MTU Research on Northern Hardwoods CLT

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Michigan Technological University (MTU)

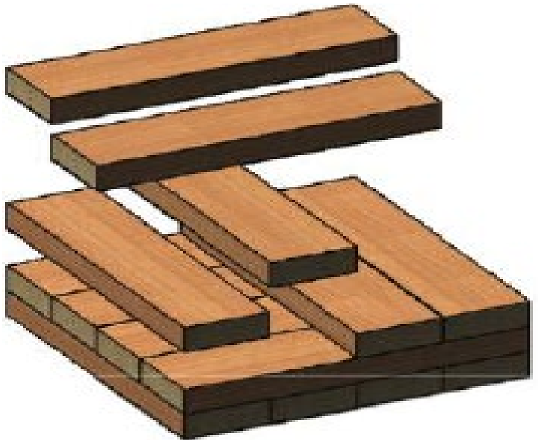
College of Forest Resources and Environmental Science (CFRES)

August, 2025

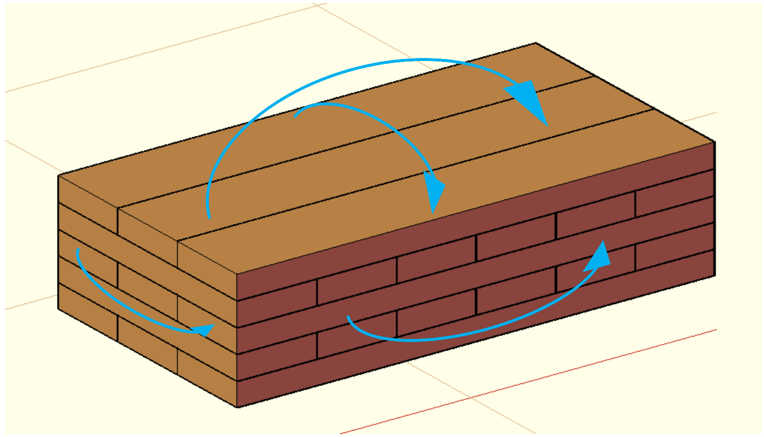
- People/The Team
  - CFRES: 1 research professor, 1 tenured associate professor, 1 tenure-track assistant professor, 1 professor of practice, 1 post doctoral scholar, 2 PhD students, 2 full-time research staff, and 1 adjunct professor
  - Department of Civil, Environmental, and Geospatial Engineering: 1 tenured professor, 1 tenure-track assistant professor
- Facilities
  - Pilot scale, from log processing to CLT panels
  - 6000 sqft building, lumber kiln, walk-in environmental rooms
  - Major equipment includes portable sawmill, 4-sided planer, CLT press (6ftx10ft or 3ftx20ft configuration), and structural finger jointing system

• Why are we working on this

- Low-grade hardwoods succeeded in engineered wood products.
- Losing pallet market; CLT provides high-value use.
- Incorporating hardwoods reduces cost, promotes acceptance of CLT.
- Hardwood species CLT standardization needed for market growth.
- Discuss the impact of layers with different species on the mechanical properties of CLT panel



Yin, X. (2018). "The Seismic Behavior of Cross-Laminated-Timber Composite Slab in High-Rise Building." International Journal of Engineering and Technology **10**(4).



- **Research Goal:** Expand engineering applications and market opportunities for low-grade and underutilized hardwoods.
- **Approach:** Advance the acceptance of hardwood CLT by identifying technical barriers and developing economically viable solutions through collaborations with the hardwood lumber industry, state governments, federal research institutes, federal funding agencies, universities, and business development organizations
- **Completed and on-going projects:**
  - Bonding properties of hardwoods in cross laminations
  - Exploration on the mechanical properties of hardwood CLT & hybrid CLT
  - Structural grading of hardwood lumber
  - Finger jointed structural hardwood lumber

- Collaborators/Sponsors
  - AJD Forest Products, Besse Forest Products Group, JM Longyear Northern Hardwoods, Lyme Great Lakes Timberlands,
  - Michigan Department of Agriculture & Rural Development, Michigan Department of Natural Resources, Wisconsin Department of Natural Resources
  - U.S. Department of Energy, U.S. Forest Service, Forest Products Laboratory
  - Innovate Marquette SmartZone, MTEC SmartZone, Great Lakes Kiln Drying Association
  - Mississippi State University and West Virginia University

Lumber grading and sorting

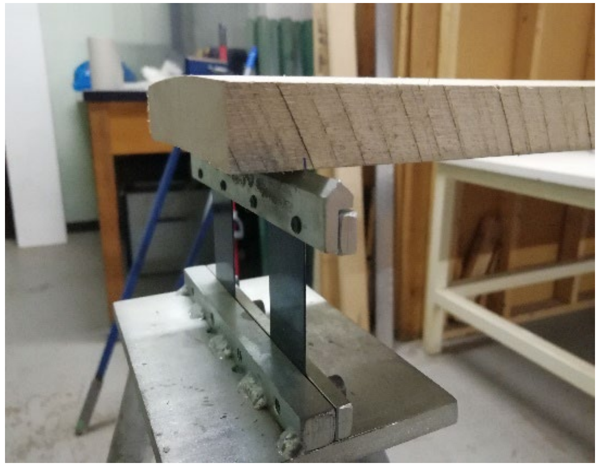
Visual inspection of common 3A lu

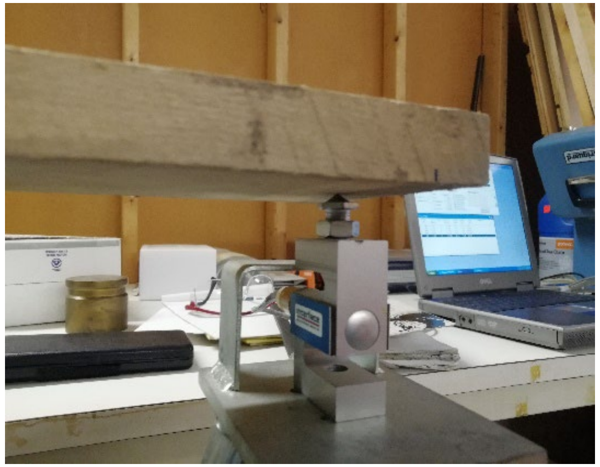
the Grade Rule Book

Sorting and Local defect measuring

Nondestructive MOE rating

- Nondestructive transverse vibration test (ASTM D6874)



