WORLD BAMBOO CONGRESS
DAMYANG, KOREA

17th -22nd Sep. 2015 -Damyang, KOREA

Measurement of the in-plane shear moduli of Guadua-bamboo using the **Iosipescu shear test** method

Dr Hector F. Archila
Researcher - Amphibia Group's CEO

Amphibia Group Ltda

UNIVERSITY OF BATH

Iosipescu shear test on Engineered Guadua-bamboo structural components

- ✓ *Motivation behind this work - Material*
- ✓ *Why shear?*
- ✓ *The actual work*
- ✓ *Outcomes*
- ✓ *Conclusions*

Motivation

Poor man's timber

Vernacular construction

- ✓ *Poor design solutions*
- ✓ *Low added value*
- ✓ *Short life span*

Poor man's timber

Scaffolding + Artisan work

- ✓ *Temporary*
- ✓ *Handcraft*

- ✓ *Labour intensive*
- ✓ *Not standardized*
- ✓ *High maintenance*

Bamboo scaffolders in Hong Kong by by Jeremy Torr, Jan 6, 2012
Source: **Red Bulletin magazine**

A way forward...

Round cane

Structural
Engineered products

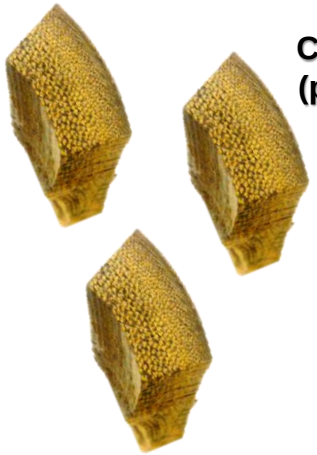
Traditional construction

- Photo: Stora Enso Building Solutions Kroika tower) **Bridport House, London, UK**

Industrial System

Straight forward processing by THM

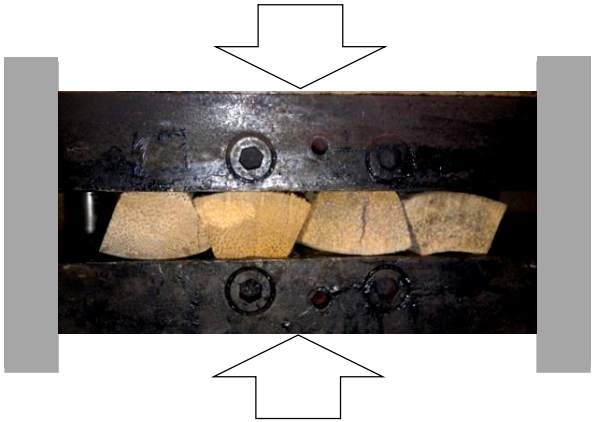
From round Guadua to flat sheets



Cut into strips (peeled skins)

Heat pressed

Vertical pressure + Temp.



Round cane

Flat densified strips

Engineered bamboo products for structural applications

- ✓ *Engineered*
- ✓ *Predictable*
- ✓ *Durable*
- ✓ *Standardisable*
- ✓ *Buildable*
- ✓ *Viable*
- ✓ *Scalable*

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Testing & Certification

Shear

[Image courtesy of **mnartists.org**]
Source: https://editions.lib.umn.edu/electionacademy/2012/03/22/paper-cuts-are-the-worst-illin/g

Shear failure

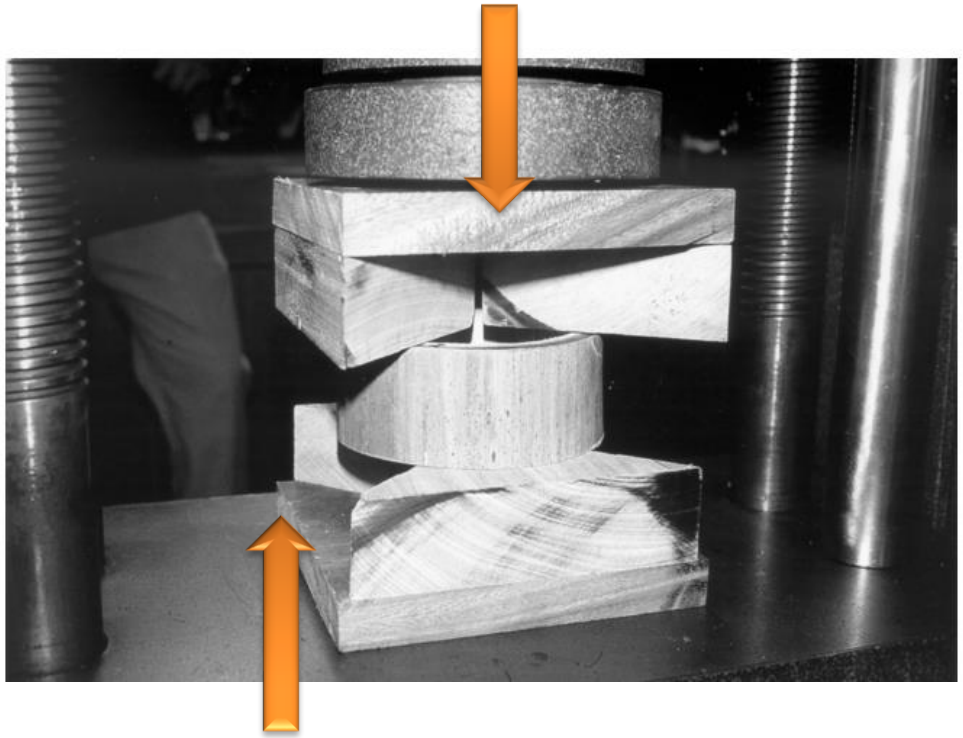
Bamboo & concrete

Shear failure of a bamboo culm along the direction of the fibres
Source: http://www.conbam.info/pagesEN/properties.html

Failure of a reinforced concrete column during the earthquake in Haiti.
Source: http://degenkolb.com/images/uploads/2010/03/Haiti1_2Sinclair/15ColumnShearFailure.jpg

