Interface Thickness and Orientation in 3D Printed Fiber-Reinforced Composites

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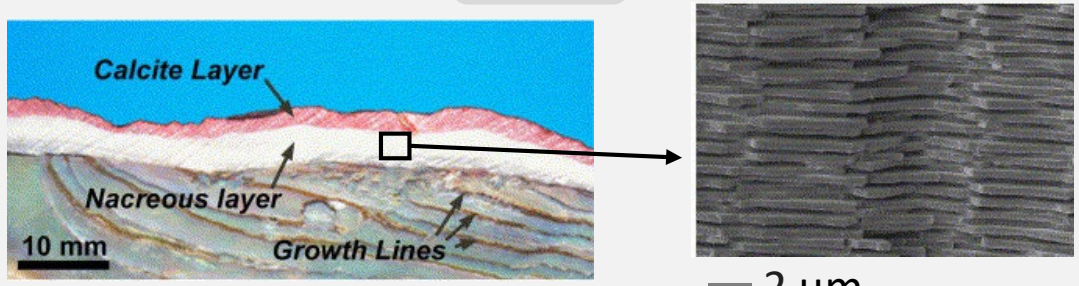
Inspiration from biological materials: *how to build resistant architectures by joining stiff blocks with soft interfaces?*

Nacre



Barthelat et al., J. Mech. Phys. Solids., 2007

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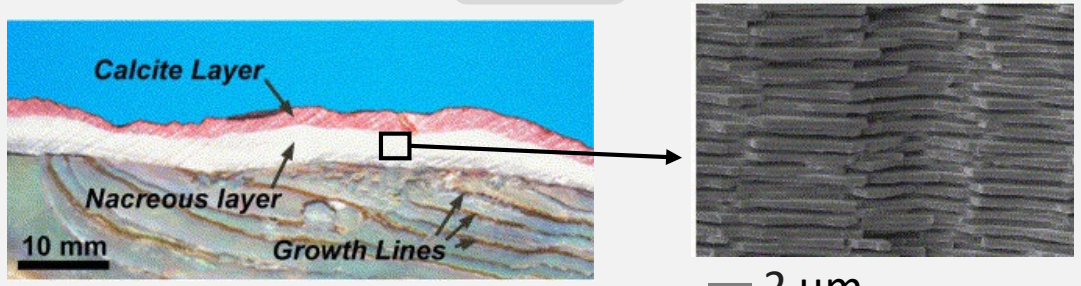

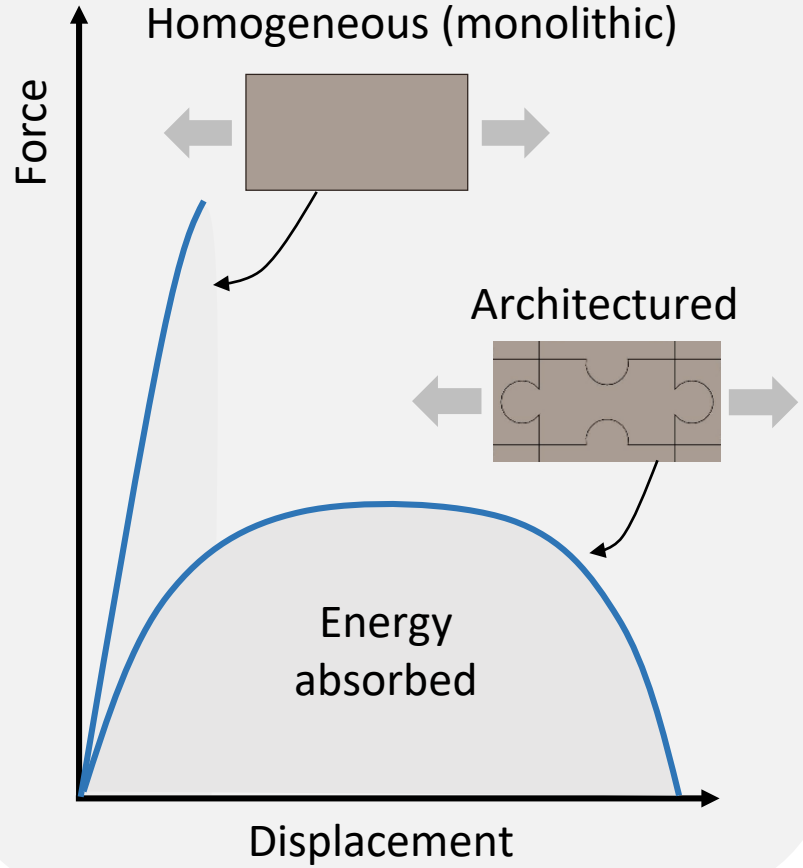

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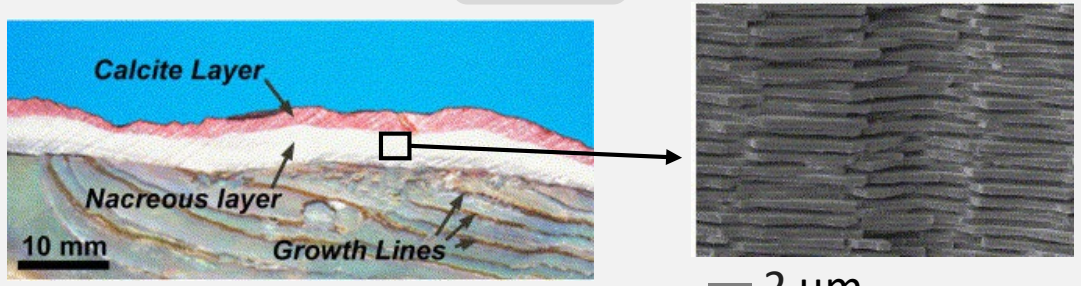
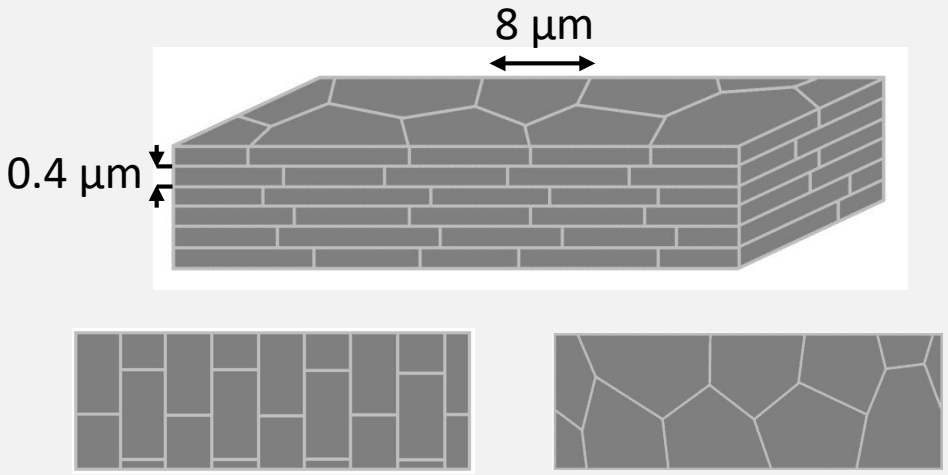
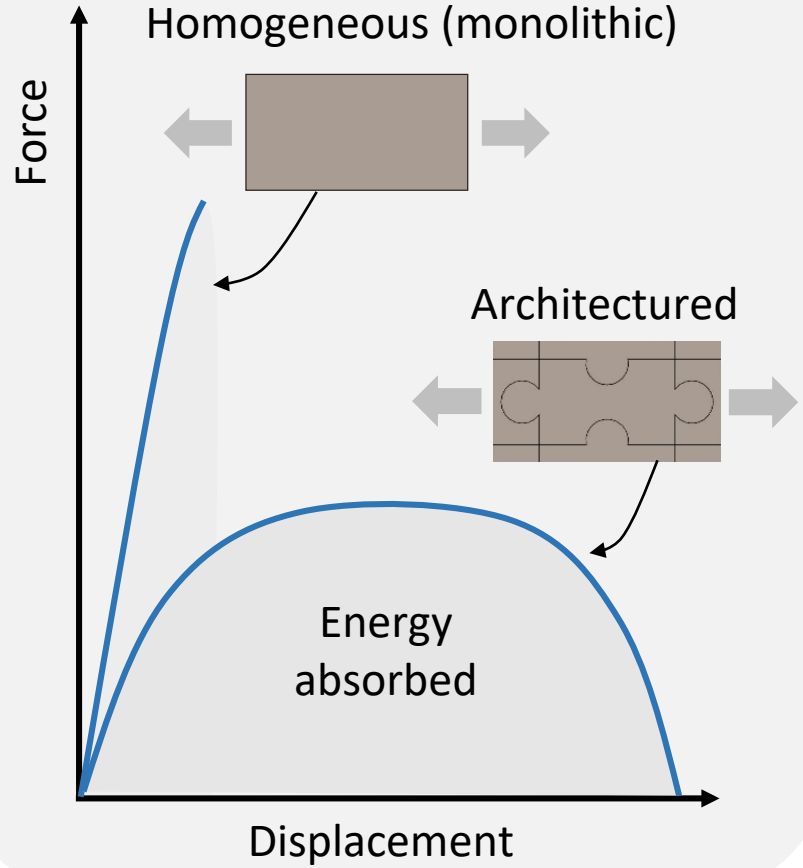




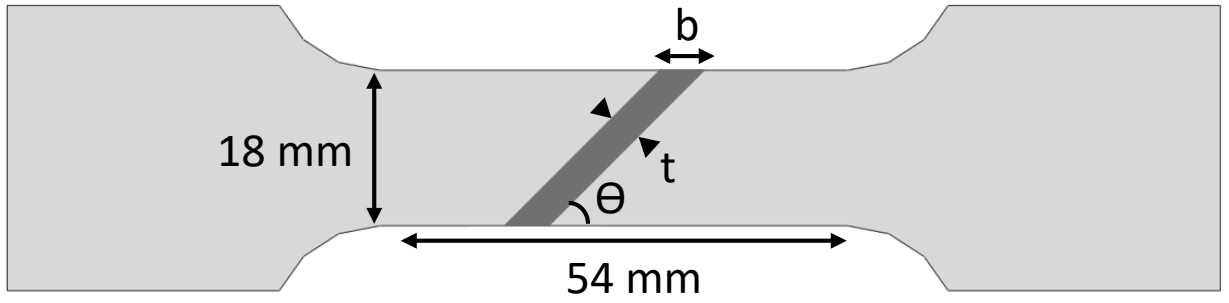


Barthelat et al., J. Mech. Phys. Solids., 2007

→ **Research question:** What is the interplay between the **layer thickness** and the **loading conditions**?

