Characterization of thermo-hydro-mechanically modified bamboo (Guadua angustifolia Kunth) for structural cross laminated panels.

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Hector F. Archila
PhD Researcher

Dr. Martin Ansell
Prof. Pete Walker

cicm
the BRE centre for innovative construction materials

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REFERENCE PICTURE
Hector Archila ©

Bamboo

Guadua angustifolia Kunth

Round bamboo

Bamboo mats

Bamboo strips

Bamboo fibre

- http://bit.ly/Y7jFO0 (bamboo bullet proof jacket)
- **http://canyaviva.com** (bamboo ropes)
- http://bit.ly/UsK3O2 (Bamboo turbine)
- 2011, Osorio et al., (Bamboo fibres)

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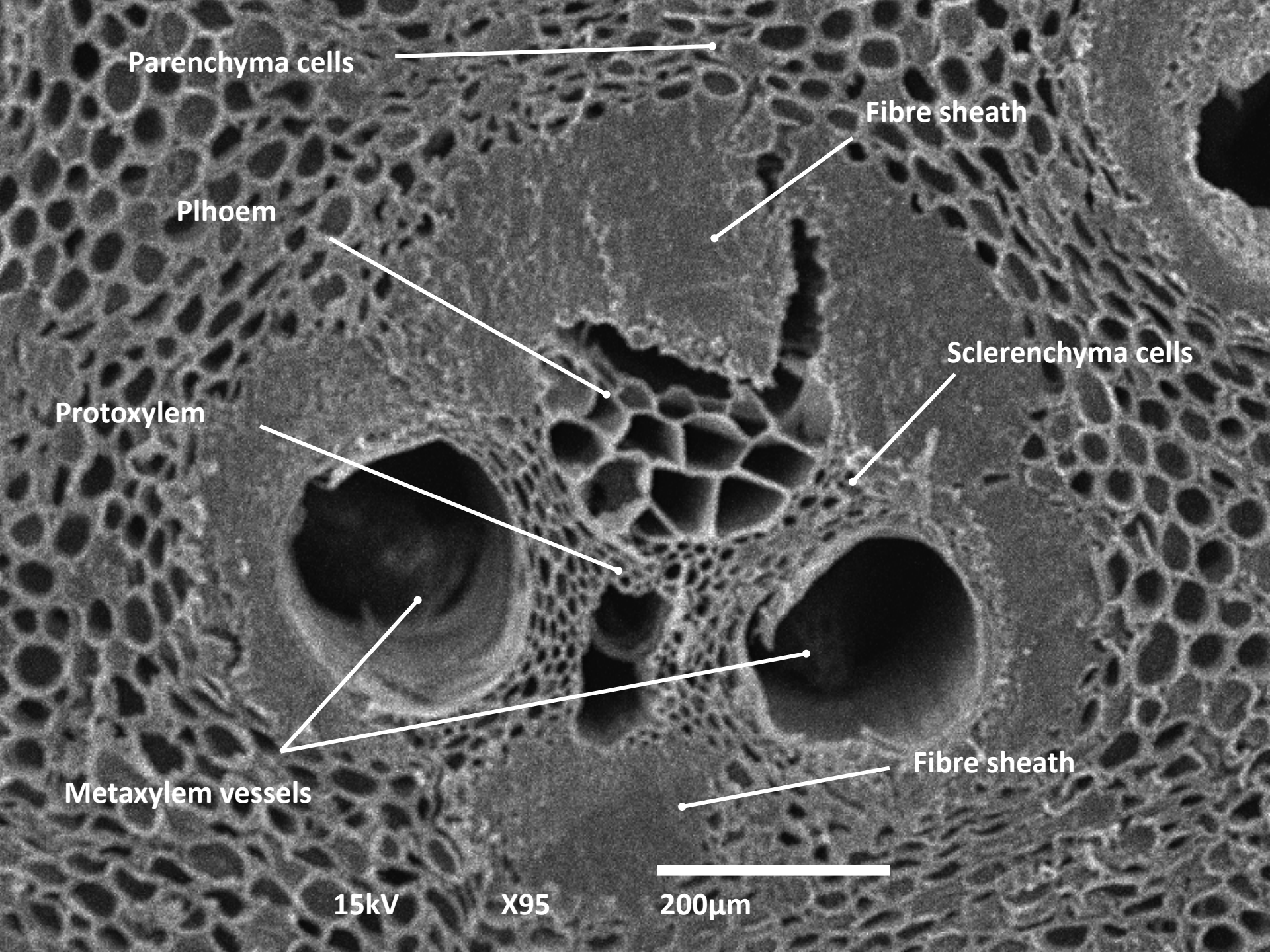
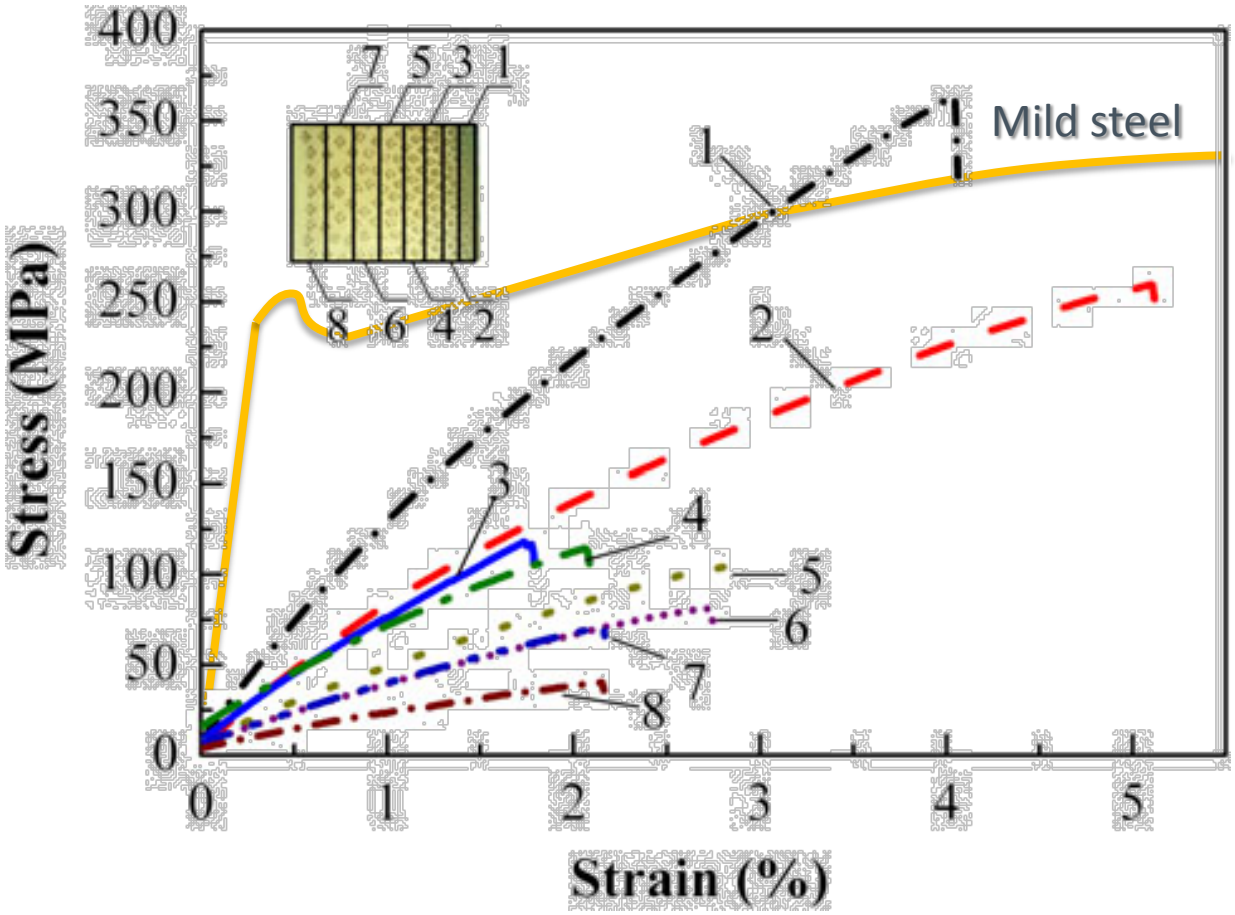

Parenchyma cells
Fibre sheath
Plhoem
Sclerenchyma cells
Protoxylem
Metaxylem vessels
Fibre sheath
15kV
X95
200µm

Crosswise variation of mechanical properties

Stress versus strain curves for sections 1 to 8 of bamboo and for steel.



Longitudinal stress vs strain percentage of a tensile test undertaken on bamboo slices cut from layer 1 (outer) to 8 (inner) of a bamboo culm wall across the section*.

