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Dog-bone specimens may not provide direct access to clear wood tensile strength parallel to grain: analytical and numerical evidences

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Motivation

Well established standards (e.g., DIN 52 188 - 79 [1] and ASTM-D143-94 [2]) prescribe the use of dog-bone shaped specimens (Fig 1) for the determination of clear wood tensile strength.

Well established knowledge assumes that;

- the gauge region is subject to a uniform distribution of pure axial stress,
- the anchoring region is subject to spurious stress produced by the jaws,
- the necking region allows stresses to regularize, avoiding any interference of the anchoring system on the measurements performed in gauge region.

However, conflicting information is available in literature.

- The failure of clear wood samples outside the gauge region is often reported in literature e.g., [3, Section 3.2.2] notices the failure of approximately 60% of the tested samples in the necking region.
- ISO 527-4 [4] allows for using three types of test sample: dog-bone, prismatic without end-tabs, and prismatic with end-tabs for fiber-reinforced plastic composites, specifying also that dog-bone sample may be used only if failure occurs in gauge region.

A closer look at stress distribution in necking region is required.

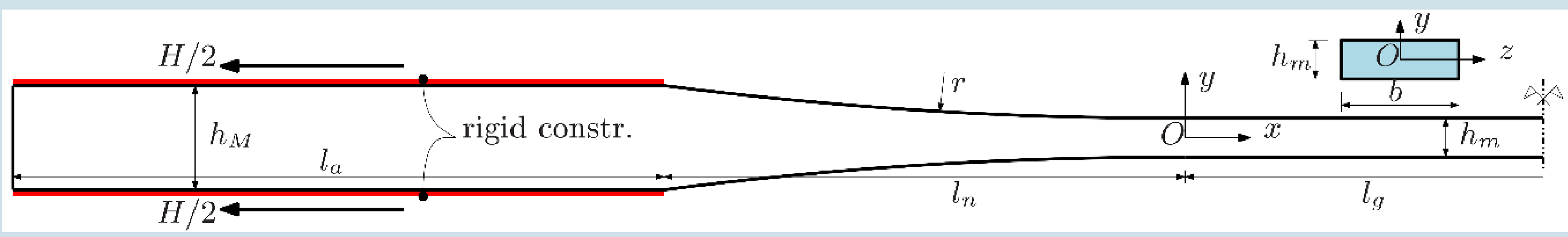

Fig 1: : Clear-wood dog-bone sample as defined in [1]. h_m = 6mm, h_M = 15mm, l_a = 100mm, l_n = 80mm, l_g = 110mm, r = 713mm, b = 18mm.

Analytical & Numerical Methods

Analytical recovery of stress distribution

2D equilibrium along x and y directions, can be written in the following form

$$\tau(x,y) = -\int \frac{\partial}{\partial x}\sigma_x(x,y)dy + C_\tau$$

$$\sigma_y(x,y) = -\int \frac{\partial}{\partial x}\tau(x,y)dy + C_{\sigma_y}$$

C_τ and C_{σ_y} have to be chosen in order to satisfy boundary equilibrium on lower and upper lateral surfaces of the beam reading

$$\tau\left(x, \pm\frac{h(x)}{2}\right) = \pm\frac{1}{2}h'(x)\sigma_x\left(x, \pm\frac{h(x)}{2}\right)$$

$$\sigma_y\left(x, \pm\frac{h(x)}{2}\right) = \frac{1}{4}(h'(x))^2\sigma_x\left(x, \pm\frac{h(x)}{2}\right)$$

Assuming that the cross-section behaves as a rigid-boy, the following distribution of stresses can be recovered (see [5] for details)

$$\sigma_x(x,y) = \frac{N}{h(x)b} \qquad \tau(x,y) = \frac{N\,h'(x)}{h^2(x)b}y$$

$$\sigma_y(x,y) = N\left(\frac{2(h'(x))^2 - h''(x)h(x)}{h^3(x)b}\frac{y^2}{2} + \frac{h''(x)}{8b}\right)$$

FE analysis

The 2D domain and the constraints depicted in Fig. 1 have been discretized with a structured mesh of CPS3 triangular FE (4701×101 uniformly distributed nodes), exploiting the highlighted symmetries, and using the commercial software Abaqus.

