Are bamboo fibers stronger and stiffer than wood fibers ?

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International Center for Bamboo and Rattan (ICBR)

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1. Background

Bamboo is a kind of special and important forest resources:

- **having a tree-like shape but belonging to the grass family;**
- **grows much faster than wood. It can be harvested sustainably on 3 to 5 year rotation;**
- **bamboo can be used to substitute wood in many aspects;**
- **stronger than most tree species, especially in tensile strength;**

Comparison of bamboo and wood in mechanical properties

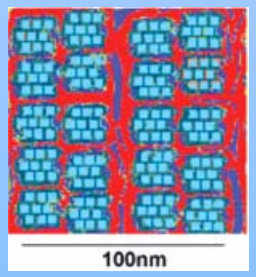
Species	Tensile strength (MPa)	MOE(GPa)
Hardwood	92.4 (51-120)	9.6 (7.6-11.9)
Softwood	77.6(45-111)	8.6(5.7-12.3)
Bamboo	140-230	11-17

Note: data on wood adapted from "wood handbook"

- The tensile strength of bamboo is nearly two times of wood. Specific strength is comparable to that of alloy steel with highest performance:
- The stiffness of bamboo is comparable to that of wood;

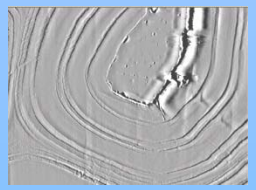
Hierarchical structure of bamboo

Nano



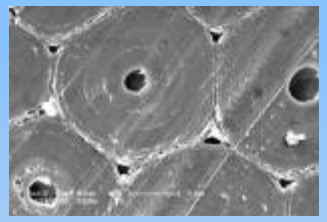
Cell wall layer: nanocomposites with cellulose nanofibers embedded in lignin/hemicellulose matrix

Cell

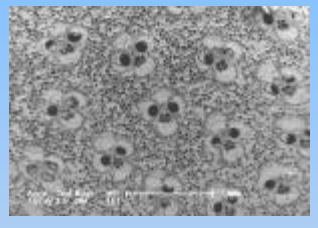


SingleFiber: muti-ply structures with alternate thick and thin cell wall layers

Tissue



Fibe bundles: fiber bonded to fibers



Two phase composite structure: fiber bundles embedded in ground parenchyma

Macro

Mechanical graded material: big variation of fiber bundles distribution across a culm wall

Fiber is the key to know bamboo !!!!

nm — Scale — cm

The increasing interests in bamboo fiber reinforced composites (BFRC) need to know more about the mechanical properties of bamboo fibers.

Molded BRFC with medium or high density

Foamed BRFC with super low density

It is very difficult to measure the mechanical properties of single bamboo fibers.

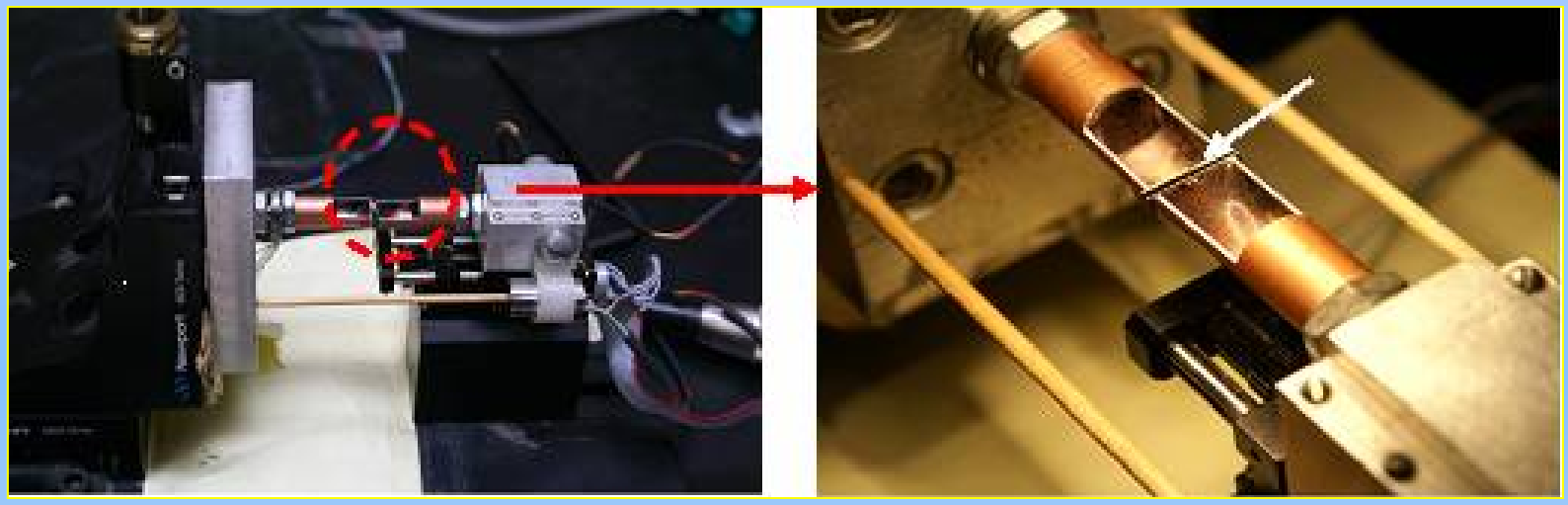
Technical challenges:

- Fiber gripping ******
- Aligning fiber with tension direction****
- Measurement of cell wall area***

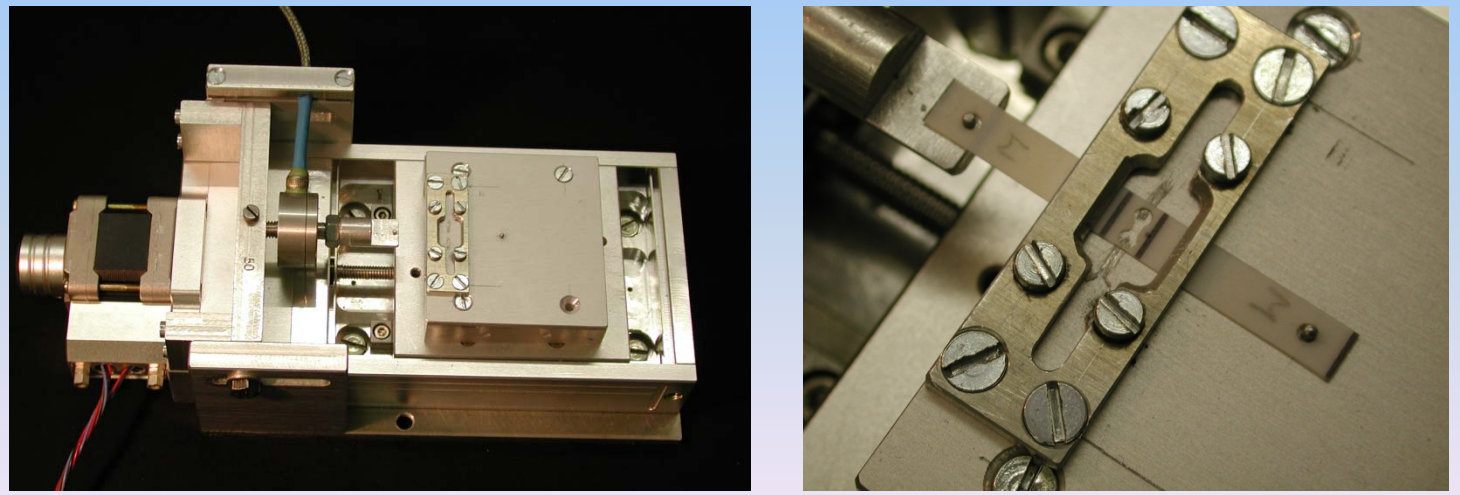
Dimensions of some selected plant fibers

Sources	Length (mm)	Diameter (μm)
Softwood fiber	2-5	20-50
Bamboo fiber	1.5-3	8-20
Rattan fiber	1-2	8-20
Flax fiber	9-70	5-38
Hemp fiber	5-55	10-50
Jute fiber	2-5	10-25

