2 PRELIMINARY RESULTS

Preliminary results to be presented at the conference will consist of mean and near-minimum (5th percentile) estimates for the following properties: elastic modulus, bending strength, tension strength parallel to grain, compression strength parallel and perpendicular to grain, and shear strength parallel to grain.

Figure 15 and Figure 16 show preliminary comparisons between data from the first bending test cell (2x4, #2) and the corresponding NDS values. Modulus of rupture (MOR) values have been plotted against elastic modulus (E) values to show a general correlation between strength and stiffness properties. As can be seen in the figure, most data points from this test cell are within the desired range in terms of MOR and E benchmarks for #2 lumber. Note that this is not a final comparison and will be followed with a more in-depth conversion from MOR to Fb values, along with a statistical comparison to NDS.

5 – CONCLUSION

Preliminary conclusions will be presented at the conference.

6 – ACKNOWLEGEMENT OF FUNDING

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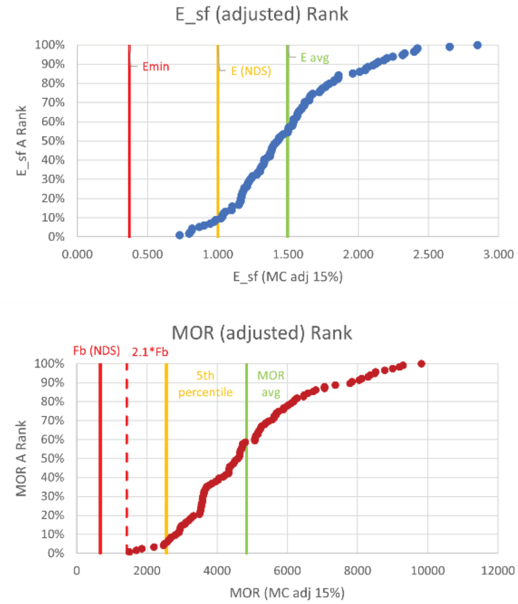

Figure 15. Graphs show relative ranking of shear-free elastic modulus (E_sf) values (top) and modulus of rupture (bottom) [11]

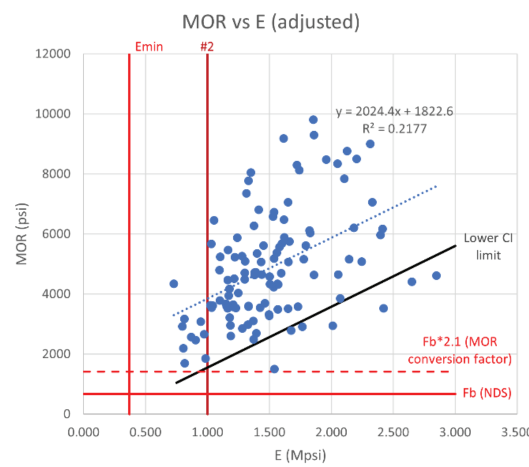

Figure 16. Visual comparison between experimental data and NDS values for first set of bending tests [11]

7 – REFERENCES

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