Shear testing

Current methods



Shear failure of a bamboo culm along the direction of the fibres
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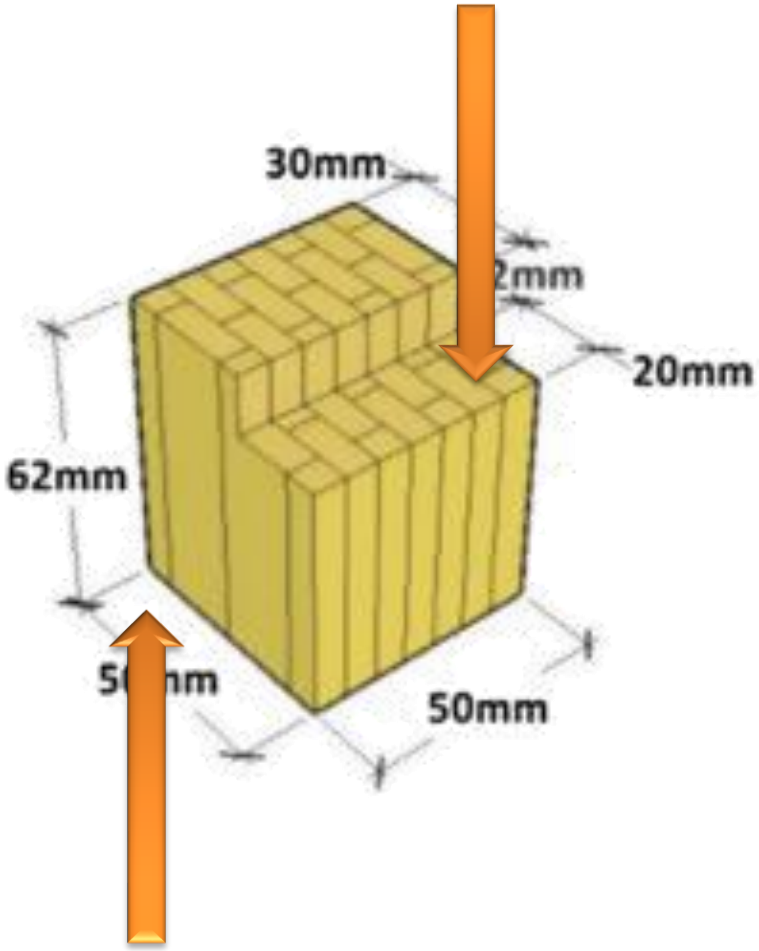


Shear block method for engineered bamboo.
Source: Correal, J. F., Echeverry, J. S., Ramírez, F., & Yamín, L. E. (2014). Experimental evaluation of physical and mechanical properties of Glued Laminated Guadua angustifolia Kunth. *Construction and Building Materials*, *73*, 105–112.

