Wood transverse compression using hyperelastic plastic behavior simulated in the Material Point Method (MPM)

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Outline

- Hyperelastic-plastic model
- Validation of the model
- Application to wood transverse compression

Hyper elastic-plastic model

- Objective: To simulate large elastic deformations involving plastic behavior that are seen in materials such as wood, composites, etc.

- The model uses a multiplicative decomposition of the deformation gradient.

$$\underline{\underline{F}} = \underline{\underline{F}}^{e} \cdot \underline{\underline{F}}^{p}$$

- The stress-strain law derives from a stored energy, the Neo-Hookean potential was considered,

$$W = \frac{1}{2}\kappa\left[\frac{1}{2}\left(J^{e2} - 1\right) - \ln J^{e}\right] + \frac{1}{2}\mu\left[\mathrm{tr}\left(\overline{\underline{\underline{b}}^{e}}\right) - 3\right]$$

- The plastic behavior is handled by a plastic flow condition
  - Mises-Huber classical condition - Isotropic hardening

$$f\left(\underline{\underline{\tau}}, \alpha\right) = \left\|\underline{\underline{\tau}}^{d}\right\| - \sqrt{\frac{2}{3}}\left[\sigma_{Y} + K\left(\alpha\right)\right]$$

Hyper elastic-plastic model - cont'd

- Stress-strain elastic constitutive law

$$\begin{cases} \underline{\underline{\tau}} = J^e p \underline{\underline{1}} + \mu \,\mathrm{dev}\left[\overline{\underline{\underline{B}}^e}\right] \\ p = U'\left(J^e\right) = \kappa\left(J^{e2} - 1\right) / J^e \end{cases}$$

- Associate flow rule and plastic cumulative strain rate

$$\begin{cases} Lv\left(\underline{\underline{B}}^e\right) = \underline{\underline{F}}^{-1} \cdot \frac{\partial}{\partial t}\left(\overline{\underline{\underline{C}}^p}^{-1}\right) \cdot \underline{\underline{F}}^{-T} = -\frac{2}{3}\lambda \,\mathrm{tr}\left(\underline{\underline{B}}^e\right) \underline{\underline{n}} \cdot \underline{\underline{F}}^{-T} \quad \text{with} \quad \underline{\underline{n}} = \underline{\underline{\tau}}^d / \left\|\underline{\underline{\tau}}^d\right\| \\ \dot{\alpha} = \sqrt{\frac{2}{3}}\lambda \end{cases}$$

- Implemented in Explicit MPM software NairnMPM
  - In NairnMPM, specific Cauchy stress is needed

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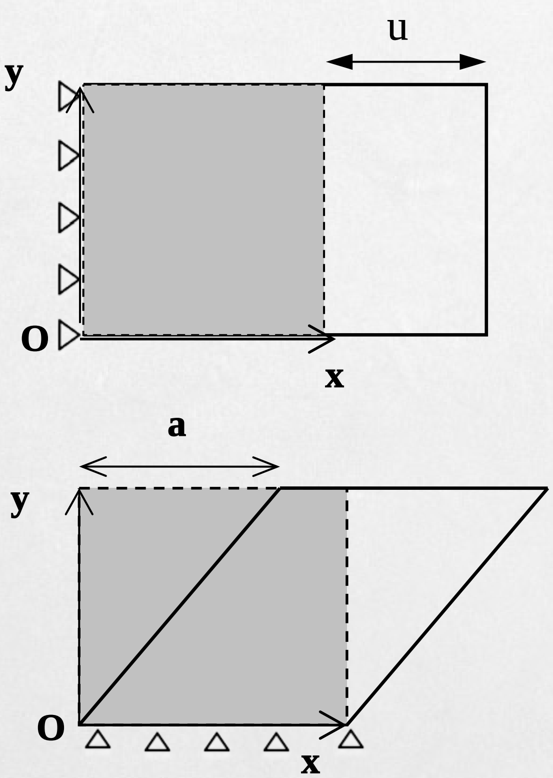
Numerical validations

- Tensile and shear elementary tests



- Isotropic material

$$E = 100\ \text{MPa}, \quad \nu = 0.4$$

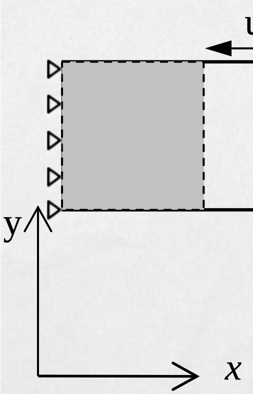
$$\rho = 1\,\text{g}/\text{cm}^3$$

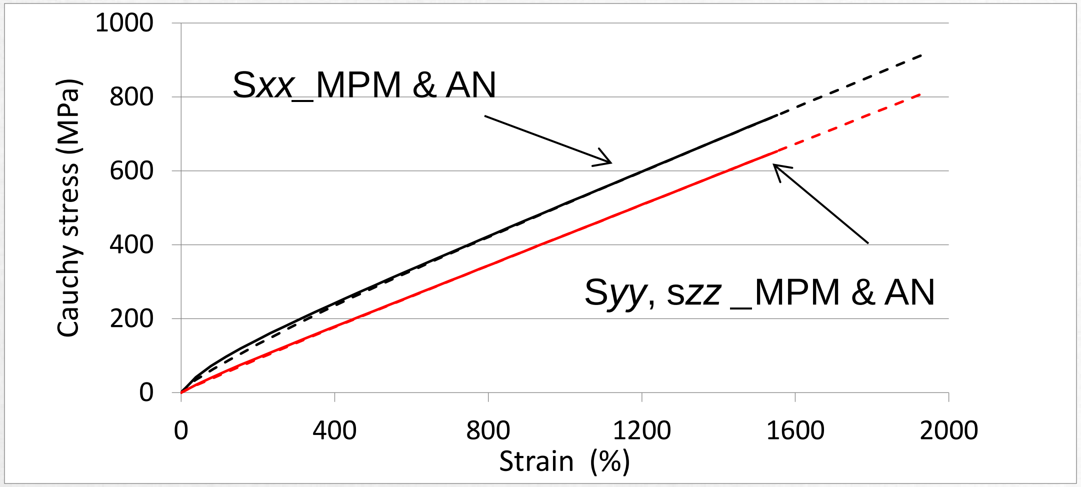
$$\sigma_Y = 100\ \text{MPa}, \quad E_P = 0\ \text{MPa}$$

