Modeling hygrothermal recovery of wood in relation with locked-in strains during tree life
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Experimental study

Species: Hinoki (Chamaecyparis obtusa)

- TMA with compression attachment,
- slight initial compression stress (equivalent to Tg)
- sample immersed into water; temperature is increased to 90–95°C during 2 hours, then specimen is cooled down
- dimensions of the sample are recorded with an accuracy of 0.01 μm.

Modeling

Where do locked-in strains come from?

1. Cell maturation process
   - longitudinal tension and tangential compression
   - last step of the genesis of a wood cell
   - increase of rigidity
   - tendency to shrink along the fibre and expand transversally
   - deformations are prevented by previously formed layers

> pre-stress level of the wood in the tree depends on the direction and the age of wood

2. Loading history during tree life
   - formation of layers: redistribution of tangential stresses
   - successive disposition of concentric layers
   - growth stress depends on radial position
   - inversion of stress (T: compression near the bark, tension near the pith)

How to release locked-in strains?

1. Elastic part = short-term viscous strains
   - tree heating
   - growth stress indicator on periphery
   - radial HTR against tangential HTR from literature

Separating HTR from reversible deformation

Evolution of tangential deformation against time

Evolution of tangential deformation against temperature: radial strain, thermal recoverable part, corrected irreversible part

HTR in T and R direction in the literature:

<table>
<thead>
<tr>
<th>Reference</th>
<th>Material</th>
<th>Age (years)</th>
<th>Temperature (°C)</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bardet et al., 1993</td>
<td>100</td>
<td>30-35</td>
<td>Pine, larch, oak</td>
<td>Sunset, Picea, Pinus, abies, larch, poplar, birch, . . .</td>
</tr>
<tr>
<td>Yano et al., 1989</td>
<td>100</td>
<td>30-90</td>
<td>Beech</td>
<td>Beech</td>
</tr>
<tr>
<td>Tani and Tsuruta, 1989</td>
<td>100</td>
<td>30-90</td>
<td>Scots pine</td>
<td>Scots pine</td>
</tr>
<tr>
<td>Newby and Jackson, 1993</td>
<td>30-90</td>
<td>90</td>
<td></td>
<td>Tagi</td>
</tr>
<tr>
<td>van der Linden et al., 1993</td>
<td>100</td>
<td>30-90</td>
<td></td>
<td>Isla, free</td>
</tr>
</tbody>
</table>

The results are not consistent with the growth stress profile which is usually proposed. In T direction, we expect the older wood (near the pith) to be under tension!

Growth stress profile for old and recent wood: inversion of stress with the age of wood

Different steps to simulate the mechanical loading of wood during tree life

Hypothesis: rheological similarity between maturation and HTR

\[
\sigma = \sigma_1 = \ldots = \sigma_f,
\]

\[
\varepsilon = \varepsilon_f + \ldots + \varepsilon_i,
\]

\[
\alpha_i = E_i (\varepsilon_i - \chi_i)
\]

\[
\frac{dx}{dt} = \varepsilon_i - \chi_i
\]

pre-stressed model: \( \chi_i > 0 \) for \( i > 0 \)

Work in progress:
- Calculation of the strain in each viscous branch
- Simulation of a thermal treatment to simulate HTR

This work is an HTR in the framework of an application for a JSPS/CNRS fellowship and a JSPS/CNRS fellowship for a scientific mission at Ritsuryo University in 2016.