Engineered Bamboo: Processing Routes towards Sustainable Building Application

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The University of British Columbia
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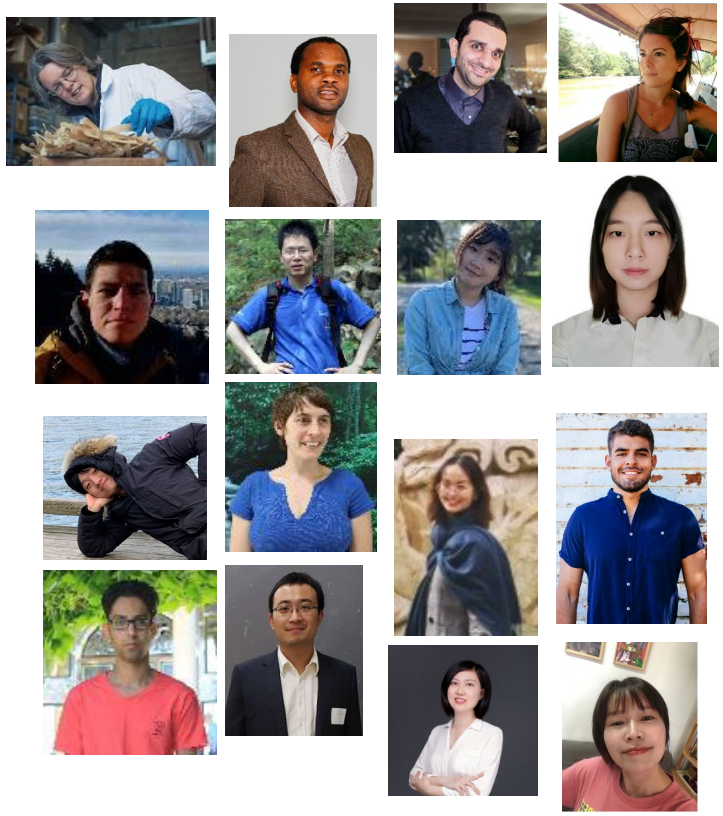
UBC BAM *Bamboo Applications and Manufacturing*

UBC's Bamboo Applications and Manufacturing Group



#	Name	Position	Background
1	Dr. Kate Semple	Research Associate	Bamboo and wood products
2	Dr. William Nkeuwa	Hon Res Associate	Bamboo bonding
3	Dr. Vahid Nasir	Postdoc	EWPs and EBPs
4	Dr. Yu-an Hu	Visit Prof	Bamboo scrimber
5	Jialin Zhang	M.Sc	Hybrid B/W Bonding
6	Milad Khajouei	Ph.D	Formability of bamboo
7	Hugo Pineda	Ph.D	New pressing tech for EBPs
8	Lucy Binfield	Ph.D	Impact of bamboo industry developments
9	Bruce Zhou	M. Sc	Bamboo packaging
10	Eric Li	M. Sc	Hybrid B/W products
11	Rain Liu	M. Sc	Carbon account
12	Monica Xia	M. Sc	Bamboo drying
13	Sol Lewites	M. Sc	Guadua glulam

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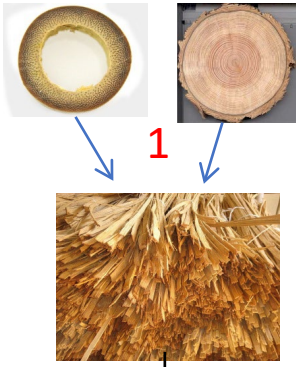
Engineered Wood Products (EWPs) vs Engineered Bamboo Products (EBPs)



