A bi-axially zero Poisson's ratio morphing skin system

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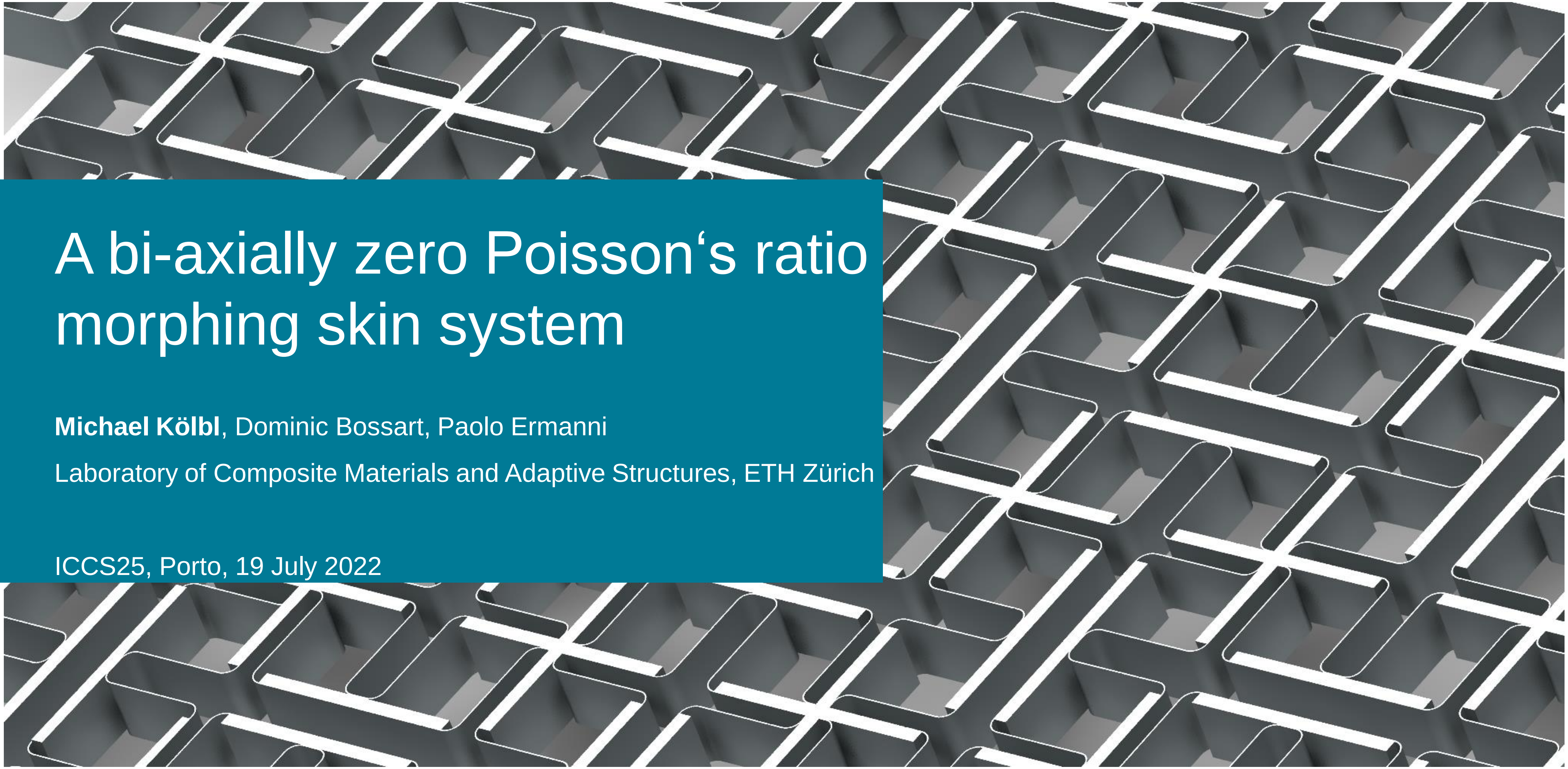

