Micro X-Ray Computed Tomography Study of Adhesive Bonds in Wood

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SWST 2015 International Convention

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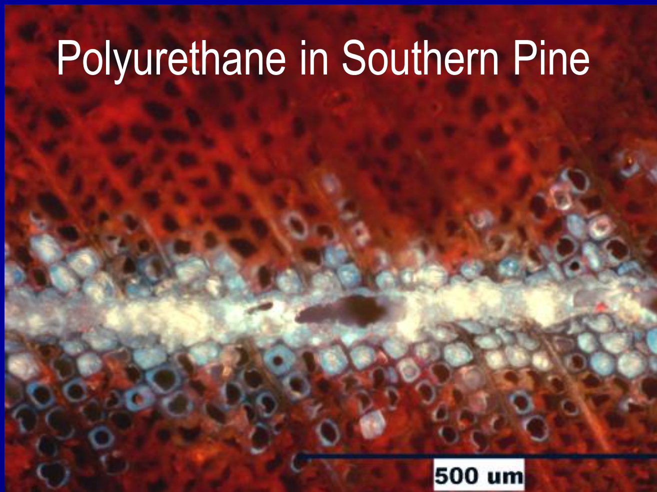
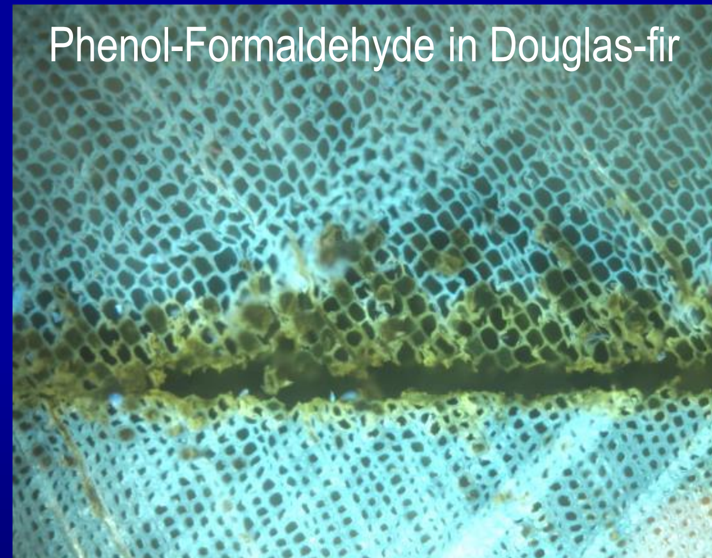
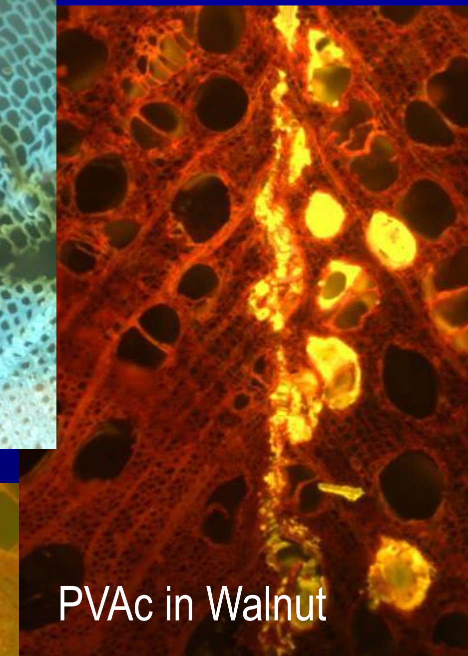
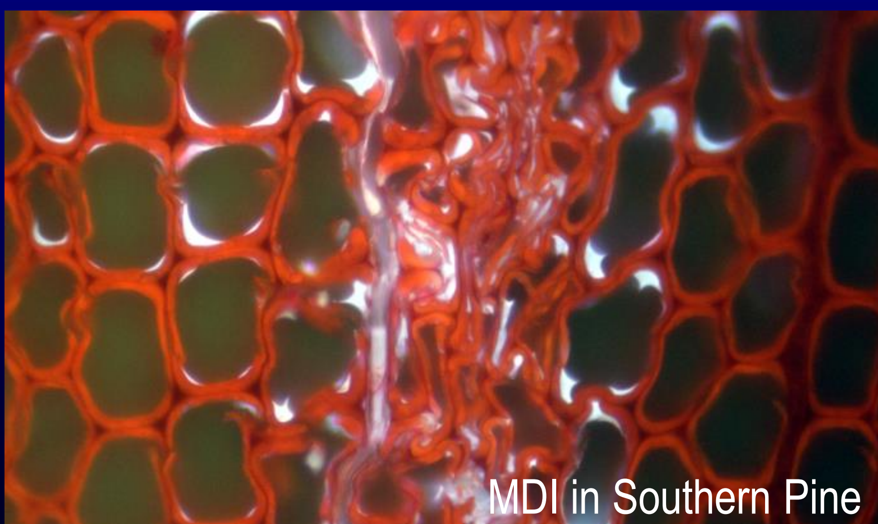
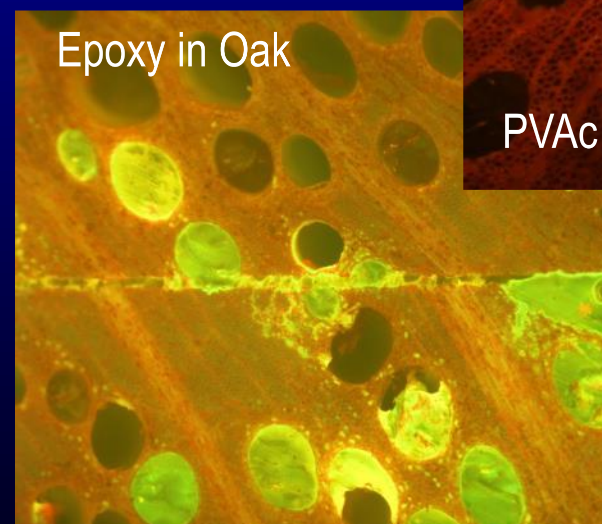