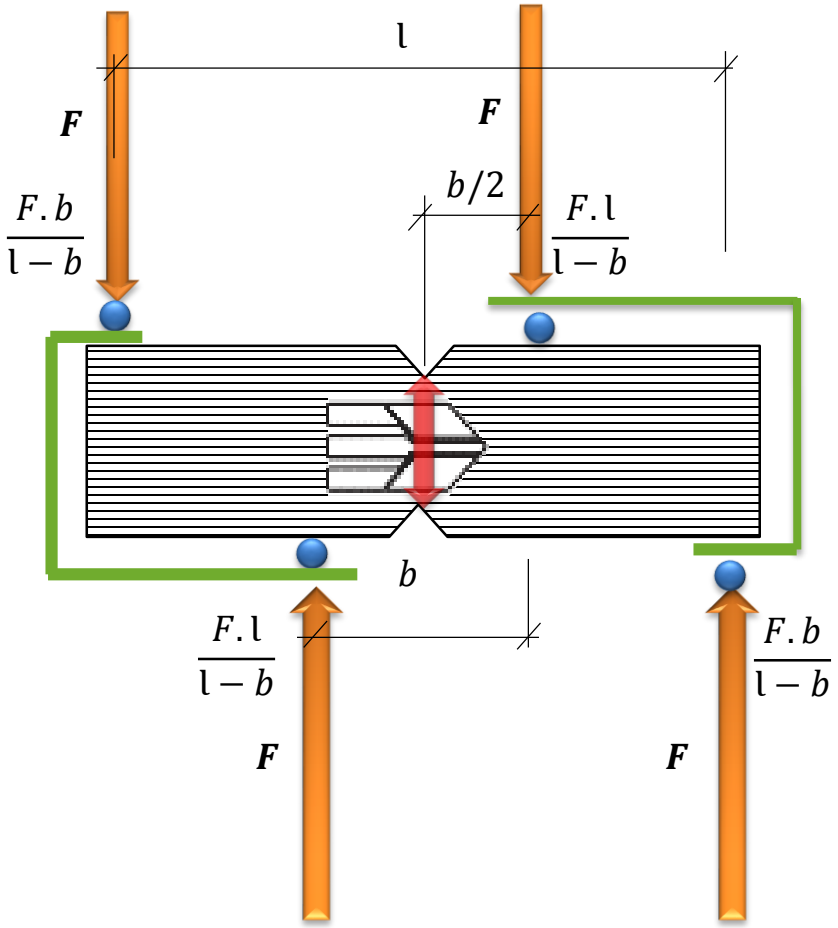
The research

Iosipescu Shear test

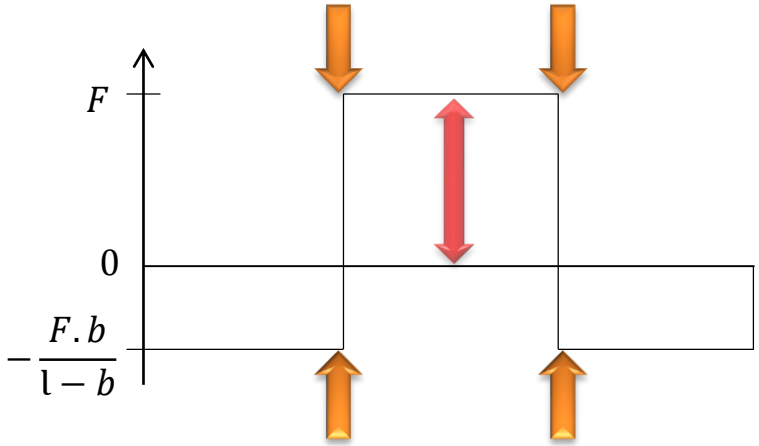
Iosipescu shear test

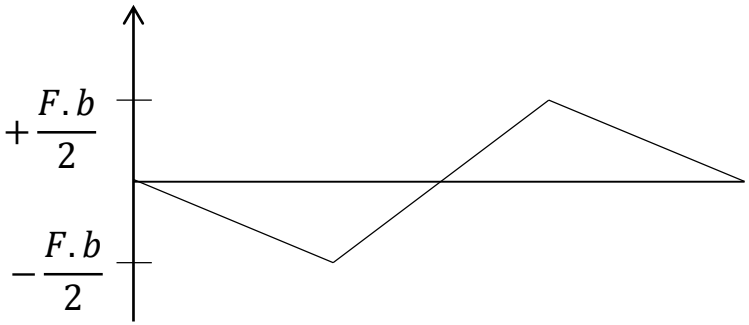
Novel method

Test diagram



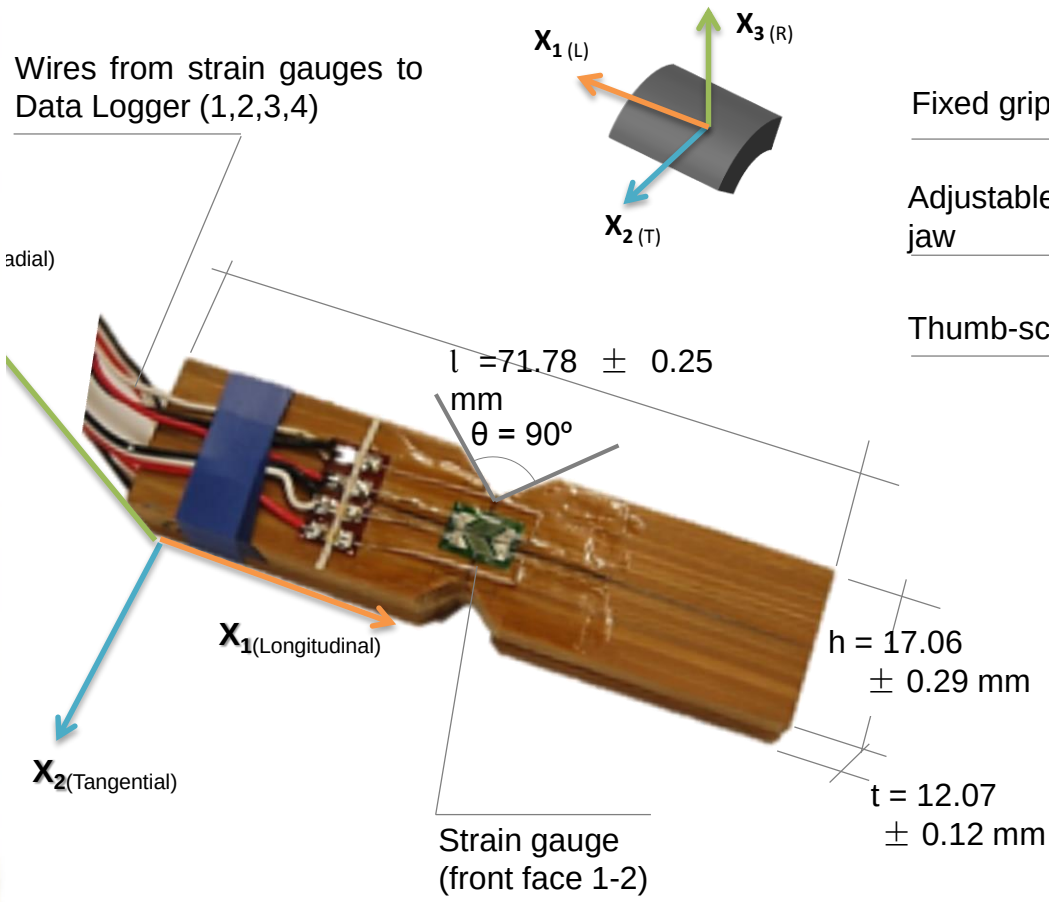
Shear diagram

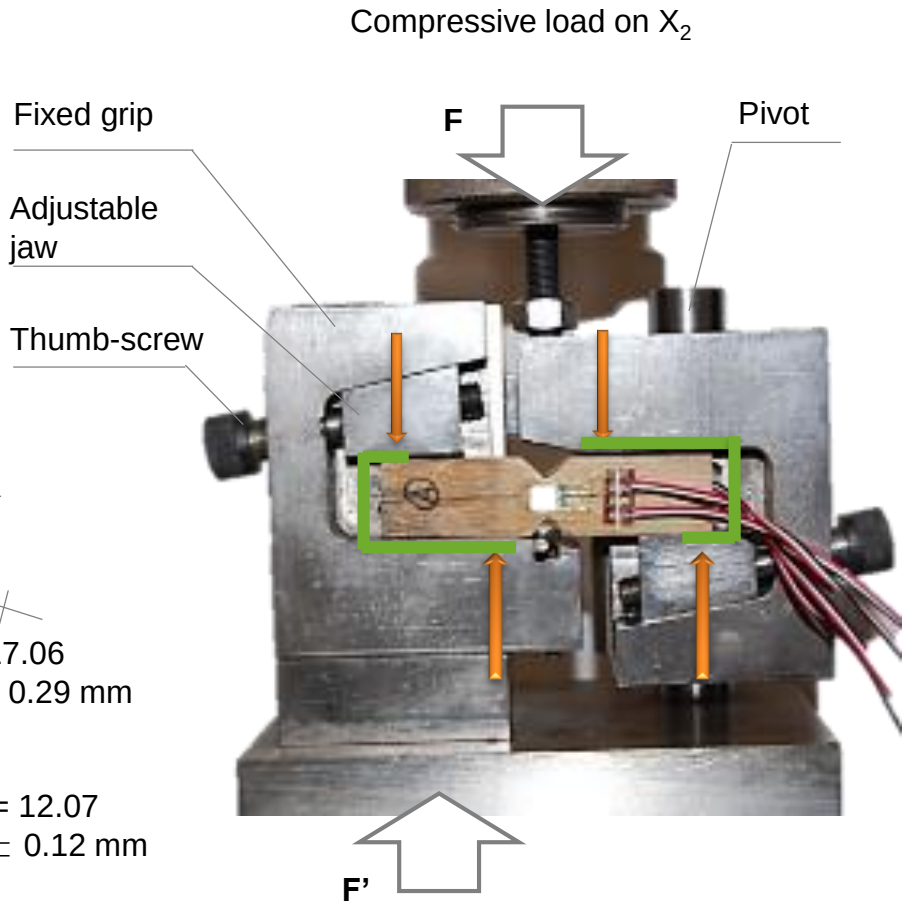




Moment diagram

Sample & Iosipescu shear fixture





