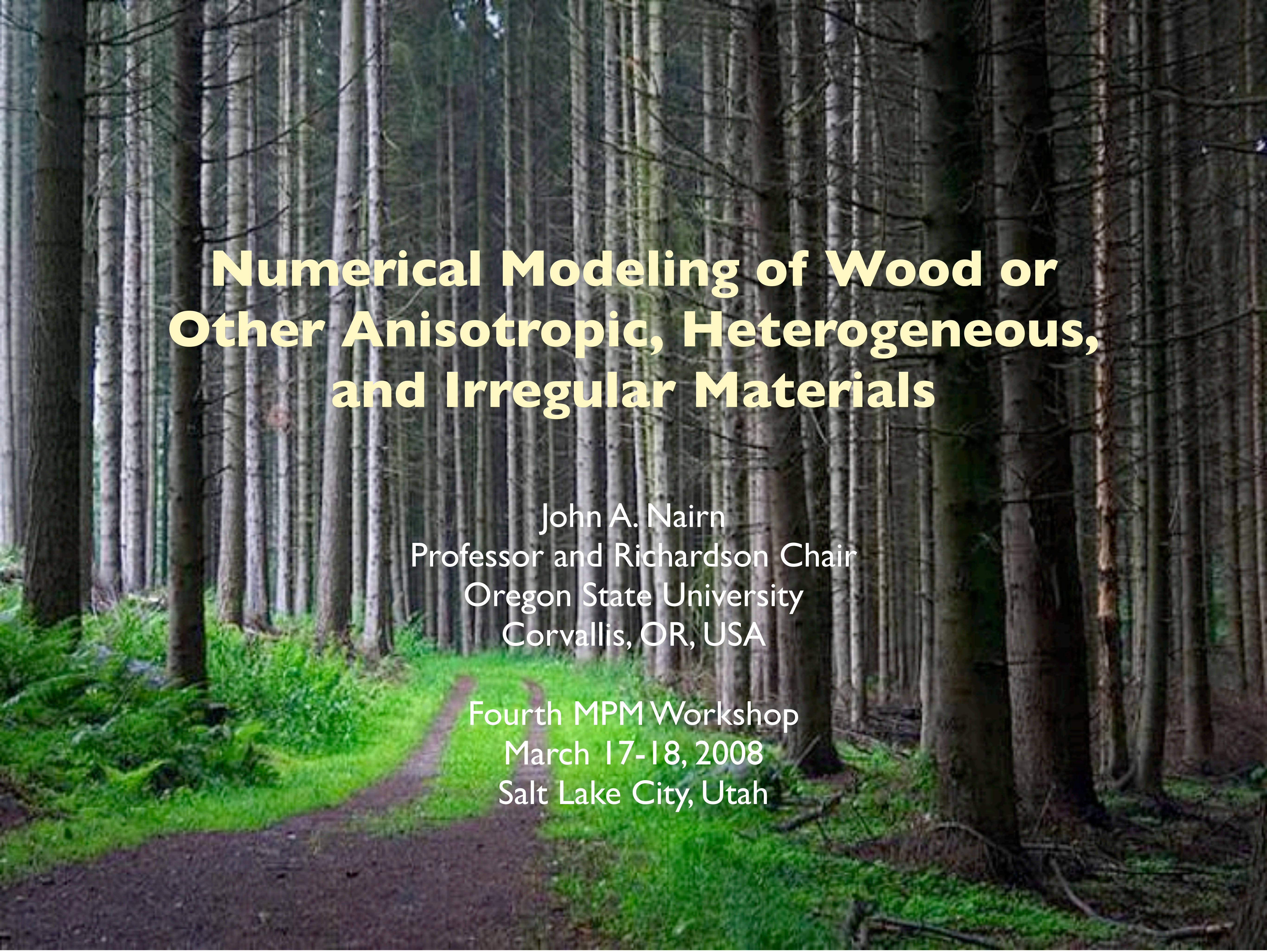
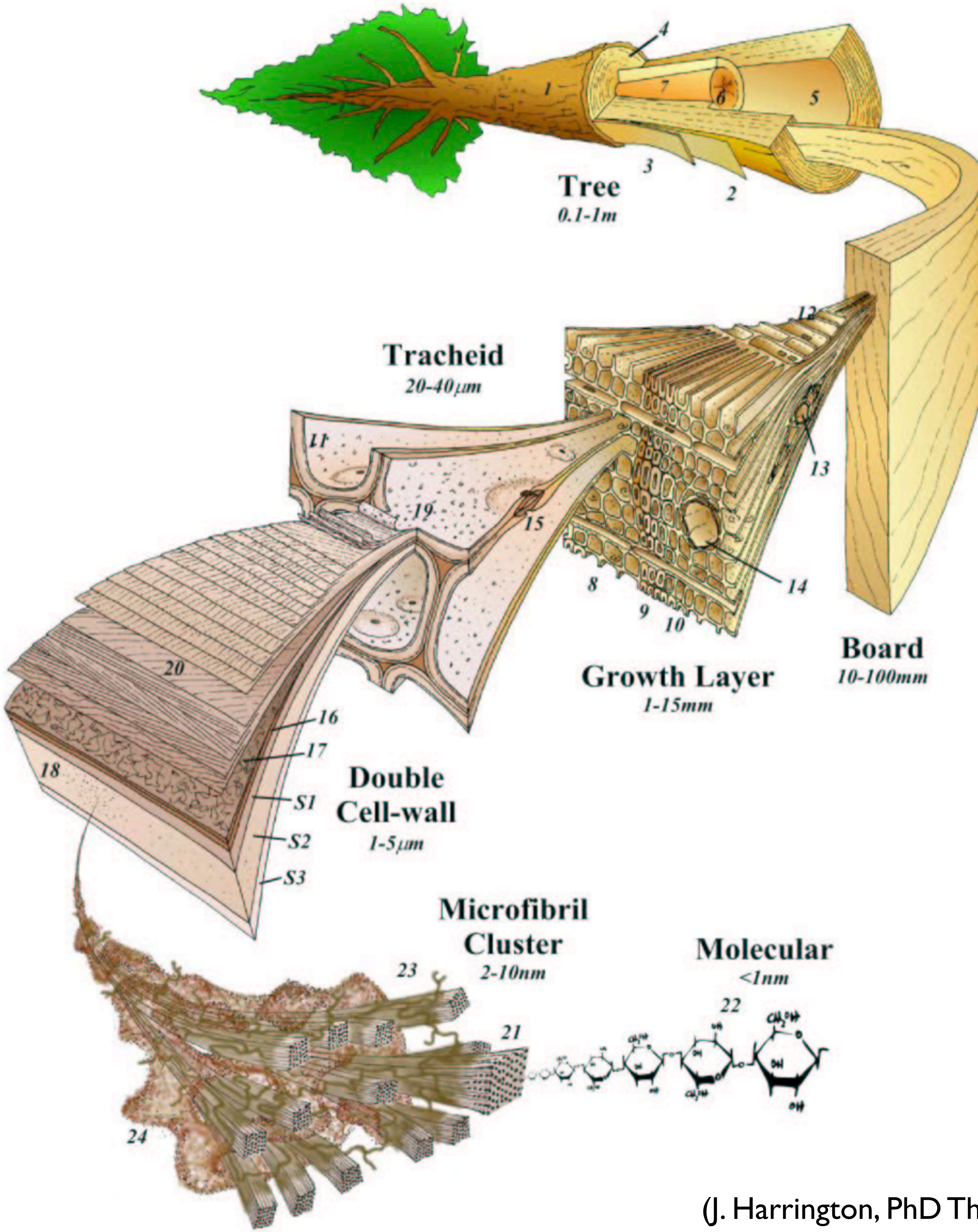


Numerical Modeling of Wood or Other Anisotropic, Heterogeneous, and Irregular Materials

John A. Nairn
Professor and Richardson Chair
Oregon State University
Corvallis, OR, USA

Fourth MPM Workshop
March 17-18, 2008
Salt Lake City, Utah



(J. Harrington, PhD Thesis)

Hierarchical

Smart

Adaptive

Self-Healing

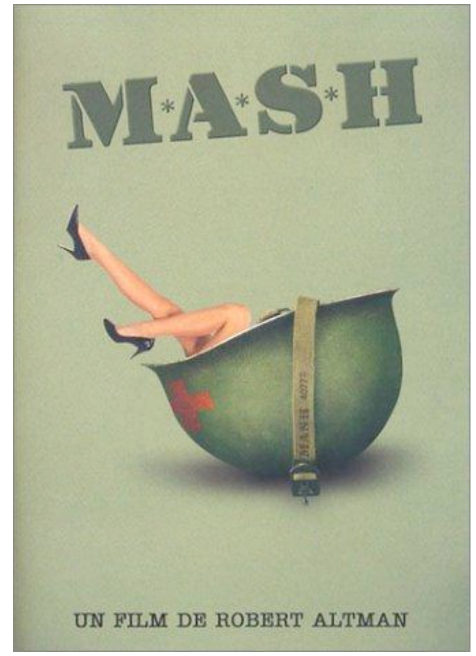
Multifunctional

Bio

Nanocomposite

Morphology-Based Modeling of Structures

M*A*S*H



- **M**aterial properties
  - Elastic, viscoelastic, plastic, moisture, temperature, *etc.*
- **A**nisotropy
  - Longitudinal, radial, and tangential directions (orthotropy)
- **S**tructure
  - Polar orthotropic, grain direction, density, cellular structure, knots, *etc.*
- **H**eterogeneity
  - Earlywood, latewood, fibers, ray cells, heartwood, knots, *etc.*

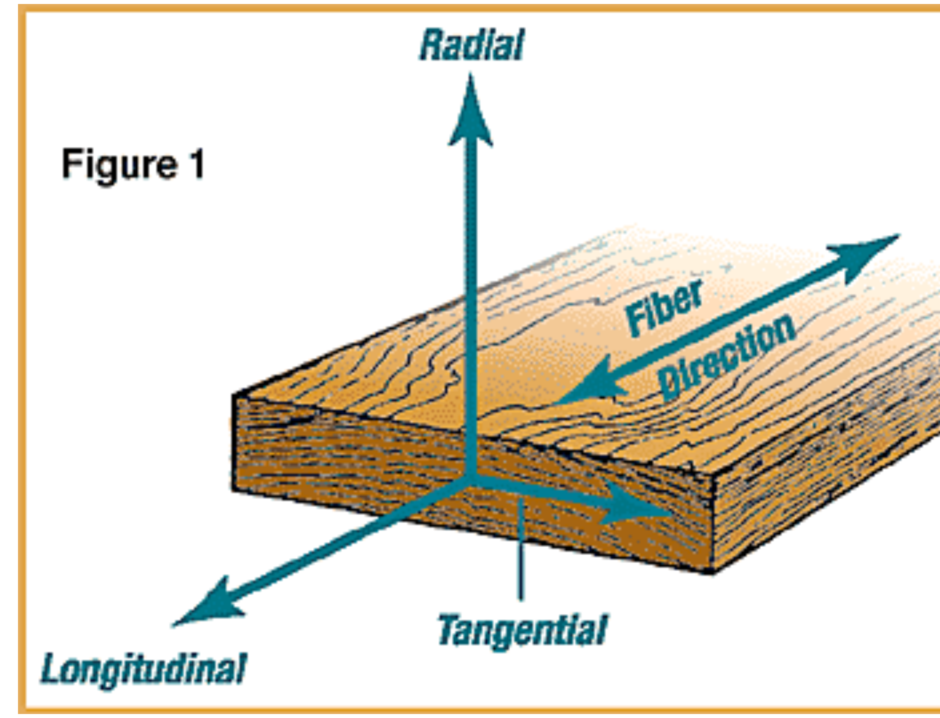
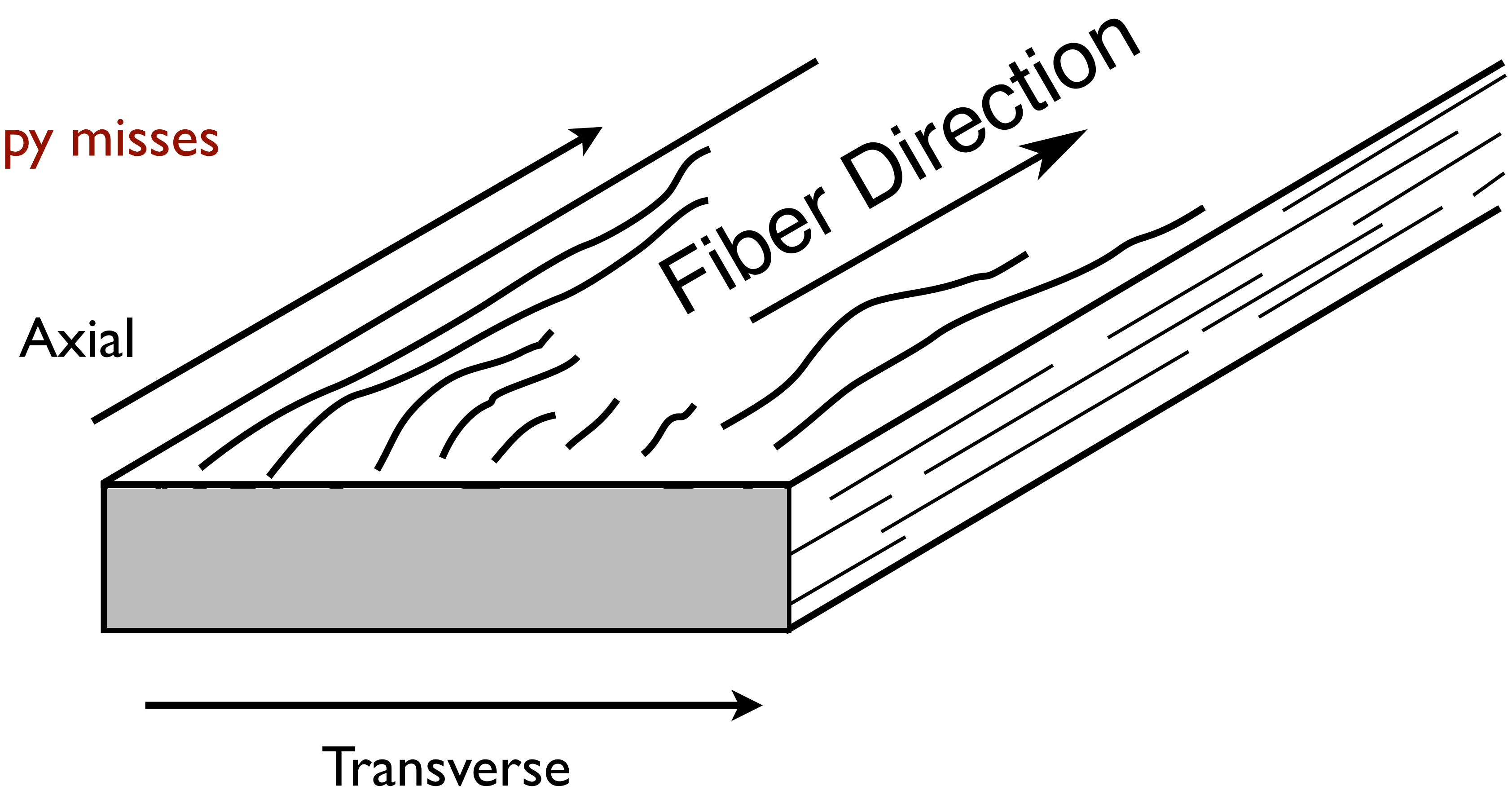


Figure 1

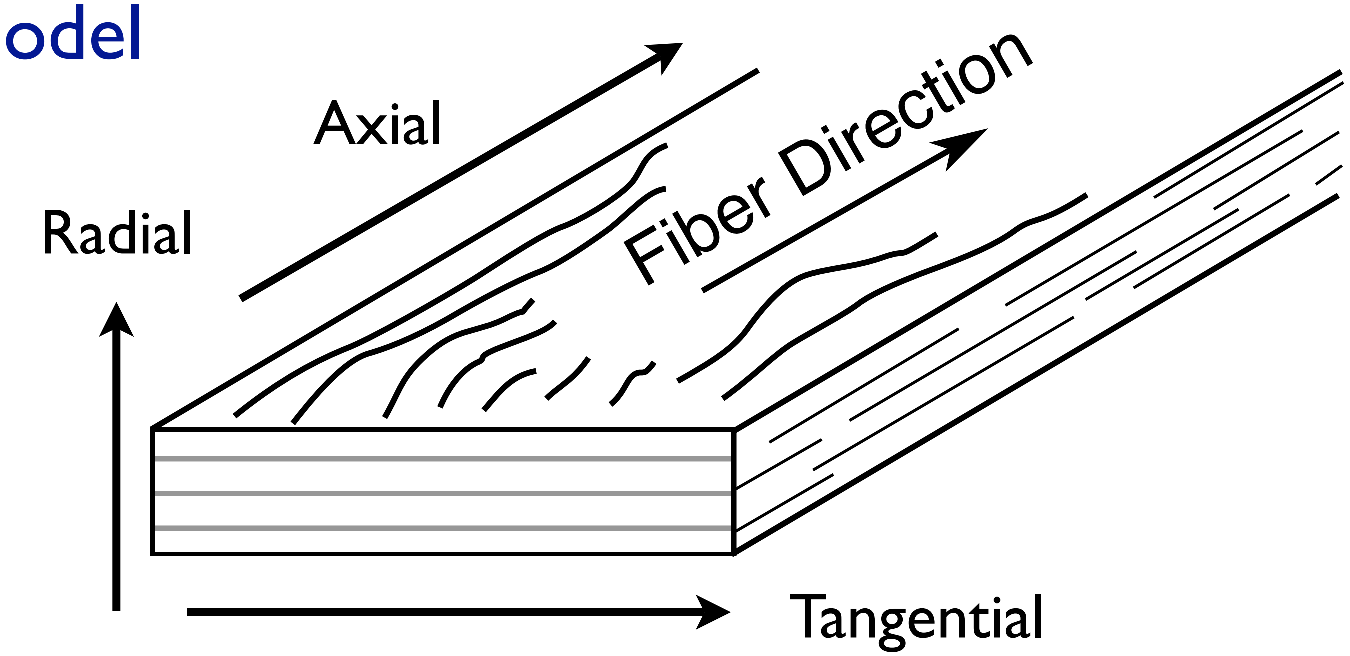
Modeling Methods

- How does any model handle M*A*S*H?
  - Lower case letter : some attempt, but crude approximation
  - Upper case letter : serious attempt, less approximate
  - Dash (–) : ignores that issue, may mean model is inadequate
- Transversely isotropic model
  - **m a – –**
  - Transverse isotropy misses low G_{RT}