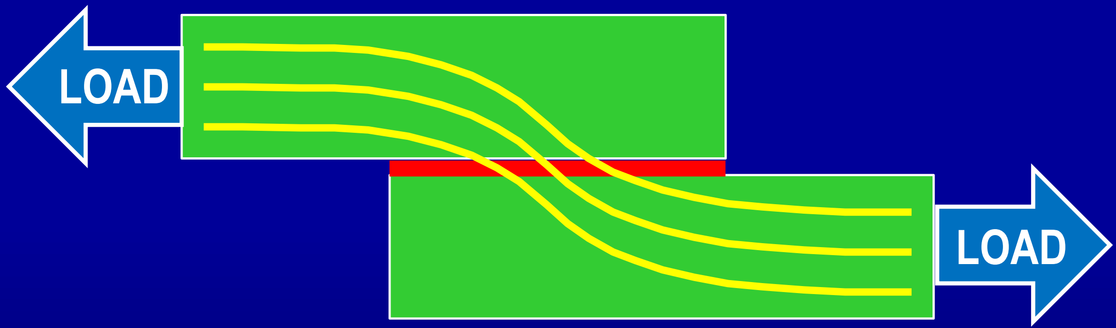






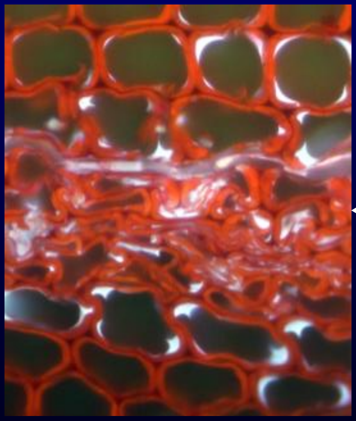
All fluorescence micrographs shown in cross-section view (RT plane) of parallel laminated wood

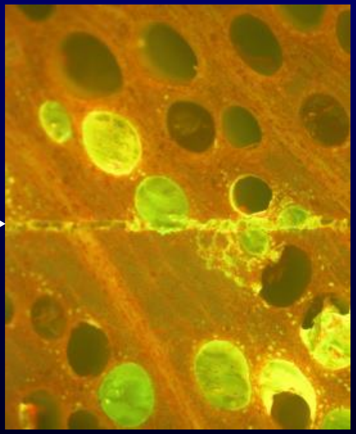
What does adhesive do?



Transfers stress from one substrate to the next.

Does adhesive penetration influence stress transfer?





Research Goal:

Develop a numerical model to simulate wood-composite joint-performance that quantitatively accounts for the role of adhesive penetration

Sponsors:

NSF Industry/University Cooperative Research Center for Wood-Based Composites

USDA National Institute of Food and Agriculture

Collaborators:

- *Oregon State University*

  Project leadership, mechanical testing, specimen prep., modeling

- *Advance Photon Source, Argonne National Laboratory*

  Tomography beamline access on synchrotron device

- *ETH Zürich, Switzerland*

  Mechanical test device

- *US Forest Products Laboratory*

  Nano-indentation & x-ray fluorescence microscopy

- *Member organizations of the Wood-Based Composites Center*

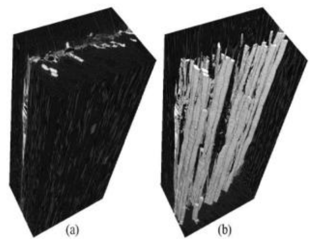
  Resin formulation and technical guidance

Outline:

- Methodology
  - Part 1 – Linear elastic model development
  - Part 2 – Non-linear model development
  - Part 3 – Moisture durability of bondline (see McKinley poster)
- *In situ* mechanical testing of bondline during XCT
- Digital volume correlation
- Examples of modeling results

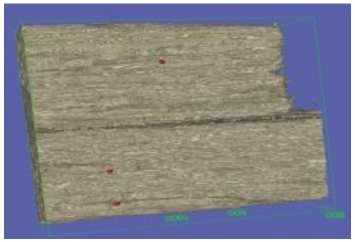
Methodology – Part 1 Linear-elastic model

Micro X-Ray Tomography



3D structure used as modeling system

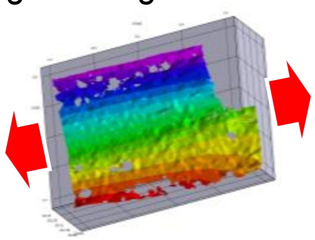
Modeling (MPM)



Material property input

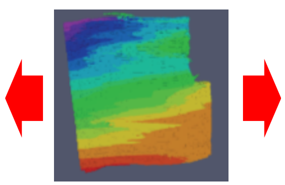
Lap-Shear Bond Testing

Digital Image Correlation



Comparison 2D surface strain

Model Simulations

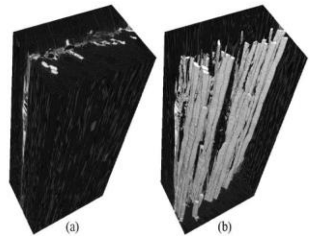


Applications:
- Loading modes
- Adhesive modulus
- Penetration pattern
- Linear range

Part 1 is completed

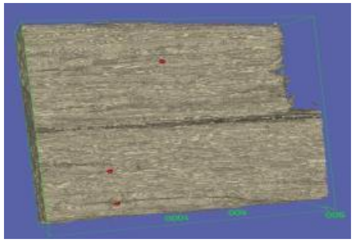
Methodology – Part 2 Non-linear model

Micro X-Ray Tomography



3D structure used as modeling system

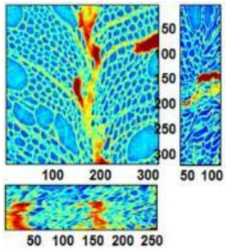
Modeling (MPM)



Material property input

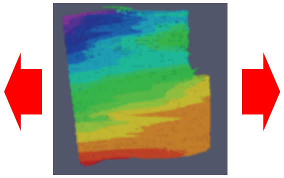
In situ Lap-Shear Testing

Digital Volume Correlation



Comparison 3D strain field

Model Simulations



Applications:

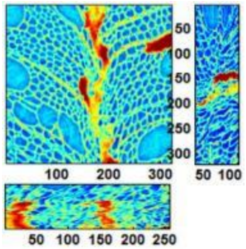
- Loading modes
- Adhesive modulus
- Penetration pattern
- Non-linear range