Face to face strain gauges - Temp= 27º±2ºC, RH = 70±5% - Elastic cycles

Test conditions

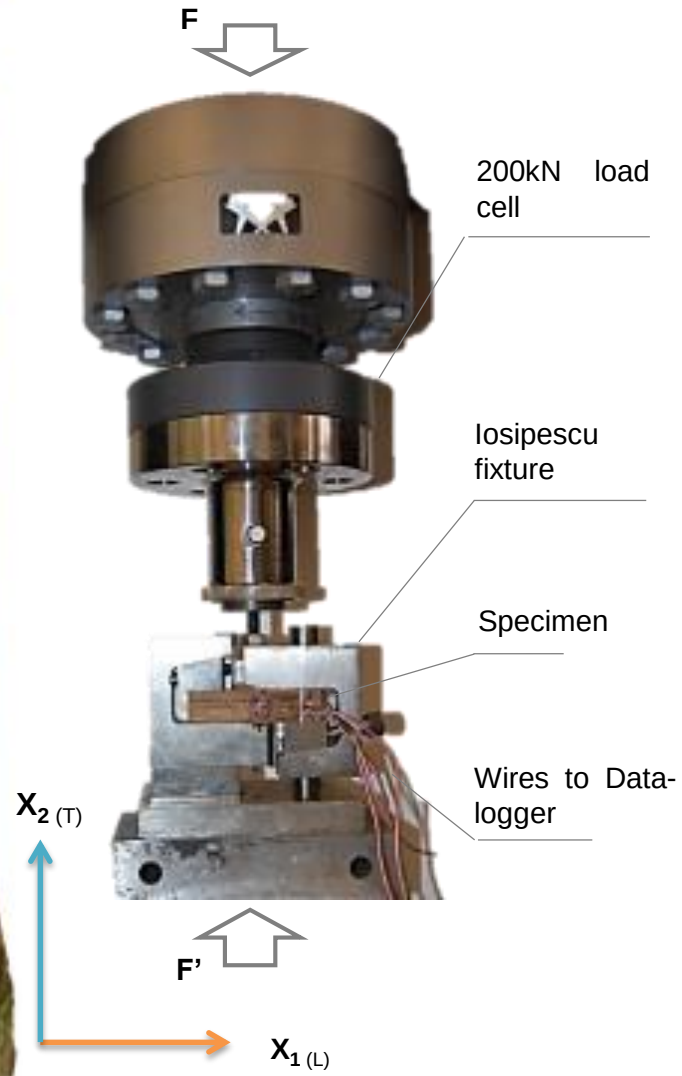
From round Guadua to flat sheets

- ✓ *ASTM D5379 (ASTM 1998); Pierron & Vautrin (1994)*
- ✓ *Samples conditioned at 27°±2°C and RH of 70±5% for a period of 20 days (MC=12%)*
- ✓ *Four specimens per sample.*