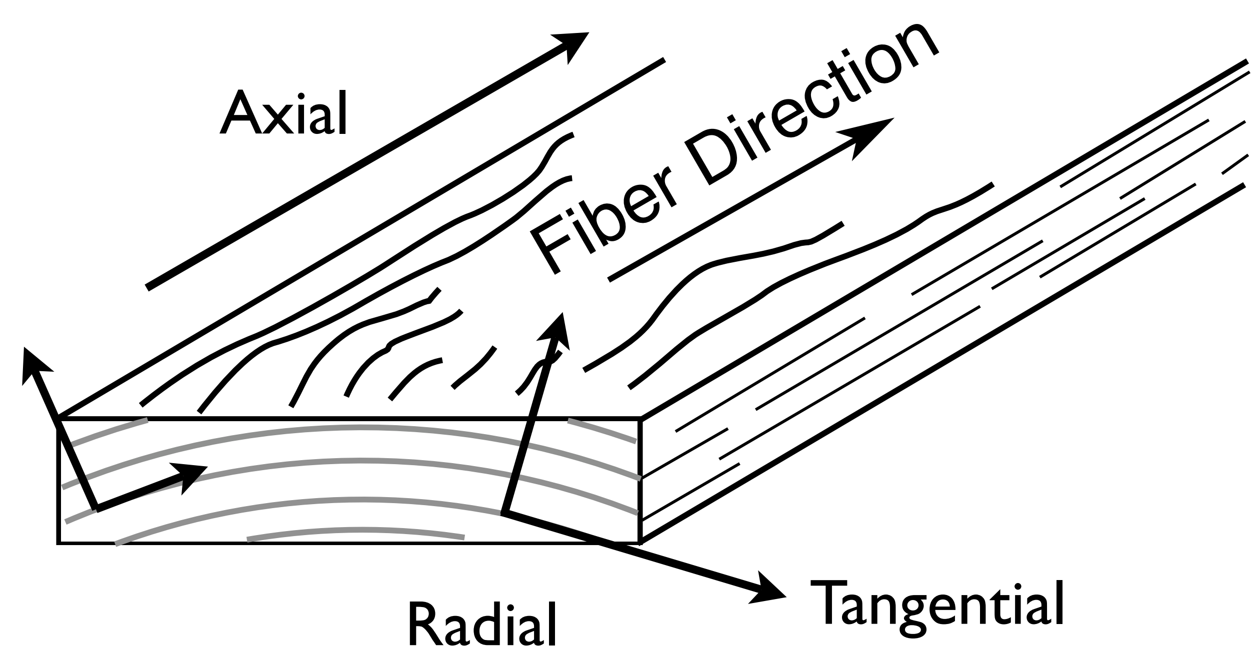


Modeling Methods

- Rectilinear orthotropic model
  - **m A – –**
  - Ignores actual structure

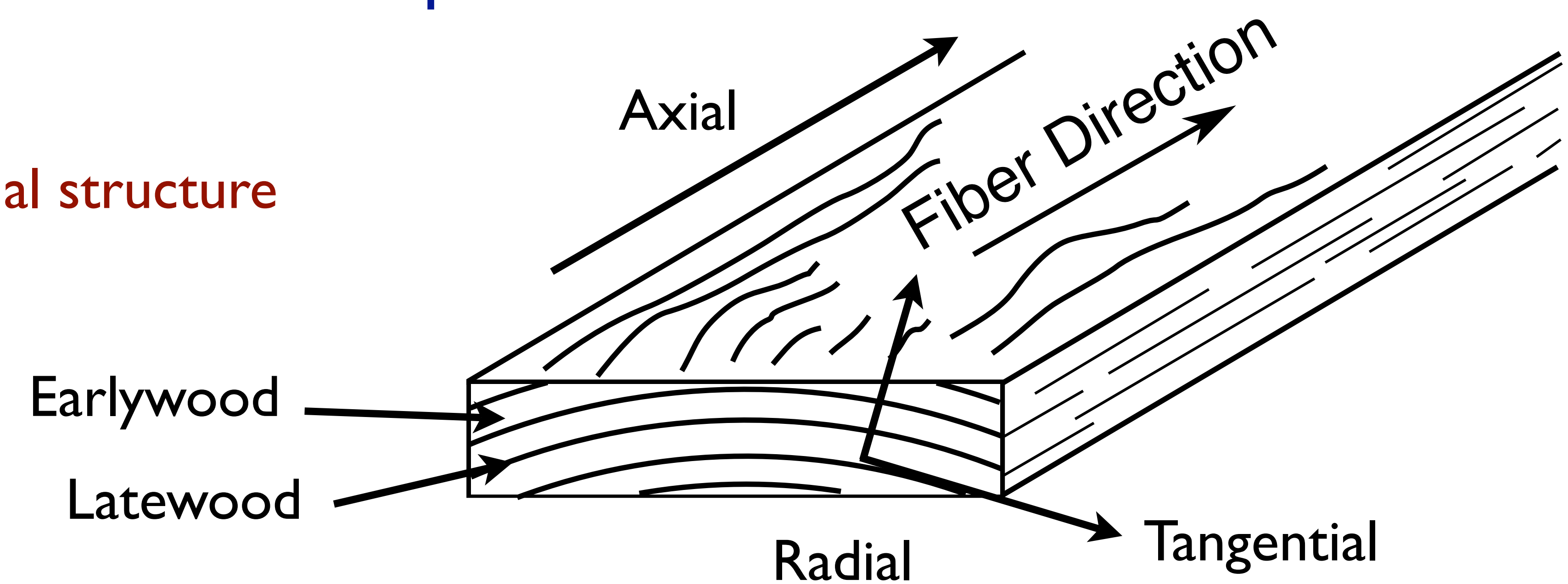


- Polar orthotropic model
  - **m A s –**
  - Ignores heterogeneity

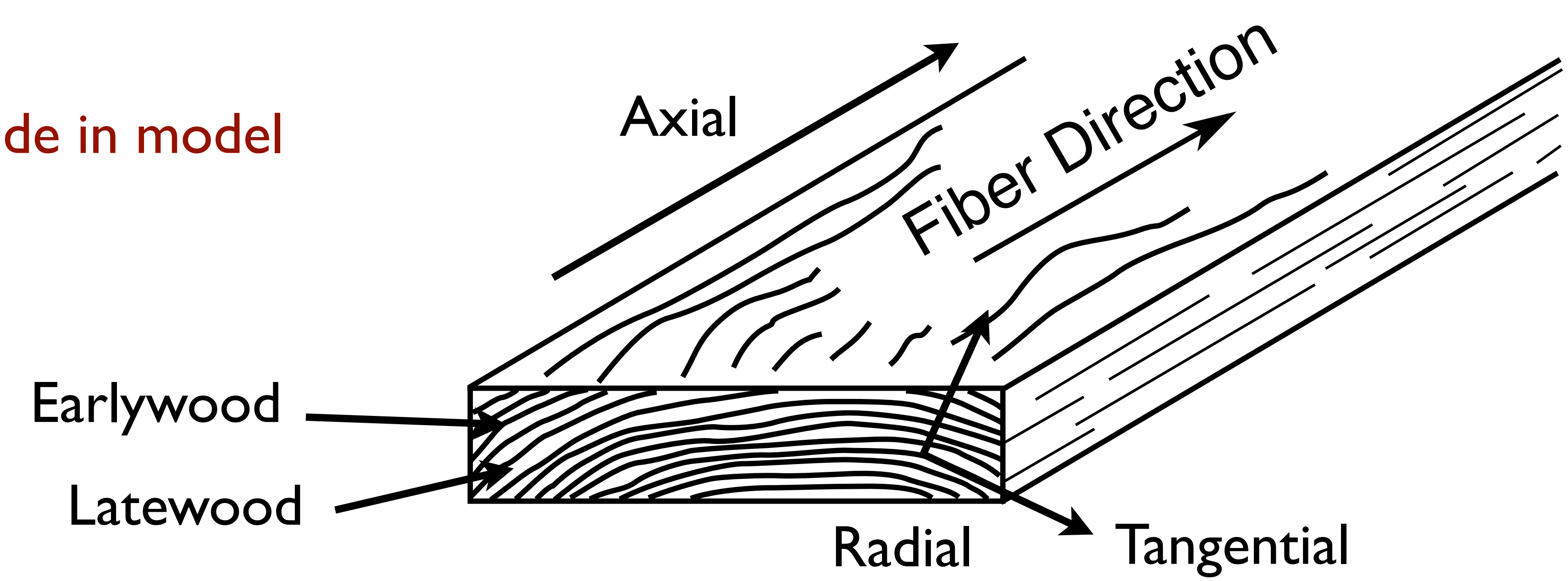


Modeling Methods

- Heterogeneous polar orthotropic model
  - **m A s h**
  - Approximate actual structure

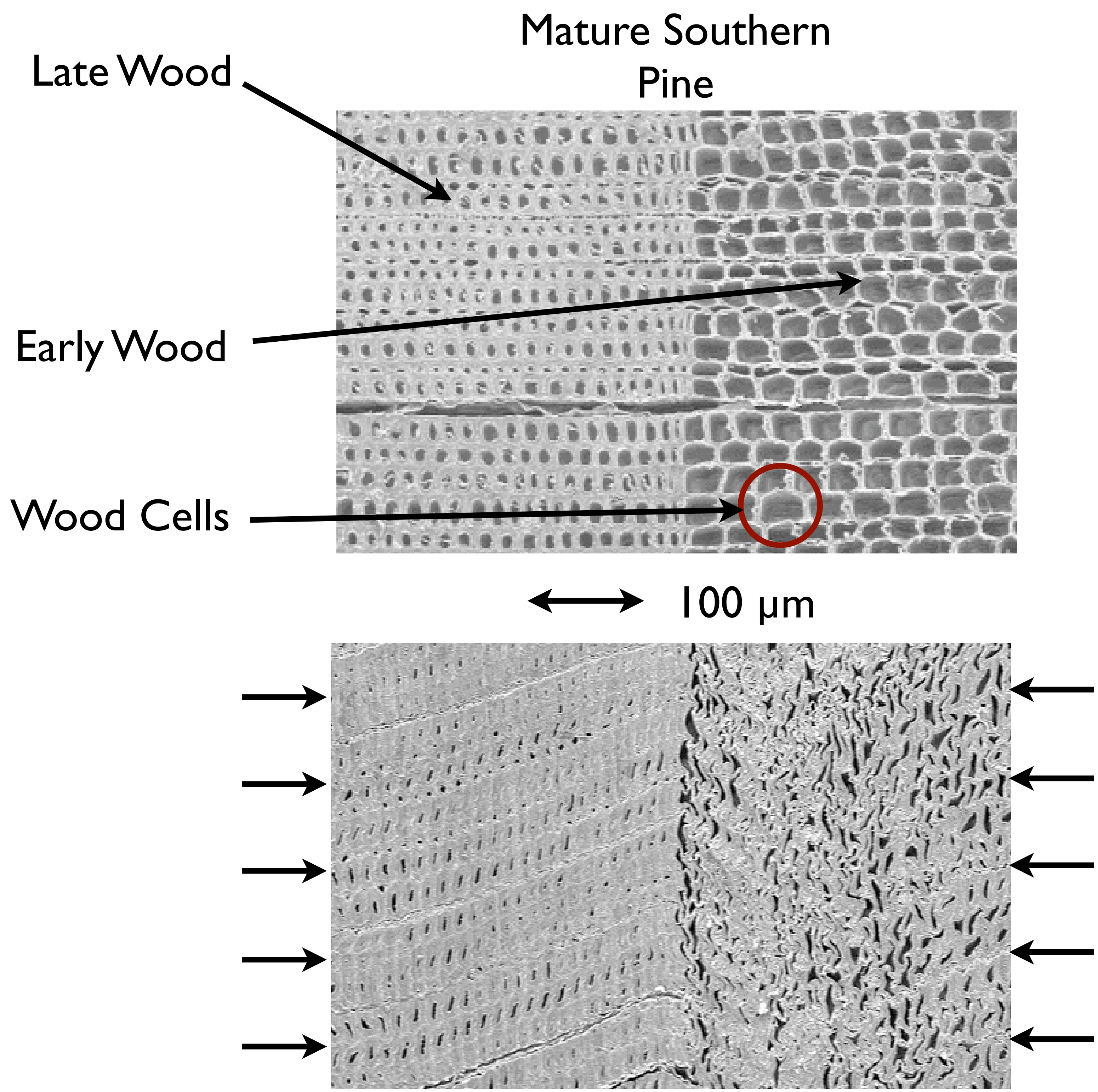


- Realistic heterogeneous polar orthotropic model
  - **m A S h**
  - Challenge to include in model



Transverse Compression in Wood

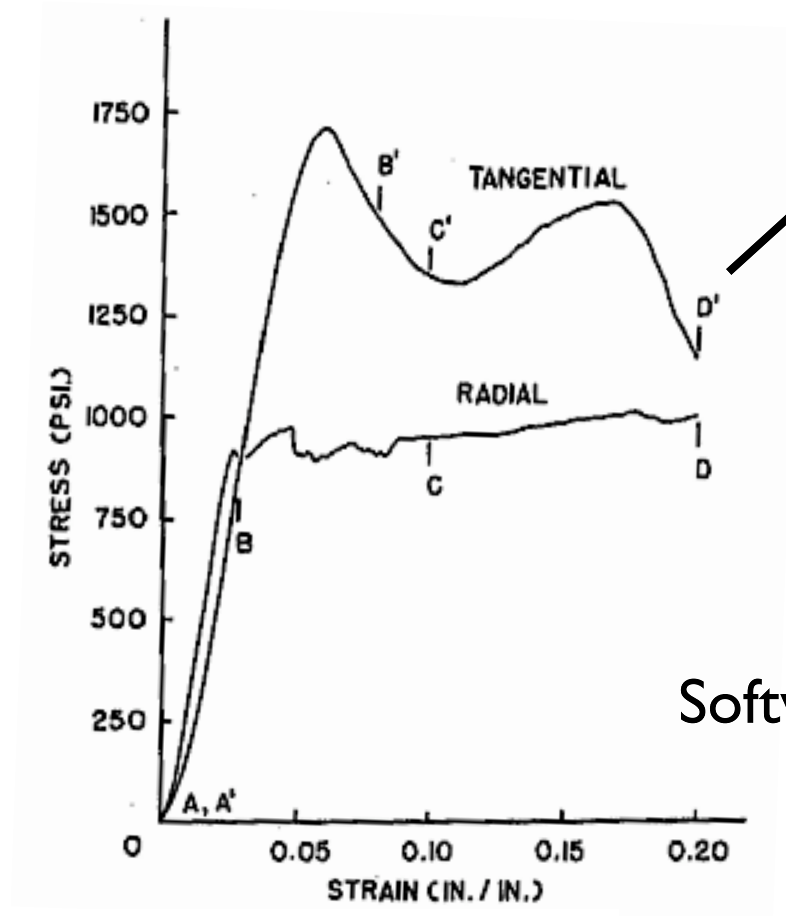
- **Motivations**
  - Compression present in structures
  - Composite processing
  - Wood densification
  - Basic science for numerical modeling of cellular materials

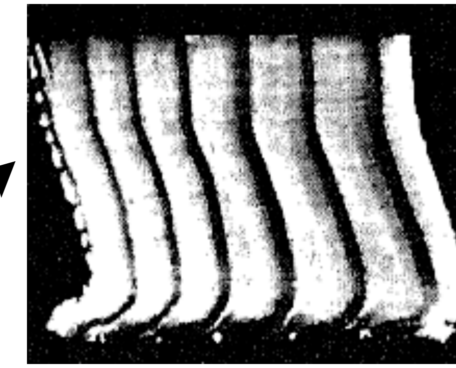


E.V. Kultikova, MS Thesis, VPI (1999)

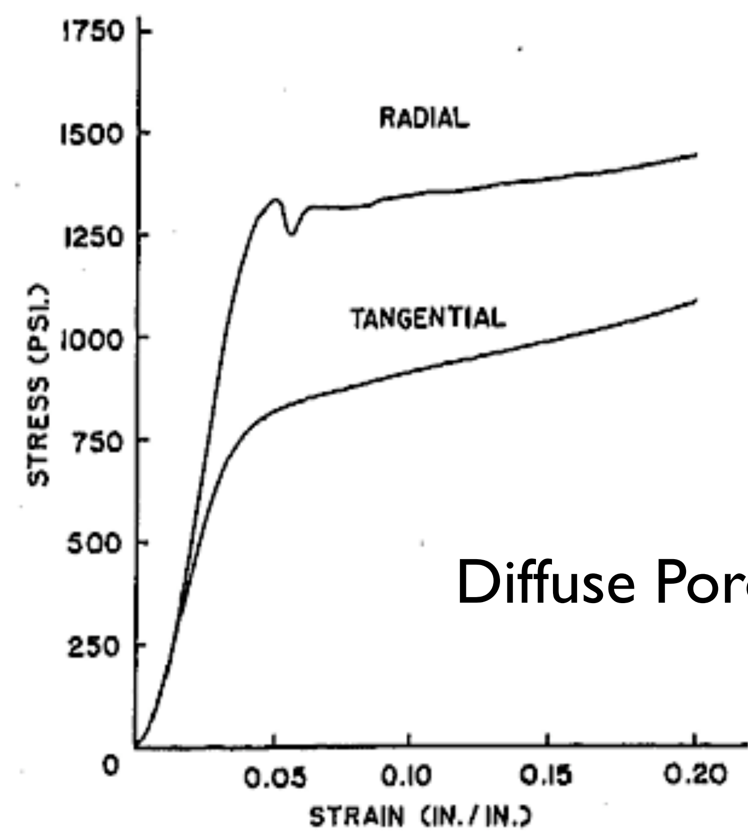
Experimental Observations

- **Some References**
  - Bodig (1963, 1965, 1966), Kennedy (1968), Kunesh (1968), Gibson, *et al.* (1981), Easterling, *et al.* (1982)
- **Key Dependencies**
  - Anatomical features
    - Softwood
    - Hardwood
    - Earlywood and latewood
    - Ray cells
  - Loading direction





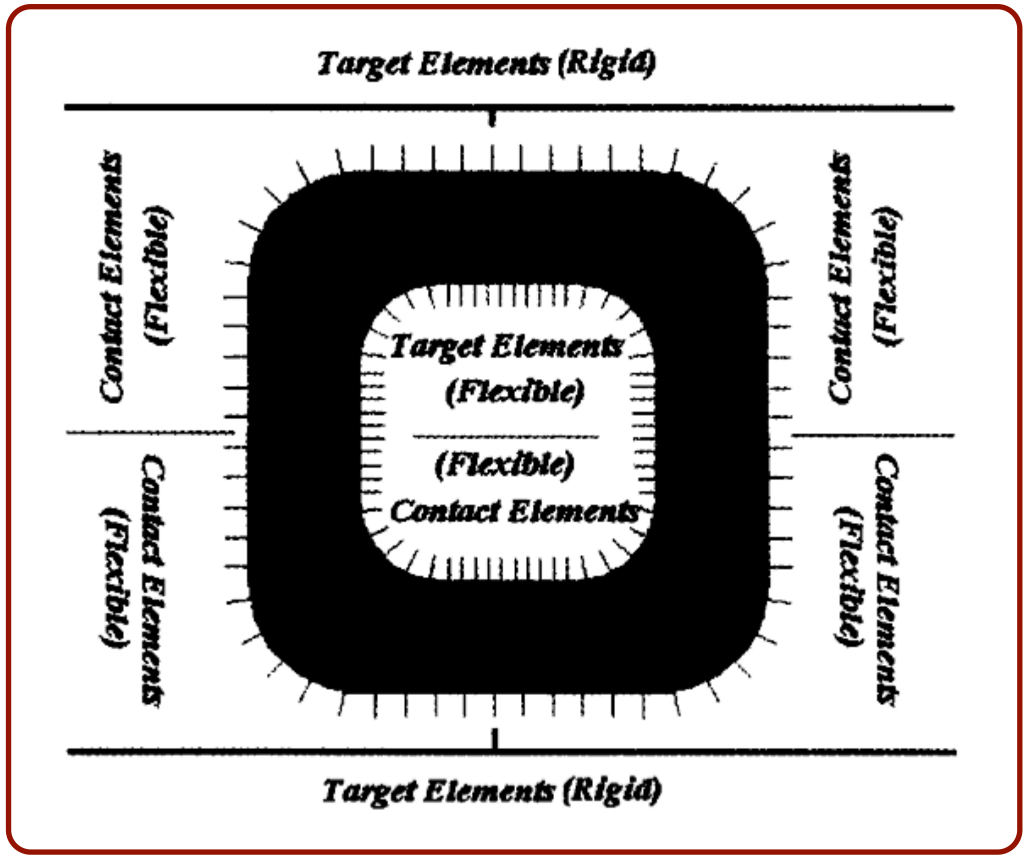
Softwood: Douglas Fir



Diffuse Porous Hardwood: Red Alder

FEA of Transverse Compression

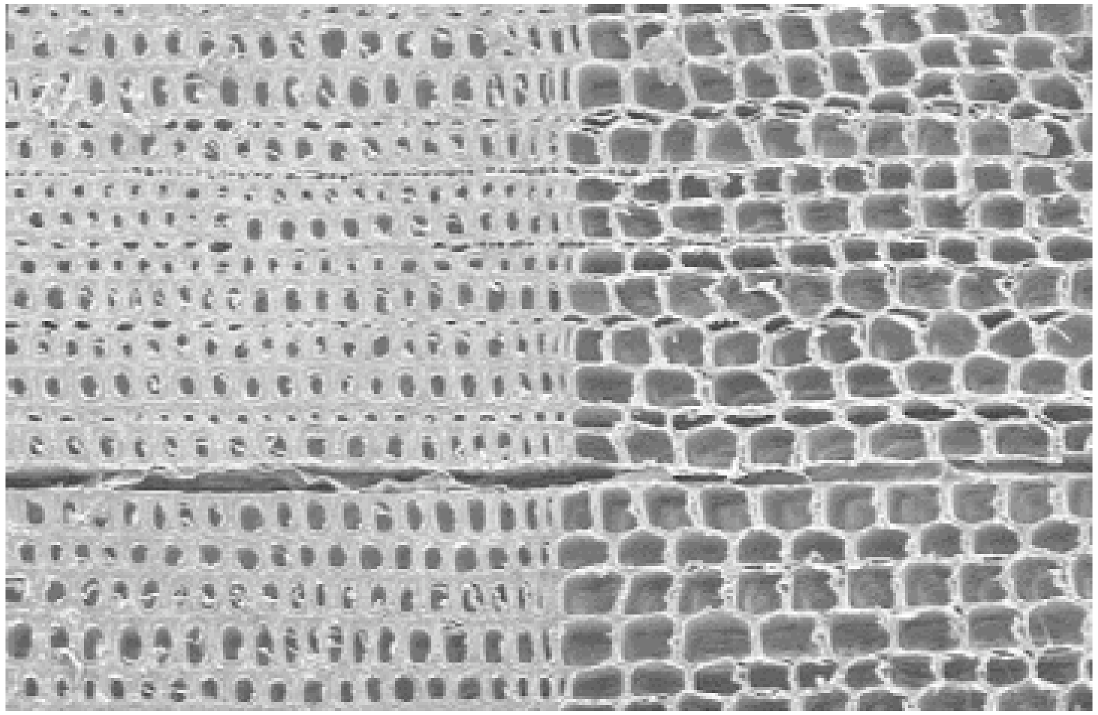
- Shiari (2004)
  - Single cell compression
  - Linear elastic, with contact (but difficult)