1

Drying 2

Glue application 3

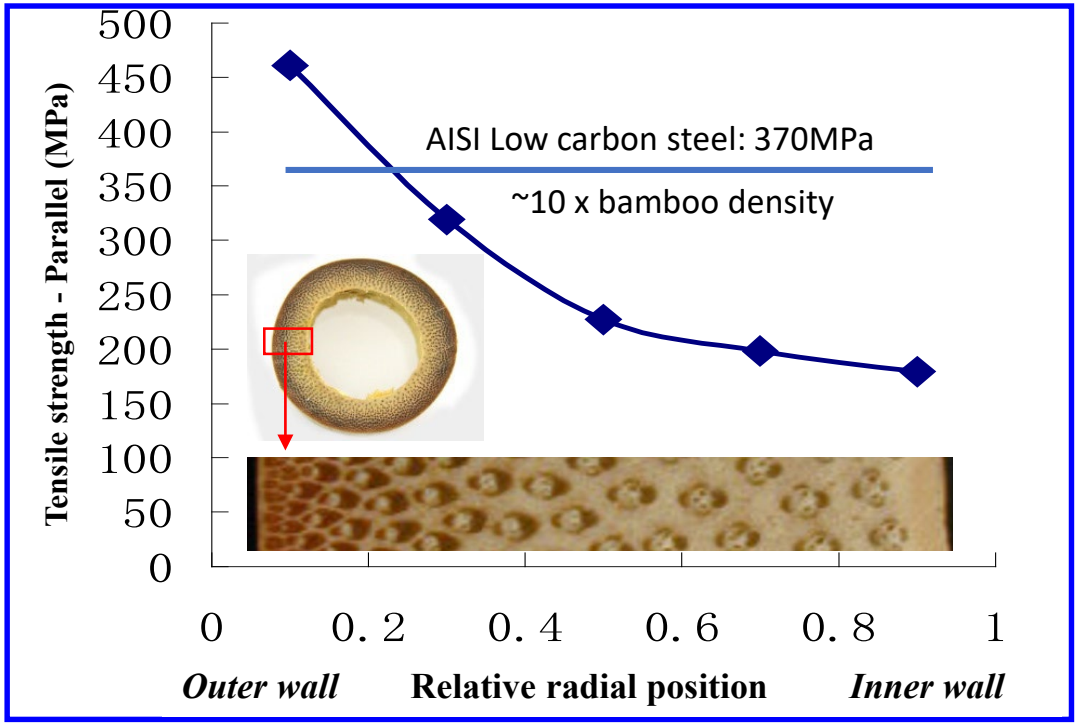
Forming 4

Pressing 5

Conversion path ways 6

- Similar processing principles, but
- Bamboo is unique and more challenging

Strength Variation Across Culm Wall



(Data source: Ge Wang)

- Max bulk strength approaching steel
- Bamboo fiber strength (615-862 MPa) higher than steel

Comparing Properties of Bamboo and North American Wood

	Density (g/cm3)	Bending MOE (GPa)	Bending MOR (MPa)	Janka hardness (N)
Moso bamboo	**0.789**	**12.1**	**152.0**	**6,100**
Douglas fir, coast	0.480	13.4	85.0	2,900
White spruce	0.360	9.6	65.0	1,880
Red oak, northern	**0.630**	**12.50**	**99.0**	**5,700**
Birch	**0.615**	**8.8**	**85.8**	**5,600**

Compared to wood, bamboo is:

- Dense and hard (equivalent to rare hardwoods),
- Extremely strong (2x softwood and medium hardwood),
- MOE is slightly lower,
- Very flexible for moulding to different shapes.

Laminated Bamboo-Wood Hybrid Composites

Adding wood to bamboo

- Improve bonding, modulus of elasticity
- Reduce density

Adding bamboo to wood

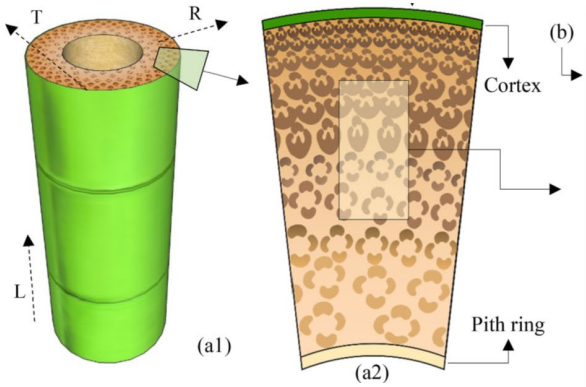
- Improve hardness, tensile, modulus of rupture

Product types

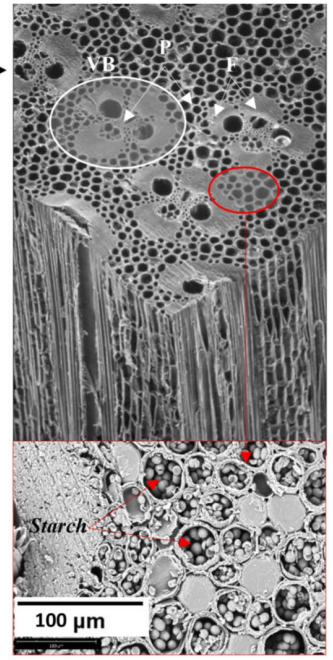
- Panel product
- Composite lumber
- Mass timber (CLT, Glulam)