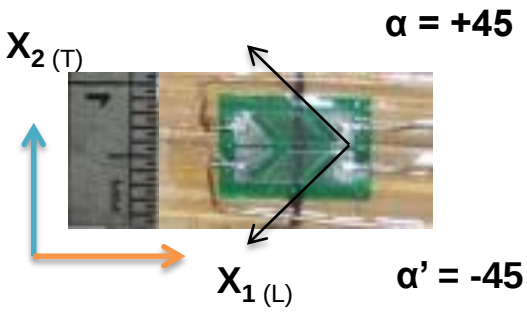
SAMPLES

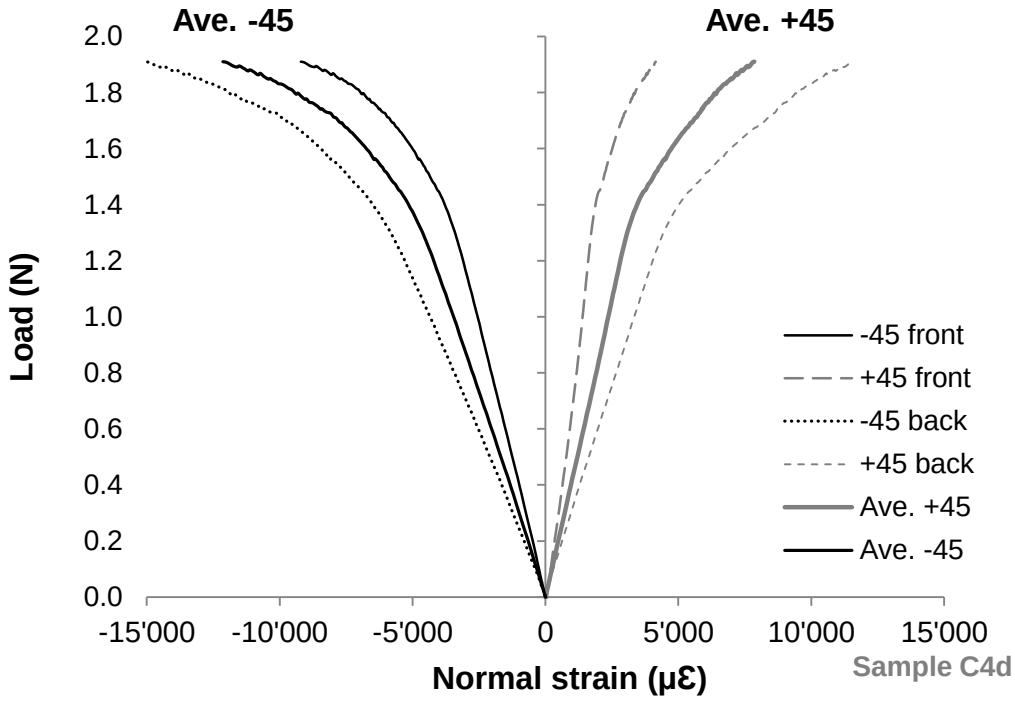
A	B	C
Control - ρ = 543.3 kg/m^3	Dried - 814.6 kg/m^3	Soaked 890.9 kg/m^3

Testing & data gathering



Strain gauges +45 & -45 on front & back faces
Type: Tee Rosette (90º)
Resistance: 350±0.2%OHMS
Gauge factor: 2.12 NOM

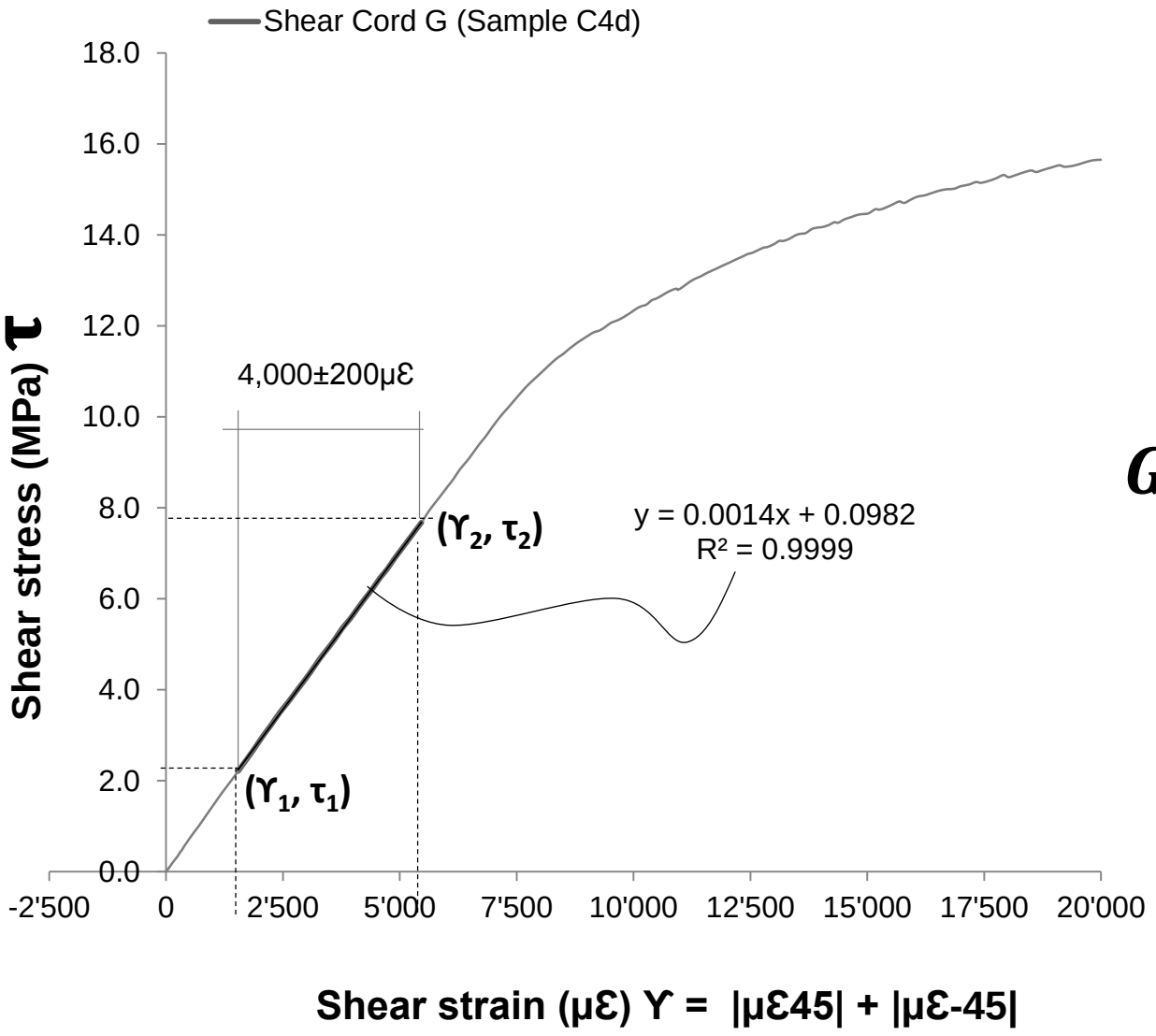




INSTRON 5585H floor model testing machine with a 200kN load cell

Shear modulus (G_{12})