*2011, Li & Shen, J. Mater. Res., Vol. 26, No. 21, Nov 14, 2011

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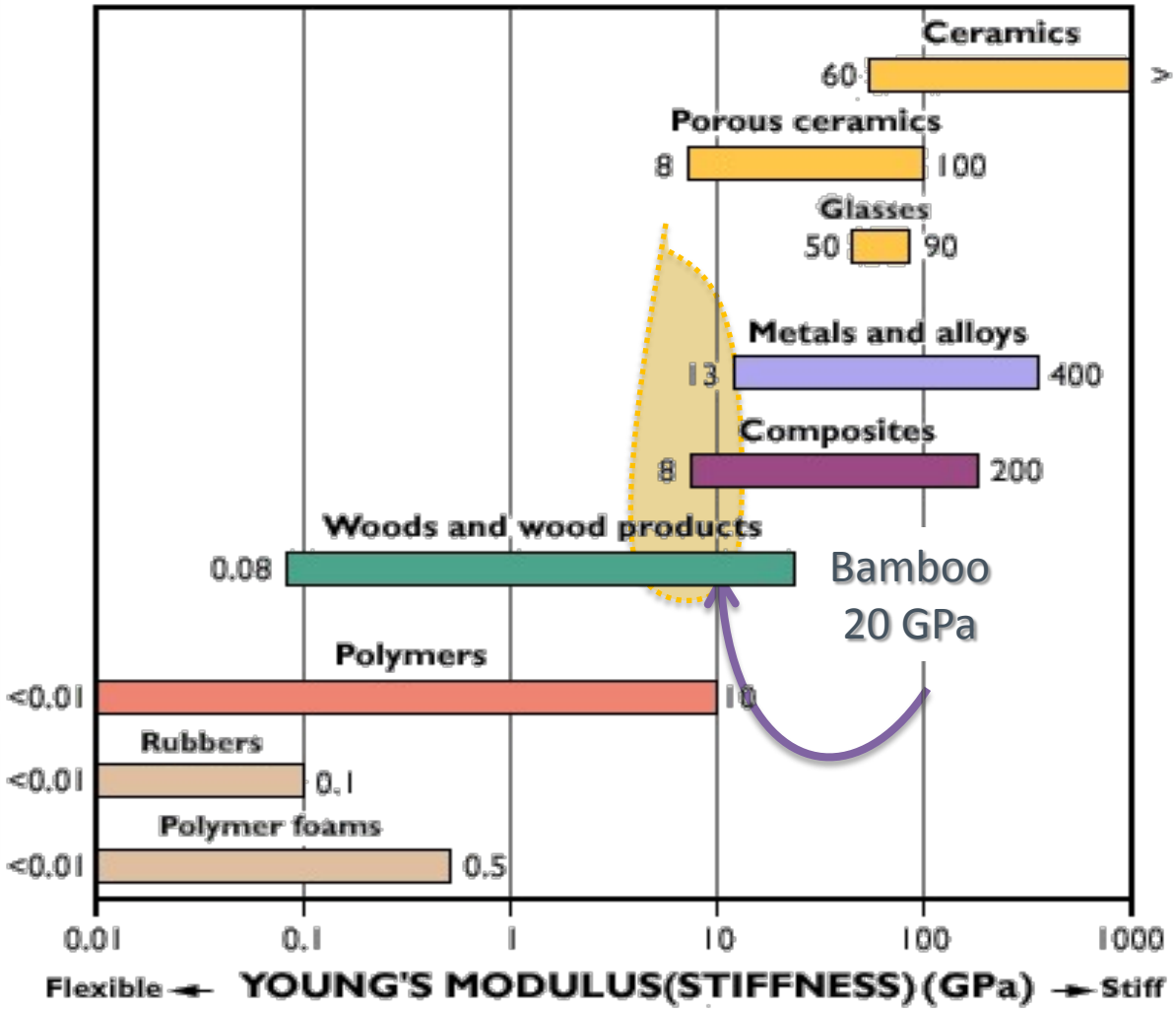
Mechanical properties

Natural steel…



Specific stiffness of
Mild steel = 25.31 m^2/s^2

ρ = 7900 kg/m^3

E = 200 GPa

Specific stiffness of
Bamboo = 25.00 m^2/s^2

ρ = 800 kg/m^3

E = 20 GPa

ρ = Density **E** = Young's modulus

* http://www-materials.eng.cam.ac.uk/mpsite/properties/

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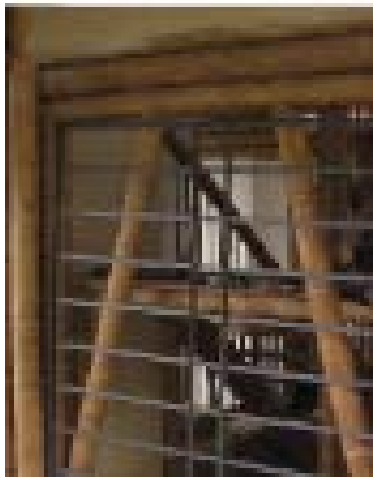

Traditional building.



Challenges

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Industrial use...

- **2009, k. De Flander & R. Rovers** (Picture by Juan Ayala)

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Appropriate technology

(Context)

Efficient use

(Enhance)

Long lasting

(Biodeterioration)

High added value

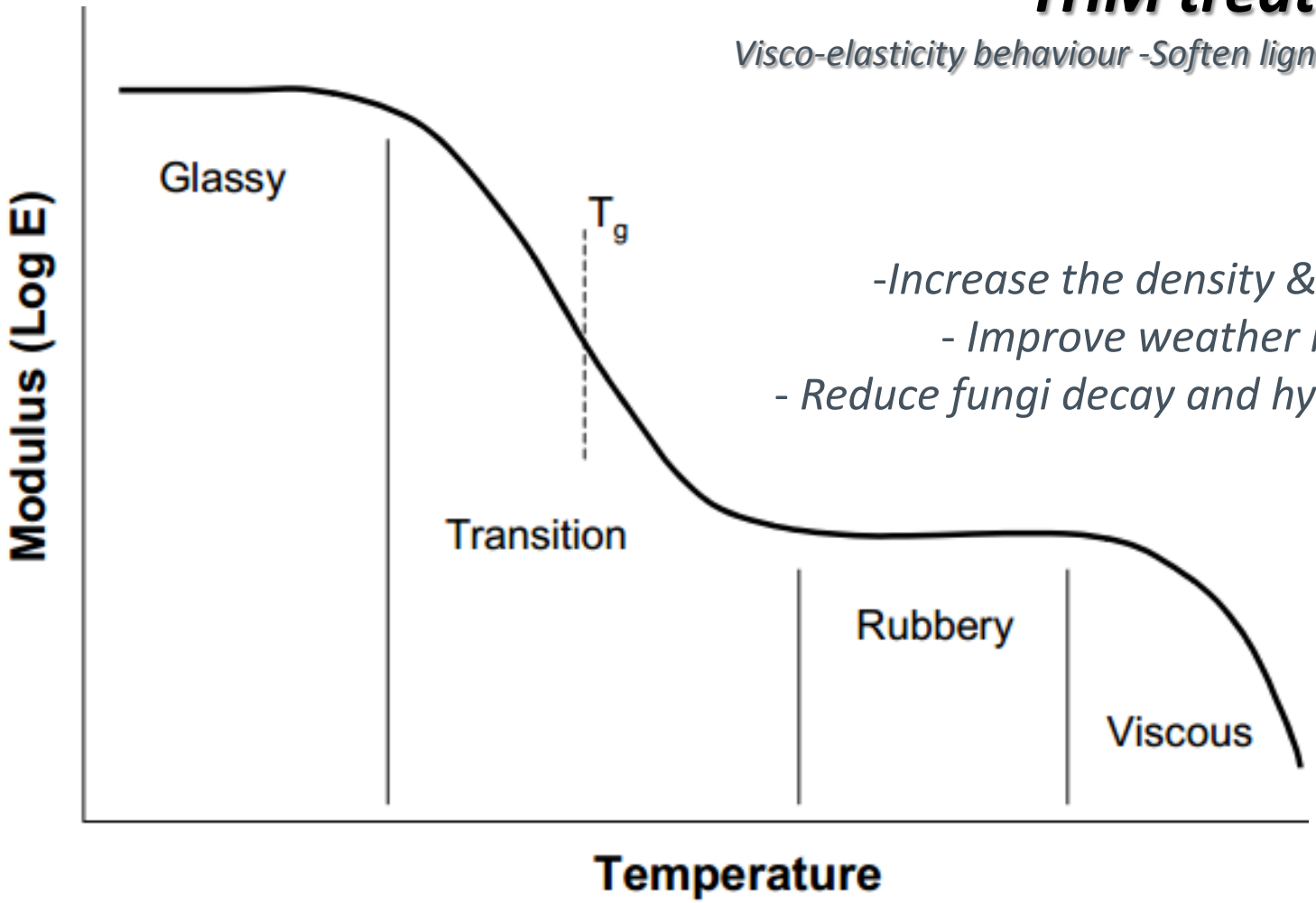
(Non-Temporary)

THMT

Thermo-hydro-mechanical treatments

THM treatments

Visco-elasticity behaviour -Soften lignin - Densify



-Increase the density & hardness
- Improve weather resistance
- Reduce fungi decay and hygrospicity

Variation of relaxation modulus with temperature for an amorphous polymer.