Methodology – Part 3 Moisture durability

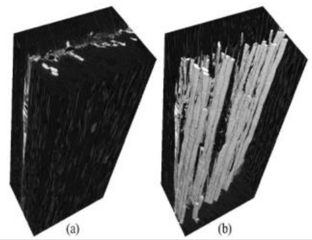
PF resins high & low molecular weight

Moisture cycling of XCT specimens

Digital Volume Correlation



Micro & Nano XCT



Lap-Shear Testing Macro-specimens

X-ray Fluorescence & Energy-Dispersive X-ray Spectroscopy

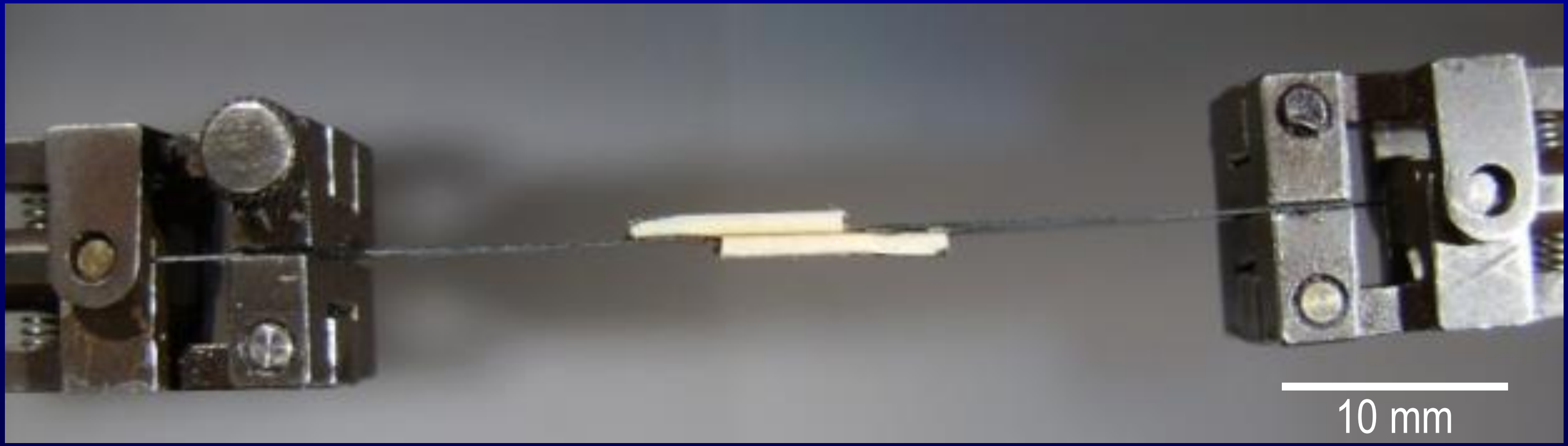
Moisture cycling of lap-shear specimens

Applications:

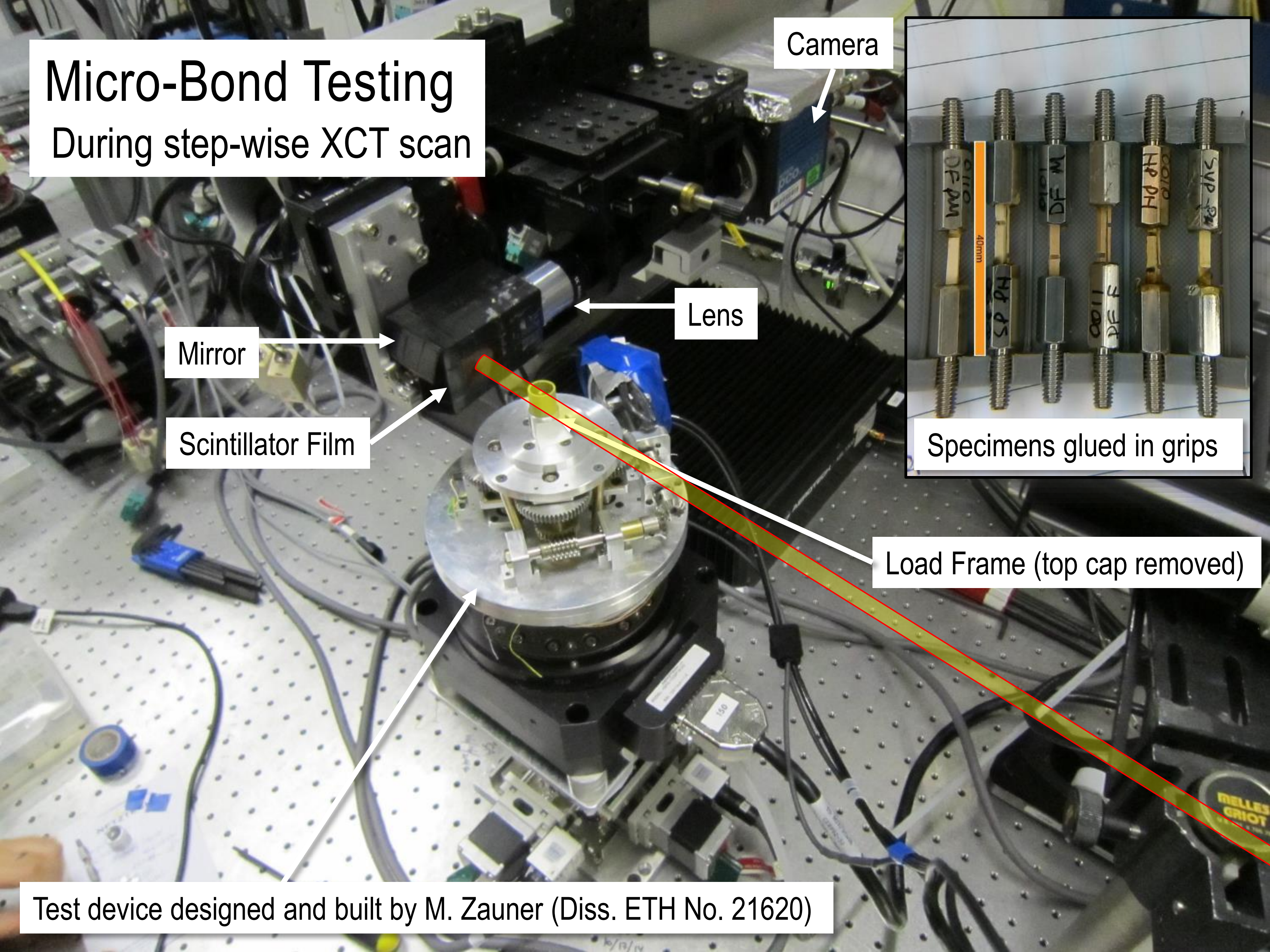
- Influence of penetration on bondline moisture resistance
- Influence of molecular weight on cell wall penetration