A bi-axially zero Poisson‘s ratio morphing skin system

Michael Kölbl, Dominic Bossart, Paolo Ermanni

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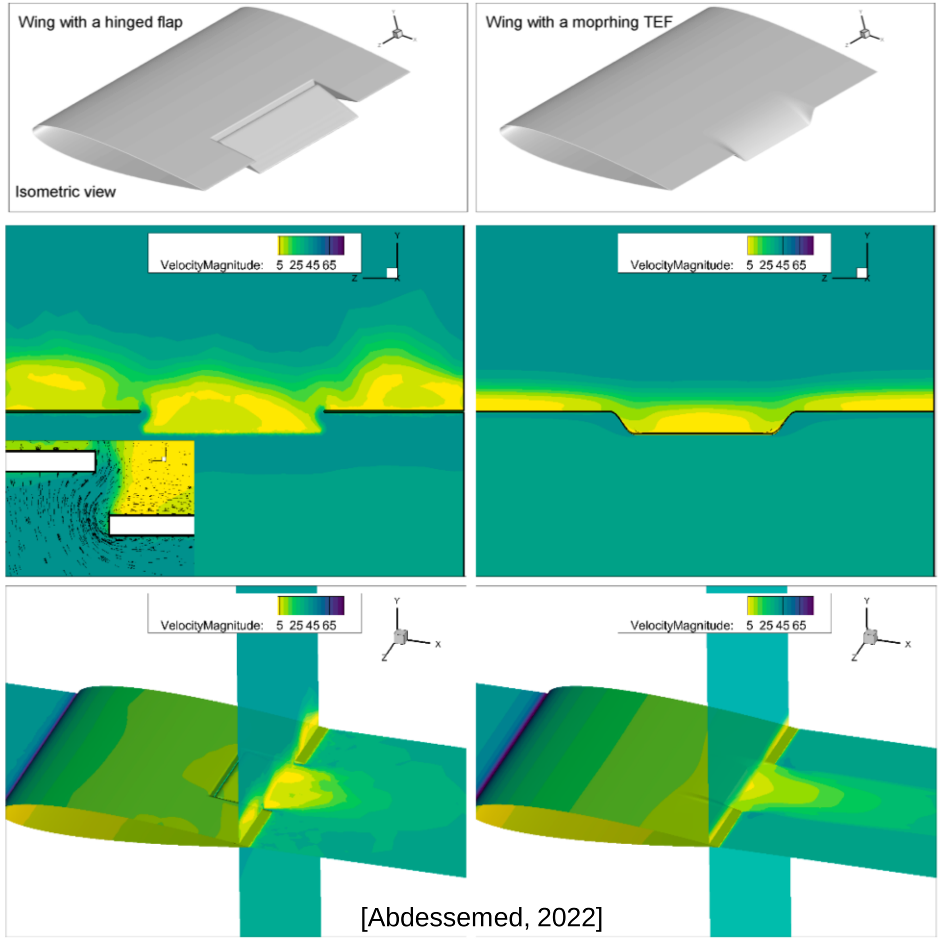
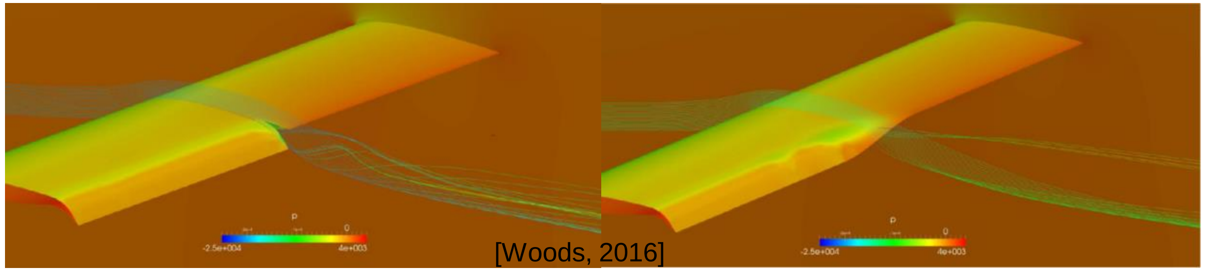
ICCS25, Porto, 19 July 2022

Bi-axially morphing skins for morphing transition regions

- Aerodynamics
  - Decreased vortex formation and drag
  - Reduced noise emission
- Mechanics
  - Strains in chord and span direction up to 20%
  - Load carrying
  - Complex shape

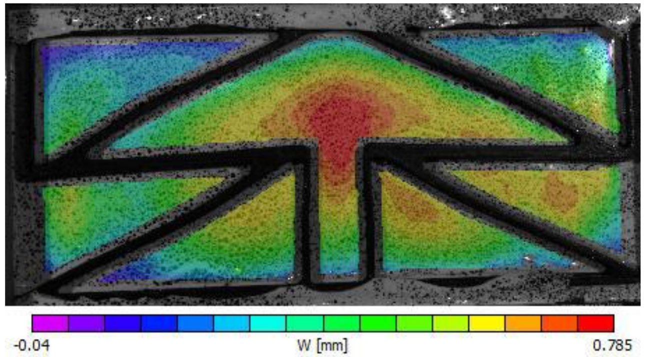


Conventional and transitioning morphing aileron

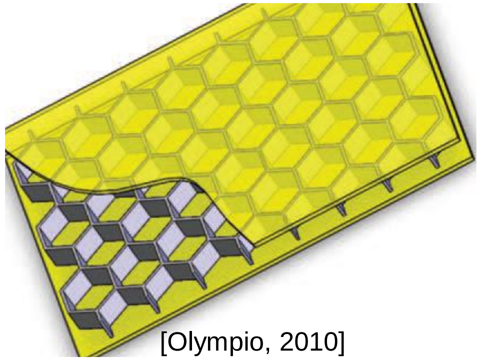


Vortex comparison with morphing aileron transition region

Requirements of a morphing wing skin system and state of the art implementations

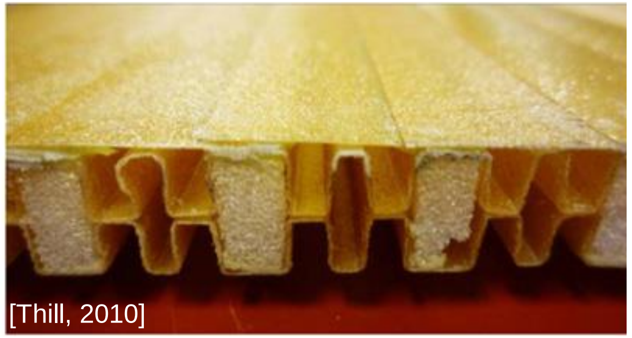


[Ott, 2019]

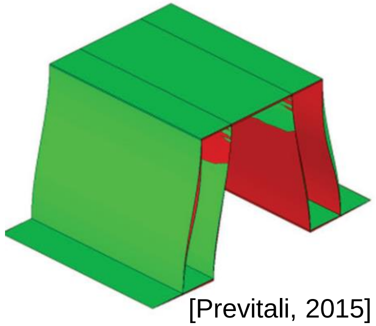


[Olympio, 2010]