Main body = stiff material

Layer = ultra soft



t → layer thickness

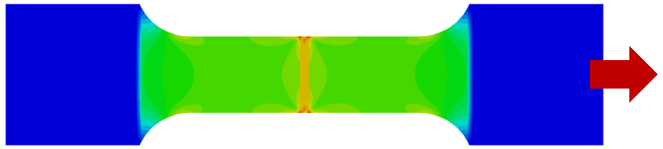
b → layer projected thickness

Θ → tilting angle

2 approaches:

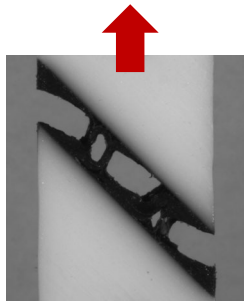
Computational part:

FE simulations: explore the parameters space



Experimental part:

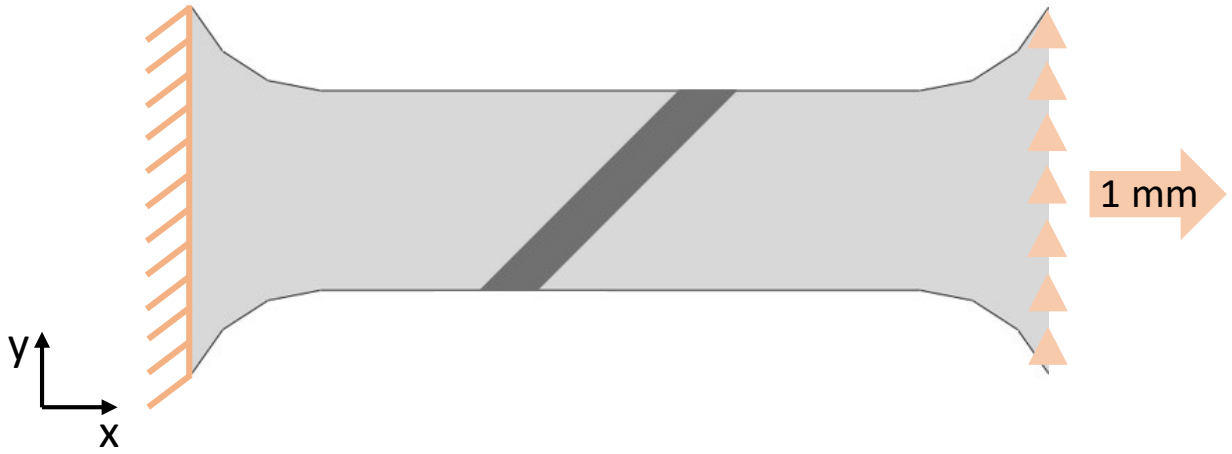
3D printing + mechanical testing



FE model

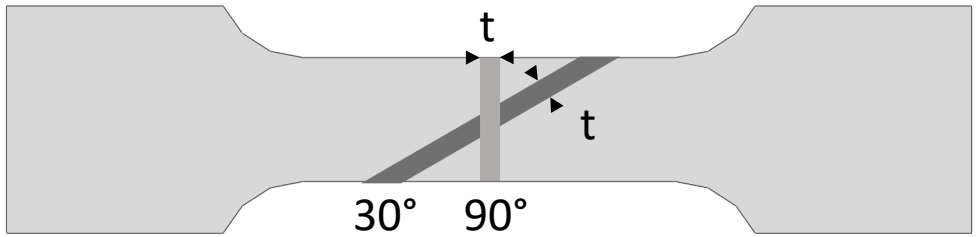
Main body → elastic:
E = 2 GPa, ν = 0.3

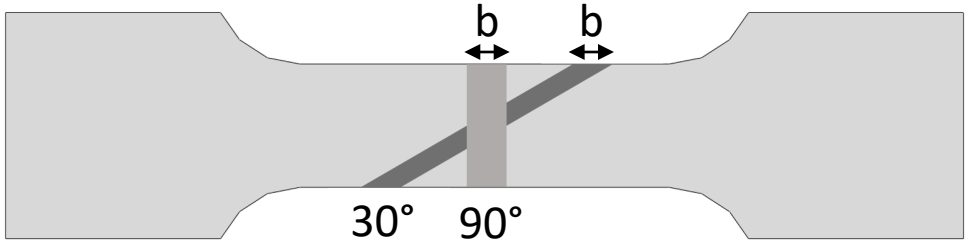
Layer → neo-Hookean:
Incompressible
E = 1 MPa, ν = 0.5

