正交胶合竹I型断裂及铺层方式的影响

Translaminar fracture of cross-laminated bamboo and lay-up effects

汇报人：吴 瑶

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1. Background

- Advantages of bamboo construction
  - Sustainable and renewable
  - Low carbon emission
  - Prefabricated offsite and quickly assembled
  - Excellent seismic performance

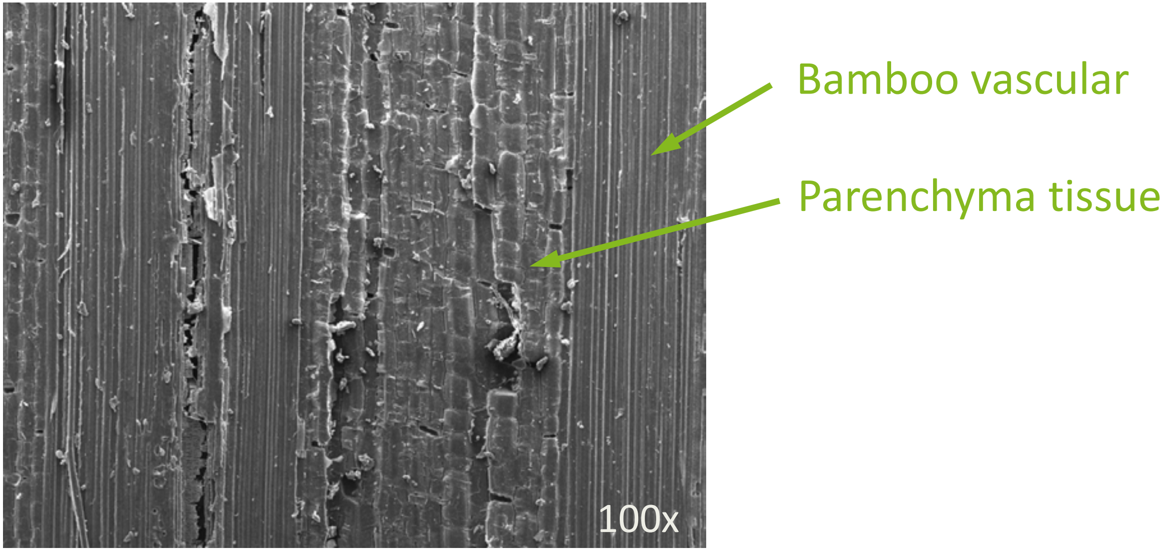
1. Background

- Splitting and fracture cracks in bamboo construction
  - Brittle failure

Wu Yao, Wan Zhichao, Li Zhi (2022). Mode I fracture behavior of unidirectional bamboo laminate and its applications to the estimation of bamboo-steel-bamboo connections' bearing capacities. Structures 45: 2226–2238.

1. Background

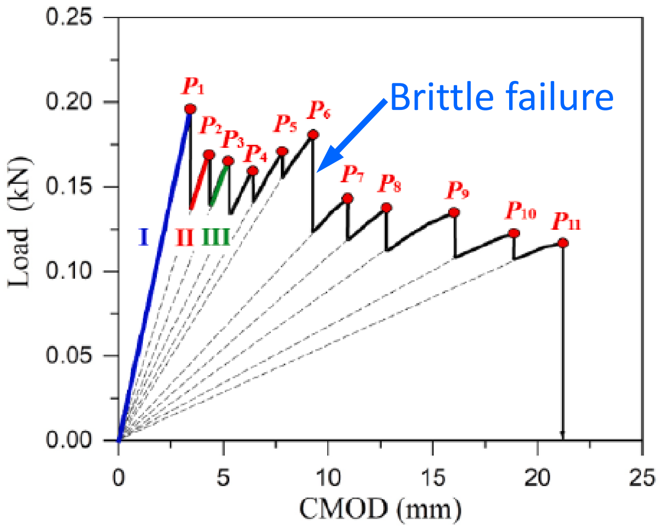
- Reasons for premature splitting and fracture cracks
  - Greater anisotropy



Microstructure photo of bamboo

1. Background

- Reasons for premature splitting and fracture cracks
  - Lower interlaminar fracture property in bamboo or unidirectional bamboo laminate

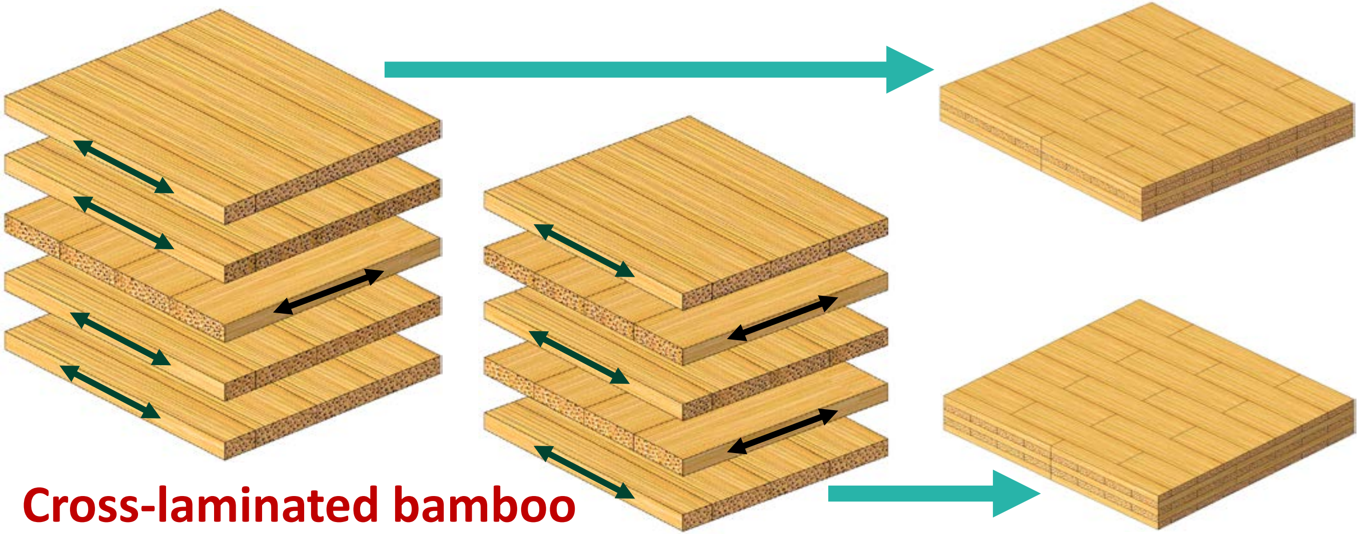


Mode I fracture toughness

G_{Ic} = 200~400 N/m

1. Background

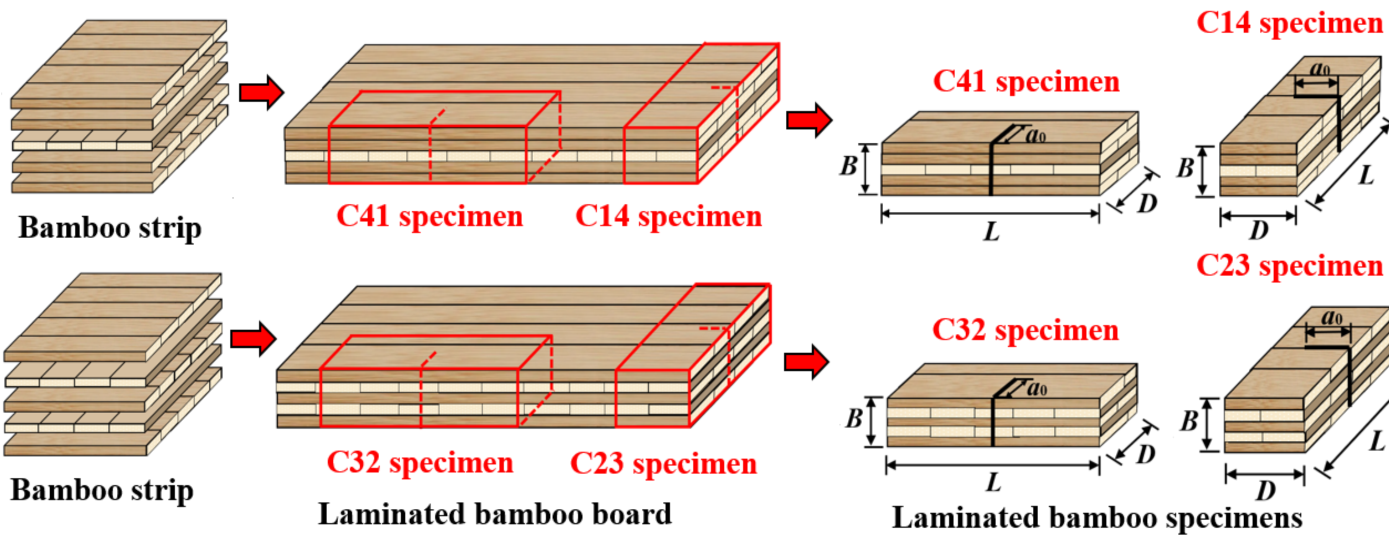
- Expected improvements of bamboo laminate
  - Greater capacity
  - Less brittle failure