Lattice structures with elastomeric covers

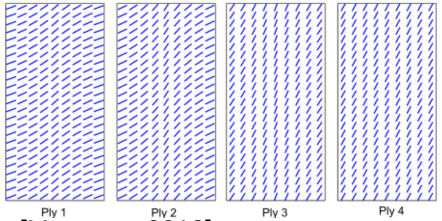


[Thill, 2010]

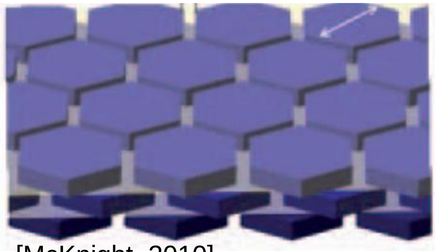


[Previtali, 2015]

(Un)covered corrugations



[Murugan, 2013]



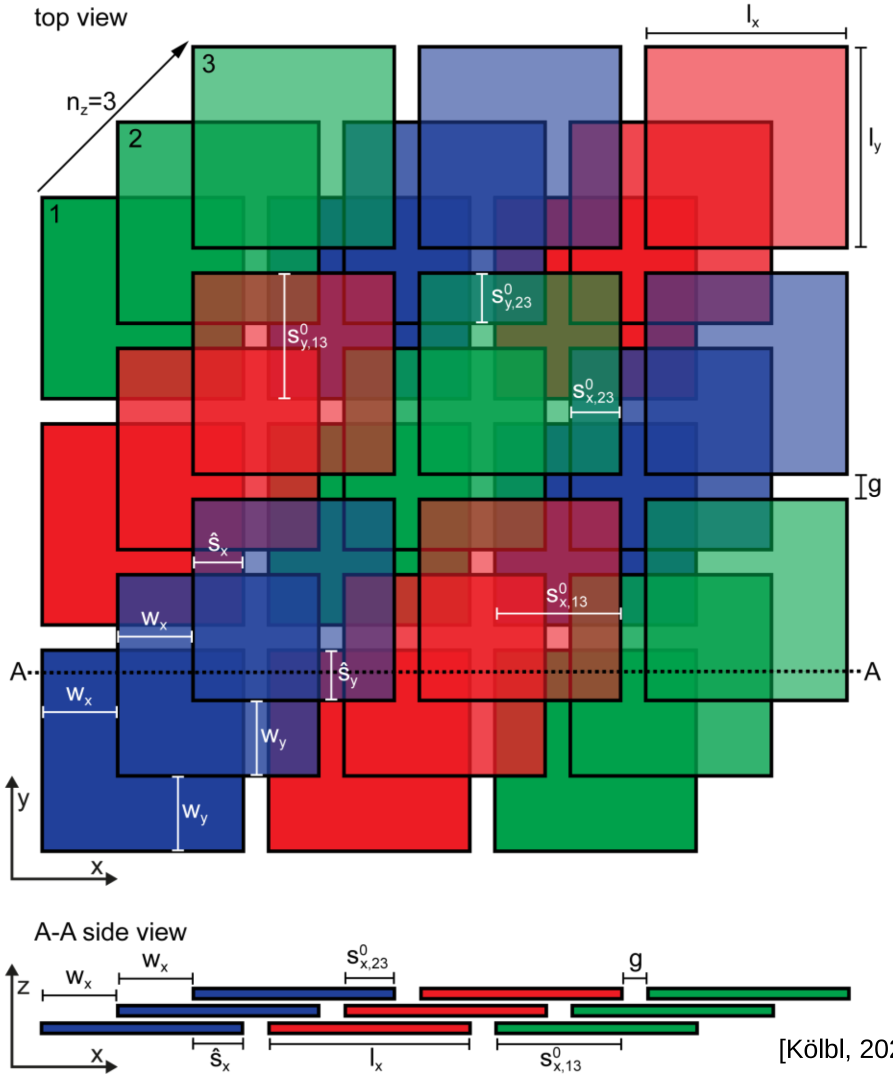
[McKnight, 2010]

Material approach

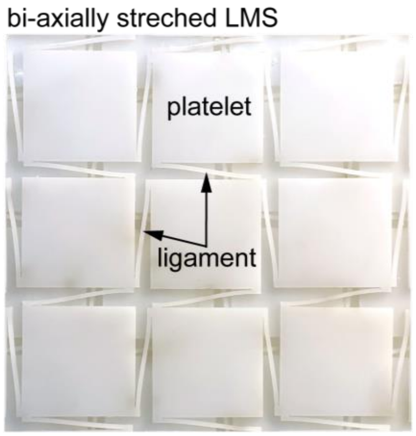
- Light
- Thin
- Highly orthotropic
  - In-plane compliant
  - Out-of-plane stiff
- Closed and smooth surface

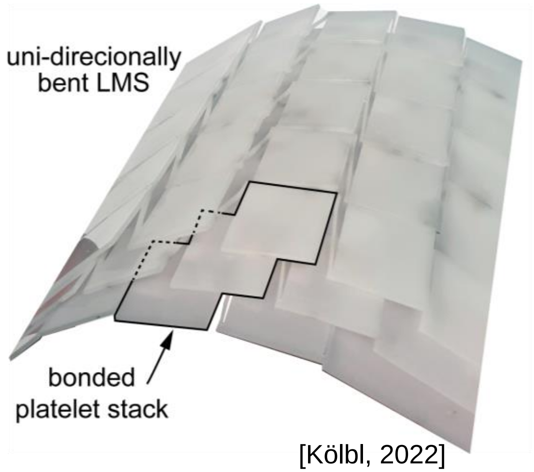
An adaptive skin is always a compromise

1st Concept bi-axially morphing skin system
Working principle



[Kölbl, 2022]

