Using Thermal Neutron Imaging in Forest Product Research

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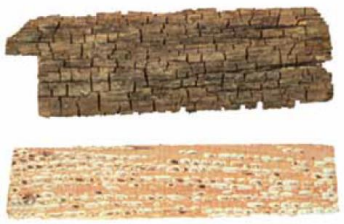
Why revisit neutron imaging in forest products research?

Moisture content in forest products impacts:

- ✓ processing, properties and performance

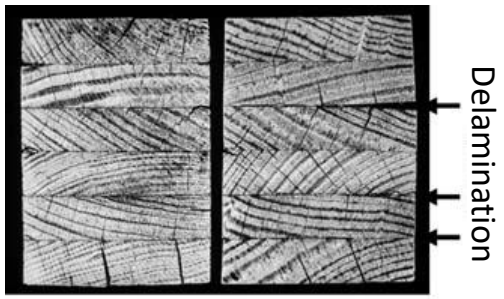
Common failure mechanisms ___



(Clausen FPL-GTR-190)

Biodegradation

Corrosion



(Frihart (2005))

Adhesive bondline durability

Yet, studies aiming to better understand durability are often difficult because...

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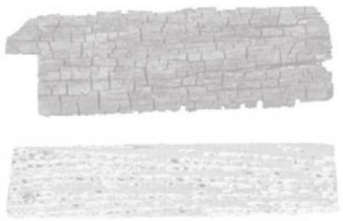

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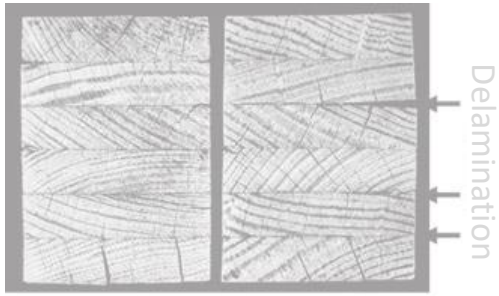


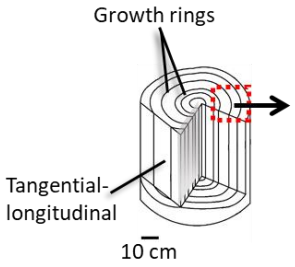
(Frihart (2005))

Adhesive bondline durability

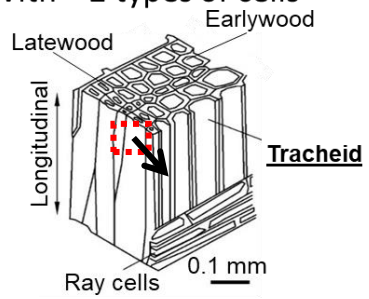
Yet, studies aiming to better understand durability are often difficult because ...

