Investigation of Structural and Mechanical Properties Of 3D Printed Bamboo-like Microstructures

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Overall View

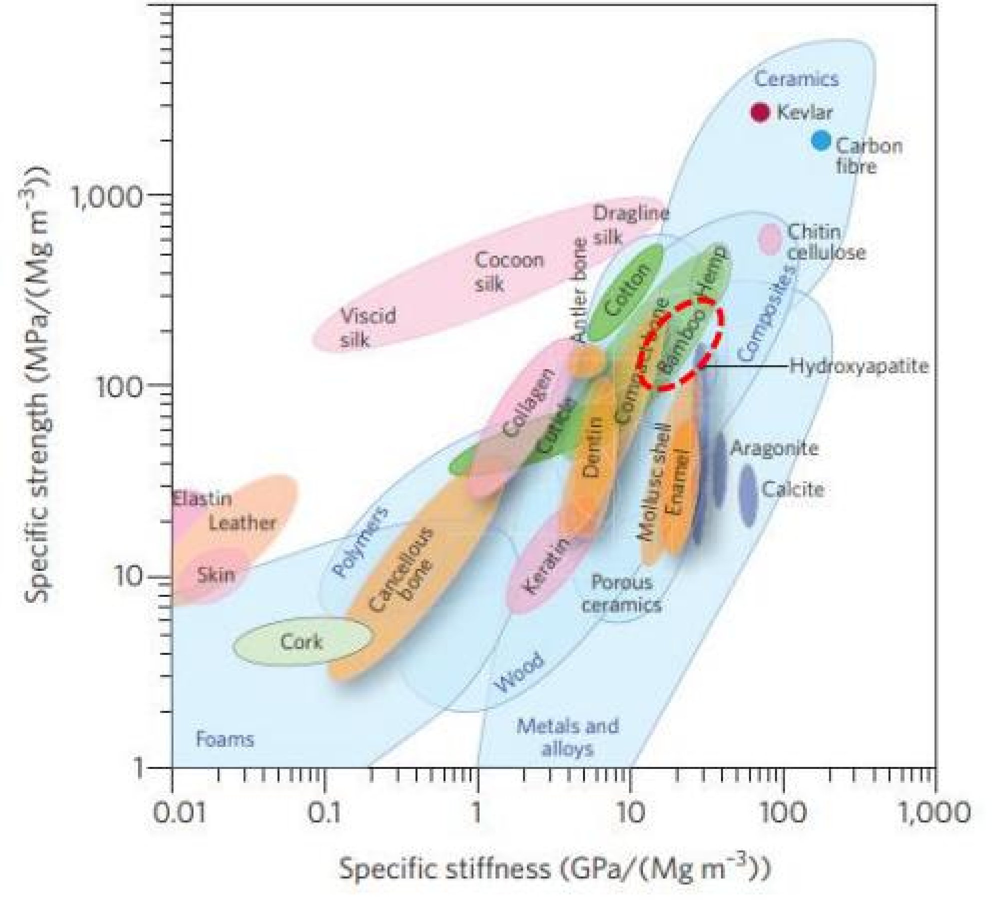
- Introduction of bamboo
- Vascular bundles of bamboo
- 3D printed continuous fibers
- Bio-inspired design through 3D printing
- Structural and mechanical characterization

Introduction of bamboo

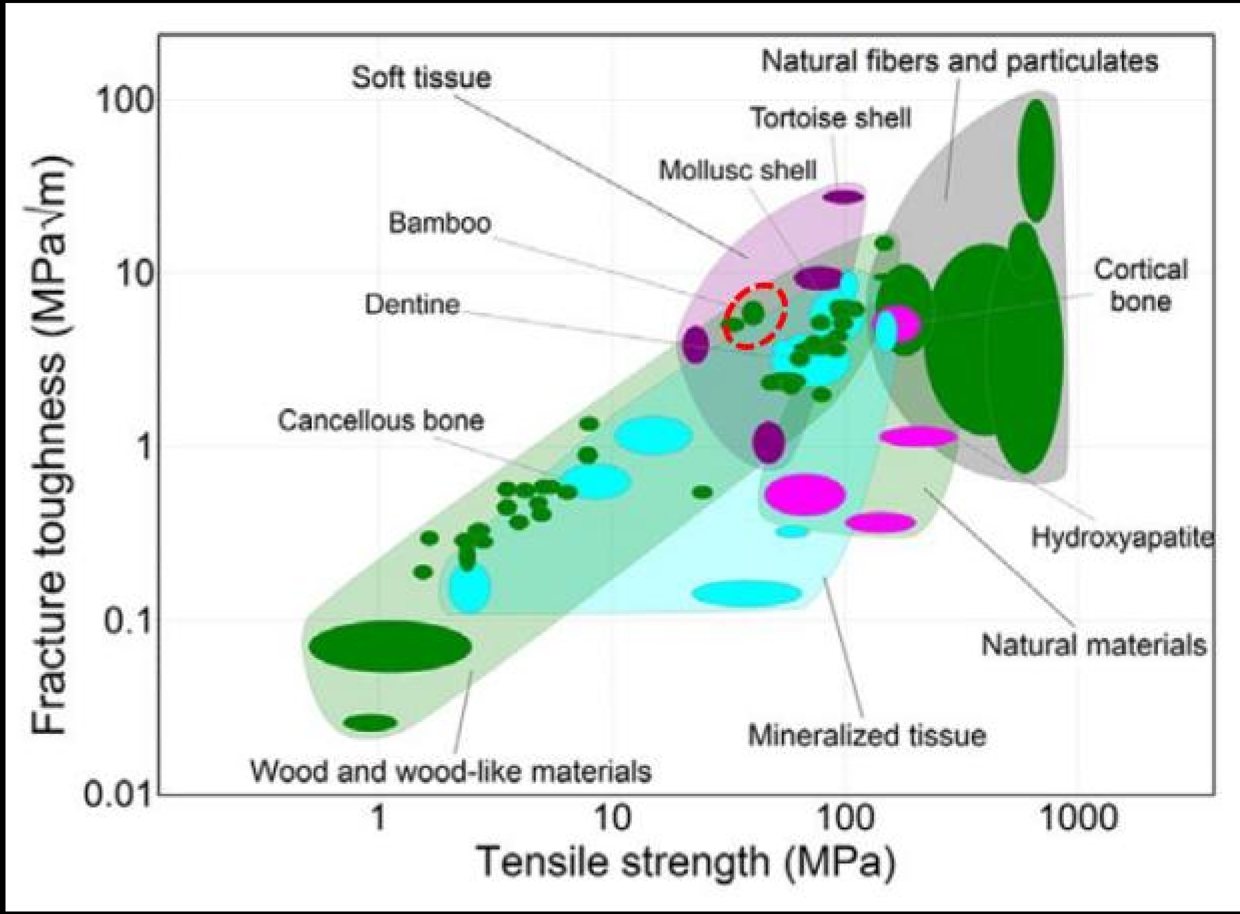
- Giant grass with wood characteristics
- 75 genera, over 1200 species
- Very fast growth rate
- Without secondary growth

Giant bamboo forest [3]