Failure Index (FI) evaluation

The specimen failure has been evaluated according to Tsai-Wu FI, defined as

$$FI = \frac{\sigma_x^2}{f_{tx}f_{cx}} + \frac{\sigma_y^2}{f_{ty}f_{cy}} + \frac{\tau^2}{f_\tau^2} + \left(\frac{1}{f_{tx}} - \frac{1}{f_{cx}}\right)\sigma_x + \left(\frac{1}{f_{ty}} - \frac{1}{f_{cy}}\right)\sigma_y$$

using characteristic strength parameters of Norway spruce: $f_{tx} = 77\frac{N}{mm^2}$, $f_{cx} = 44\frac{N}{mm^2}$, $f_{ty} = 2.7\frac{N}{mm^2}$, $f_{cy} = 5.8\frac{N}{mm^2}$, $f_\tau = 6.7\frac{N}{mm^2}$.

Results & Discussion

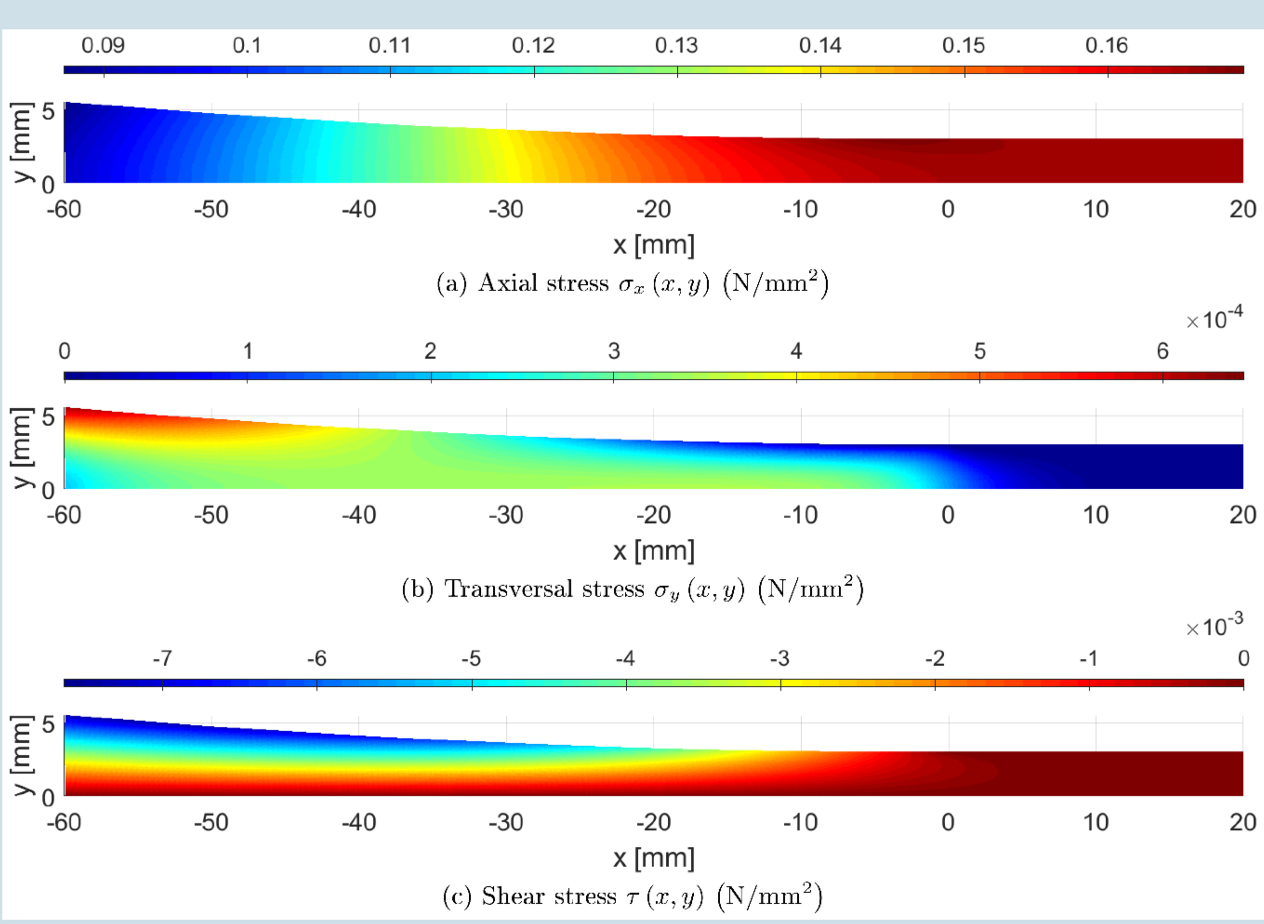

Fig 2: Stress distributions in dog-bone sample (axial force H=1N) evaluated according to FE analysis.

