

Analysis of Fractures Propagating in Silver Fir (*Abies alba*) Using High-Resolution Full-Field Measurements and Imagery

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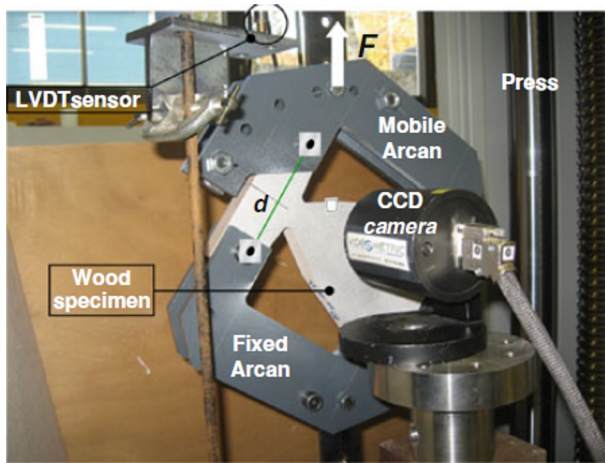
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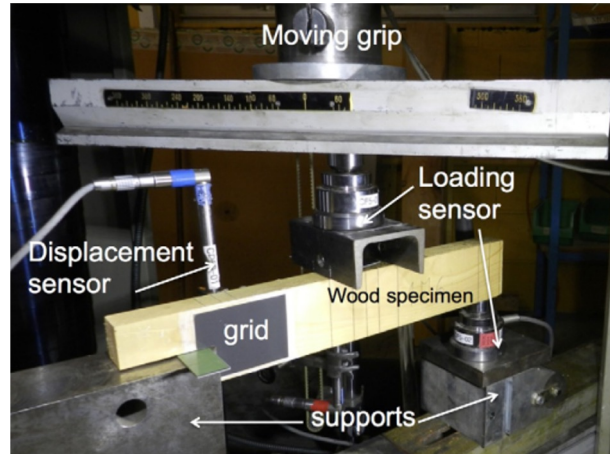
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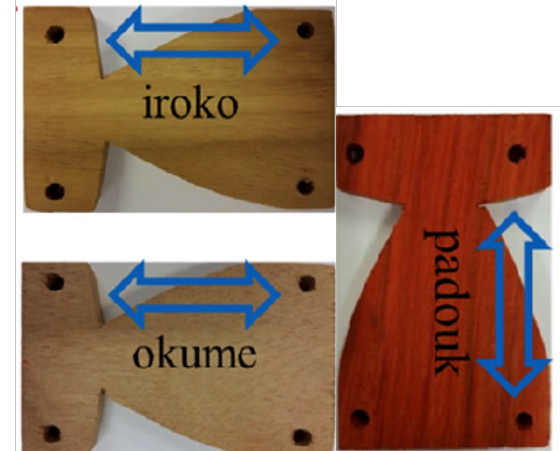
Research on wood fracture mechanics at Institut P.



- R. Moutou Pitti et al. (2012), WST
- Characterization of Mixed-mode fracture properties in wood



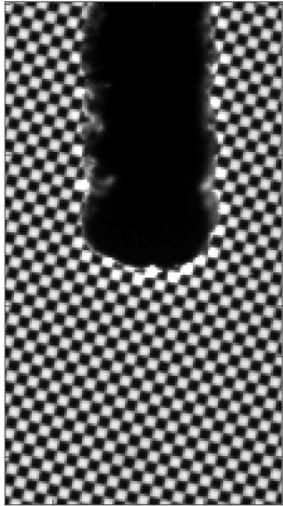
- E. Toussaint et al. (2016), ES
- Stress-state determination in notched-beams using full-field measurement (Grid-method)



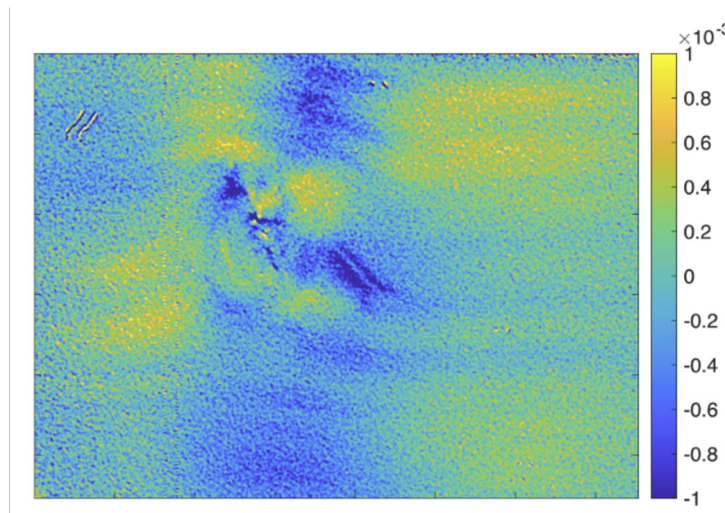
- B. Odounga et al. (2019), EFM
- Characterization of the fracture properties of tropical woods

Research on experimental mechanics at Institut P

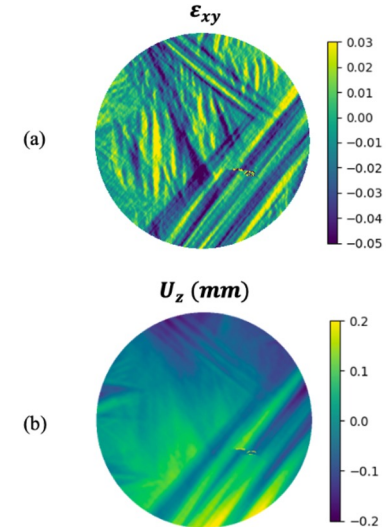
Checkerboard pattern



In-plane strain measurements (LSA)