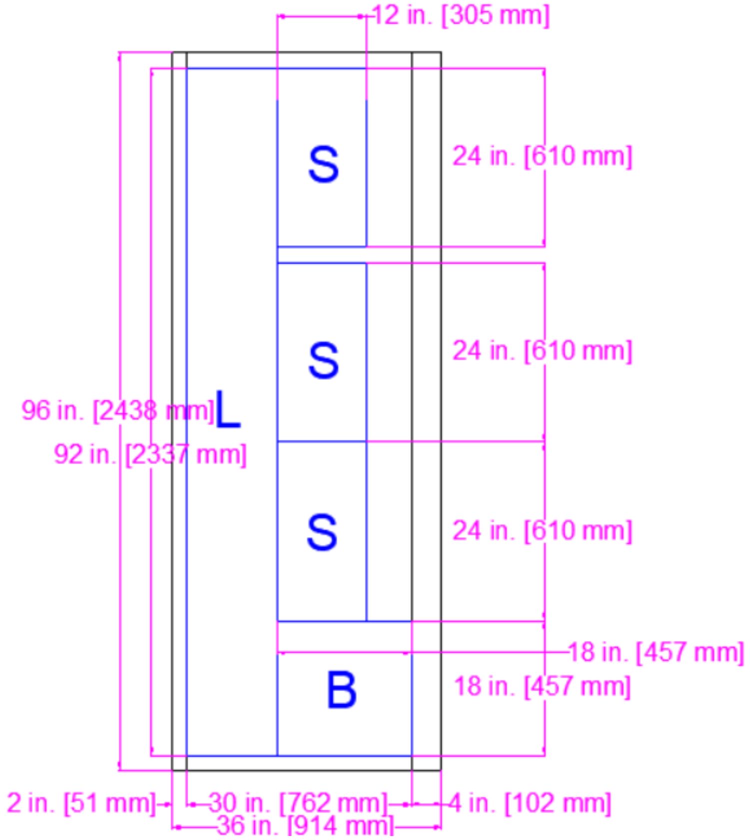


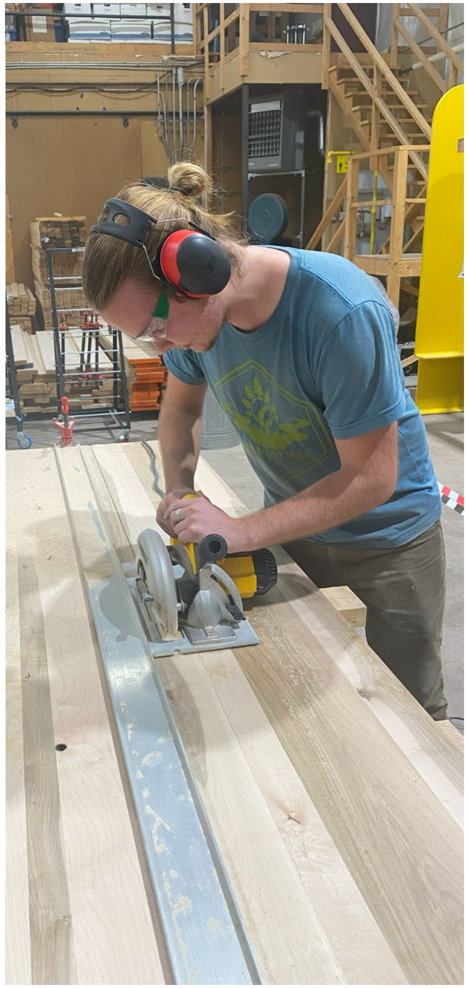
CLT manufacture

Three pressures: 0.86 MPa (125 psi), 1.03 MPa (150 psi) and 1.21 MPa (175 psi)

Sample Preparation

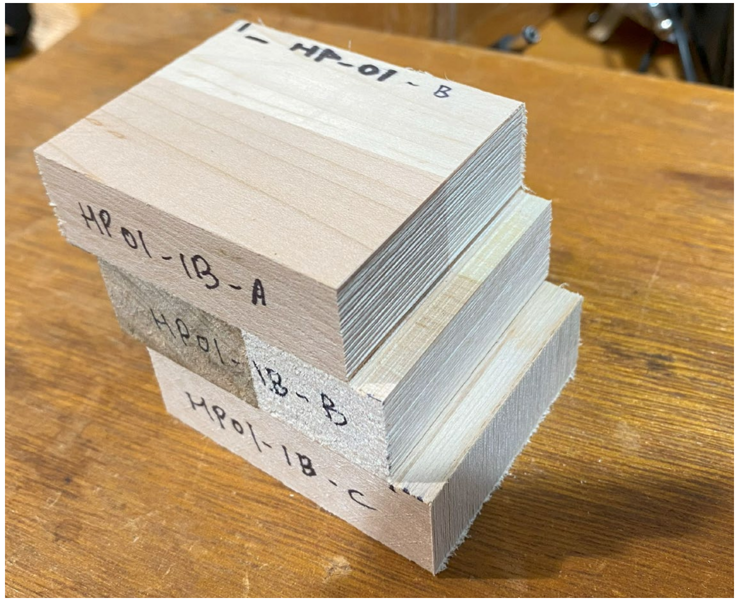
- Stored in condition room (80F, 75% RH) after pressing.
- 1 long span sample, 3 short span samples and 1 block test samples can be cut from each panel.