- All simulations are 2D plane strain

Elementary tests

- Restrained Tensile Test

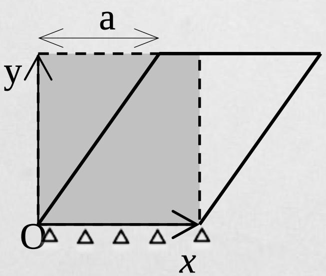


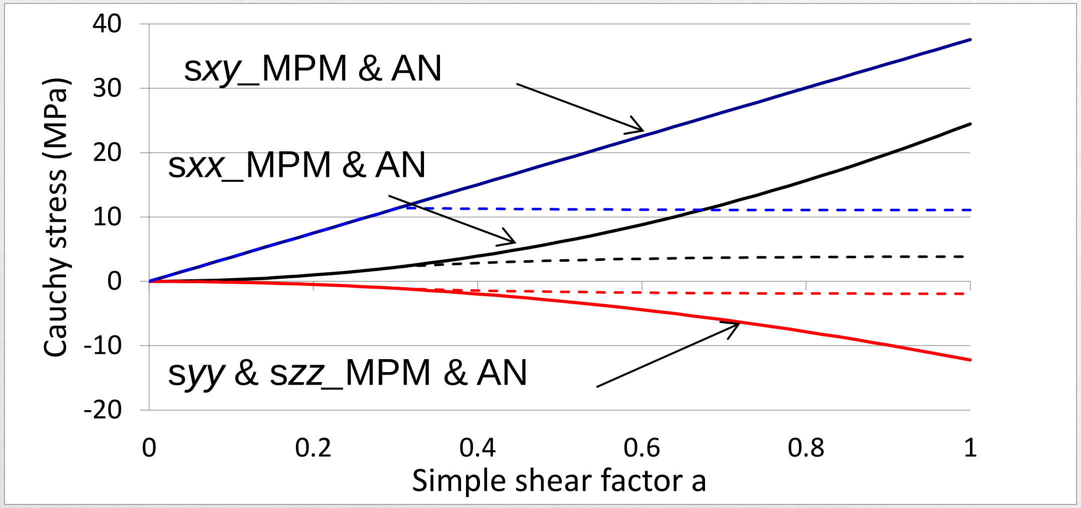


More than 2000% of strain

(using CPDI)

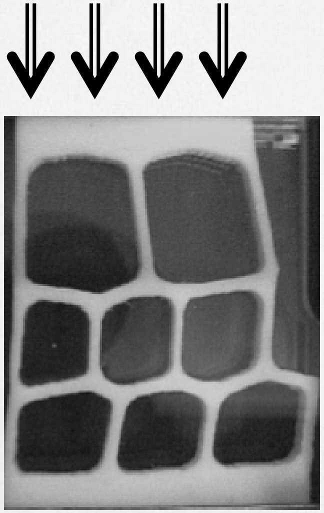
- Simple Shear Test





Numerical validations

- Compression test on a cellular material sample



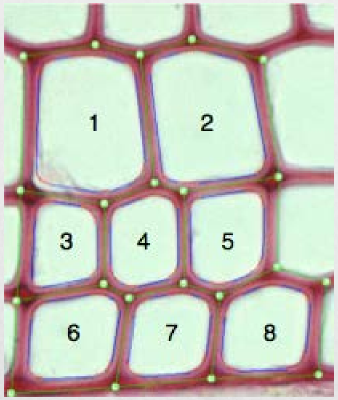
- Polyoxymethylene (POM)

$$E = 3100 \text{ MPa}, \quad \nu = 0.4$$

$$\rho = 1.4 \text{ g/cm}^3$$

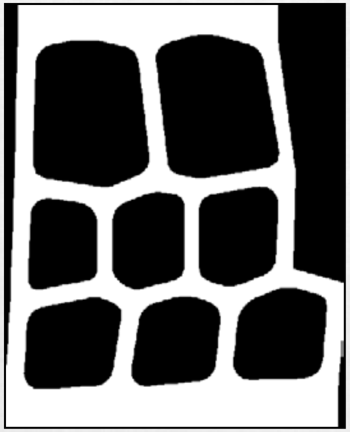
$$\sigma_Y = 72 \text{ MPa}, \quad E_P = 0 \text{ MPa}$$

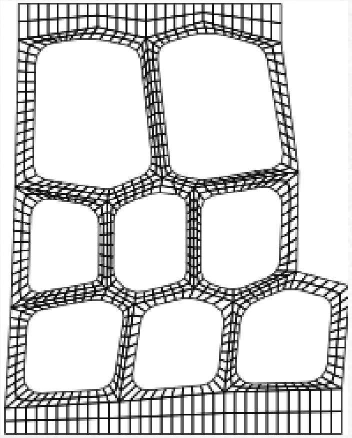
- Image of a cross-section of soft wood anatomy with 8 selected cells



Cellular material sample

- MPM and finite elements discretization





- Micrograph Area : 0.832 x 0.541 mm^2
- MPM Grid discretization: 300 x 194 elements
- Number of particles : 47114
- Res: 300 ppp