Data analysis



$$G_{12} = \frac{\tau}{\Upsilon}$$

$$G_{21}^{app} = \frac{\tau^{av}}{\Upsilon^{av}}$$

$$G_{12}^{chord} = \frac{(\Delta\tau)}{(\Delta\Upsilon)}$$

$$\left|\frac{(G_a - G_b)}{(G_a + G_b)}\right| \cdot 100$$

where

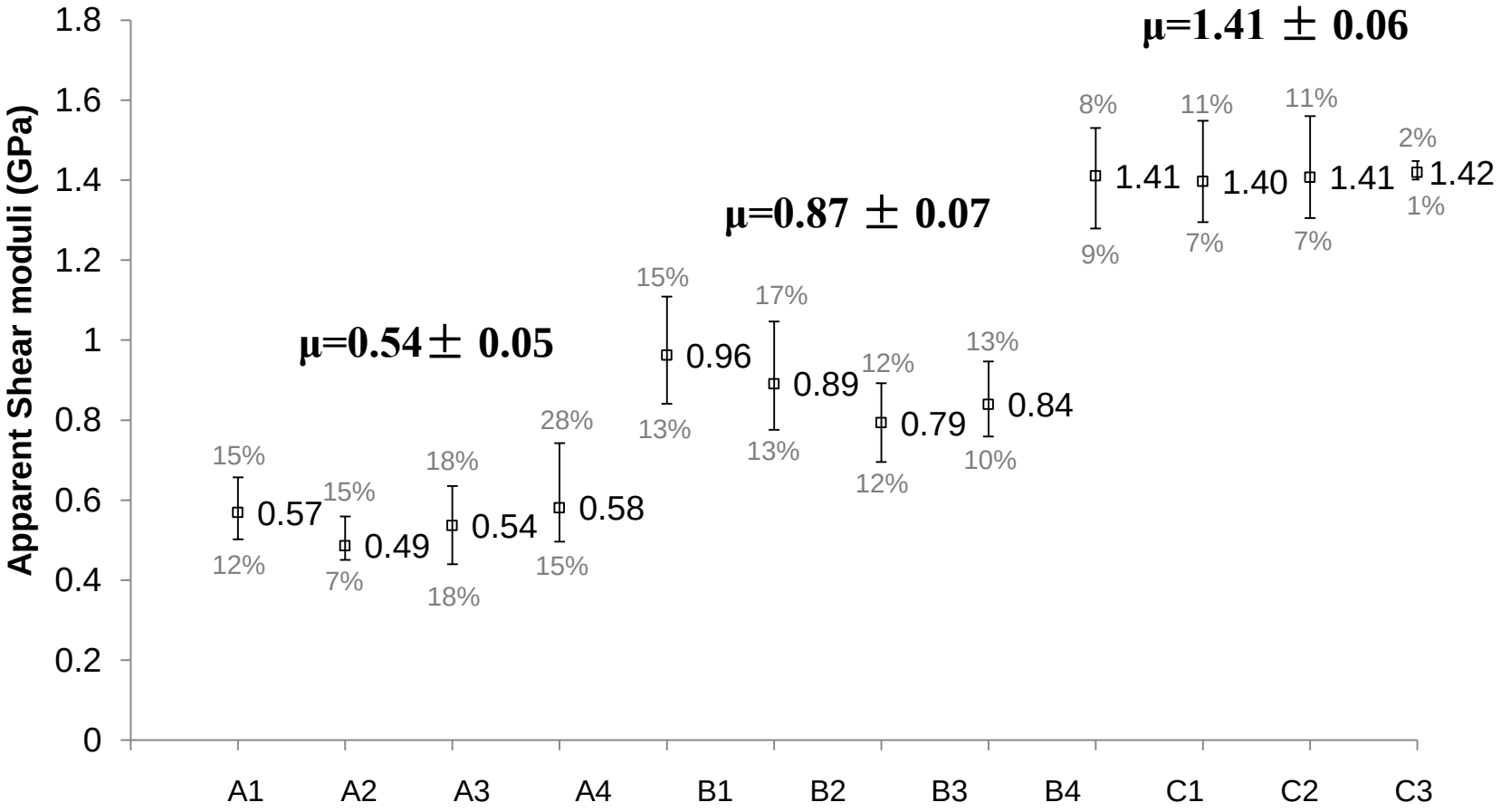
$\Delta\tau$ is the difference of shear stress between τ_2 and τ_1 and $\Delta\Upsilon$ is the difference of shear strain between Υ_2 and Υ_1.

G_a is the shear modulus of the sample's side (a) and G_b is the shear modulus of the sample's side (b)