No commercial instruments are available in the market



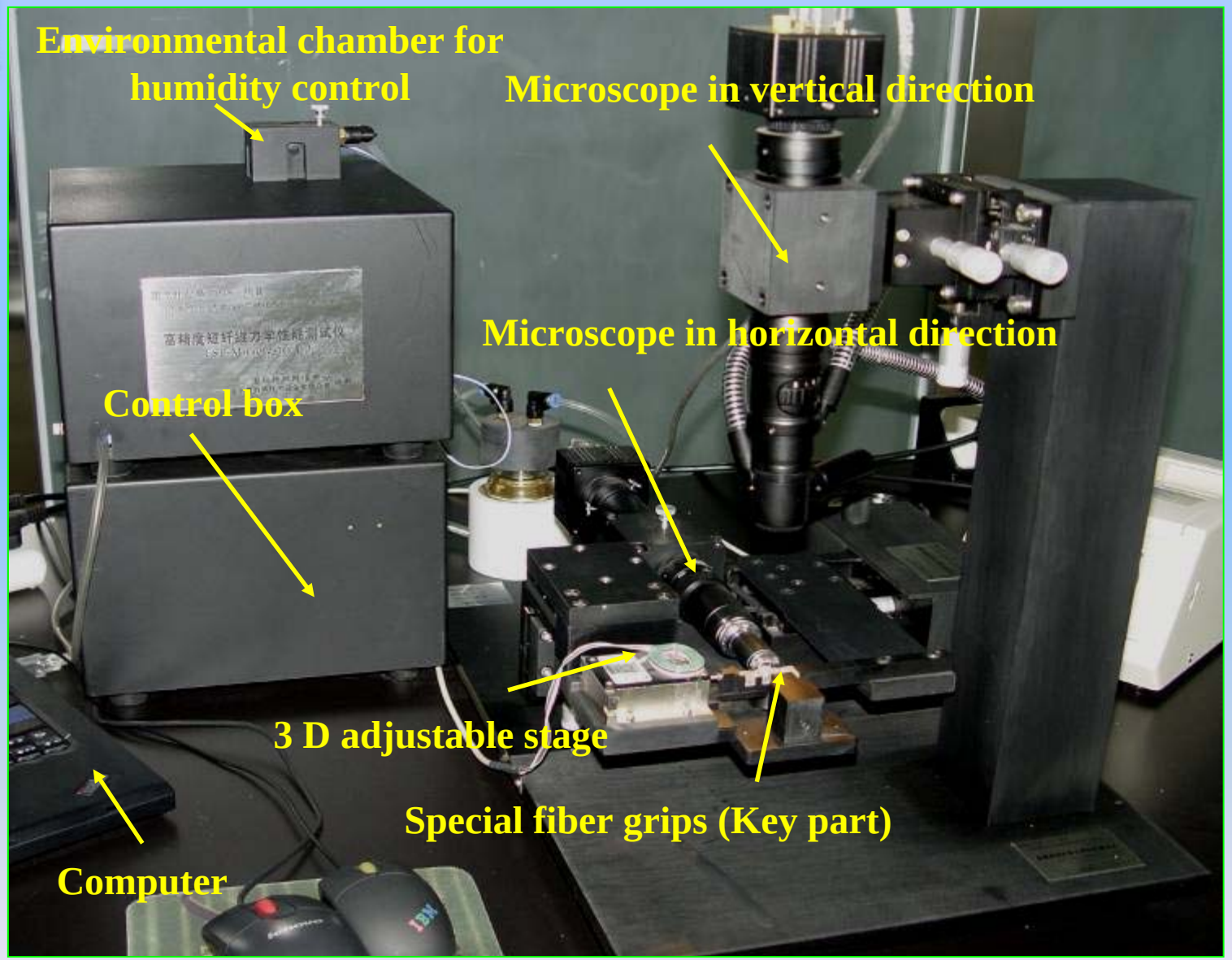
Custom-built microtester developed by Groom et al, SRS, USA



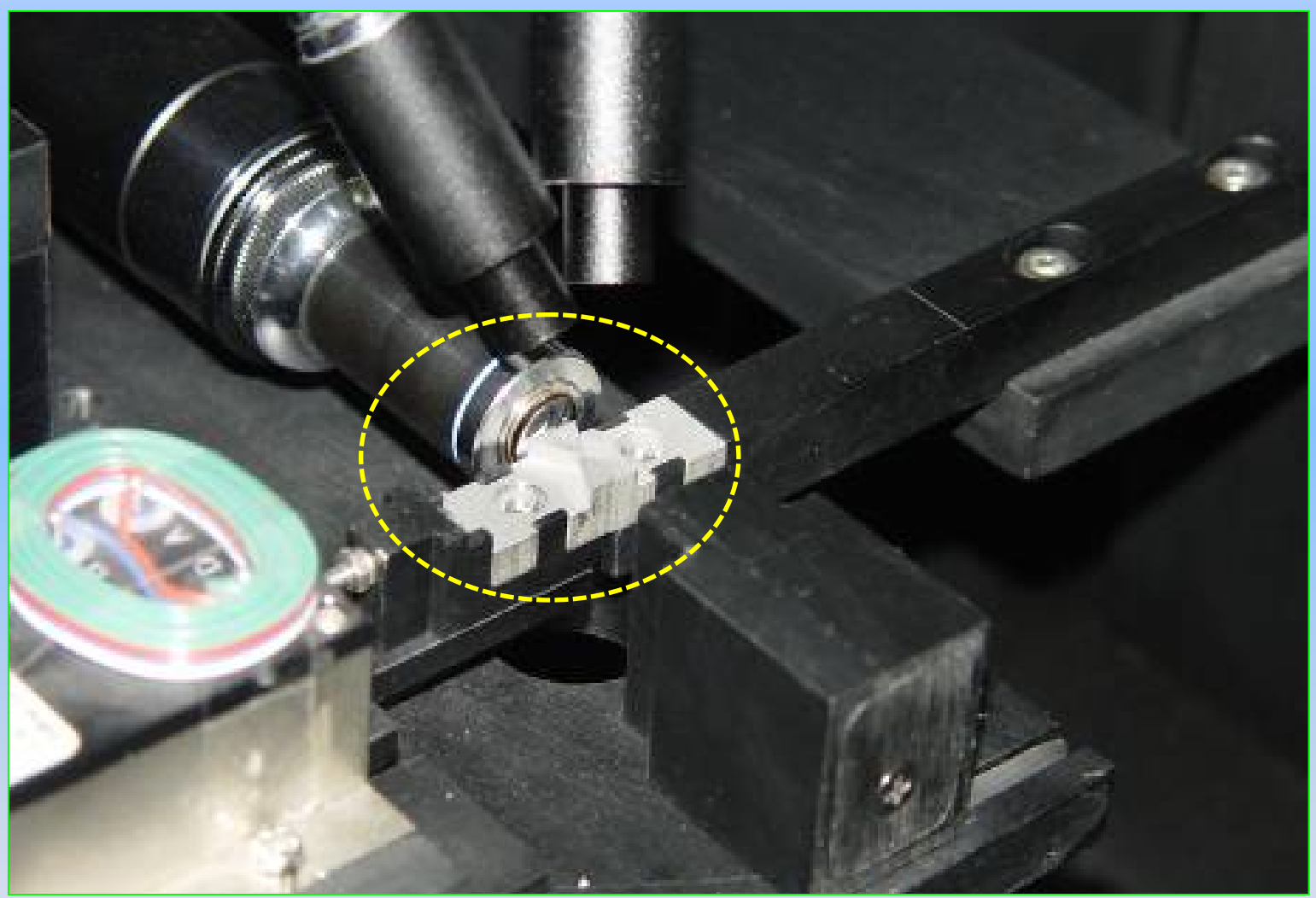
Custom-built microtester developed by Burgert et al, Max Plank, Germany