Stereo-Measurements (LSA)



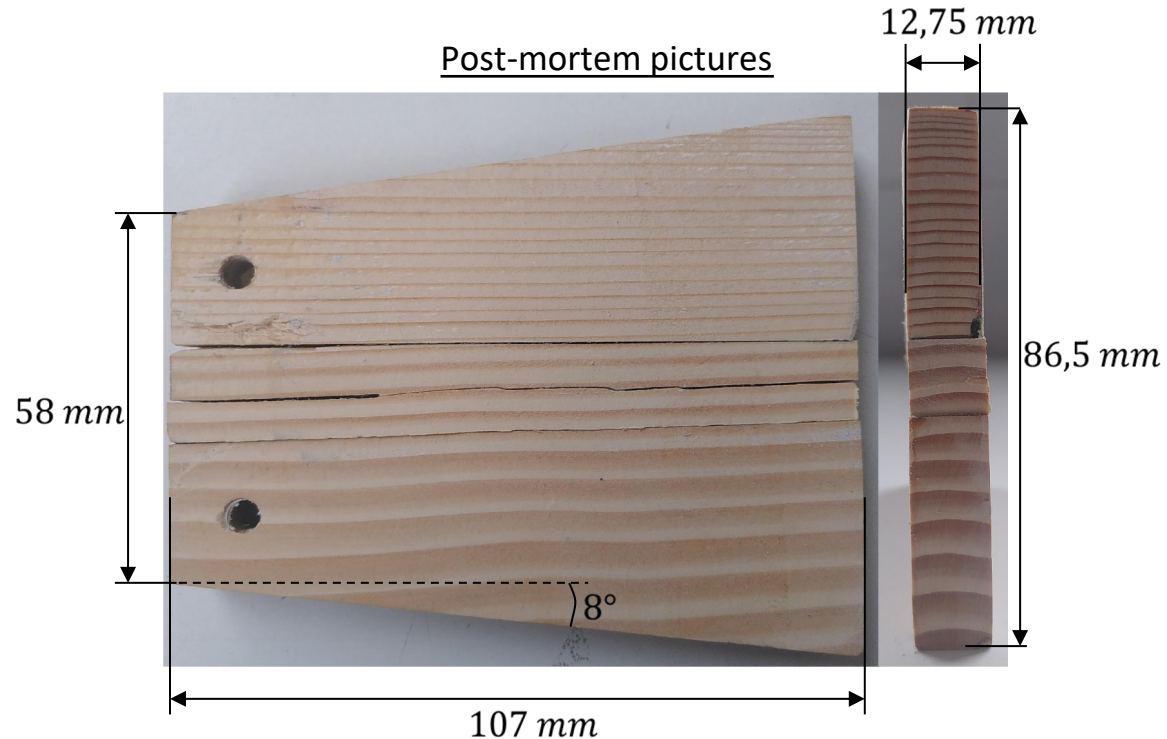
Development of Full-Field Measurements methods such as:

- Localized Spectrum Analysis (LSA) (Grédiac et al. (2018), EM; Jailin et al. (2024), in preparation)
 - Digital Image Correlation (Shi et al. (2023), EM; Langlois et al. (2024), in preparation)
- For the characterization of heterogeneous materials

1. Context
2. Introduction
3. Material and methods
4. Results and discussion
5. Conclusion and outlook

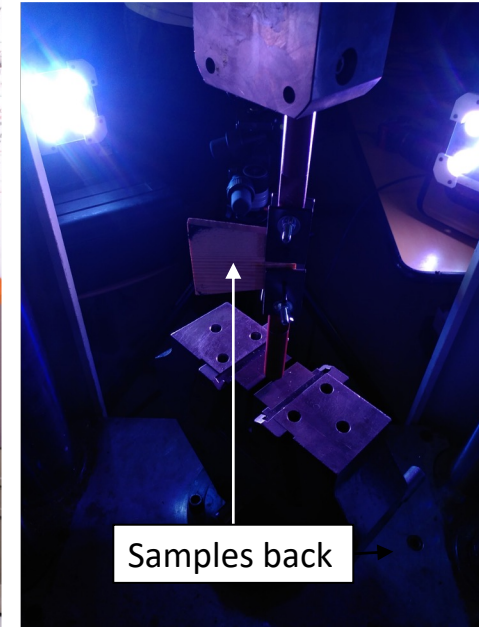
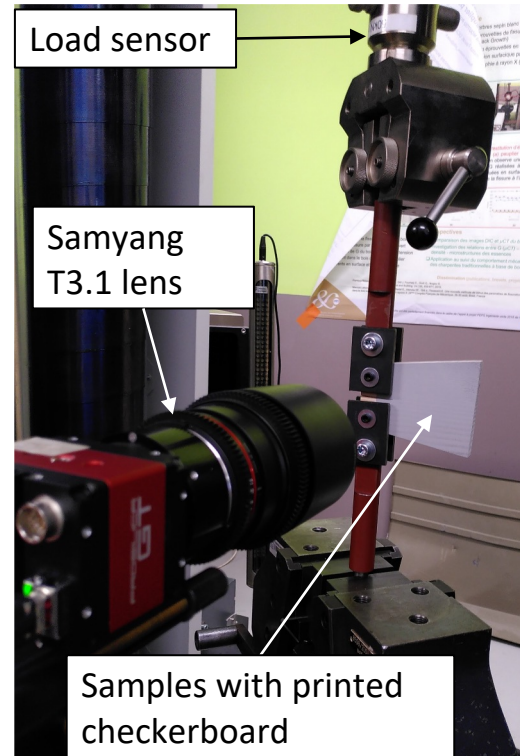
Sample used