Inspiration from Nature

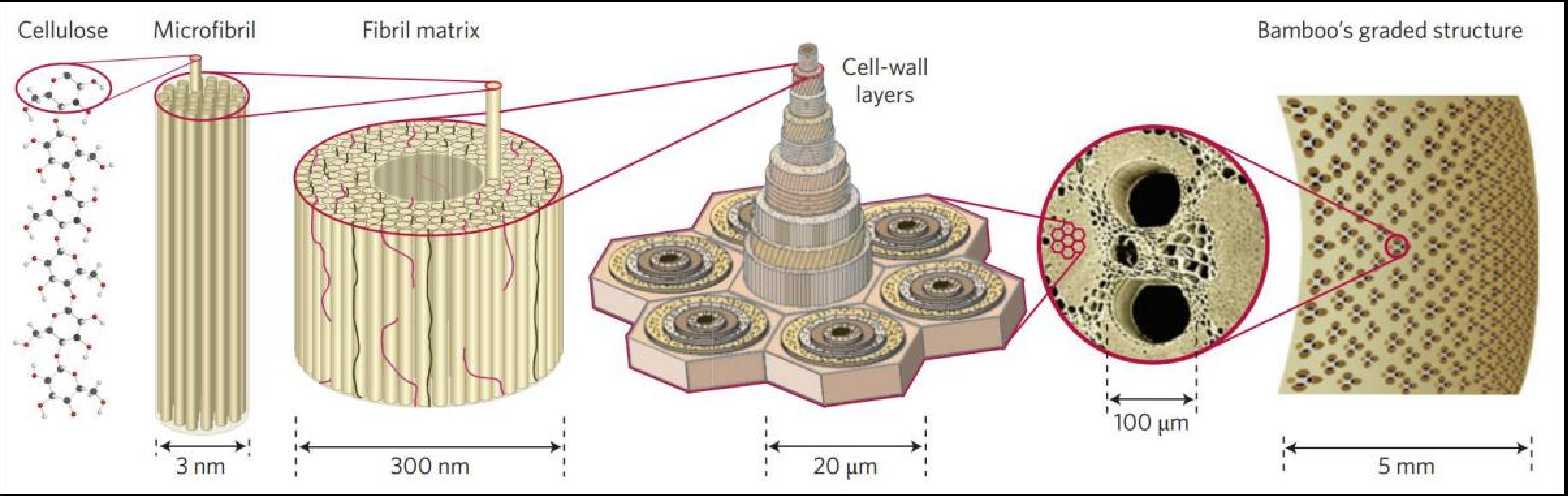


Specific strength and stiffness for both natural and synthetic materials [1]



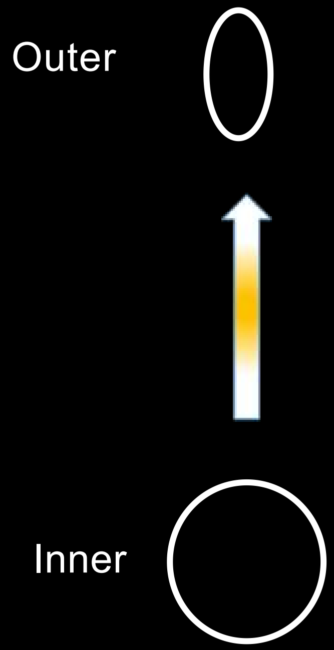
Relationship of tensile strength and fracture toughness for engineering materials [2]

Vascular Bundles of Bamboo

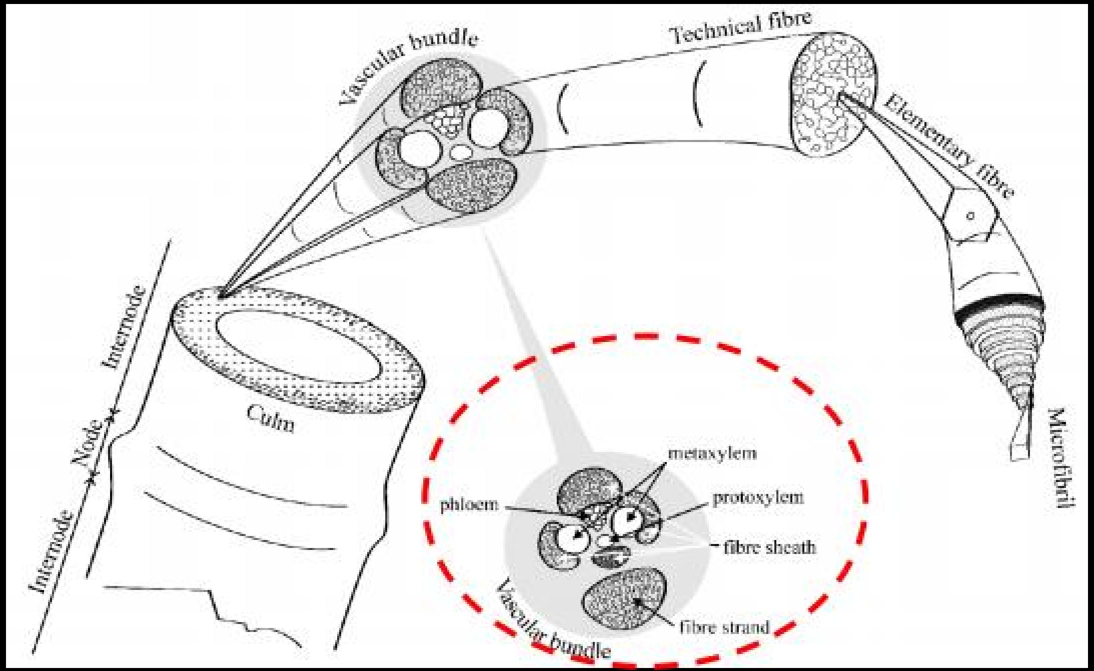


Hierachical microstructure of bamboo [4]

Mechanical properties of bamboo



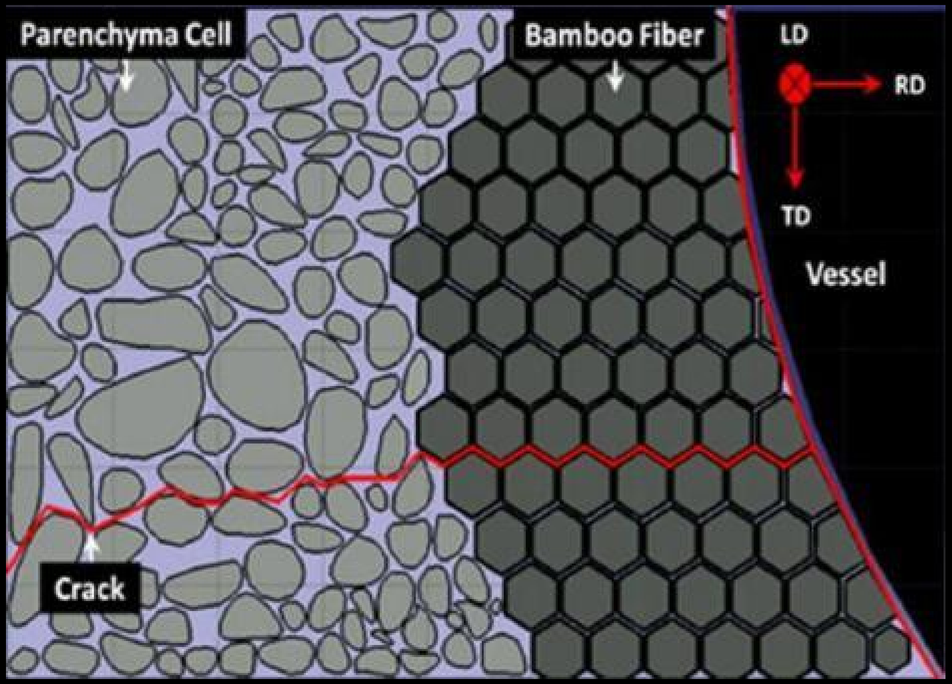
Vascular bundle distribution [5]



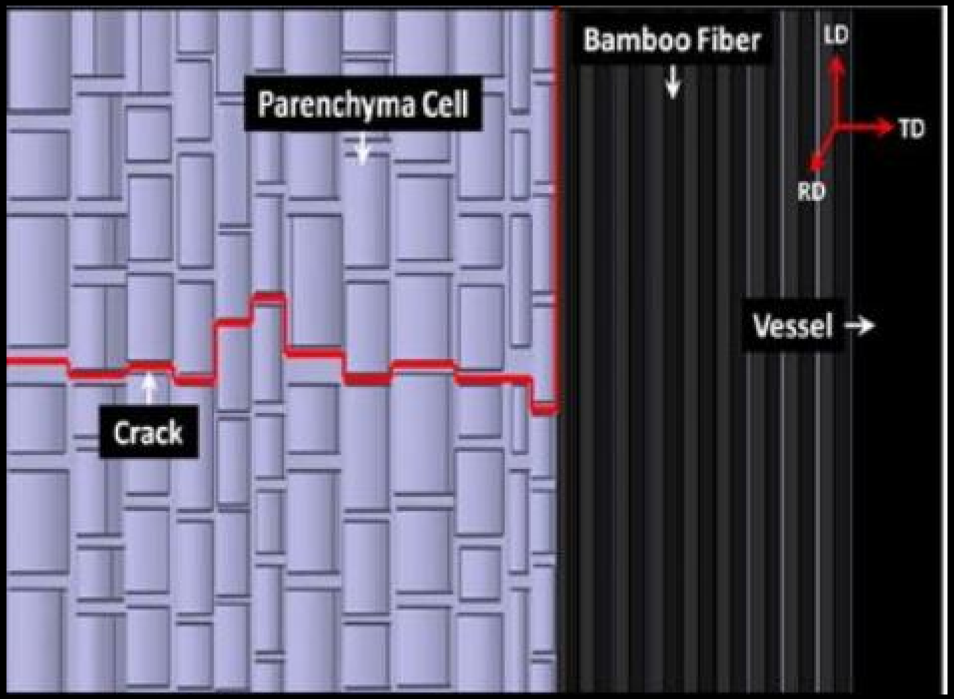
Structural display of VB [6]