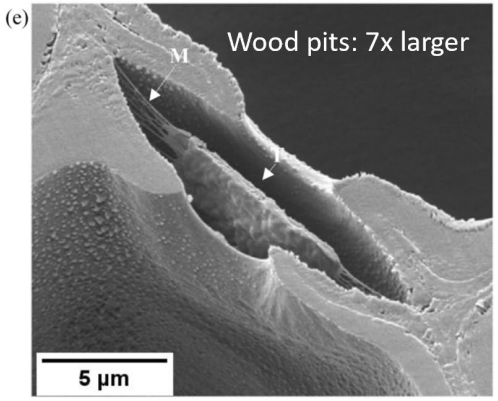
(Zhang, J. 2021)

Bamboo is much more difficult to dry and bond

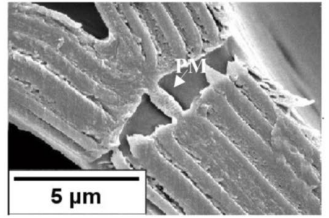


Waxy and siliceous surfaces and impermeable cell walls





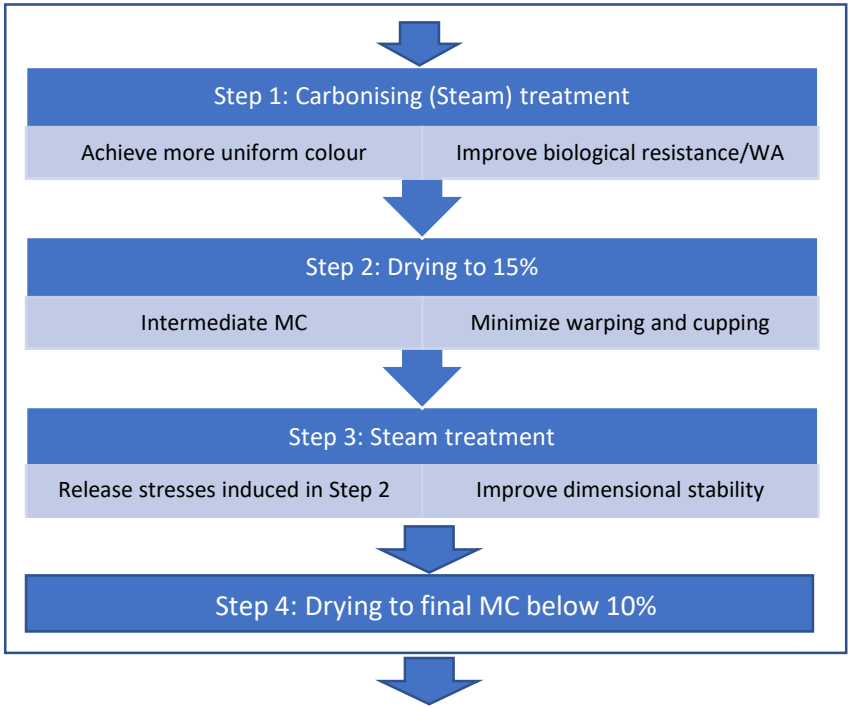
Wood



Bamboo

Nkeuwa, W. N., Zhang, J., Semple, K. E., Chen, M., Xia, Y., & Dai, C. (2022). Bamboo-based composites: A review on fundamentals and processes of bamboo bonding. *Composites Part B: Engineering*, 109776.

Lengthy Drying & Heat Treatment Process



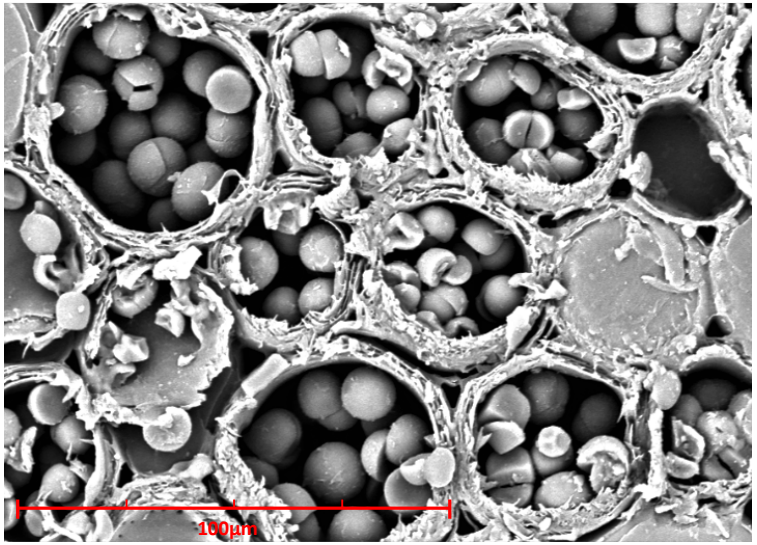
Conditioning Room
(3-4 days)