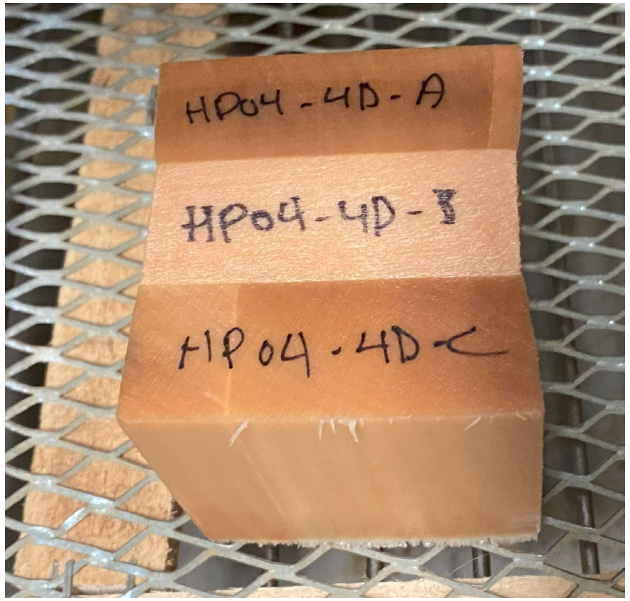


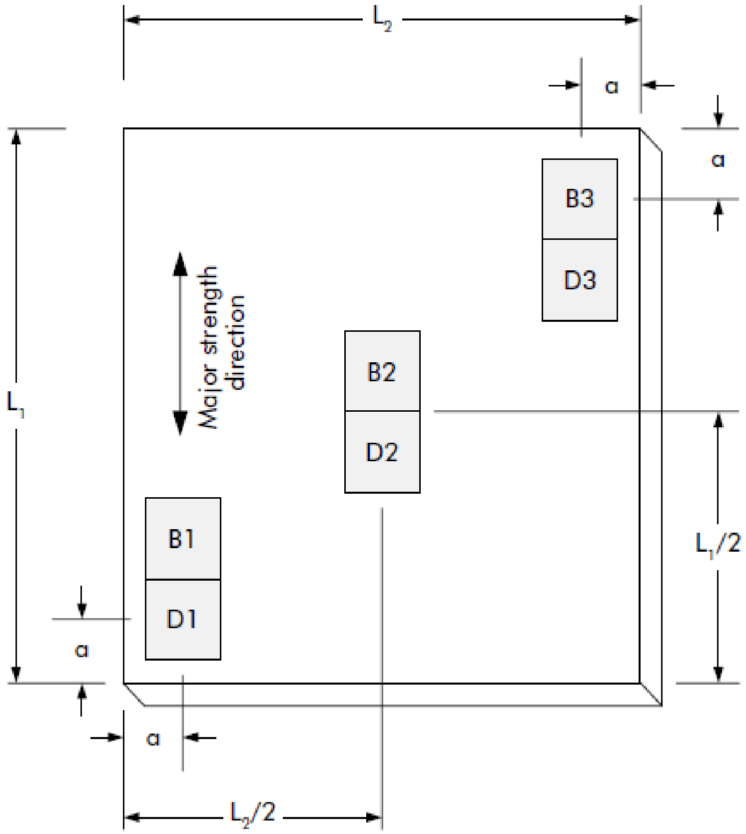


Block Shear and Delamination Test

- Sample based on PRG 320-2019
- Test based on ASTM D905 and AITC T110







Flexural test of CLT panels

- *P* is the peak load of the test, *a* is the distance between the center of the support to the nearest loading location, Δ_{max} is the maximum displacement of the beam during the test, l is the beam span, and *I* represents the moment of inertia of the CLT beam.

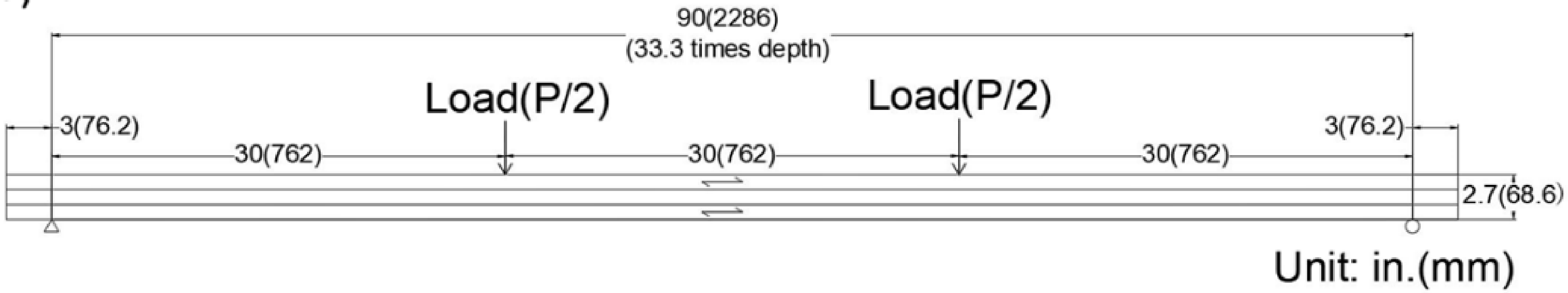
$$MOE_{CLT} = \frac{Pa}{2\Delta_{\max} I}\left(\frac{l^2}{8} - \frac{a^2}{6}\right)$$

- *M* is the mid-span moment of the beam ($M=P\times a/2$) and *y* is the distance from beam bottom to the neutral axis

$$MOR_{CLT-L} = \frac{My}{I}$$

(a)

(b)



Flexural test of CLT panels

- $EI_{app\text{-}test\text{-}S}$ is the apparent bending stiffness, which is calculated as the flexural stiffness of the short span sample considering no shear effective; K_s is the shear influence factor, which is 14.4 for pinned-ends three-point bending beams; EI_{eff} is the effective bending stiffness of the combination of all layers

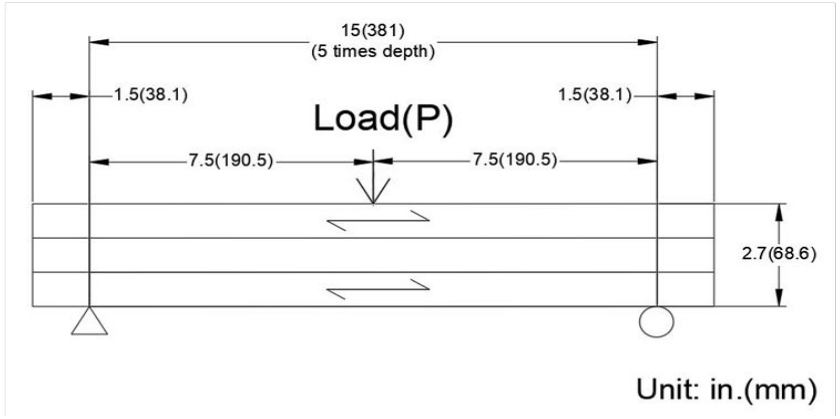
$$EI_{eff} = \sum_{i=1}^{n} E_i b_i h_i^3 / 12 + \sum_{i=1}^{n} E_i A_i z_i^2$$

$$GA_{eff-test-S} = \frac{K_s EI_{eff}}{\left(\frac{EI_{eff}}{EI_{app-test-S}} - 1\right) l^2}$$

$$G = GA_{eff-test-S} / A$$

(a)

(b)



Effects of wood species on bonding performance

Wood species:

Covered the 75% of the major hardwood species in lake states.