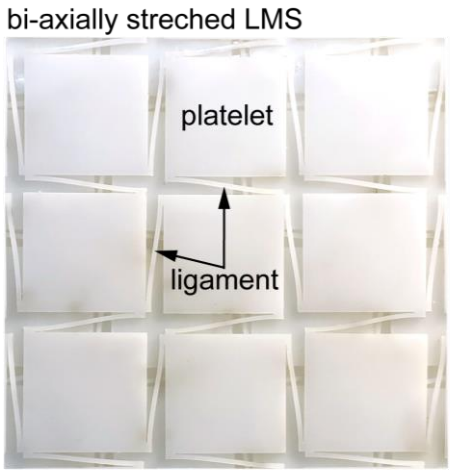




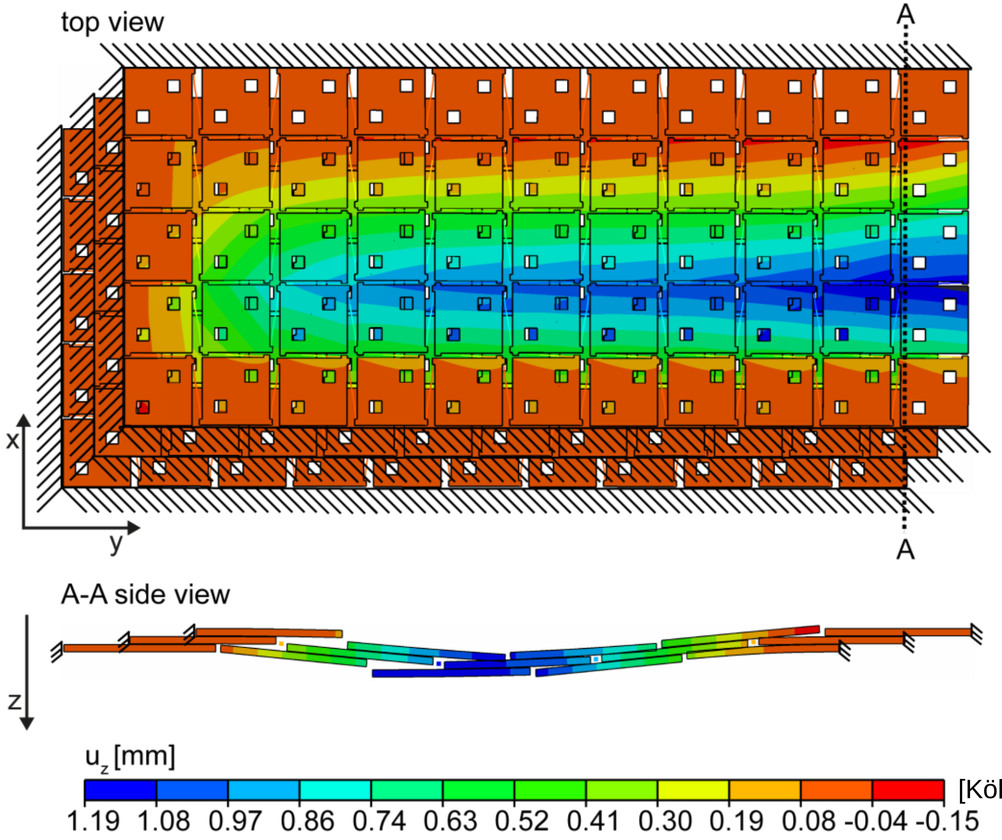
[Kölbl, 2022]

- 3 shifted platelets form a stack
- Overlapping platelet stacks
  - Create a closed surface
  - Provide local out-of-plane stiffness
  - Move relative to each other
- Ligaments connecting platelet stacks
  - Provide in-plane compliance
  - Meander for Zero Poisson's ratio

1st Concept bi-axially morphing skin system
Challenges



[Kölbl, 2022]

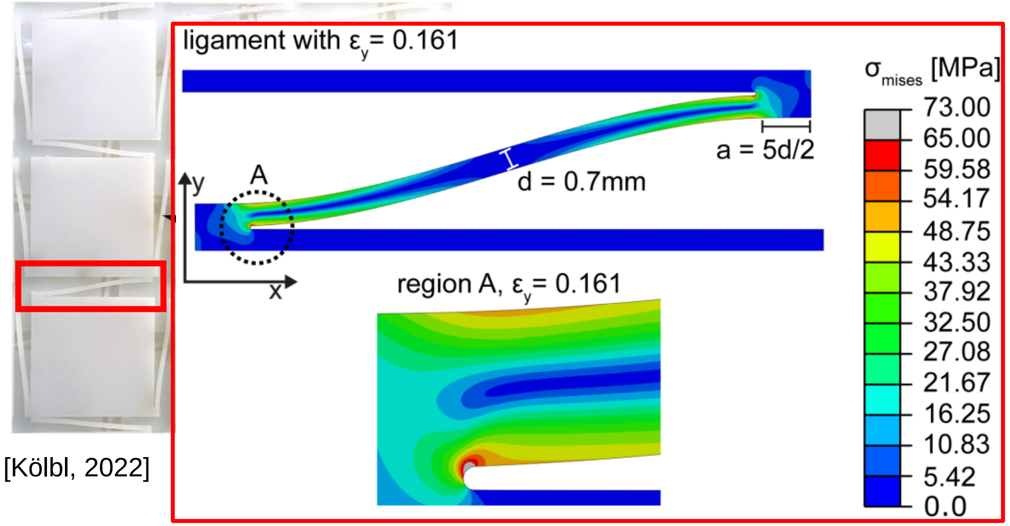


[Kölbl, 2022]