Cross-laminated bamboo

2. Experiments

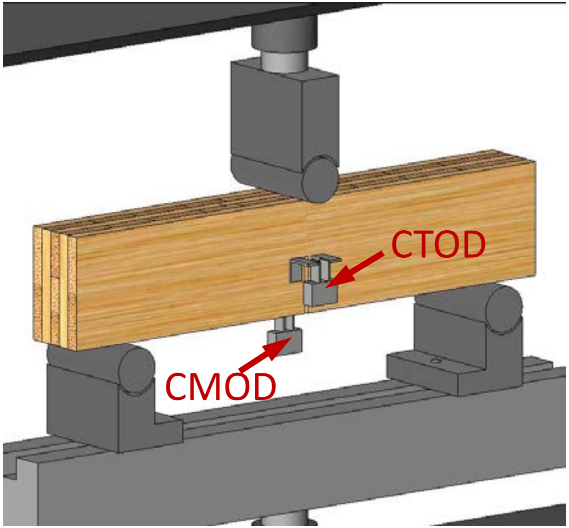
- Three-point bending (TPB) tests
  - Specimens



2. Experiments

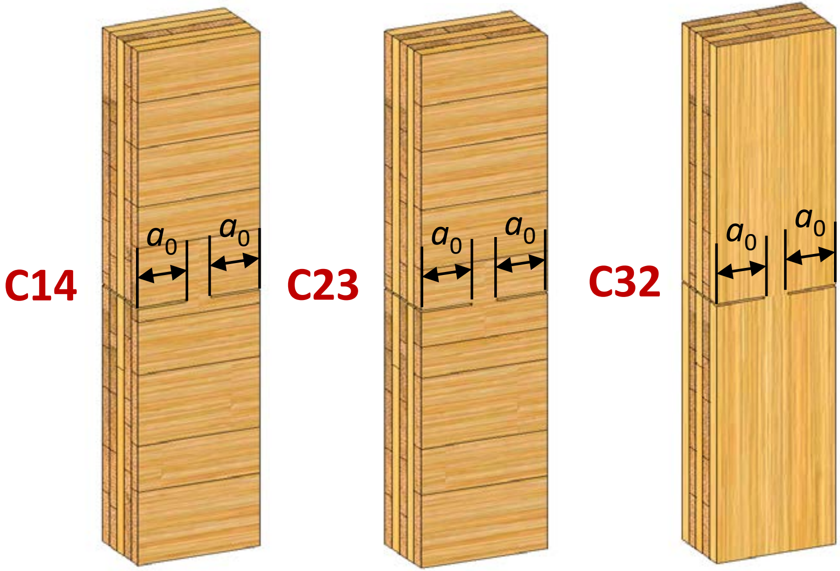
- Three-point bending (TPB) tests
  - Specimens and test setup

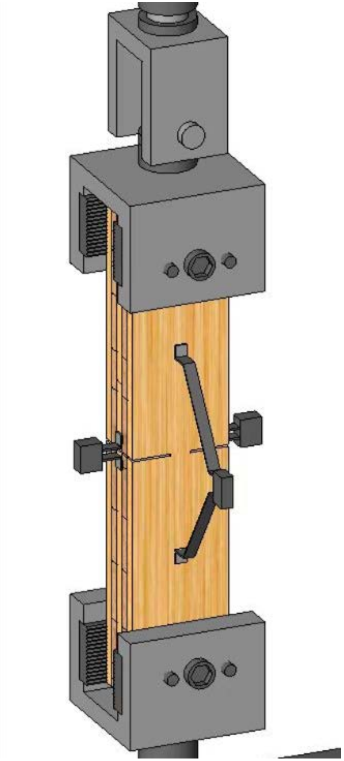
Specimen	*D*	*B*	*L*	a_0
C14-0.4-s	50mm	30mm	250mm	20mm
C14-0.5-s	50mm	30mm	250mm	25mm
C23-0.4-s	50mm	30mm	250mm	20mm
C23-0.5-s	50mm	30mm	250mm	25mm
C32-0.4-s	50mm	30mm	250mm	20mm
C32-0.5-s	50mm	30mm	250mm	25mm
C41-0.4-s	50mm	30mm	250mm	20mm
C41-0.5-s	50mm	30mm	250mm	25mm



2. Experiments

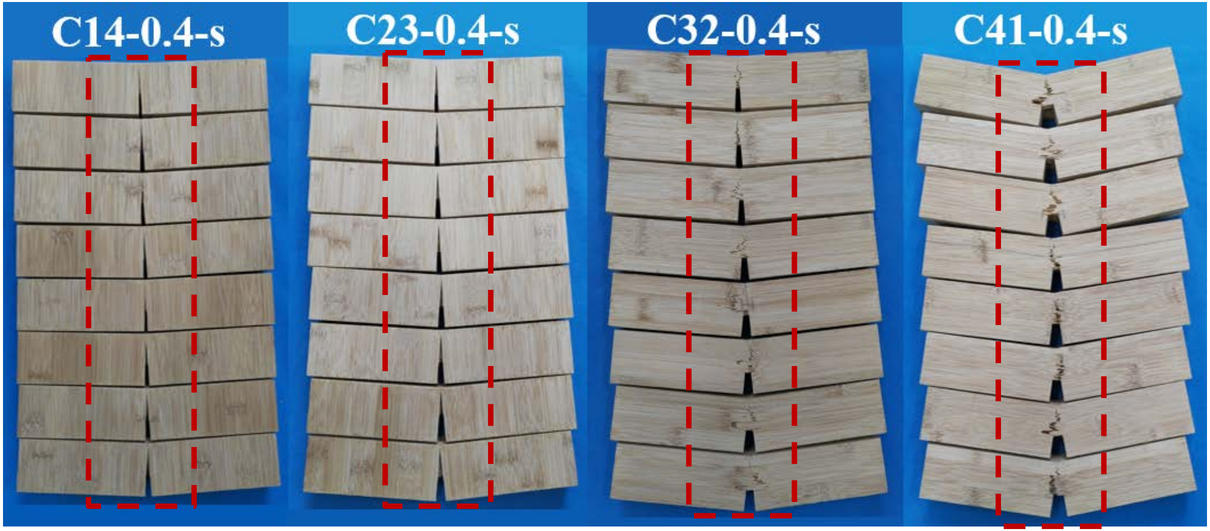
- Tensile tests (Double edge notched tension)
  - Specimens and test setup





3. Test results

- TPB tests
  - Failure photos of specimens

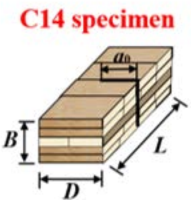


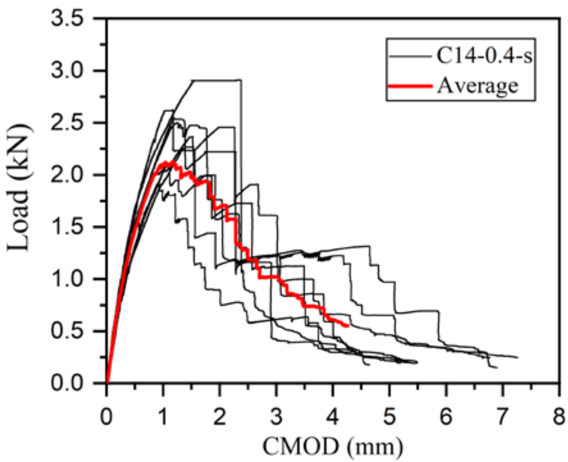
3. Test results

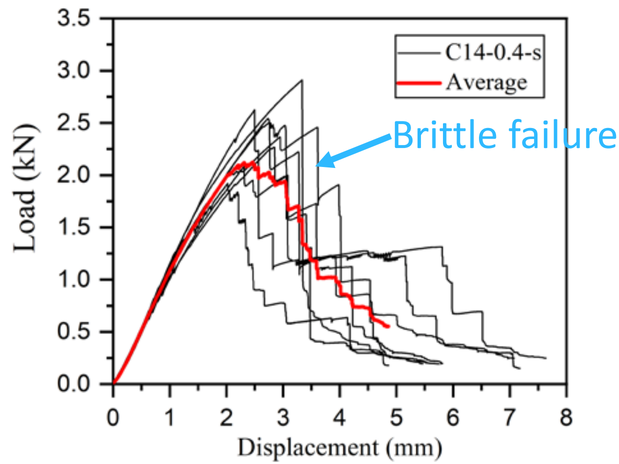
- TPB tests
  - Failure photos of specimens