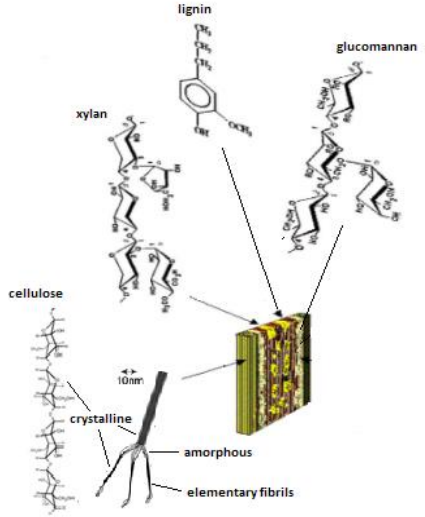
Wood has a hierarchical structure…

Anisotropic
with 3 primary planes

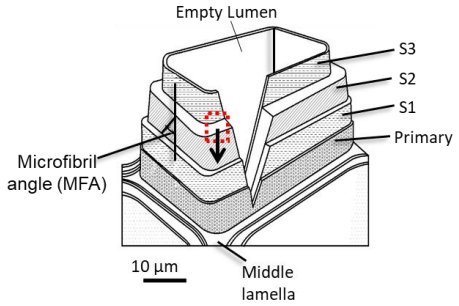


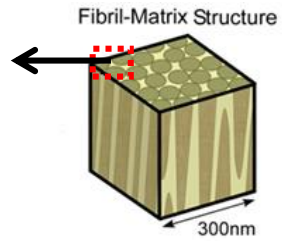
Cellular
With ~ 2 types of cells





Tracheid cell wall
with 3 layers

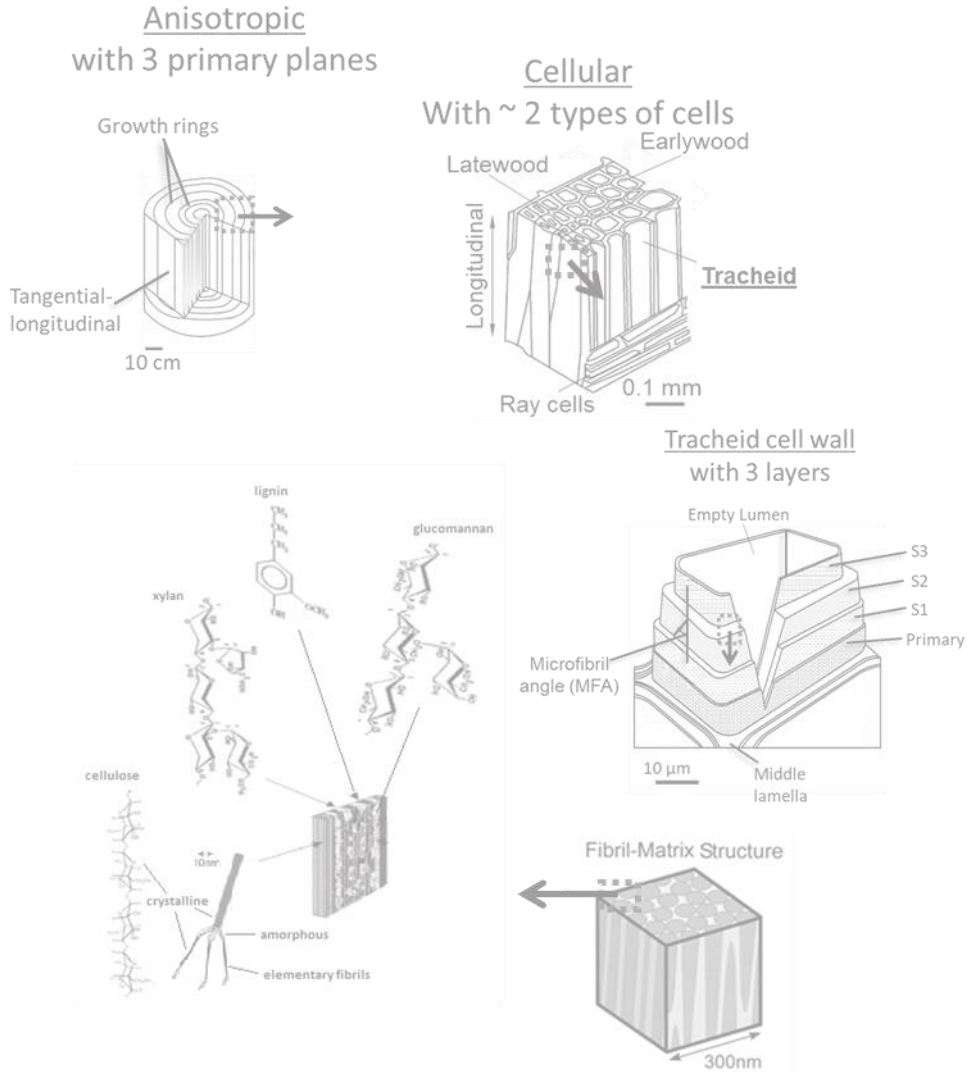




Why revisit neutron imaging in forest products research?