- FEM mesh

Cellular material compression

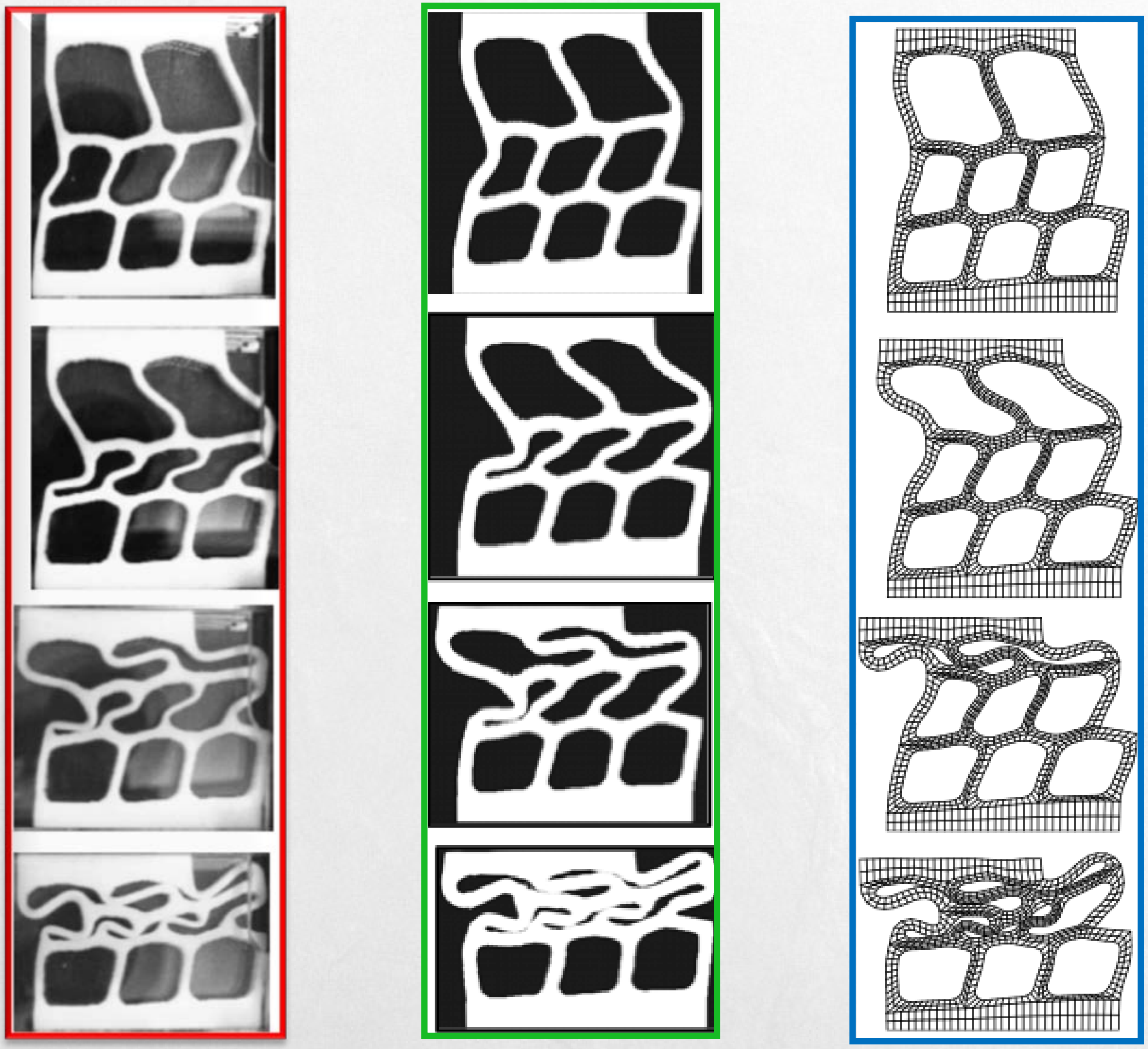
- Comparing experimental, MPM and FEM deformed shapes