- Variable inertia following TDCB geometry (8°)
- Quarter-sawn sample
- Crack propagation in the Longitudinal-Tangential plane
- 32 mm of initial notch
- 3 Samples tested



Tensile test

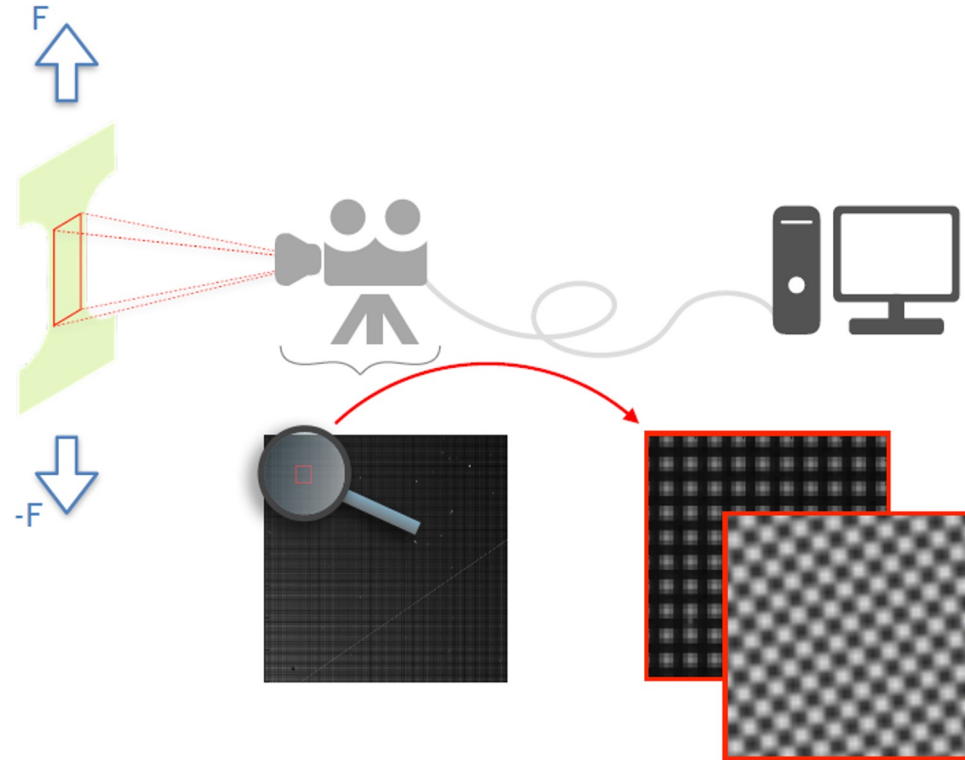
- Zwick-Roell tensile test machine
- Displacement imposed ensuring stable crack propagation : 0.005 mm.s^{-1}
- High-Resolution camera (29 MPix)



Lights installation

Sample preparation

- Periodic pattern engraved on the specimen
- Images of the pattern captured by a camera before and during loading
- Displacement and strain fields deduced by processing these images

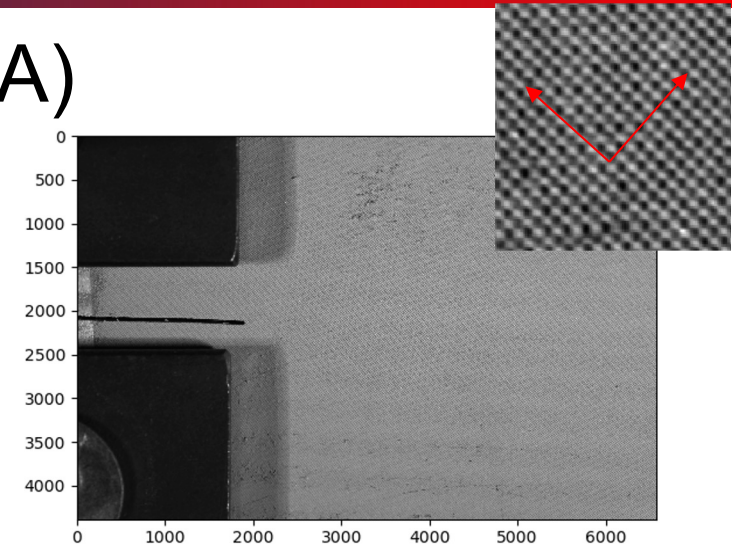


Displacement measurement (LSA)

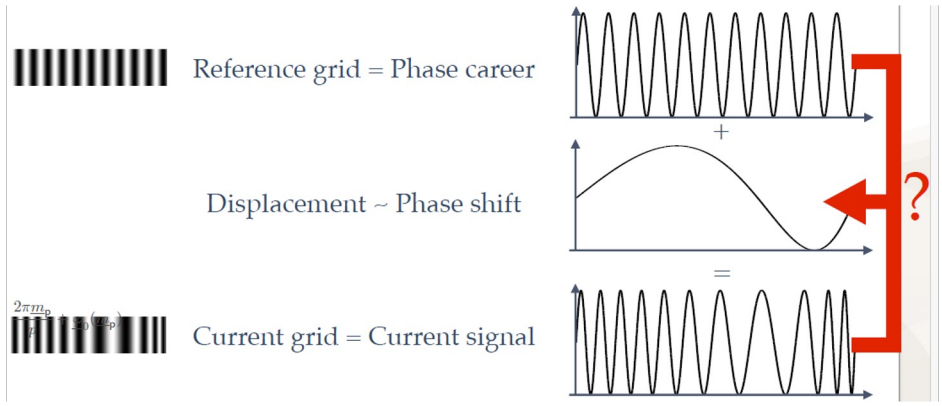
Phase extraction from images (WFT)

$$(\varphi_{\bullet} \cdot \mathbf{e}_{\theta}) = \arg\left(\sum_{\mathbf{x} \in \text{RoI}} I_{\bullet}(\tilde{\mathbf{x}}) \times w_h(\mathbf{x} - \tilde{\mathbf{x}}) \times e^{i\mathbf{x} \cdot \frac{1}{p} \mathbf{e}_{\theta}} \right)$$