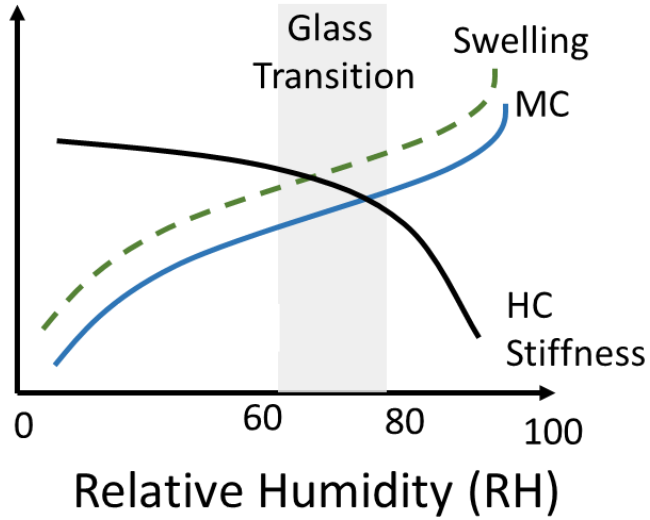
Wood has a hierarchical structure…

… and it is hygroscopic



The amount of moisture in wood is defined as

$$MC\% = \frac{Mass_{water}}{Mass_{oven\ dry\ wood}} x\ 100$$



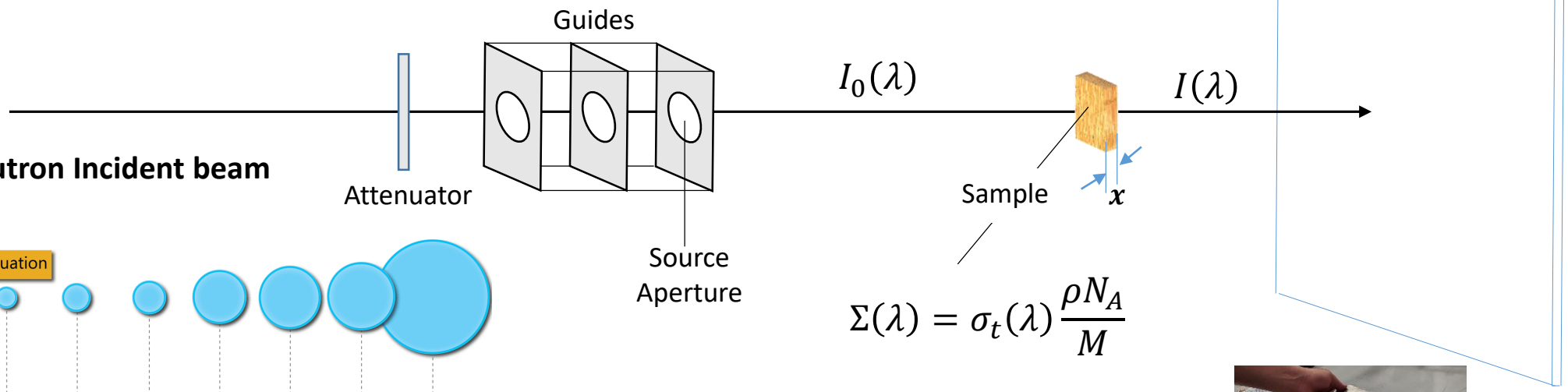
The MC depends on the environment's humidity and temperature

<u>In neutron scattering controlling the MC can help us change the contrast!</u>

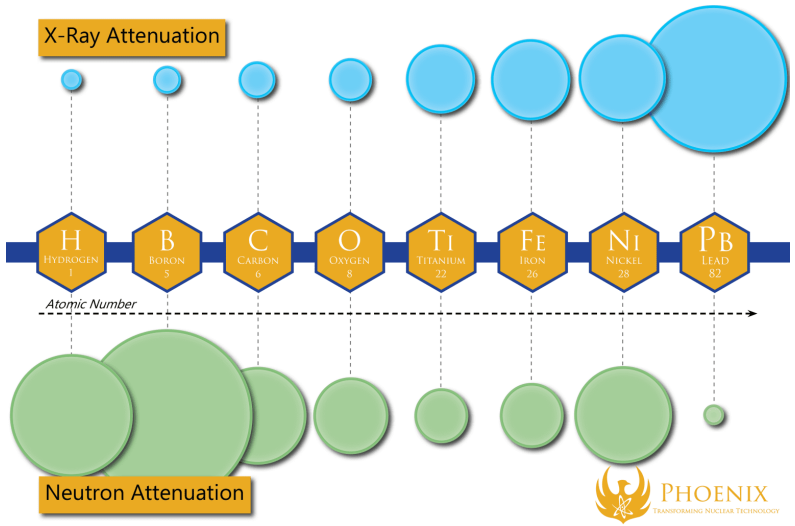
What is neutron imaging?