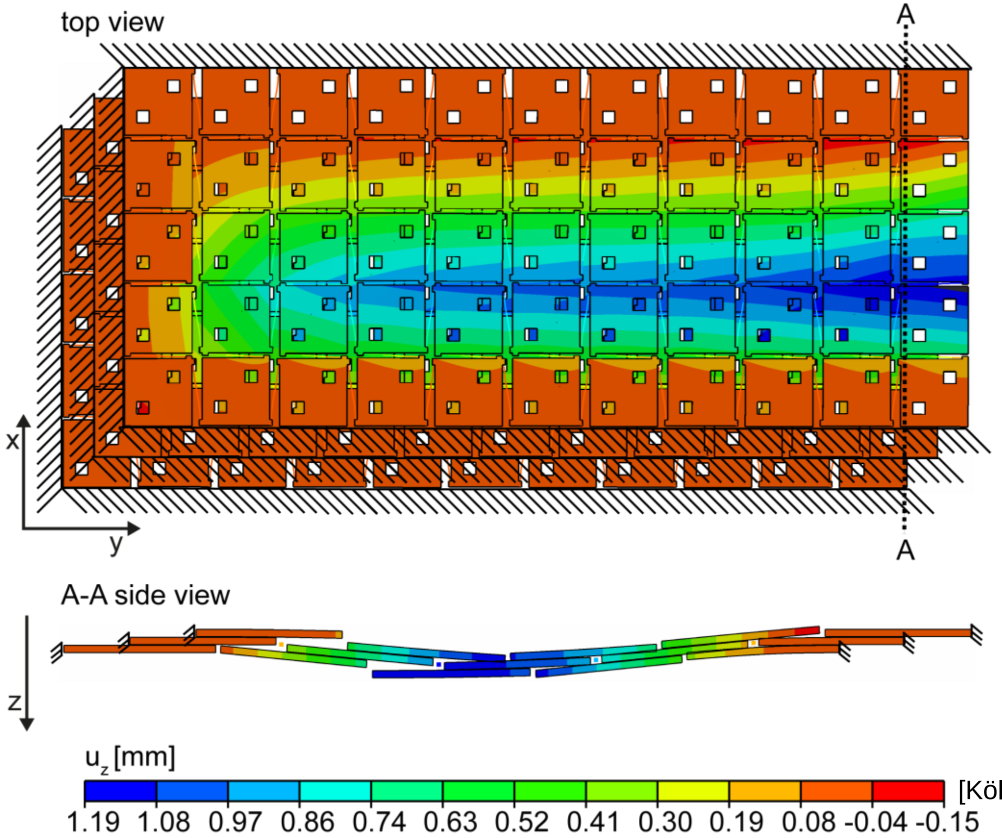
- Ligament stresses at 16.1% in-plane strain
  - Stress concentration
  - Local Plastification

- Out-of plane deformation under 632 Pa (Cessna)
  - Global out-of-plane stiffness sufficient only with regular structural support

1st Concept bi-axially morphing skin system
Challenges



[Kölbl, 2022]



[Kölbl, 2022]