1999, Christopher A. Lenth
http://scholar.lib.vt.edu/theses/available/etd-08302000-12360026/unrestricted/cal.pdf

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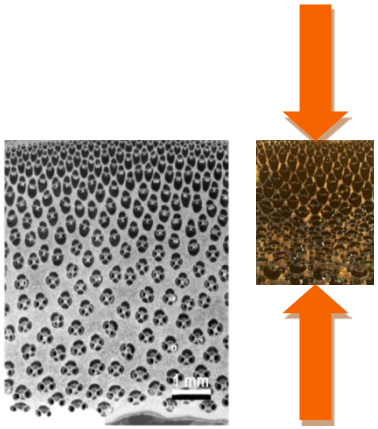
Round cane

ρ_i = 540 kg/m^3

MOE = 16.21 GPa

Specific stiffness = 29.84 (m^2/s^2)

Cross laminated panel



ρ_i = 830 kg/m^3

MOE = 31.04 GPa

Specific stiffness = 37.58 (m^2/s^2)

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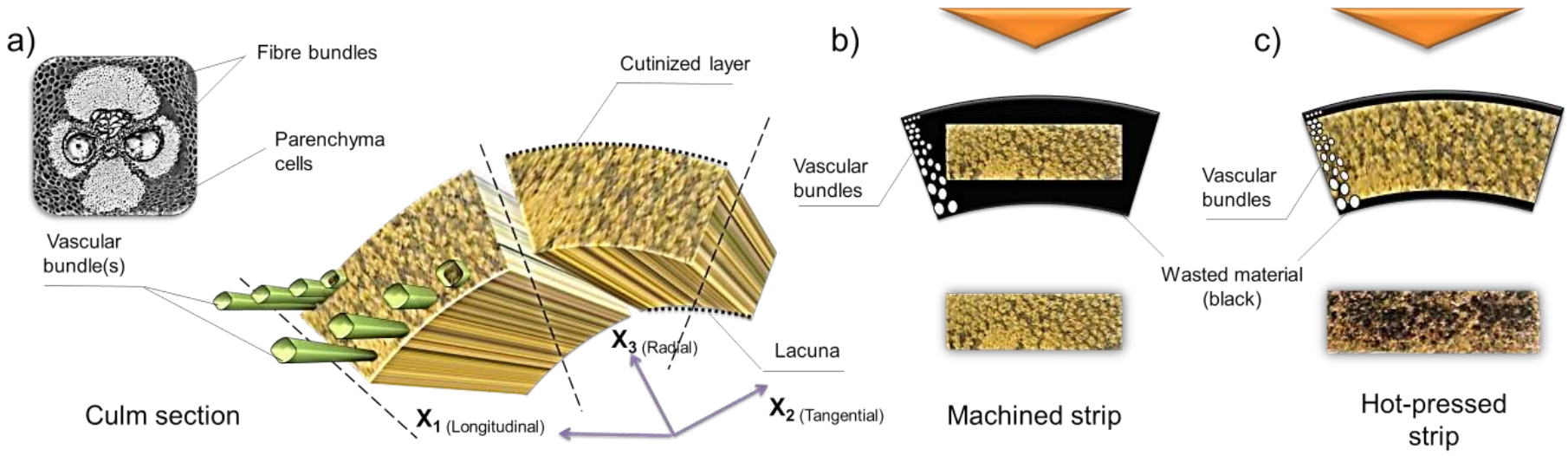
Preparation of the material

Material and methods

Material loss

47 %

20 %



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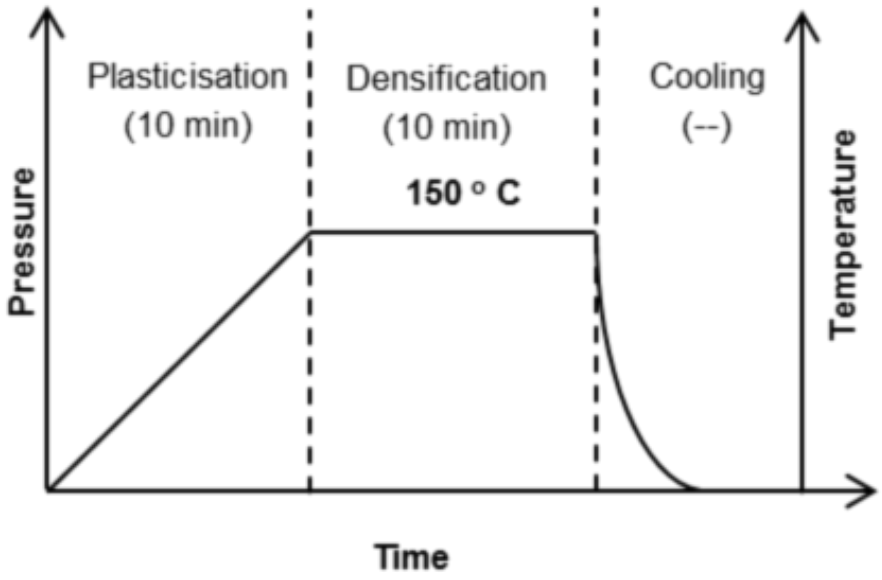
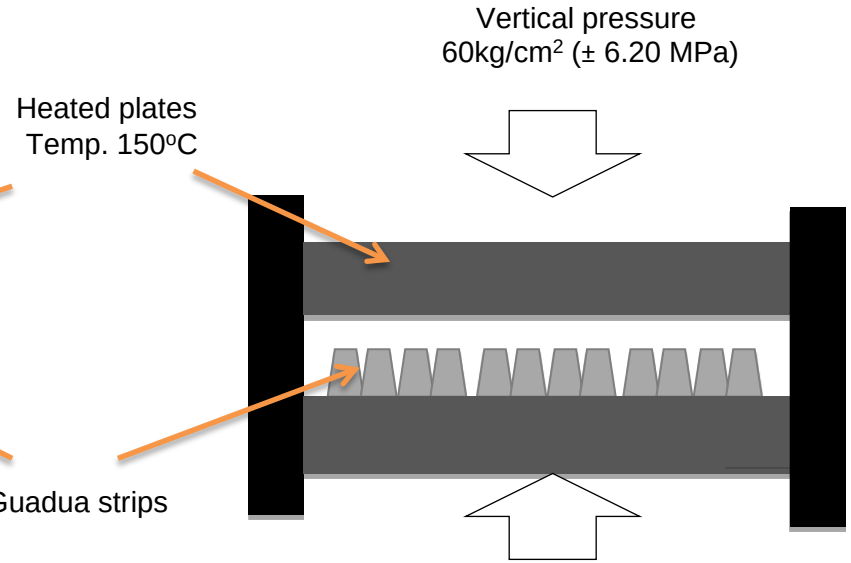
THM modification

Materials and method





* http://www-materials.eng.cam.ac.uk/mpsite/properties/ (right)
* **Wegst et al.** (left)

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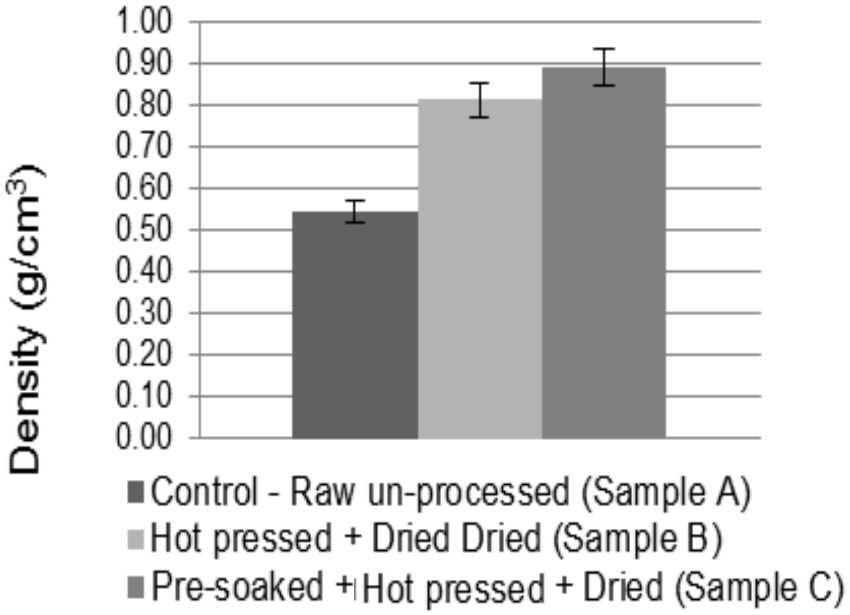
Experimental plan

Materials and method



Bamboo species: *Guadua angustifolia Kunth*	Section: Middle (in height)		Age: Mature (3-5 years old)
	Samples A Raw un-processed	Samples B Hot pressed + Dried	Samples C Pre-soaked + Hot pressed + Dried
Time	0	20 min	20 min
Pressure	0	60 kg/cm^2	60 kg/cm^2
Temperature	0	150^o C	150^o C
Compress. Set (C)	**0**	**46.08%**	**42.51%**
Oven dried density	**540 kg/m^3**	**810 kg/m^3**	**830 kg/m^3**