2. The R § D of fiber testing instrument

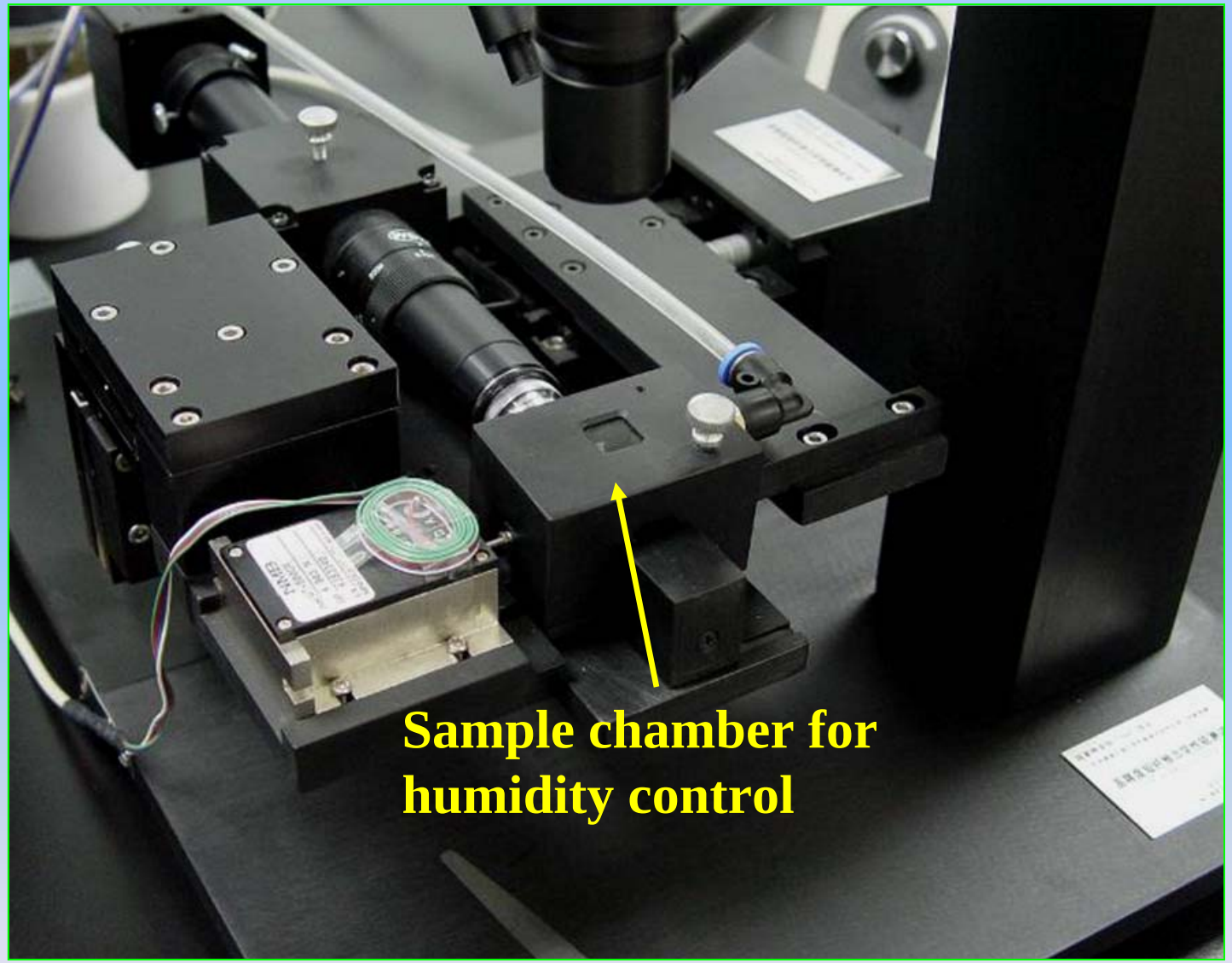
A overview of SF-Microtester I developed by ICBR



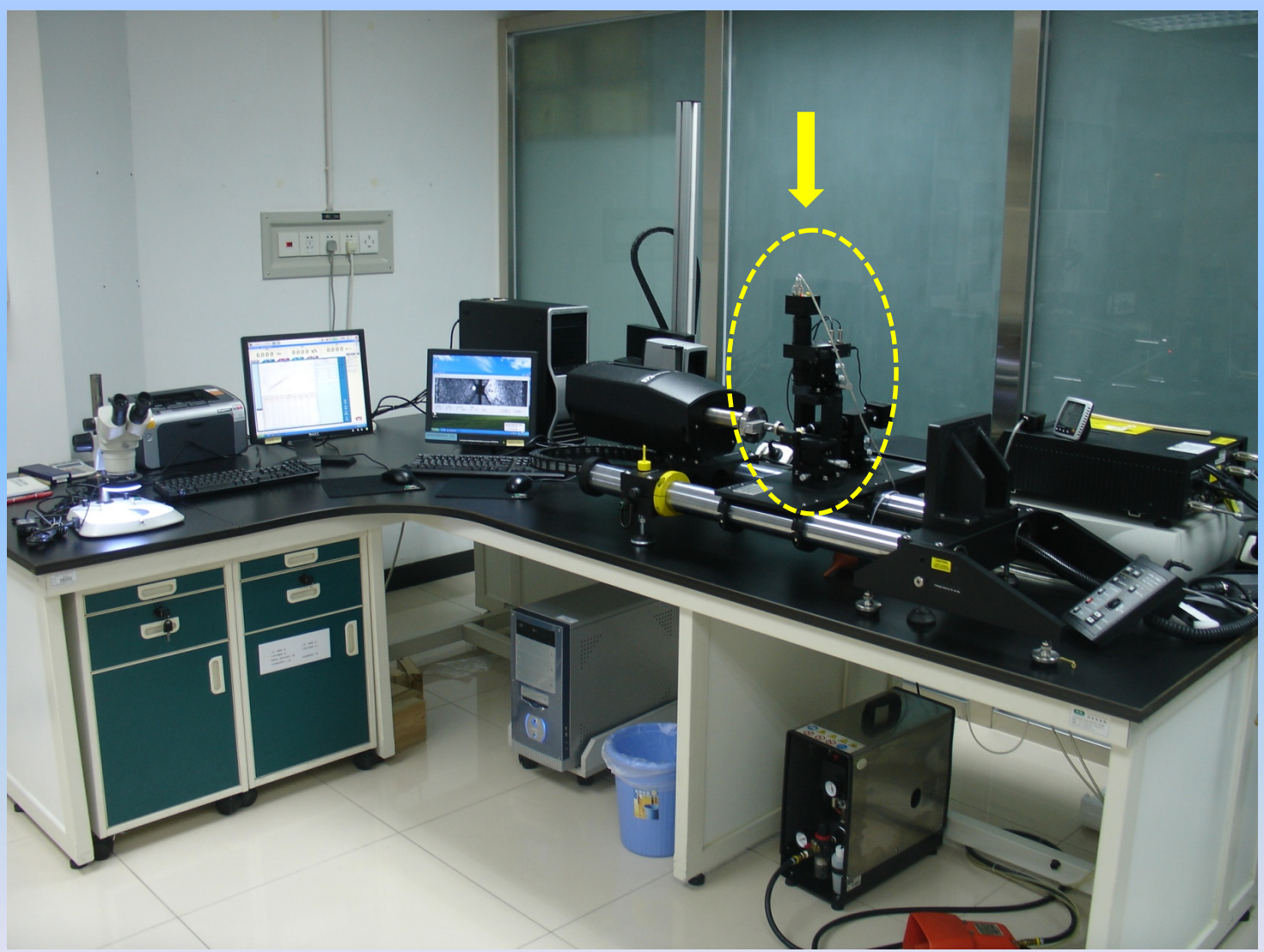
Main component parts of SF-Microtester I