A neutron beam is focused on a sample and interacts with the nuclei within the sample. After passing through the sample, the beam becomes attenuated. The attenuated beam is measured on a 2D CCD camera or a film.

$$I(\lambda) = I_0(\lambda)e^{-\Sigma(\lambda)x}$$



$$\Sigma(\lambda) = \sigma_t(\lambda)\frac{\rho N_A}{M}$$



$$\Sigma(\lambda) = \frac{-1}{\mathrm{x}}\ln\left(\frac{I(\lambda)}{I_0(\lambda)}\right)$$

Our neutron imaging experiments

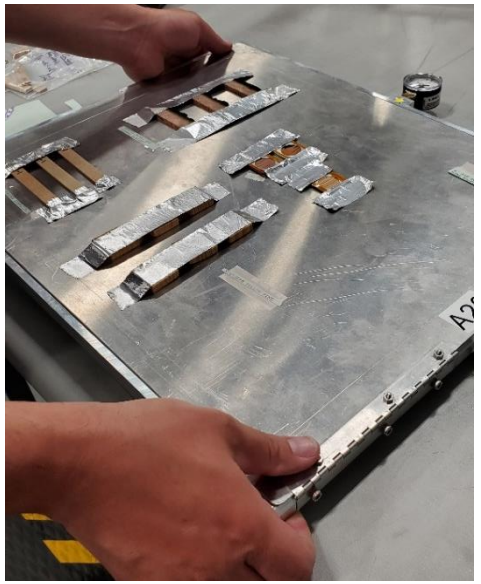
1. Measure dry samples at ambient condition

- Wood-plastic composites
- Chemically modified wood blocks
- Carbonized wood

2. Measure wet samples

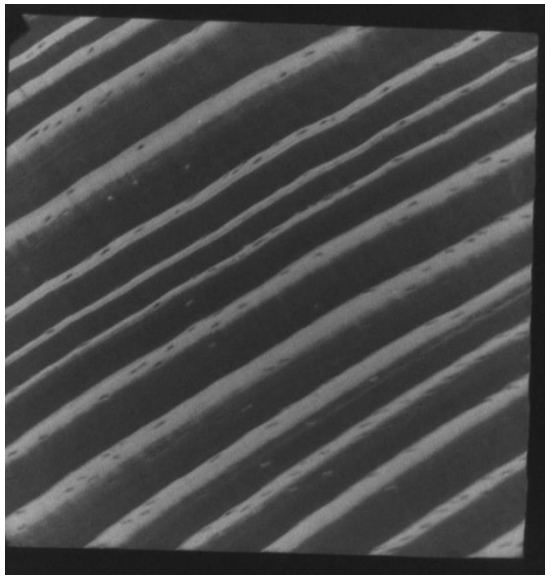
- Samples soaked in H_2O for 24hrs and sealed the samples using Al foil

Experiments were performed at the Phoenix Neutron Imaging Center using thermal neutrons produced via a compact neutron generator, with an exposure time of about 1.5 hours.