- **Number:** Gradient increased
- **Shape:** Circular to oval
- **Size:** 2.5 times ratio relationship

Bamboo’s Failure



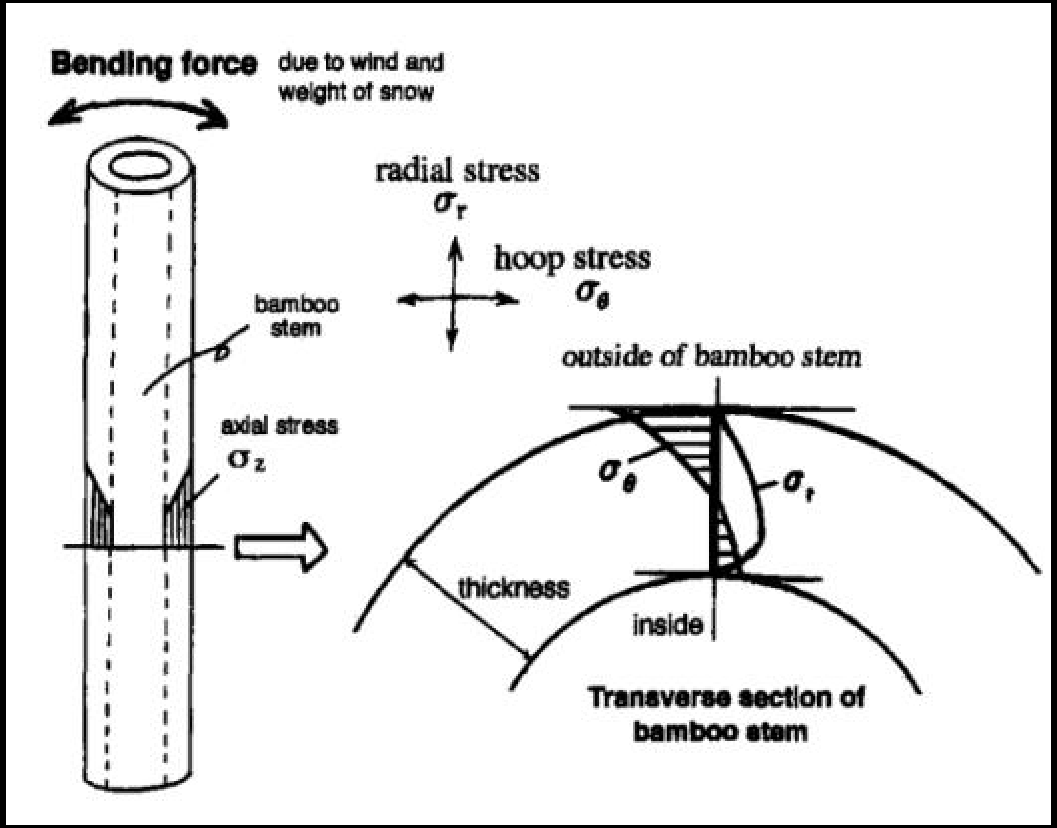
Microhardness indentation-induced crack growth transverse view [7]

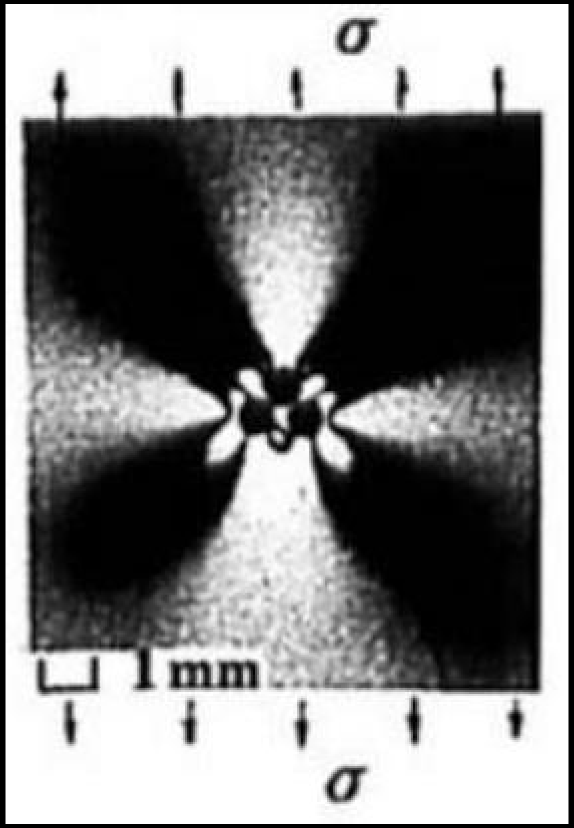


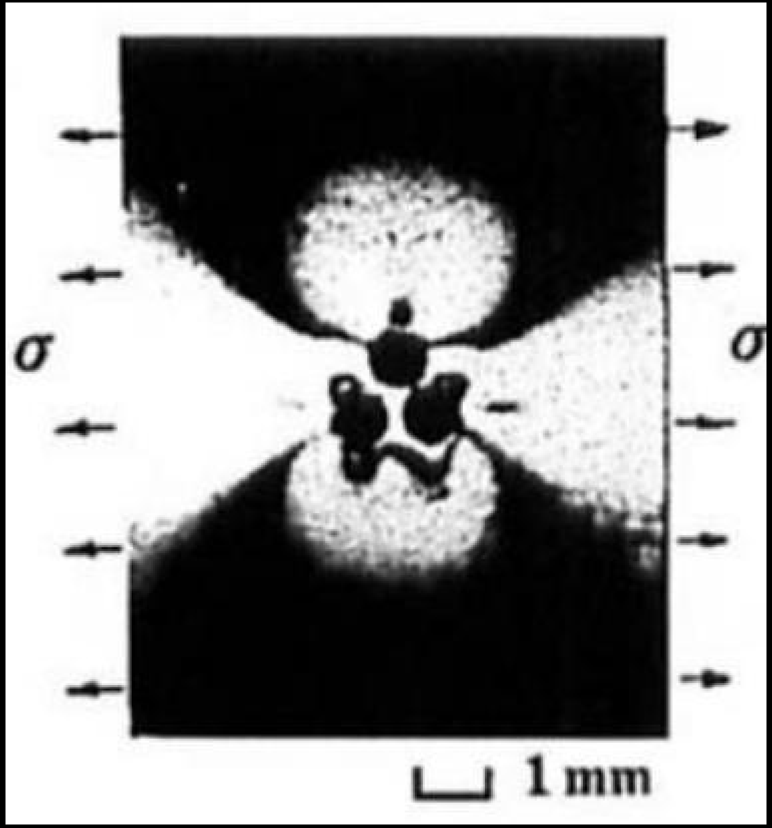
Tensile failure induced crack growth longitudinal view [7]

- Crack propagate in a tortuous way through vascular bundles
- The interfacial fractures are responsible for the remarkable fracture toughness