Common name (Scientific name)	Species code	Specific gravity	Pore distribution or early/latewood transition
Sugar maple (*Acer Saccharum*)	HM	0.63	Diffuse porous
Red oak (*Quercus rubra*)	RO	0.63	Ring porous
Yellow birch (*Betula alleghaniensis*)	YB	0.62	Diffuse porous
White ash (*Fraxinus americana*)	WA	0.60	Ring porous
Red maple (*Acer rubrum*)	RM	0.54	Diffuse porous
Quaking aspen (*Populus tremuloides*)	ASP	0.38	Diffuse porous
Basswood (*Tilia americana*)	BW	0.37	Diffuse porous
Red pine (*Pinus resinosa*)	RP	0.46	Abrupt early/latewood trans.
White pine (*Pinus strobus*)	WP	0.35	Gradual early/latewood trans.

Adhesives: melamine formaldehyde and phenol-resorcinol formaldehyde @ 7.5 lbs per 1000 sqf

Pressing parameters: 8 hrs under 130 psi @ 70F

Evaluations: ASTM D905 and AITC T110

Bonding performance cont.

Evaluation of the suitability of individual species for cross lamination

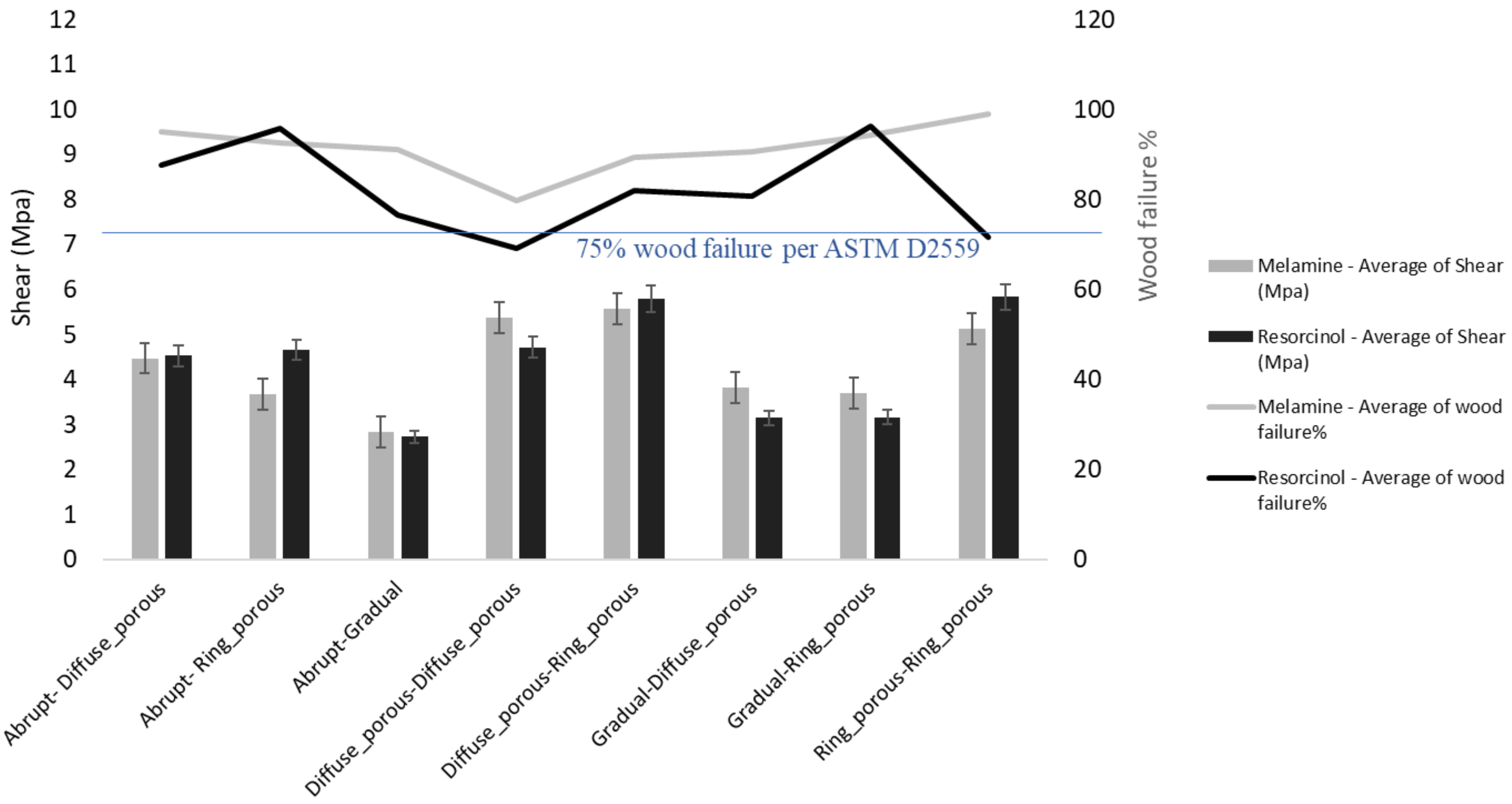
	ASTM D905		AITC T110		Remarks
	Melamine	Resorcinol	Melamine	Resorcinol	
HM	X	X	Y	Y	OK
RO	Y	Y	Y	X	Good
YB	X	X	X	X	Poor
WA	Y	Y	X	Y	Good
RM	X	Y	Y	Y	Good
ASP	Y	X	X	Y	OK
BW	Y	Y	Y	Y	Excellent
RP	Y	Y	Y	Y	Excellent
WP	Y	Y	X	Y	Good