Micro-Bond Testing

Non-destructive, linear range, tensile loading
Same specimen used for micro X-ray computed tomography
DIC of surface deformation compared to model results

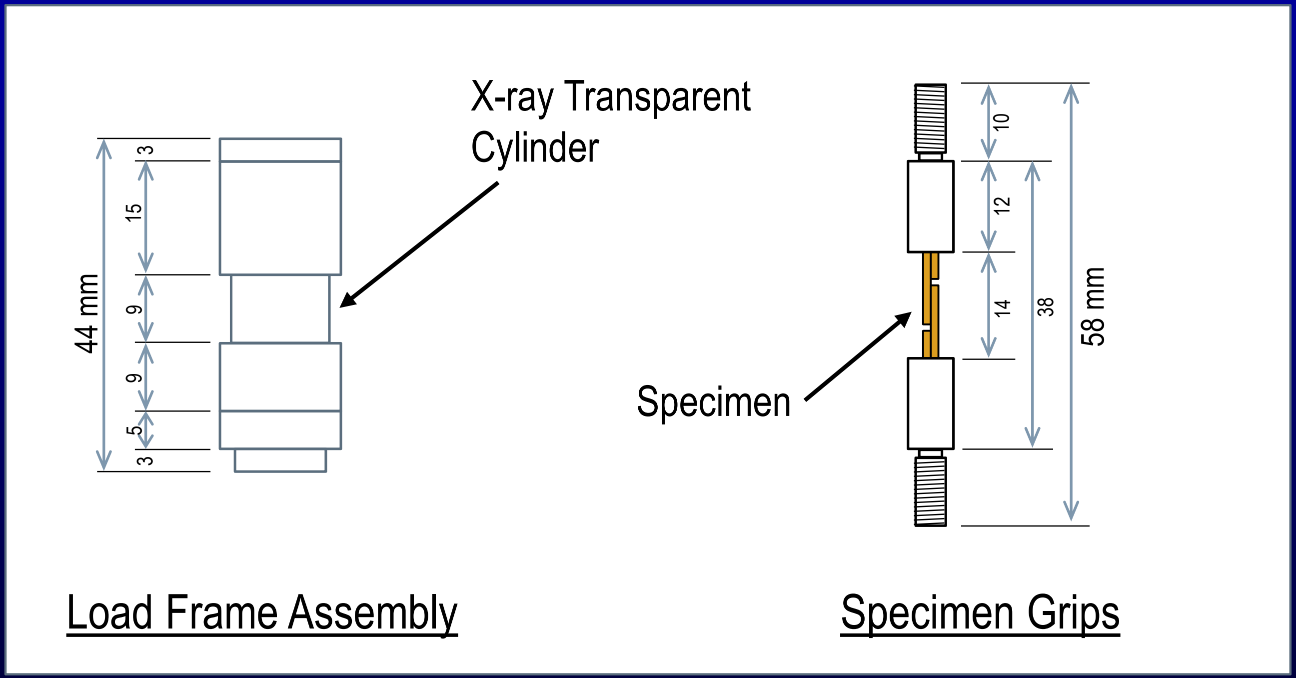


Load Cell: +/- 100 N (+/- 0.1 N)
Displacement: 0.16 mm (+/- 0.0001 mm)


Micro-Bond Testing
During step-wise XCT scan
Camera
Lens
Mirror
Scintillator Film
Specimens glued in grips
Load Frame (top cap removed)
Test device designed and built by M. Zauner (Diss. ETH No. 21620)

In situ Micro-Bond Testing

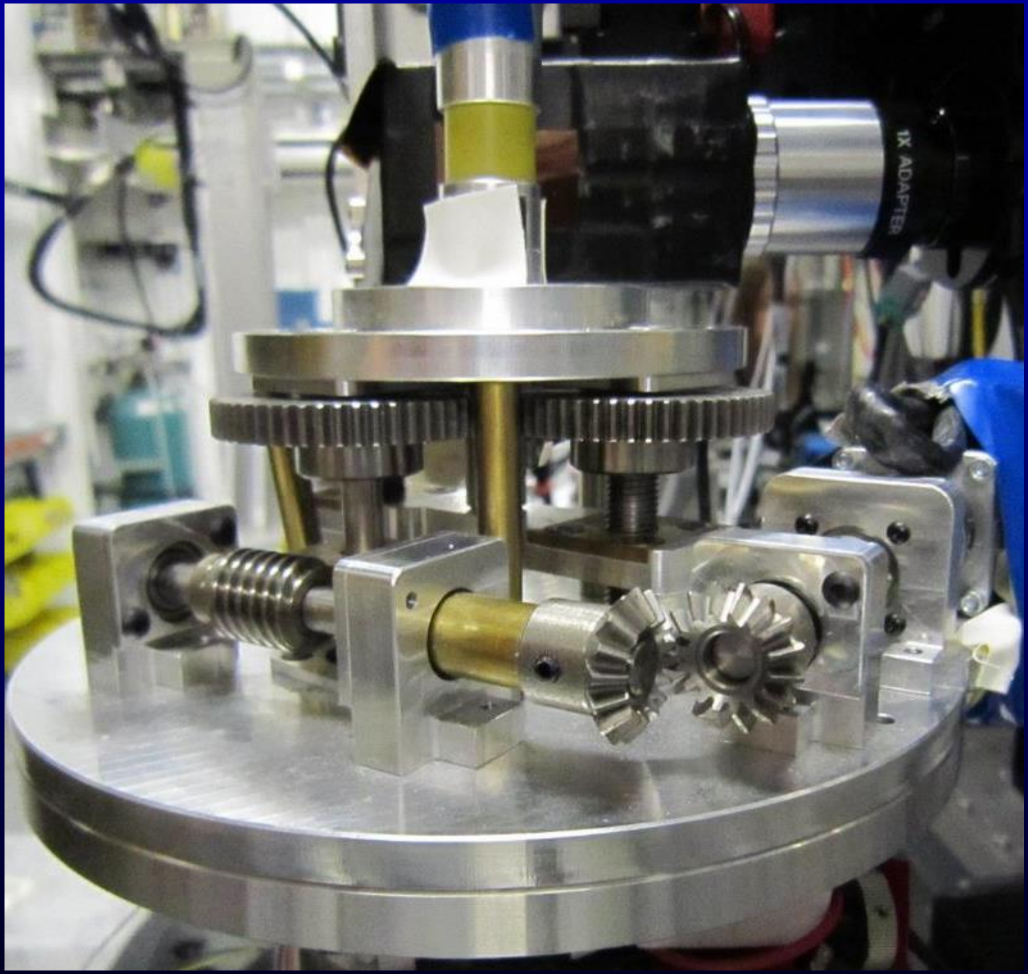
Destructive lap-shear test during step-wise XCT scan