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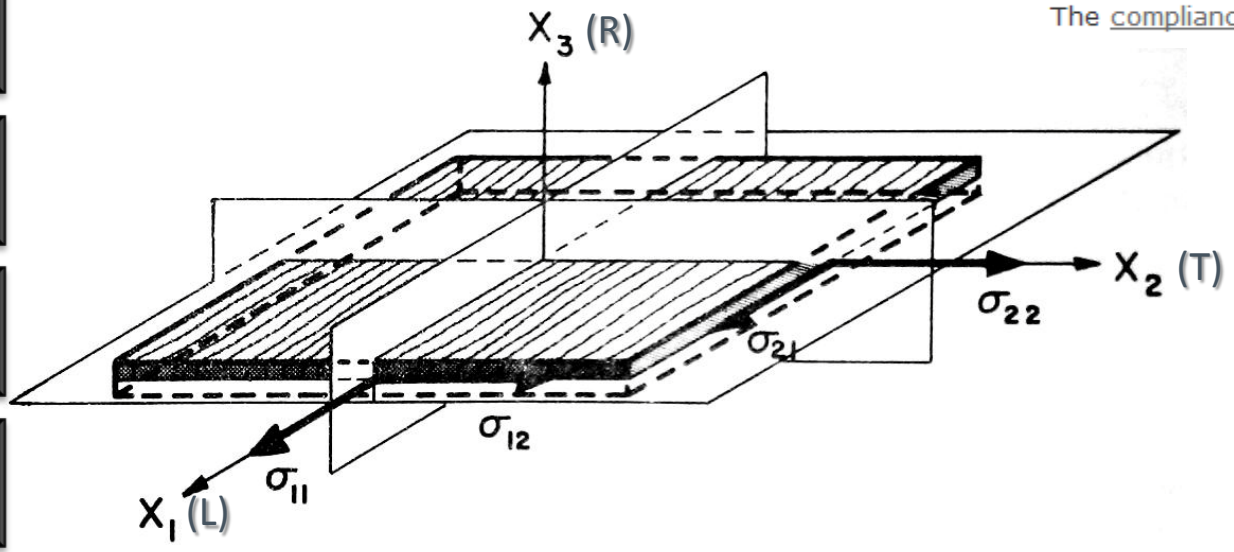
Testing

Flat sheet orthotropic material

*- Two normal components of stress: σ_1 , σ_2 and σ_{12} (shear)**



The compliance matrix [S] in the principal direction

$$[S]=\begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{12}}{E_1} & 0 \\ -\frac{\nu_{21}}{E_2} & \frac{1}{E_2} & 0 \\ 0 & 0 & \frac{1}{G_{12}} \end{bmatrix}$$

**Remaining two shear stresses σ_{13} , σ_{23} and normal stress σ_3 are so small that can be safely ignored* (Bodig & Jayne, 1993).

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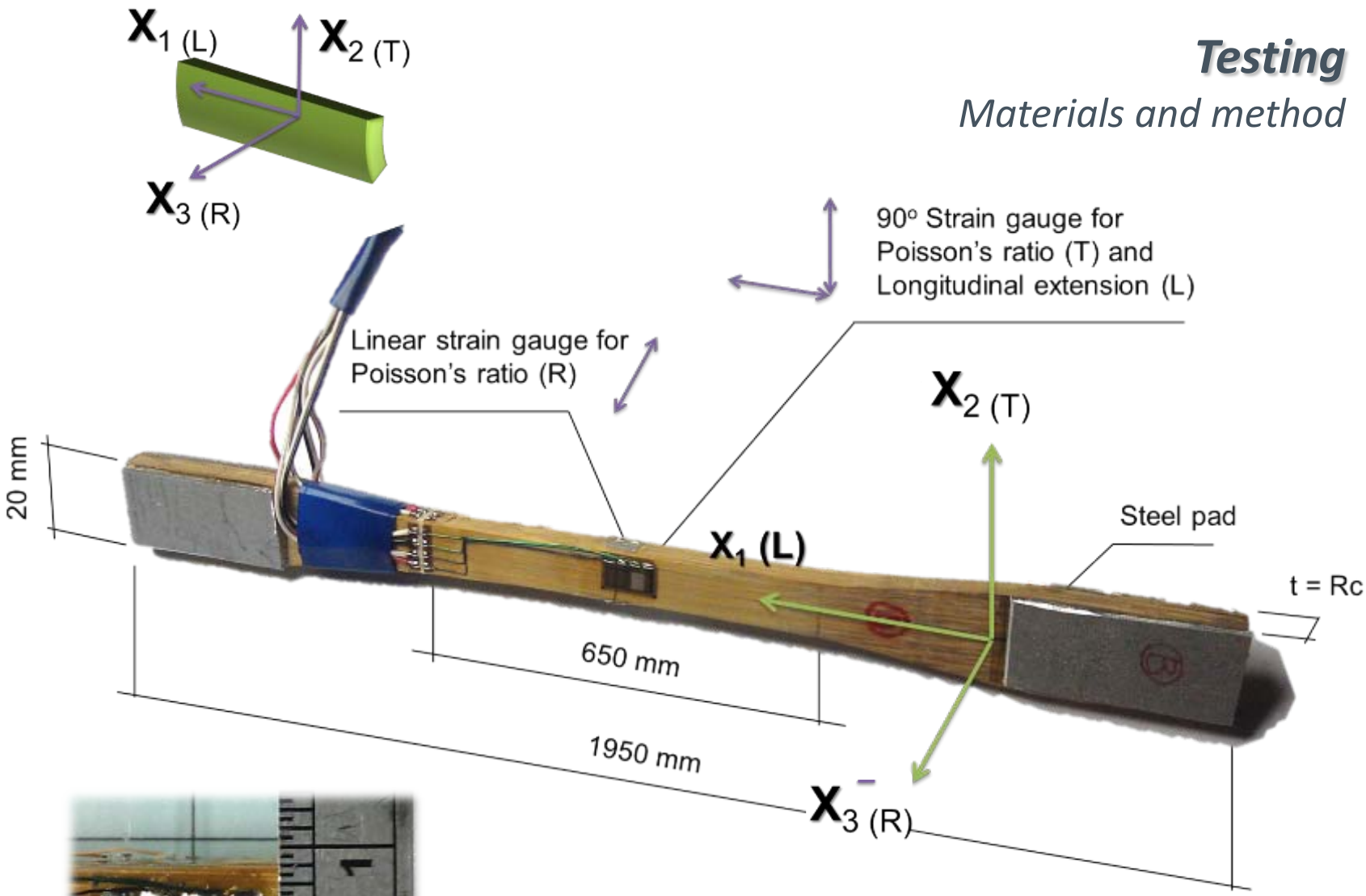
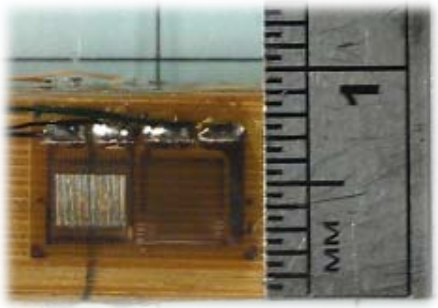
Testing

Materials and method





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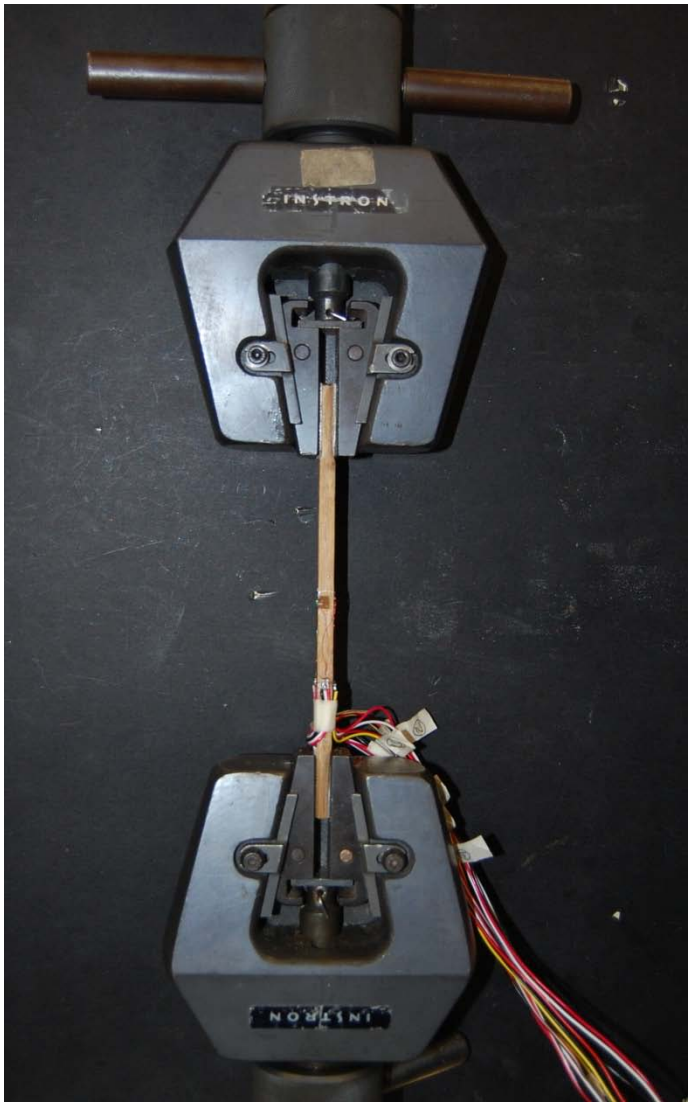
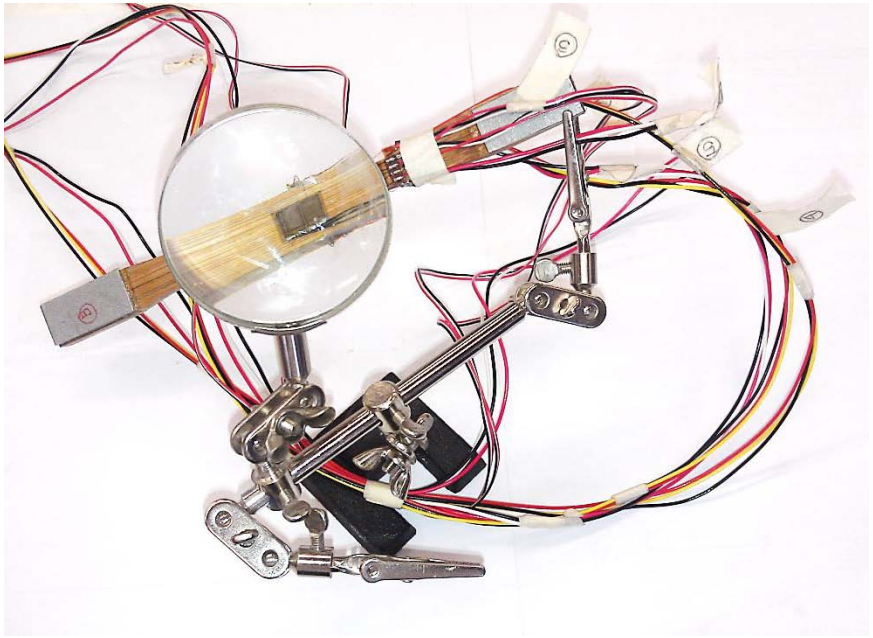
Tensile test