X: failed; Y: pass

BW, (RP) > RO, WA, RM, (WP) > HM, ASP >>YB

High — **Suitability for Cross Lamination** — Low

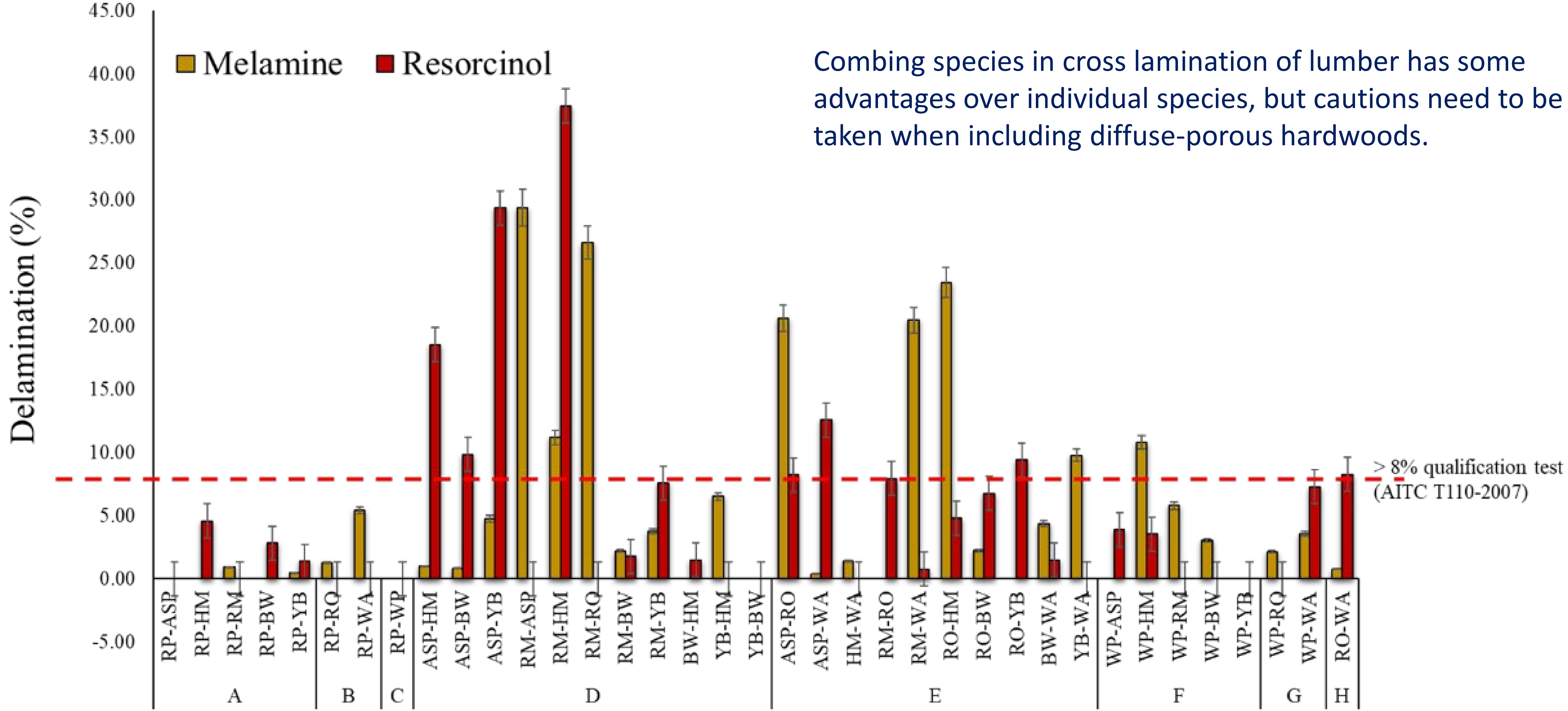
Bonding performance cont.



- Overall combination of species with different anatomical features help with bonding strength and percentage of wood failure
- Melamine based adhesive has higher wood failure rate than resorcinol-based adhesive
- Combinations of diffuse-porous hardwoods, diffuse-porous and ring-porous, and ring-porous have the highest bonding strength

Average bonding strength and percentage of wood failure of cross laminated mixed species (ASTM D905)

Bonding performance cont.



Combing species in cross lamination of lumber has some advantages over individual species, but cautions need to be taken when including diffuse-porous hardwoods.

A = Abrupt-Diffuse porous, B= Abrupt- Ring porous, C= Abrupt-gradual, D= Diffuse porous- Diffuse porous, E= Diffuse porous-ring porous, F= Gradual-Diffuse porous, G= Gradual-Ring porous and H= Ring porous- Ring porous cross laminations.

Cyclic delamination of cross laminated mixed species (AITC T110)

Mechanical Properties of Sugar Maple CLT.

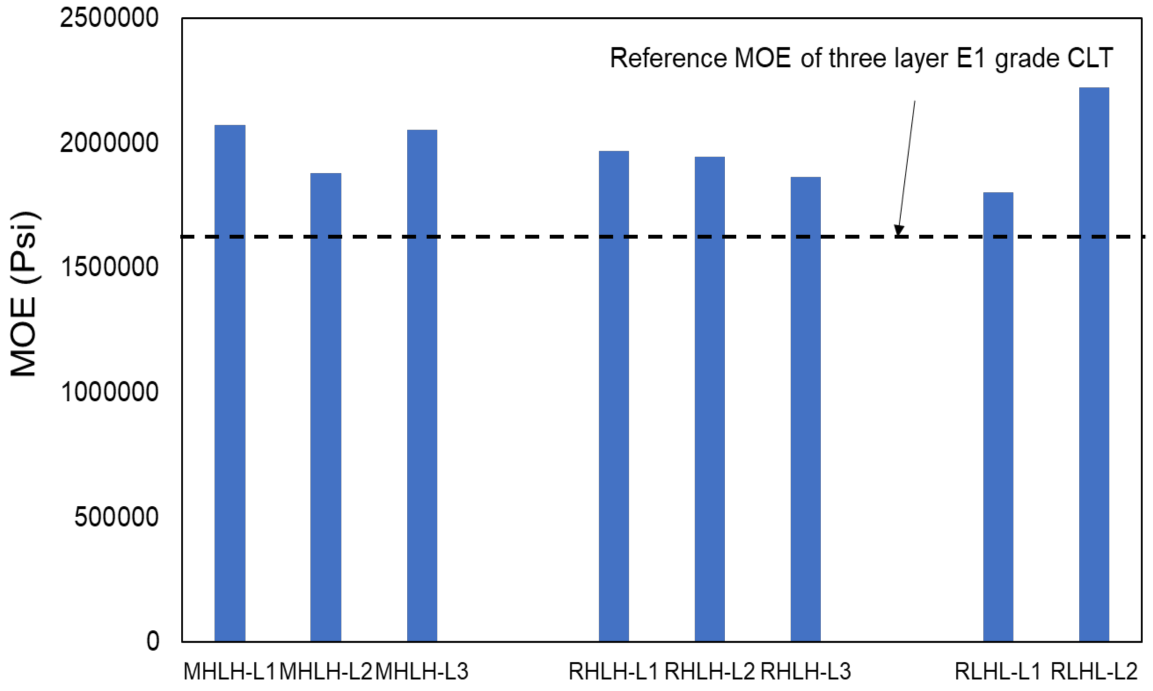
3-layer CLT panel types and the lamination MOE in each layer (unit: 10^6psi)