3. Test results

- TPB tests
  - Load-CMOD curves and load-displacement curves







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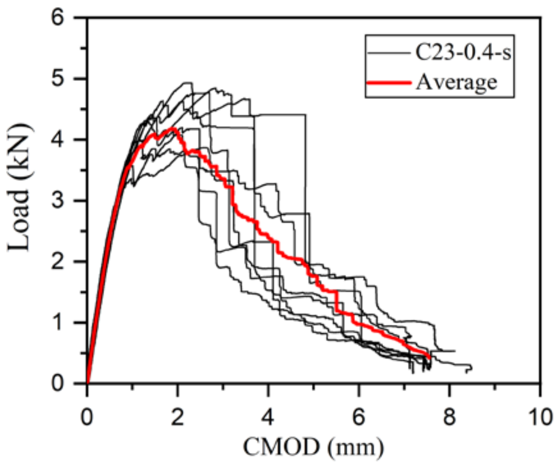

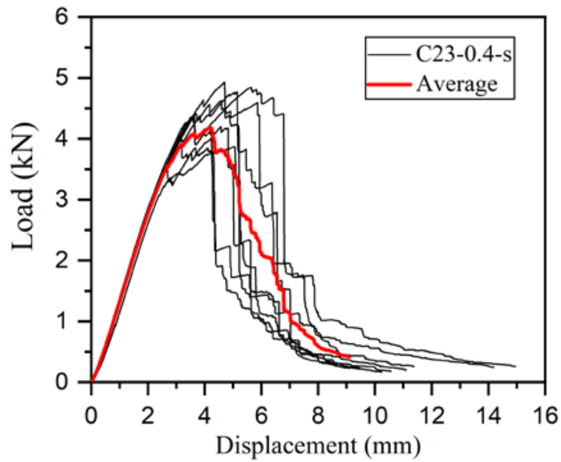

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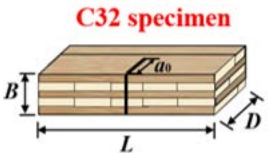
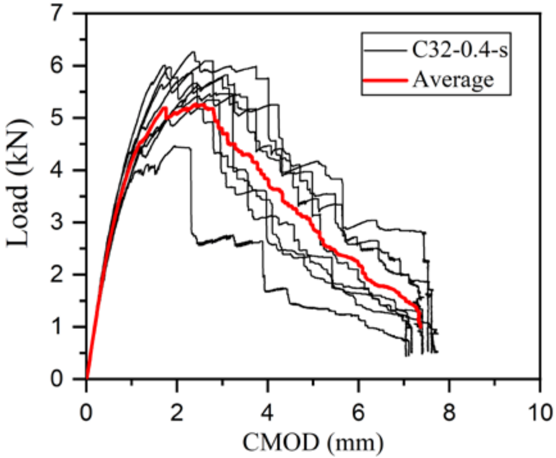
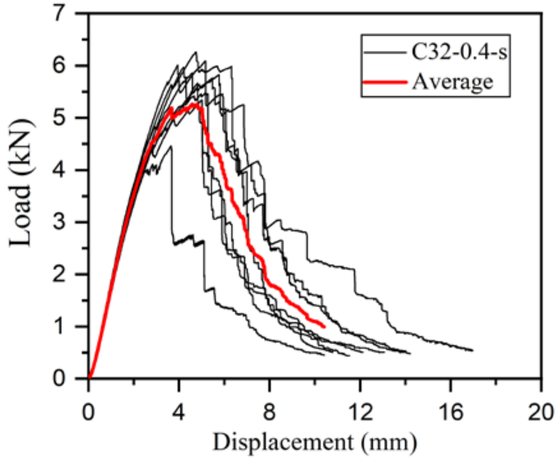


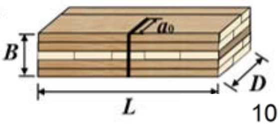


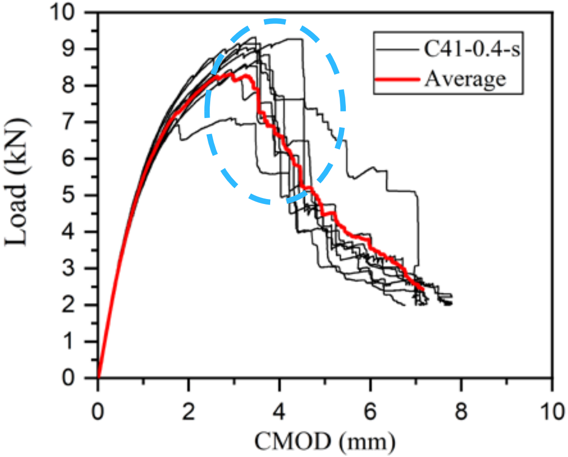


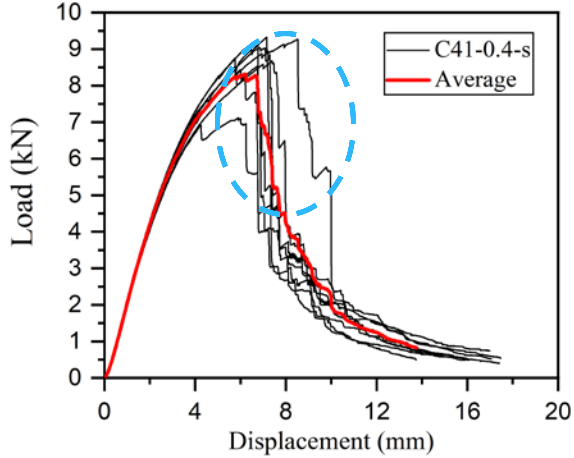
3. Test results

- TPB tests
  - Load-CMOD curves and load-displacement curves

C41 specimen

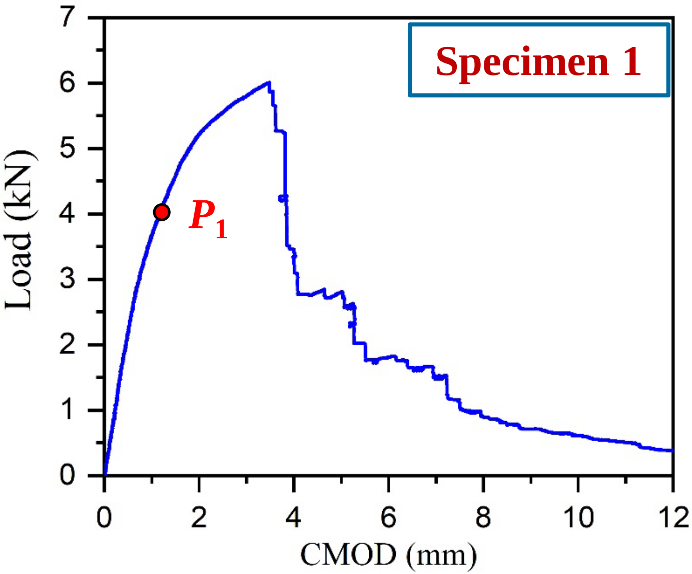


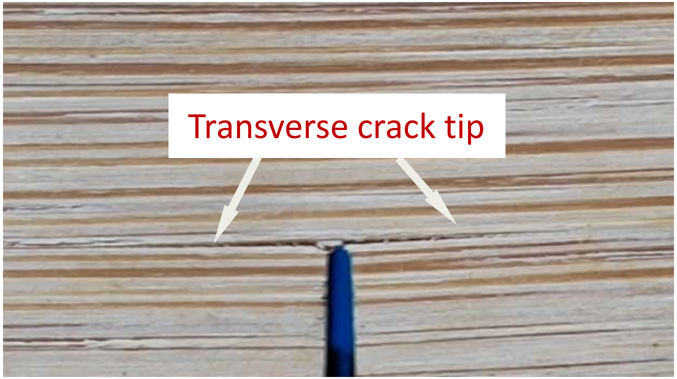




3. Test results

- TPB tests
  - Fracture process





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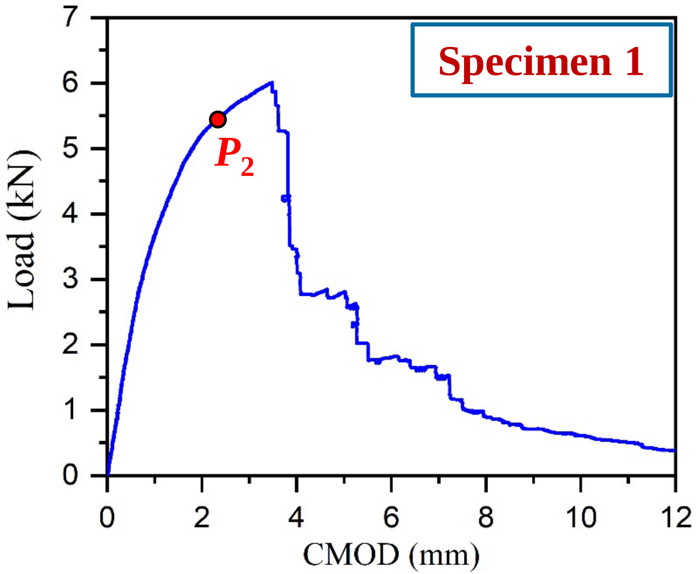