Elastic zone applied load limits of 0,5kN, 1kN, 2kN and 3kN
Rate 0.10 mm/min
Strain gauges, resistance 350 Ohms

INSTRON 5585 (Mech. Eng)
VISHAY Data Logger SERIES 6000 (Civil. Eng)

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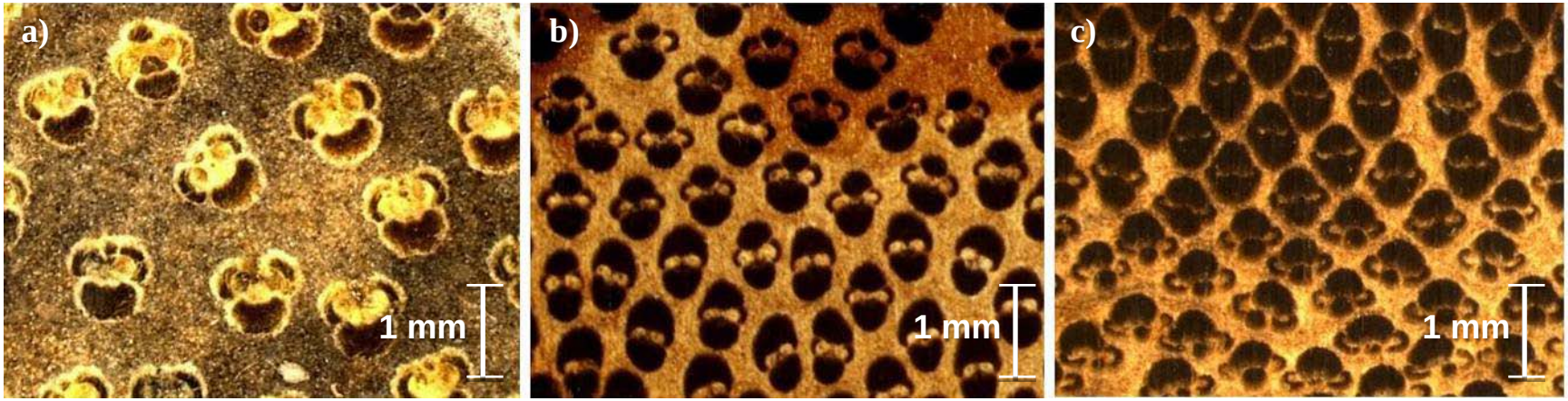
Optical microscopy

Stereo microscope

Samples A Raw un-processed	Samples B Hot pressed + Dried	Samples C Pre-soaked + Hot pressed + Dried



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Optical microscopy

Inverted reflected-light microscope

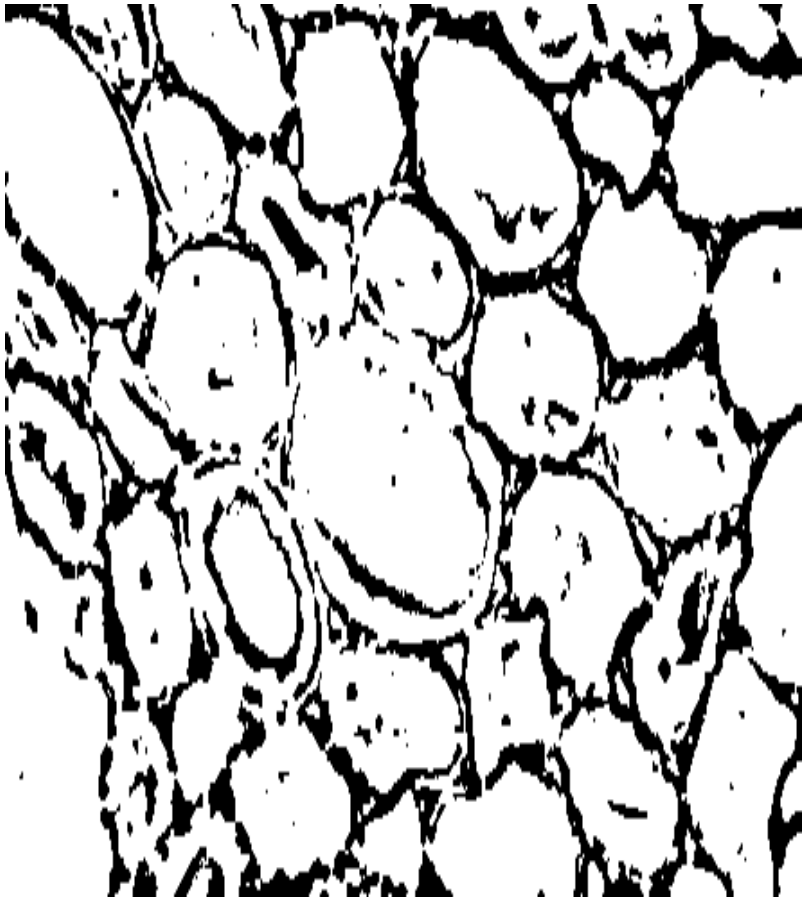
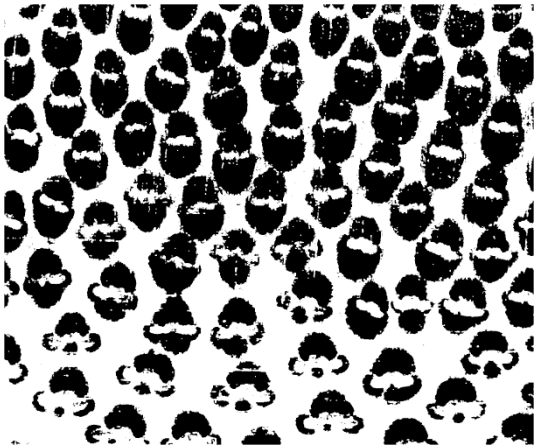
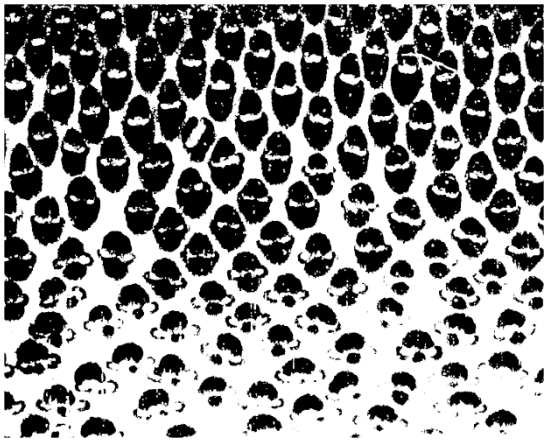


Image-J Analysis

Fibre's surface area

Samples A Raw un-processed	Samples B Hot pressed + Dried	Samples C Pre-soaked + Hot pressed + Dried
		