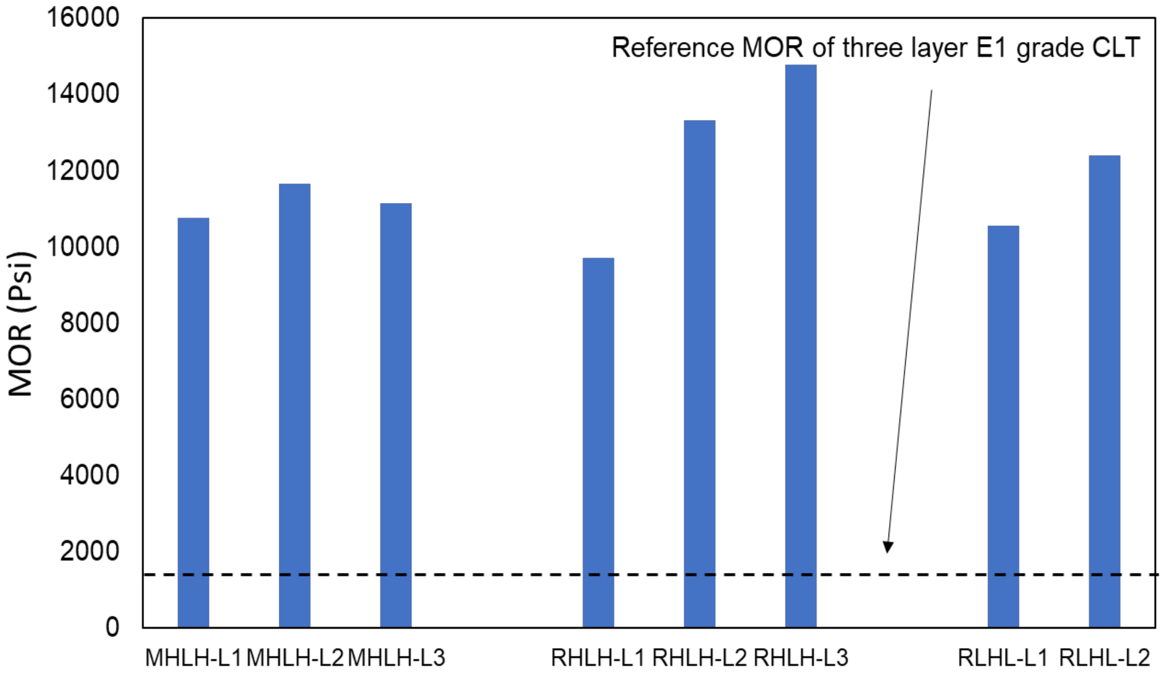
Panel Types	Longitudinal layers		Transverse layer	Average: longitudinal layers	Average: transverse layer
	Top layer	Bottom layer	Middle layer		
MHLH-1	2.69	2.534	1.0718		
MHLH-2	2.8675	2.425	0.9915	2.531783	1.050367
MHLH-3	2.2275	2.4467	1.0878		
RHLH-1	2.167	2.487	1.747		
RHLH-2	2.455	2.3	1.592	2.45125	1.6273
RHLH-3	2.485	2.565	1.6626		
RLHL-1	1.4	1.232	2.966	1.17035	2.82995
RLHL-2	0.9914	1.058	2.6939		

M: melamine adhesive; R: resorcinol adhesive; H: high MOE; L: low MOE

Mechanical Properties of Sugar Maple CLT cont.

Comparison of MOE and MOR between the reference value in APA/PRG-320 and the tested value.





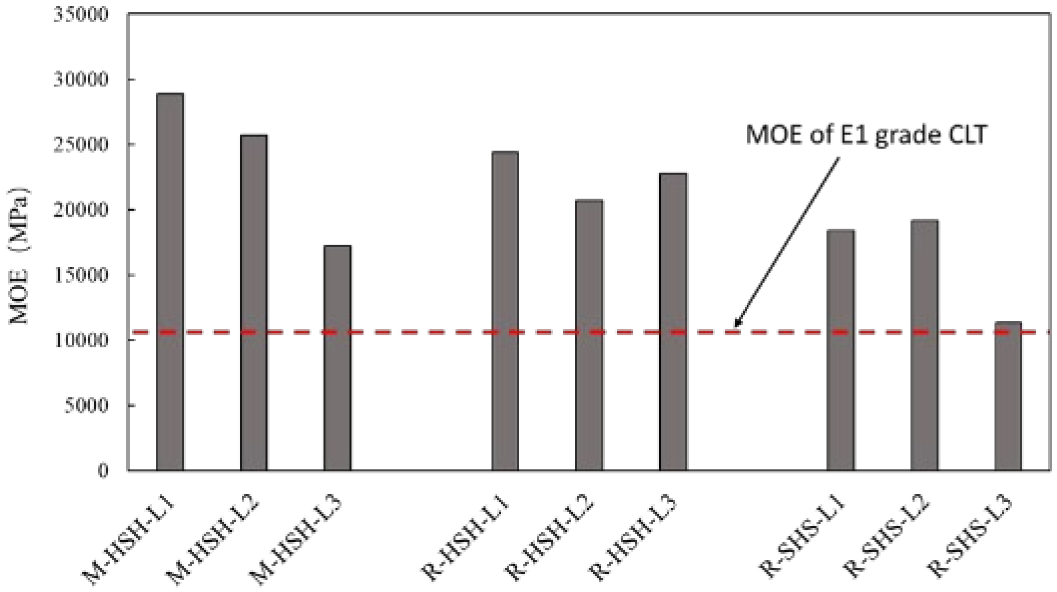
The bending MOEs of sugar maple CLT were up to 35% higher than that of layup E1 (3 layers), which is the highest in the Standard. The MORs of all tested sugar maple CLT panels were at least 5 times that of layup E1 in the PRG-320 standard.