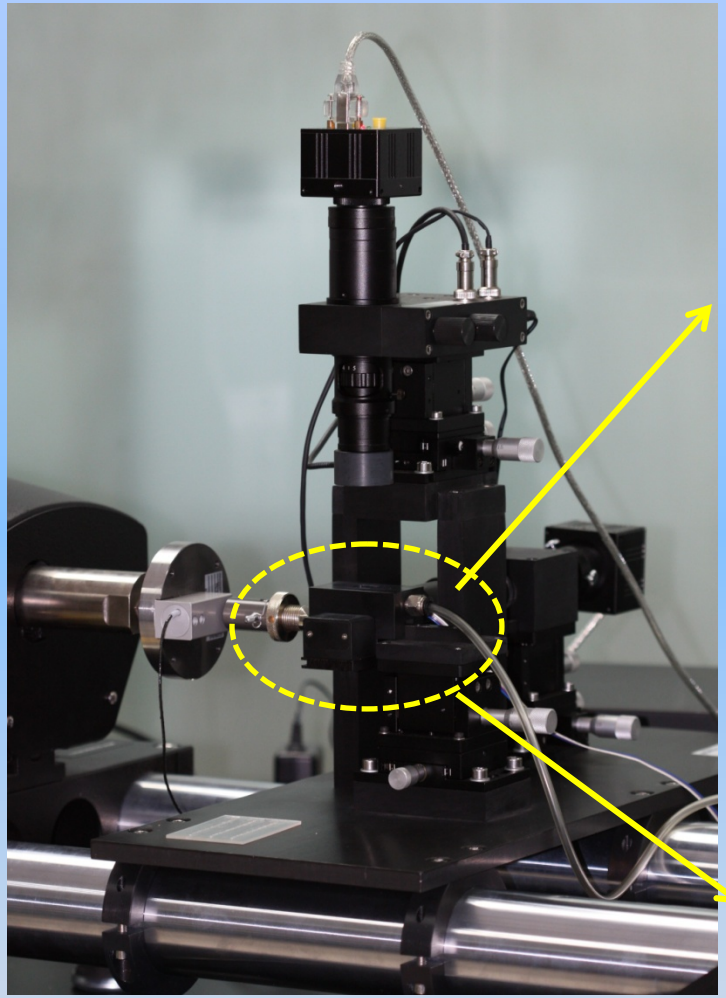
The patented special fiber grips fabricated with laser incision