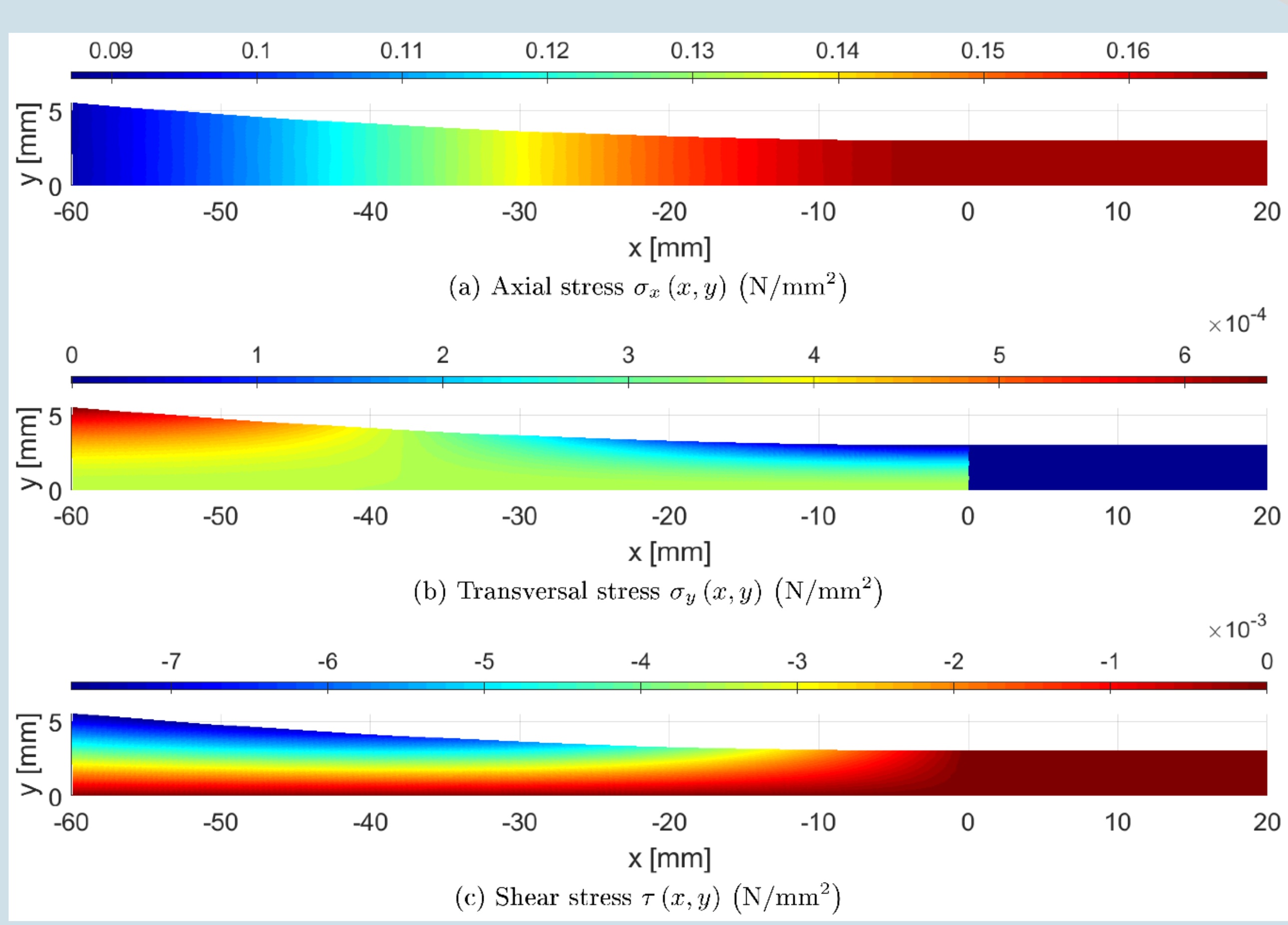

Fig 3: Stress distributions in dog-bone sample (axial force H=1N) evaluated according to analytical stress-recovery.

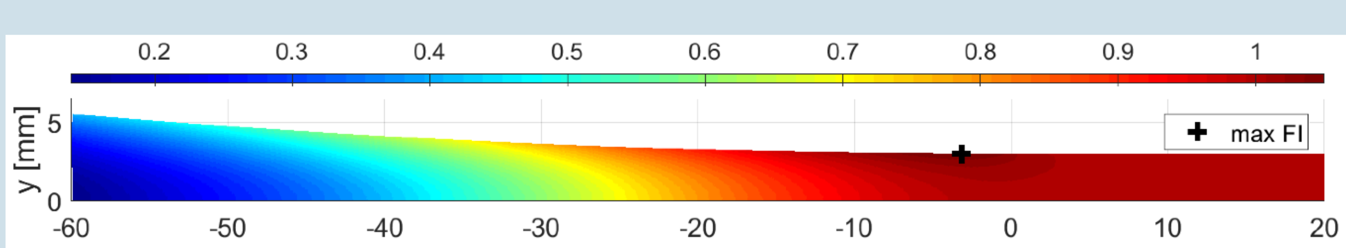

Fig 4: Distribution of the Tsai-Wu Failure Index (FI) in a Norway spruce clear-wood dog-bone sample hypothetically breaking in gauge region evaluated according to FE analysis. Black mark highlights the position of the maximal FI ≈ 1.05.

Discussion

- Both FE analysis (Fig 2) and analytical stress recovery (Fig 3) confirm the presence of spurious stresses in necking region, controlling the failure of the specimen.
- Accept as valid also test on specimens breaking outside gauge region introduces an ≈ 5% error on the strength evaluation (Fig 4), but leads the testing procedure to become faster and cheaper.

References:

[1] DIN 52 188 - 79. Bestimmung der Zugfestigkeit parallel zur Faser. Technical report, DIN, 1979.

[2] ASTM-D143-94. Standard test methods for small clear specimens of timber. Technical report, ASTM, 2000.

[3] Eberhardsteiner, J., Mechanisches Verhalten von Fichtenholz: Experimentelle Bestimmung der biaxialen Festigkeitseigenschaften. Springer-Verlag, 2002.

[4] ISO 527-4. Plastics - determination of tensile properties - part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites. Technical report, ISO, 1997.

[5] Balduzzi, G., Zelaya-Lainez, L., Hochreiner, G., & Hellmich, C., Dog-bone Samples may not Provide Direct Access to the Longitudinal Tensile Strength of Clear-wood *The Open Civil Engineering Journal*, *15*(1).

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