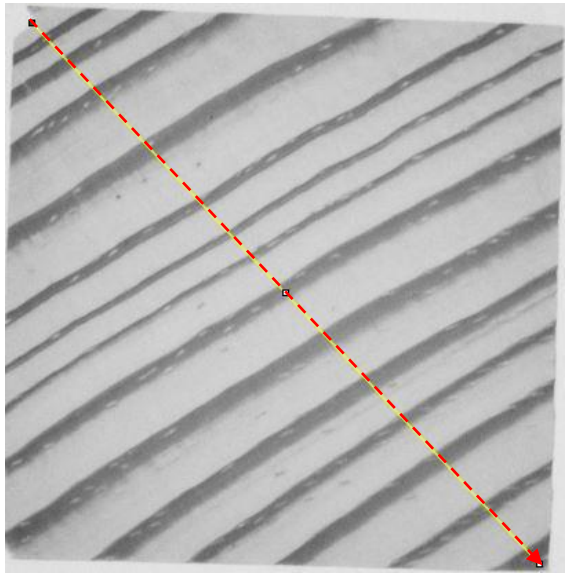


Quantitative image analysis

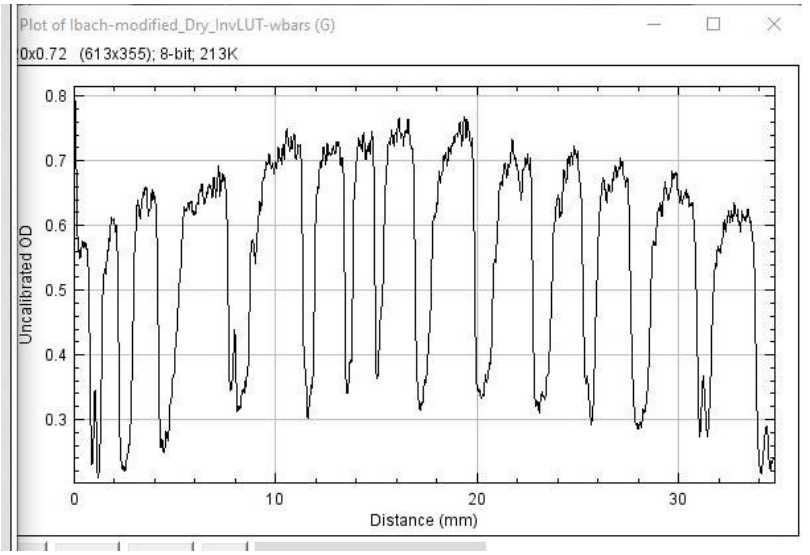
Raw image



Inverted LUT



Transmitted intensity profiles



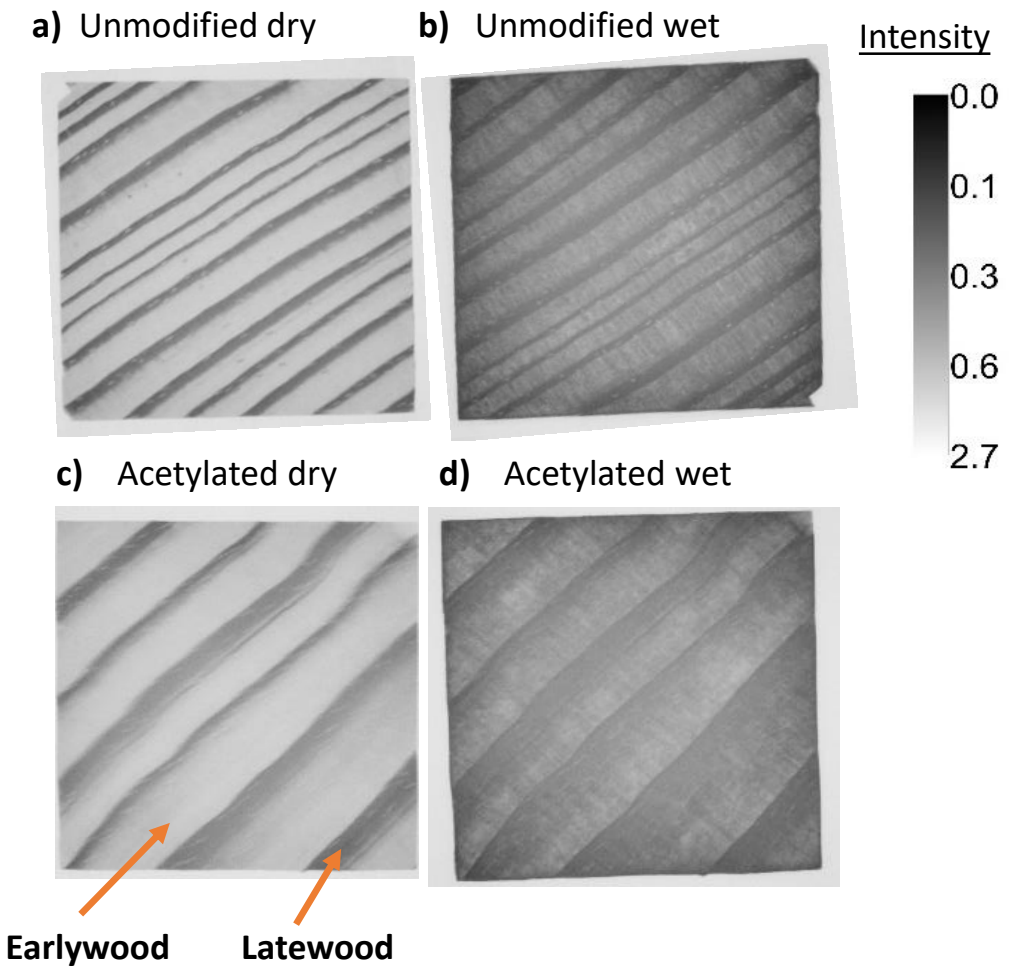
Incident intensity

$$\Sigma = \frac{1}{\mathrm{d}} \ln\left(\frac{I_0}{I}\right)$$

Transmitted intensity

All calibrations and quantitative analysis were done using ImageJ tools in FIJI.

1. Unmodified and acetylated sapwood blocks