5.3%

13.6%

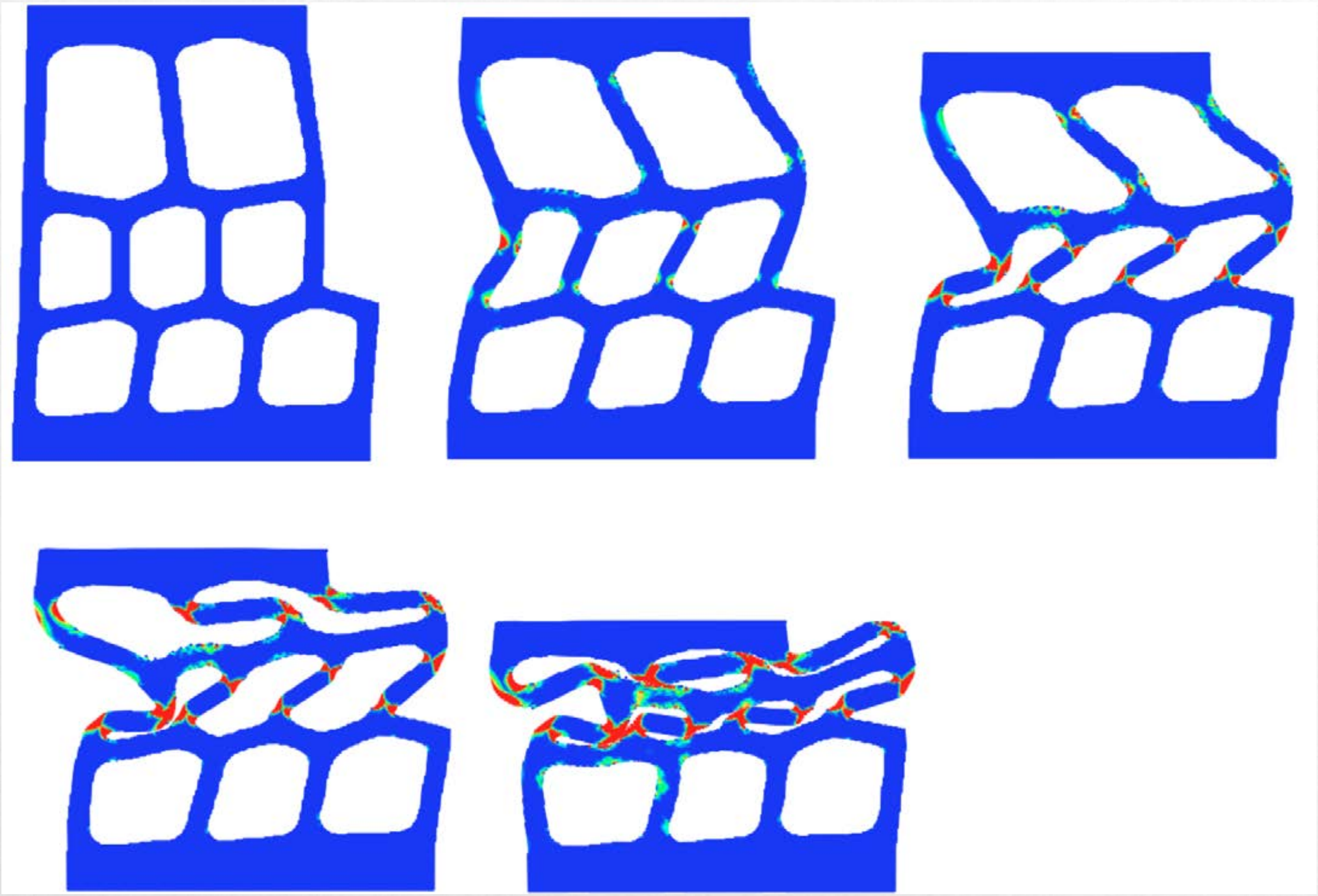
27.3%

42%

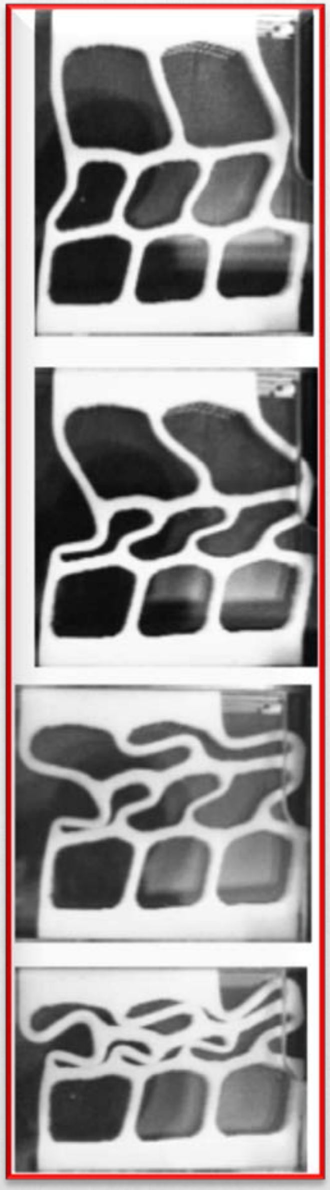


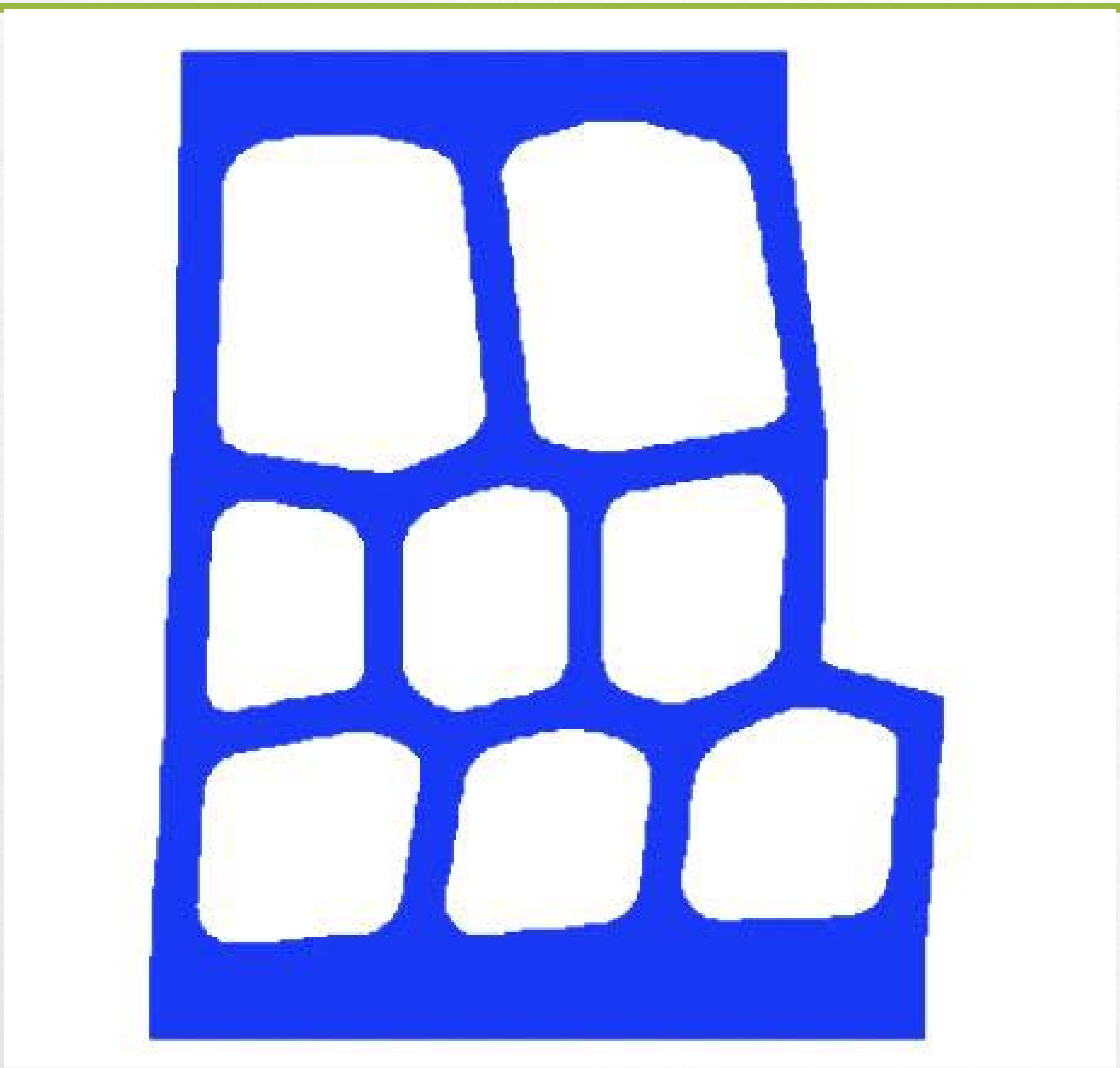
Cellular material compression – cont'd

- Localization of the cumulative plastic energy in MPM simulations



Cellular material compression – cont'd