6-7 days

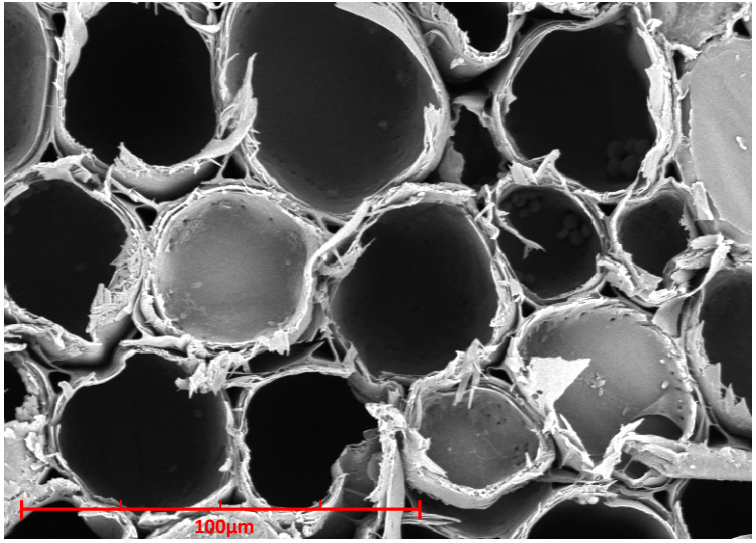
Steam treatment autoclave

Brick tunnel

Developing Novel Treatment and Drying Methods



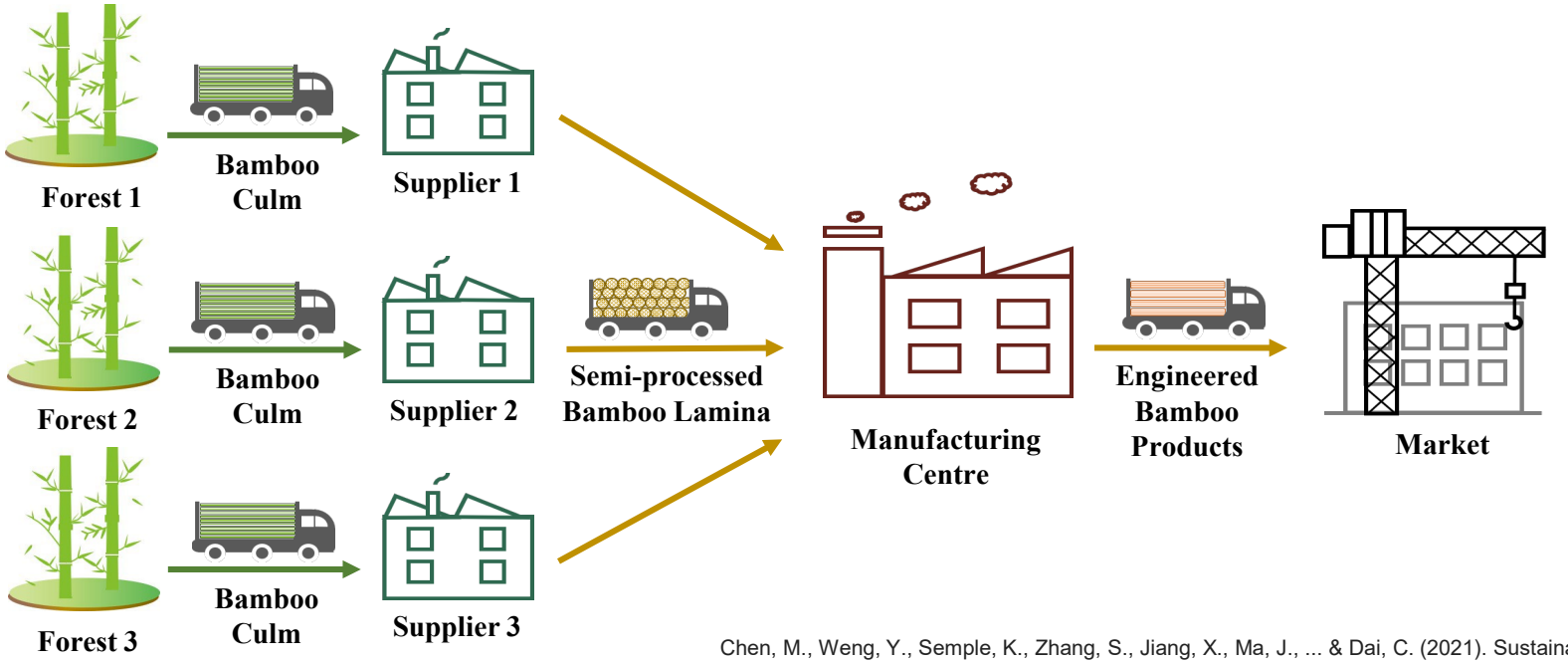
Parenchyma cells with starch granules



Parenchyma cells without starch granules

(Xia, M. Y 2021)

Satellite Manufacturing Model



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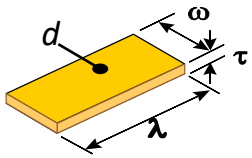
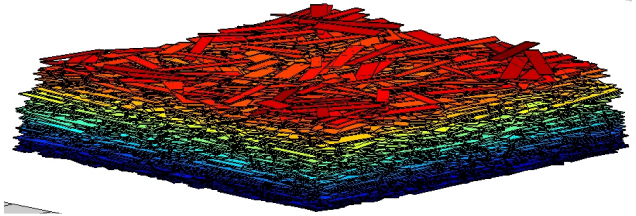
Formation of Wood/Bamboo Composites

- Fundamentals
  - Same mathematics, physics, mechanics, material science principles