↑
image convolved with gaussian kernel



Checkerboard pattern for sample 2
pitch = 6.28 Pix (= 63.6 μm)

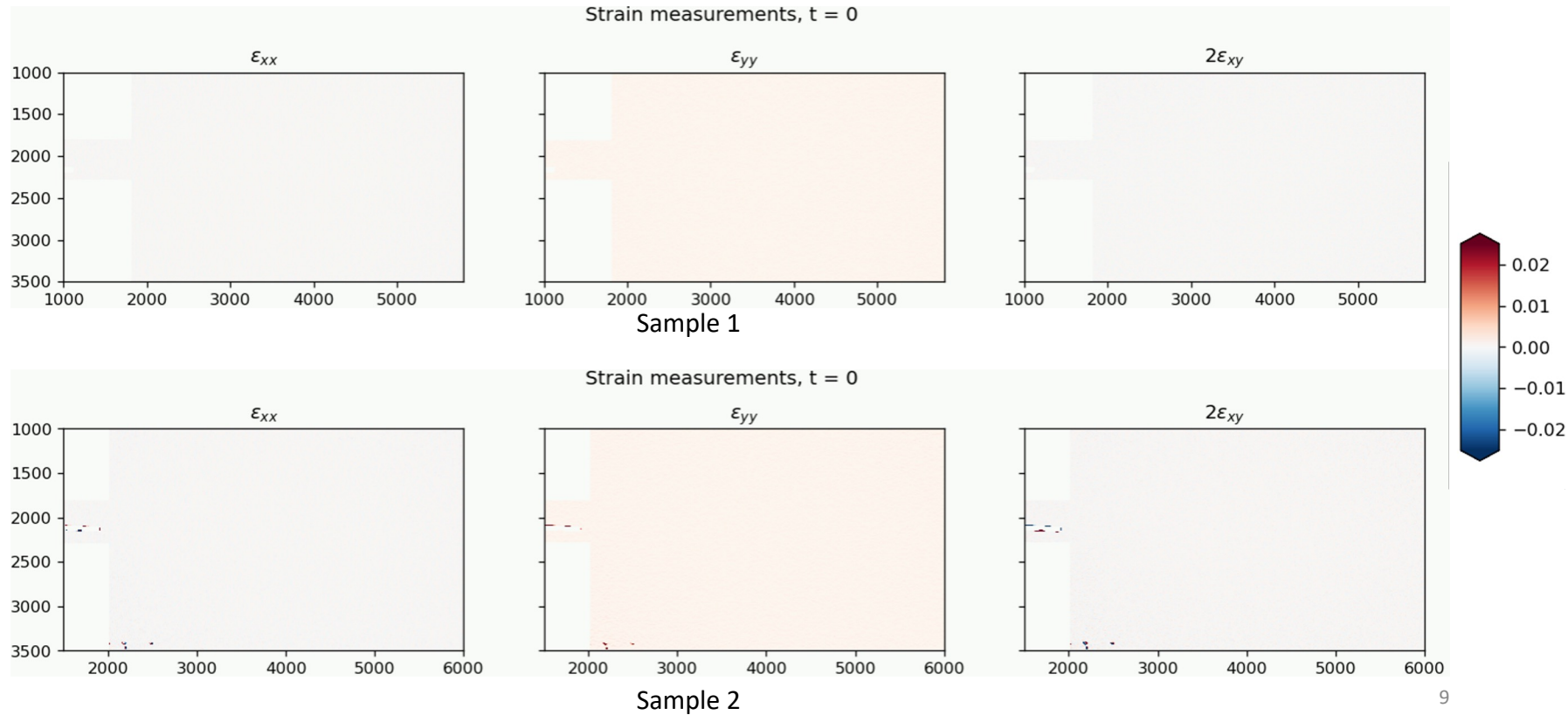


Displacement from Phase variation

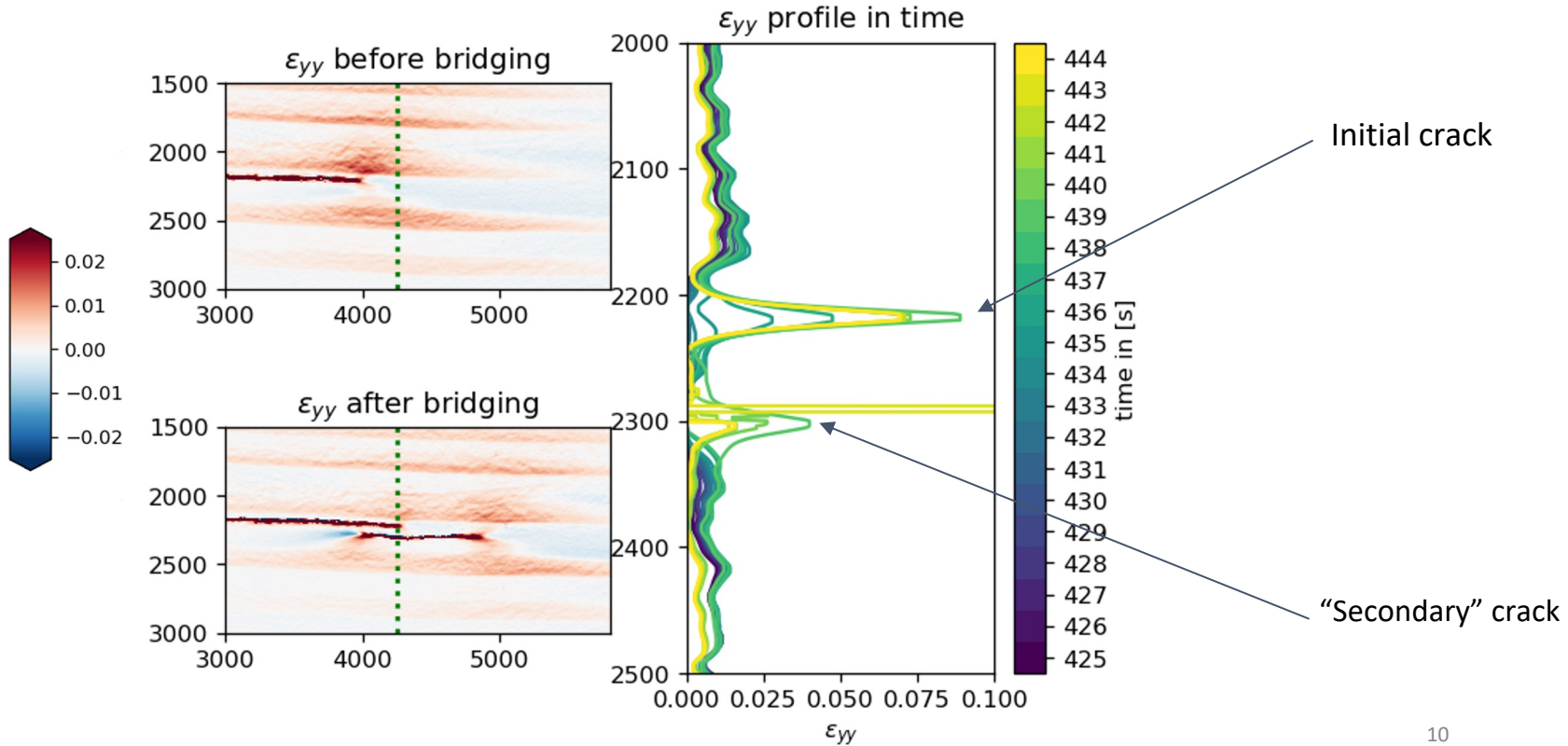
$$\mathbf{u}_t(x, y) = \frac{2\pi}{p} (\varphi_0(x, y) - \varphi_t(x, y))$$