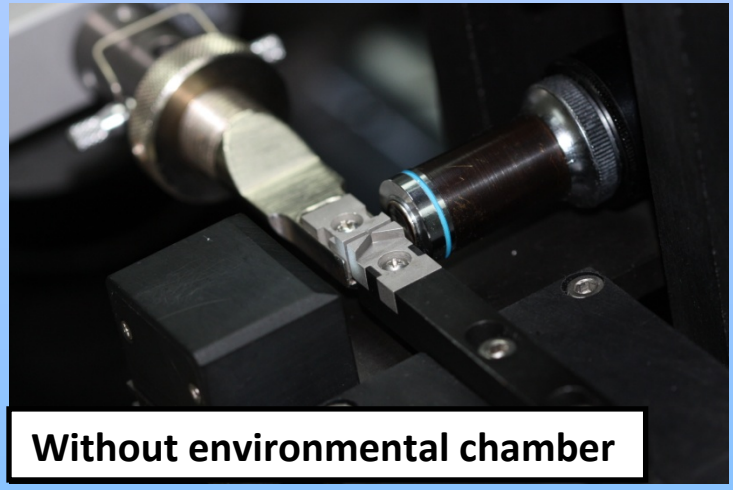


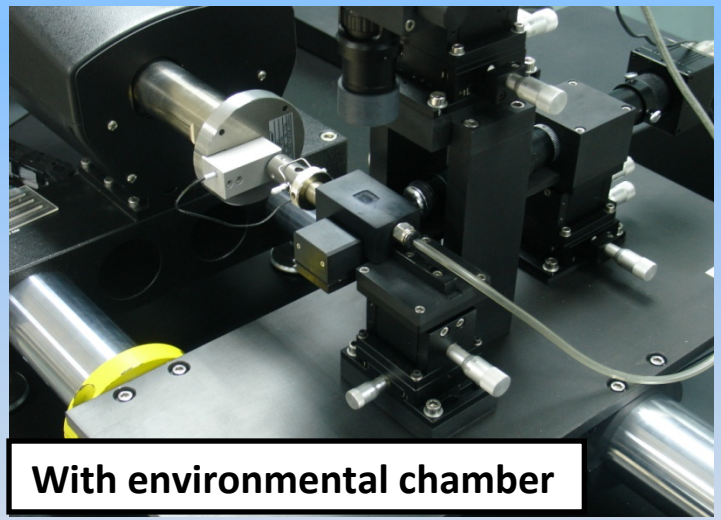
Range of RH control: 30%-95%



Fiber gripping system designed for specific commercial mechanical tester



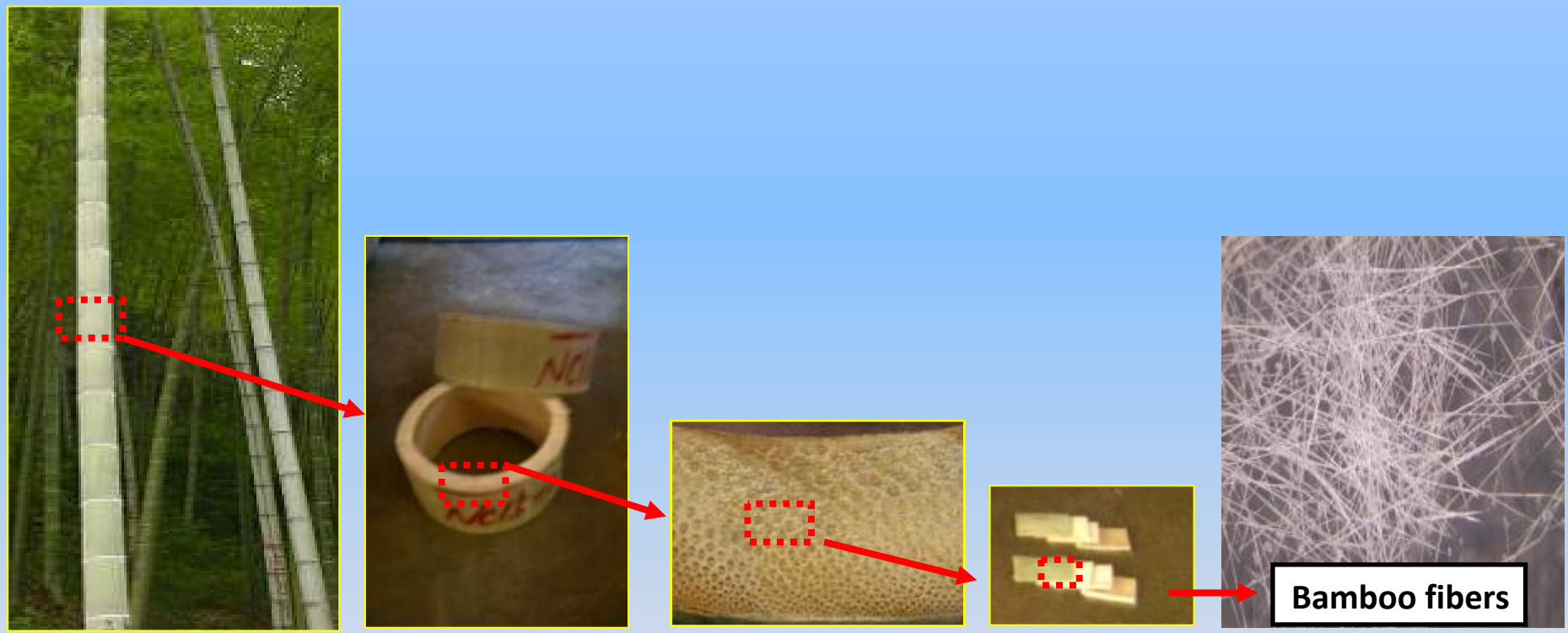




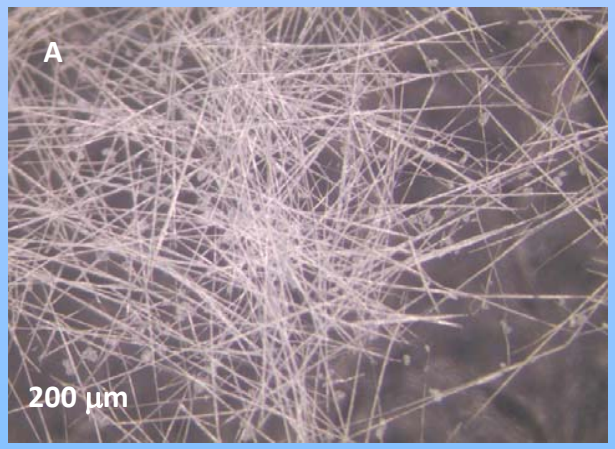
Fiber gripping system

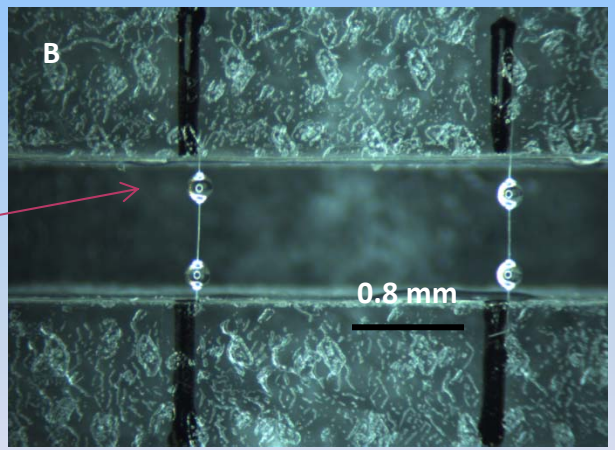
- reducing cost
- Data analysis is much more easier
- Much more options for loading control