- Computer simulations
  - Use 3D simulations and movie animations for numerical solution and graphical presentation
- Applications:
  - Insights into material structure and properties
  - Solutions to complex industry problems and staff training



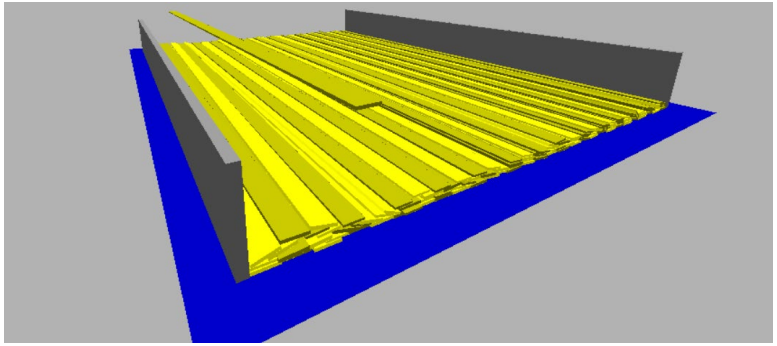
Basic constituent element (strand)

Real strand mat before pressing



3D computer simulation

Bamboo Bundles: Too Thick and Too Many Cracks



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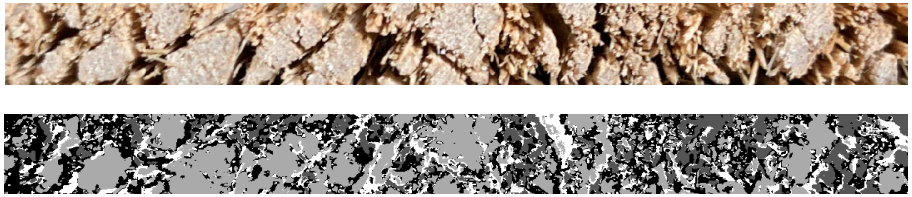
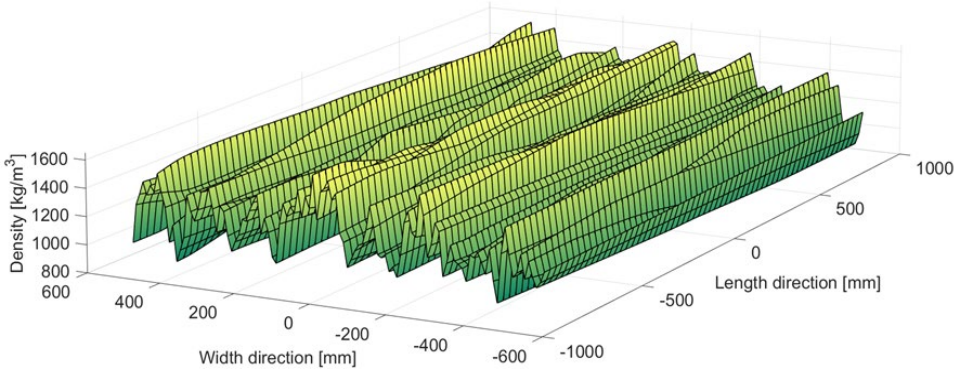
High resin usage