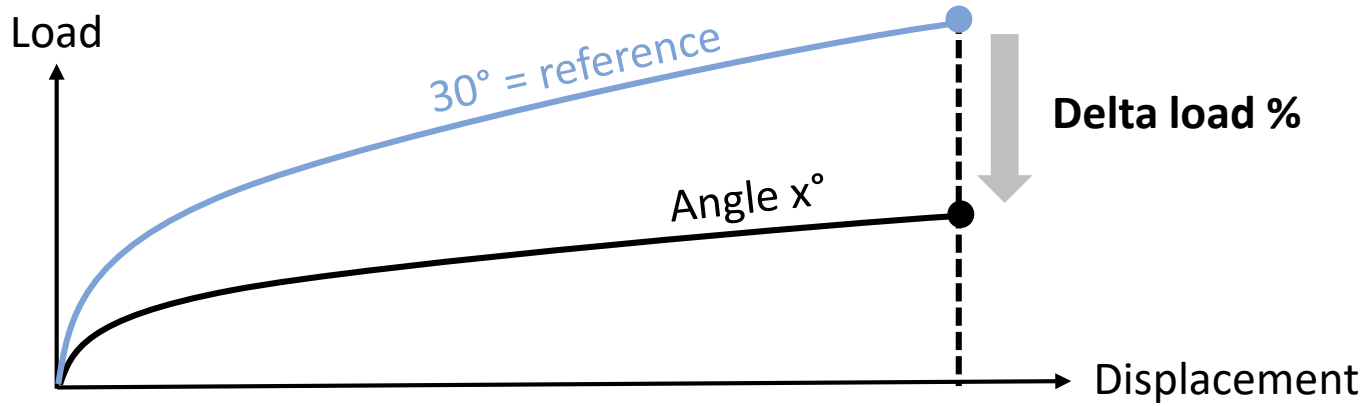


→ 2 configurations

t constant → b(Θ) varies ← Θ = 30°, 45° and 90° → **b constant** → t(Θ) varies



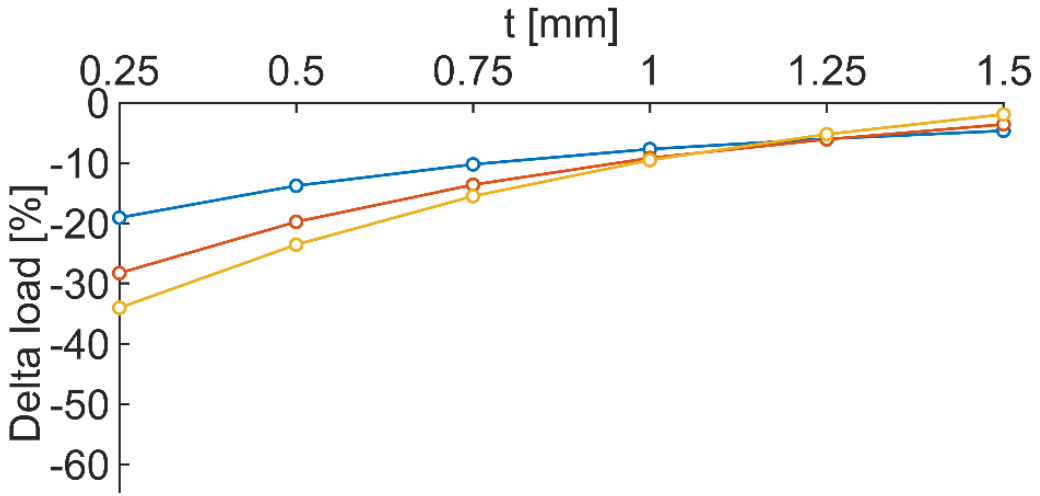




t constant → b(Θ) varies

→ At 50% displacement

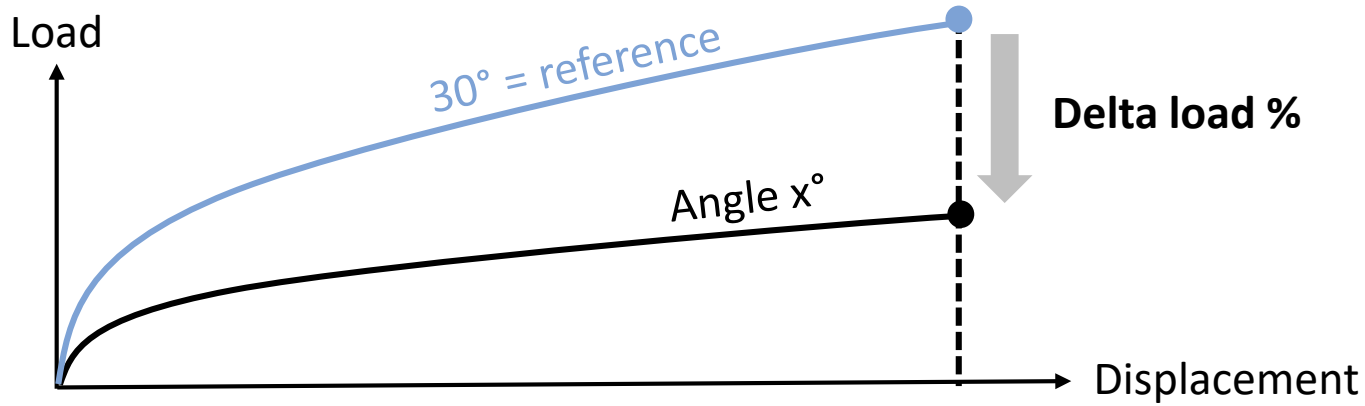
b constant → t(Θ) varies



30° → 45°

30° → 60°

30° → 90°



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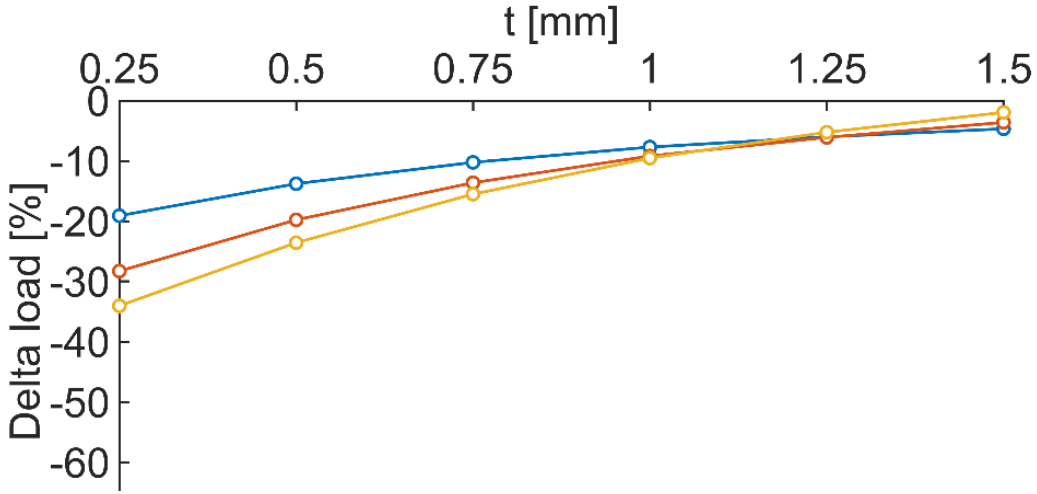
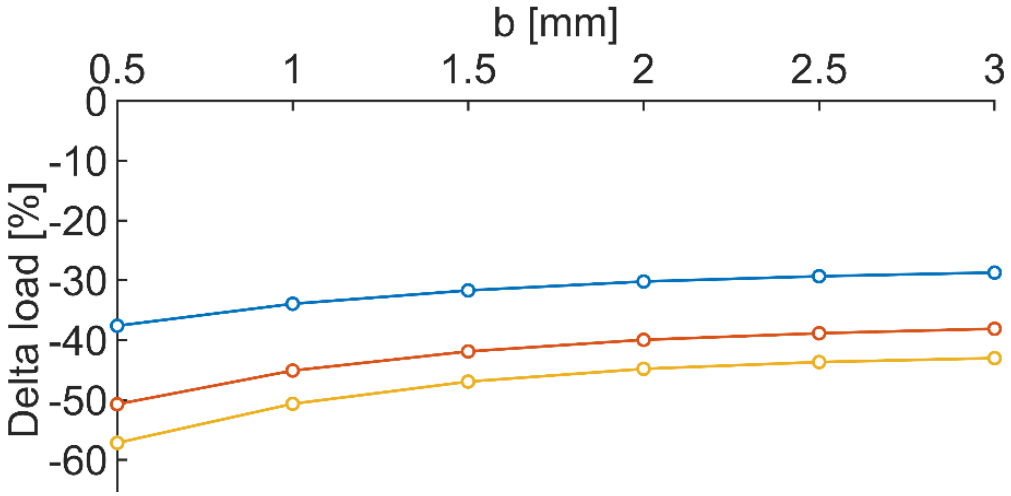
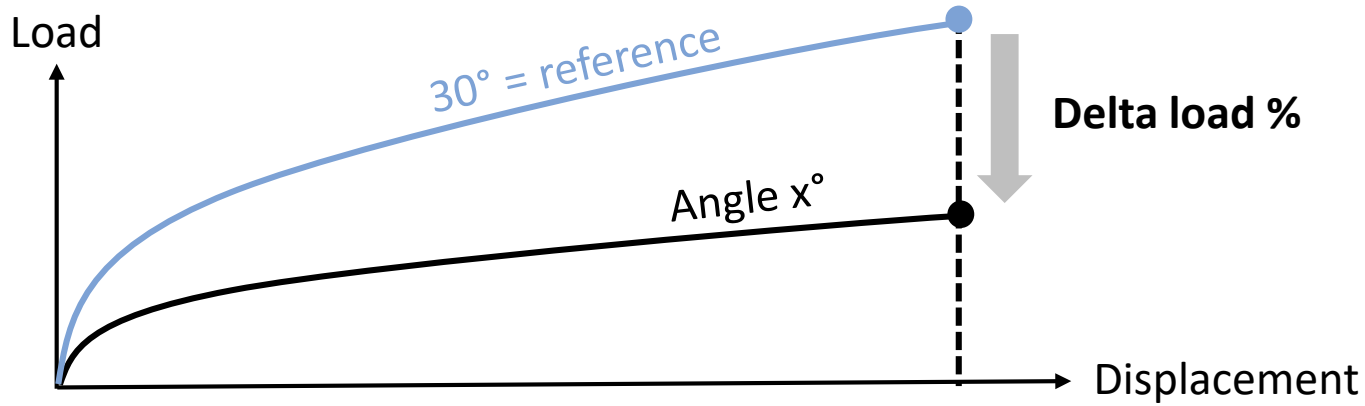


30° → 45°

30° → 60°

30° → 90°





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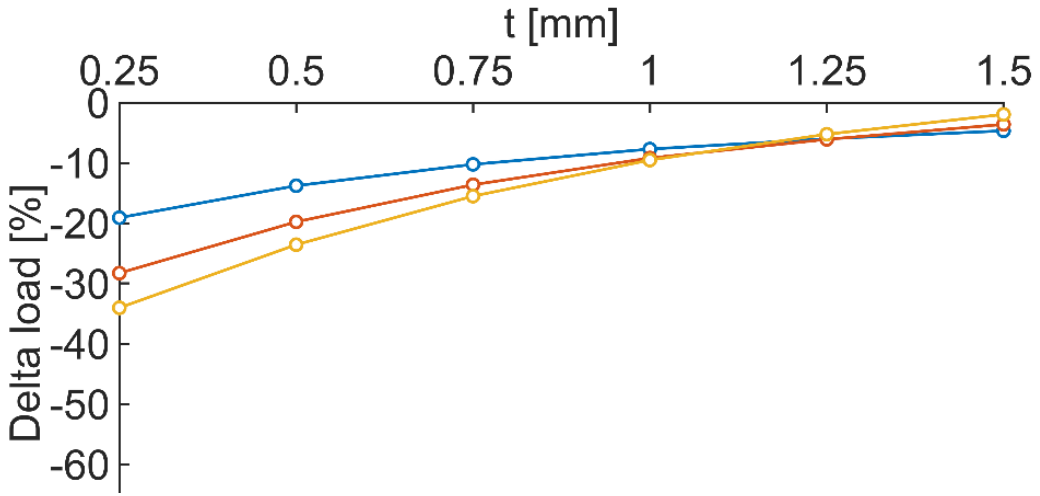

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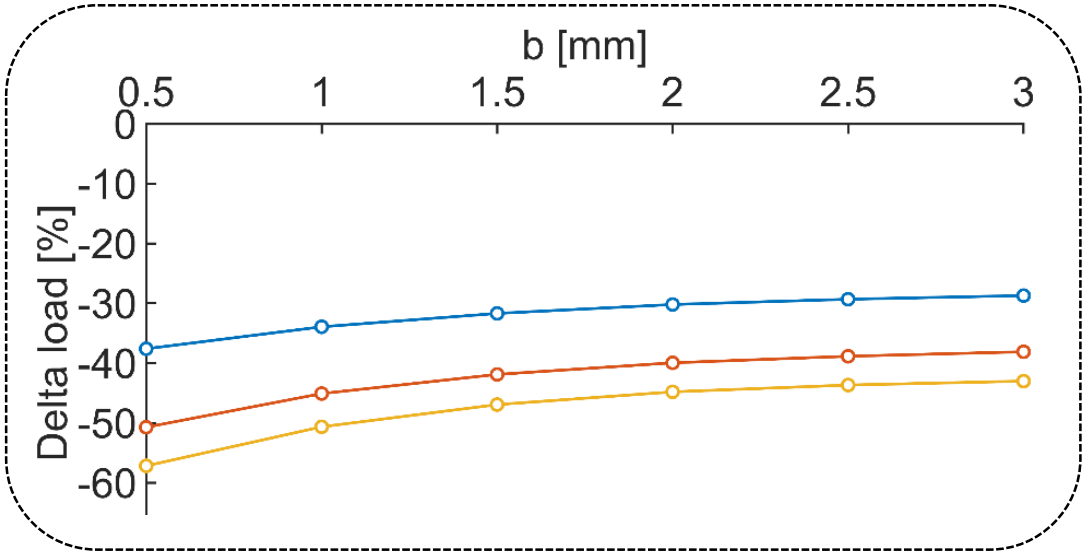
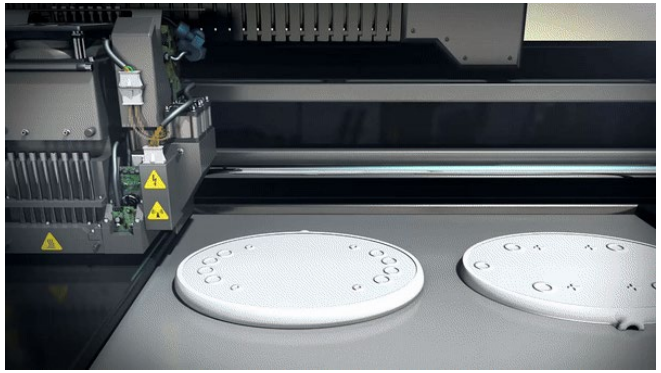