Load Cell: +/- 100 N (+/- 0.1 N)
Displacement: 0.16 mm (+/- 0.0001 mm)

In situ Micro-Bond Testing

Destructive lap-shear test during step-wise XCT scan

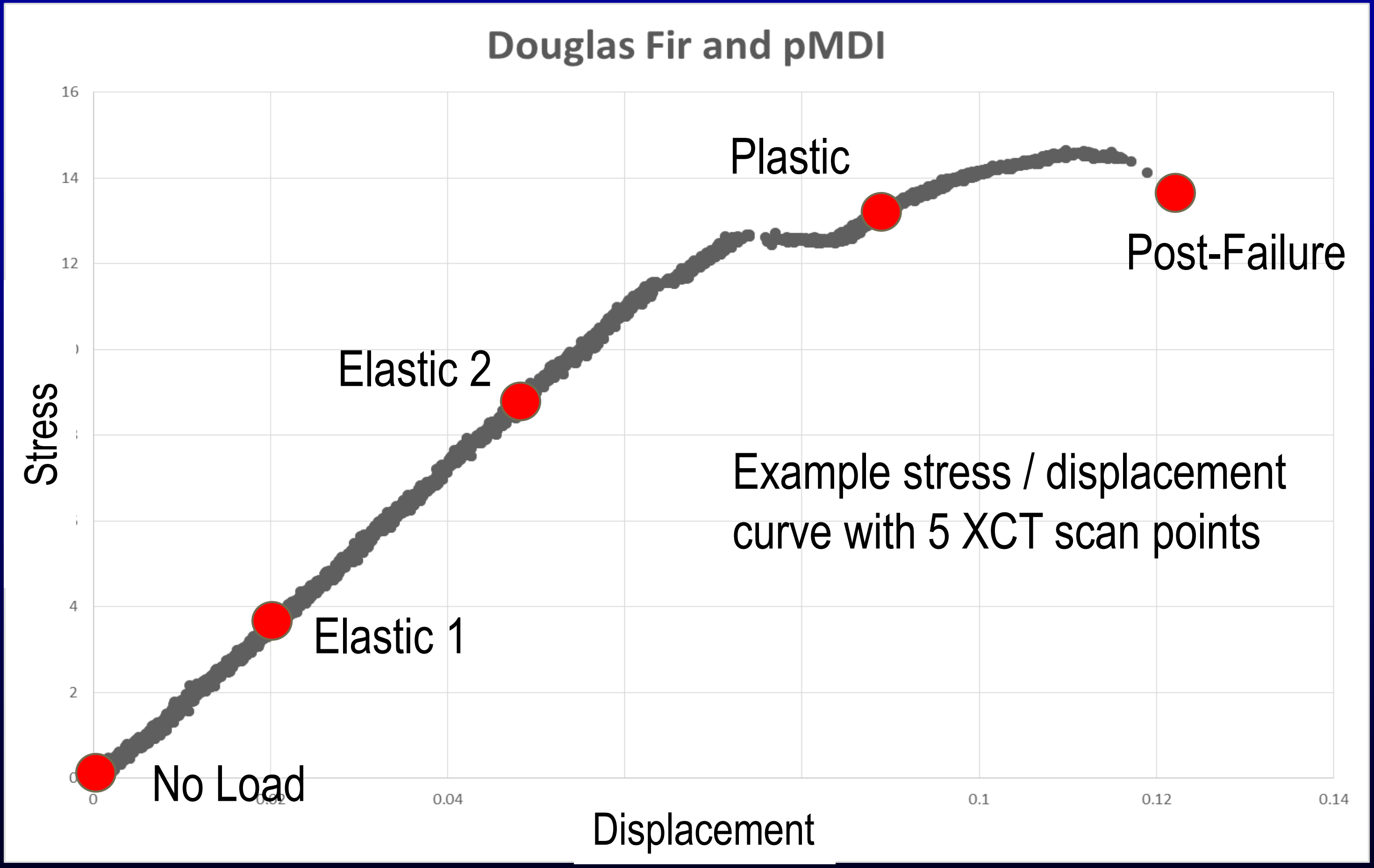


10 mm

Load Cell: +/- 1 kN (+/- 0.03 kN)
Displacement: 0.0002 mm/sec

In-situ Micro-Bond Testing

Step-wise XCT Scan



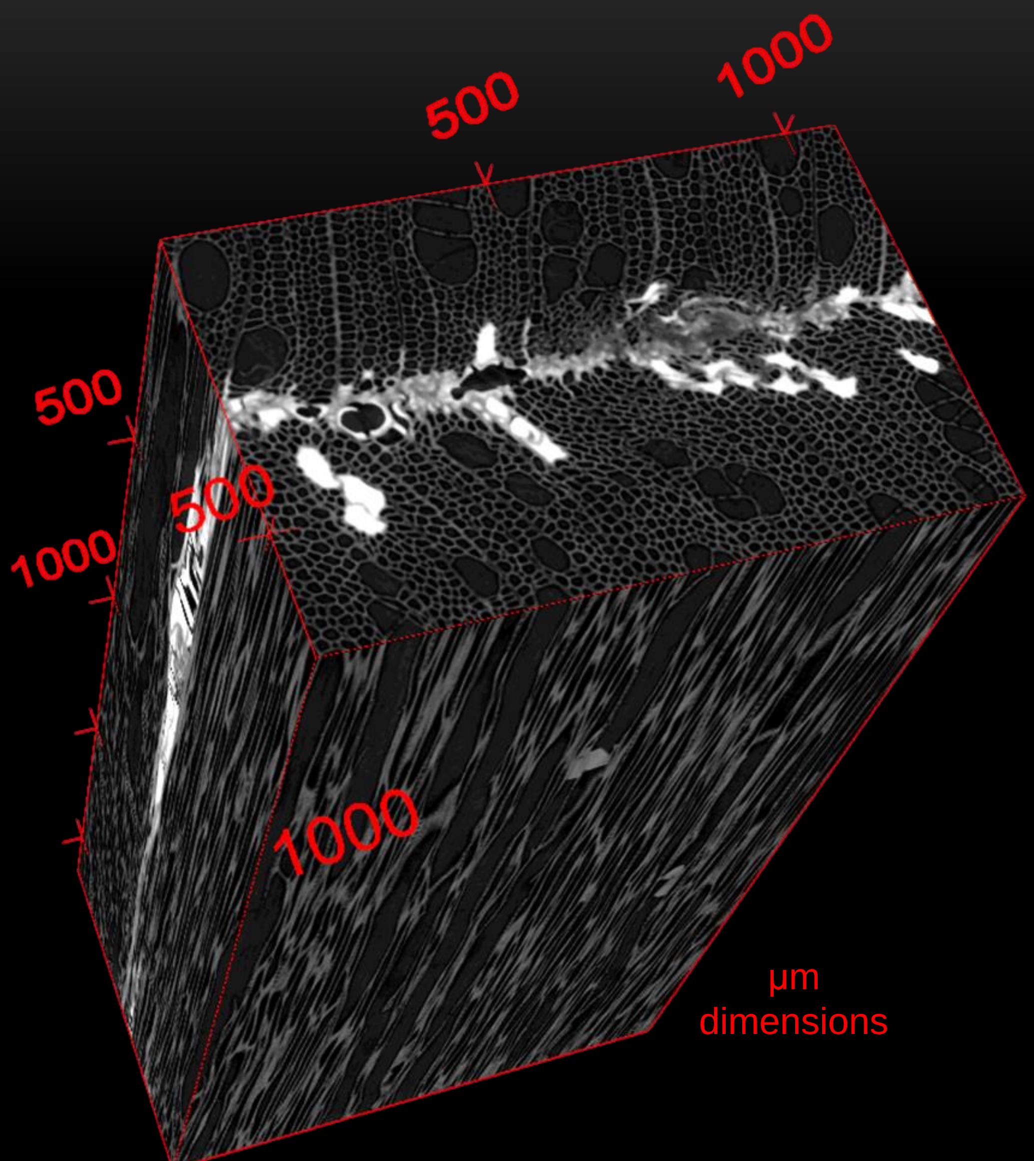
Baseline

Segmentation

