Wood transverse fracture analysis at the mesoscopic scale

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Beautiful damaged work of art in wood...

Madonna, 1870

Guitar
Beautiful damaged work of art in wood...

Federal work table

Bottom of a mid-19th century American drawer (poplar)
Damage arrest and fixing
How do cracks propagate in softwood?

What are the conditions for crack arrest or propagation?

Which mechanisms have an influence on the direction of propagation?

Which model to simulate and predict propagation?
Table of content

- Mechanical model of softwood
  (application to spruce)
  - Spruce wood analysis
  - Experimental study
  - Numerical model at the mesoscopic scale

- Fracture analysis
  - Experimental study
  - Local analysis at the crack tip
  - Implementation of fracture criteria

- Conclusion and perspectives
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- Conclusion and perspectives
Softwood analysis and hypothesis

- Spruce wood is
  - Heterogeneous
  - Anisotropic
  - Dependent on temperature and humidity
  - ...
  - Complex!

- Study in the transverse plane
  - Polar and orthotropic
  - “clear” wood study

- Temperature and humidity controlled and regulated
Scales of observation

- Mechanical model of softwood
- Fracture analysis
- Conclusion and perspective

Macroscopic scale: 0.1-1m
Mesoscopic scale: 1-10 mm
Microscopic scale: 1-100 μm
Transverse compression of spruce wood

- Mechanical test realized inside a thermo-hydro-regulated chamber (25°C, 12% H Mc.)

*Simon P.* PhD thesis, INSA Lyon, 2009
Transverse compression

- Mechanical test realized inside a thermo-hydro-regulated chamber (25°C, 12%H Mc.)
- Full field measurements with 2D digital image correlation

Conclusion and perspective

www.icasoft.insa-lyon.fr
Transverse compression

- Mechanical test realized inside a thermo-hydro-regulated chamber (25°C, 12%H Mc.)
- Full field measurements with digital image correlation
- Local heterogeneity at the annual ring scale


www.icasoft.insa-lyon.fr
Annual ring homogenization

Relative position along an annual ring

Mechanical model of softwood
Fracture analysis
Conclusion and perspective

Cellular model
Continuum model

Simulation tools

Material point method

Frank and Perré, 2009
Sulskey, 1995

Mechanical model of softwood
Fracture analysis
Conclusion and perspective
Simulation with Material Point Method

- Numerical model capacities
  - Orthotropic
  - Polar
  - Multilayer
  - Realistic annual ring shape

- Numerical model specificities
  - No local remeshing
  - Fit to fracture analysis
  - Time consuming

Conclusion and perspective

Professor John A. Nairn
Richardson chair in wood sciences & engineering
Adjunct Professor of Mechanical Engineering
Oregon State University
http://oregonstate.edu/~nairnj
Input generation

Mechanical model of softwood

Fracture analysis

Conclusion and perspective

Scan

Threshold

Angular orientation of rings

≈

+
Input generation

- Relative density
- Orientation repartition
- Stiffness repartition

Conclusion and perspective
Wood mechanical model

- Orthotropic, polar, multilayer
- Addition of the ray cells mechanical properties (mixing law)

![Graph showing elastic modulus variations along an annual ring](image)

Schniewind, 1959
Farruggia et al, 2000
Guitard, 2004
Comparison of experimental results vs. numerical simulation

Mechanical model of softwood

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Comparison experimental results vs. numerical simulation

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Wood fracture experimental analysis

Mechanical model of softwood

Fracture analysis

Conclusion and perspective

Radiography with cold neutrons
Neutron spallation source
PSI Viligen Switzerland

Inside crack propagation
Mechanical model of softwood

Fracture analysis

Conclusion and perspective

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Modeling mechanical behavior of wooden cultural objects
Wood fracture experimental analysis

Crack arrest

Secondary crack creation

Thuvander, 2001
Numerical analysis at the crack tip

Stress 22 repartition

-16.23 MPa  50.62 MPa

Strain 22 repartition

-8.8  18.69

Secondary cracks appear in the latewood layer (high stress concentration)
Secondary cracks may appear at defects ahead of the crack tip

Thuvander, 2000
Nairn, 2006
Numerical analysis at the crack tip

Stress 22 repartition

-16.23 MPa  50.62 MPa

Strain 22 repartition

-8.8  18.69

Secondary cracks appear in the latewood layer (high stress concentration)
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Thuvander, 2000
Nairn, 2006
Numerical analysis at the crack tip

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Increasing of stress as latewood is approached can explain step by step crack propagation
Numerical analysis at the crack tip

Crack direction of propagation is governed by main strain direction at the crack tip

*Baillie, 1999*
Fracture criteria

- Implementation of energetic fracture criteria
  - Crack propagation condition: when total energy release rate $G \geq G_{lc}$ and $G_{lc} = 100\text{J/m}^2$
  
  "Attack, 1961"

- Crack propagation direction: principle direction of the deformation field of the crack tip
Fracture criteria validation

Experimental results

Simulation

Scan
Fracture criteria validation

Experimental results

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Conclusion

- Wood can be simulated at the mesoscopic scale as orthotropic, polar, multilayer... with realistic morphologies

- Wood fracture is complex and may be controlled by energetic criteria.

- Specific wood fracture knowledge helps to preserve wood structure or work of art!
Perspectives

- Implementation of variable $G_c$ with the layers ($G_c(r)$) and with the material orientation ($G_c(\theta)$)
- Implementation of growing stresses
- Study of preexisting drying microcracks
- Non linear characterization and implementation of a cohesive crack model

*Navì, Heger 2005
Smith, Landis and Gong 2003*
Fracture criteria validation

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Material repartition

Mass repartition

Stress 22 repartition

Strain 22 repartition

-73 MPa

110.4 MPa

-14.5

73.6

-1.26e-4

4.03e-5
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Laboratoire de Mécanique des Contacts et des Structures
Modeling mechanical behavior of wooden cultural objects
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