Micromechanics of moisture-induced instability of wood-based composites

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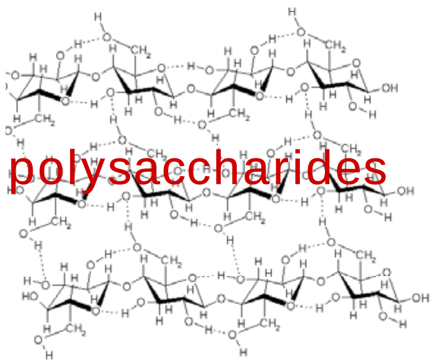
Moisture uptake in wood-based materials



→ Dimensional instability, degradation of properties, fungal attack etc.

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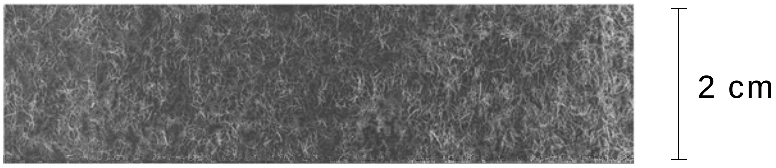
Wood-fibre composites

Slender fibres as reinforcements,
not wood particles as fillers...



- ❑ Uniform properties (in-plane isotropic)
- ❑ 3D shapes
- ❑ Polymer surface

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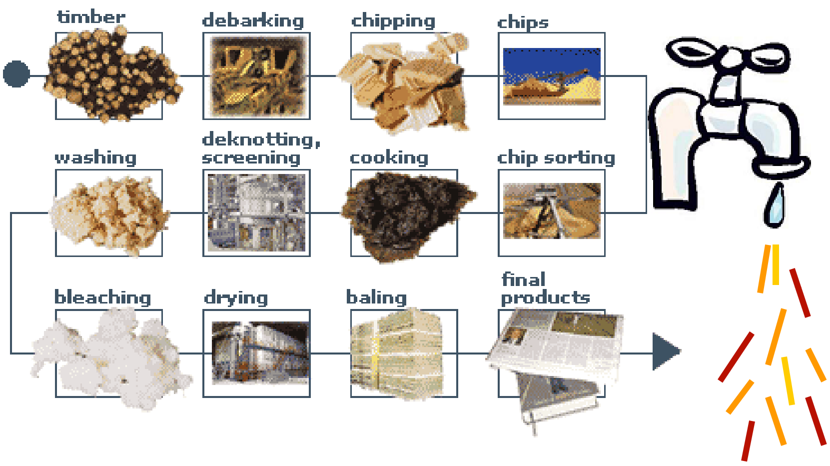
Fibre selection and modification



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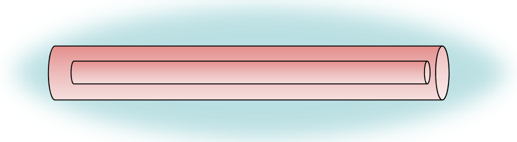
Fibre swelling



Radial hygroexpansion $\beta_r = \frac{\varepsilon_r}{\Delta c}$

Axial hygroexpansion $\beta_l = \frac{\varepsilon_l}{\Delta c}$

$\beta_r >> \beta_l \quad (E_l >> E_r)$

K. Schulgasser, J Mech Phys Solids **35**, 35 (1987)

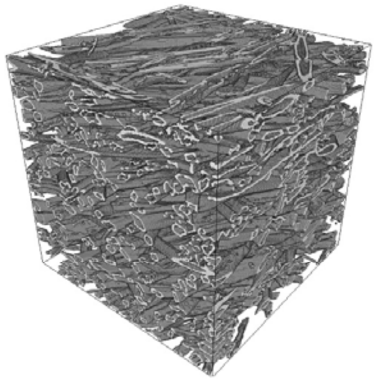
Hygoexpansion measurement of individual fibres?

Dry

Moist

Cumbersome, time consuming, …

Hygroexpansion from consolidated fibre mats?