3. Mechanical testing of single bamboo and wood fibers

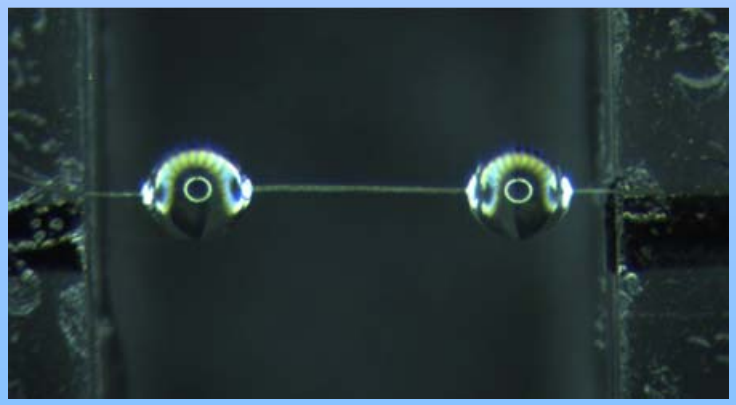


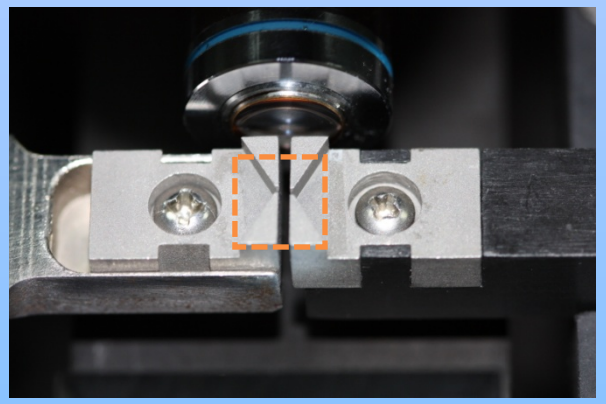
Bamboo fiber preparation

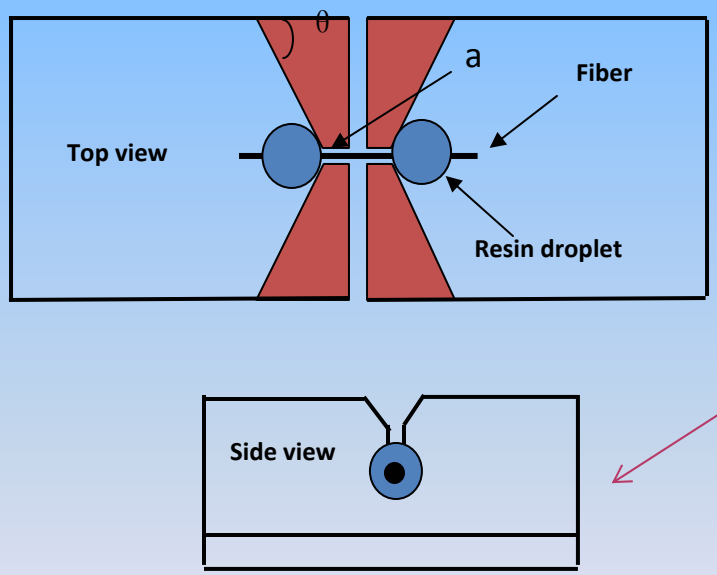


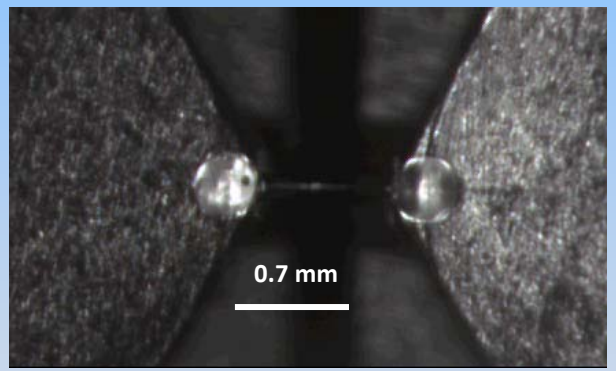


Micro resin droplets formed on fibers with a space about 1 mm

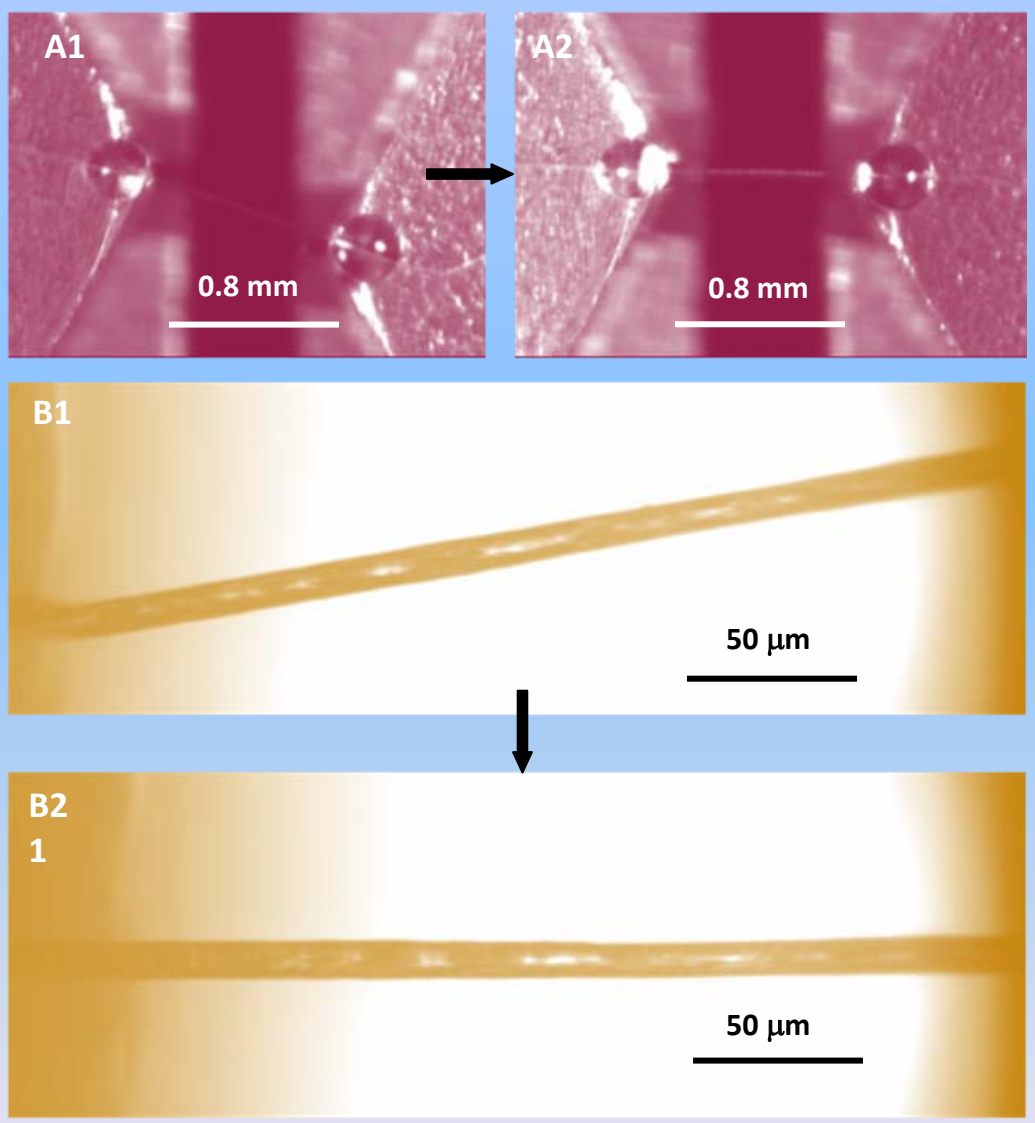




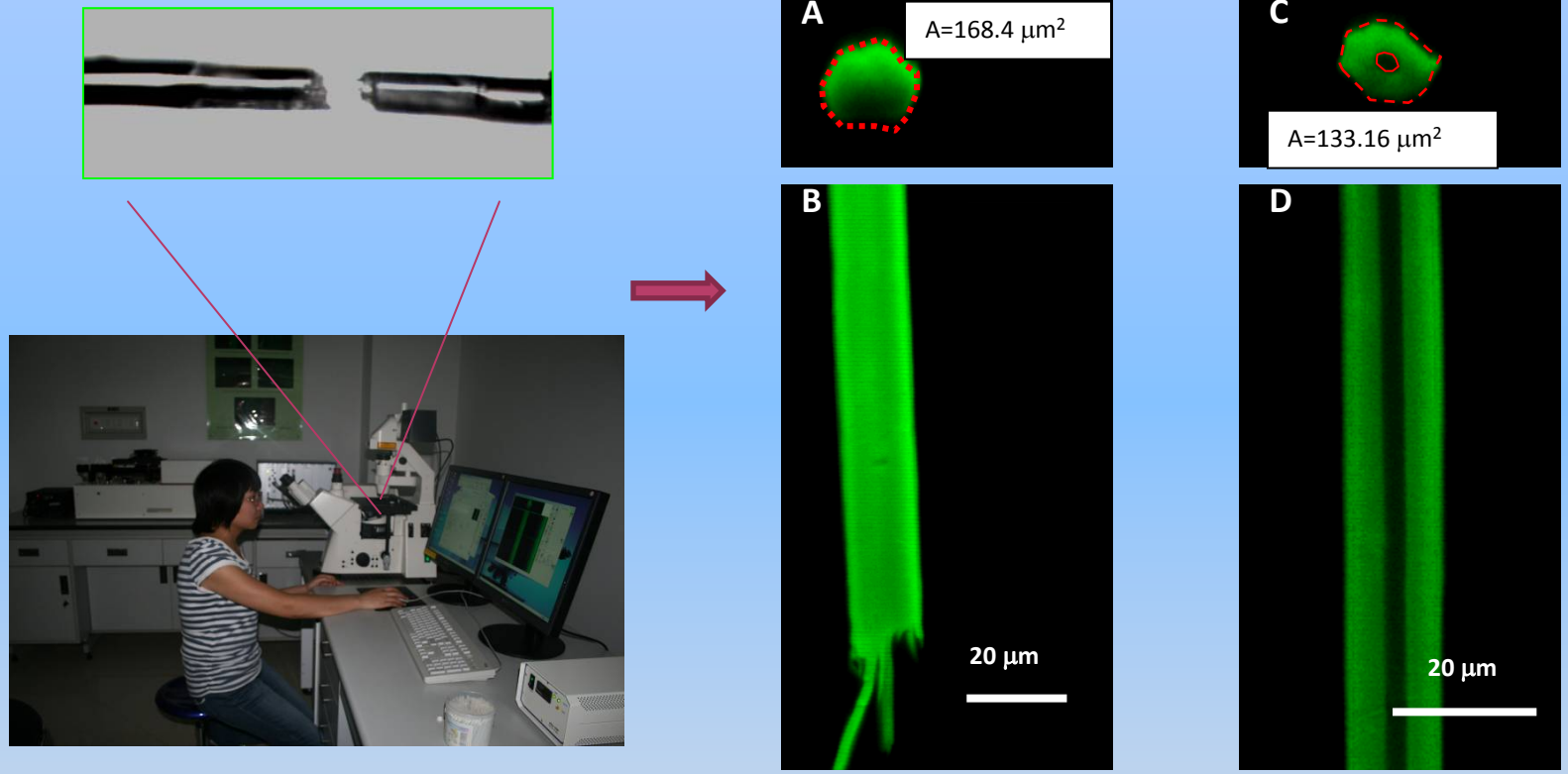




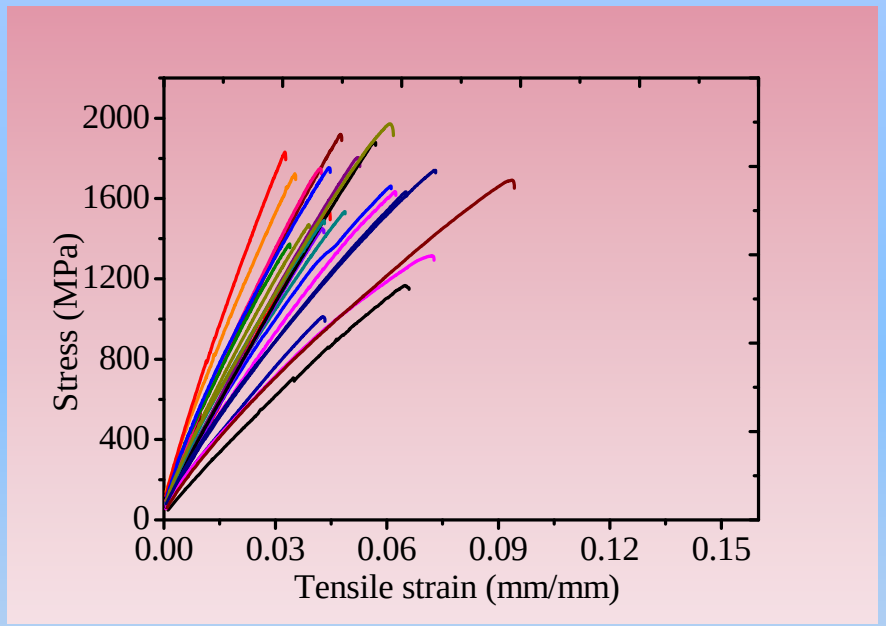
Fiber installation

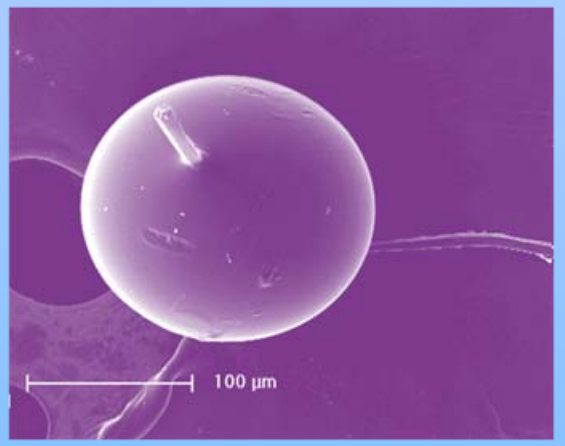


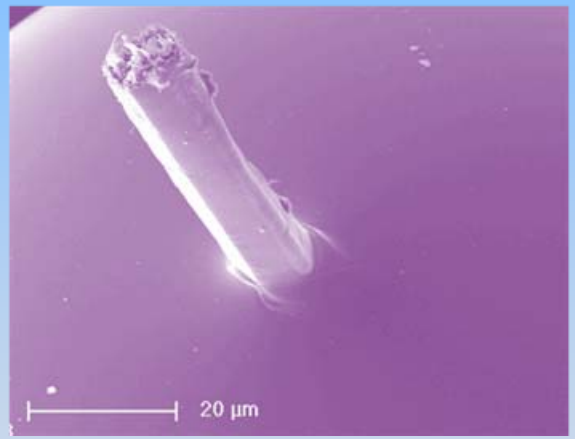
Micro-adjustment of fiber orientation before testing