Mechanical Sensing Capability



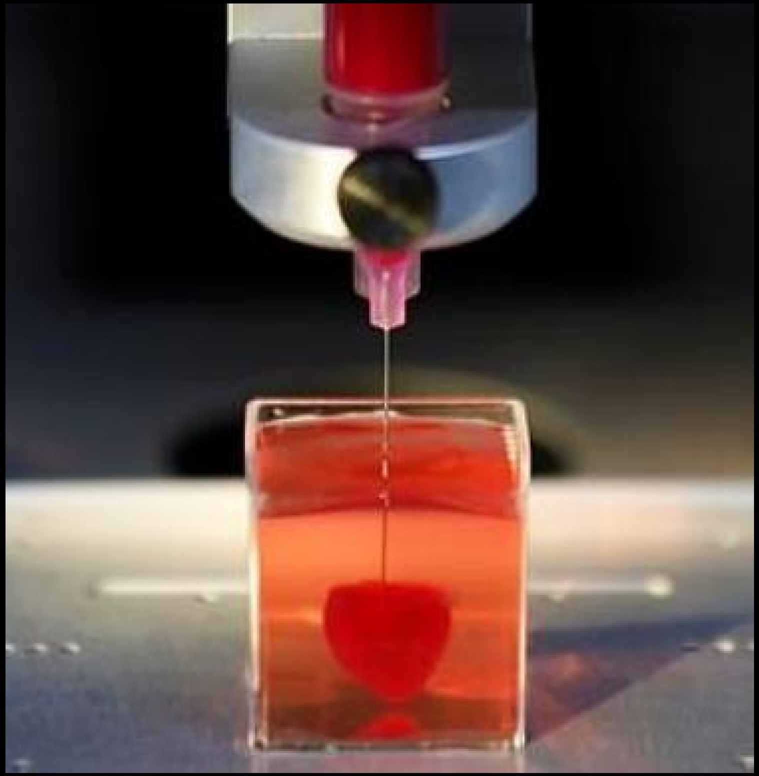




Stress distributions induced in bamboo structure due to bending moment [8]

Photoelastic test for radial and hoop direction [8]

Wide range of application for 3D printing



Innovations in Healthcare [9]

Auto-mobile [10]

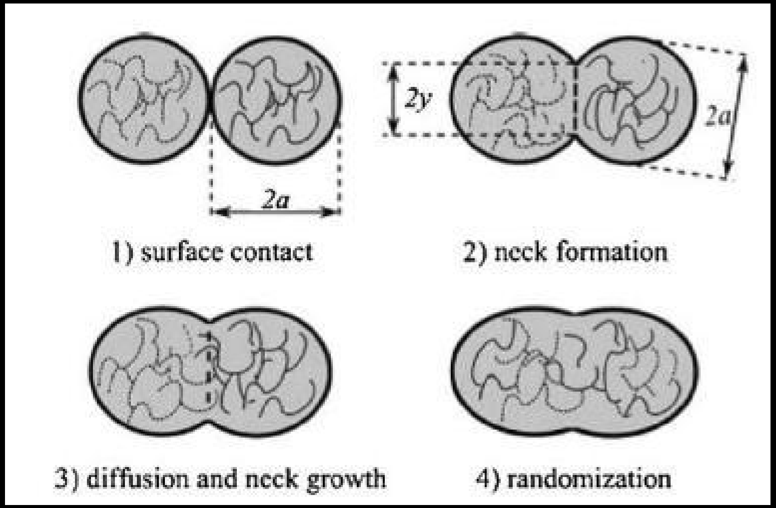
Fashion&Design [11]

Construction [12]

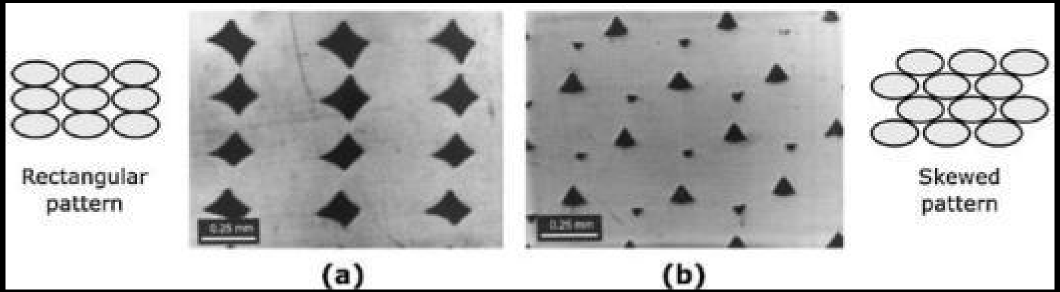
Micro → Macro

Common methods for 3D printing: FFF, SLA, SLM, SLS

Main Challenge in FDM 3D printing



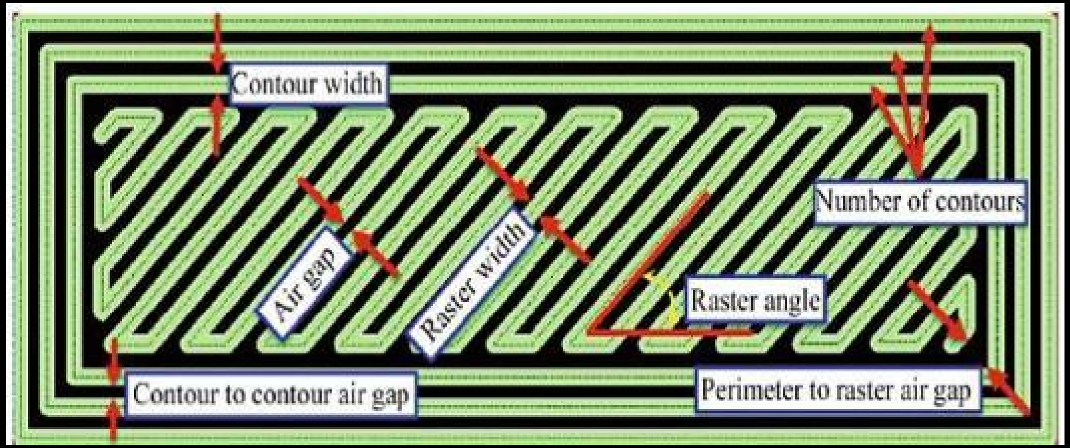
Polymer sintering process [16]



Micrographs and schematics of two different meso-structures, a) rectangular and b) skewed, showing typical triangular void formation [13]

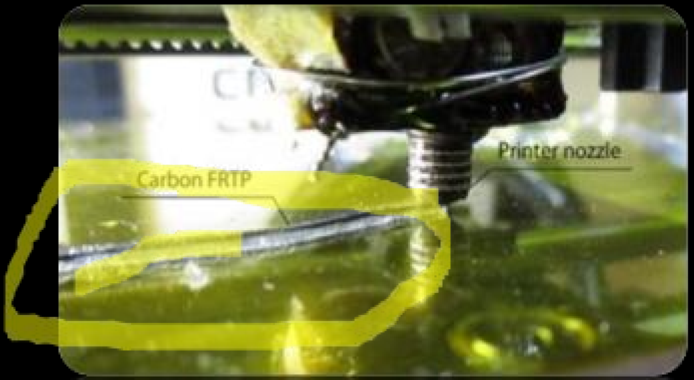
Main influential factors :

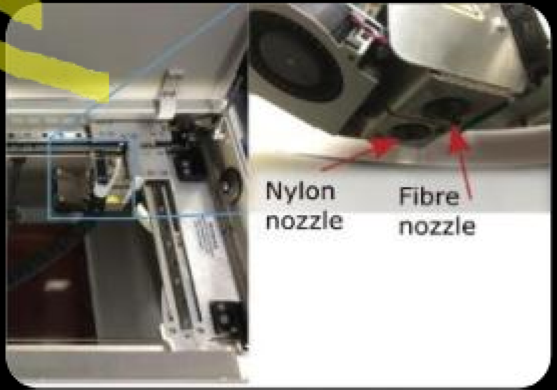
- Raster angle
- Layer thickness
- Filament feed rate
- Temperature



FDM tool path parameters [14]

3D Printing Composite

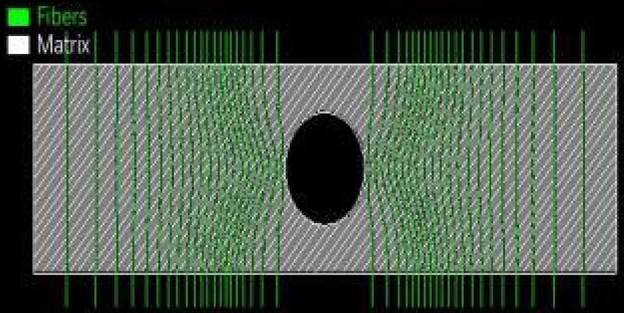




- Almost eliminated material waste
- Mold required for AFP
- Various methods to print continuous fibers

https://www.nonplanar.xyz/
https://www.youtube.com/watch?v=gmePlcU0TRw&t=209s
Matsuzaki, Ryosuke, Scientific reports (2016)
http://www.automateddynamics.com/about-us
Caminero M A, Polymer Testing, 2018, 68: 415-423.