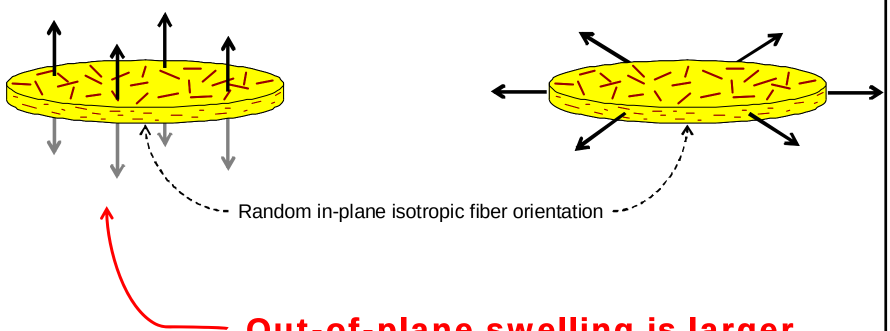


Relative contribution from fibres?

Composite hygroexpansion

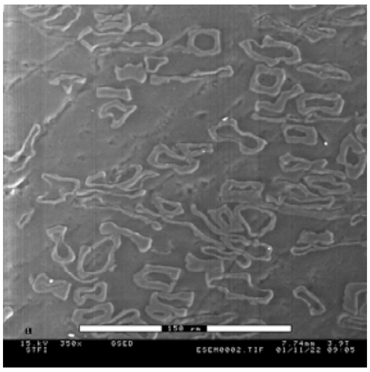
Out-of-plane hygroexpansion
Thickness direction

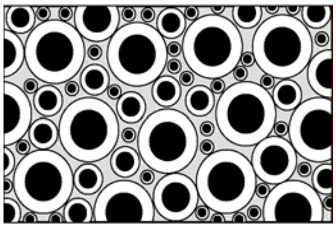
In-plane hygroexpansion
Radial direction



Out-of-plane swelling is larger

Fibrous microstructure

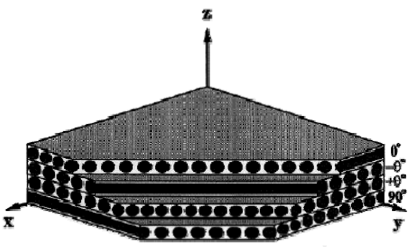


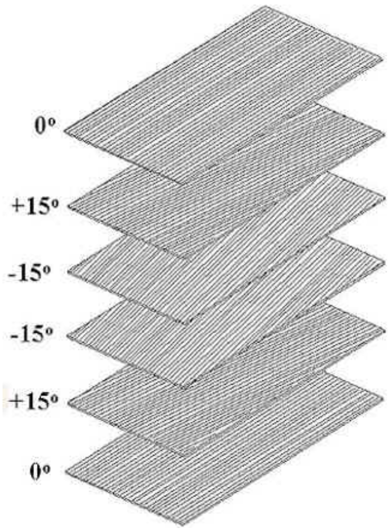


Concentric cylinder assembly,
Self-consistent scheme

Z. Hashin, J. Appl. Mech., **50**, 481 (1983).

Laminate analogy





Laminate theory

In-plane stiffness

$$Q_{11}^{\text{LAM}} = Q_{22}^{\text{LAM}} = \frac{1}{8}(3Q_{11} + 3Q_{22} + 2Q_{12} + 4Q_{66})$$

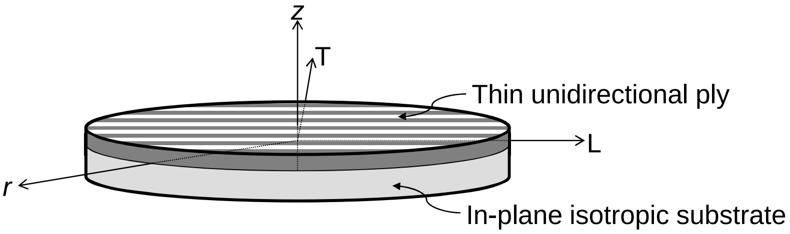
$$Q_{12}^{\text{LAM}} = \frac{1}{8}(Q_{11} + Q_{22} + 6Q_{12} - 4Q_{66})$$

$$Q_{66}^{\text{LAM}} = \frac{1}{8}(Q_{11} + Q_{22} - 2Q_{12} + 4Q_{66})$$

In-plane hygroexpansion

$$\beta_r^{LAM} = \frac{E_{\text{L}}\beta_{\text{L}} + E_{\text{T}}\beta_{\text{T}} + \nu_{\text{LT}}E_{\text{T}}(\beta_{\text{L}} + \beta_{\text{T}})}{E_{\text{L}} + E_{\text{T}} + 2\nu_{\text{LT}}E_{\text{T}}}$$