- Problems with FEA of Realistic Wood Structures
  - Meshing realistic morphology
  - Large deformation/mesh distortion
  - Cell-wall contact
- Why MPM
  - MPM simulation of compaction of foam - Bardenhagen, Brydon, and Guilkey (2005)
  - Easy to discretize complex morphologies
  - Automatically handles contact

Material Point Method Analysis

Loblolly Pine



E.V. Kultikova, MS Thesis, VPI (1999)

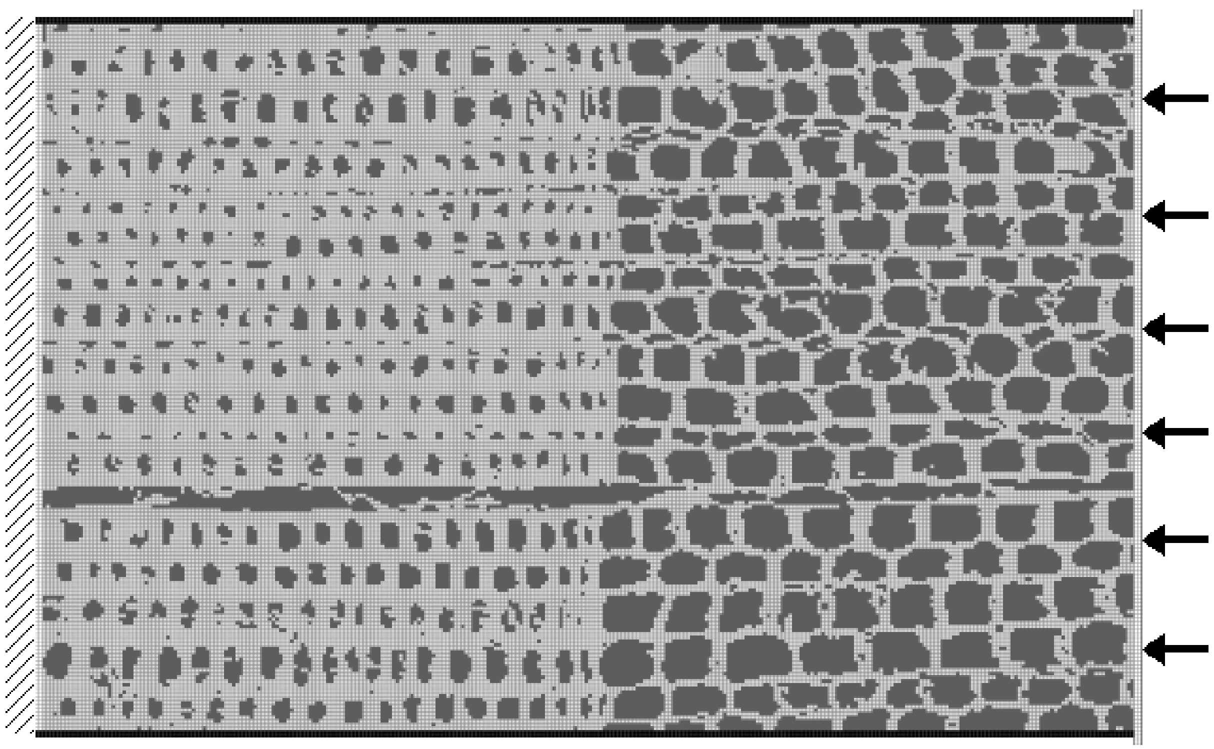
- Microscopy of wood specimen
- Digitize into BMP file at desired resolution
- Convert pixels to material points

m - S h

- Virtual compression test in desired directions.
- Interpretation of results or analysis of experiments

Material Point Method Analysis

Loblolly Pine



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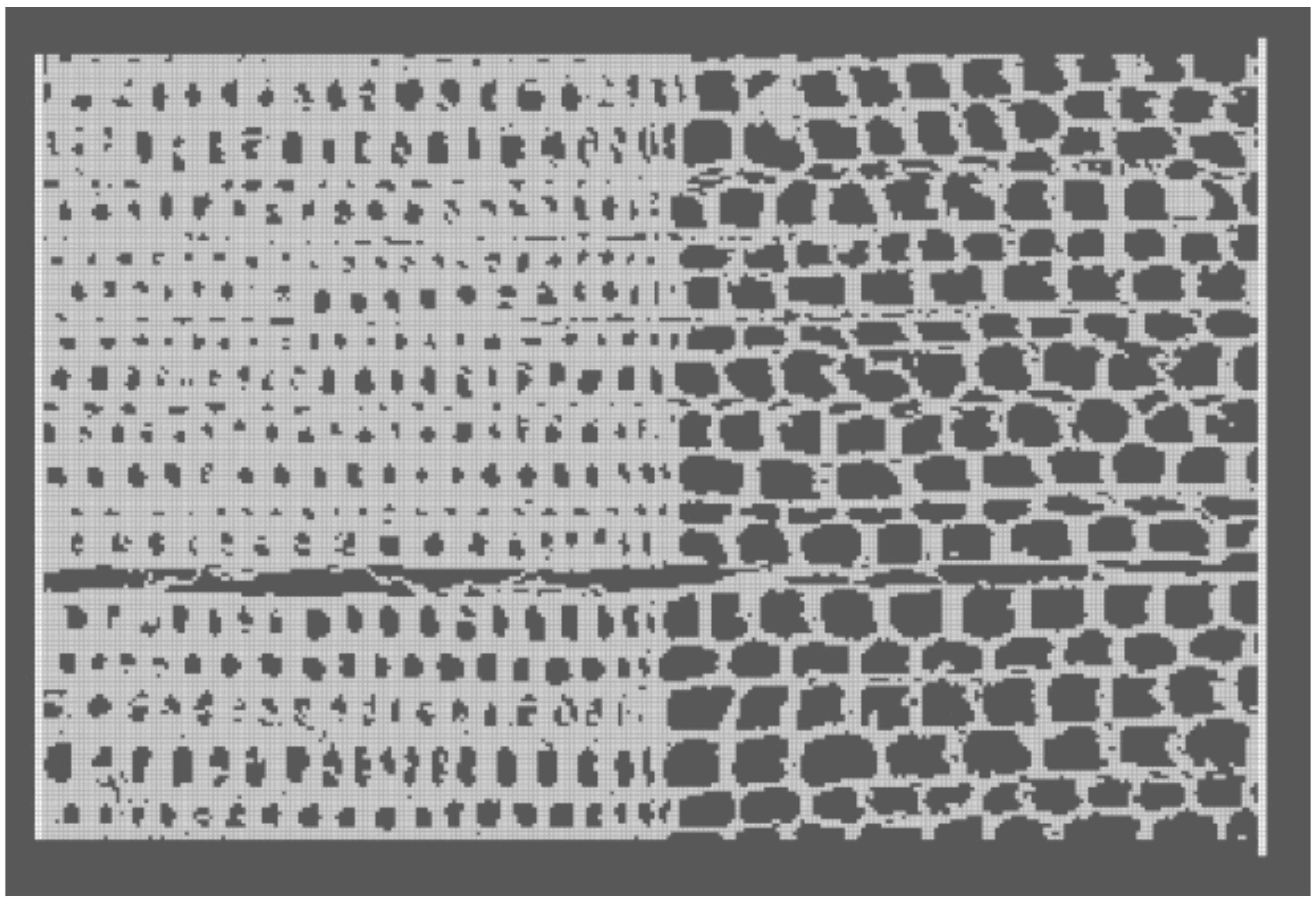

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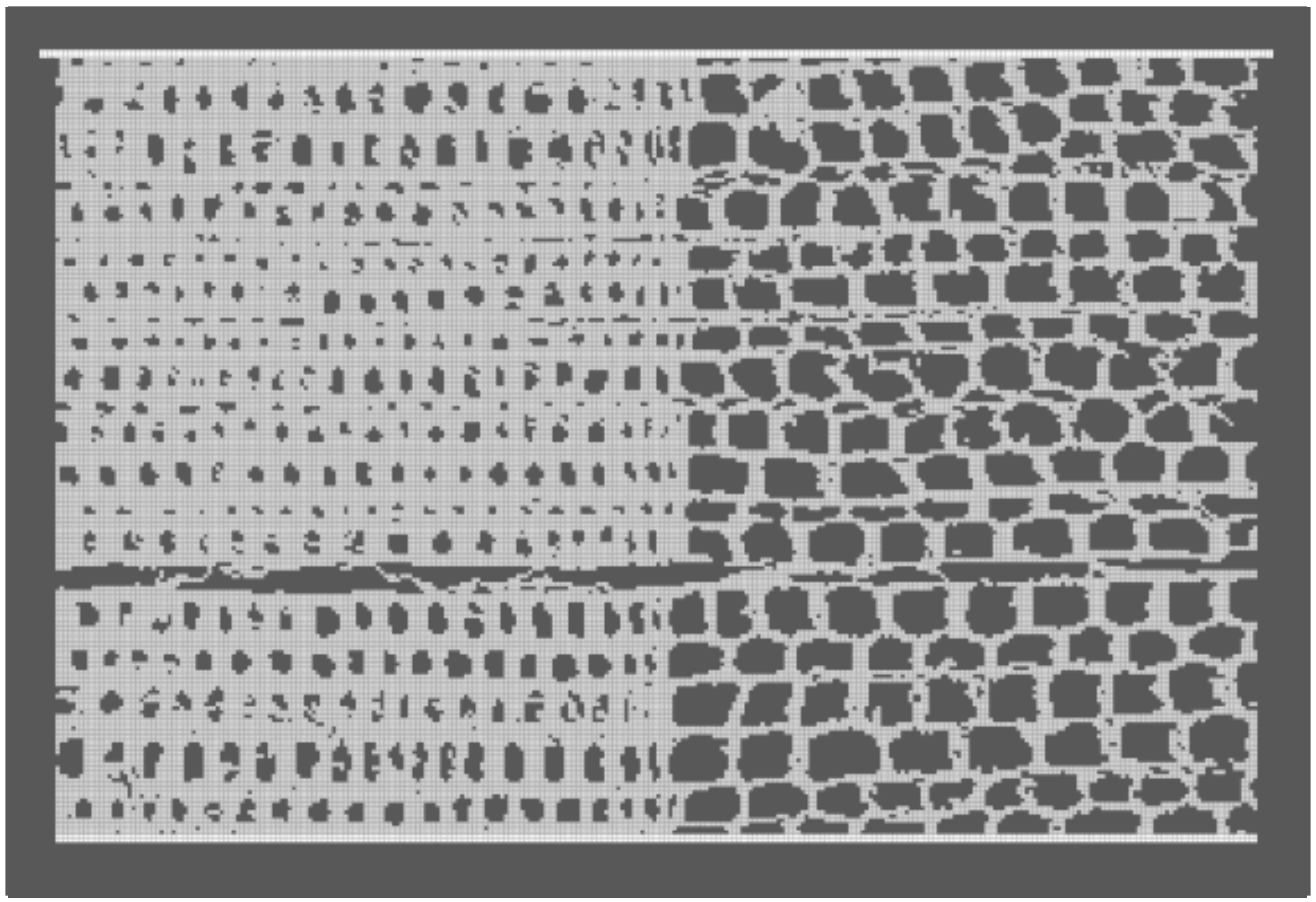

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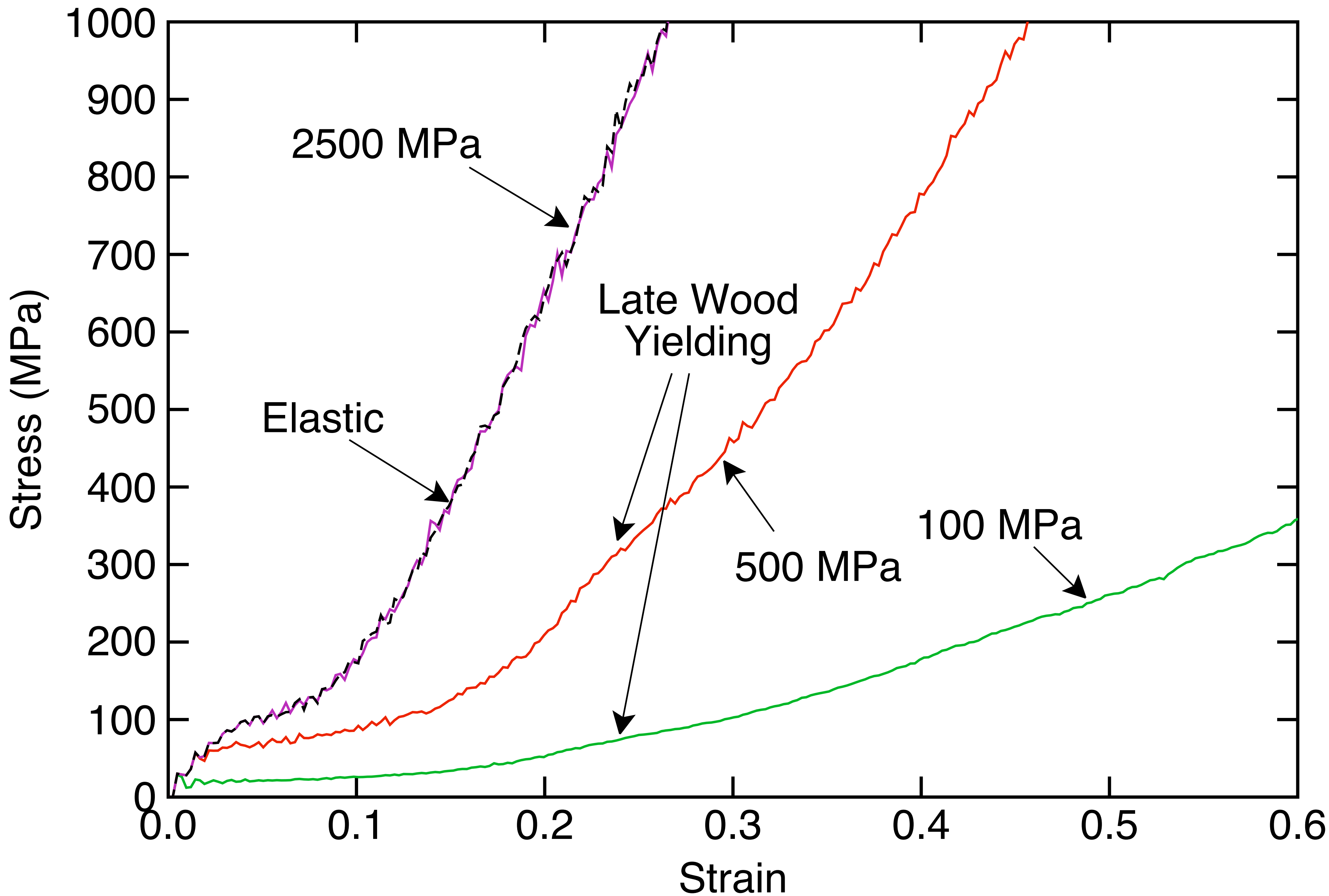
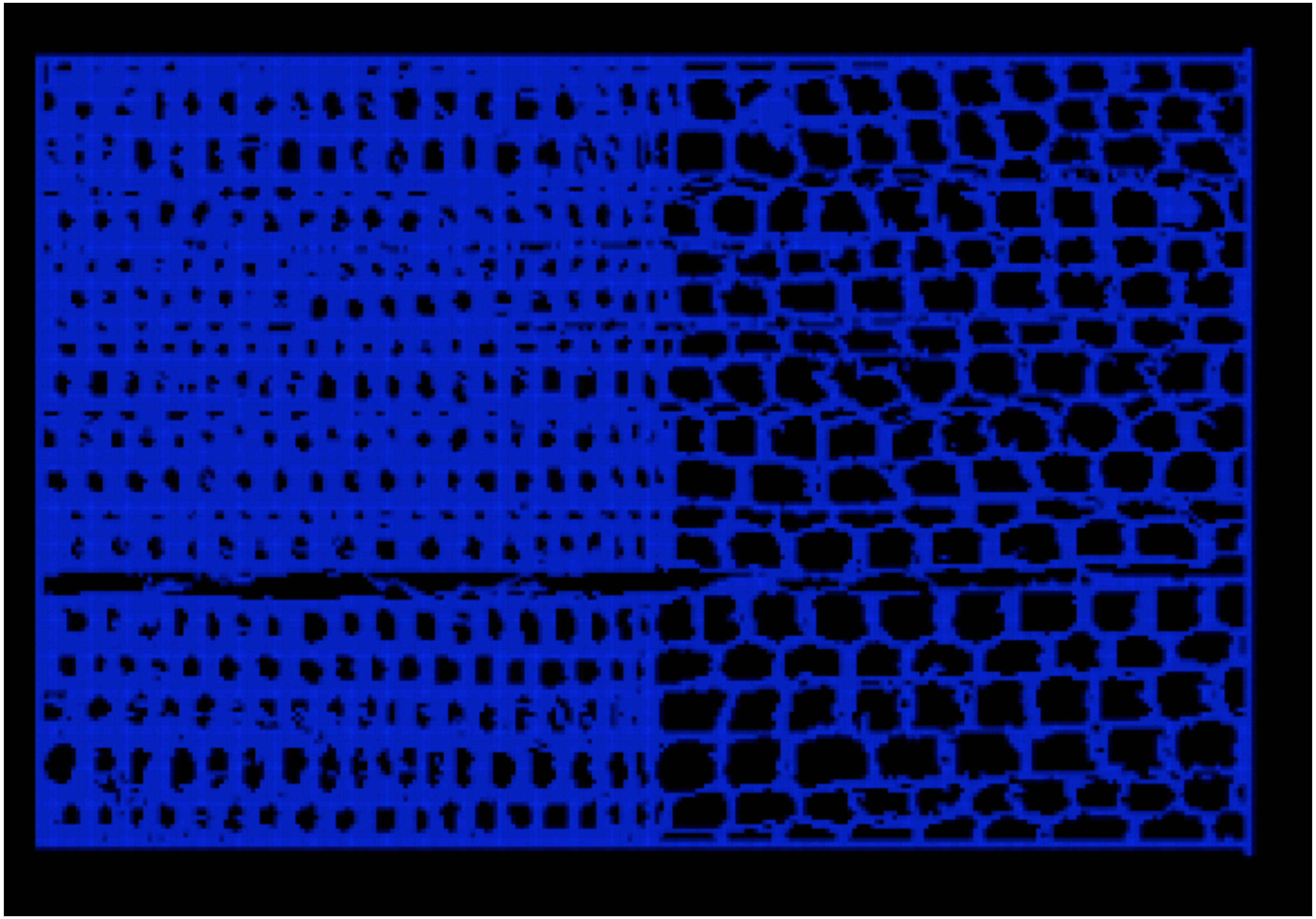
Loblolly Pine - Radial Loading