25.53 %	**45.57 %**	**47. 78 %**

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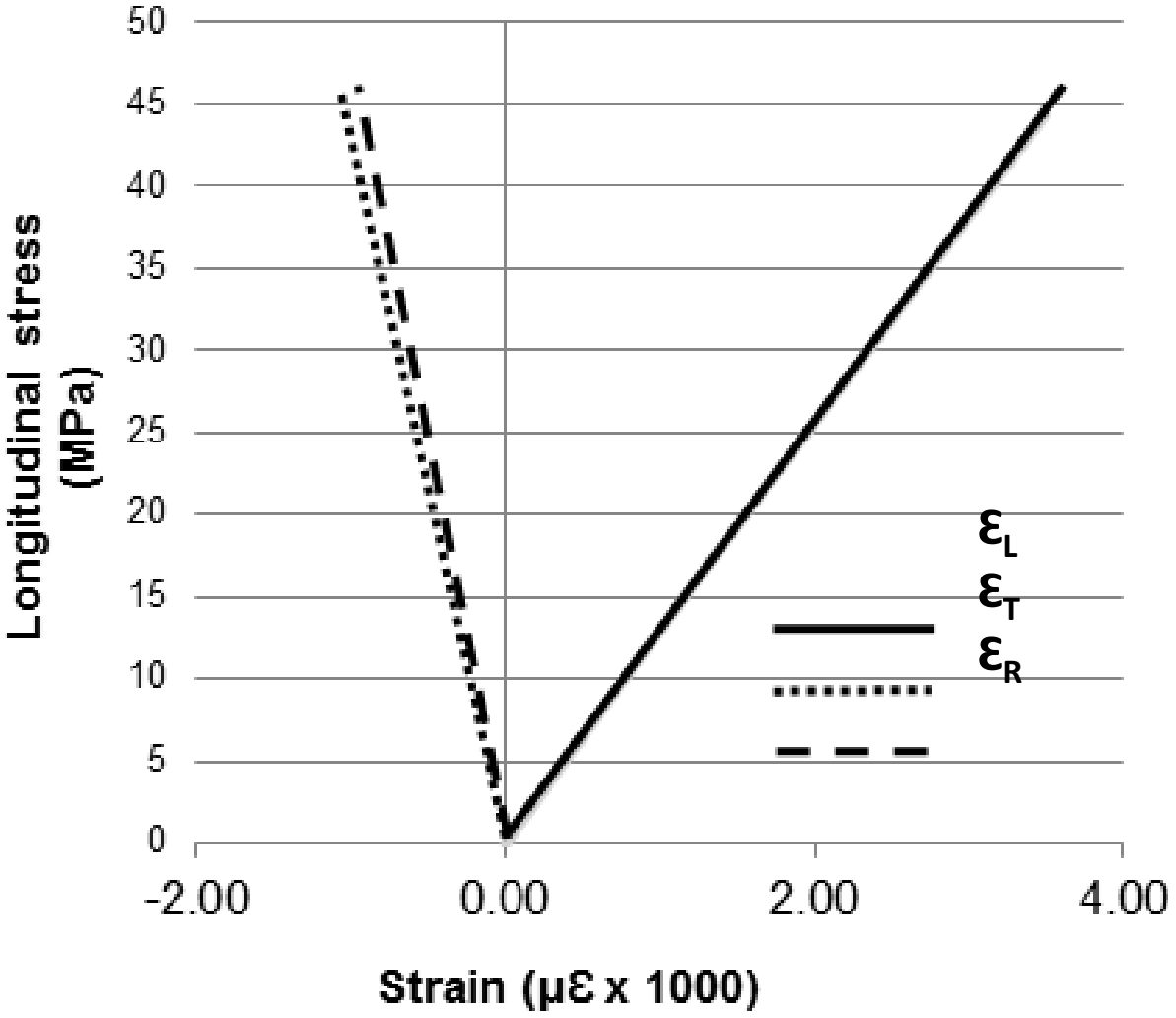
Material characterization

Elastic stress versus strain plots for longitudinal loading



$$\lambda \stackrel{\text{def}}{=} \frac{\text{stress}}{\text{strain}}$$

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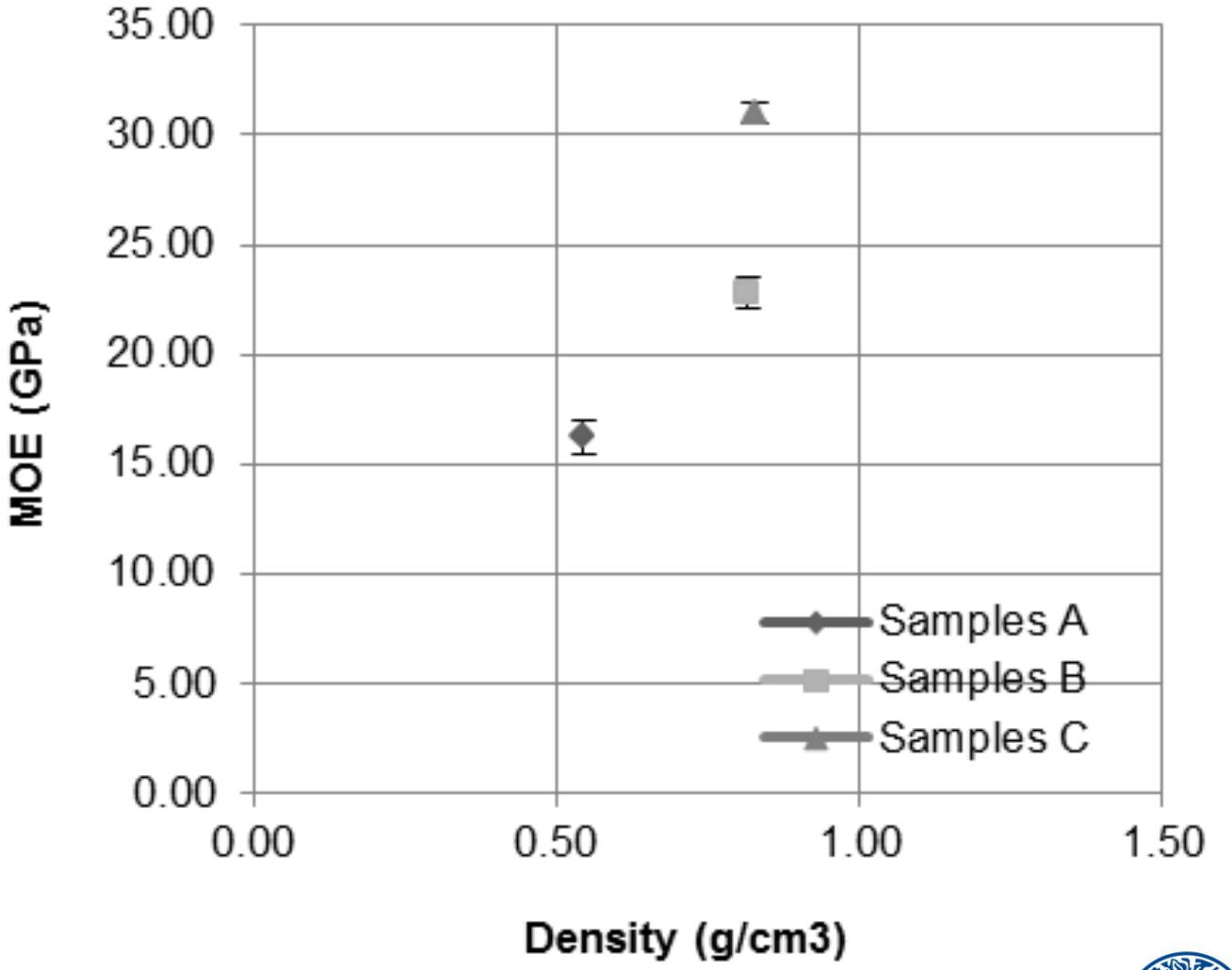
Material characterization

MOE versus density



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Material characterization

Results

	Sample A	Sample B	Sample C
E_L	16.21 GPa	22.80 GPa	31.04 GPa
STA DEV	0.76 GPa	0.73 GPa	0.47 GPa
Density (ρ)	540 kg/m^3	810 kg/m^3	830 kg/m^3
Specific stiffness (average)	**29.84**	**27.99**	**37.58**
ν_{LT}	0.27	0.33	0.27
STA DEV	0.01	0.01	0.01
ν_{LR}	0.29	0.33	**0.14**
STA DEV	0.02	0.01	0.02

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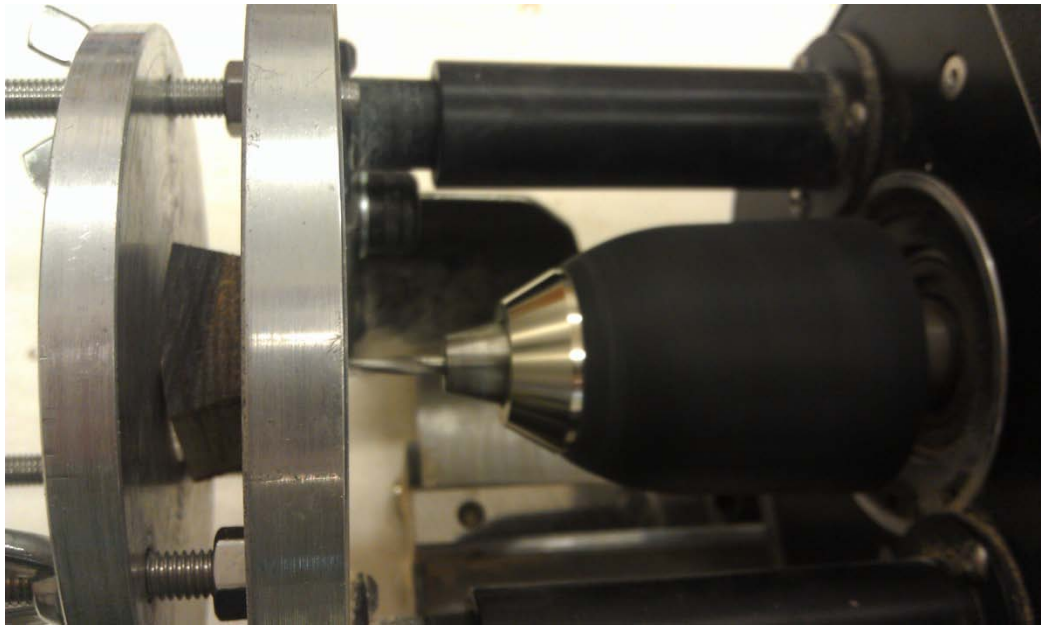
DRMS