Swelling constraint



Calculated out-of-plane hygroexpansion

$$\beta_z^{\mathrm{LAM}} = \beta_{\mathrm{T}} + \underbrace{\left(\frac{\nu_{\mathrm{T'}}}{E_{\mathrm{T}}} - \frac{\nu_{\mathrm{LT}}}{E_{\mathrm{L}}}\right)\frac{E_{\mathrm{L}}E_{\mathrm{T}}(\beta_{\mathrm{T}} - \beta_{\mathrm{L}})}{E_{\mathrm{L}} + E_{\mathrm{T}} + 2\nu_{\mathrm{LT}}E_{\mathrm{T}}}}$$

Depends on E and β of consituents

Experimentally measured

Back out fibre hygroexpansion:

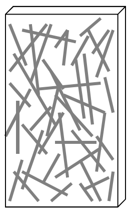
$$\min_{\beta_{\mathrm{fT}}} \sum_{i=1}^{N} \left(\overline{\beta}_{z,i}^{\mathrm{LAM}} - \beta_z^{\mathrm{LAM}}(\mathbf{x}_i, \beta_{\mathrm{fT}})\right)^2$$

Materials

Fibres
- Bleached kraft softwood fibres, Imatra Mill, Finland
  - *Untreated - reference*
- Same fibres
  - *Cross-linked* BTCA (butyltetracarboxylic acid)

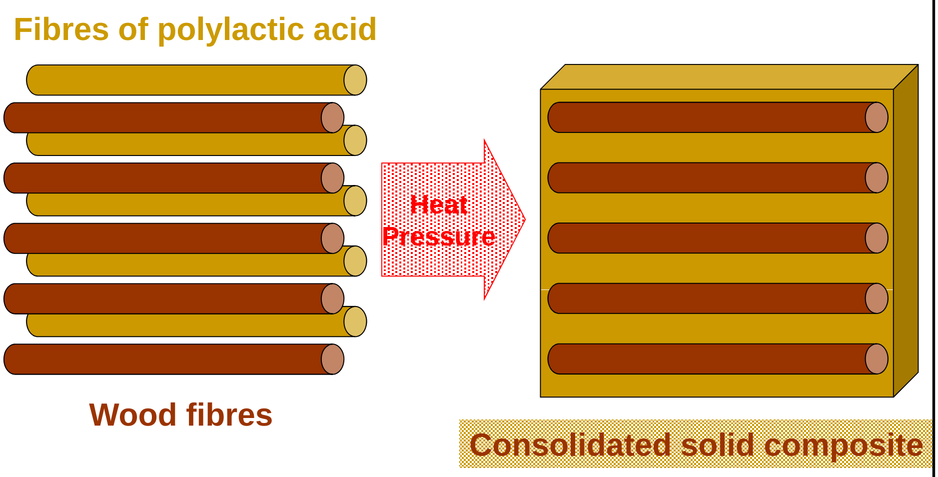
Matrix
- Polylactic acid

Composite
- 30 and 40 v% fibres
- Hot-press moulding



Hot-pressing of commingled fibre mats

Maintained fibre slenderness



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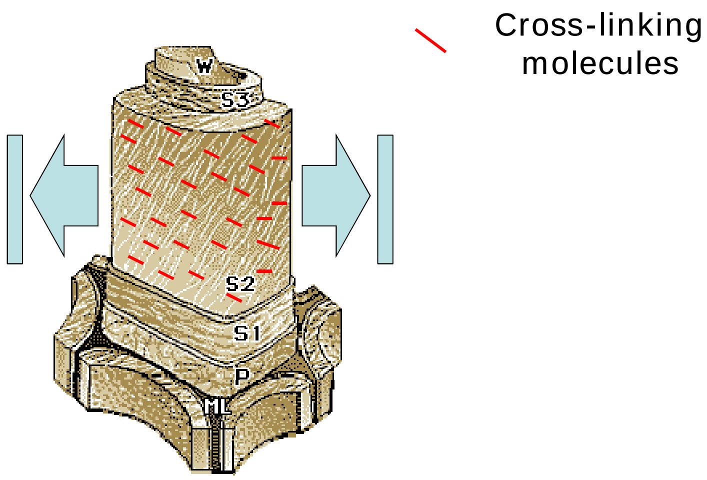
Cell-wall cross-linking