Results

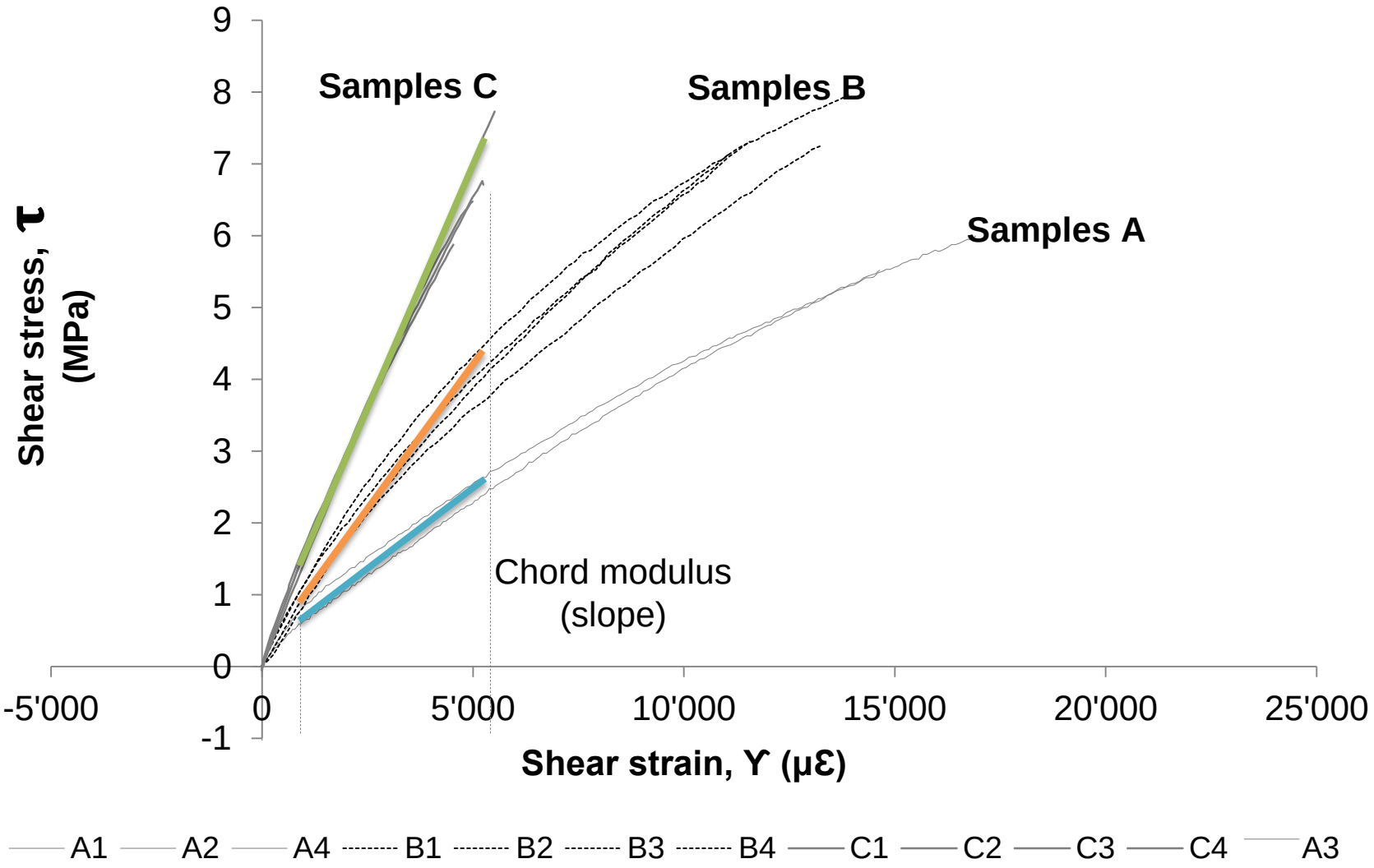
Apparent Shear modulus (G_{12}^{app})

Low CoV and St. dev.



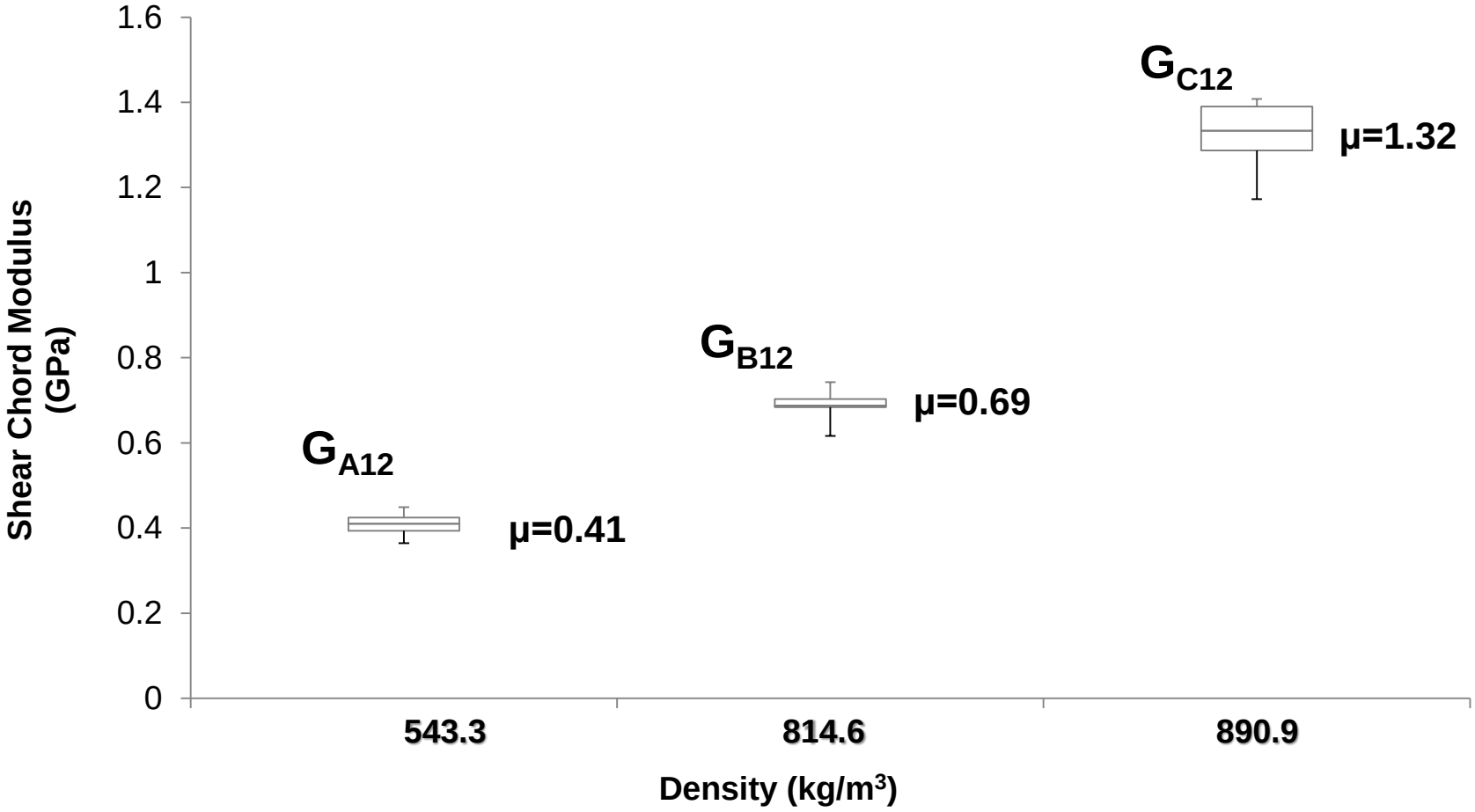
Shear chord modulus (G_{12}^{chord})

Typical shear stress vs. shear strain graph of specimens A, B & C.