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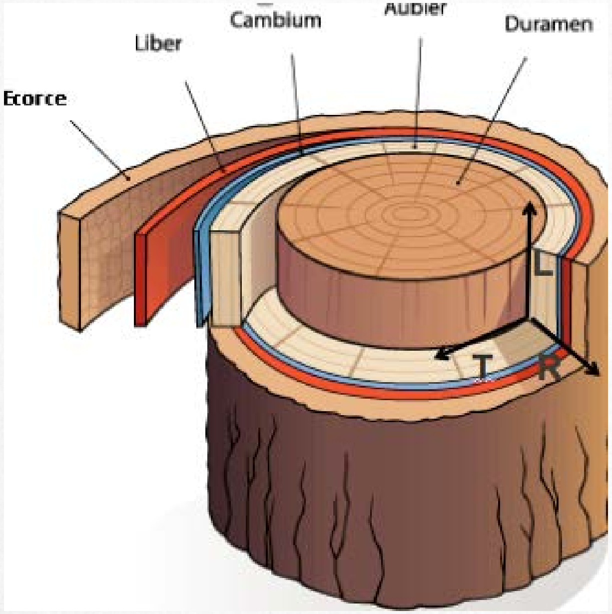
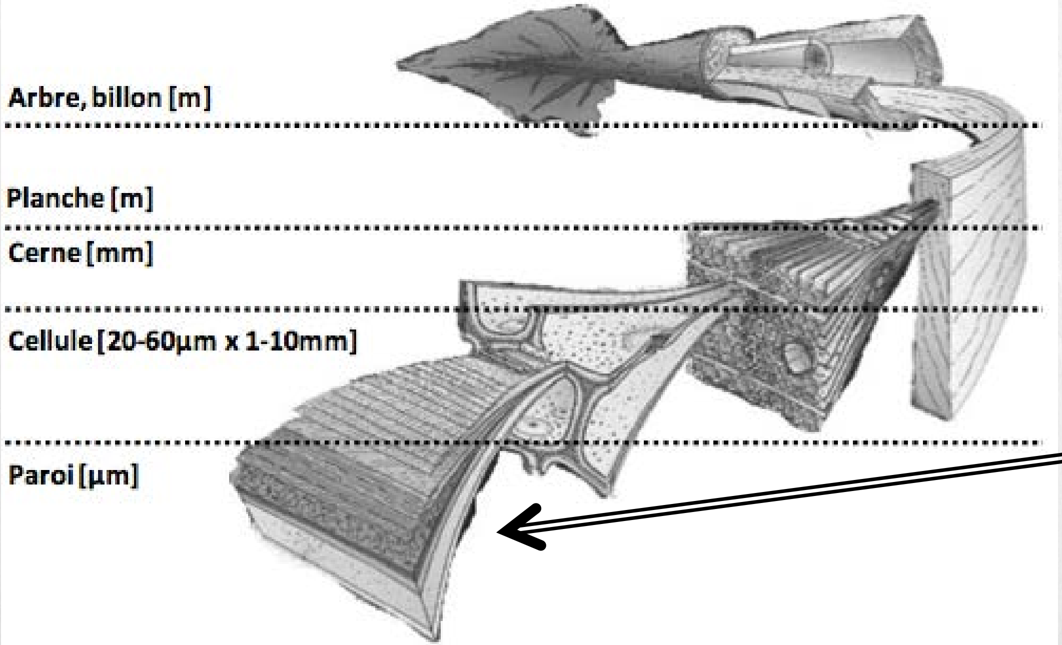
Wood, a very challenging material

- Wood: a complex material
  - Multiscale,
  - Anisotropic,
  - Composite,
  - . . .



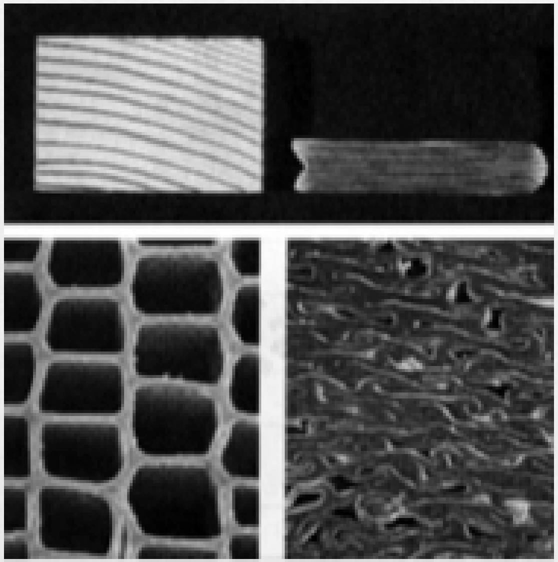


Cell-wall scale :

composite material (microFiber + matrix)