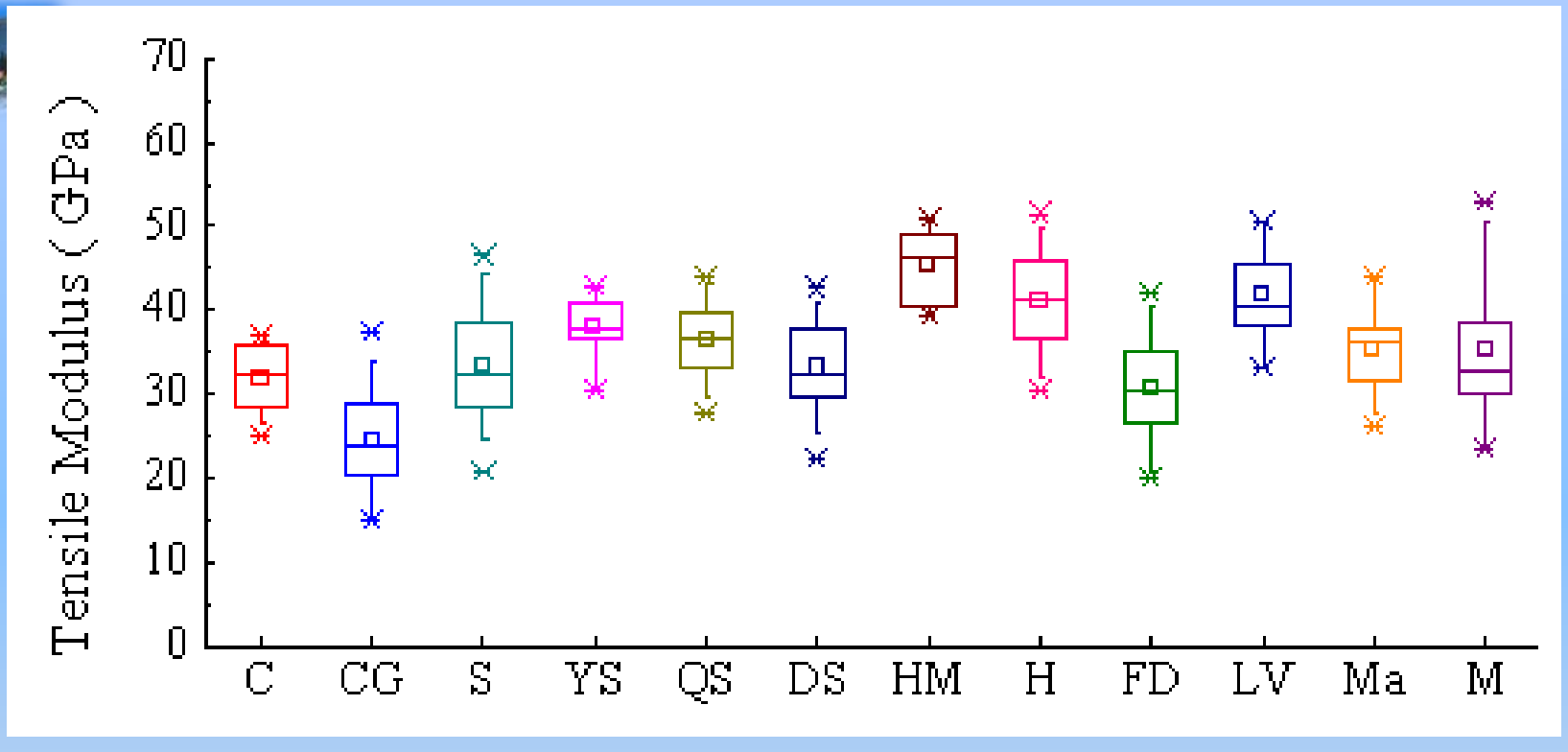
Using CLSM to measure the cell wall area of single broken bamboo fibers





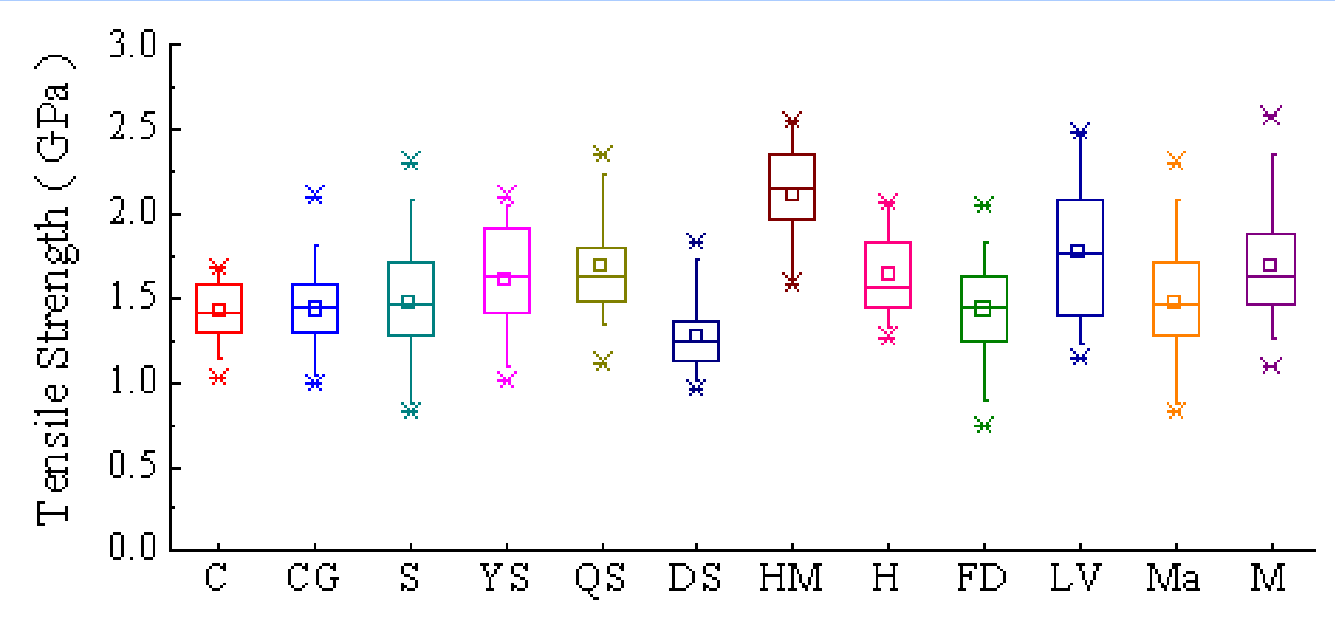


Strain-stress curves of single Moso bamboo fibers with ages from 1.5 to 4.5 years



The tensile elastic modulus of single bamboo fibers from 12 species

C: Neosinocalamus *affinis* (Rendle) Keng f. CG: *Bambusa pervariabilis* McClure
S: *Phyllostachys heteroclada* Oliver YS: *Bambusa multiplex* cv. 'Sliverstripe'
QS: *Bambusa eutuldoides* var. *viridi-vittata* (W.T.Lin) Chia
DS: *Dendrocalamopisis .vario-striata* (W.T.Lin) Keng f. HM: *Bambusa longispiculata* Gamble ex Brandis
H: *Bambusa albo-lingata* Chia FD: *Bambusa chungii* McClure
LV: *Dendrocalamopisis oldhami* (Munro) Keng f. Ma: *Dendrocalamus latiflorus* Munro
M: *Phyllostachys heterocycla* (Carr.)