→ 3D printed configuration: **b is kept constant**

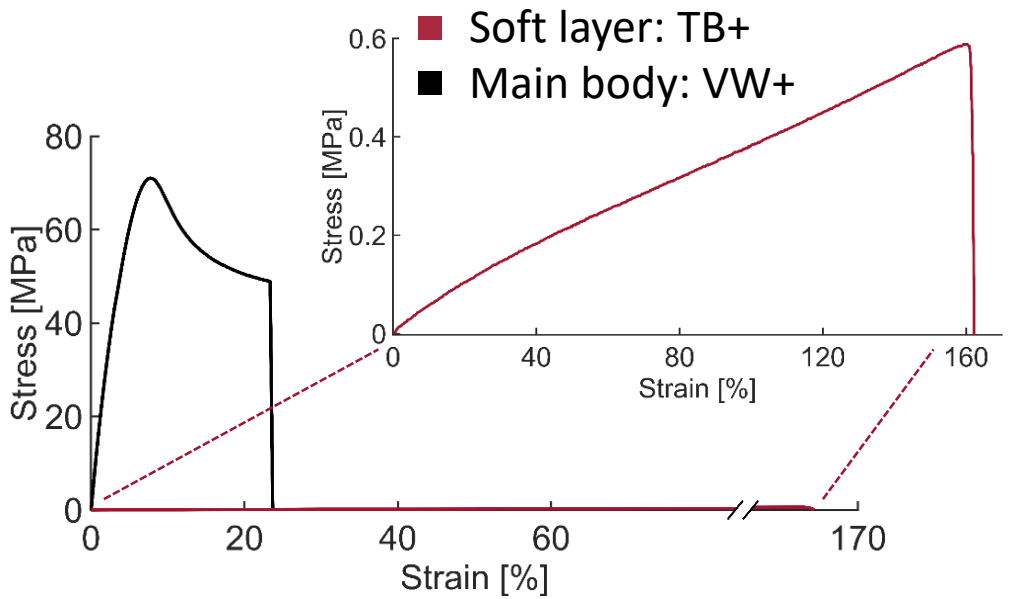
Θ → 30°, 45° and 90°

b → 0.5, 1, 2 and 3 mm

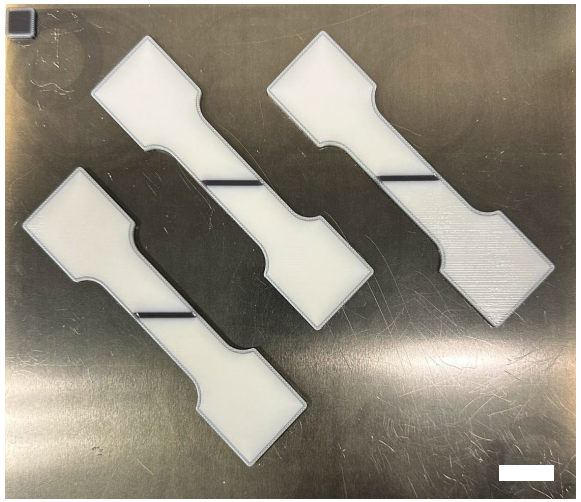
Polyjet 3D printing:



Materials used:



Printing set up:

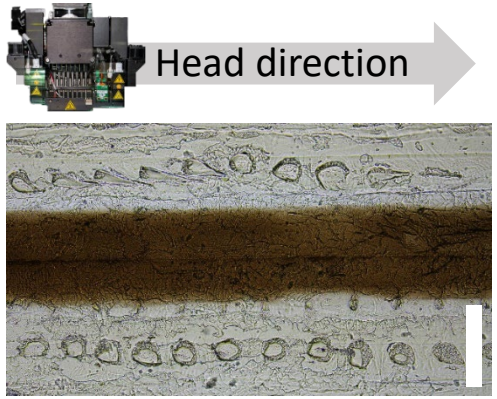


2 cm

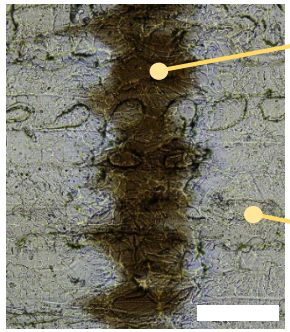
→ The samples are then tested in tension with an applied displacement of **b/min**

Printing orientation

Scale bar: 0.5 mm



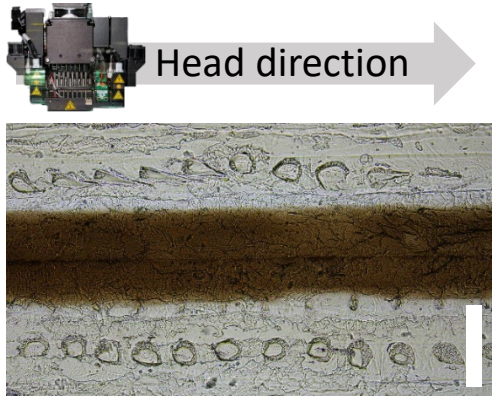
Printed horizontally



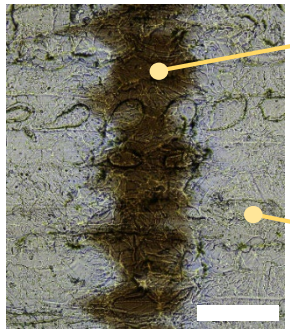
Printed vertically

Printing orientation

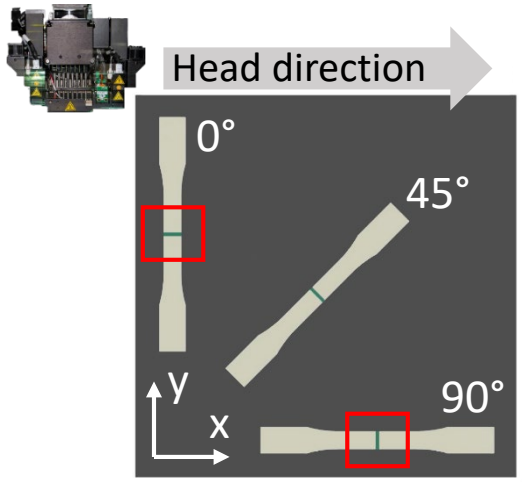
Scale bar: 0.5 mm

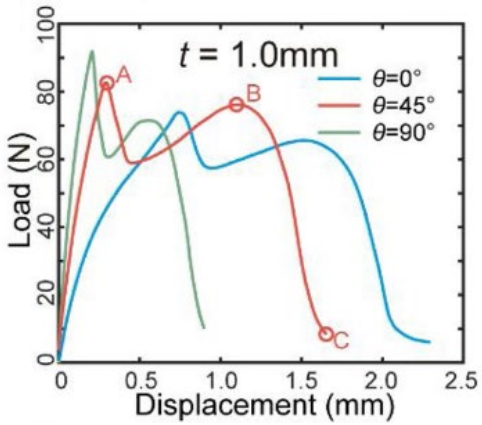


Printed horizontally



Printed vertically

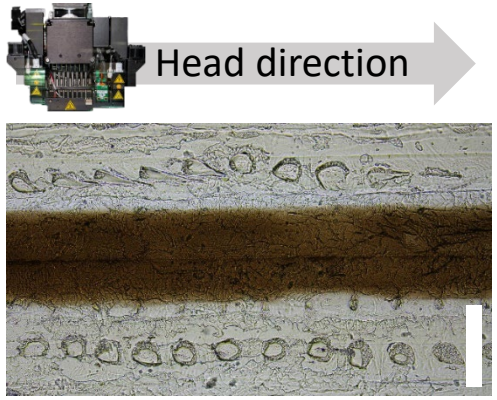




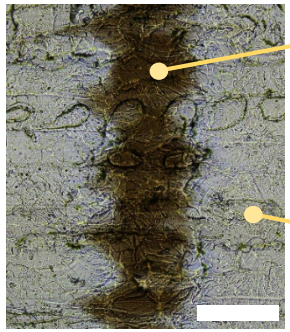
Liu et al., Addit. Manuf., 2020

Printing orientation

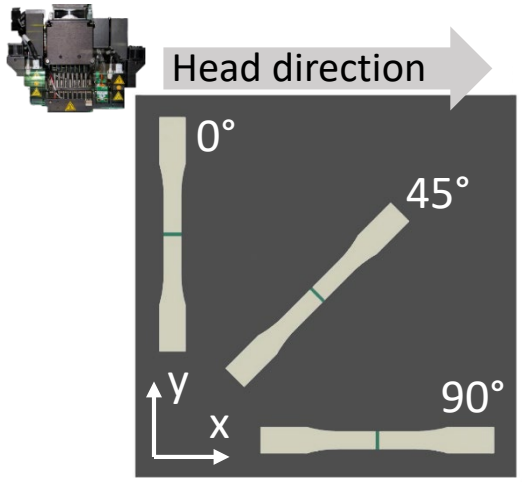
Scale bar: 0.5 mm

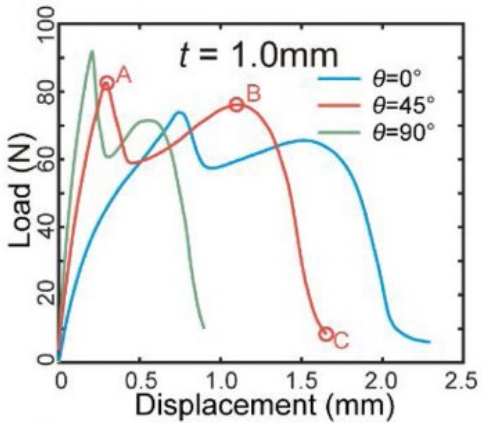


Printed horizontally

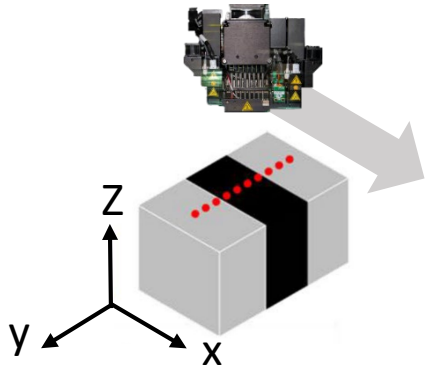


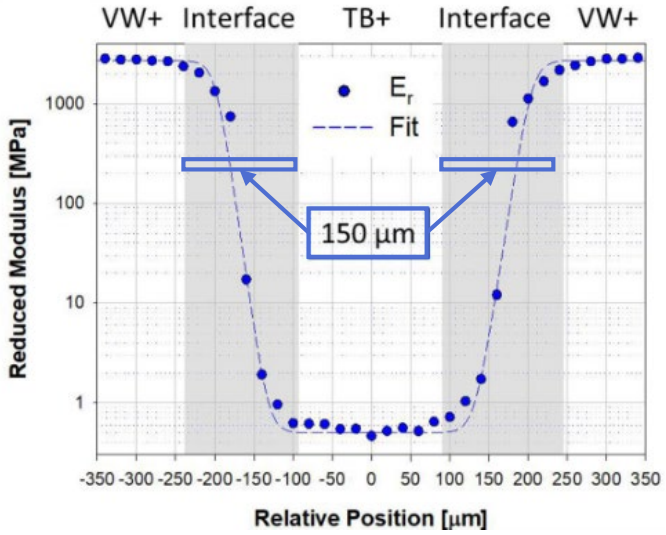
Printed vertically





Interface mixing resolution





→ **Interface mixing size** = 150 µm x 2 = **300 µm**

For b = 0.5 mm:

30°→ t = 0.25 mm

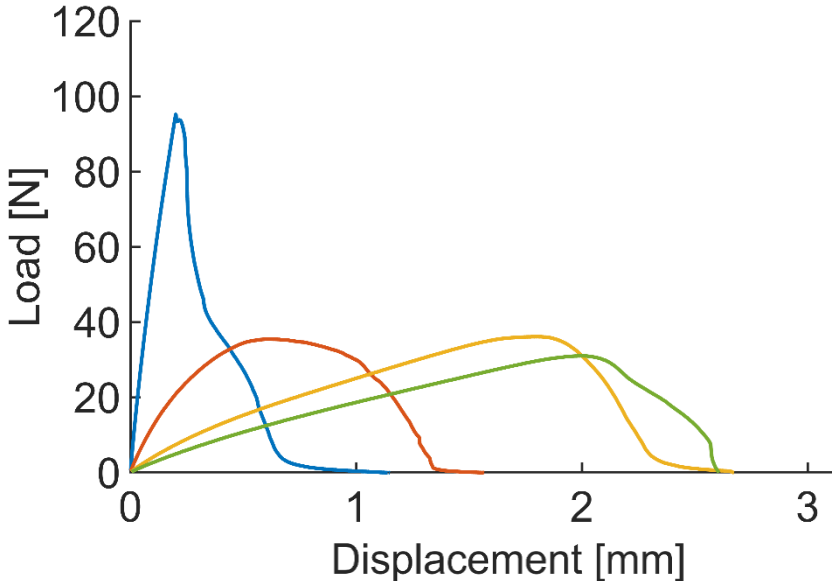
45°→ t = 0.355 mm

90°→ t = 0.5 mm

Liu et al., Addit. Manuf., 2020

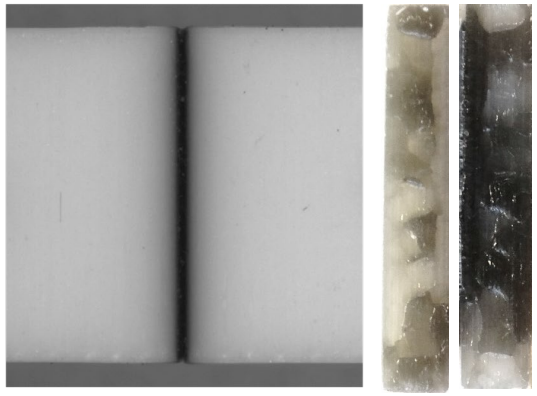
Zorzetto et al., Sci. Rep., 2020

90°

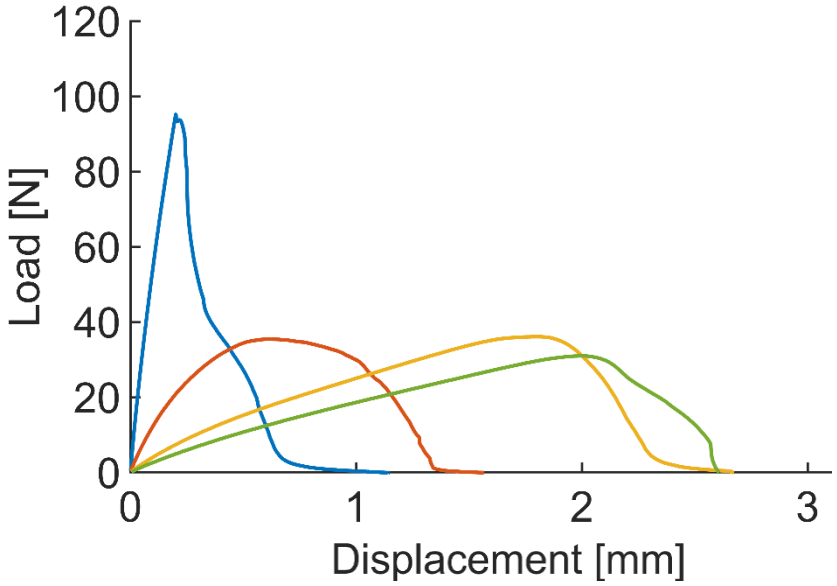


Strong adhesive effect

b = t = 0.5 mm



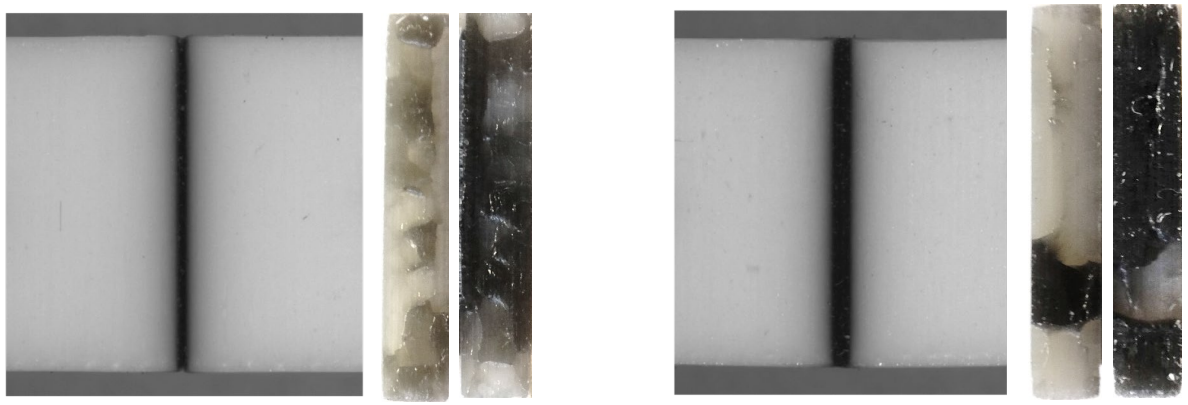
90°



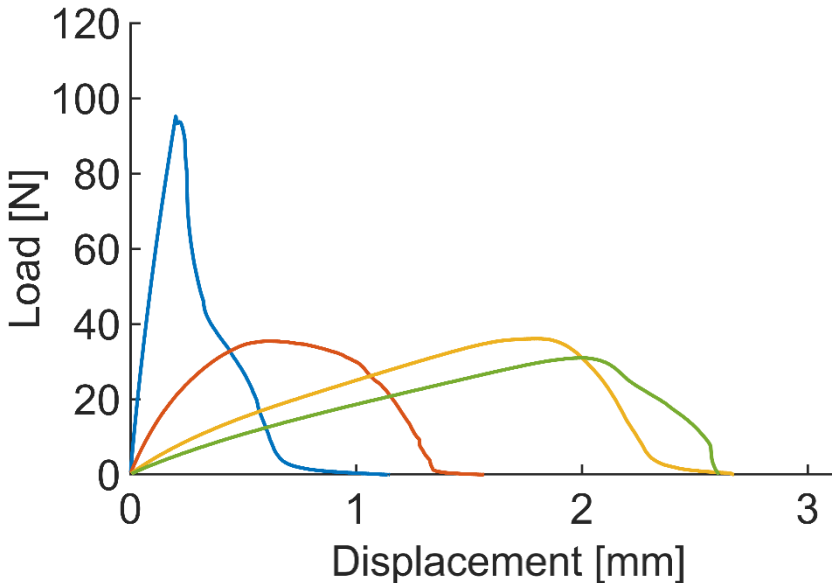
Strong adhesive effect

Multi delamination

b = t = 0.5 mm → **b = t = 1 mm**



90°



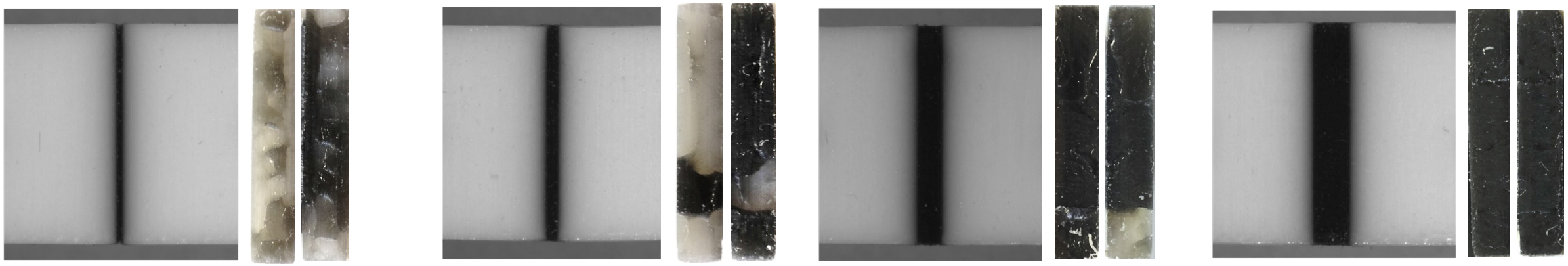
Strong adhesive effect

Multi delamination

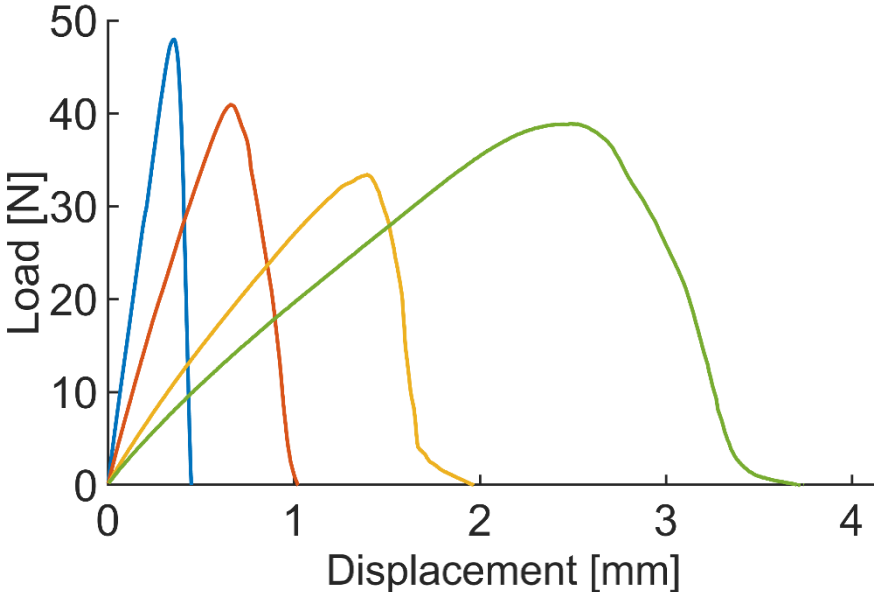
Layer rupture (from the edges)

Layer rupture (from inside)