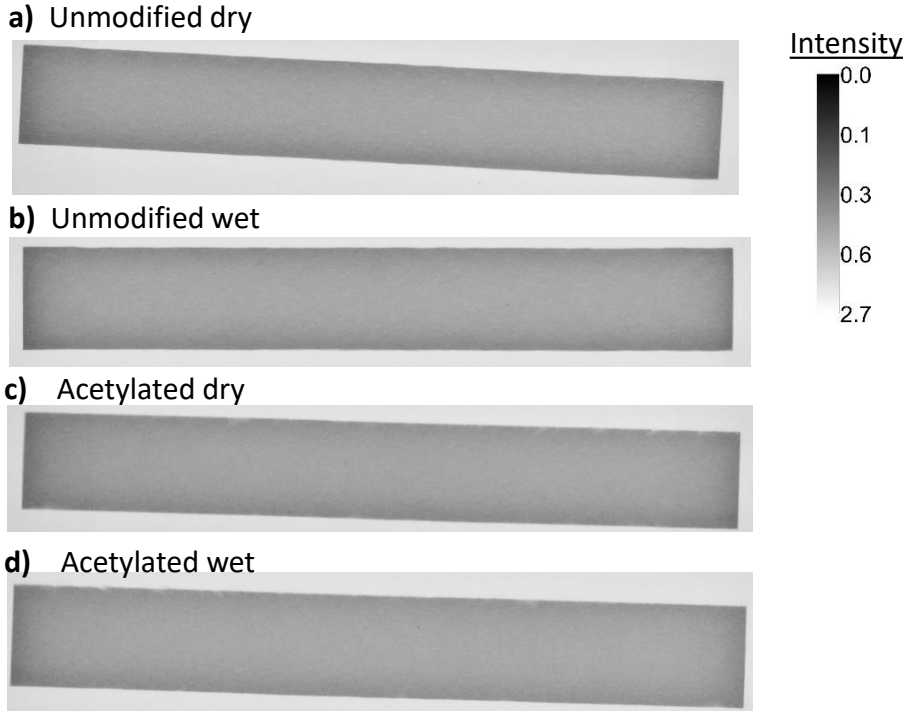
- For all dry samples, the contrast between earlywood and latewood bands is very strong.
- Increasing the moisture content decreases this contrast, and the attenuation coefficient in the earlywood bands increases considerably, suggesting that the increase in water led to an apparent increase in density.
- Changes due solely to acetylation are not easily detectable in these measurements.