4) Results and discussion: Strain fields

Strain fields evolution



Focus on crack bridging in sample 1

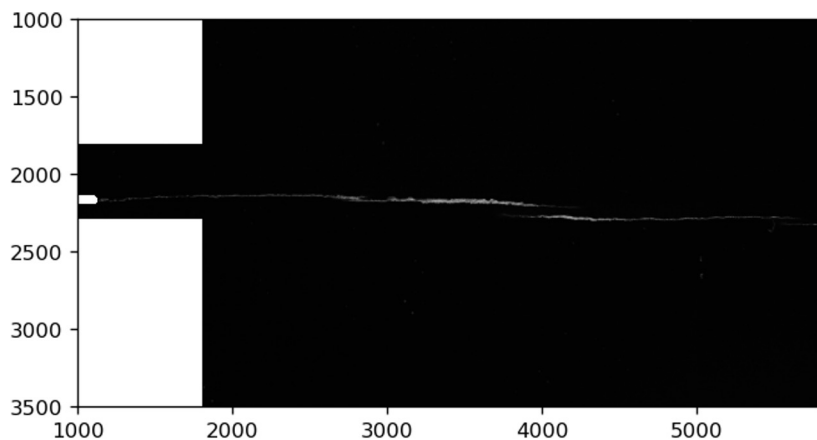


Crack features evaluation

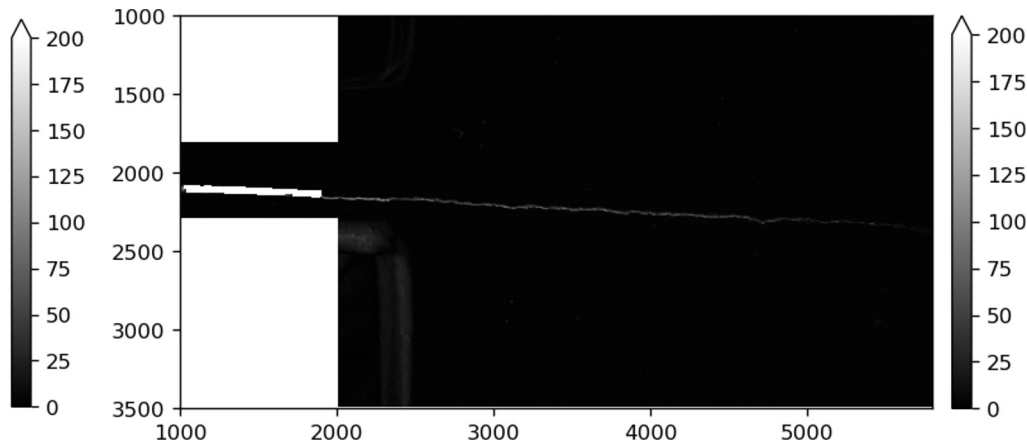
(Feld-Payet et al (2020), STR; Langlois et al (2021), PM-iDICs 2021)