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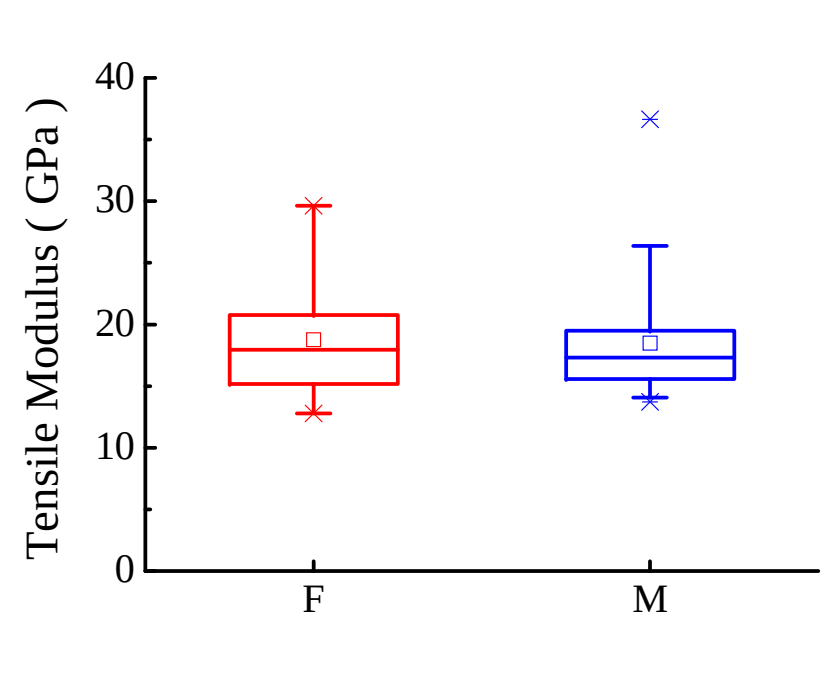
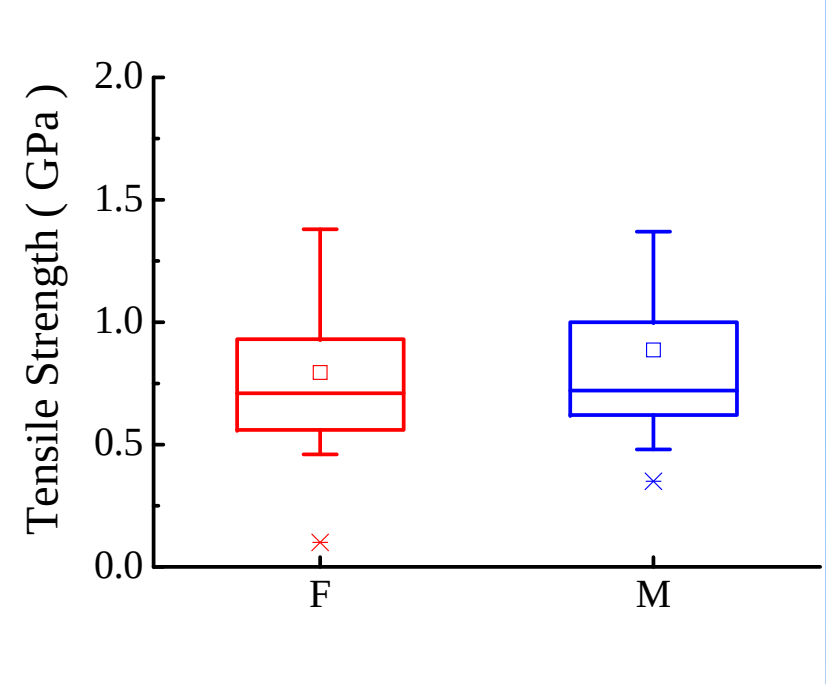
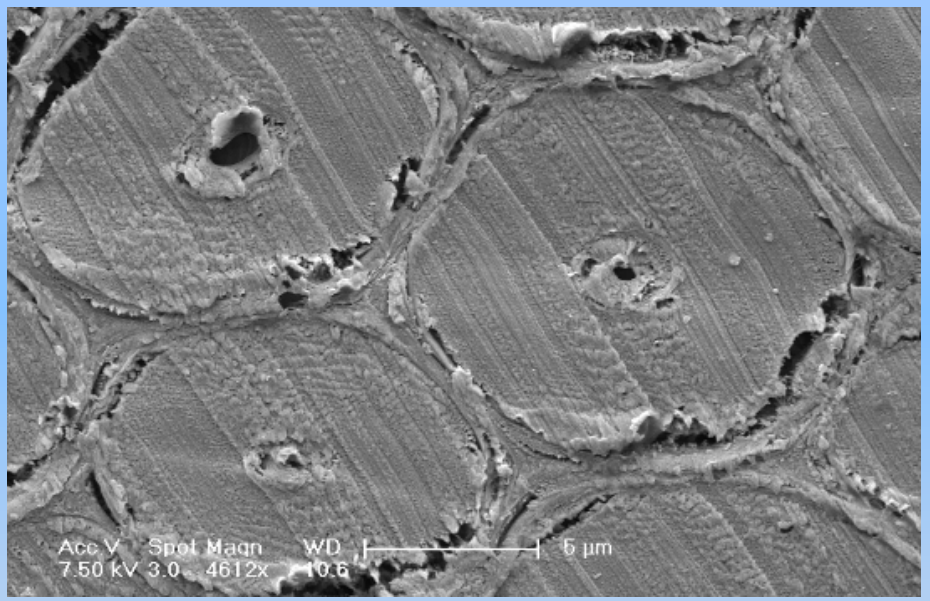


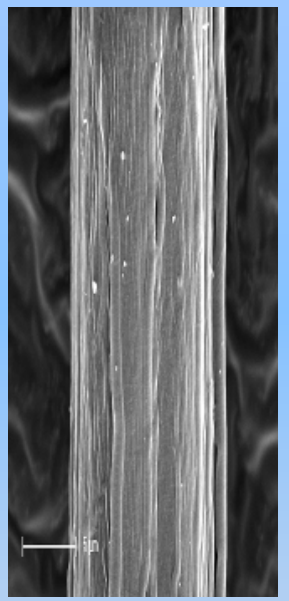


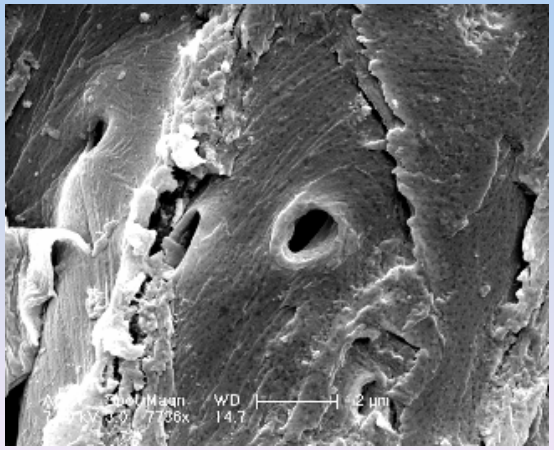
The tensile elastic modulus and strength of two kinds of softwood fibers

F：*Cunninghamia lanceolata*（Lamb.）Hook.
M：*Pinus massoniana*（Lamb.）

Why is mechanical performance of bamboo fibers much better than wood fibers?







- Small MFA, about 10 degree
- Pits are small (700 nm), distribution is scarce;
- high defects tolerance due to thick cell wall

Conclusions

- The average tensile modulus and strength of bamboo fibers are both significantly higher than wood fibers, which could be attributed to the microstructural characteristics of small microfibrillar angle (MFA) and scarcity of pits in bamboo fibers;
- Bamboo fibers are promising reinforcements for the production of high-performance structural fiber/polymer composites;
- The instruments we developed provide valuable approach for the study of plant short fibers and its composites.

Acknowledgements

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- National Natural and Science Foundation of China (PI: Fei Benhua, Yu Yan)
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Thank you for your attentions !