3 Materials for Segmentation

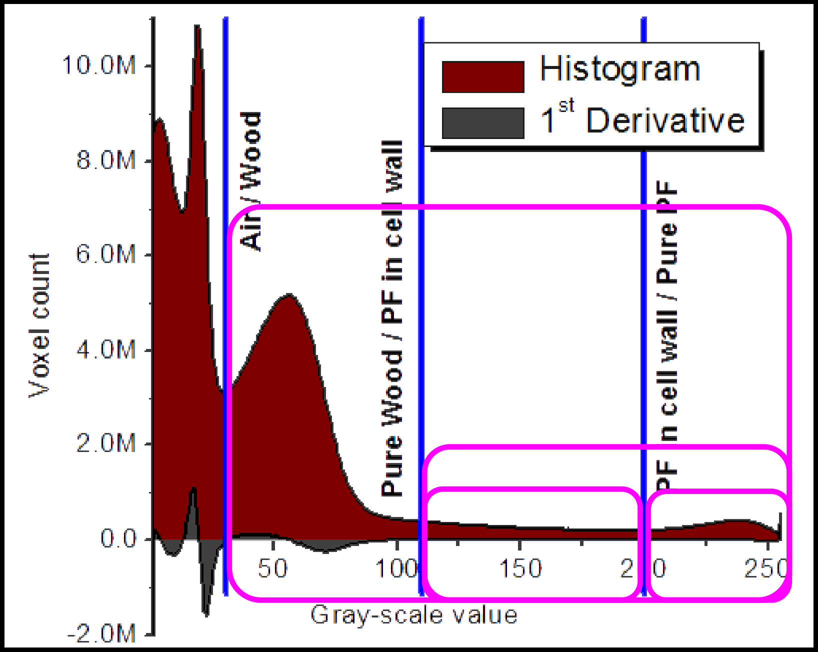
Increasing attenuation ↓

- Air (lumens)
- Wood cell walls
- Adhesive



Phenol-formaldehyde in poplar

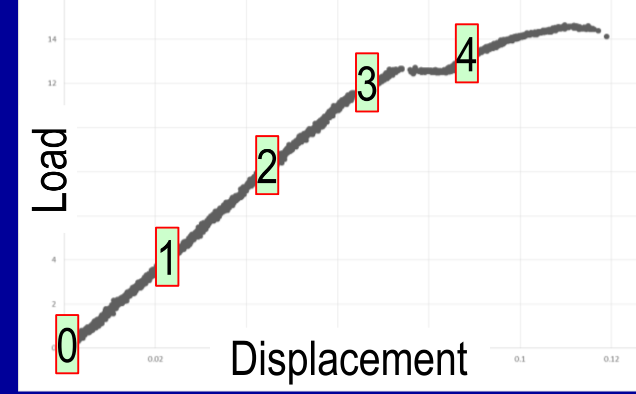
Gray-Scale Histogram of Voxels

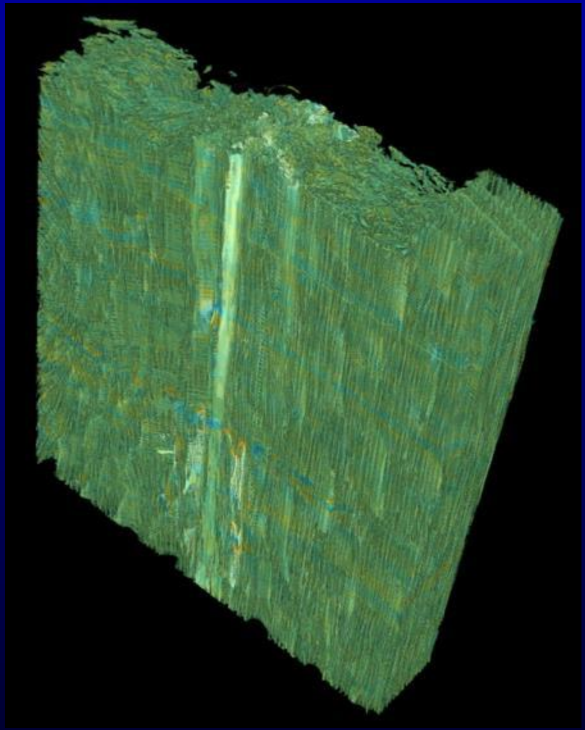


Increasing attenuation →

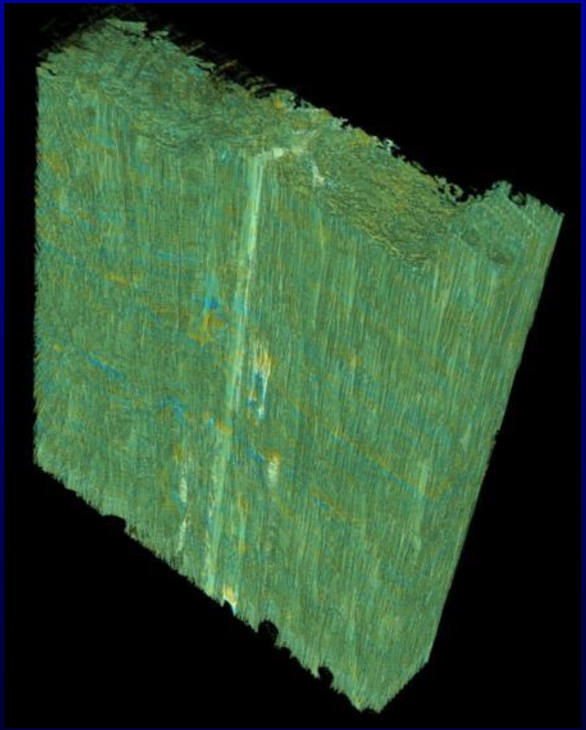
Digital Volume Correlation