b = t = 0.5 mm → **b = t = 1 mm** → **b = t = 2 mm** → **b = t = 3 mm**

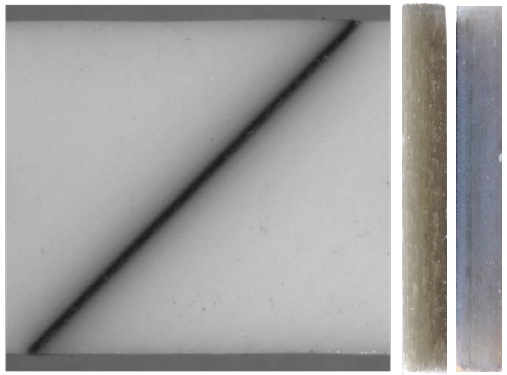


45°

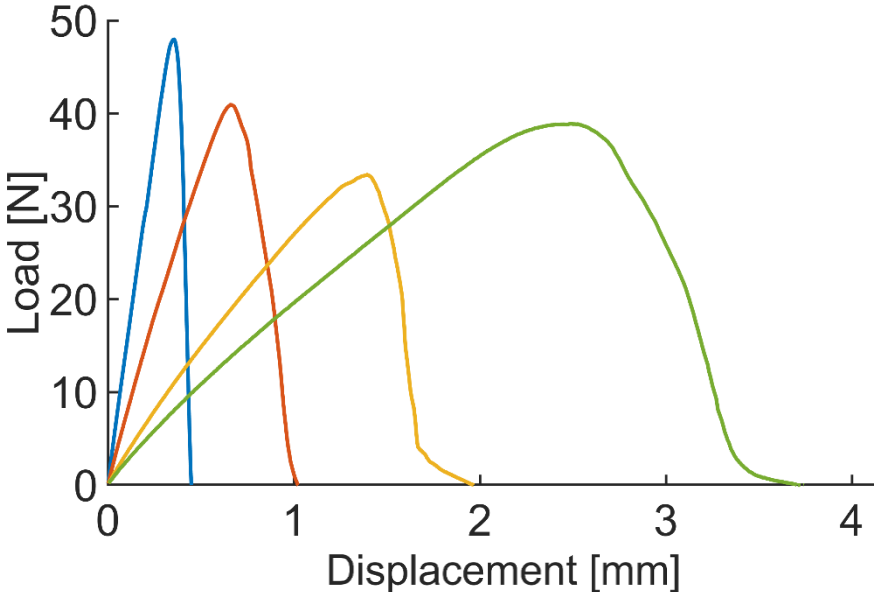


Weak adhesive

b = 0.5 mm → *t = 0.35 mm*



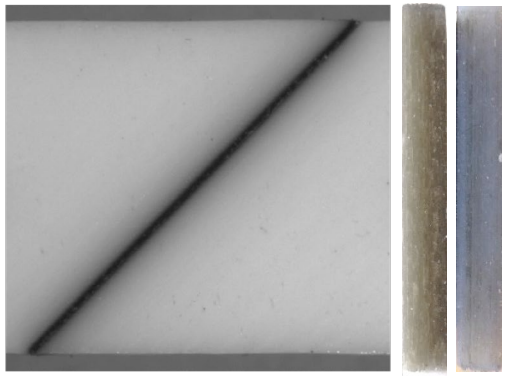
45°



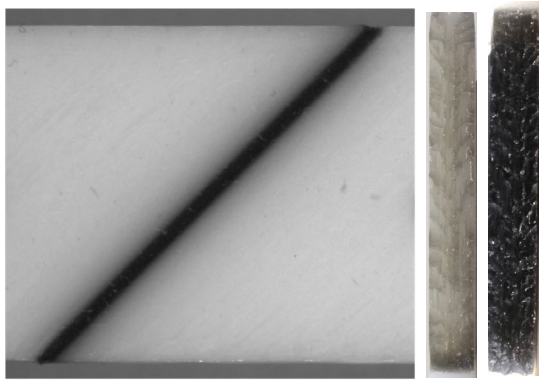
Weak adhesive

Layer detachment

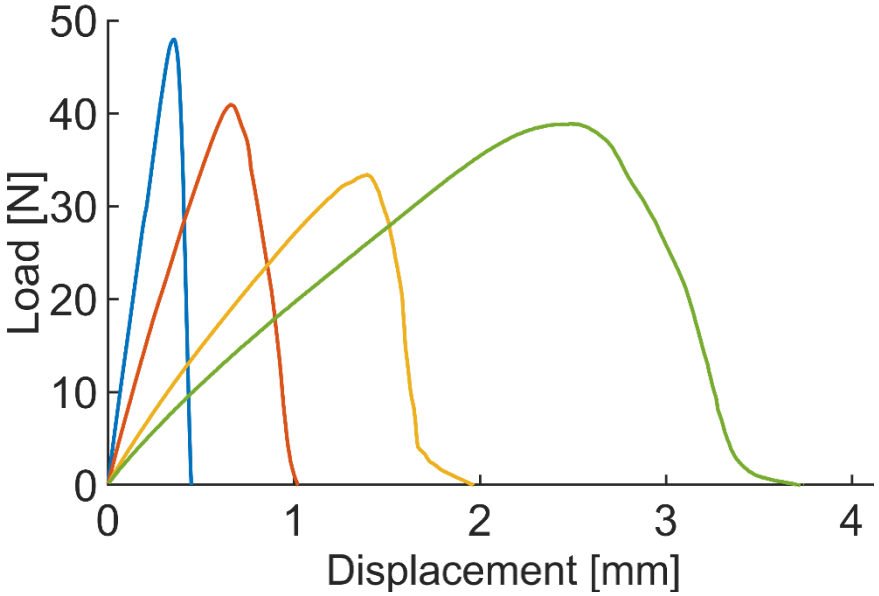
b = 0.5 mm → *t = 0.35 mm*



b = 1 mm → *t = 0.71 mm*



45°

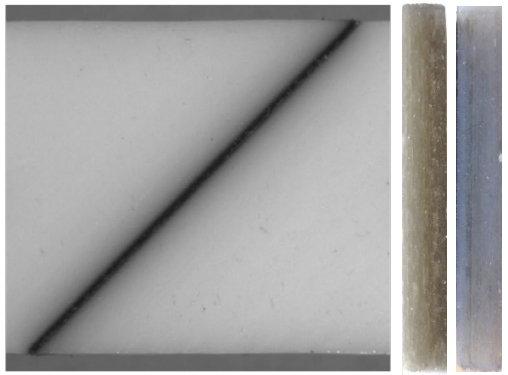


Weak adhesive

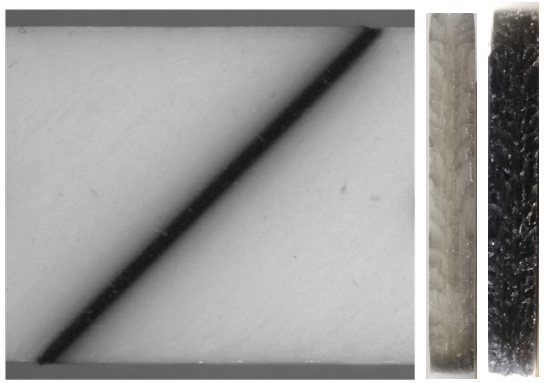
Layer detachment

Layer delamination

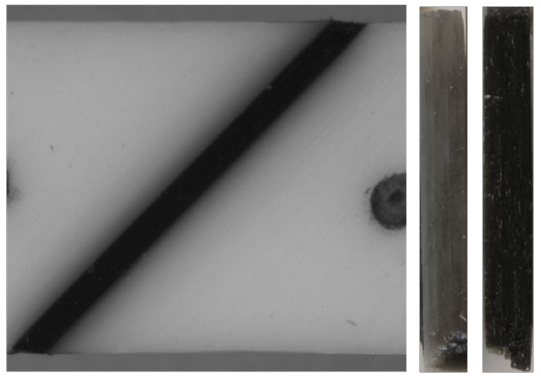
b = 0.5 mm → *t = 0.35 mm*



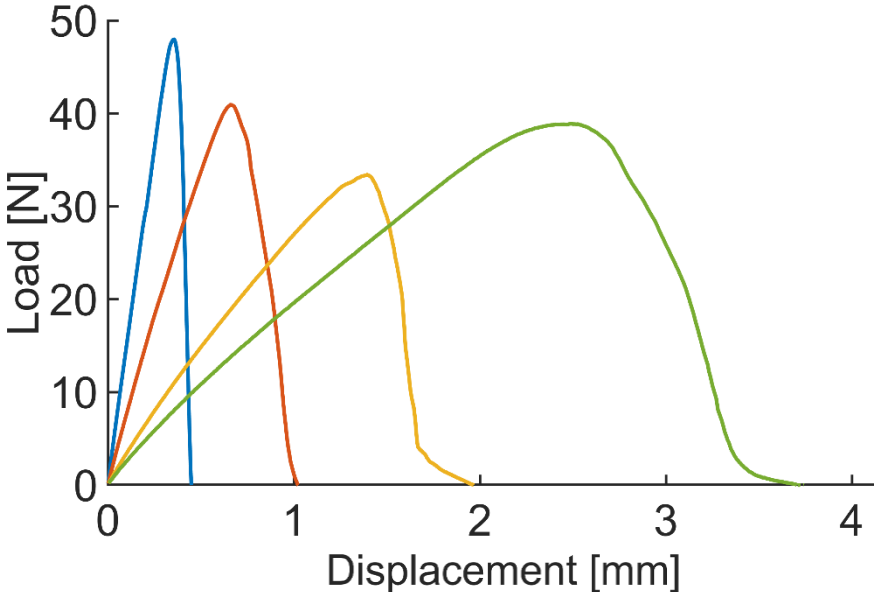