Gray-level residual for crack path and length

$$r_t(x, y) = (I_0(x, y) + I_t(x + u_t^x, y + u_t^y))^2$$



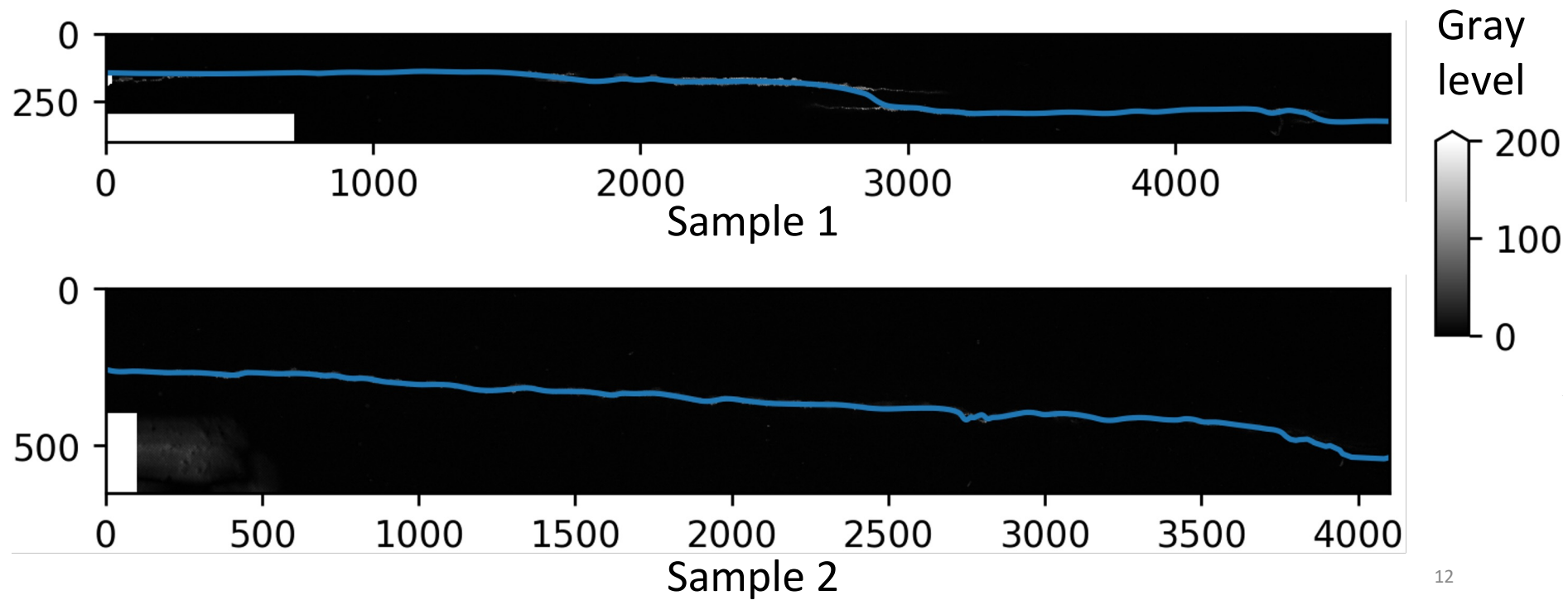
Sample 1 - last image



Sample 2 - last image

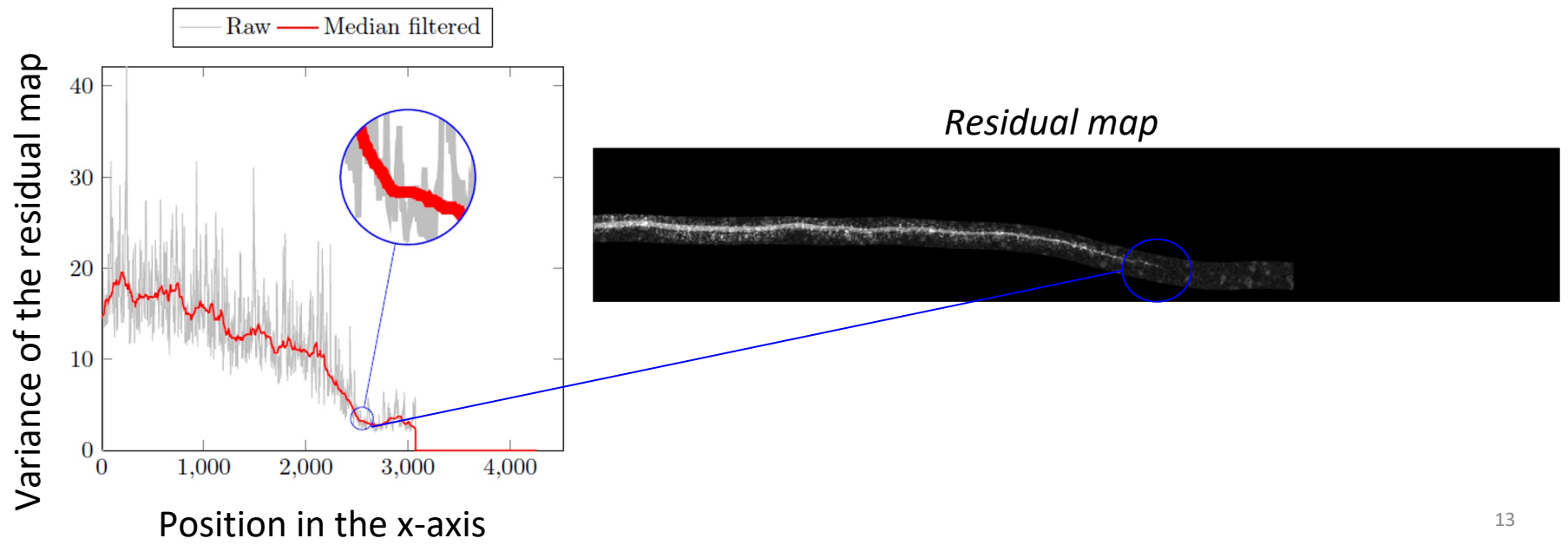
Crack path evaluation

Fitting a **single** spline to the residual map



Crack tip detection

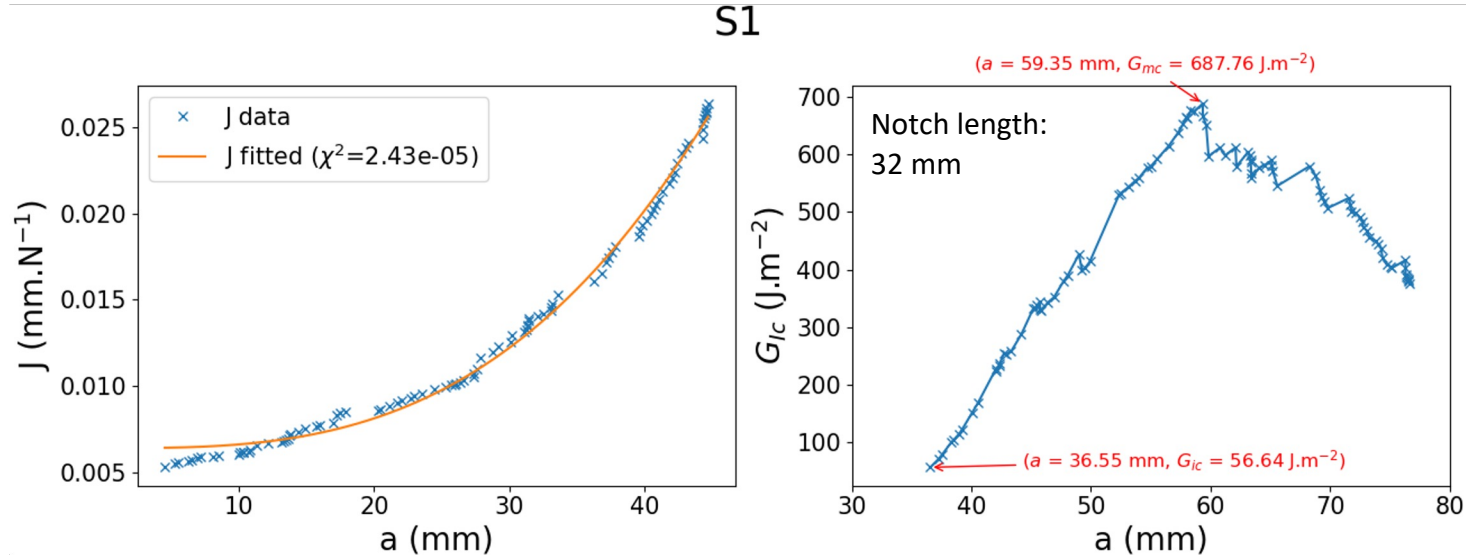