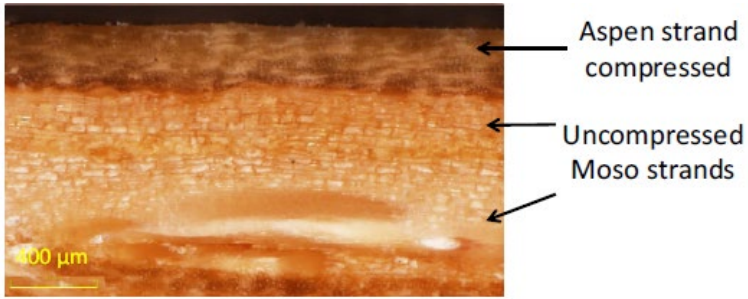


High variability



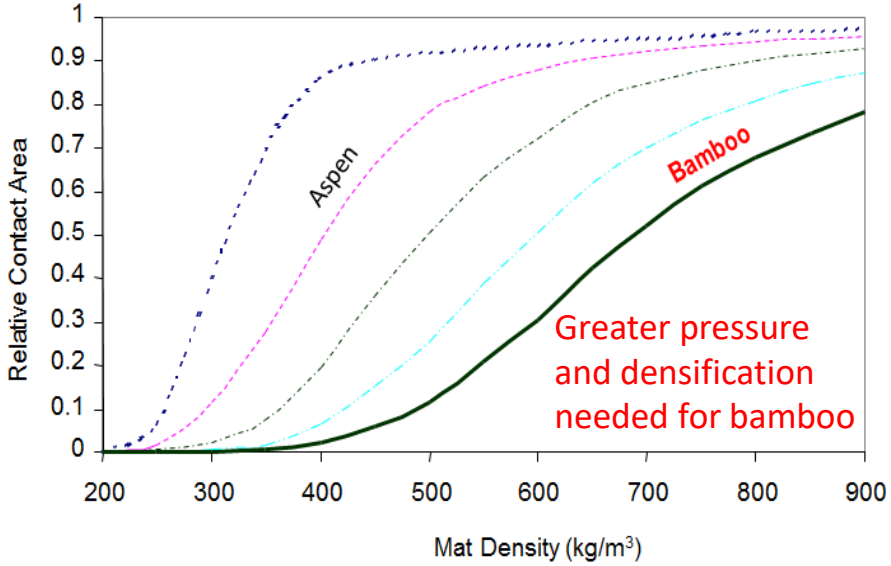
Pineda, H., Semple, K., Chen, M., & Dai, C. (2021). Computer simulation of the mat formation of bamboo scrimber composites. *Composites Part A: Applied Science and Manufacturing*, *149*, 106542.

Consolidation: Bamboo is Incompressible Compared to Wood



Microscopic view: highly densified wood vs uncompressed bamboo

Semple, K. E., Zhang, P. K., & Smith, G. D. (2015). Hybrid oriented strand boards made from Moso bamboo (Phyllostachys pubescens Mazel) and Aspen (Populus tremuloides Michx.): species-separated three-layer boards. *European Journal of Wood and Wood Products*, *73*(4), 527-536.



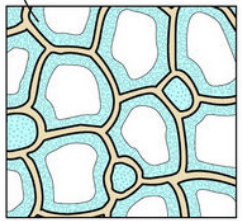
Dai, C., Yu, C., & Zhou, C. (2007). Theoretical modeling of bonding characteristics and performance of wood composites. Part I. Inter-element contact. *Wood and Fiber Science*, *39*(1), 48-55.