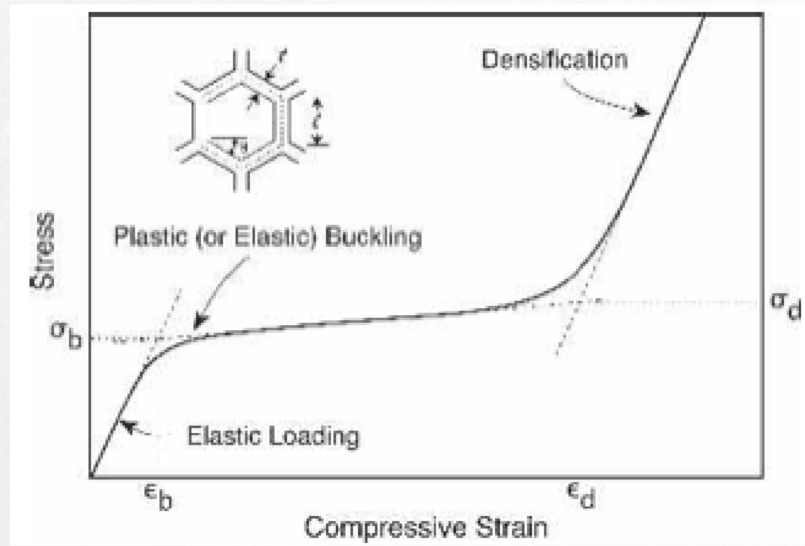
Specific wood behavior

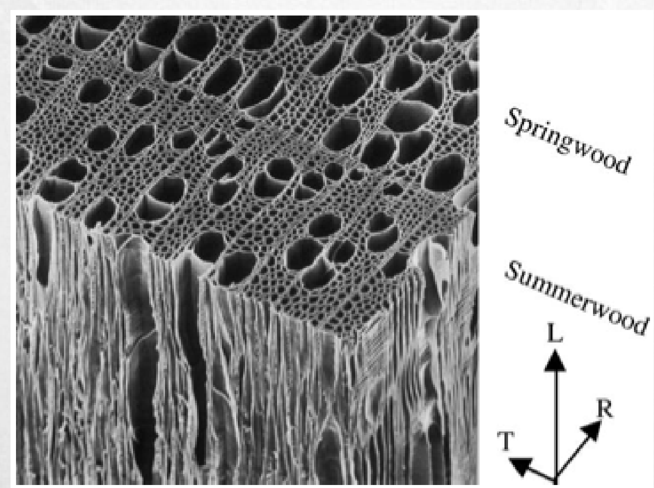
- Compression, main deformation of wood processes



Transverse compression

(Plywood, OSB, etc.)

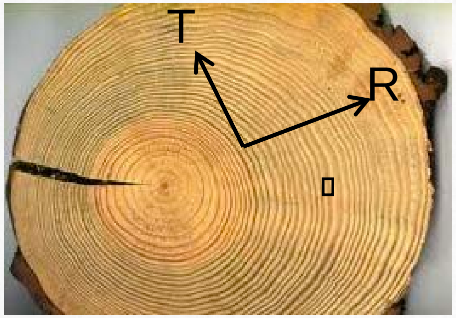




Transverse wood compression

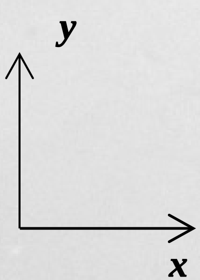
- Wood properties
  - Wood : Loblolly pine

$$E_w = 10.6 \text{ GPa}, \quad \nu_w = 0.33, \quad \rho_w = 1.5 \text{ g/cm}^3$$
$$\sigma_Y = 500 \text{ MPa}, \quad E_P = 0 \text{ MPa}$$

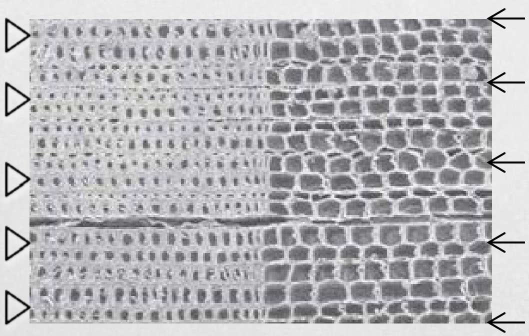


- Micrograph image
  - Micrograph area: : 0.832 x 0.541 mm^2
  - MPM Grid discretization: 300 x 194 elements

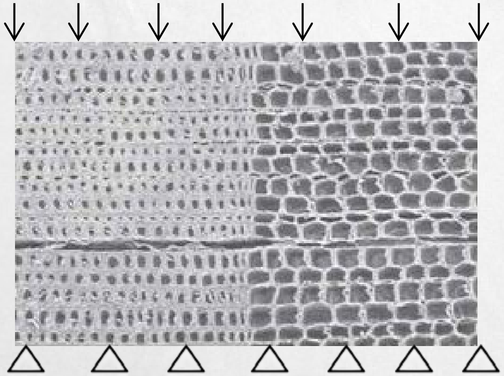
- Boundary conditions



Radial compression

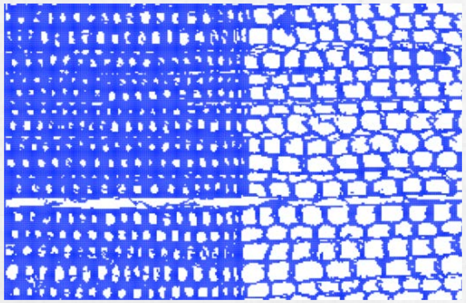


Tangential compression



Radial wood compression

- Localization of plastic zones in the specimen



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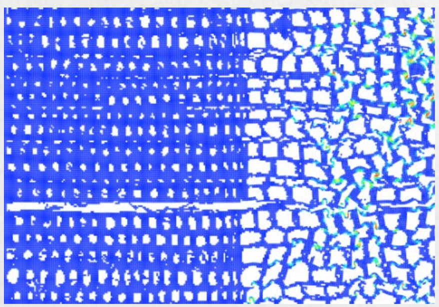