b = 1 mm → *t = 0.71 mm*



b = 2 mm → *t = 1.42 mm*

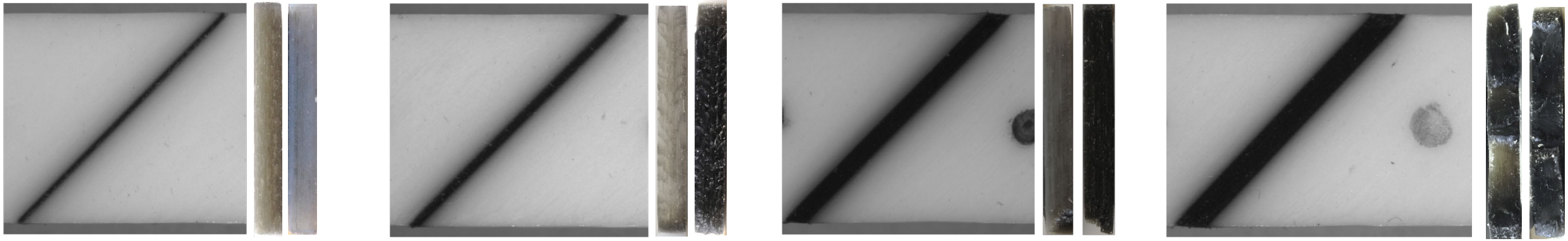


45°

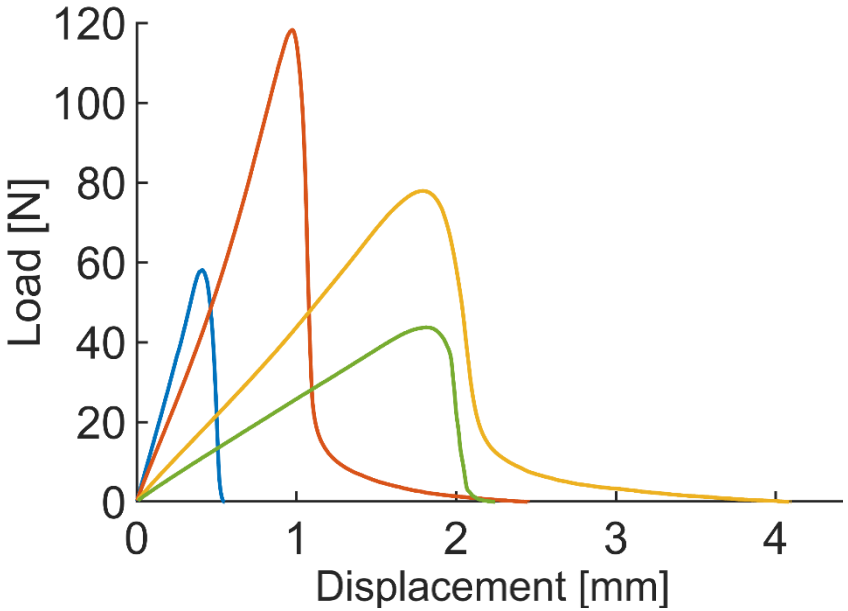


- Weak adhesive
- Layer detachment
- Layer delamination
- Complex cohesive layer rupture

b = 0.5 mm → *t = 0.35 mm* → **b = 1 mm** → *t = 0.71 mm* → **b = 2 mm** → *t = 1.42 mm* → **b = 3 mm** → *t = 2.12 mm*

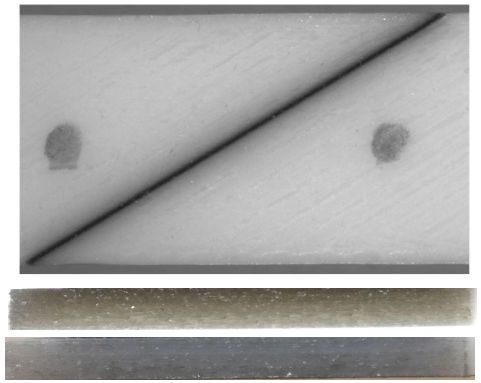


30°

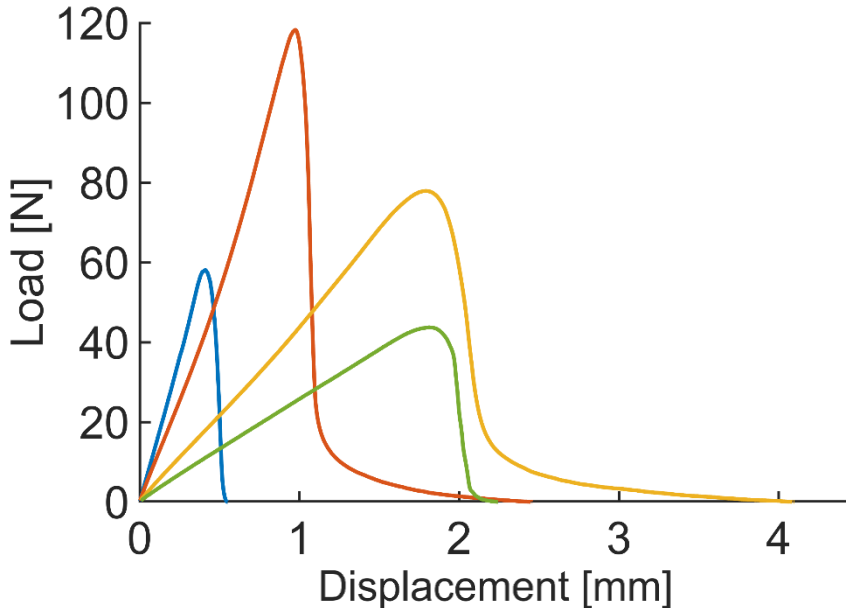


Weak adhesive

b = 0.5 mm → *t = 0.35 mm*



30°

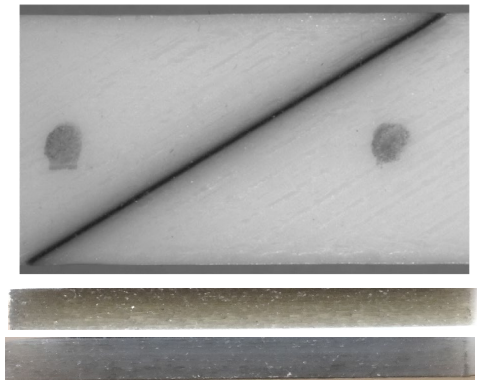


Weak adhesive

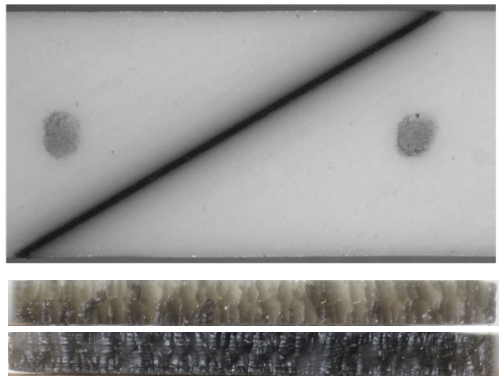
Cohesive layer rupture with multiple thin ligaments