Average macroscopic attenuation coefficients

Sample	Σ (1/cm)	
	Dry	Wet
Unmodified Wood	0.86 (0.15) [1]	0.92 (0.33) [1]
	0.15 (0.04) [2]	0.63 (0.21) [2]
Acetylated Wood (20% WPG)	0.71 (0.16) [1]	0.75 (0.21) [1]
	0.16 (0.07) [2]	0.60 (0.21) [2]

[1] Latewood. [2] Earlywood

2. Unmodified and acetylated wood-plastic composites



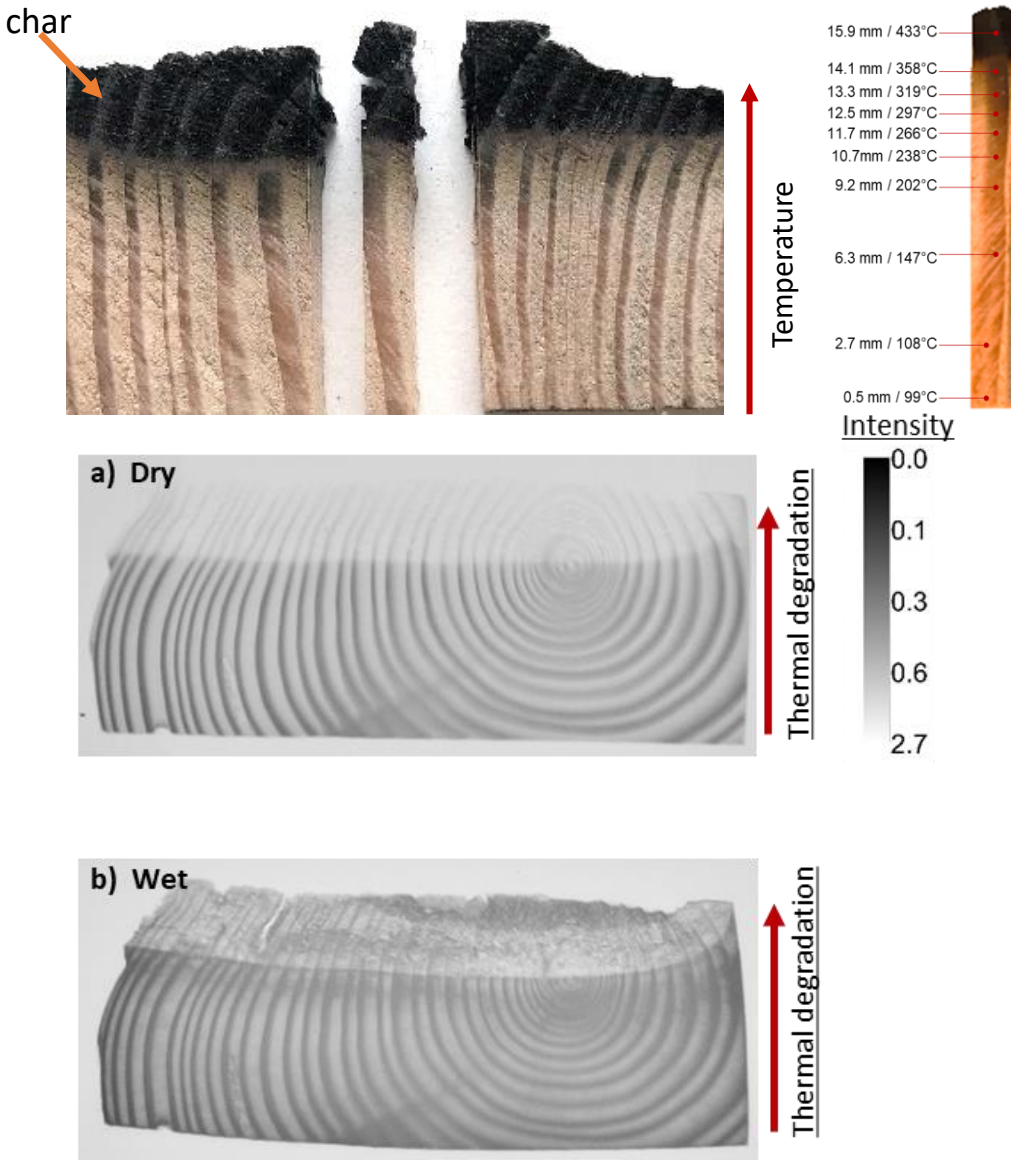
- Soaking the samples in water for over 24 hours did not yield observable differences, probably because the moisture content in the samples increased less than 5%.
- Interestingly, all samples exhibited an increased attenuation near the edges, this suggests that there might be attenuation gradient due to sample fabrication process, or because the wood fibers on the surfaces are more accessible to water compared to the inside of the sample.
- Future experiments with longer soaking times to increase the moisture content might yield new insights.