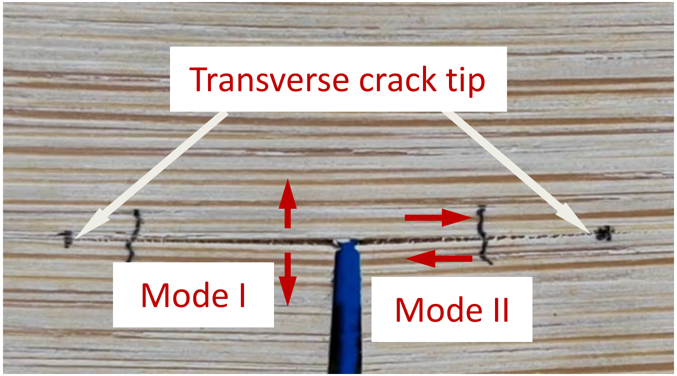

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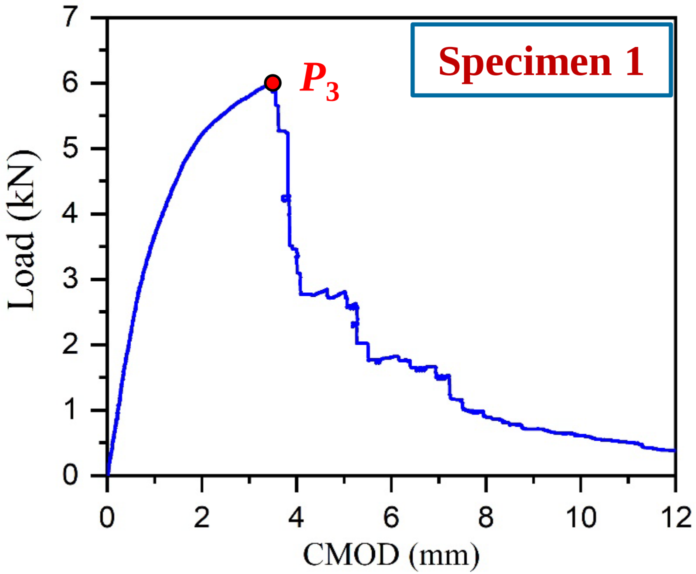

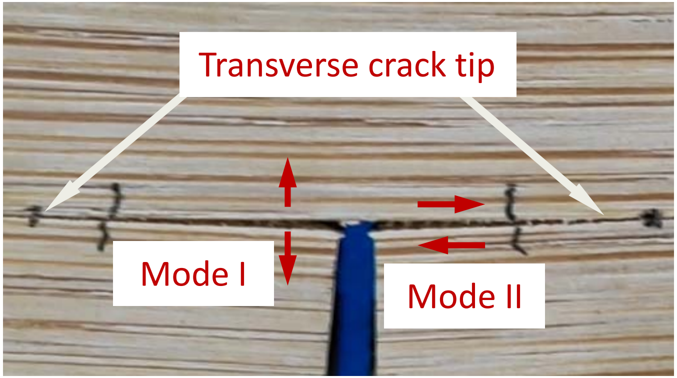

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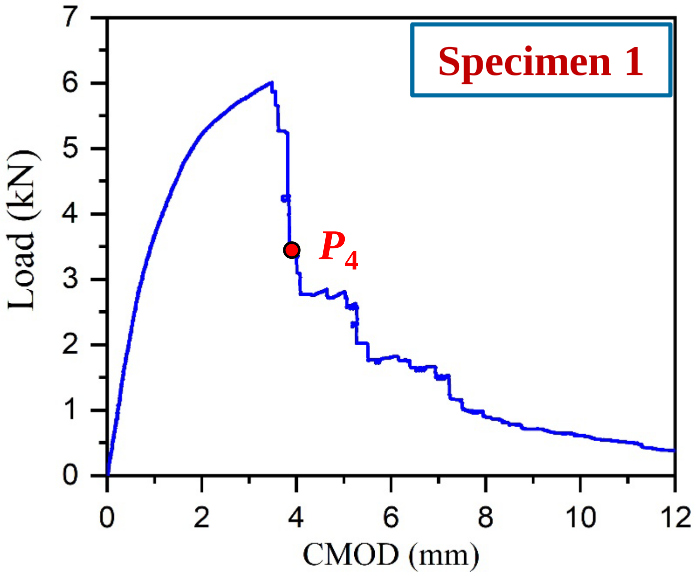

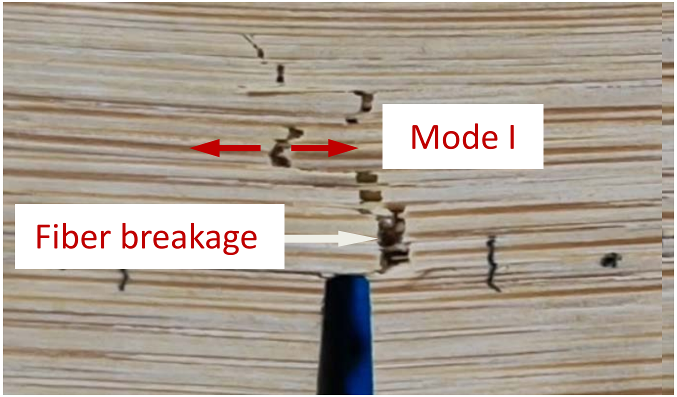

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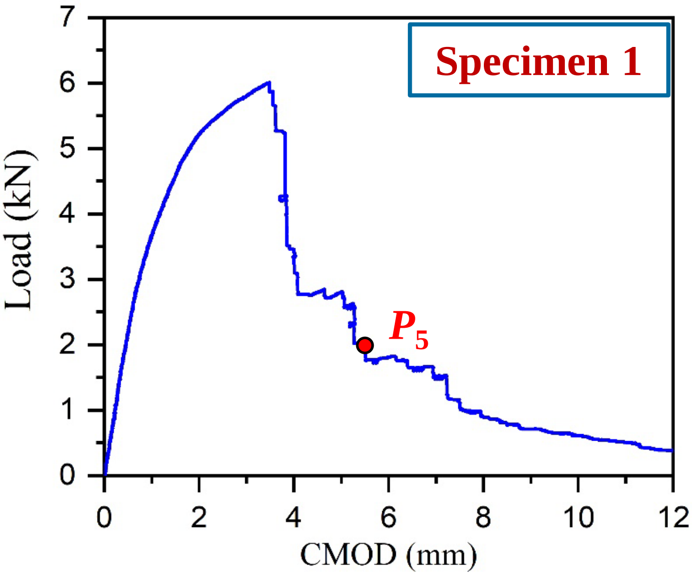