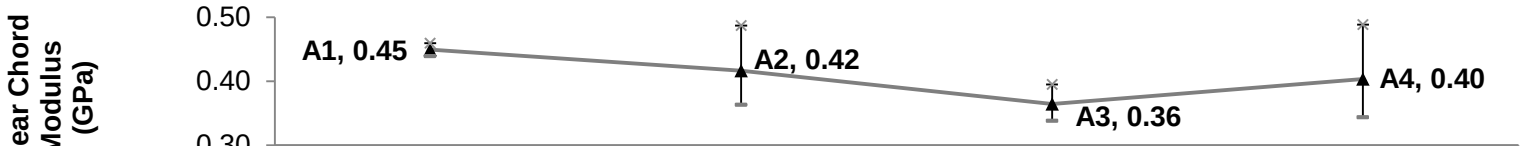


Shear chord modulus (G_{12}^{chord})

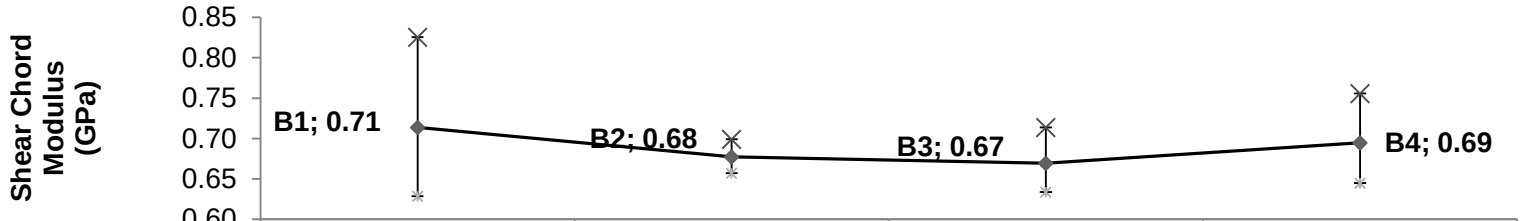
Box and whisker plots for shear chord results of samples A, B & C.



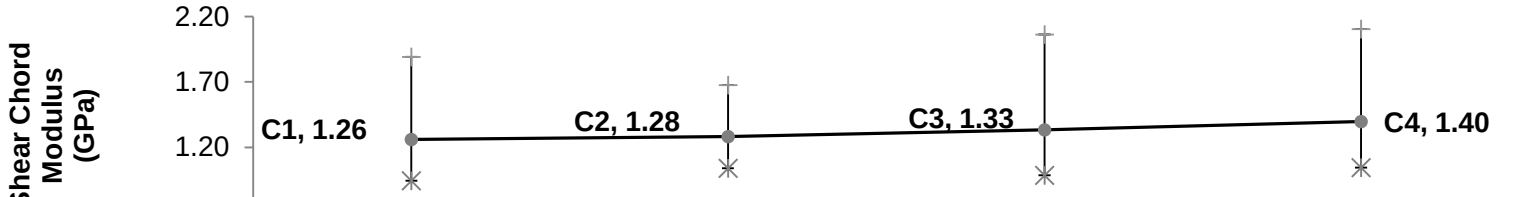
Average, Ga (outer) and Gb (inner) shear chord moduli values.



	A1	A2	A3	A4
A (G average)	0.45	0.42	0.36	0.40
A (Ga outer)	0.44	0.36	0.34	0.34
A (Gb inner)	0.46	0.49	0.39	0.49



	B1	B2	B3	B4
B (G average)	0.71	0.68	0.67	0.69
B (Ga outer)	0.83	0.70	0.71	0.76
B (Gb inner)	0.63	0.66	0.63	0.64



	C1	C2	C3	C4
C (G average)	1.26	1.28	1.33	1.40
C (Ga outer)	1.89	1.68	2.06	2.10
C (Ga inner)	0.94	1.04	0.99	1.05

Remarks

	A	B	C
ρ	543.3 kg/m^3	814.6 kg/m^3	890.9 kg/m^3
G_{12}^{app}	0.54 GPa	0.87 GPa	1.41 GPa
G_{12}^{chord}	0.41 GPa	0.69 GPa	1.32 GPa
G_{12}^{round}	0.58 GPa	Takeuchi-Tam (2004)	
	0.644 GPa	Ghavami & Marinho (2005)	

Increase in shear modulus » THM modification » Higher density

Twist was high within the 0.1% strain range and stabilized as the load increased; tangential local crushing was observed.

Conclusions & recommendations

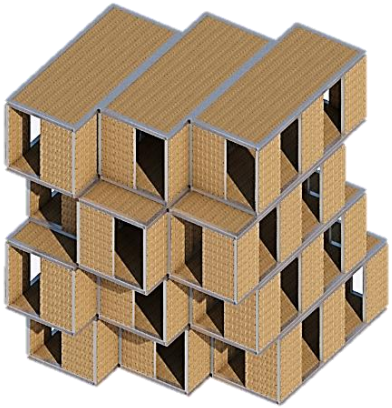
- ✓ *Adequate method for assessing the shear modulus G_{12} of small samples of bamboo.*
- ✓ *Setting guidelines for aiding the development of standards*
- ✓ *Errors due to misalignment, twisting and poor specimen preparation.*
- ✓ *Key for the development of engineered bamboo products*

Future of bamboo Challenge!

- ✓ Professionalize the “art”
- ✓ Exhaustive – rigor
- ✓ Learn from mistakes
- ✓ Partnership
- ✓ International standards

Bamboo **based forest sector**

Bamboo **architecture, construction and engineering**



Building block

Acknowledgments

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Thanks & Questions...?

Dr. Hector F. Archila
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