Drilling Resistance Measurement System



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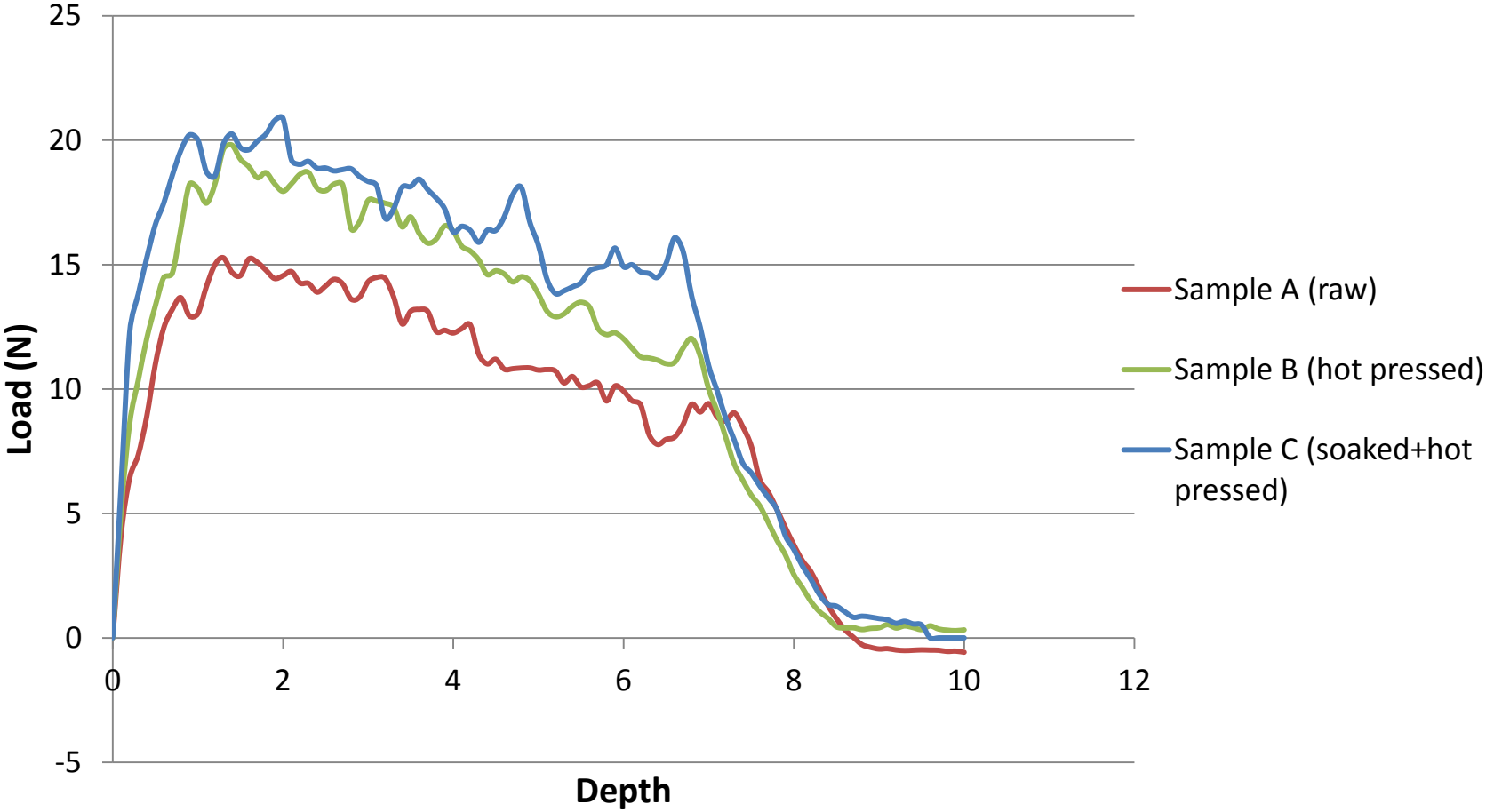
Results from DRMS

Drilling Resistance Measurement System



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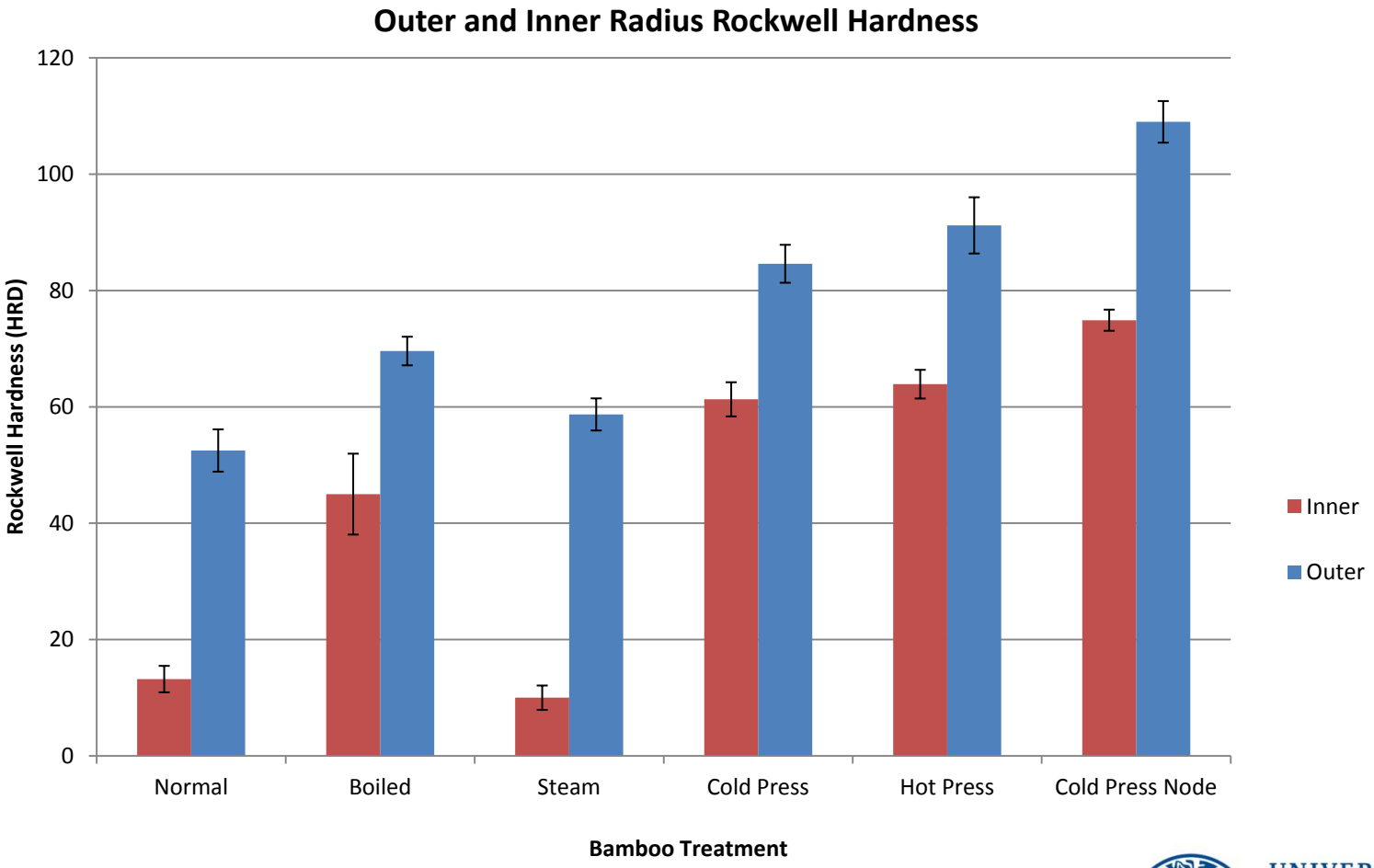
THM modifications