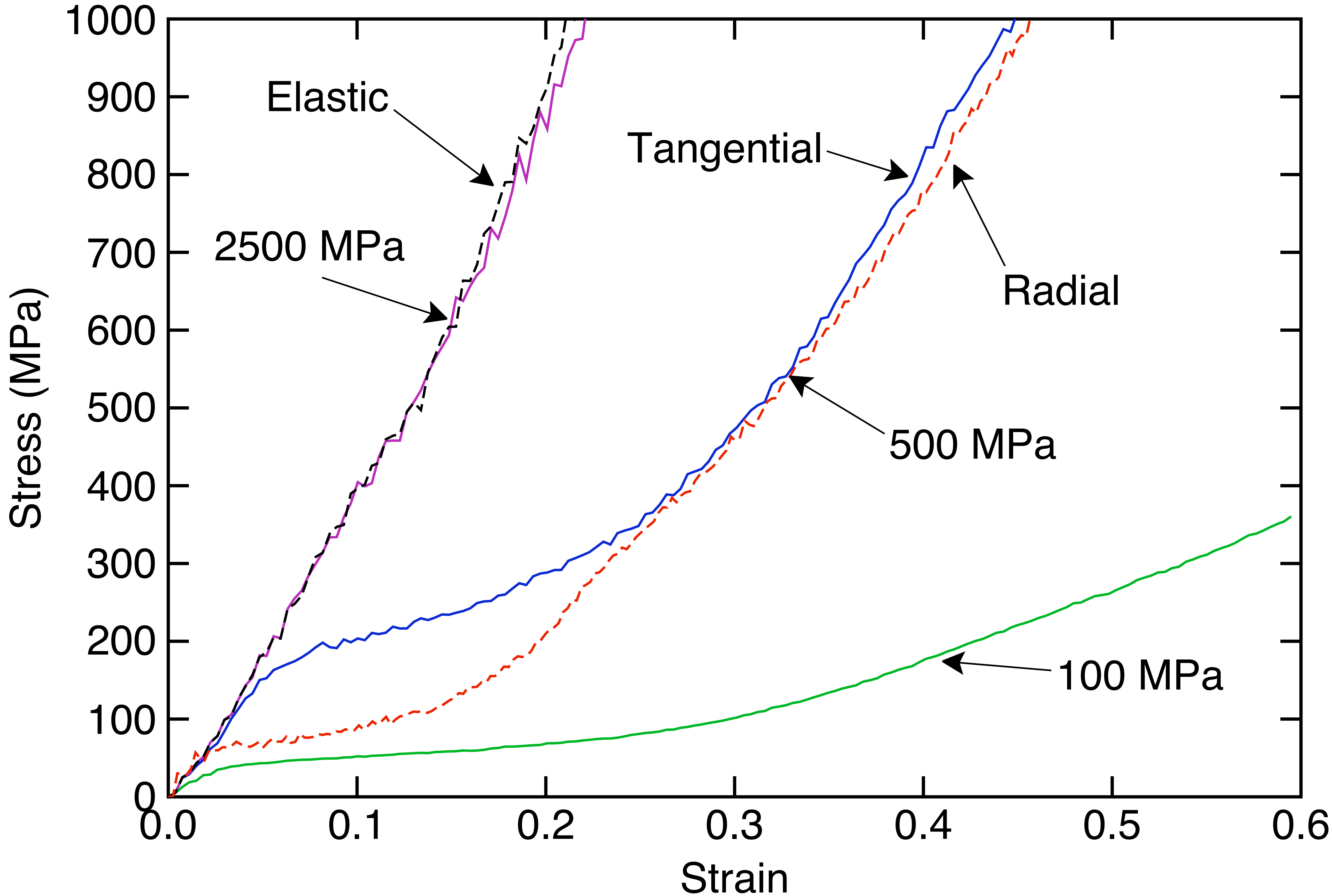
Cell Wall: E = 10.6 GPa, ν = 0.33, ρ = 1.5 g/cm^3, elastic-plastic with various yield stresses

Radial loading at 10 m/sec (<0.4% wave speed)

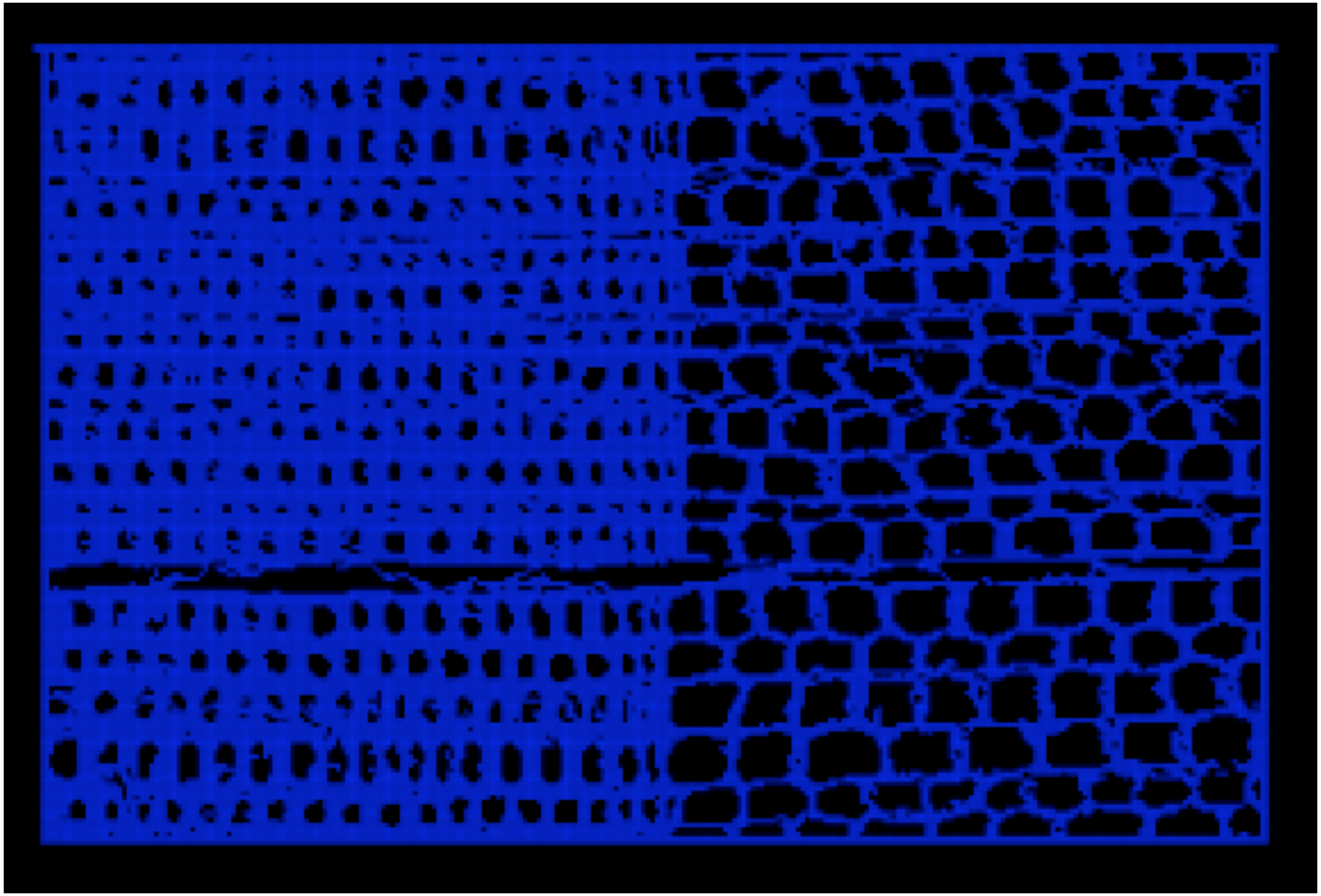
Plastic Deformation



Loblolly Pine - Tangential Loading

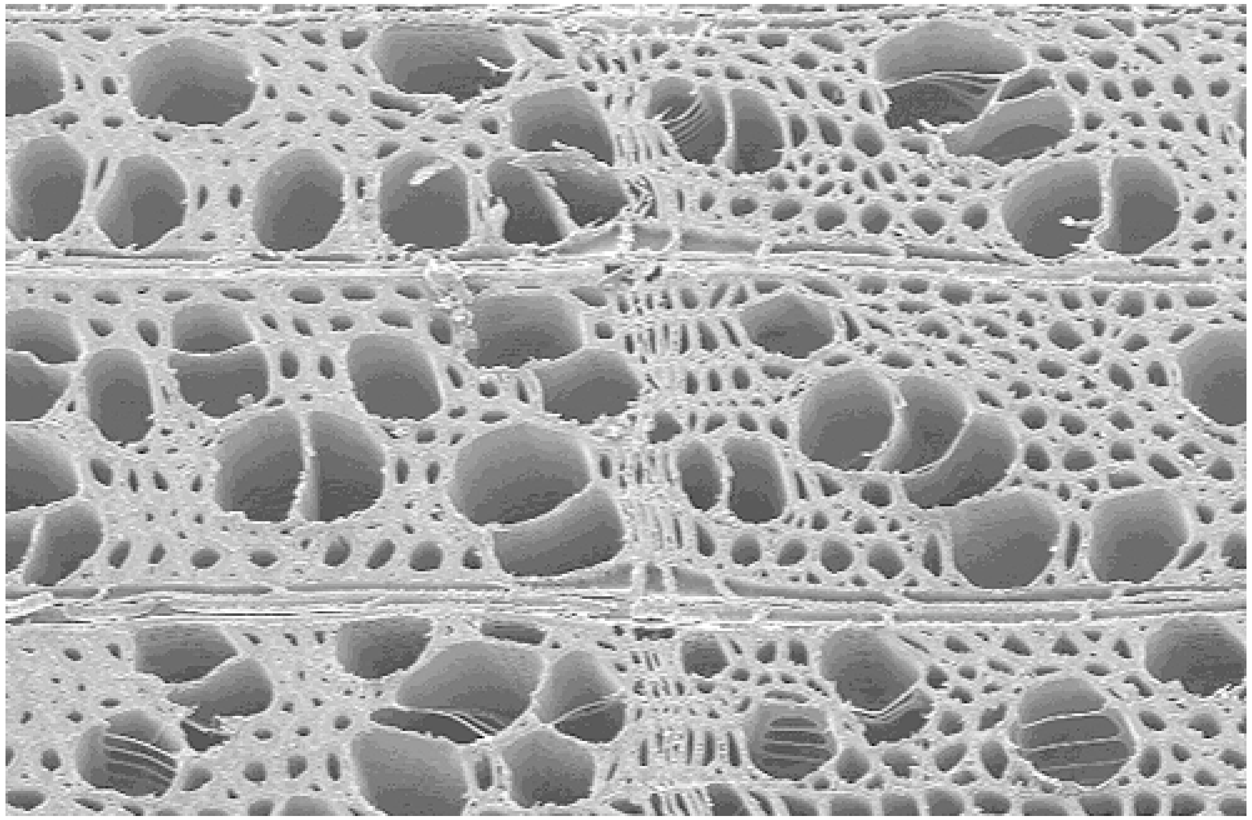


Plastic Deformation



Hardwood Compression

Yellow Poplar

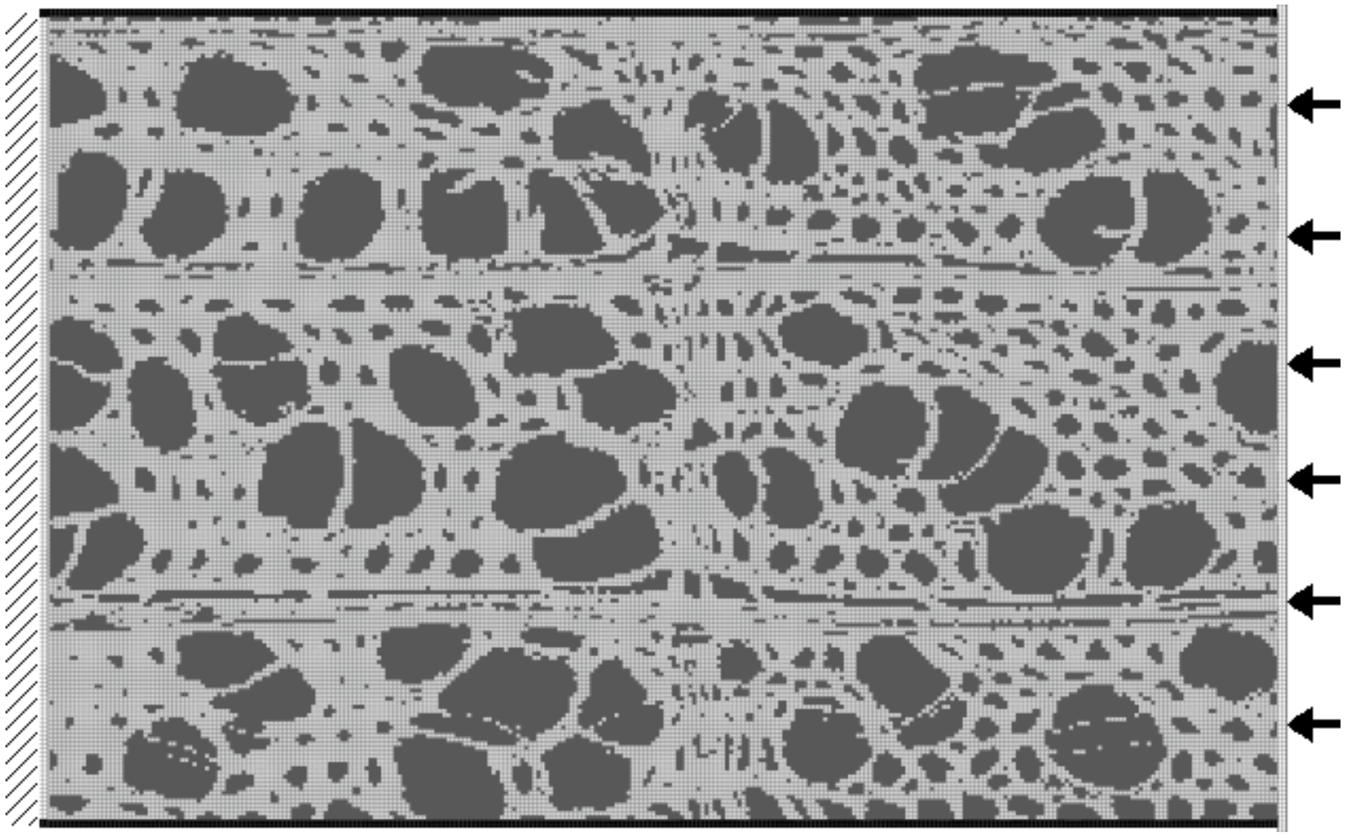


E.V. Kultikova, MS Thesis, VPI (1999)

- Mature yellow poplar
  - Diffuse porous hardwood
  - Wider ray cells
- Digitize to MPM model
- Load in radial or tangential directions
- Examine stress state and compare to softwood results

Hardwood Compression

Yellow Poplar



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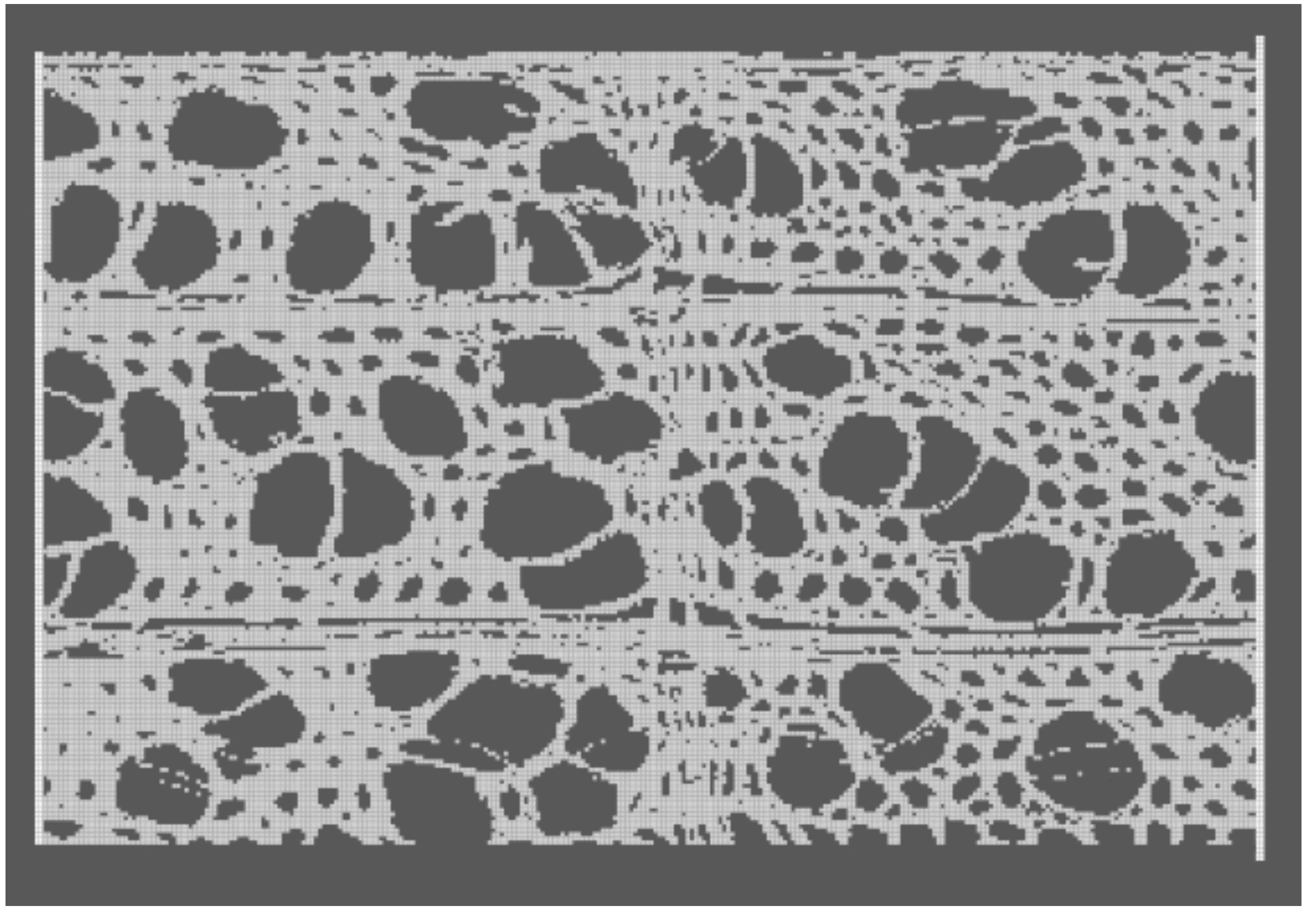

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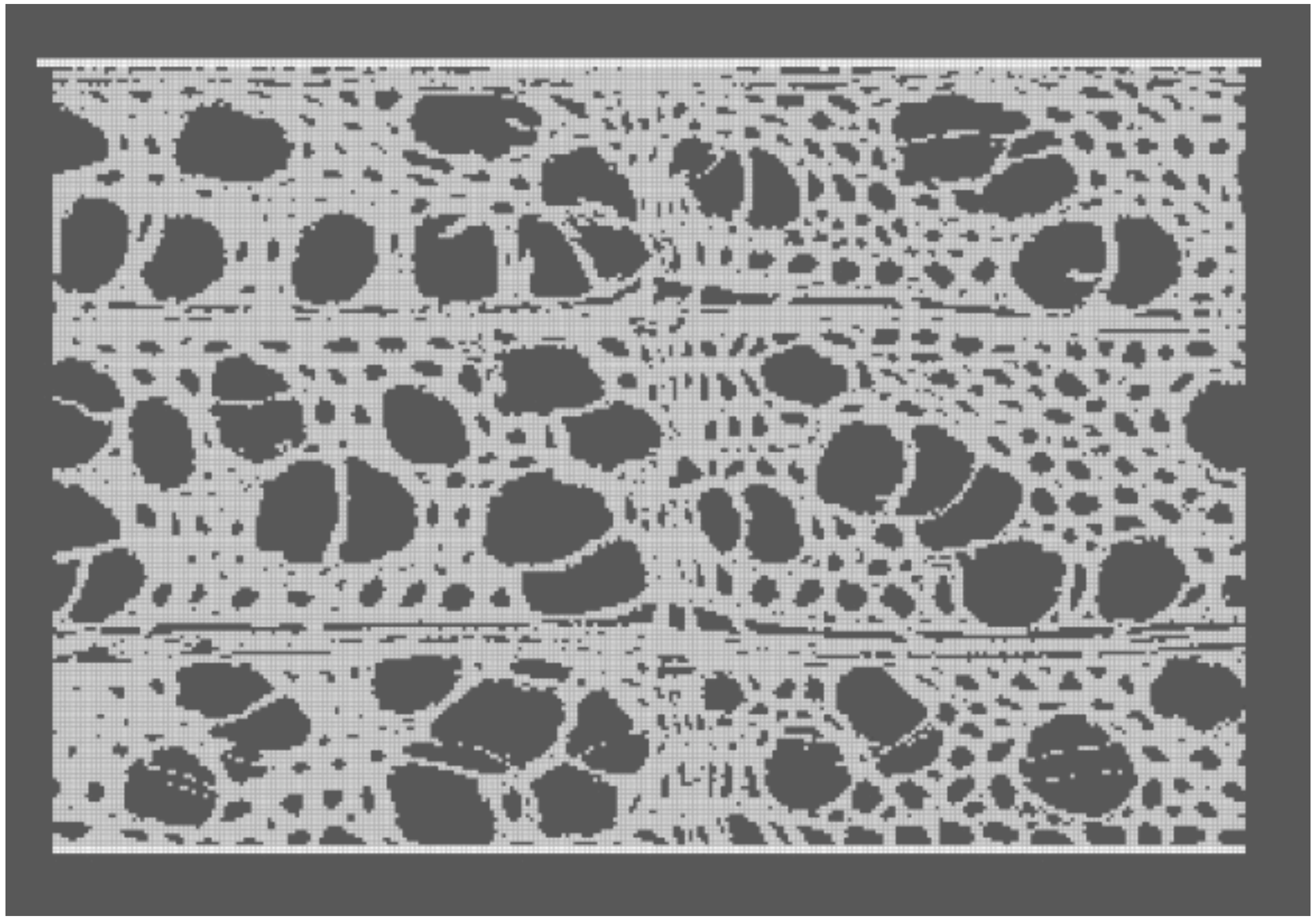