- Ligament stresses at 16.1% in-plane strain
  - Stress concentration
  - Local Plastification
- Out-of plane deformation under 632 Pa (Cessna)
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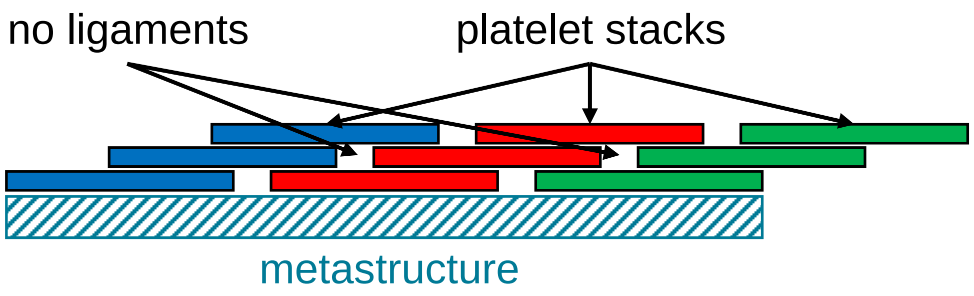
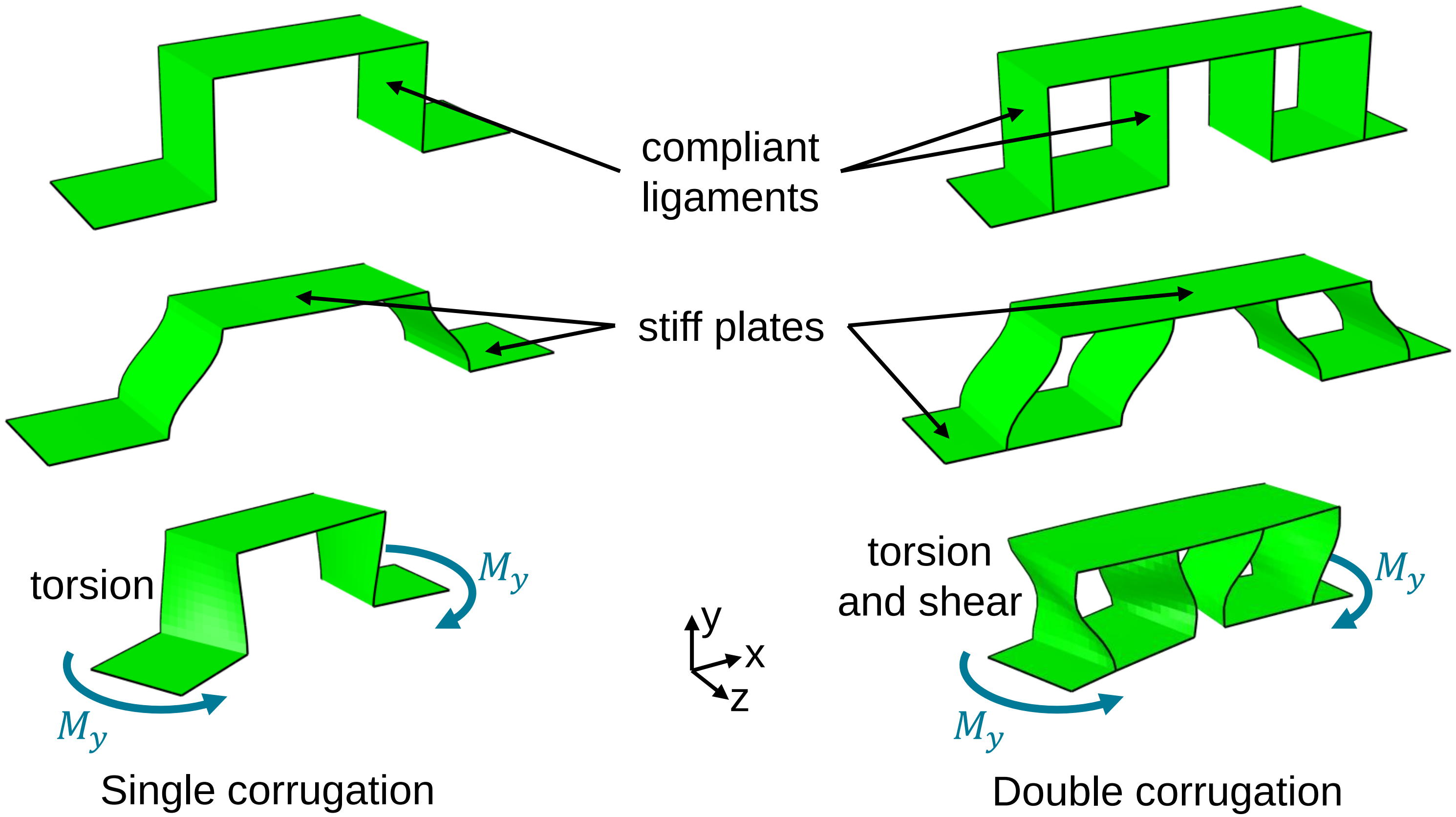
2^{nd} Iteration bi-axially morphing skin system

Working principle



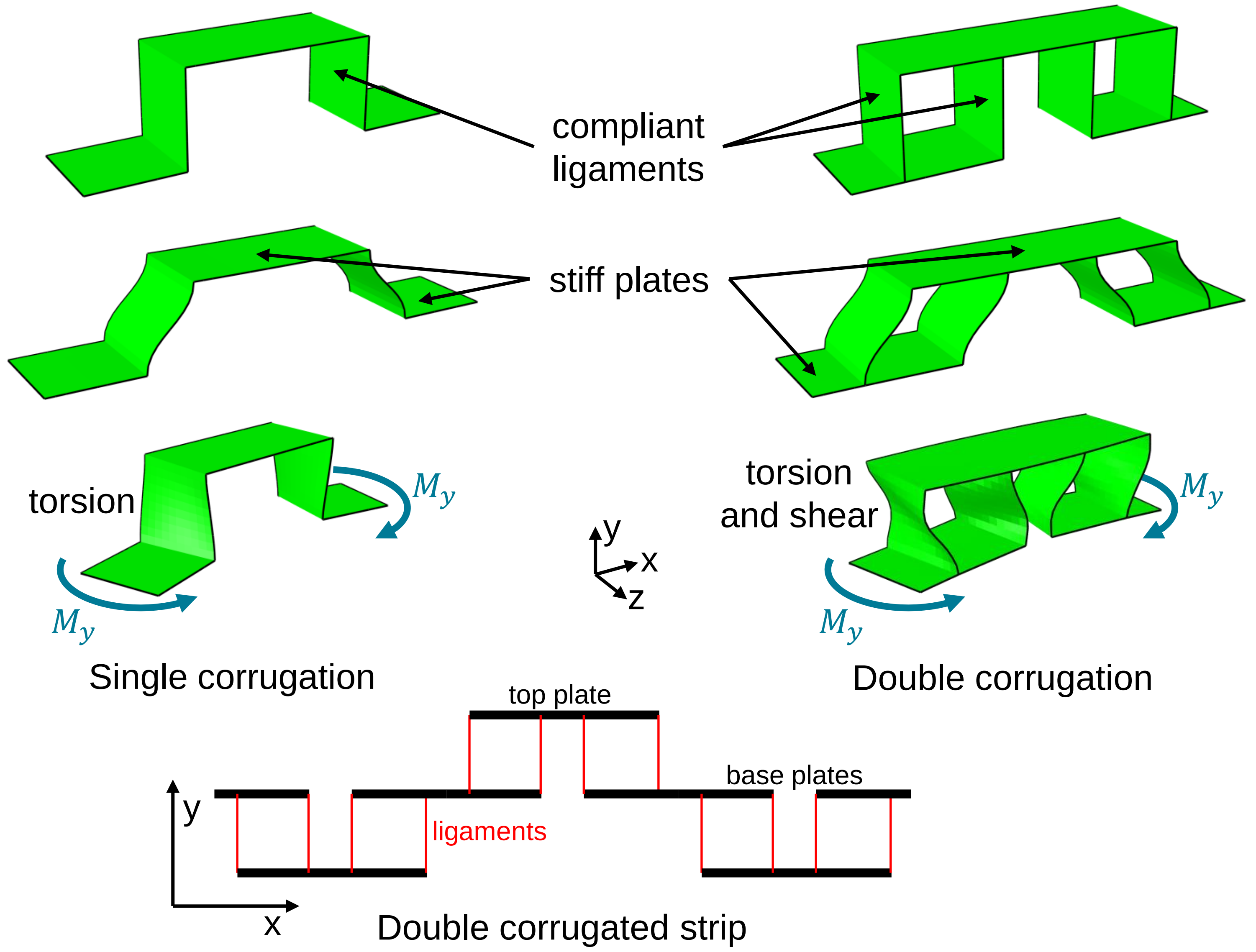
- Platelet stacks provide
  - Local out-of-plane stiffness
  - Closed surface
- Metastructure
  - Supports and positions platelet stacks
  - No ligaments required for platelet stacks
  - Provides global mechanical properties
- Requirements on metastructure
  - Highly orthotropic
  - Lightweight
  - Zero Poisson’s ratio