Mechanical Properties of Hard Maple/Spruce Hybrid CLT– Bending Properties

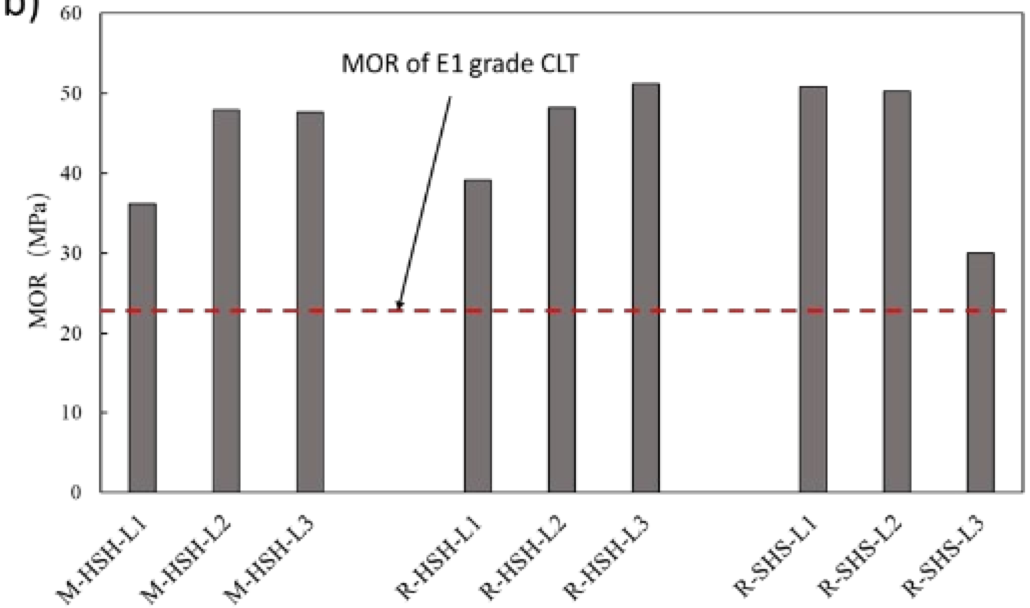
Simulation results and their comparison with test results

Sample type	Peak load (kN)	Peak displacement (mm)	MOE_{CLT} (MPa)	MOE_{CLT} relative difference	MOR_{CLT} (MPa)	MOR_{CLT} relative difference
M-HSH-L	4.53×10^{1}	2.97×10^{1}	2.27×10^{4}	-5.21%	4.99×10^{1}	13.66%
R-HSH-L	4.01×10^{1}	2.10×10^{1}	2.84×10^{4}	25.64%	4.41×10^{1}	-4.45%
R-SHS-L	4.62×10^{1}	2.29×10^{1}	1.87×10^{4}	14.71%	3.72×10^{1}	-14.89%

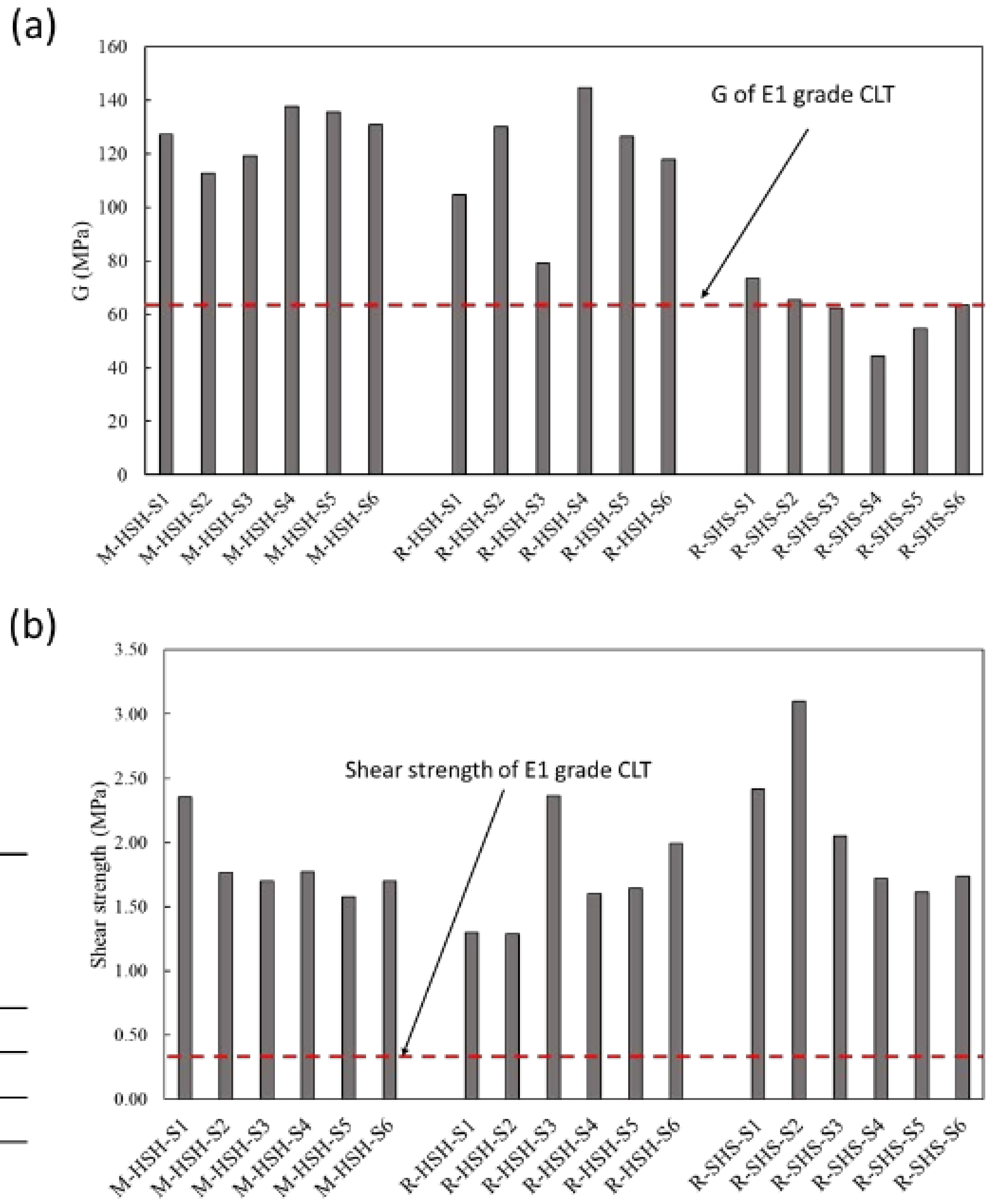
(a)