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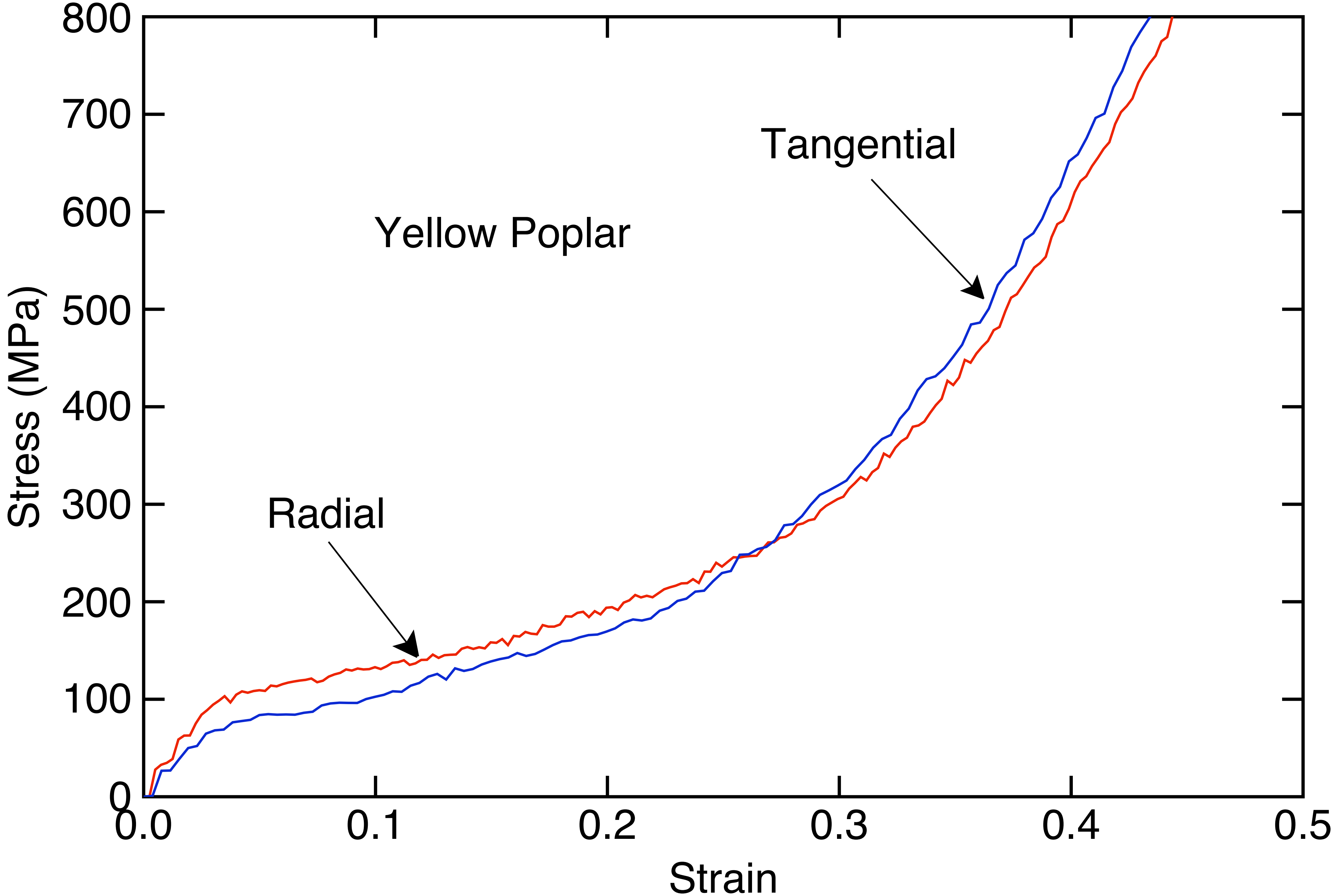
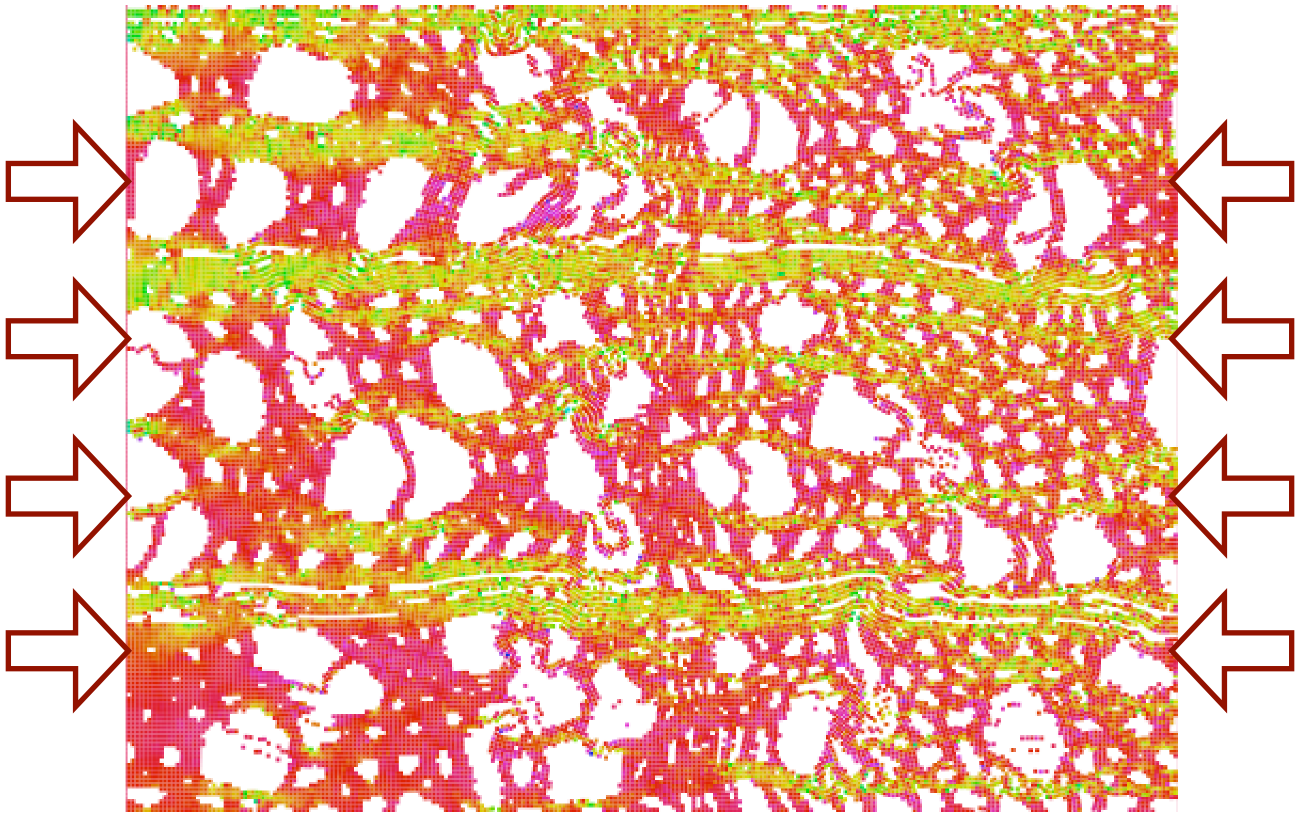
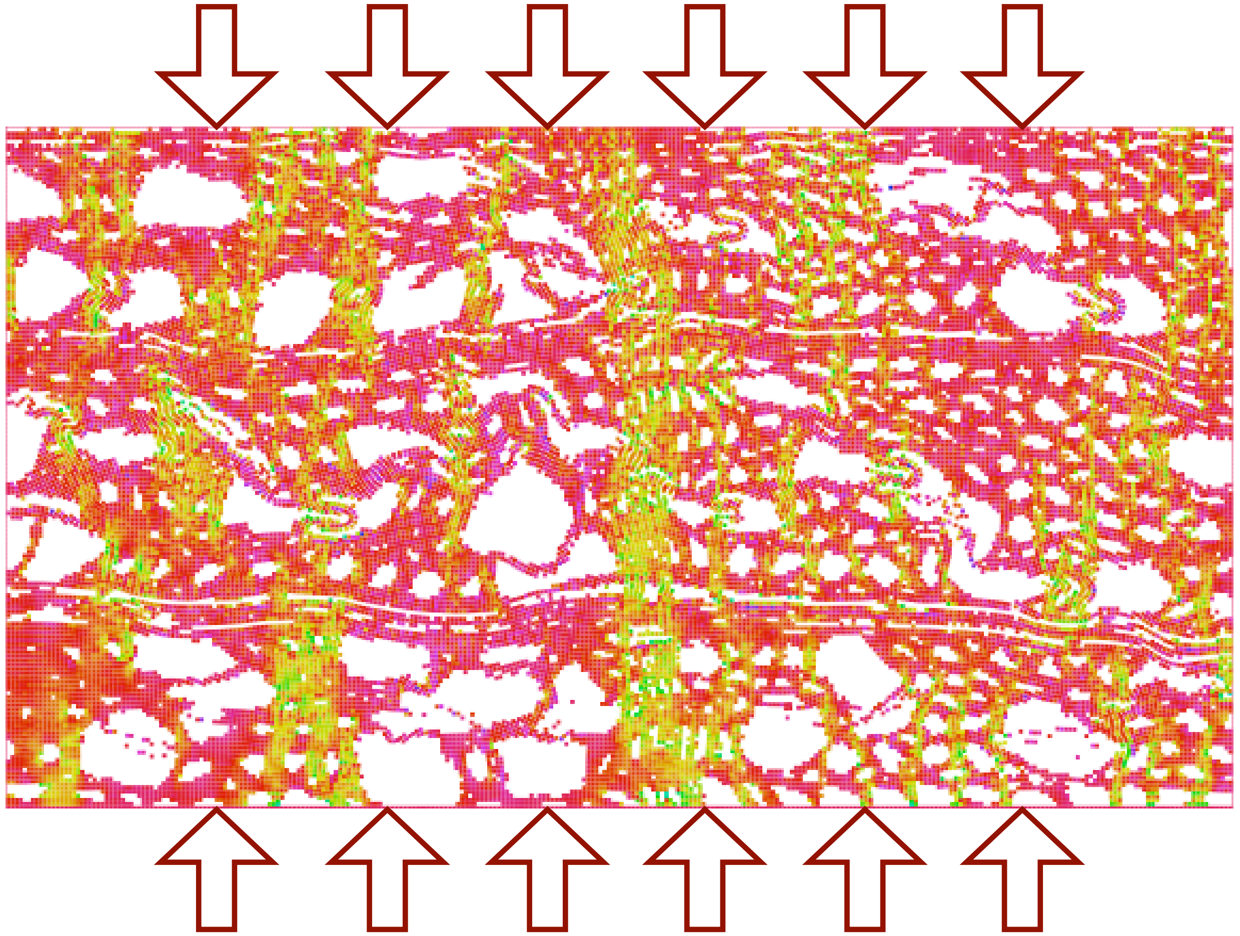