Cohesive layer rupture with multiple thin ligaments

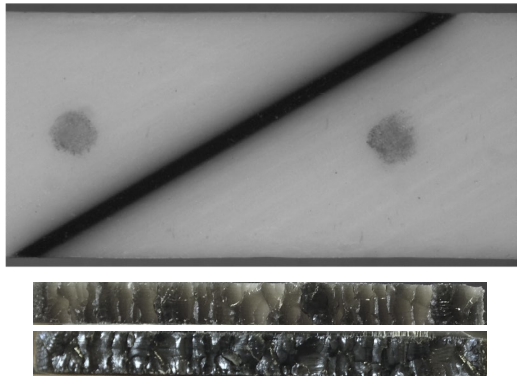
b = 0.5 mm → *t = 0.35 mm*



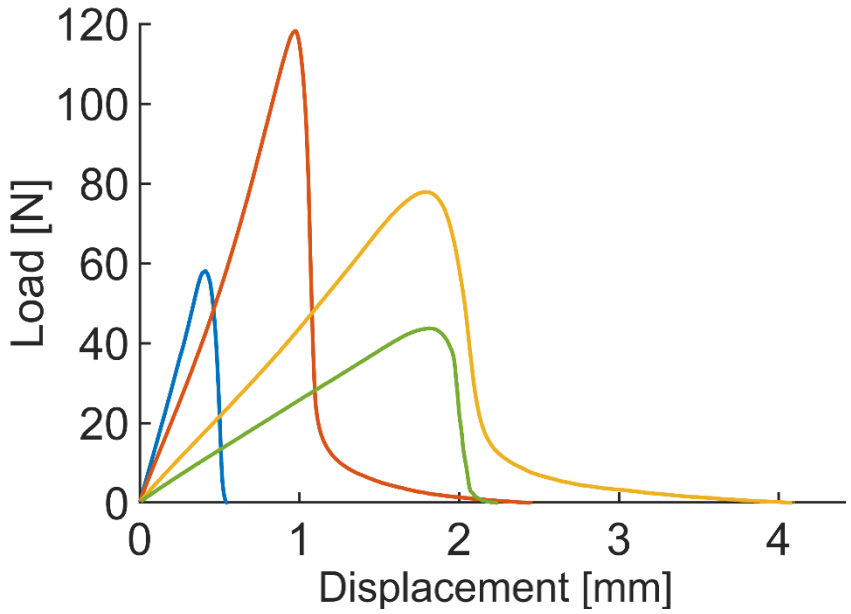
b = 1 mm → *t = 0.71 mm*



b = 2 mm → *t = 1.42 mm*



30°



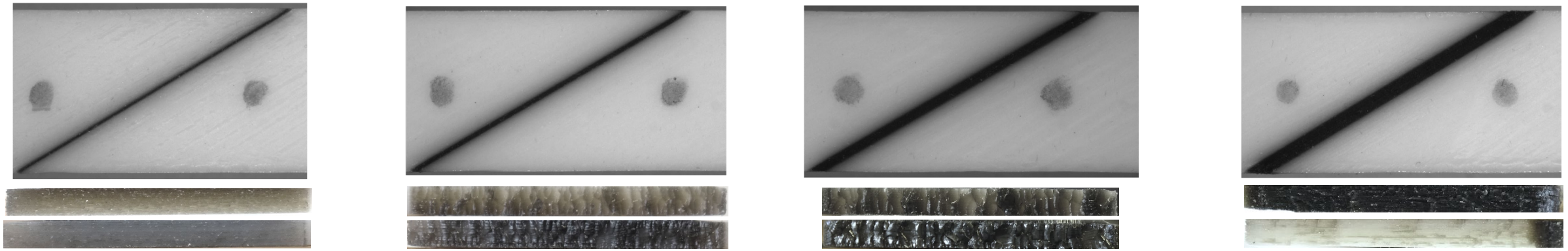
Weak adhesive

Cohesive layer rupture with multiple thin ligaments

Cohesive layer rupture with multiple thin ligaments

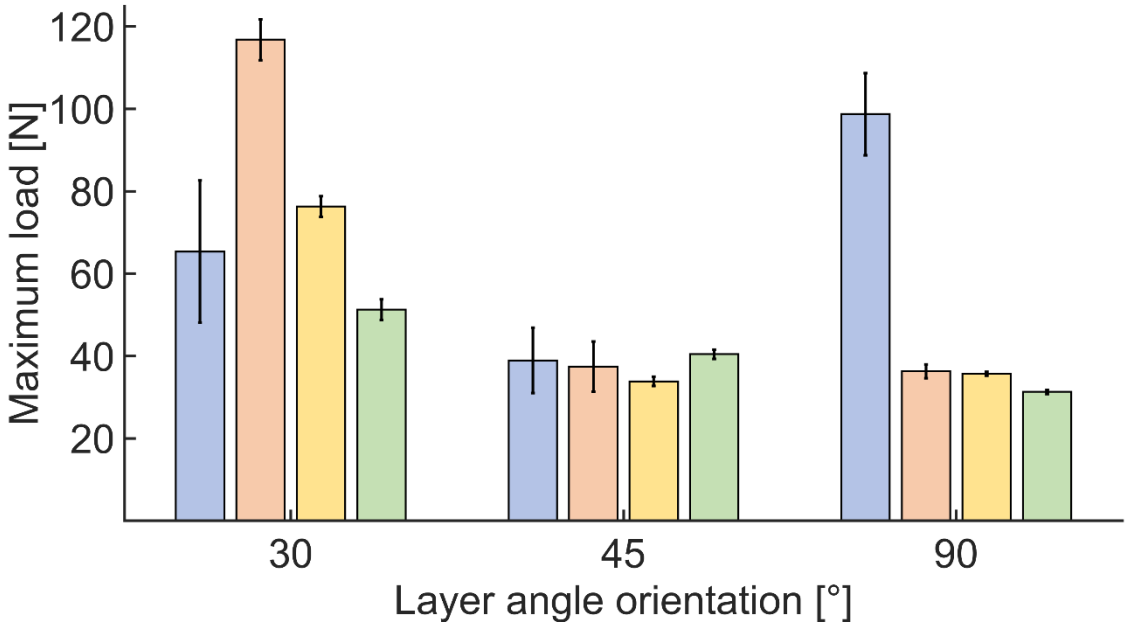
Layer delamination

b = 0.5 mm → *t = 0.35 mm* → **b = 1 mm** → *t = 0.71 mm* → **b = 2 mm** → *t = 1.42 mm* → **b = 3 mm** → *t = 2.12 mm*



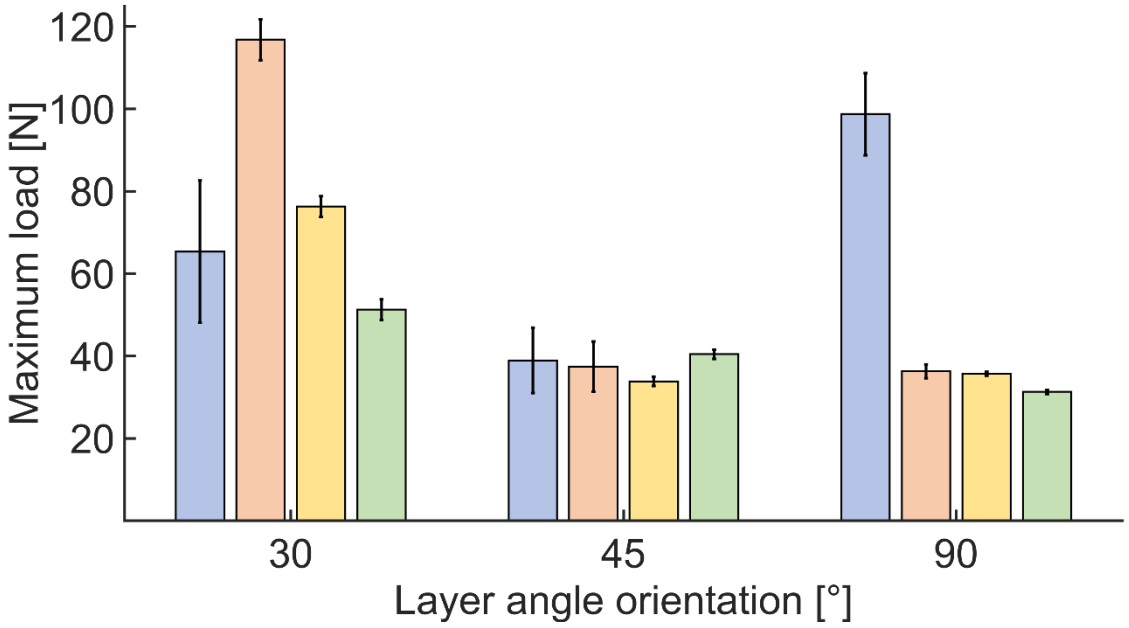
b = 0.5 mm | b = 1 mm | b = 2 mm | b = 3 mm

Maximum load

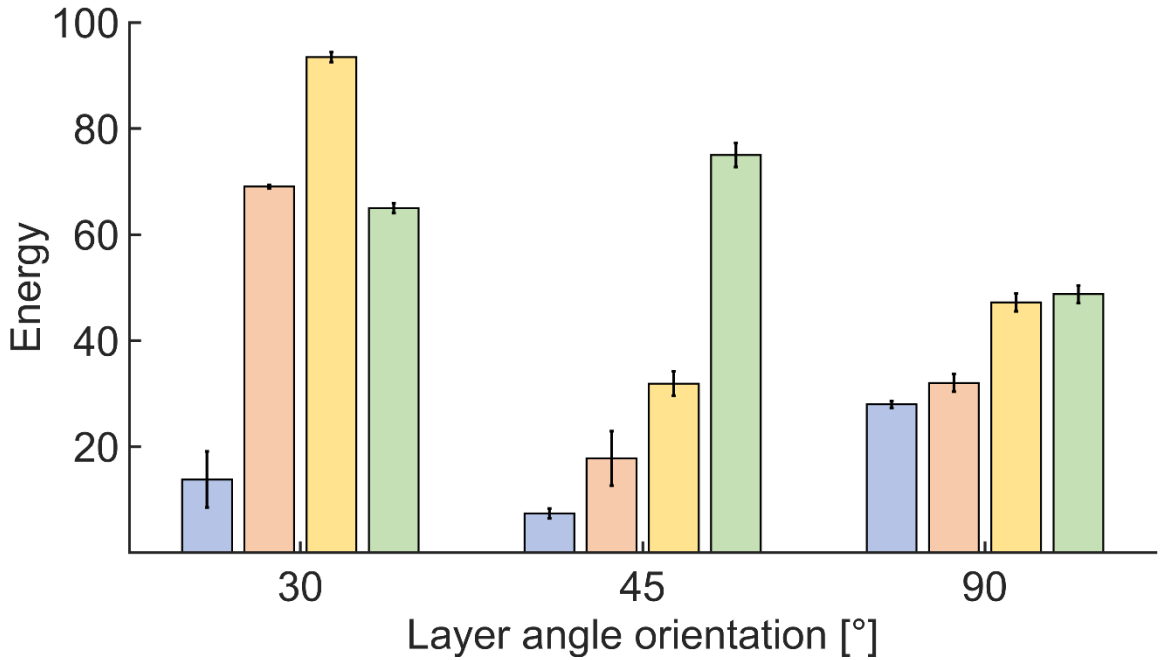


b = 0.5 mm | b = 1 mm | b = 2 mm | b = 3 mm

Maximum load



Energy



Main messages:

- By changing the layer thickness and the loading conditions (i.e layer orientation):
  - A wide range of fracture mechanisms is observed
  - High load bearing or/and deformation capability is achievable depending on the combinations

Perspectives:

- Exploring the other configuration: t constant
- Investigate more complex architecture, for example multi-layers

Thanks to all co-authors!

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Thank you for your attention!

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