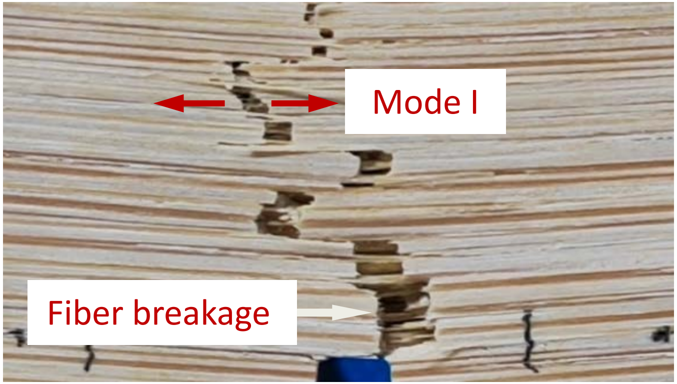

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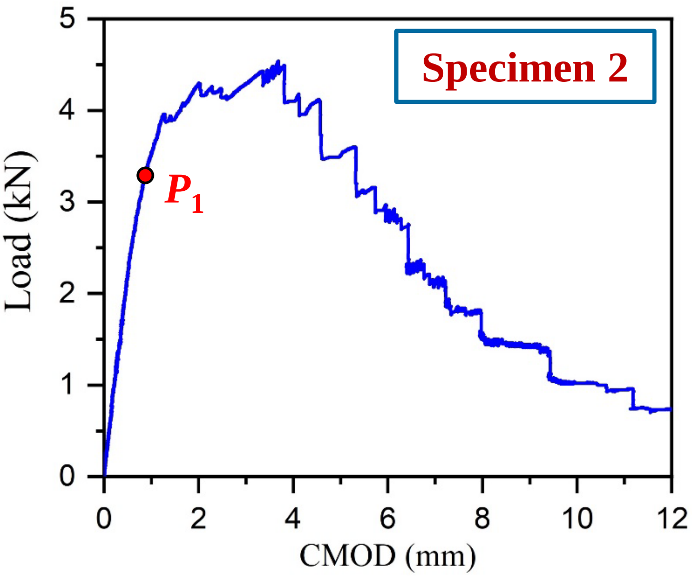
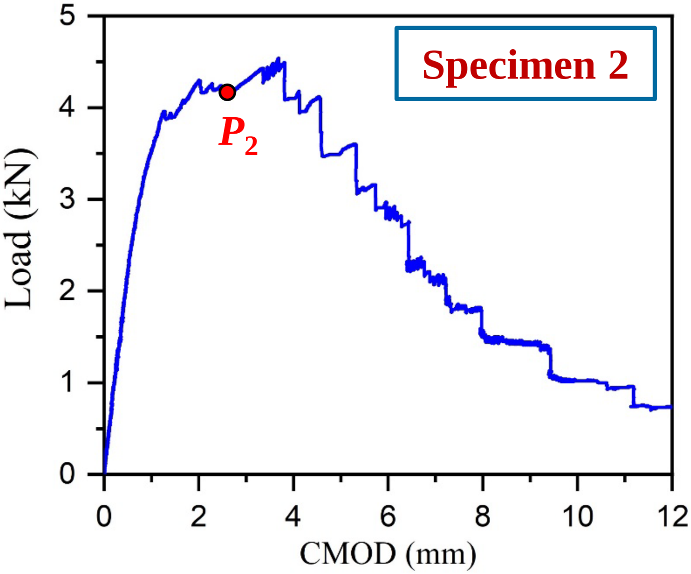


Transverse crack tip

3. Test results

- TPB tests
  - Fracture process



Transverse crack tip

3. Test results

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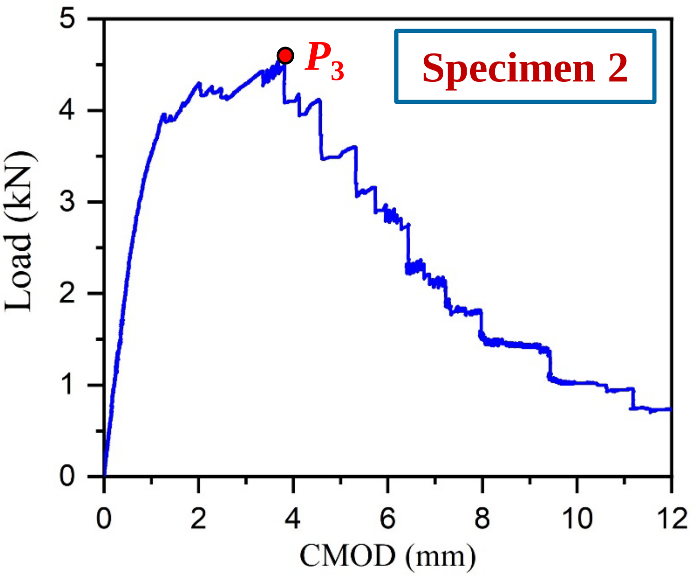
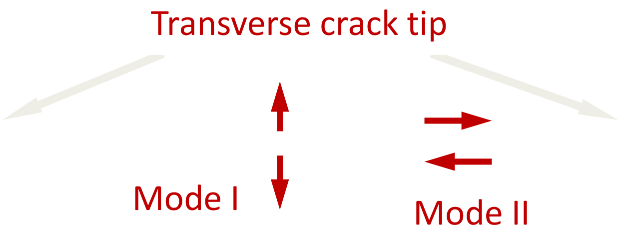
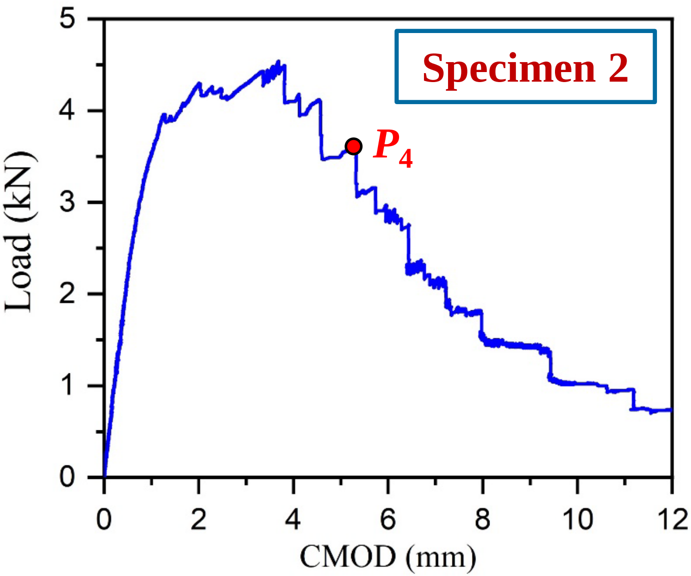
  - Fracture process