Evaluation of the error along the identified path (from Langlois (2023), PhD thesis)



4) Results and discussion: Energy release rate estimation

Energy release rate G_c calculation

- Compliance method $G_c = \frac{F^2}{2d} \frac{\partial J}{\partial a}$ where $J = u/F$ (Brittle fracture hypothesis)

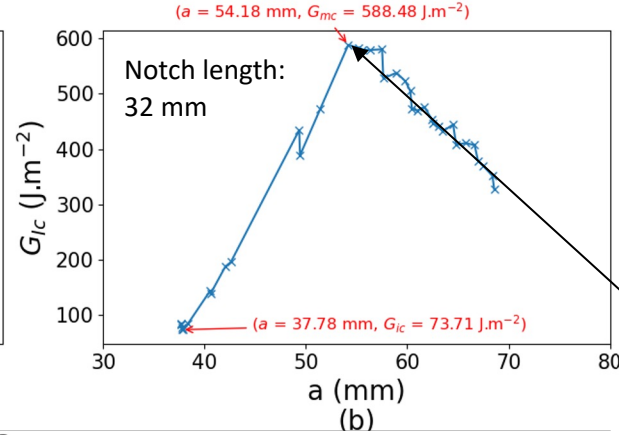
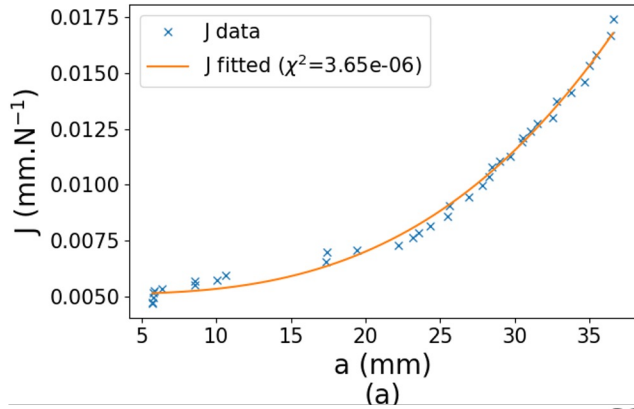