Average macroscopic attenuation coefficients

Sample	Σ (1/cm)	
	Dry	Wet
Unmodified WPC	1.18 (0.04)[1]	1.06 (0.20)[1]
	0.84 (0.07)[2]	0.77 (0.06)[2]
Acetylated WPC	1.31 (0.24)[1]	1.12 (0.20)[1]
	0.85 (0.07)[2]	0.79 (0.05)[2]

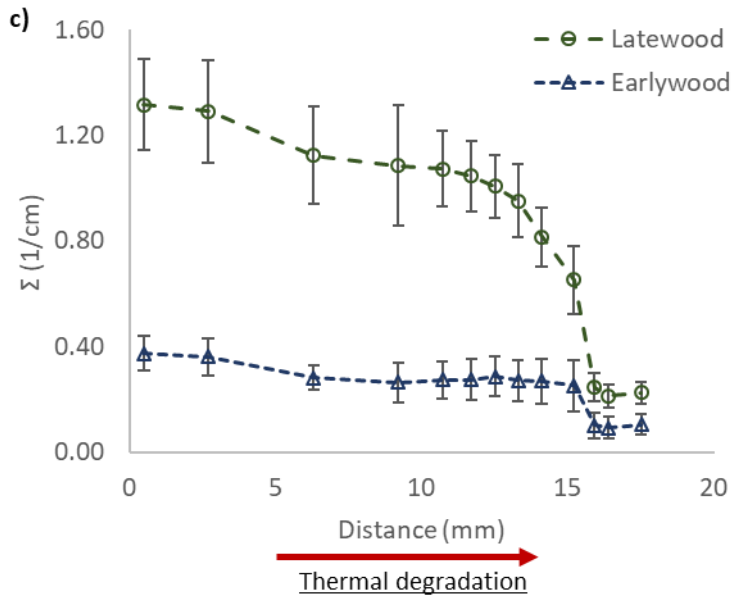
[1] Surface regions. [2] Non-surface areas

3. Thermal Degradation of Wood



- Soaking the samples in water for over 24 hours improved the overall contrast in the sample and revealed features in the char region that were otherwise indistinguishable.

- Quantitative analysis of the transmitted intensities along the thermal degradation profile in the dry sample, allowed us to track the decrease in the attenuation coefficient caused by the thermal degradation of the wood polymers. We attribute this decrease mostly to a loss in hydrogen content.



Summary and future work

- Demonstrated that using thermal neutron imaging we can detect differences due to:
  - Moisture content in unmodified and modified wood
    - Effect of chemical modification is still under investigation
  - Thermal degradation in wood
    - We can control to moisture content in these samples to increase the contrast and reveal defects like cracks and cavities that would otherwise be indistinguishable

- Future work will include:
  - Post-processing analysis techniques to improve the accuracy of the results
  - Contrast variation techniques, including the use of water vapor as a contrast agent
  - Investigations on degradation in wood and other forest products including wood-plastic composites

Thanks!

Questions?

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