3. Test results

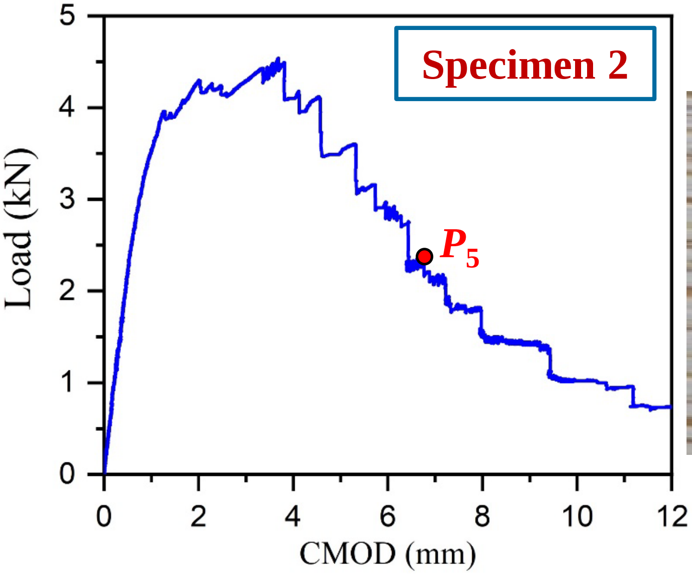
- TPB tests
  - Fracture process

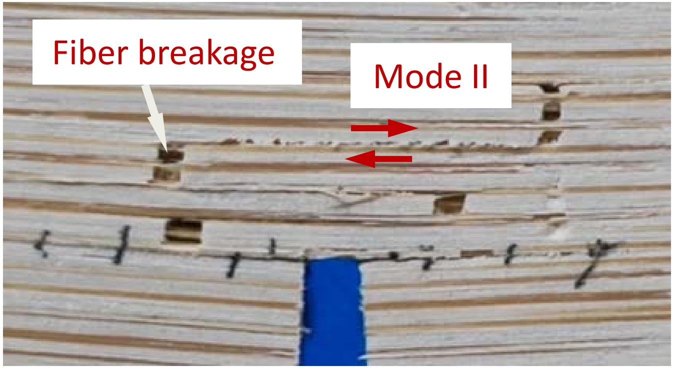


Fiber breakage

3. Test results

- TPB tests
  - Fracture process





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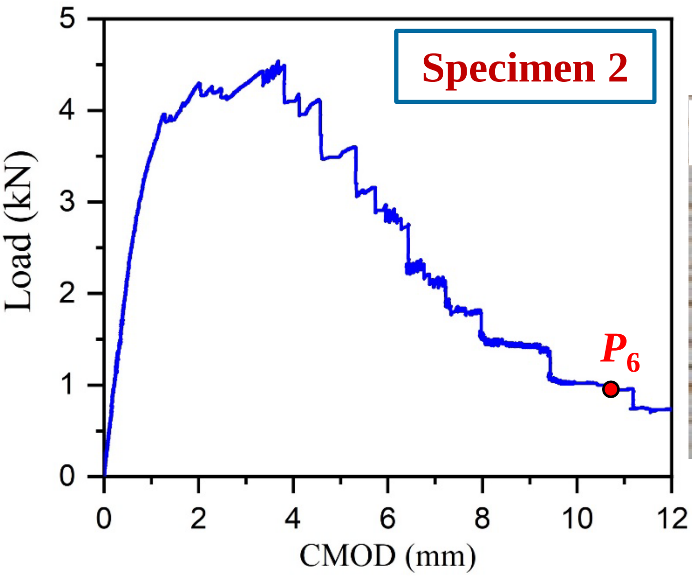
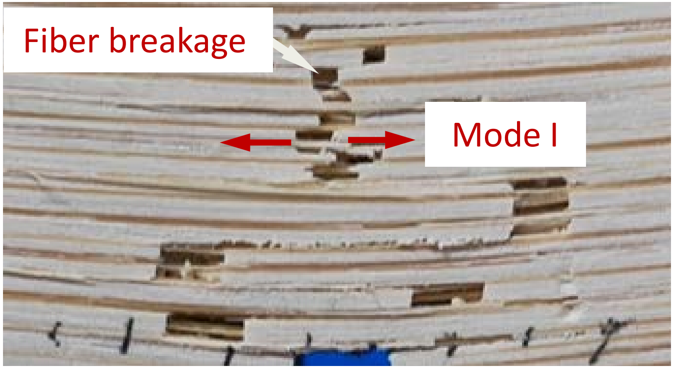
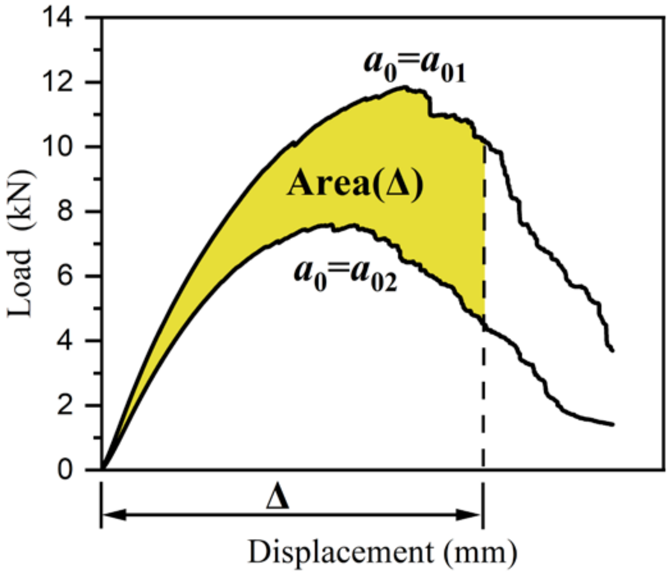




3. Test results

- TPB tests
  - Calculation of R-curves (Method 1)



$$R(\Delta) = \frac{\text{Area}(\Delta)}{B(a_{02} - a_{01})}.$$

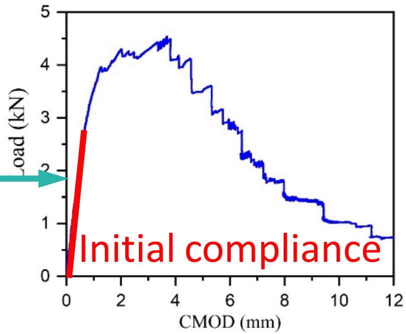
3. Test results

- TPB tests
  - Calculation of R-curves (Method 2)

$$CMOD = \frac{24Pa}{DBE}V(\alpha) \qquad V(\alpha) = 0.76 - 2.28\alpha + 3.87\alpha^2 - 2.04\alpha^3 + \frac{0.66}{(1-\alpha)^2}\ , \alpha = a/D$$

$$K_{\mathrm{Ic}} = \frac{6P}{DB}\sqrt{a}F(\alpha) \qquad F(\alpha) = \frac{1.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)}{(1+2\alpha)(1-\alpha)^{3/2}}, \alpha = a/D$$

$$G_{\mathrm{Ic}} = \frac{{K_{\mathrm{Ic}}}^2}{E}$$



3. Test results

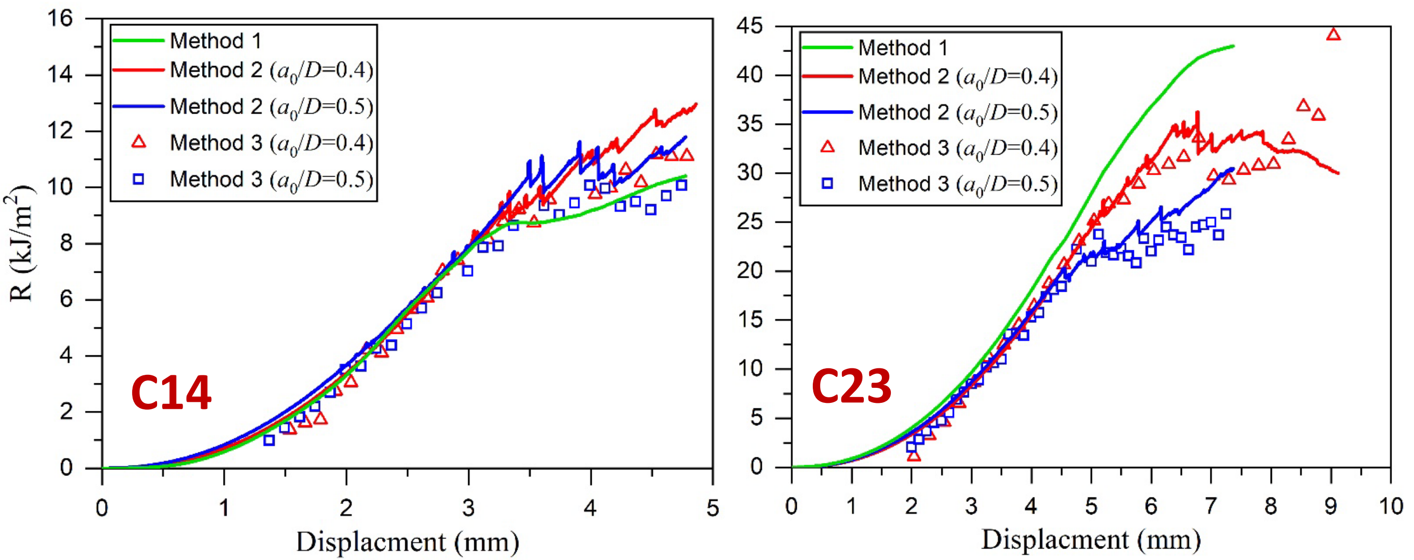
- TPB tests
  - Calculation of R-curves (Method 3)