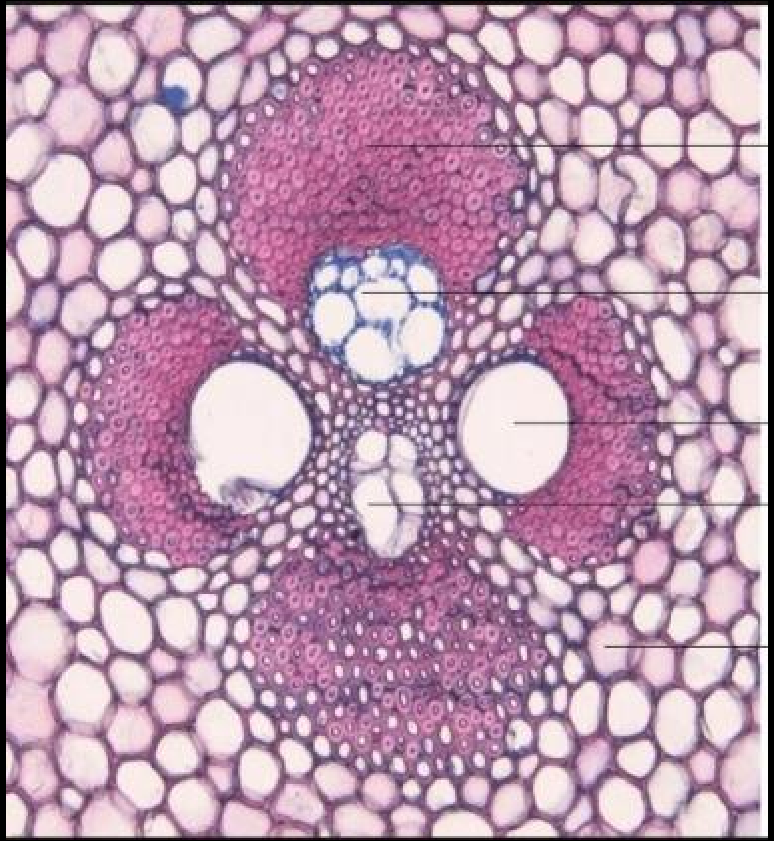
Limitations and Findings



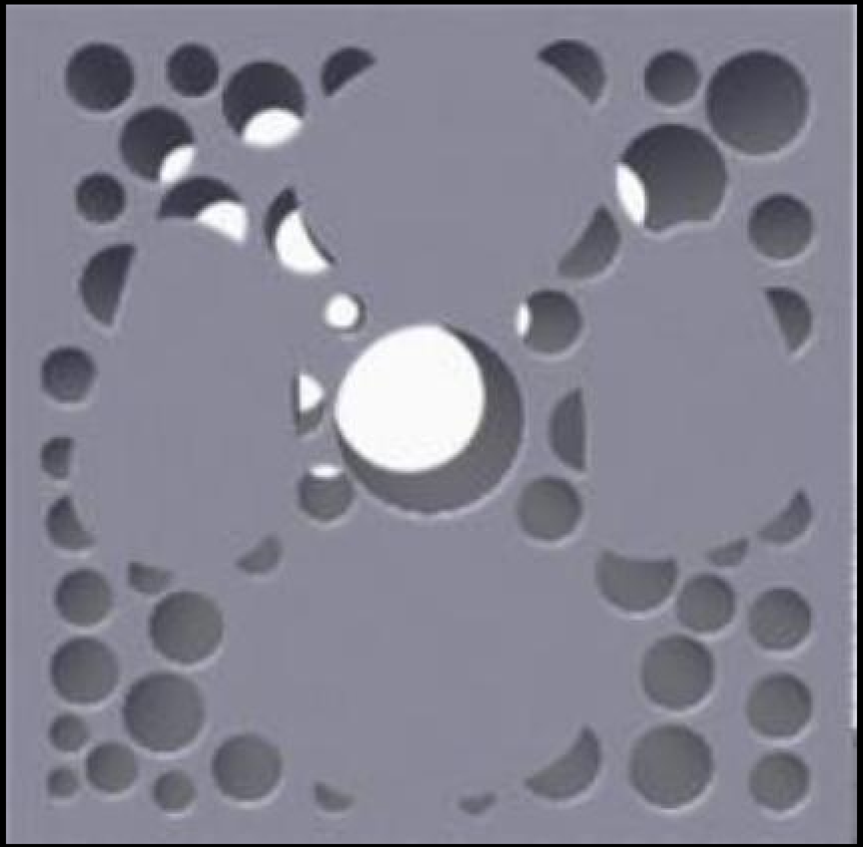
- There are different ways of printing continuous fibers, but it has advantages and disadvantages
- It would be promising if more efforts can be paid for improving the existing slicing software

https://markforged.com/
https://anisoprint.com/

Bio-inspired design



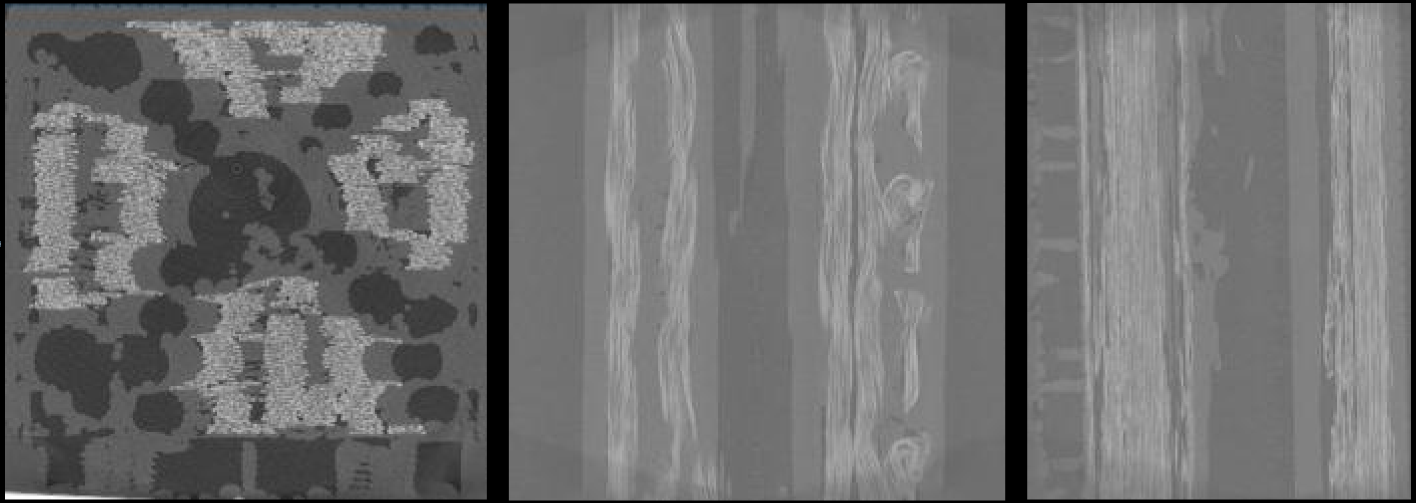
Simplification



Typical vascular bundle of bamboo [16]