Douglas-fir bonded with PF adhesive





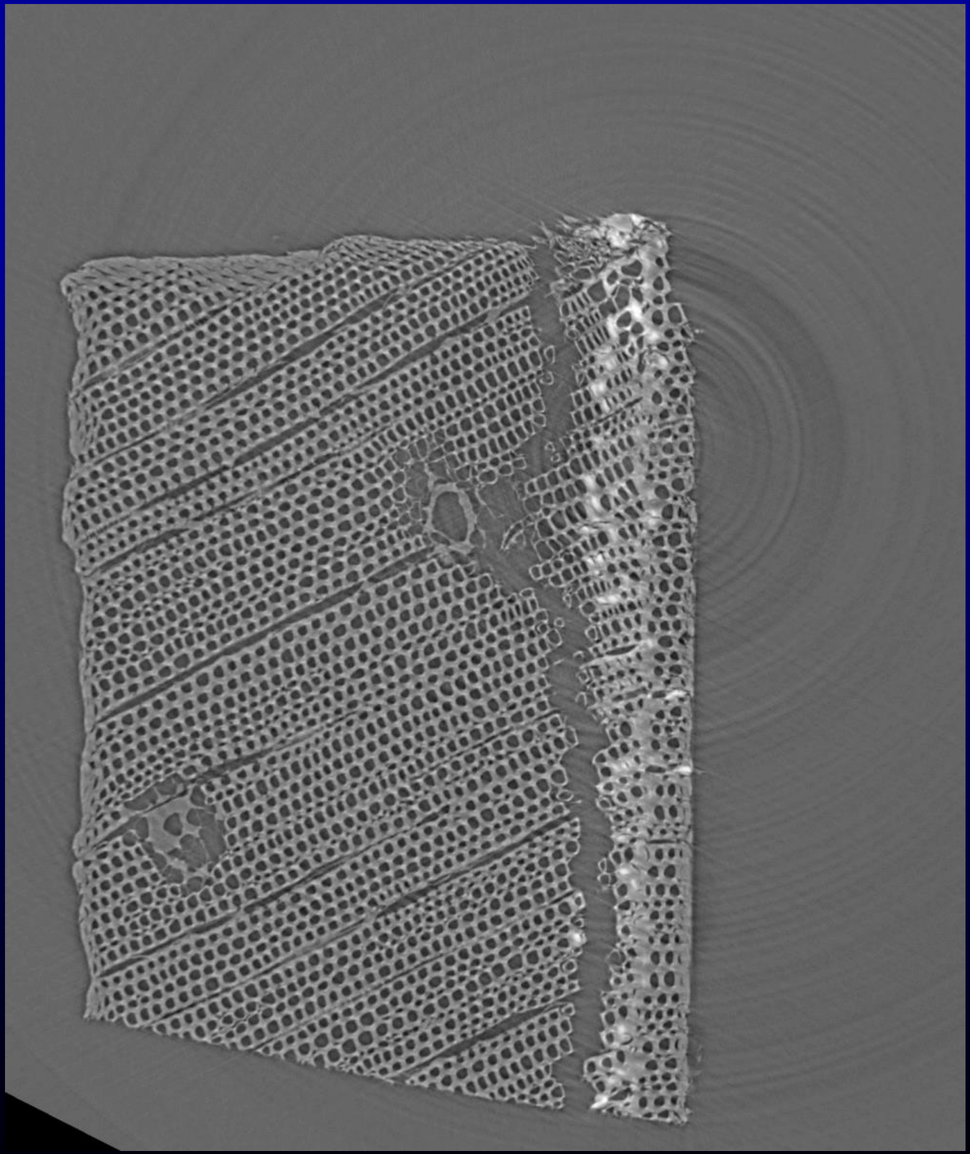
Strain Step 0 to 1

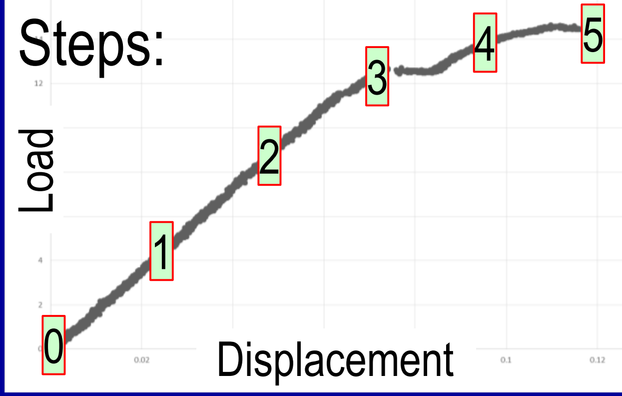


Strain Step 0 to 3

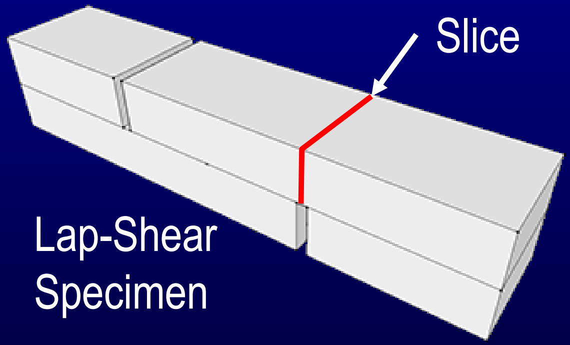
Method adapted from: Bar-Kochba E., et al. 2014. A fast iterative digital volume correlation algorithm for large deformations. Experimental Mechanics. DOI: 10.1007/s11340-014-9874-2