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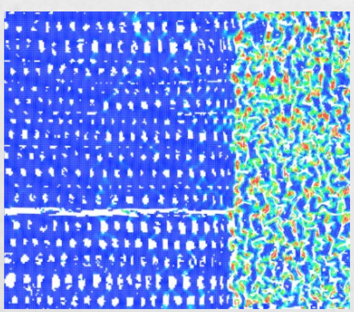

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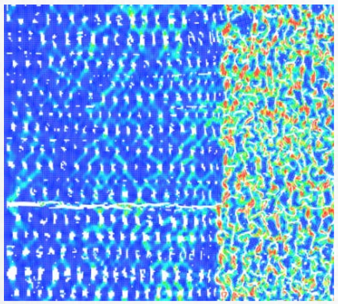

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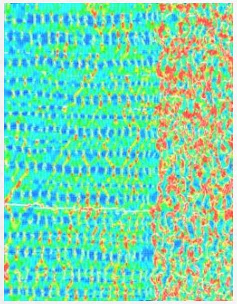

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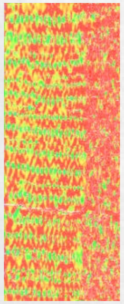
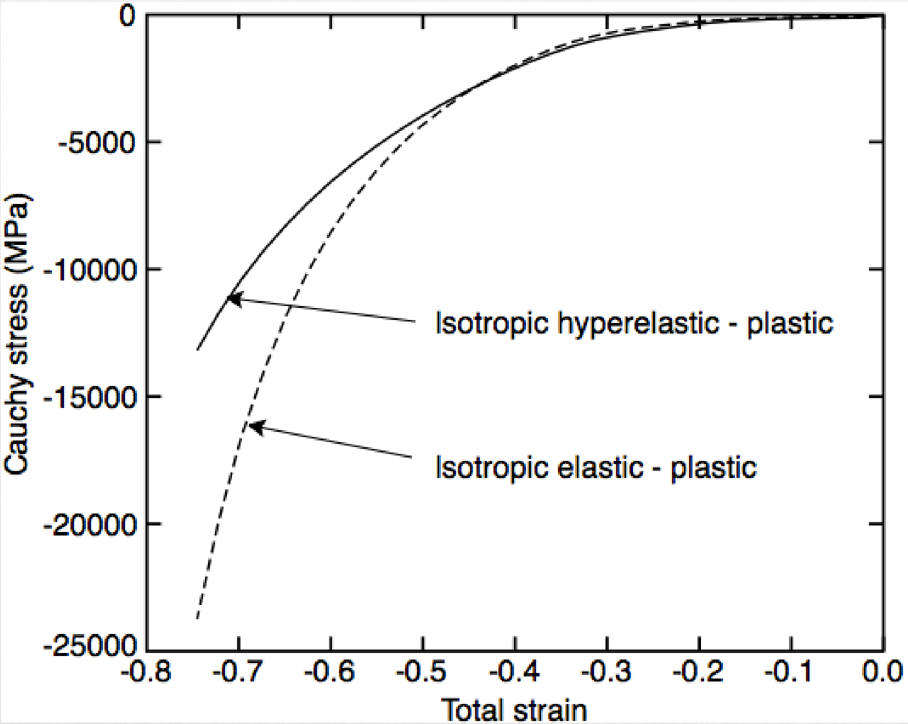
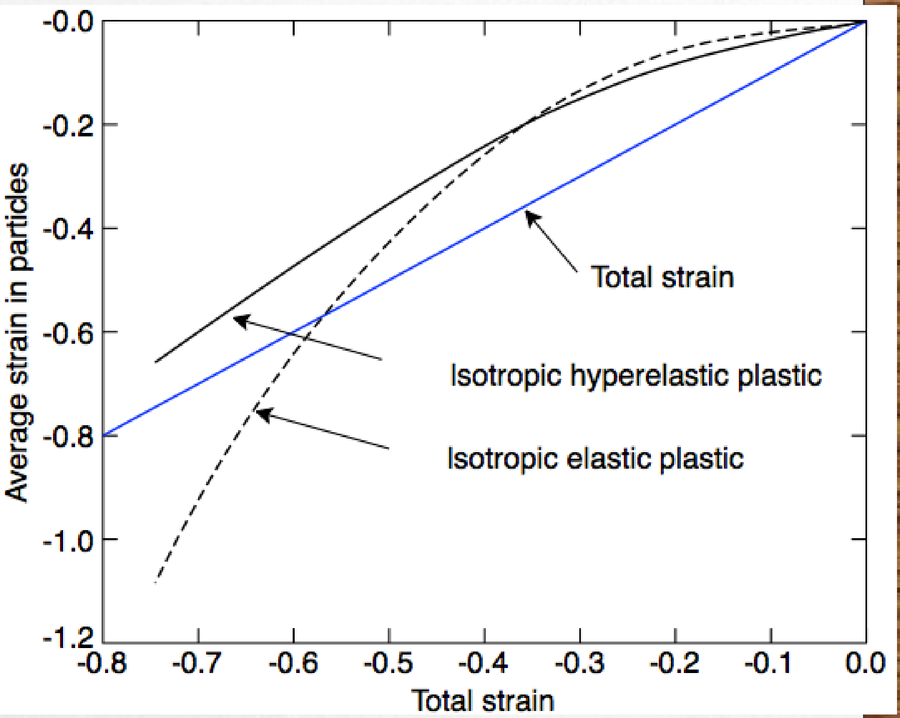