Area method

$$G_{\mathrm{Ic}} = \frac{1}{2B\Delta a}\left(P_1 u_2 - P_2 u_1\right)$$

3. Test results

- TPB tests
  - R-curves of CLB



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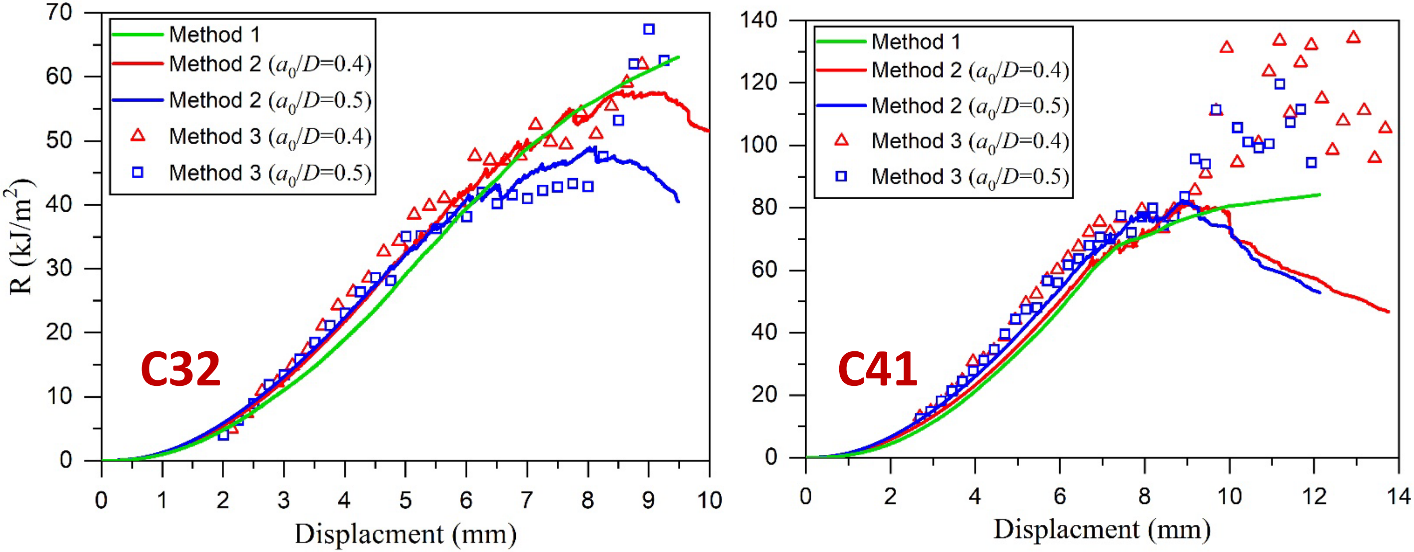
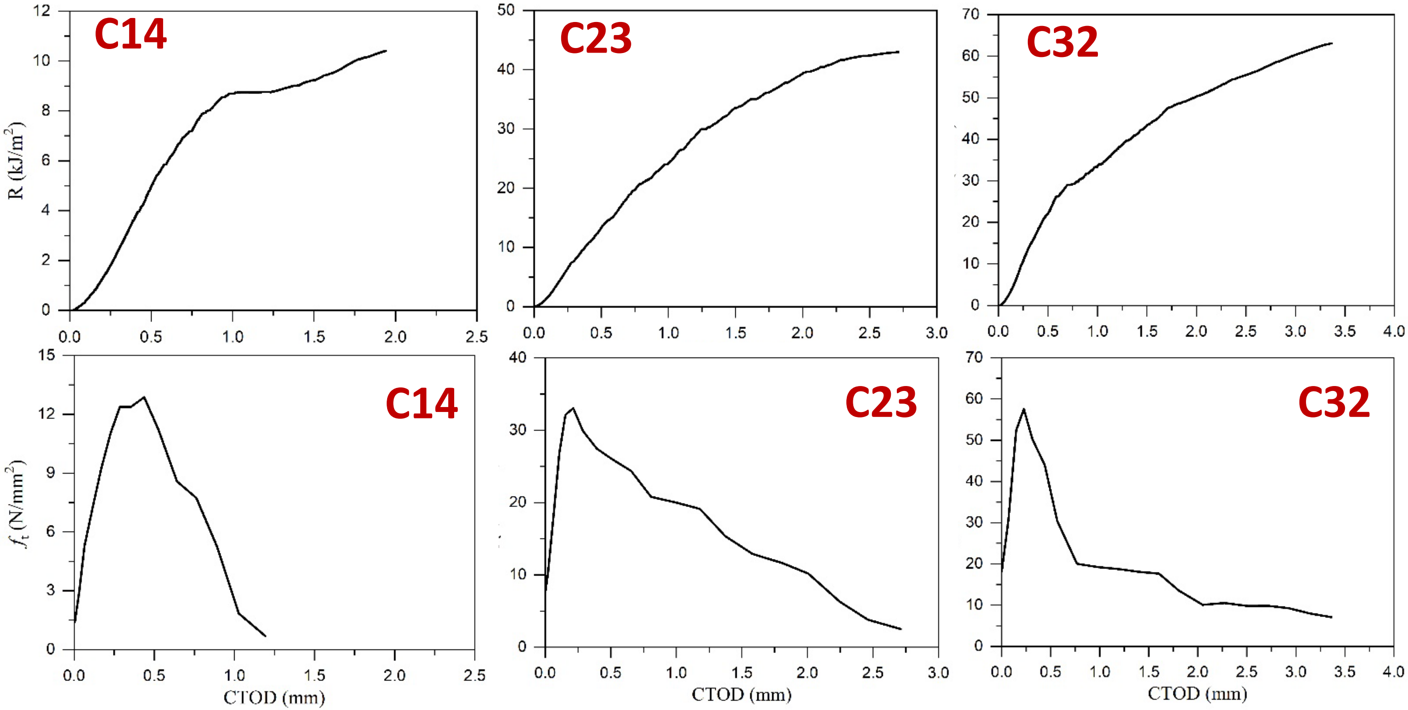


3. Test results

- TPB tests
  - Traction-separation relation obtained from R-curves



3. Test results

- Tensile tests
  - Failure patterns

C14

3. Test results

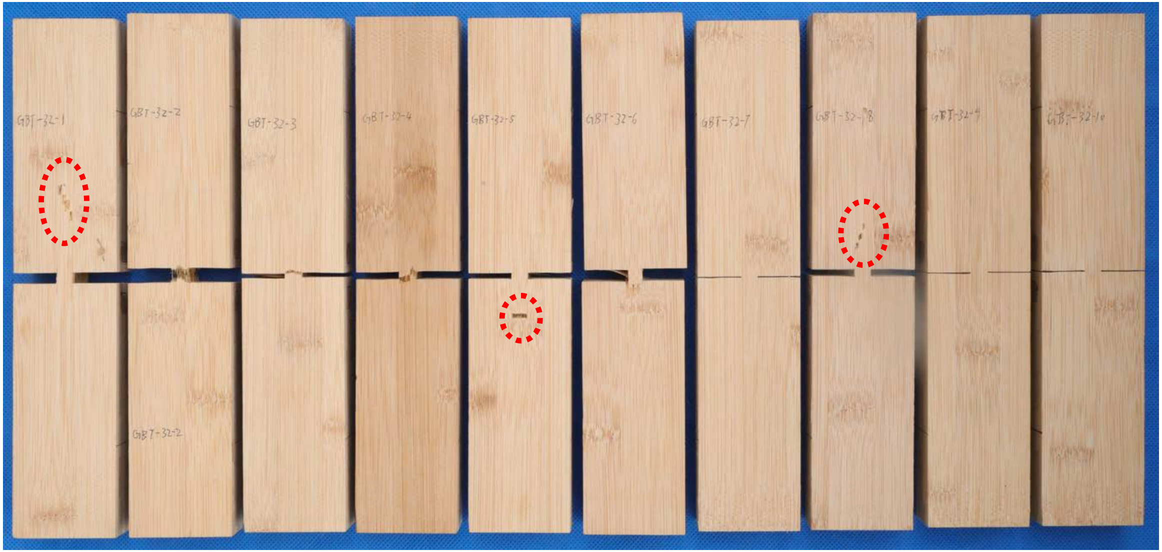
- Tensile tests
  - Failure patterns

C23

3. Test results

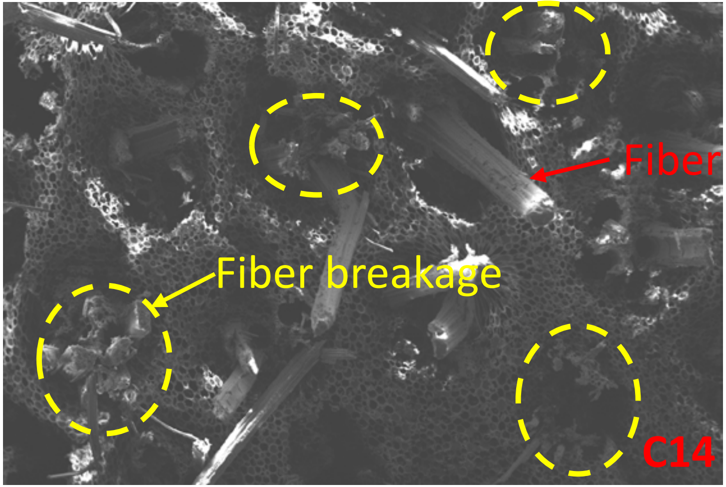
- Tensile tests
  - Failure patterns

C32



3. Test results

- Tensile tests
  - Fracture failure surface



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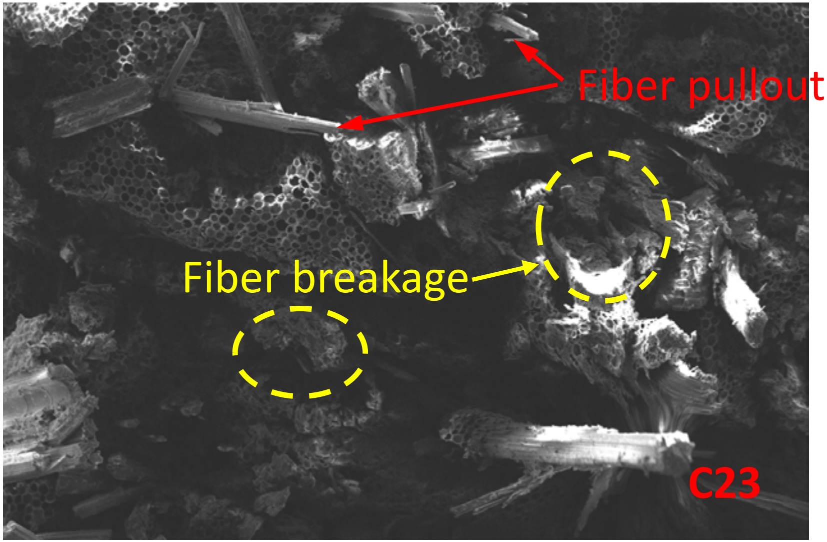