Restrained transverse swelling

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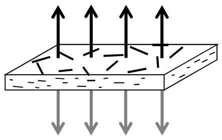
Experiments



Out-of-plane swelling:
50%RH to FSP

Tensile testing

E_f from Neagu et al. J Comp. Mater. **40**, 663 (2006)

Microscopy

Input parameters

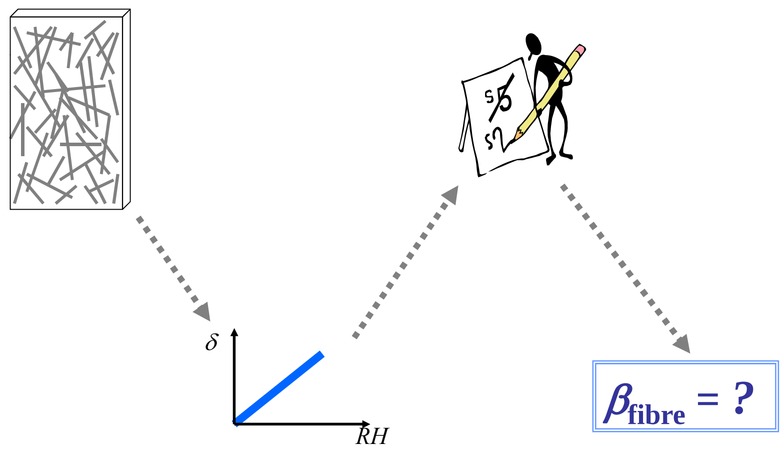
Constituent properties (measured or assumed)

E_m (GPa)	ν_m	β_m (ε/RH)	$E_{fL\ BTCA}$ (GPa)	$\nu_{fL\ ref}$, $\nu_{fT\ ref}$	$E_{fL\ ref}$ (GPa)	$\nu_{fL\ BTCA}$, $\nu_{fT\ BTCA}$
3.6	0. 35	10^{-4}	34.4	0.3	37.7	0.3

Composite swelling (V_f = 0.40)

Reference 8.5 %
Cross-linked 4.8 %

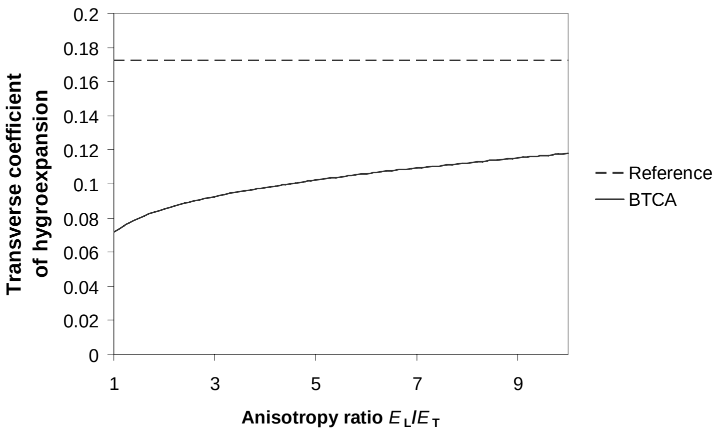
Back calculation



Results

Type	***β (ε/RH)***
Reference	0.17
Cross-linked	0.10
Estimated from paper properties I. Kajanto & K. Niskanen. Paper Physics, Fapet(1998)	0.22
Determined by FEM simulations K. Persson, PhD thesis LTH (2000)	0.12-0.13
Estimated from wood samples L. Wallström et al. Holz Roh Werkst. **53**, 87 (1995)	0.21

Effect of anisotropy ratio



$$\frac{E_L}{E_T} = \frac{\beta_T}{\beta_L}$$ must be assumed

Concluding remarks

- Sensitivity to moisture
- Inverse modelling to identify transverse fibre hygroexpansion coefficient
- Cell-wall cross-linking reduce hygroexpansion coefficient significantly
- Simple method that could be used in ranking fibre modification
- Almgren et al. *Polym. Compos*. **31**, 762 (2010)

Regards from Biocomposites Group KTH, Sweden

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