(b)



Mechanical Properties of Hard Maple/Spruce Hybrid CLT – Shear Properties



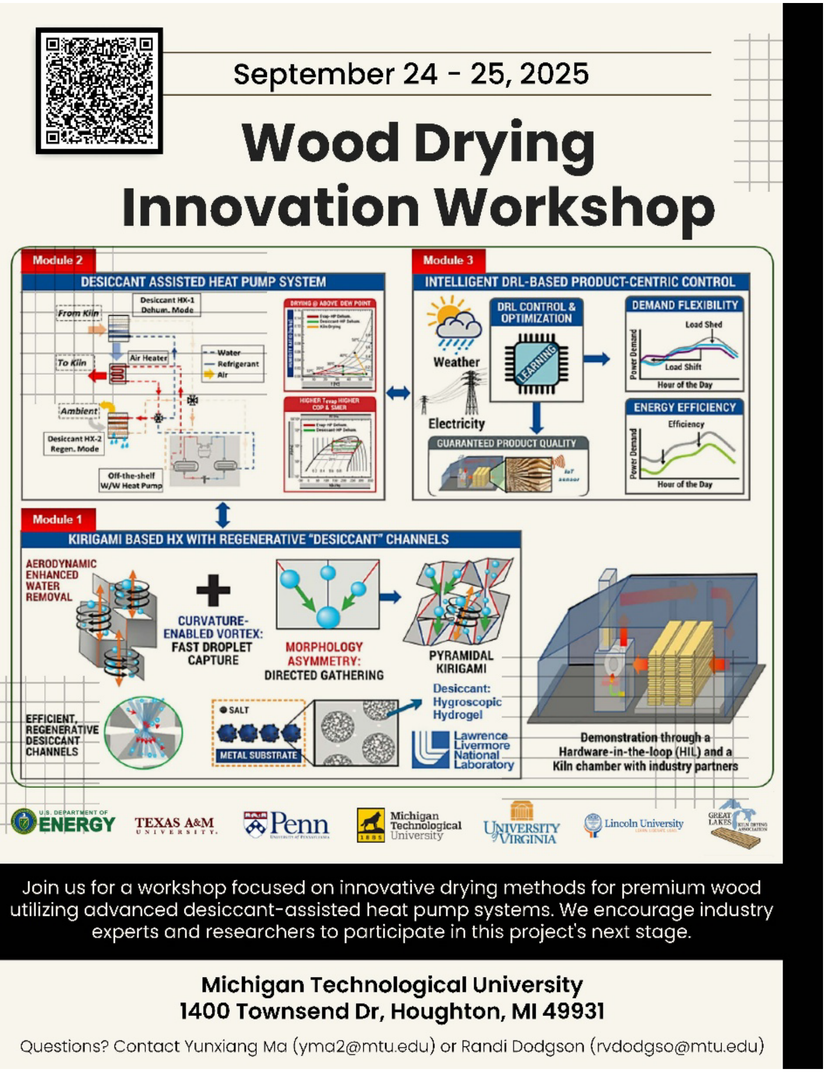
Simulation results and their comparison with test results

Sample type	Peak load (kN)	Peak displacemen t (mm)	G (MPa)	G relative difference	Shear strength (MPa)	Shear strength relative difference
M-HSH-S	50.99	3.9	71.30	22.09%	1.38	-23.67%
R-HSH-S	60.14	4.28	76.65	27.11%	1.63	-4.16%
R-SHS-S	84.29	4.9	61.30	73.81%	1.43	-32.29%

Selected publications

- Musah, M., Ma, Y., Wang, X., Ross, R., Hosseinpourpia, R., Jiang, X. and Xie, X., 2024. Face bonding strength of cross laminated northern hardwoods and softwoods lumber. *Construction and Building Materials*, *421*, p.135405.
- Ma, Y., Musah, M., Si, R., Dai, Q., Xie, X., Wang, X. and Ross, R.J., 2021. Integrated experimental and numerical study on flexural properties of cross laminated timber made of low-value sugar maple lumber. *Construction and Building Materials*, *280*, p.122508.
- Musah, M., Wang, X., Dickinson, Y., Ross, R.J., Rudnicki, M. and Xie, X., 2021. Durability of the adhesive bond in cross-laminated northern hardwoods and softwoods. *Construction and Building Materials*, *307*, p.124267.
- Ma, Y., Si, R., Musah, M., Dai, Q., Xie, X., Wang, X. and Ross, R.J., 2021. Mechanical property evaluation of hybrid mixed-species CLT panels with sugar maple and white spruce. *Journal of Materials in Civil Engineering*, *33*(7), p.04021171.
- Ma, Y., Wang, X., Begel, M., Dai, Q., Dickinson, Y., Xie, X. and Ross, R.J., 2021. Flexural and shear performance of CLT panels made from salvaged beetle-killed white spruce. *Construction and Building Materials*, *302*, p.124381.

Wood Drying Innovation Workshop 2025



Date & Location: Workshop scheduled for **Sept 24–25, 2025** at **Michigan Tech**, including a sawmill tour and full-day sessions.

Thank You!

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