Load Bearing Paths



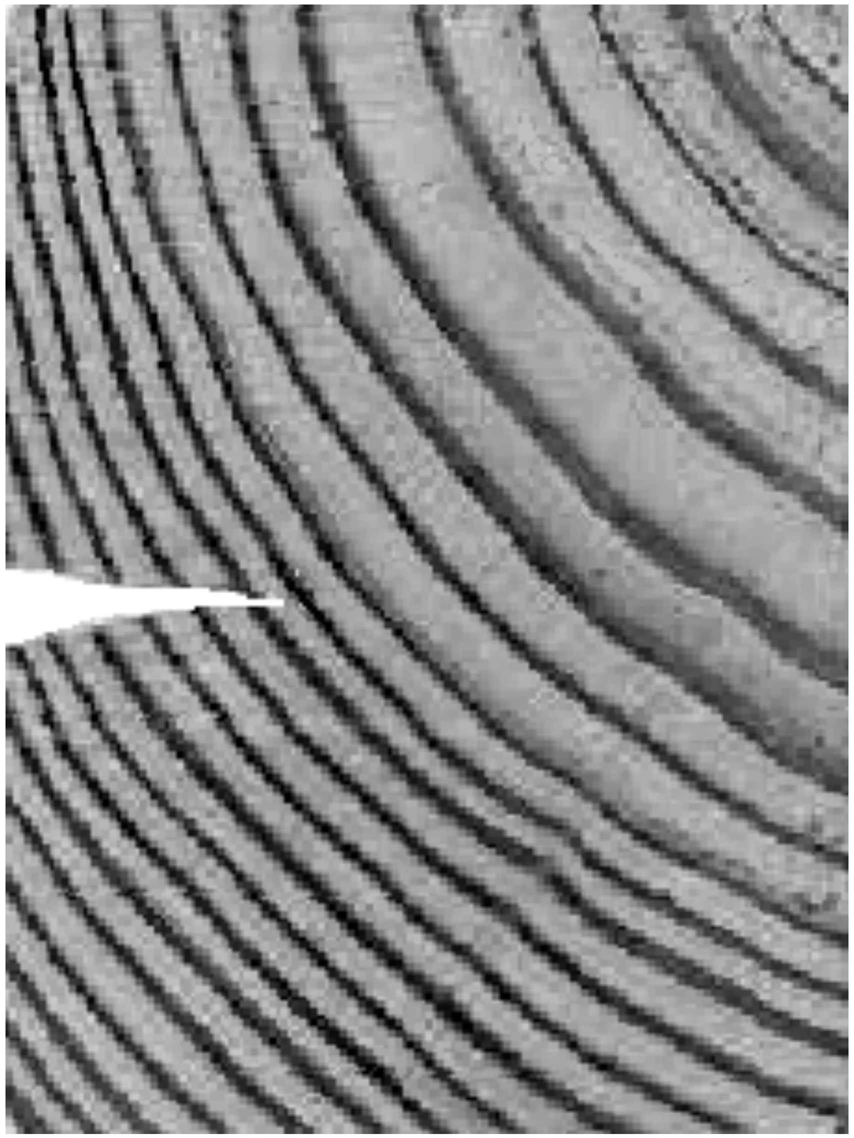
Radial Loading



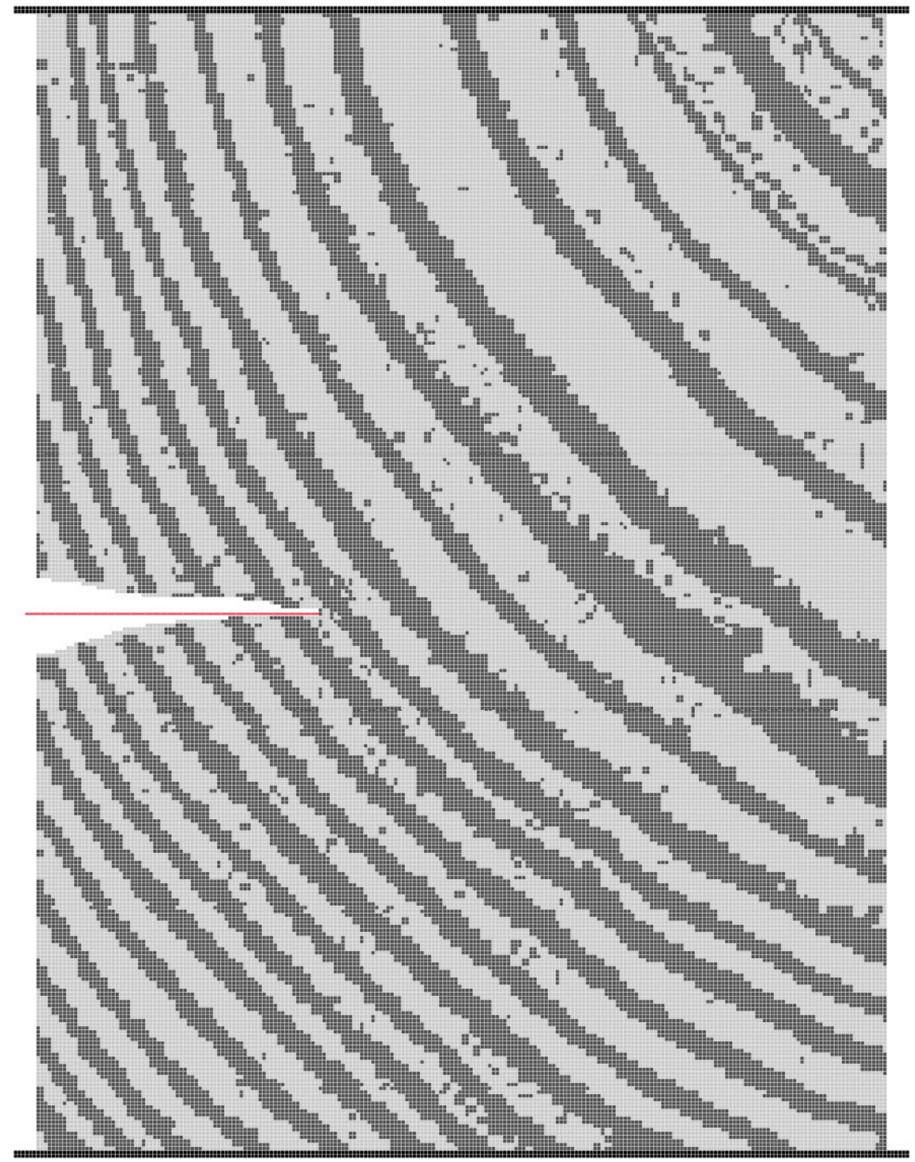
Tangential Loading

Transverse Fracture of Wood

Actual Specimen

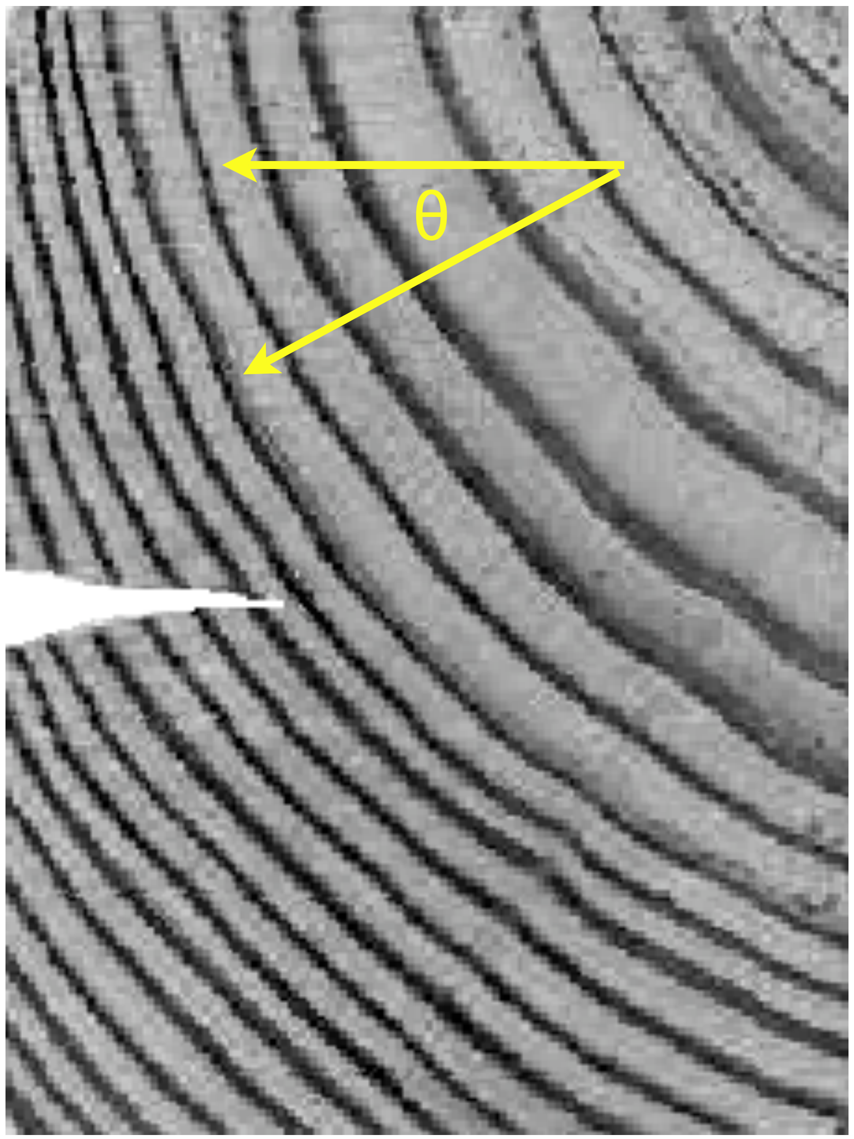


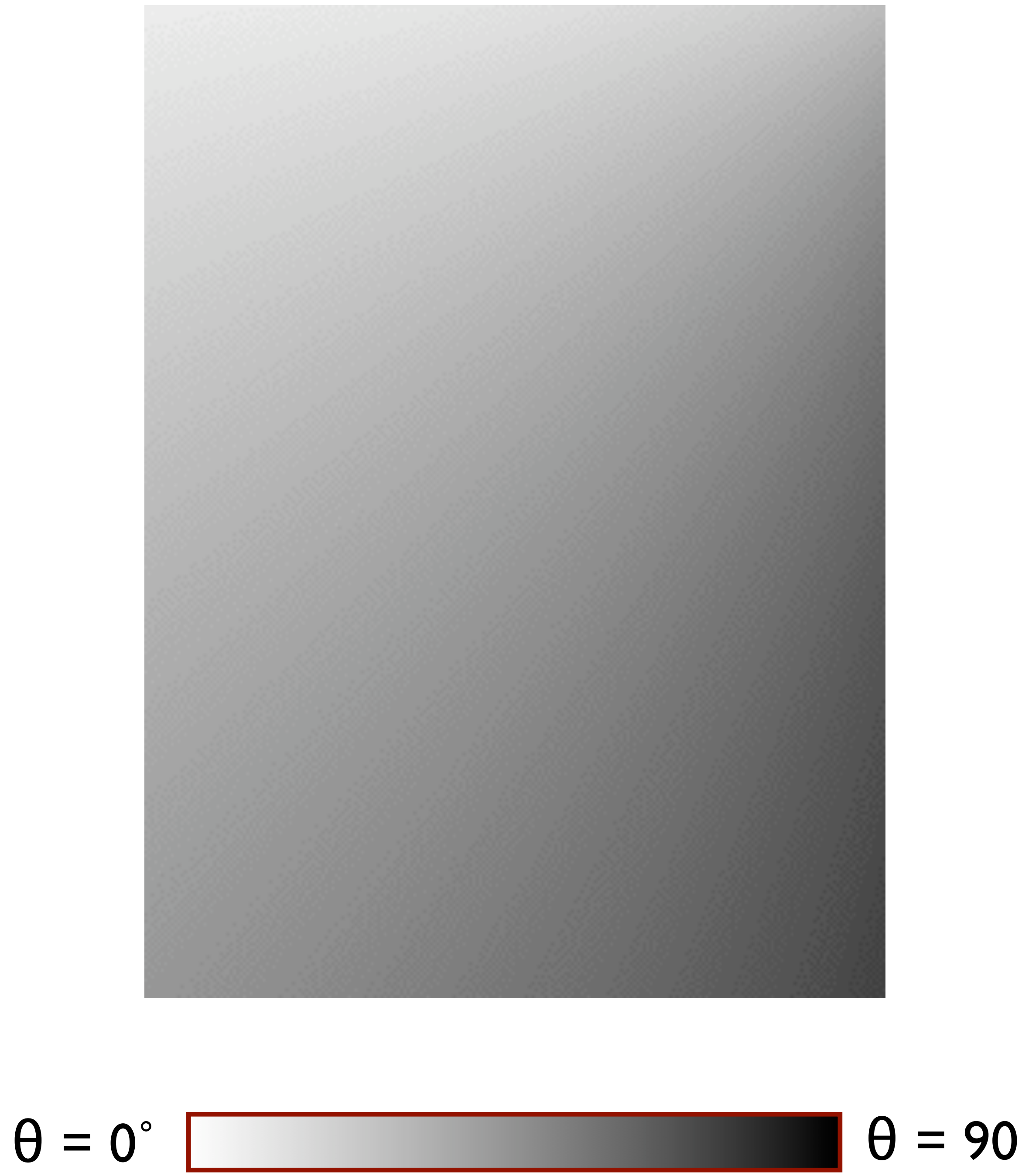
MPM Model



Defines earlywood and latewood
but not radial and tangential directions

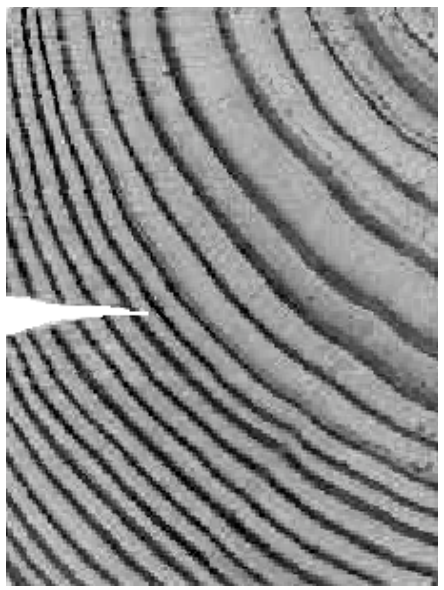
Polar Orthotropy



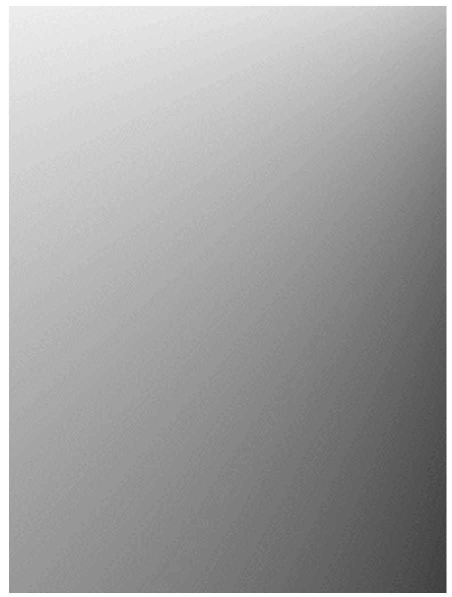


Two Images for Structure and Orientation

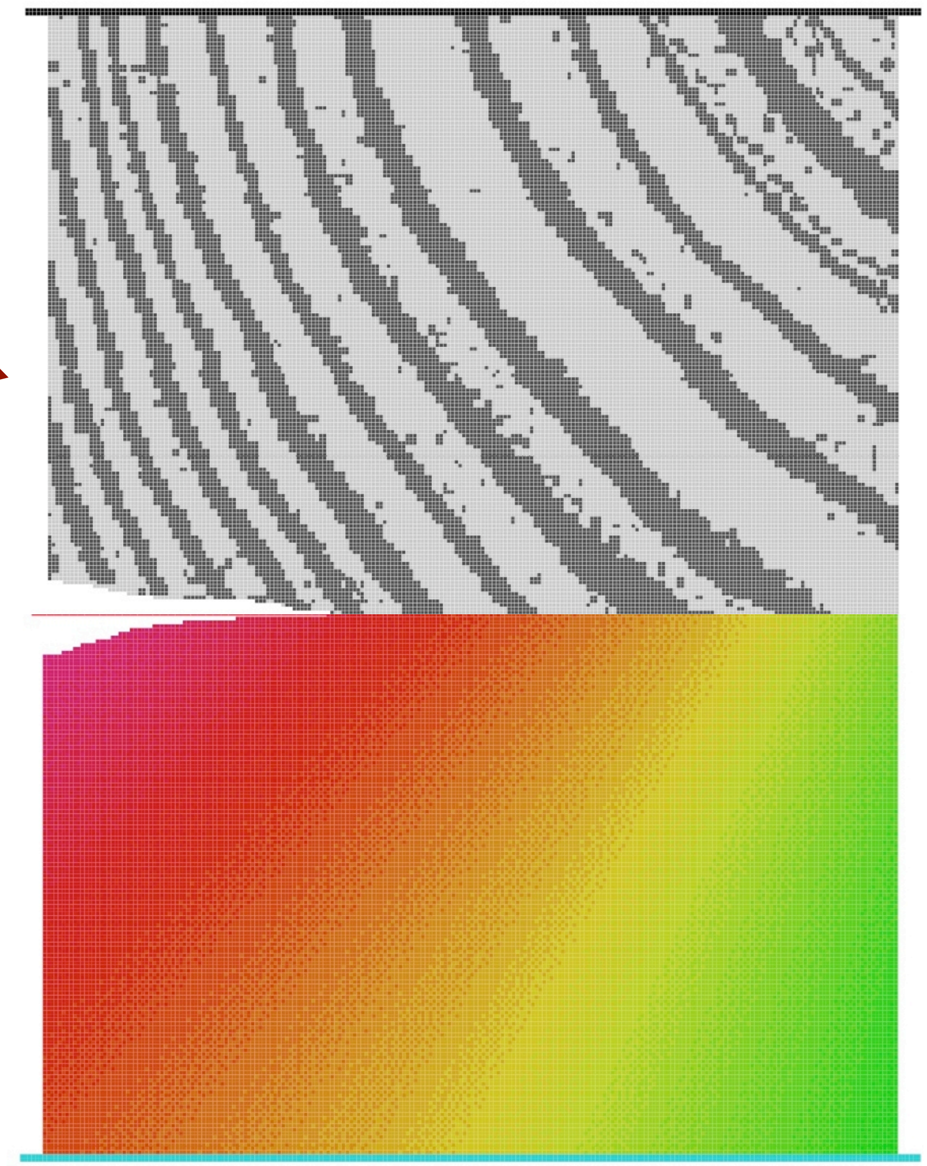
Input Images



+



Generated Model



mASh

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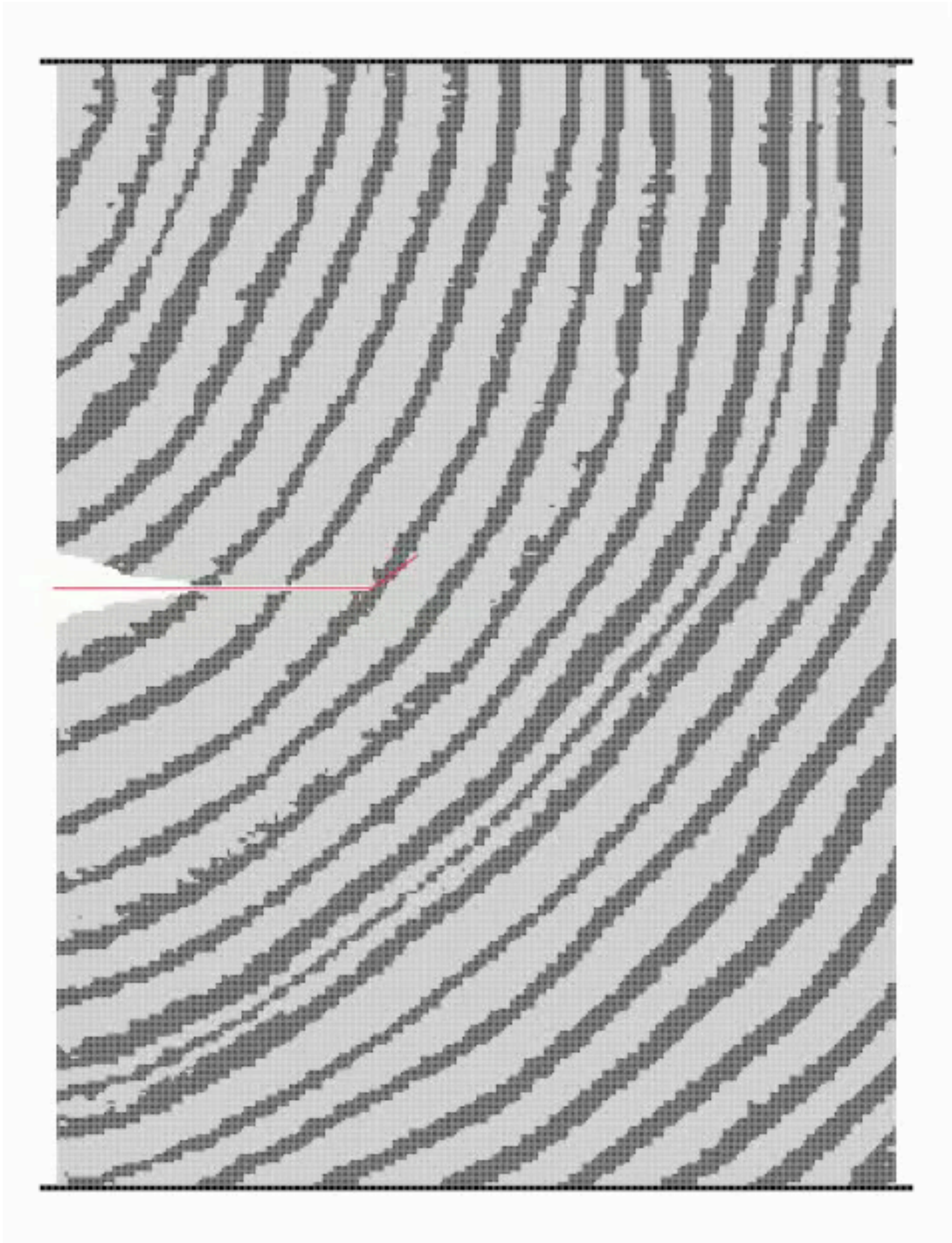
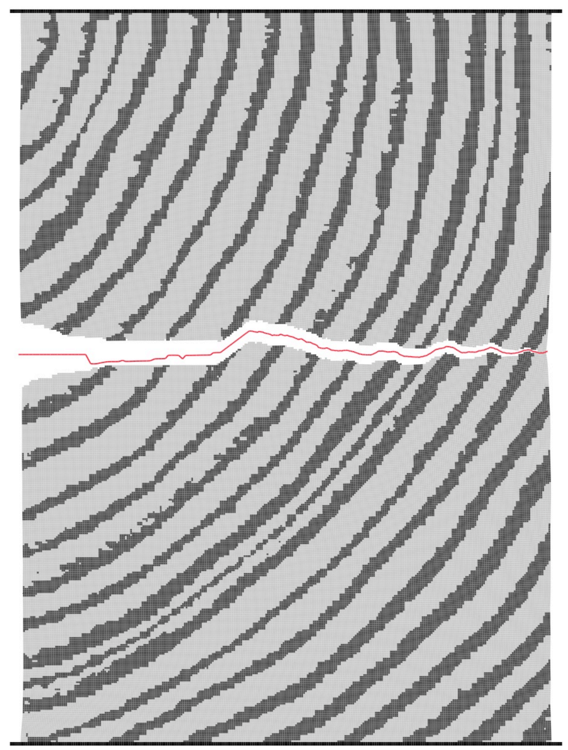
  </Intensity>
  <Intensity imin="0" imax="255" minAngle="0.0" maxAngle="90.0"/>
</BMP>
```

Another Sample



The **CRAMP** Algorithm - **CRA**cks in **MP**M

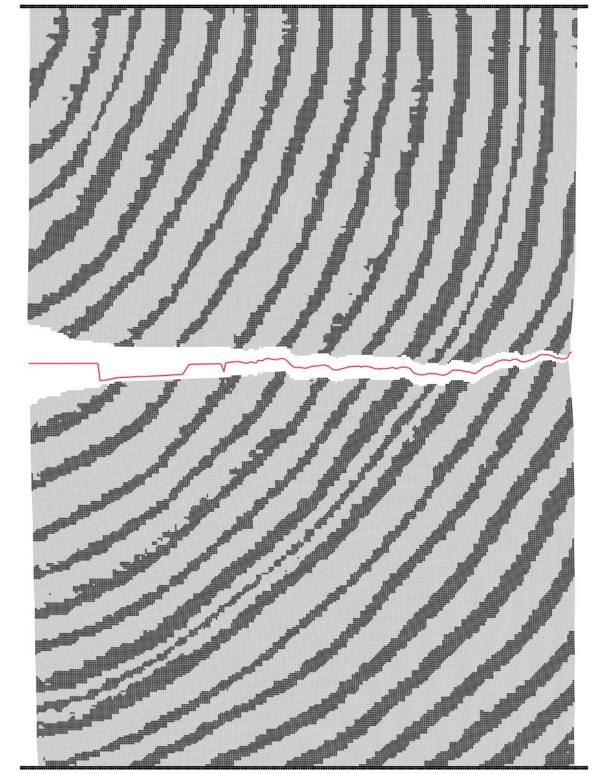
Sample #4 Results



High contrast, hoop criterion, helped by initial flaw

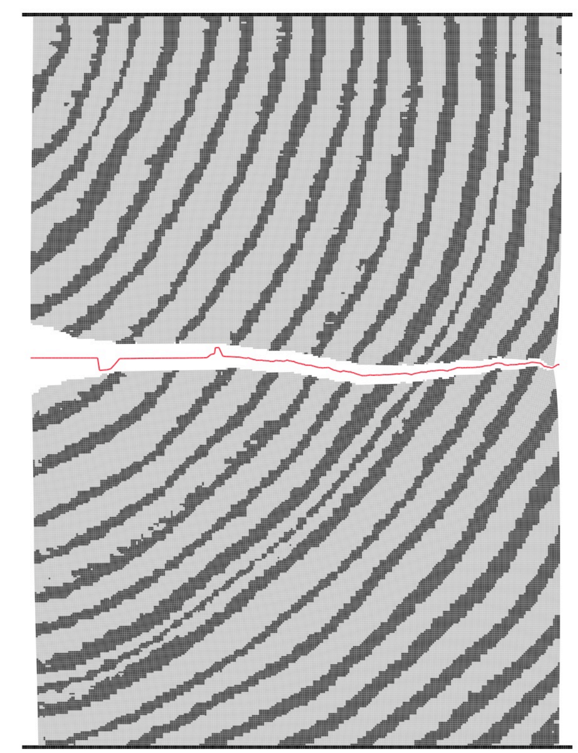
m A S h

No Initial Flaw