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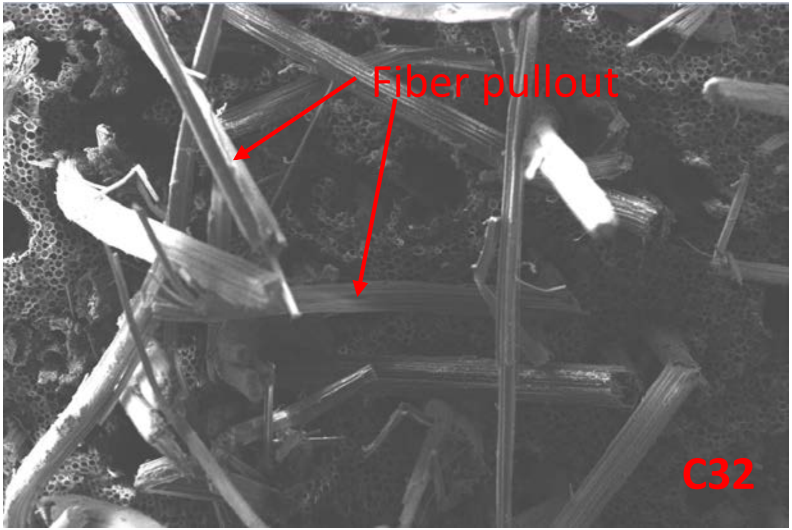
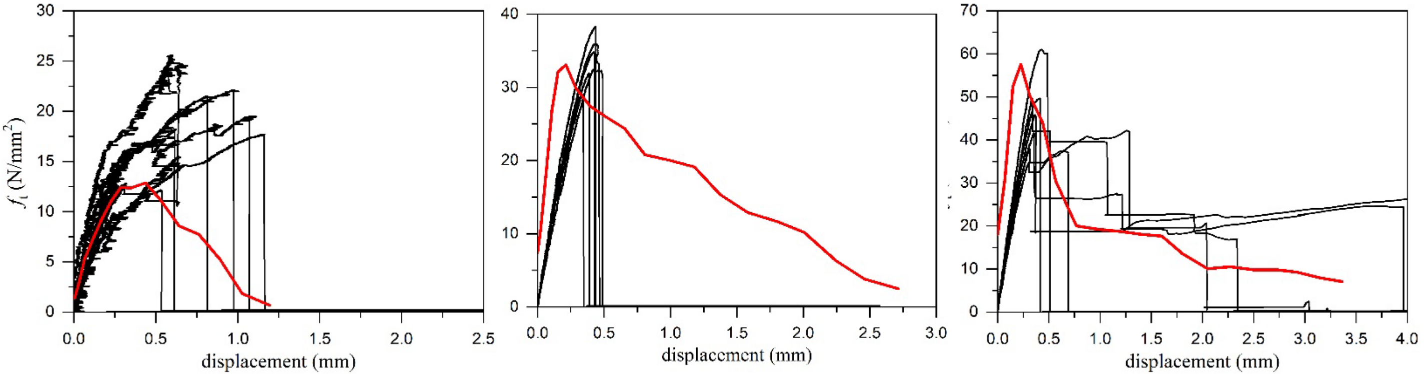


3. Test results

- Comparison between TPB and tensile test results



- The difference between the average curve and the curve of a single specimen, especially at descending part after the peak load;
- The error of fracture toughness caused by the R-curve calculation method;
- The rigidity of the testing machine for tensile tests is not large enough.

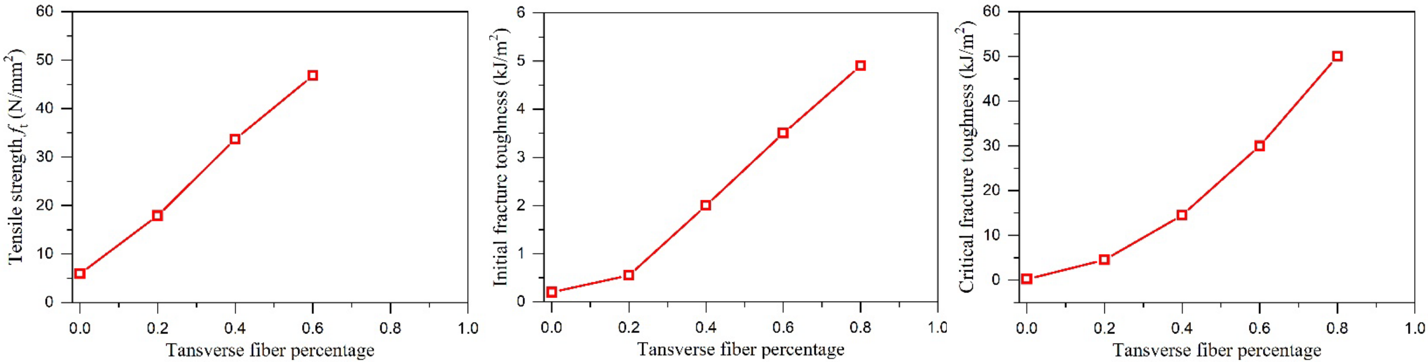
3. Test results

- Comparison of fracture toughness between CLB and unidirectional laminated bamboo

Laminated bamboo		Initial fracture toughness G_{Ic}^{ini}	Critical fracture toughness G_{Ic}^{un}	Tensile strength f_t
Unidirectional		0.2 kJ/m² (matrix-dominate)		5.9 N/mm²
Bidirectional	C14	0.55 kJ/m²	4.5 kJ/m²	17.9 N/mm²
	C23	2.0 kJ/m²	14.5 kJ/m²	33.7 N/mm²
	C32	3.5 kJ/m²	30 kJ/m²	46.8 N/mm²
	C41	4.9 kJ/m²	50 kJ/m²	

3. Test results

- Layup effects



The tensile strength and initial fracture toughness basically increase linearly with the transverse fiber percentage. The increasing trend of critical fracture toughness is greater than that of the transverse fiber percentage.

$$G_{Ic}(\alpha,\beta,\gamma,\ V_f) = G_{Ic}^{0}(V_f)\ \alpha + G_{Ic}^{90}(V_f)\ \beta + G_{Ic}^{\pm 45}(V_f)\ \gamma \qquad (13)$$

being $G_{Ic}^{0}(V_f)$, $G_{Ic}^{90}(V_f)$ and $G_{Ic}^{\pm 45}(V_f)$ respectively the specific fracture energy of the lamina placed at 0°, 90° and ±45°, having fibre volume concentration equal to V_f.

4. Conclusions

- 纤维横向纵向布置可以对断裂韧度及耗能有明显提高，特别对失稳韧度的提高极大。
- The transverse and longitudinal arrangement of fibers in CLB significantly improves the fracture toughness and energy consumption, especially the critical fracture toughness.

- 随着纤维含量增加，纤维由拉断转变为拔出破坏耗能，可一定程度改善脆性破坏特性。
- With the increase in fiber content, the failure mode changes from fiber breakage to fiber pullout, which can improve brittle failure characteristics.

- 纤维含量过多，造成横纵向强弱差异过大，会引起另一方向破坏和其他薄弱环节破坏。
- Larger fiber content in one direction will cause greater anisotropy in CLB, which will cause failure in a relatively weak direction.

- 拉伸强度和起裂韧度与横向纤维含量基本呈线性关系，但断裂韧度的增长趋势大于横向纤维含量的增长。
- The tensile strength and initial fracture toughness basically increase linearly with the transverse fiber percentage. The increasing trend of critical fracture toughness is greater than that of the transverse fiber percentage.

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Thank you!