Screen shot model from eiger slicing software

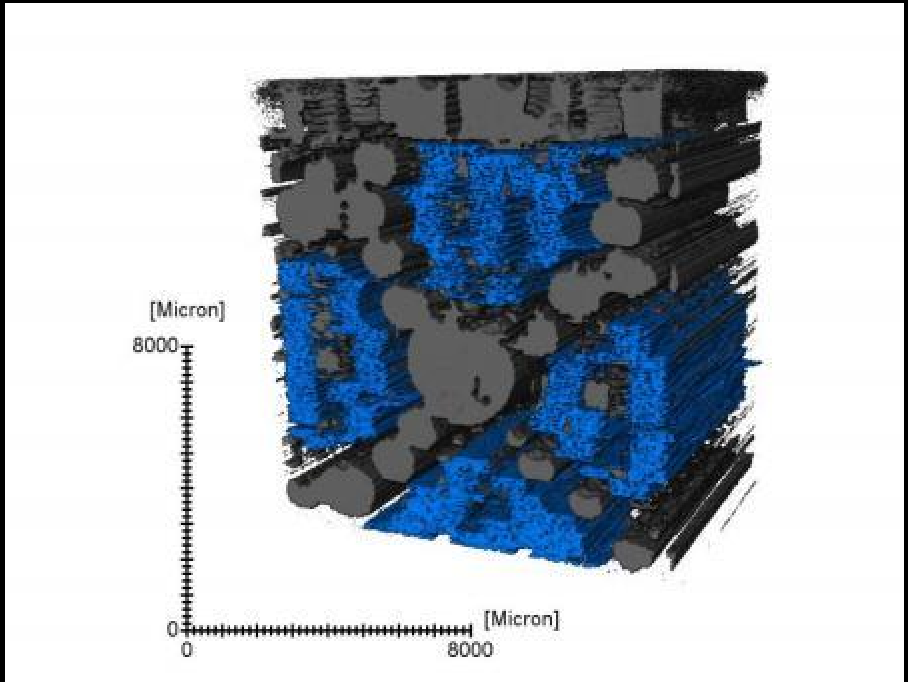
Structural characterization

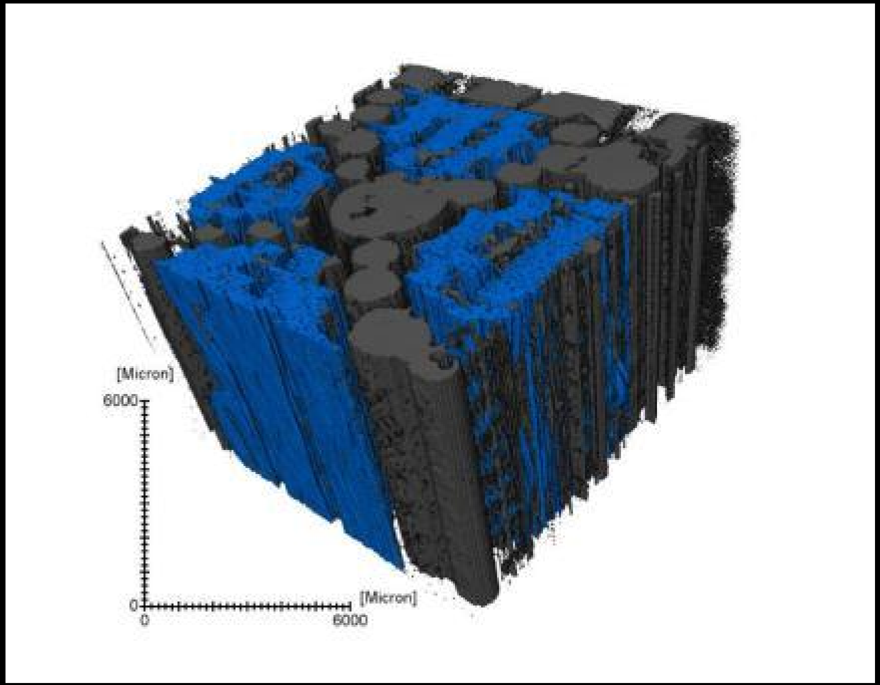


Transverse and longitudinal view of X-ray

- Designed volume fraction
  - V(Glass): 21.16%
  - V(Pores): 12.83%
- Fiber direction : 0 °

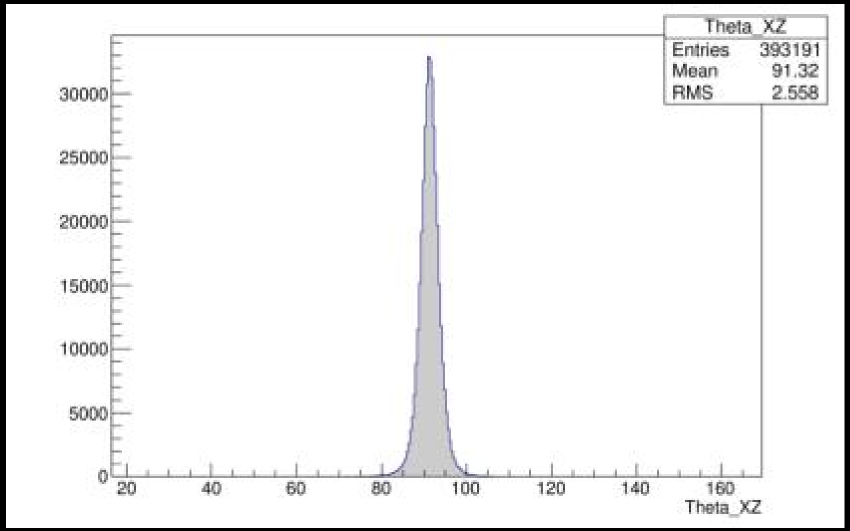
Structural Visualization

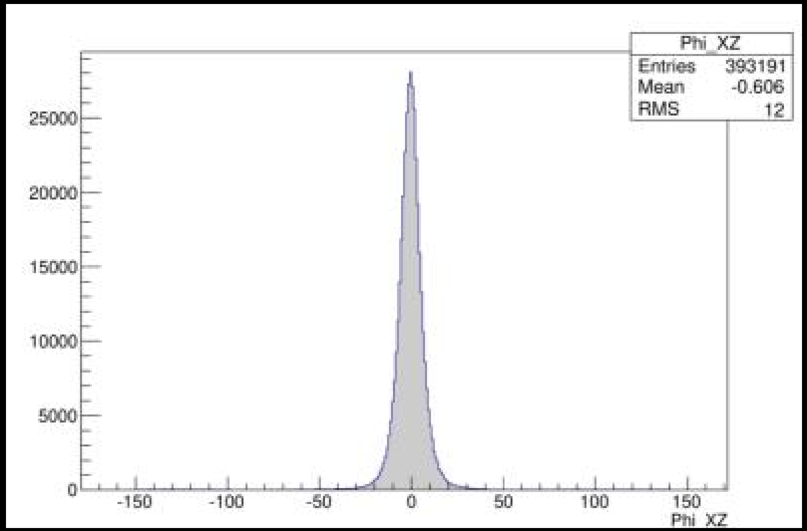


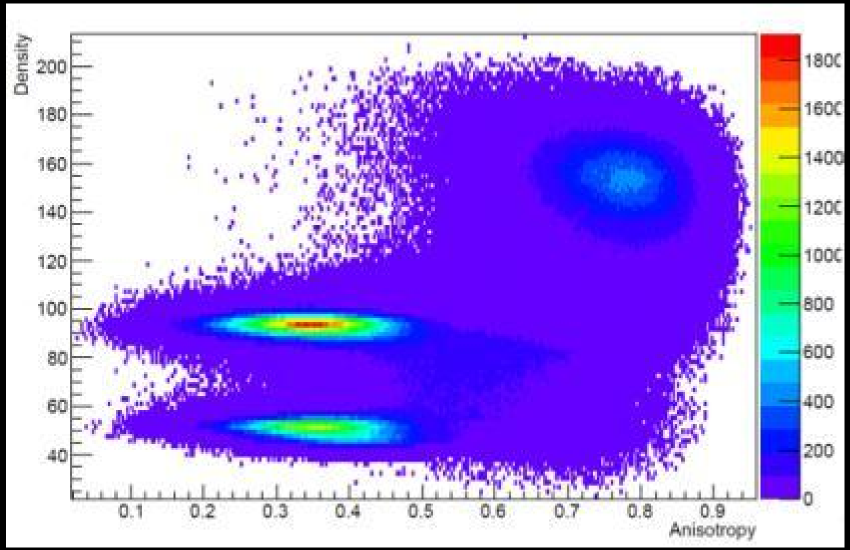


- Voids inside fiber bundles
- Fiber misalignment found
- Voids found in cutting position during printing process