Fitting of a cubic function $J = Aa^3 + B$
→ Smoothing

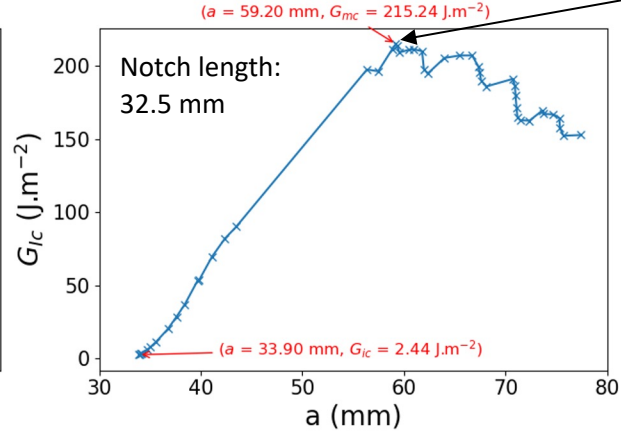
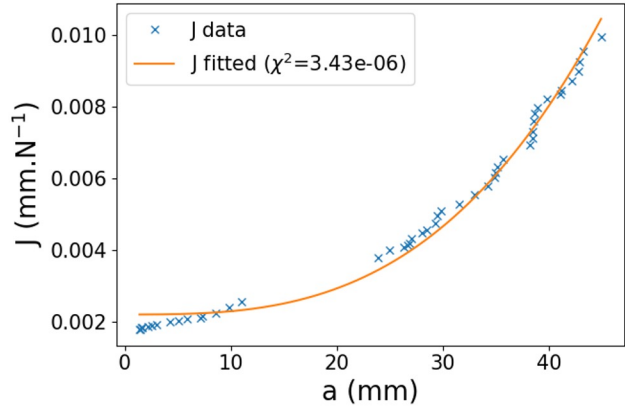
G_{IC} : Initial G_c (crack onset)
 G_{mC} : Maximum G_c (sample failure)

4) Results and discussion: Energy release rate estimation

S2



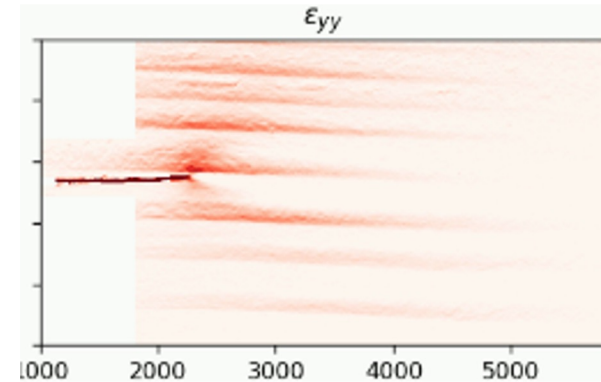
S3



Failure of the specimens observed around 57 mm for all samples:
FPZ is known to be a **material property**

Conclusions

- LSA allows to clearly identify annual rings in the strain fields, based on stiffness variations
- Crack tip position is estimated without any assumption on the constitutive model of the material and allows direct estimation of “elastic” fracture properties
- Crack tip position can be localized with respect to the surrounding annual rings, leading to a precise crack path identification

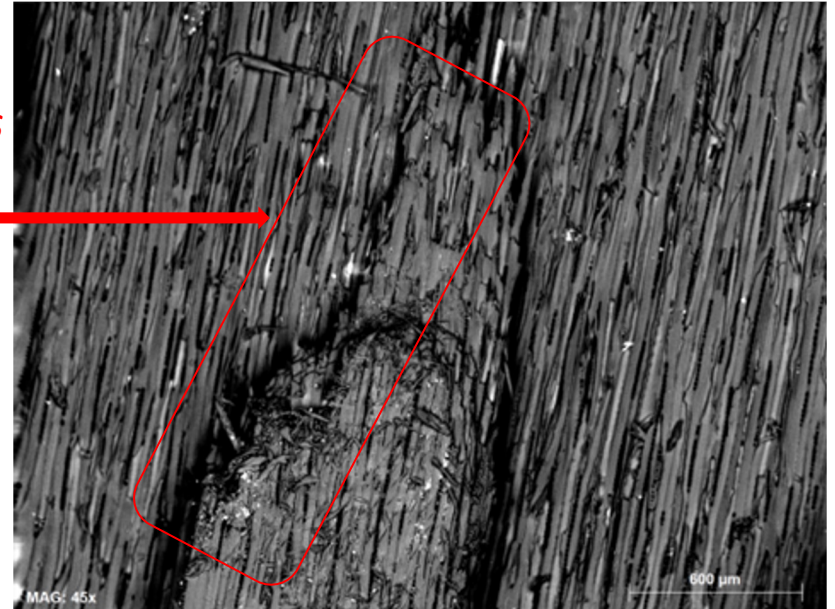


Perspectives

Coupling 2D crack path tracking with SEM analysis to identify anatomical crack trajectory

- How crack goes from early to late wood ?
- Why fibrous bridges occur ?
- What drives a crack in wood, mechanical configuration or anatomy ?

*Tracheids
pull-off*



Post-mortem SEM observation of a sample

Perspectives

- Will LSA be applicable at different moisture content ?
⇒ Quantify the energy release rate of a purely hygroscopic crack
- Does LSA identify a real crack length or an equivalent crack length ?
⇒ Check if a finite element model is still needed for quasi-brittle material
- Use LSA in mixed-mode crack process to separate mode I/II fracture properties of wood
⇒ Improve material characterization

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