75%

Radial wood compression – cont'd

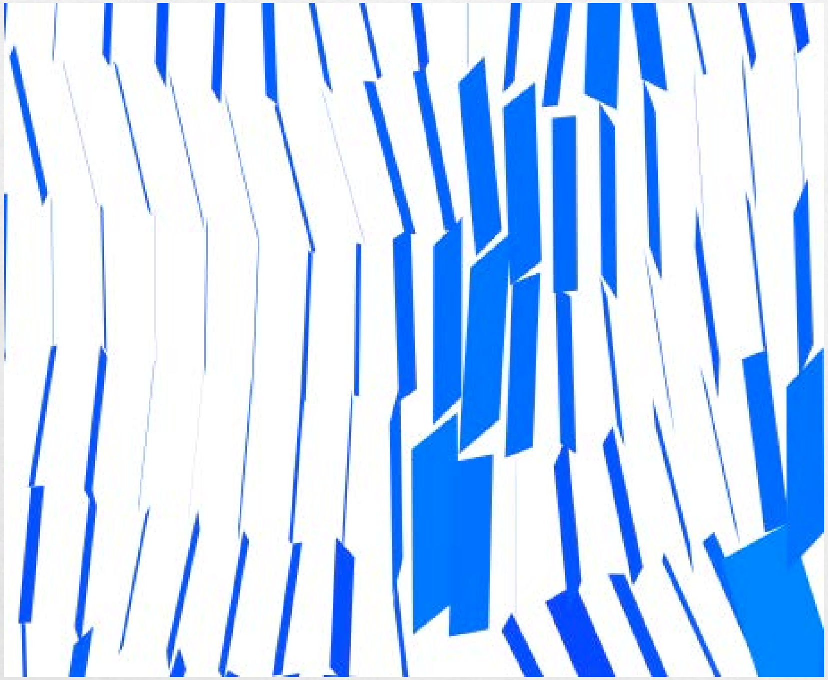
- Comparison between models in small and large deformation

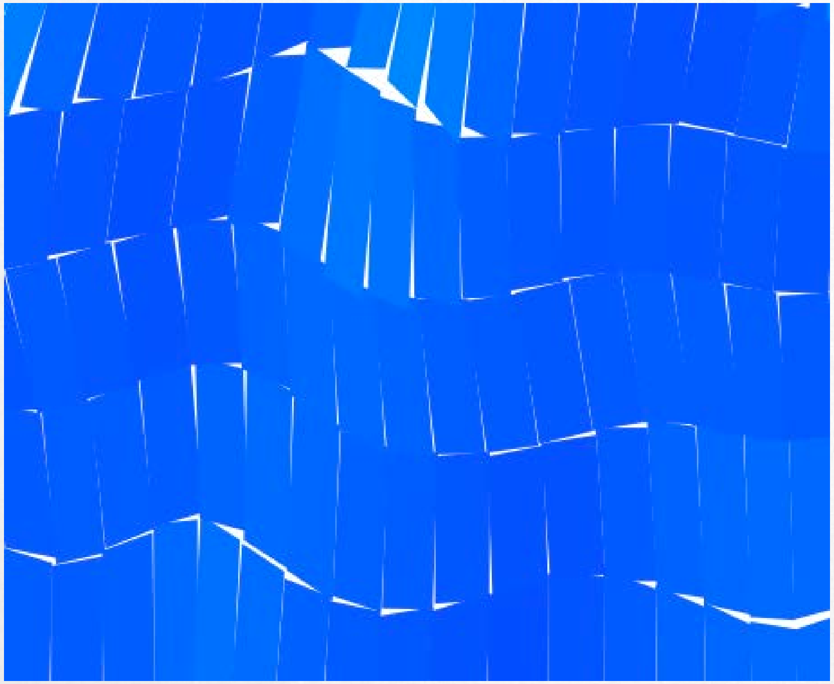




Radial wood compression – cont'd

- Shape of elements at large strains





- Small strain model

Large strain model

Tangential wood compression

- Localization of plastic energy in the specimen

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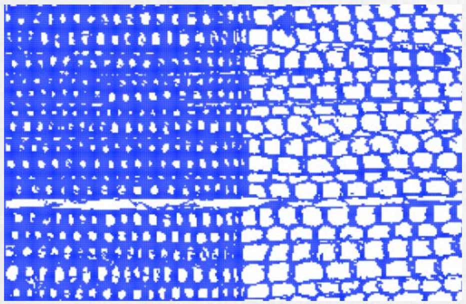

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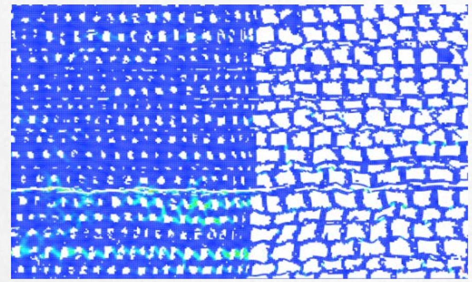

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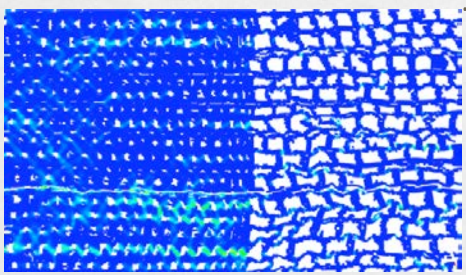

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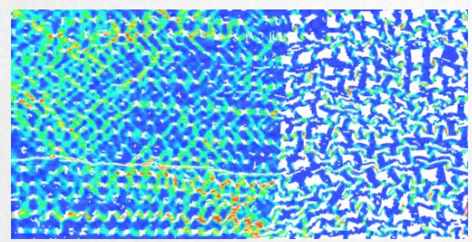

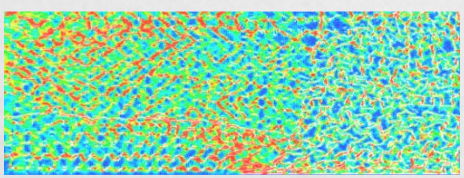

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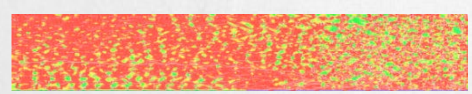

Conclusions

- A hyper elastic-plastic model was successfully implemented in NairnMPM, an MPM software with multiple capabilities
- The hyper elastic-plastic behavior was able to reproduce complex experimental observations seen in wood materials
- The validated hyper elastic-plastic law simulated in MPM allows a better understanding of the distribution of the plastic energy which is critical to many industrial problems

Thank you !