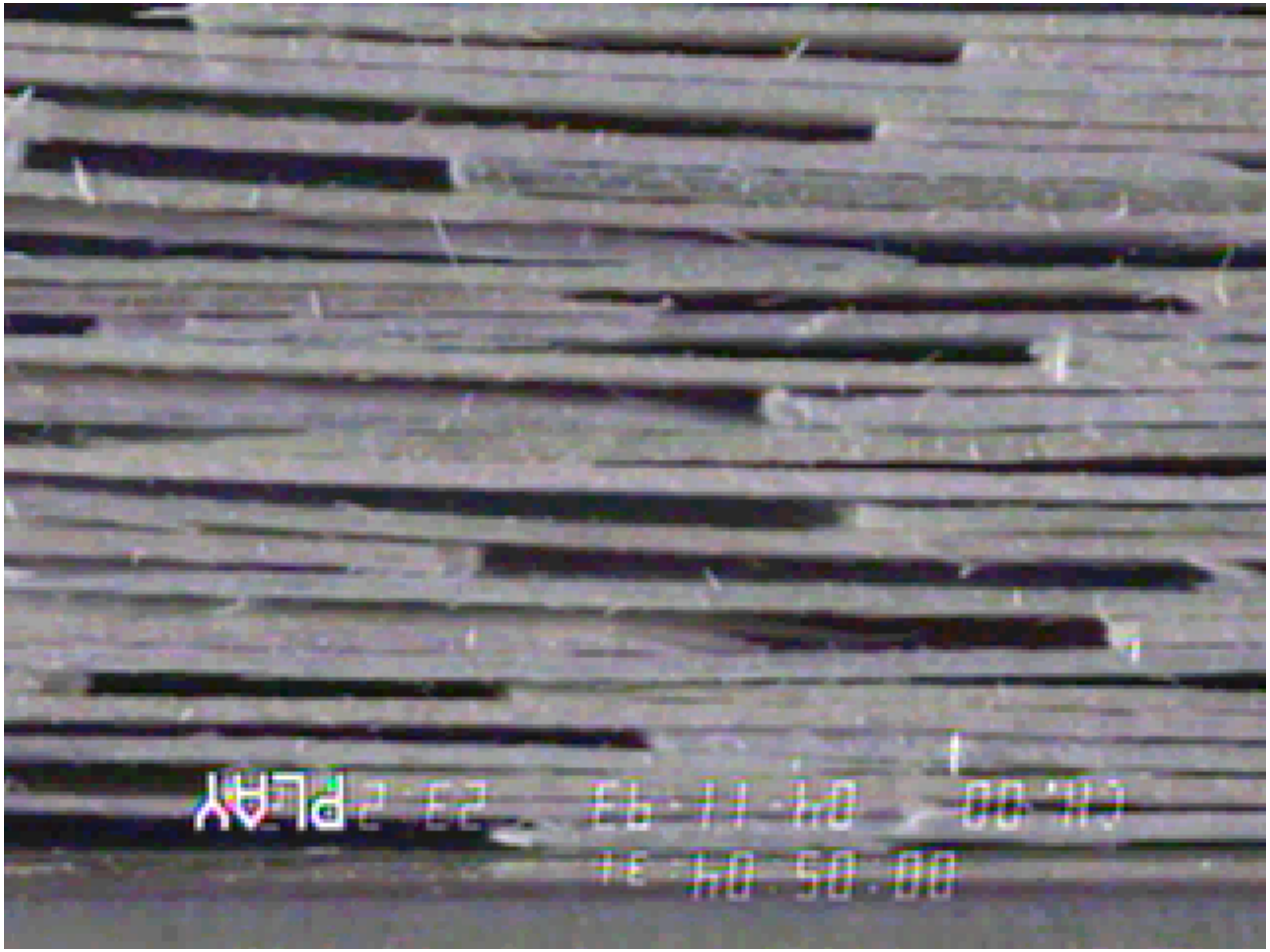


Homogenized RT Plane

m A S –

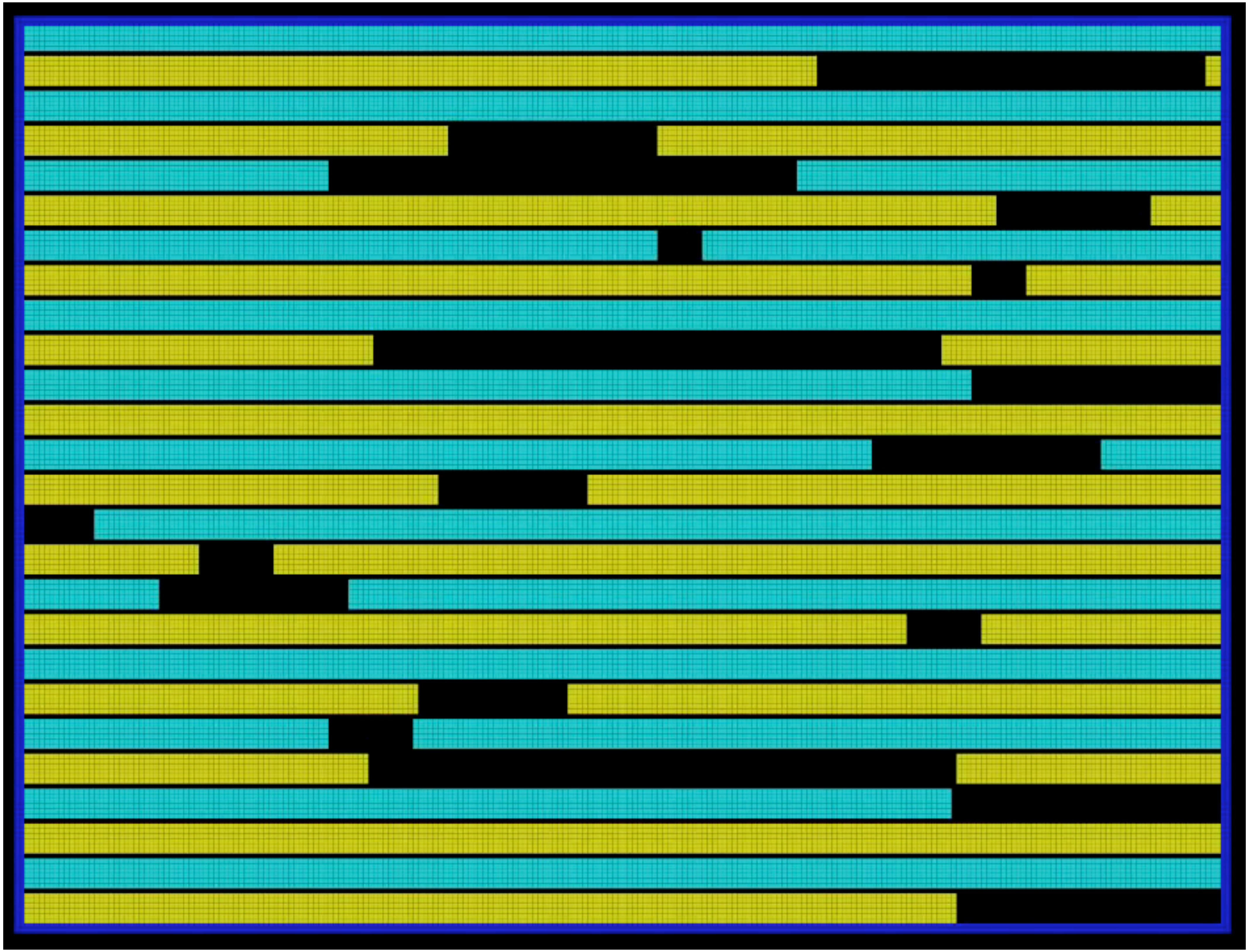


OSB Compaction

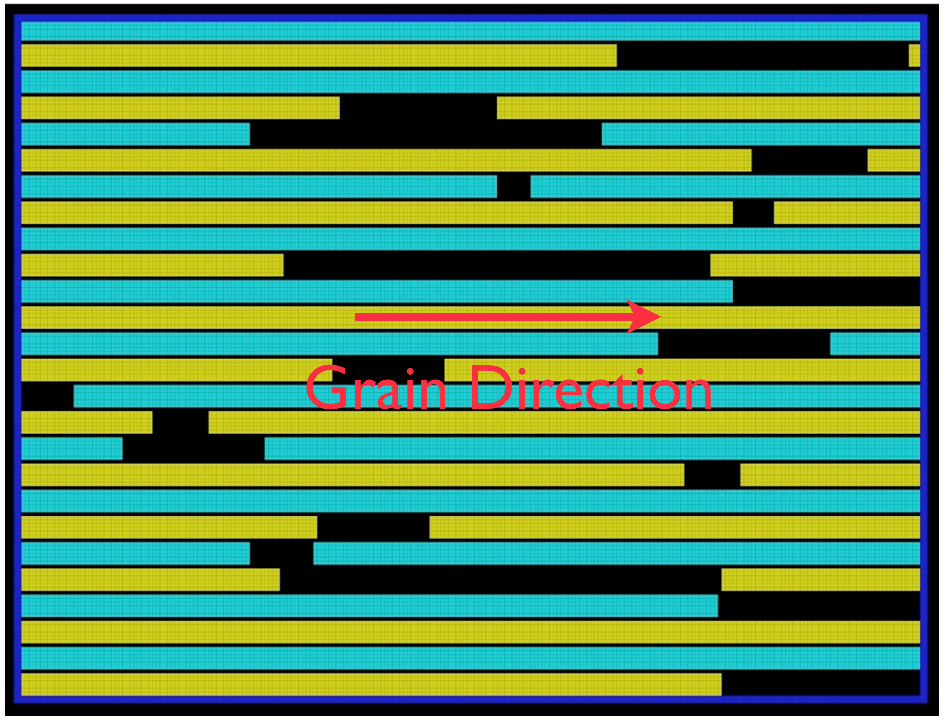


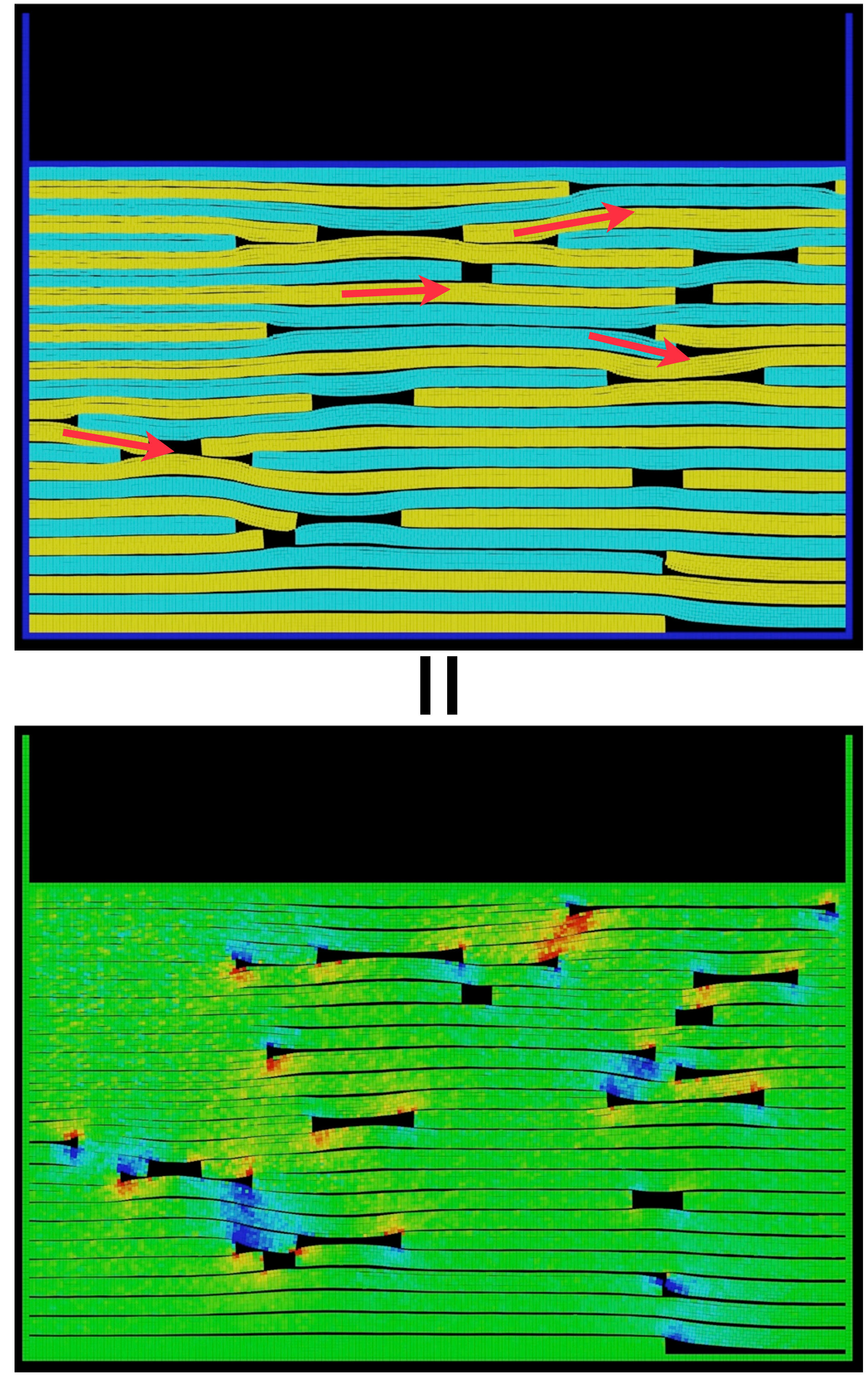
Movie from Fred Kamke (OSU), field of view = 30 mm

Compaction Simulations



Anisotropy Complications



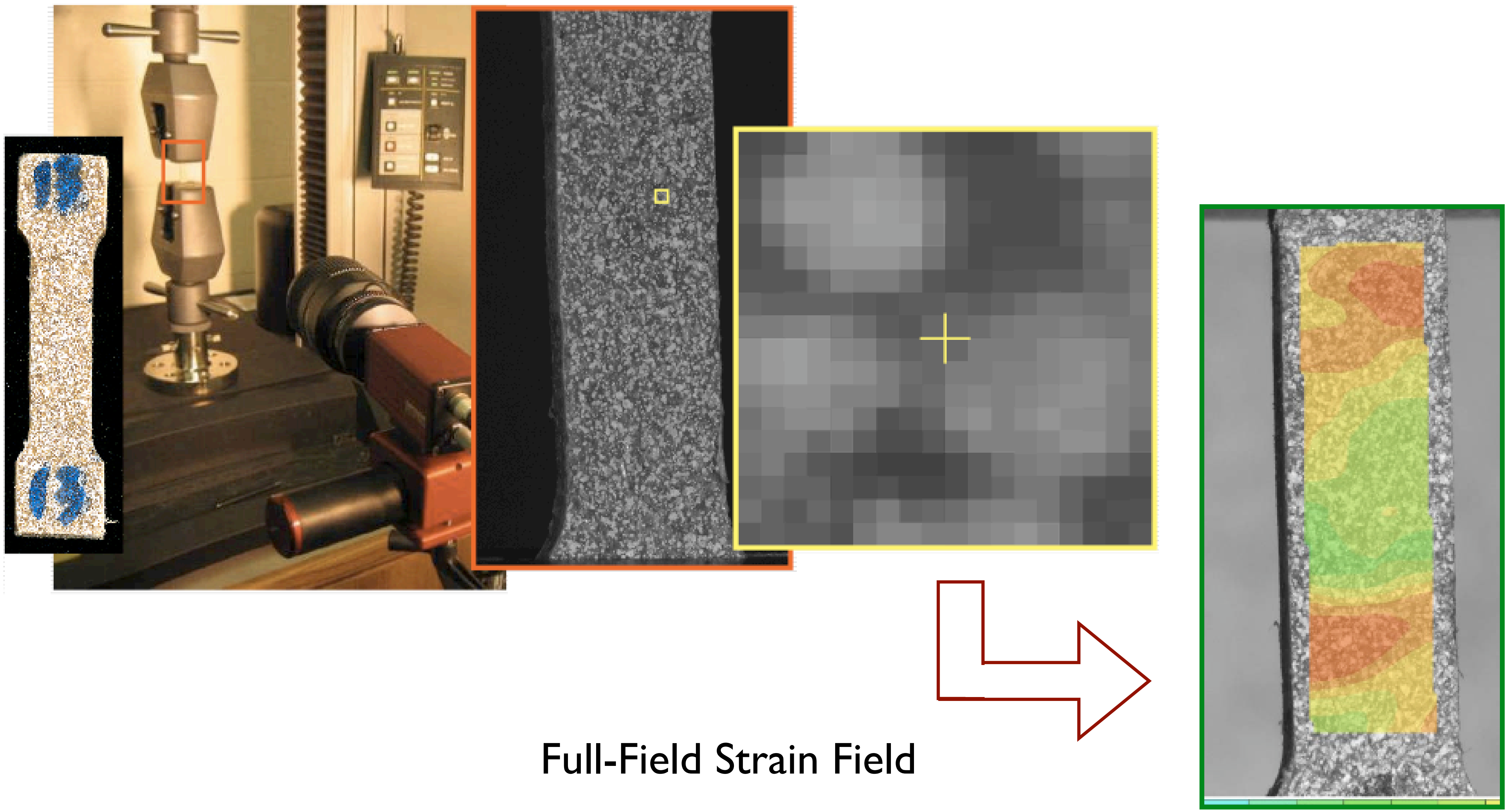


Red for counter clockwise
Blue for clockwise

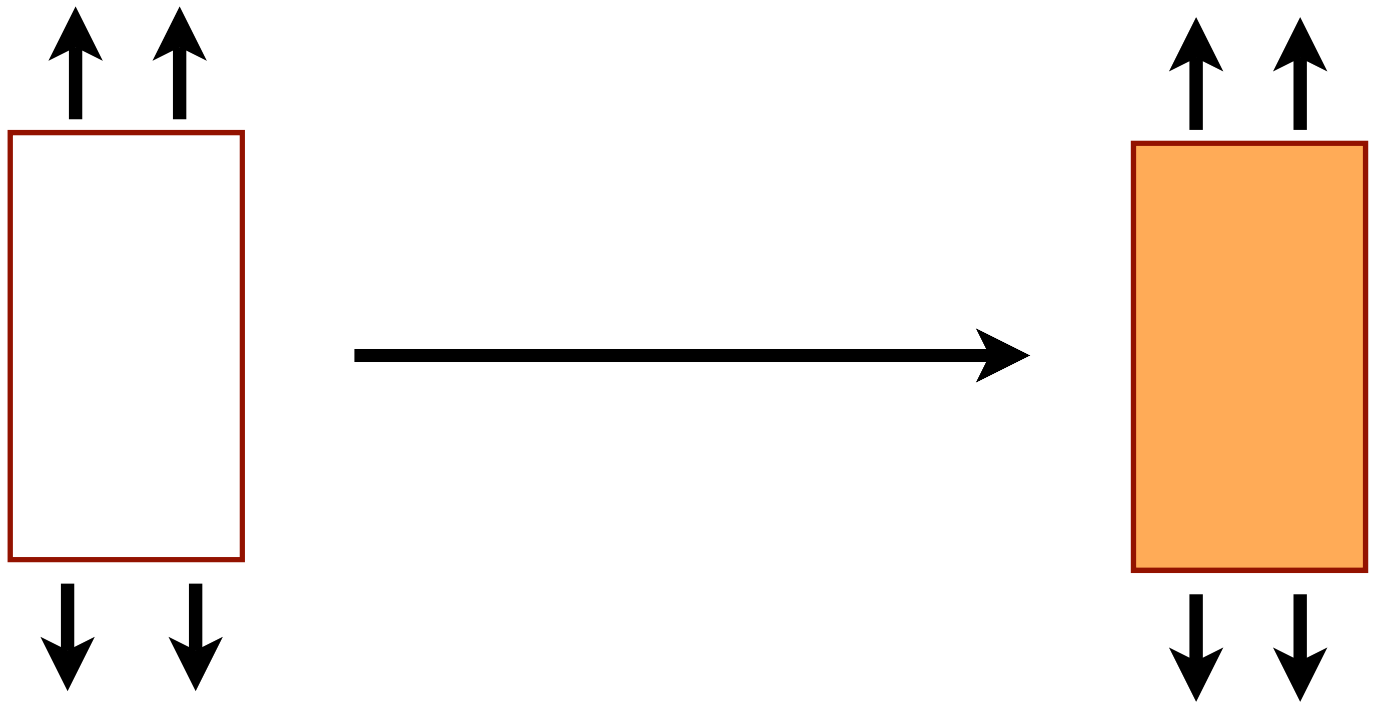
- Grain direction changes
- Orientation part of solution
- Anisotropic yielding needed

Coupled Experiments and Modeling

- Digitial Image Correlation (DIC)



Simple Tensile Test



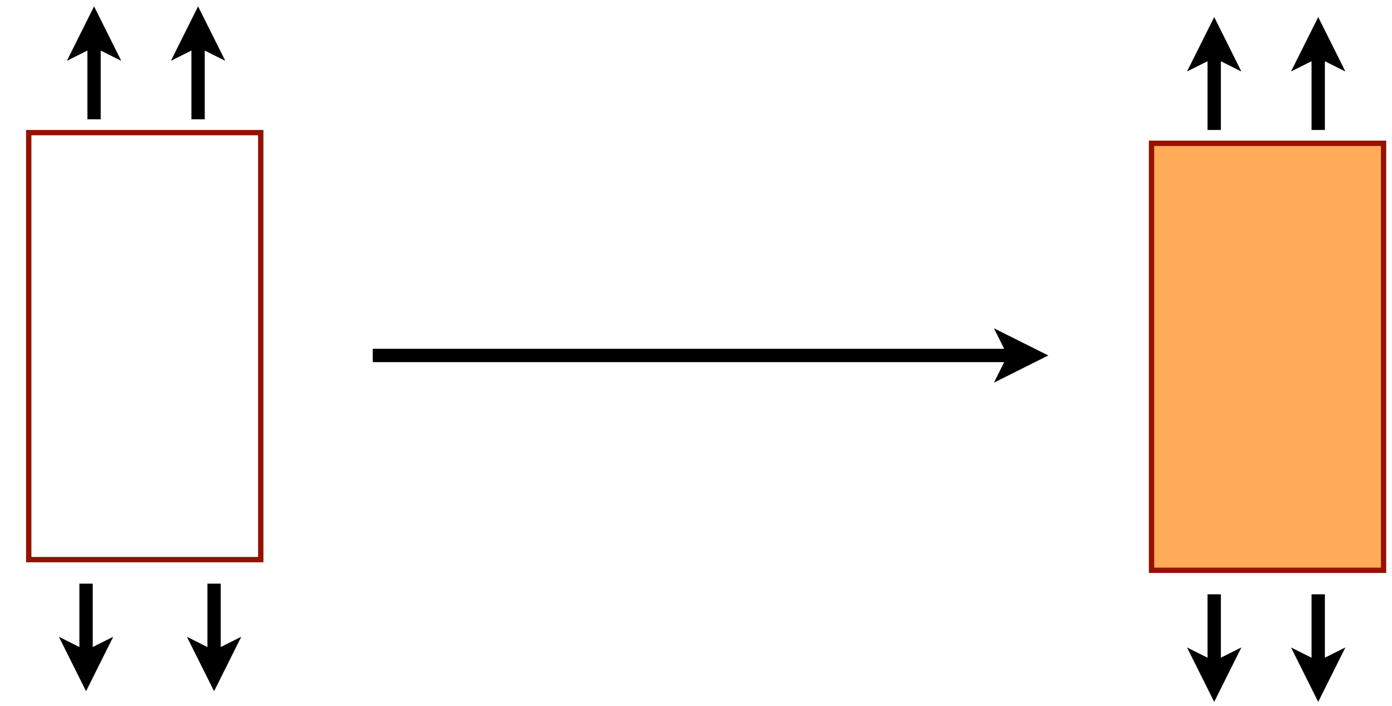
Stress σ

Uniform Strain ϵ

$E_{xx} = \sigma/\epsilon$

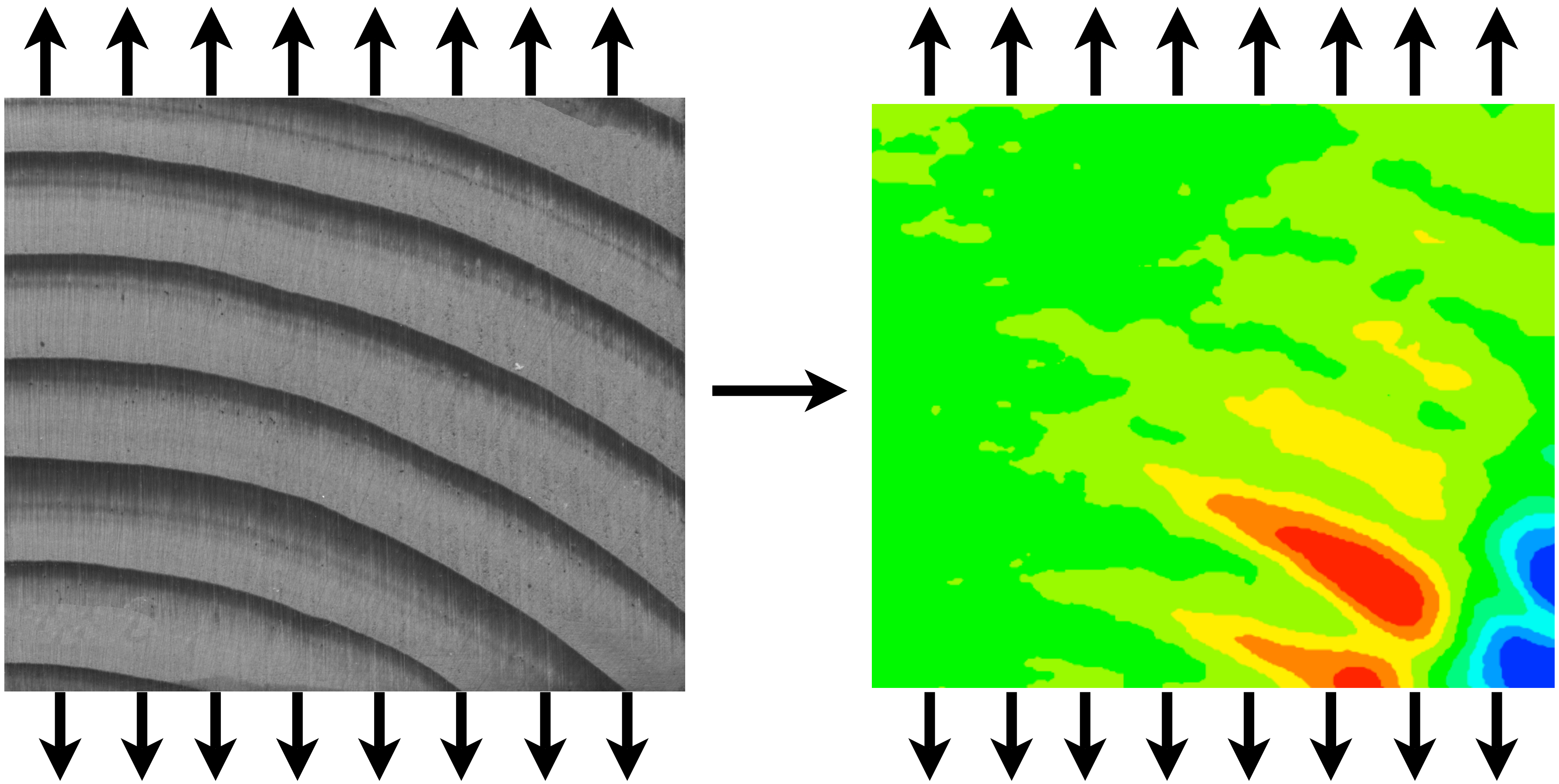
Simple Tensile Test

Stress σ



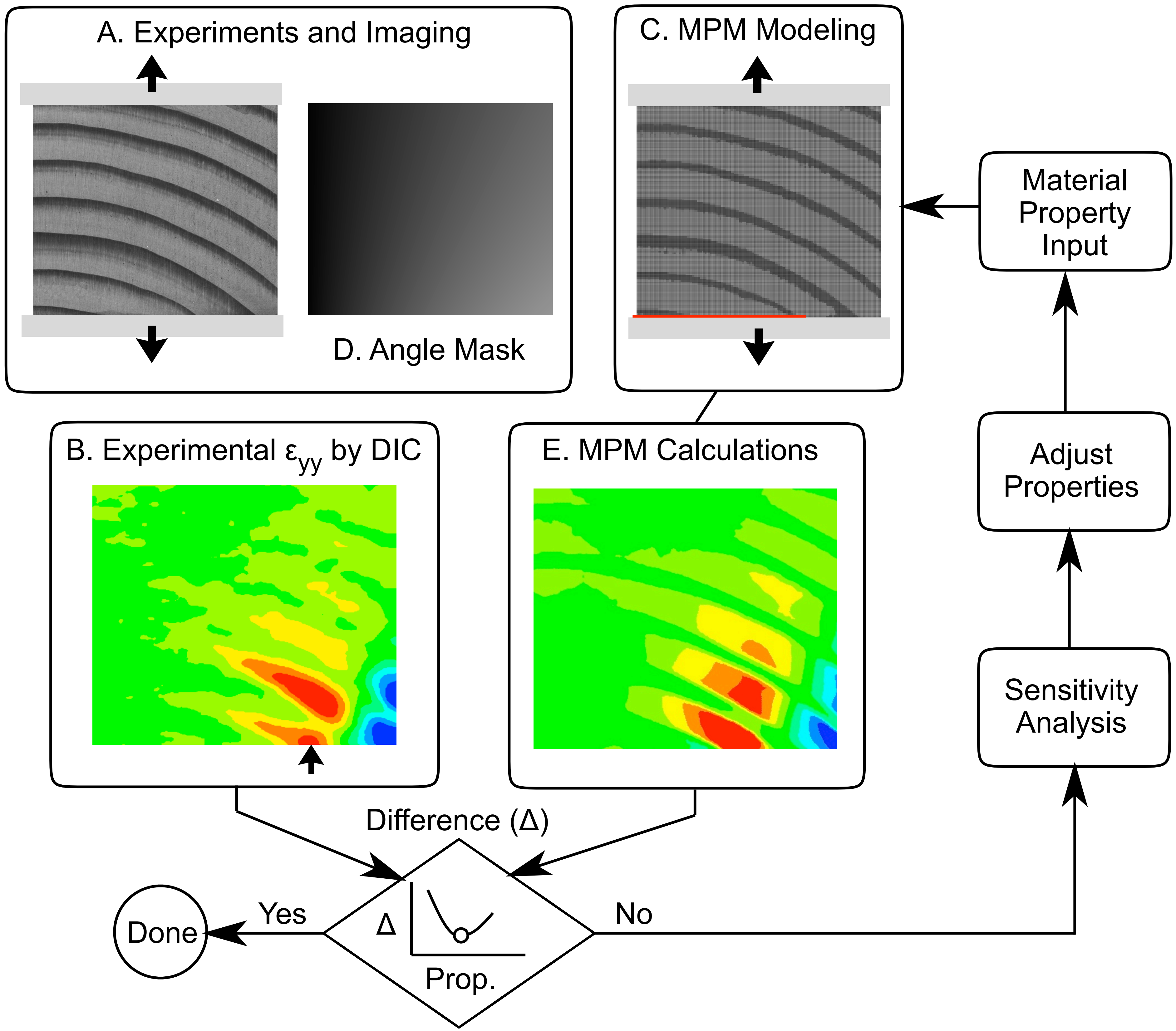
Uniform
Strain ϵ

$E_{xx} = \sigma/\epsilon$

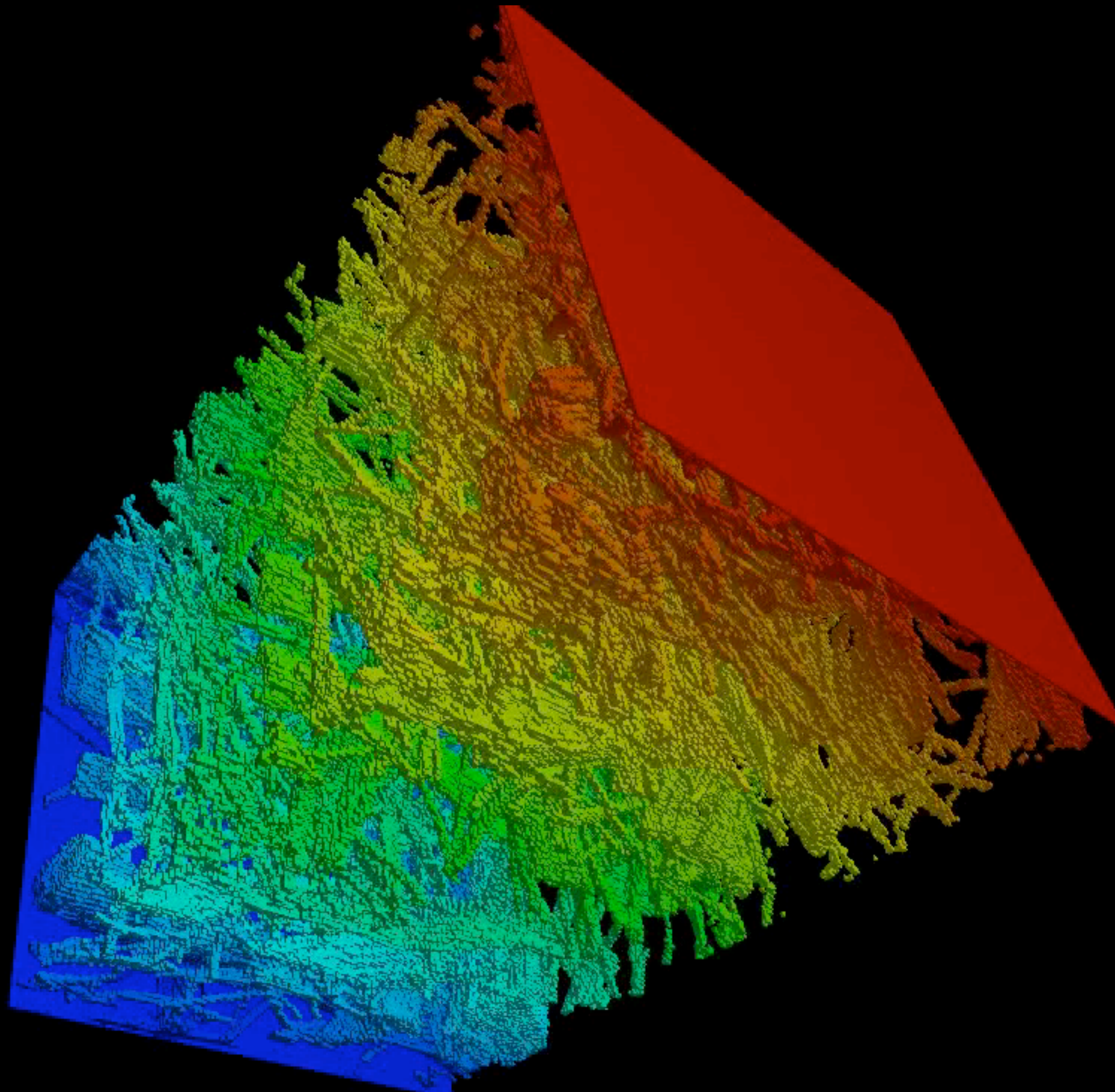


Nonuniform
Strain

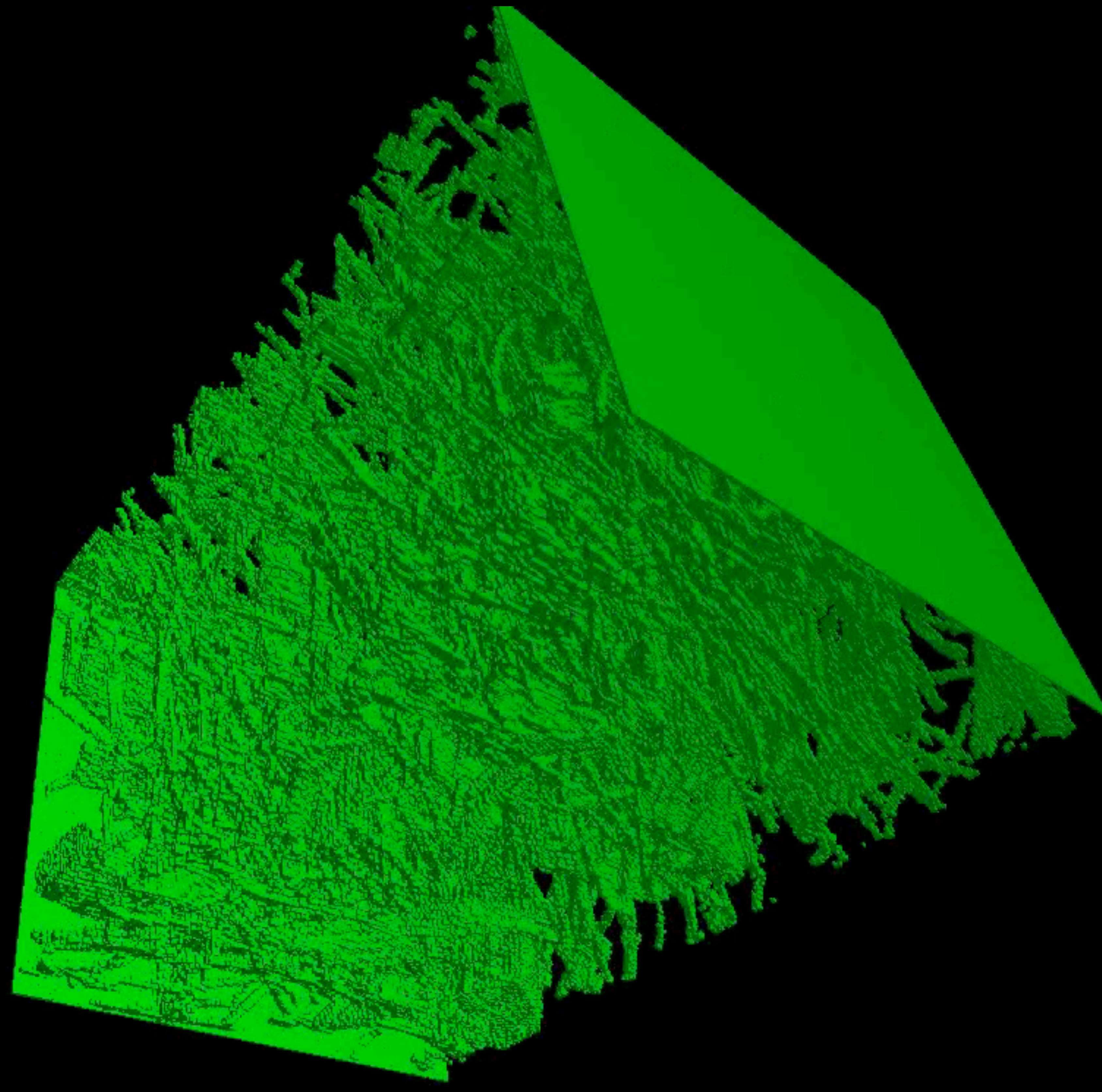
Coupling Modeling with Experiments



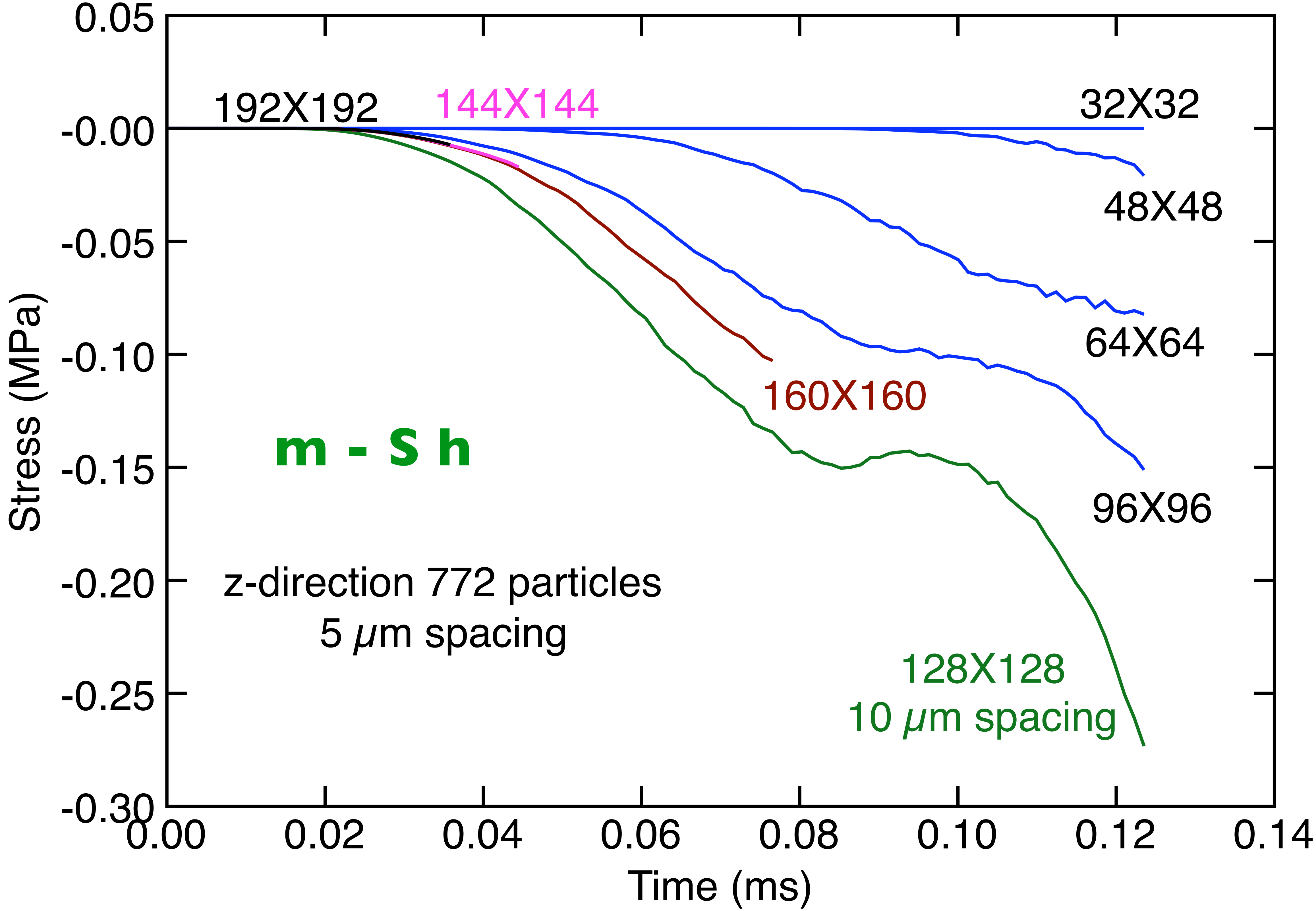
Wood Fiber Mat Compaction