Previous treatments to the bamboo structure



* Graph from Chris Williams

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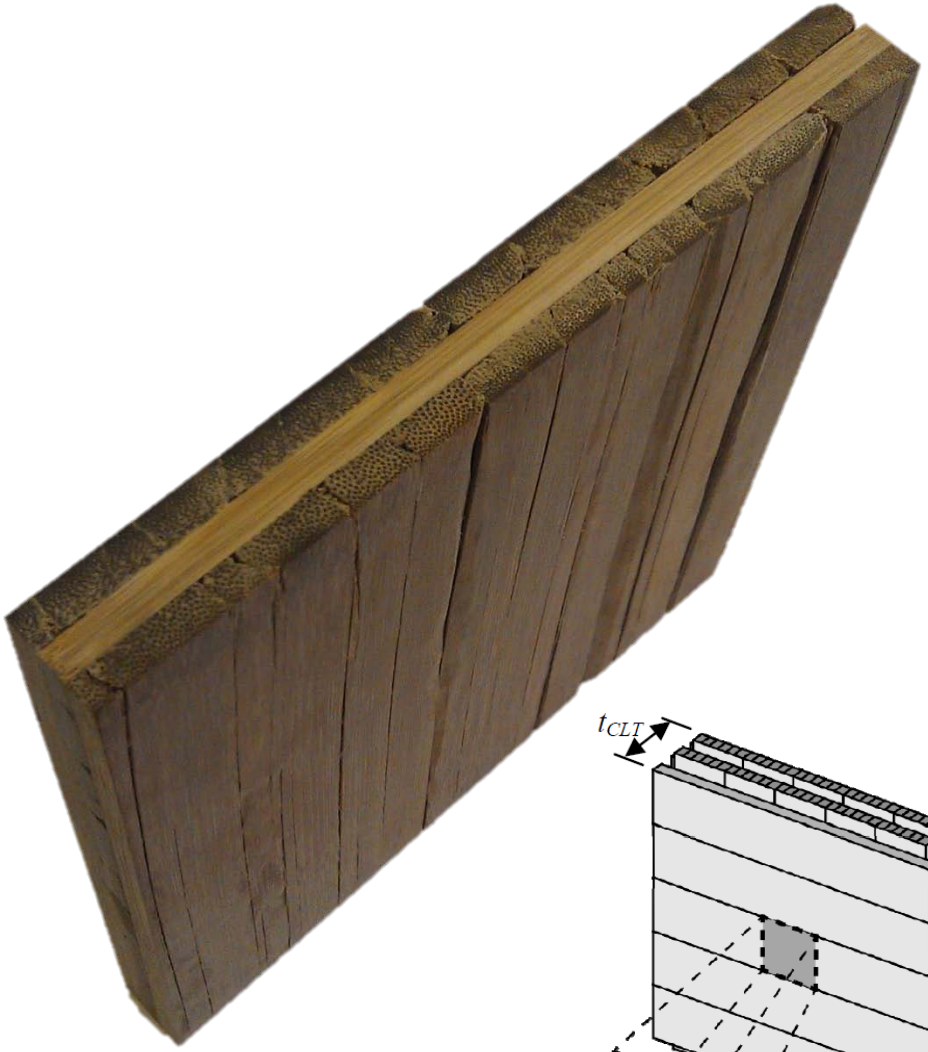
Future work

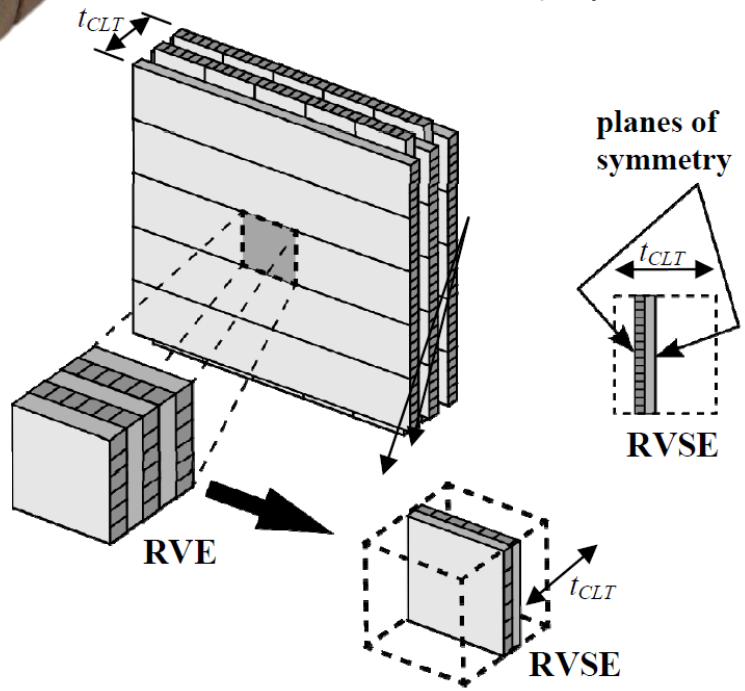
PANEL DESIGN

Cross Laminated Bamboo panels



- *3-ply and 5-ply*
- *Laminated with epoxy resin*
- *RVE (Representative Volume Element) &*

RVSE (Representative Volume Sub-Element



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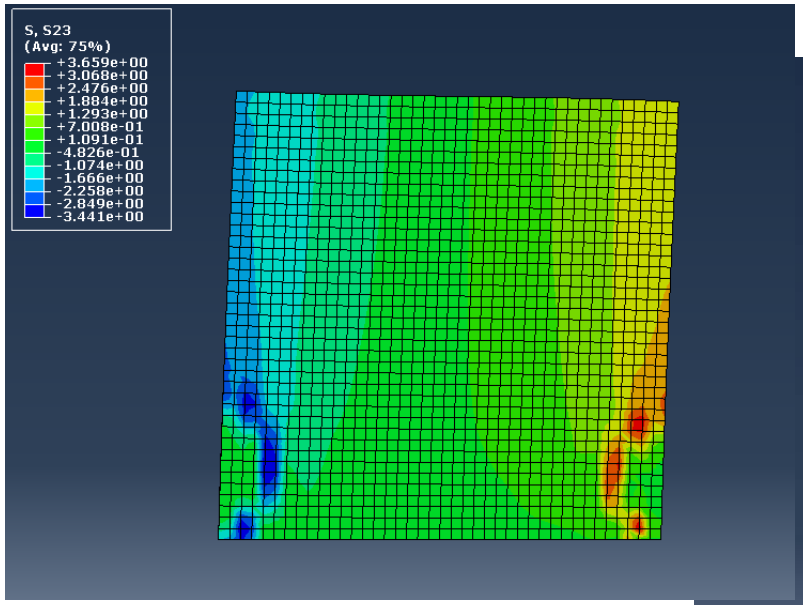
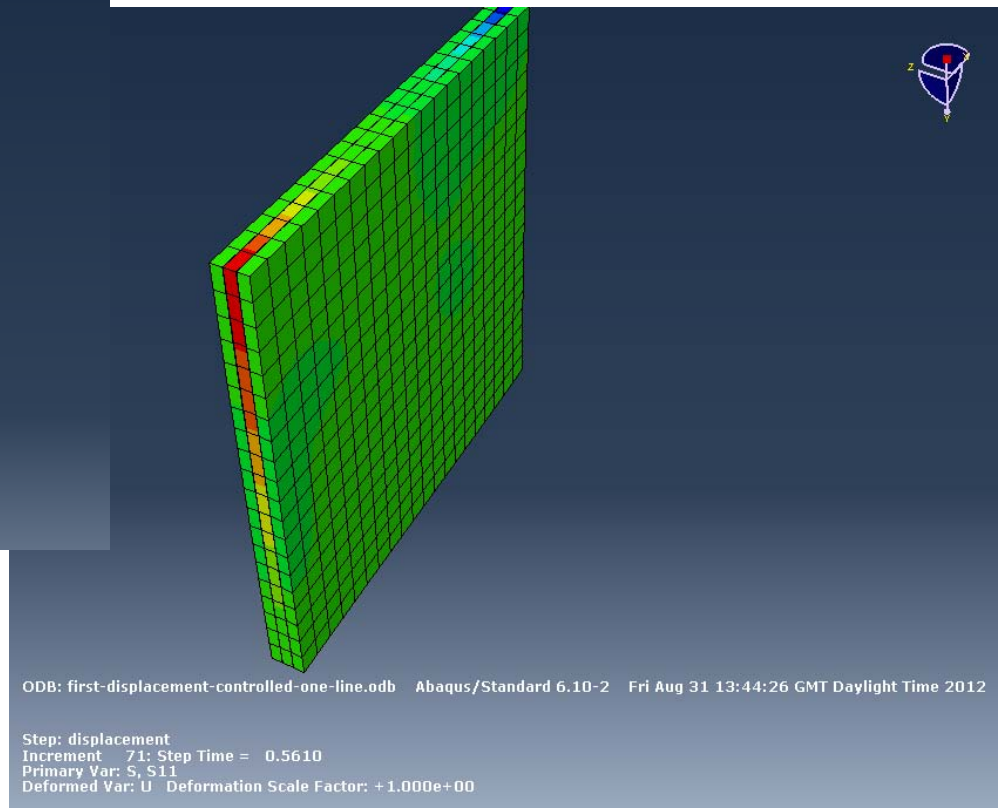
Mechanical Characterization & FEM of panels

Future work





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Conclusions

THMTs can be applied to bamboo for improving its physical and mechanical properties and for providing a new and more predictable and durable material for structural CLG.

Straight-forward densification method that can be easily applied in industry.

Further studies need to be undertaken on the reduction of the water uptake and spring-back effect (little investigation into the subject has been carried out for bamboo to date).

Traditional processes can be enhanced with the use of simple technology.

The achievement of a dimensionally stable FGS by THM, with a ***uniform density and achieved with reduced labour effort during manufacture,*** *will be of key importance for the development of structural applications, and could have a significant impact in the bamboo industry.*

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Thanks...!

&

Questions...?

BRE Centre for Innovative Construction Materials
Telephone +44(0) 1225 385943
Fascimile +44 (0) 1225 386691
Webpage http://mahara.bath.ac.uk//user/view.php?id=17
Email. H.F.Archila.Santos@bath.ac.uk

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