Heat and Mass Transfer in Hot Pressing

Water in Resin

Free water - easy to evaporate

Water in cell wall



Bound water – more energy needed

Hot Platen

7-15 MPa Pressure

140-160 C Temperature

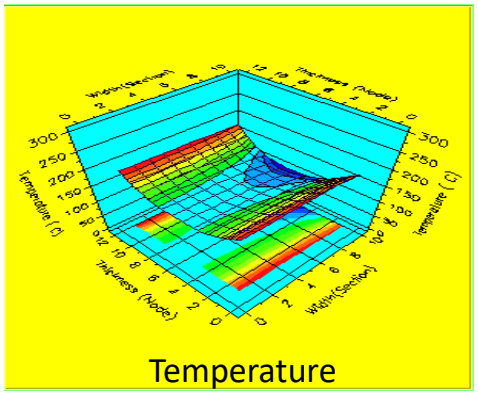
Heat

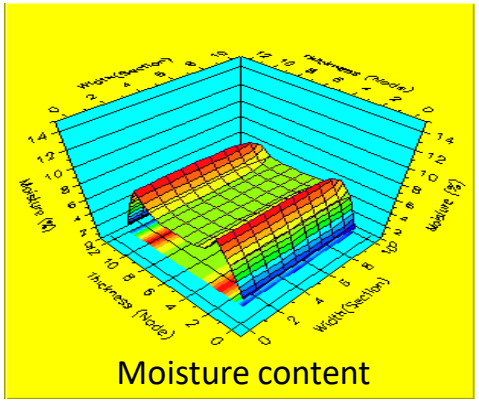
Hot Platen

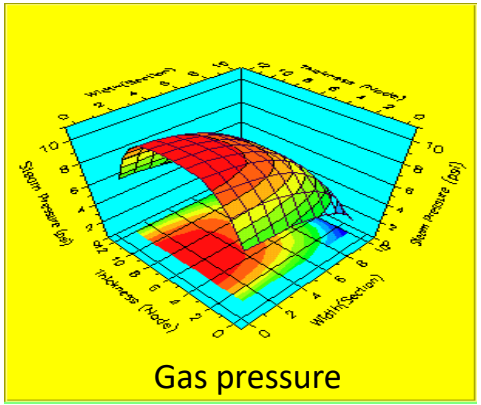
Water turns to steam

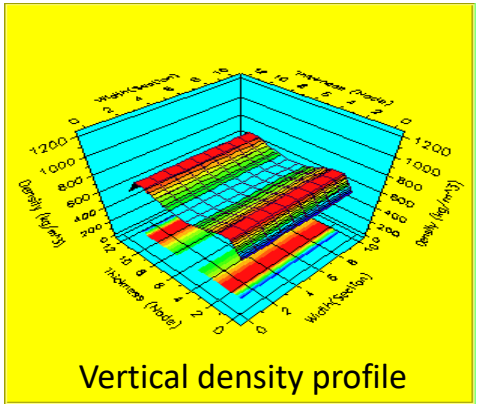
"Blows"?

Physics of Hot Pressing Processes









Dai, C., & Yu, C. (2004). Heat and mass transfer in wood composite panels during hot-pressing: Part I. A physical-mathematical model. *Wood and fiber science*, *36*(4), 585-597.

Highly Inefficient Pressing for Bamboo Scrimber

- Internal gas pressure too high, cooling required.
- Net hot pressing time:
  - More than double (2x) than wood PSL/LSL
- Cold-in and cold-out process:
  - Extremely low energy efficiency
  - 1/5 productivity of wood counterparts
- More efficient pressing techniques are needed.

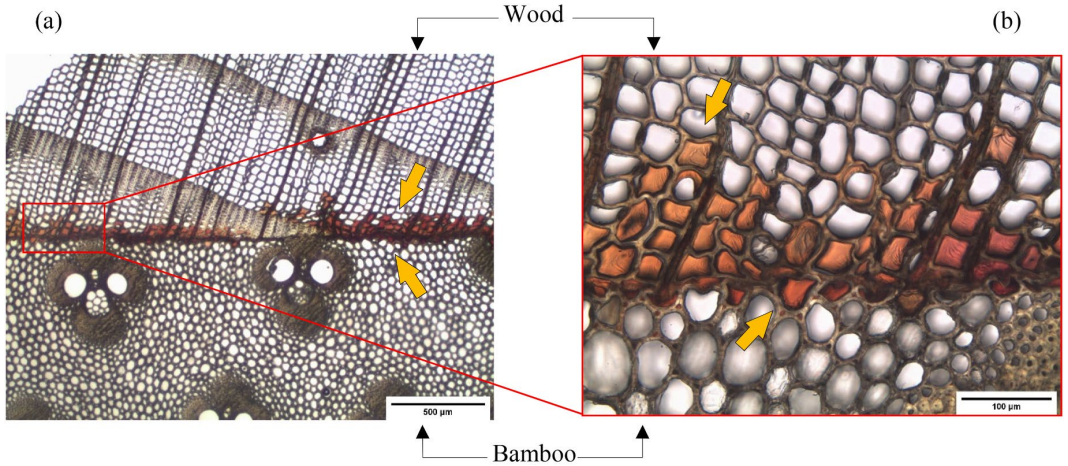
Over 1 hour pressing time (heating + cooling)