Structural Components Analysis







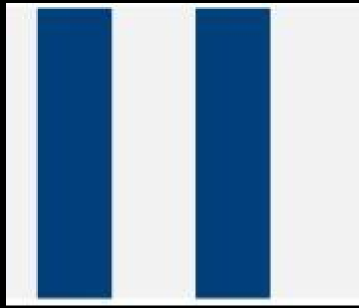
VoxTex from KU Leuven

- Volume Fraction
  - V (Glass): 20.07%
  - V (Pores): 28.42%
- Fiber Misalignment
  - In plane: 2.6 °
  - Out of plane: 12 °

Impact Resistance Result

Layout 1

Layout 2

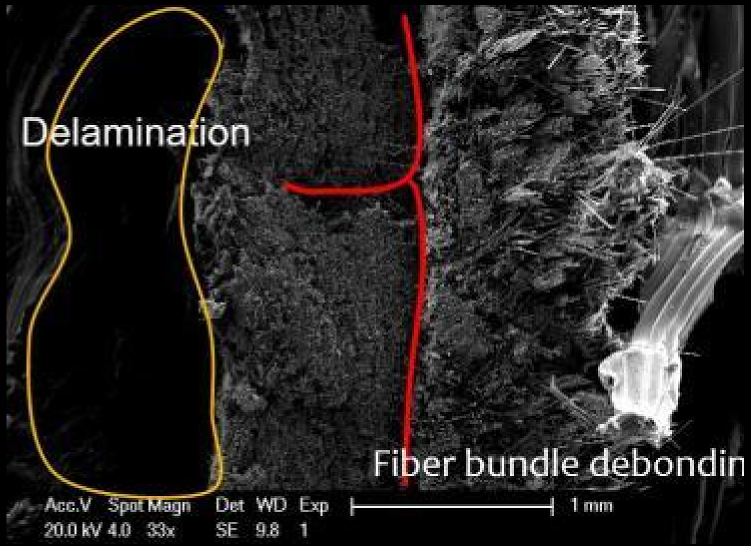


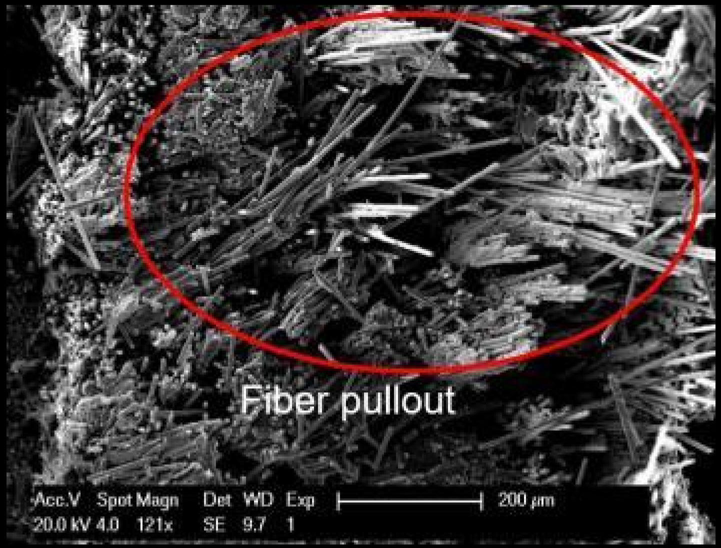
Layout 3

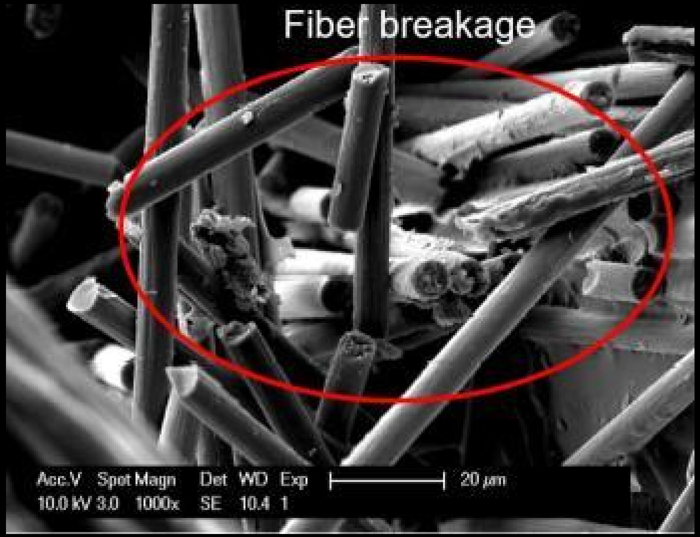
Category	Pure Nylon	Layout1 Vf = 25%	layout2 Vf = 25%	layout3 Vf = 25%
Impact strength (kJ/m²)	5.9	75.6	27.9	73.1
Weight (g)	7.97	13.01	13.05	10.55

- Highly anisotropic for 3D printed material
- Fiber bundle shape has influence on impact resistance of 3D printed material

Impact resistance result

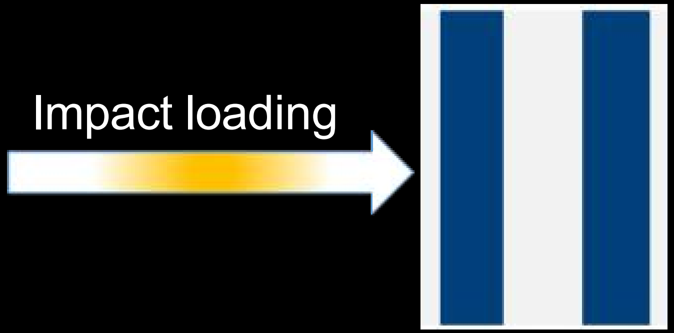




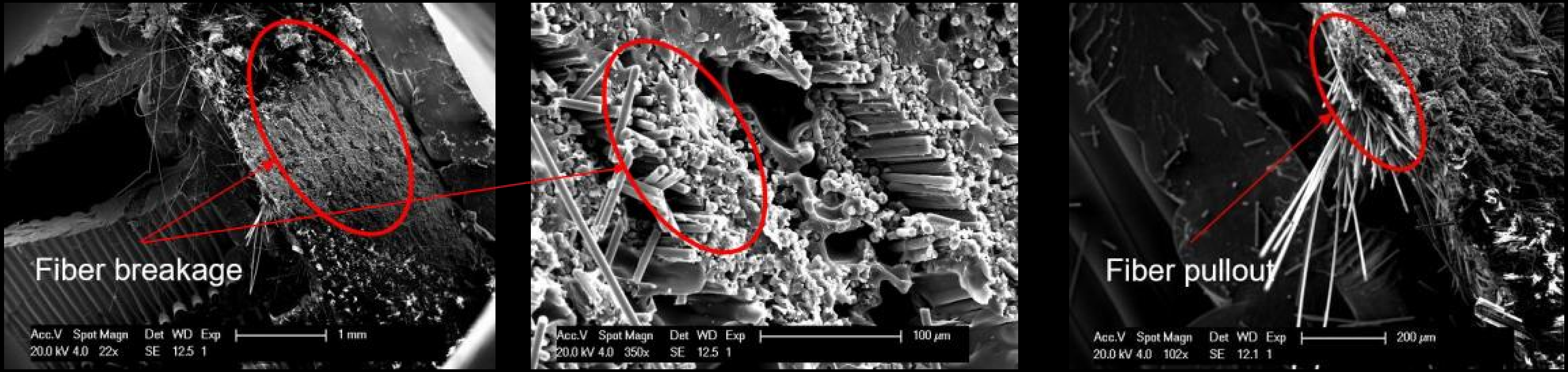


Energy Absorption Mechanism:

- Fiber breakage
- Fiber pull-out
- Delamination
- Fiber bundle debonding



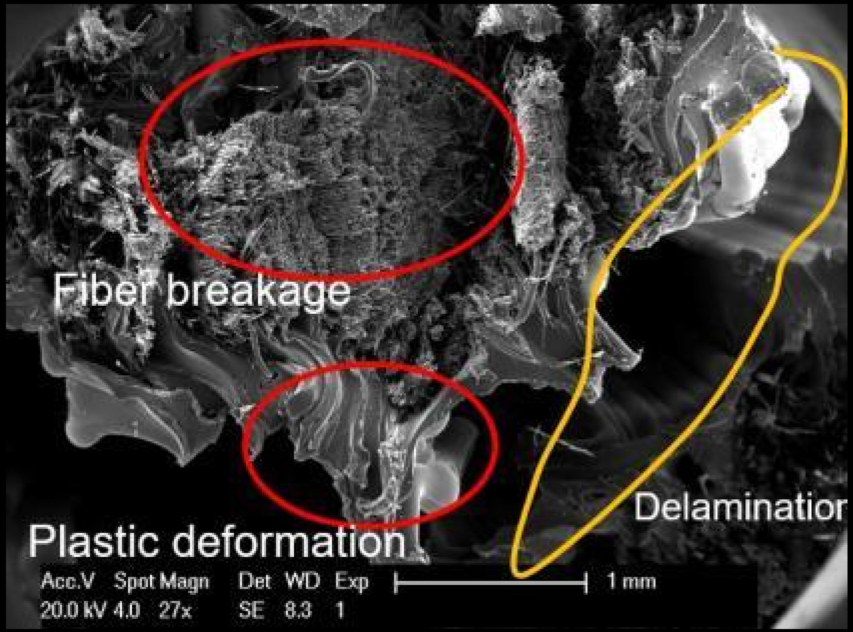
Impact resistance result

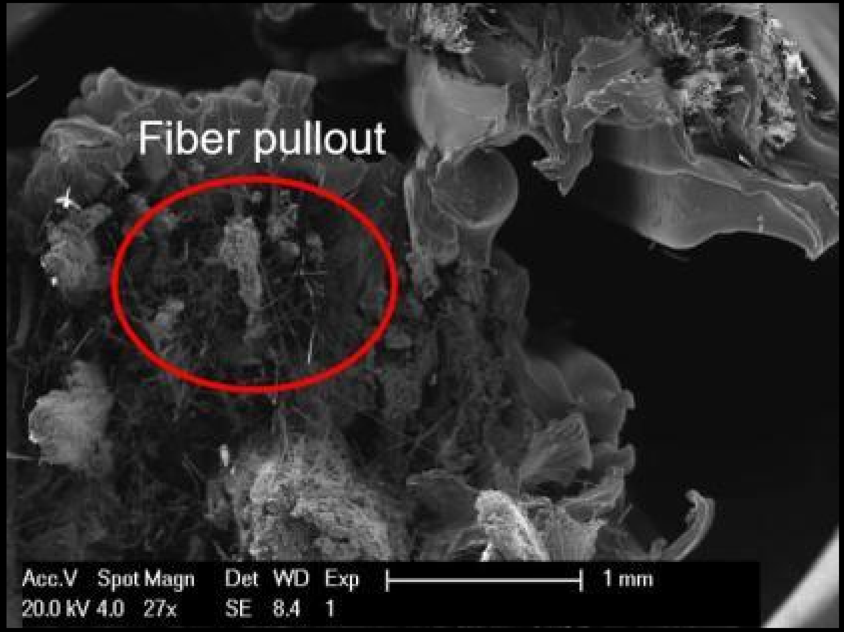


Energy Abosorption Mechanism:

- Fiber breakage
- Fiber pullout

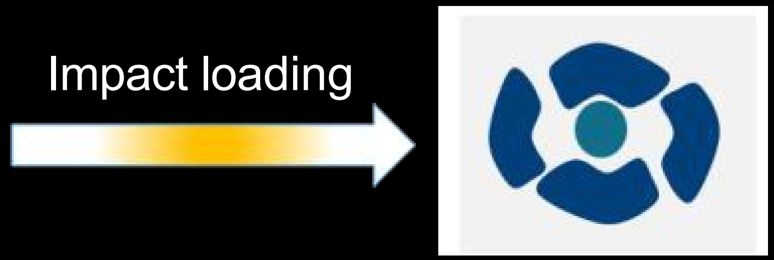
Inspiration from nature





Energy abosorption:

- Fiber breakage
- Fiiber pullout
- Delamination
- Matrix plastic deformation



Conclusion

- There are different ways of printing continuous fibers, but it has advantages and disadvantages
- The real printed material can vary from the original design in software
- Spatial distribution of fiber bundles have an influence on mechanical properties of printed structure

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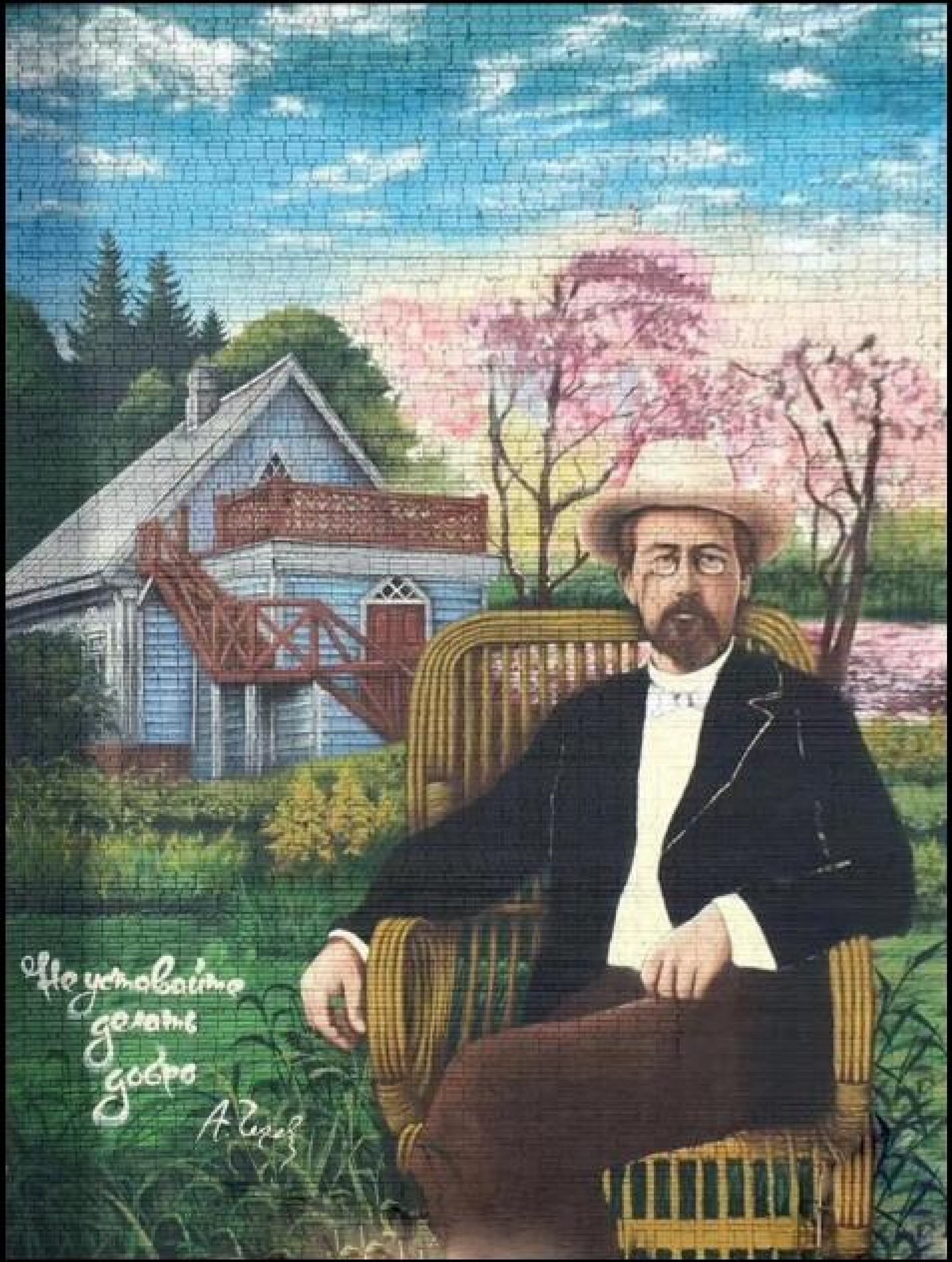
[15] https://www.nlr.org/news/nlr-wins-award-for-new-fibre-placement-processes/

[16] DENiZ, Ilhan, et al. "Kraft and modified kraft pulping of bamboo (Phyllostachys bambusoides)." *Drewno: prace naukowe, doniesienia, komunikaty* 60 (2017).

Composite
Materials
group



Obrigado.

Спасибо!

Thanks.

Grazie.

谢谢!