XCT & Lap-Shear Testing





Douglas-fir bonded with PF adhesive



Step 5

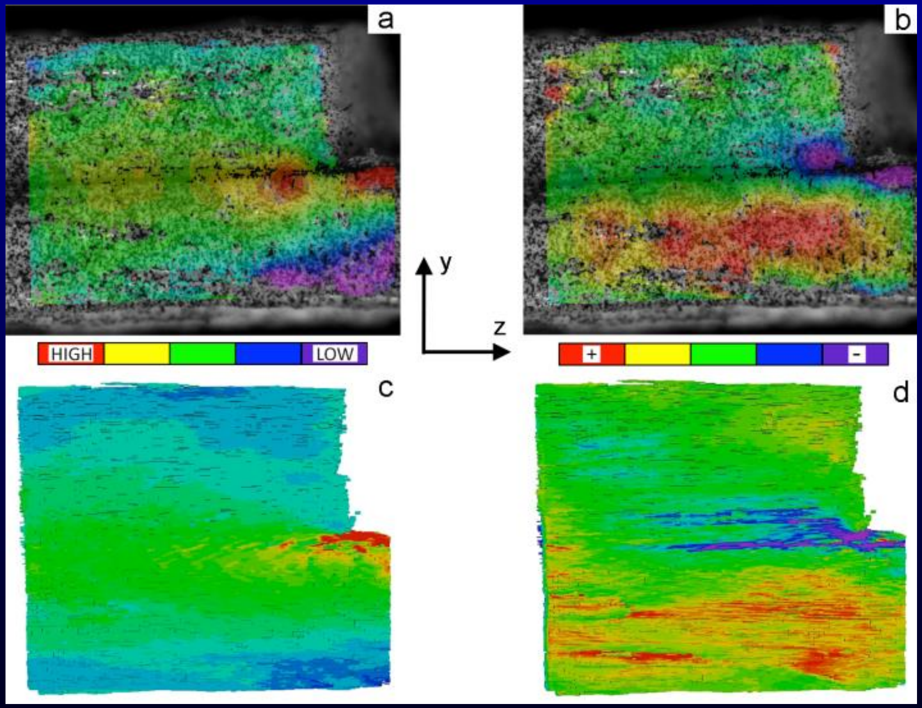
Modeling by Material Point Method (MPM)

Physical system defined by voxels contained in tomogram (MPM model points), including material segmentation.

Material properties assigned to MPM points based on segmentation.

Micro-Bond Test

Model Simulation

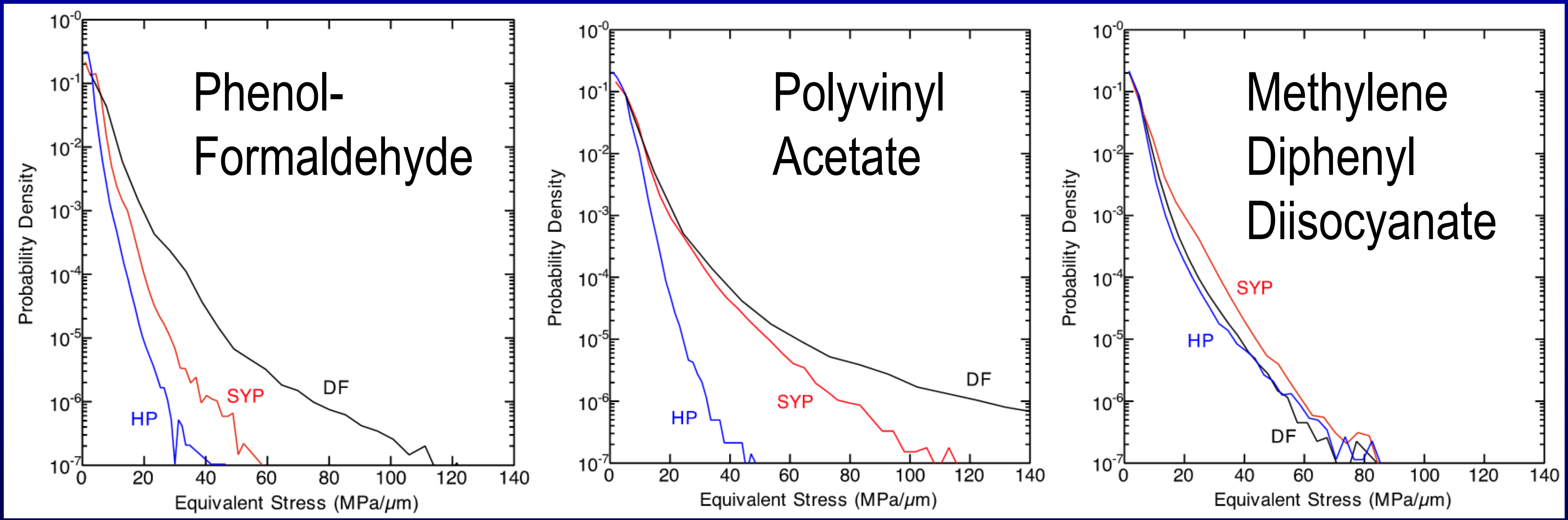


Displacement

Shear Strain

Model Simulation of Bondline Shear Stress

Probability Distribution of Local Stress in 3D Space



HP = Hybrid Poplar
SYP = Southern Pine
DF = Douglas-fir

- Higher probability of large local stress condition means bond is more likely to fail.
- Depends of adhesive penetration pattern, wood micro-structure, and adhesive modulus.

Acknowledgements

WBC

National Science Foundation
Industry/University Cooperative Research Center for Wood-Based Composites

NSF

Advanced Photon Source
Argonne National Laboratory

USDA

OSU
Oregon State University