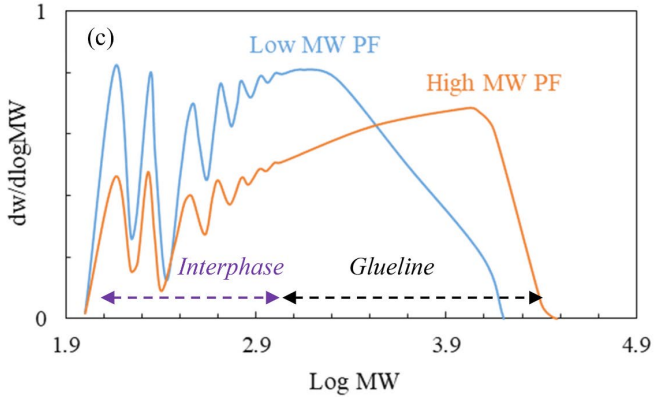
Bond Durability (wood failure %) for EWPs

- PRG 320 standard for CLT
- ANSI+117-Standard for Glulam

* CSA Standard 0151 Canadian softwood plywood, or PS-2 Performance standard for structural wood panels

Manipulating resin chemistry for optimum bonding





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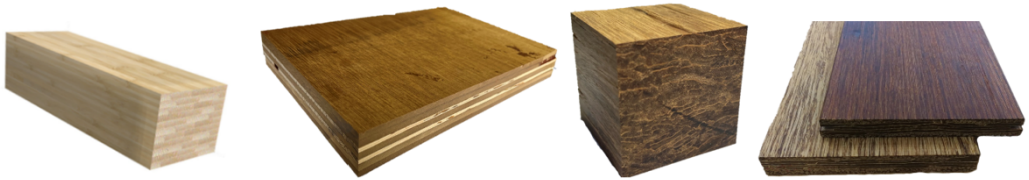
Utilization Rates of Typical Engineered Bamboo Products

Type of bamboo composite	Density (g/cm^3)	Constituent element	Bamboo utilization rate (%)
Laminated bamboo (a)	0.66	Bamboo strips	35–40
Laminated flattened Bamboo (b)	0.70	Flattened bamboo sheet	50-55
Bamboo scrimber (c)	1.08	Bamboo bundles	60–70
Bamboo laminated veneer lumber (d)	1.12	Bamboo bundle curtain	90–95



(a) (b) (c) (d)

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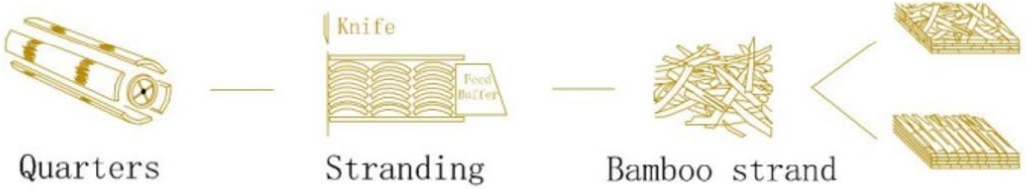
Opportunity for Strand-based Bamboo Products

- Only one small bamboo OSB mill
- High performance for container floor
- Bamboo LSL or PSL: Stranding is key.

Mill bamboo strands (Courtesy: WBPI)

LSL



Development of Bamboo Composite Pipes for Green Infrastructure Applications

- Partners: Zhejiang Xinzhou Bamboo-based Composites Technology Co. (Xinzhou), and ICBR.
- Utilizing high strength and ductility of Bamboo.
- Applications: water transportation, agriculture irrigation and utility tunnels.

Sewage pipe

Drinking water pipe

Utility tunnel

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Pipe Winding: Revolutionizing Bamboo Processing and Product Supply Chain

Pipe winding using ribbon and resin

Other Potential Applications

Assembling

House

Interior of house

Train car

Interior of train car

Concluding Remarks

- Bamboo is markedly higher in strength but moderately lower in modulus of elasticity. Combining bamboo and wood offer plausible material design and processing strategies.
- Bamboo's high density, high hardness and impermeability present processing challenges for drying, bonding and hot pressing.
- Great opportunities exist in developing novel processing methods to produce cost-effective engineered bamboo products, similar to EWPs.
- Further bamboo product development can benefit from advanced science and technology in wood composites.

Thank You!