Strain Uniformity



Force-Displacement Convergence

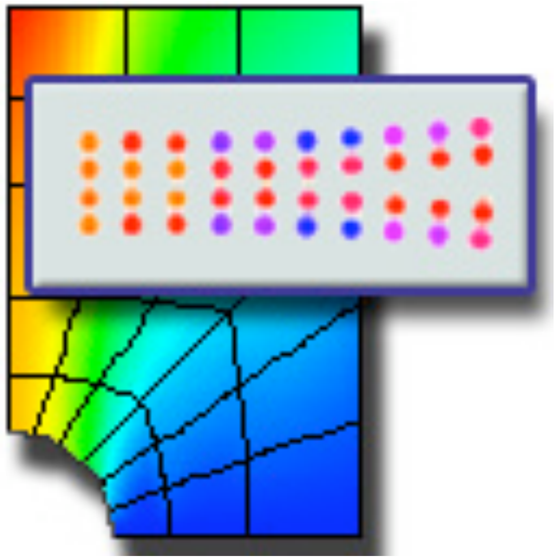


Directions

- Realistic modeling requires attention to
  - **M**aterial properties
  - **A**nisotropy
  - **S**tructure
  - **H**eterogeneity
- Simultaneous inclusion of anisotropy and structure is a challenge
  - Nearly solved in 2D
  - Serious challenge in 3D
- Analysis of realistic morphologies has many applications in wood science as well as composites science
- Direct coupling of modeling to actual specimens opens up new possibilities

Material Point Method

- **MPM useful properties**
  - Discretizing realistic structures
    - Requires new work to discretize realistic anisotropy
  - Explicit cracks with crack propagation
  - Handling contact



- **You can try it at home**
  - Open-source 2D/3D MPM (and matching 2D FEA):

    http://oregonstate.edu/~nairnj/

  - Can Run Calculations and Visualize Results in Graphical Front End
    - Mac Users - complete package available for downloading
    - All Others - java application controls running and visualization (2D only)