Design of metastructure



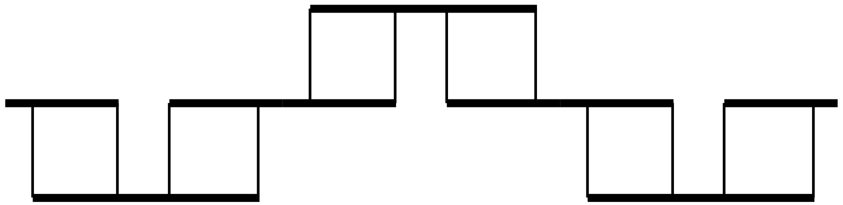
- Soft ligaments connected to stiff plates provide in-plane compliance
- Double corrugation
  - Higher out-of-plane stiffness
  - Increased orthotropy

Design of metastructure

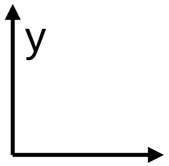


- Soft ligaments connected to stiff plates provide in-plane compliance
- Double corrugation
  - Higher out-of-plane stiffness
  - Increased orthotropy
- Double corrugated strip also exhibits increased orthotropy

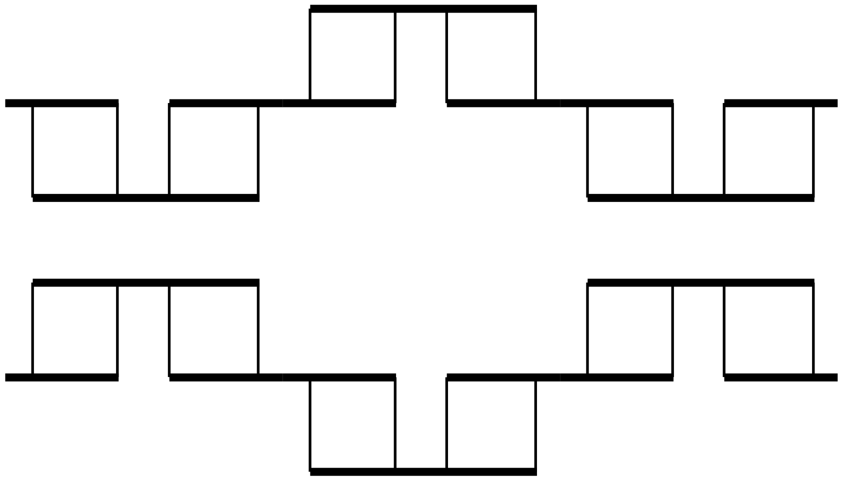
Design of metastructure



- Metastructure assembled from double corrugated strips



Design of metastructure



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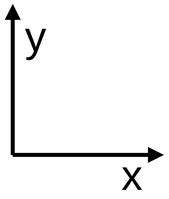
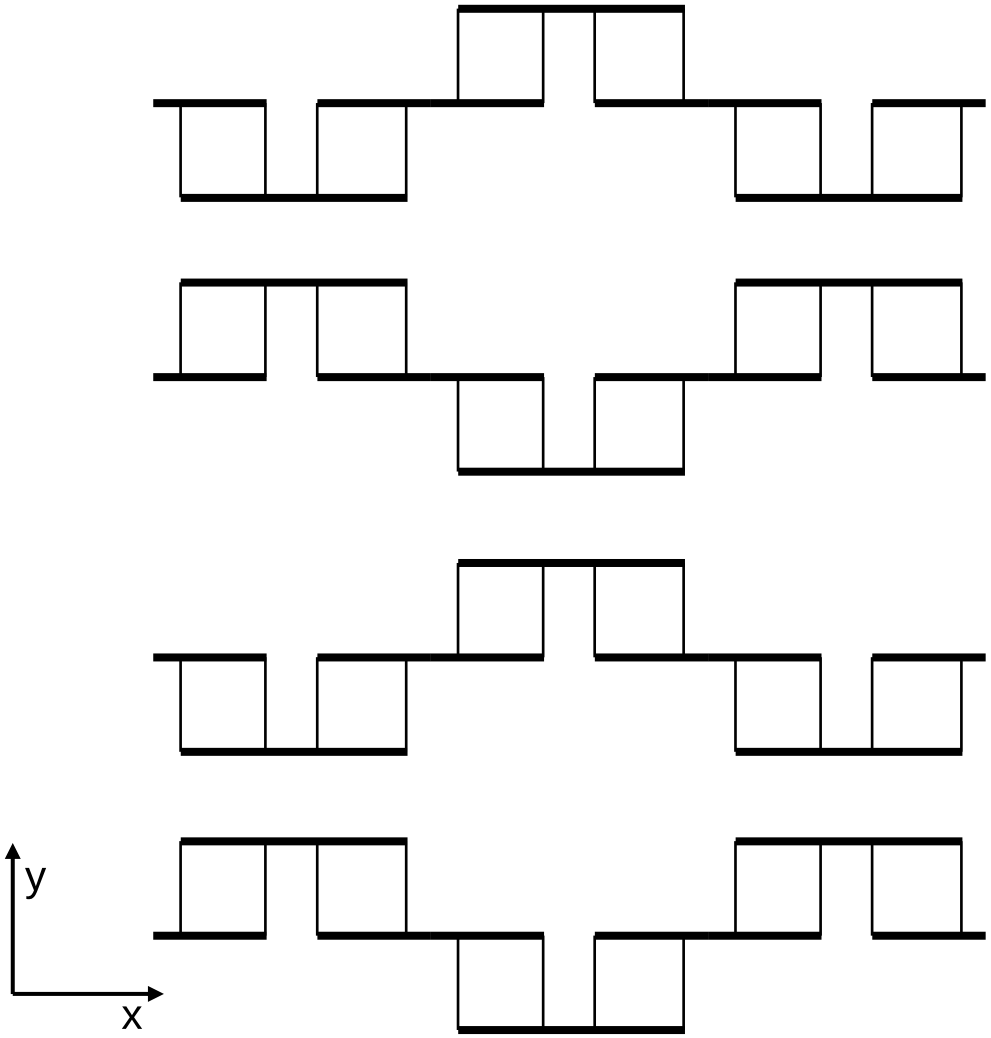


Design of metastructure



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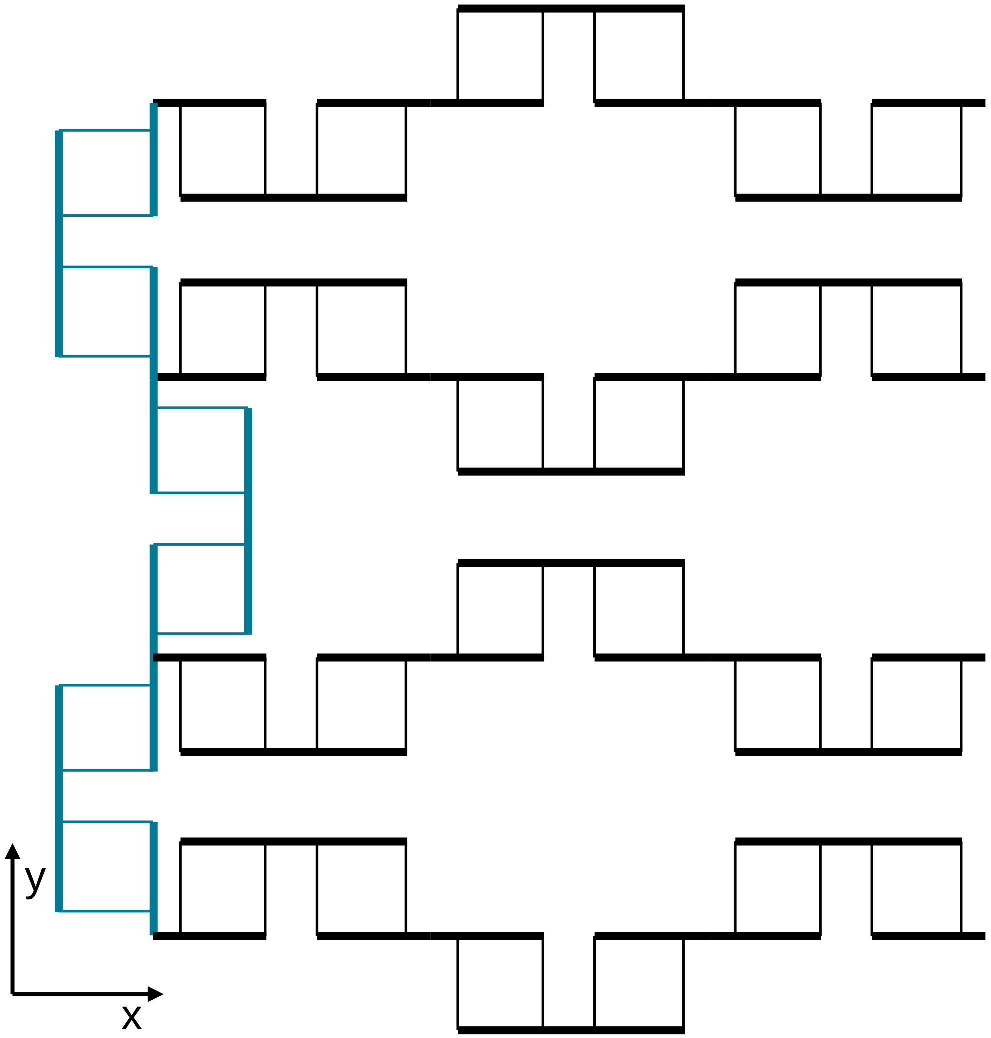
Design of metastructure



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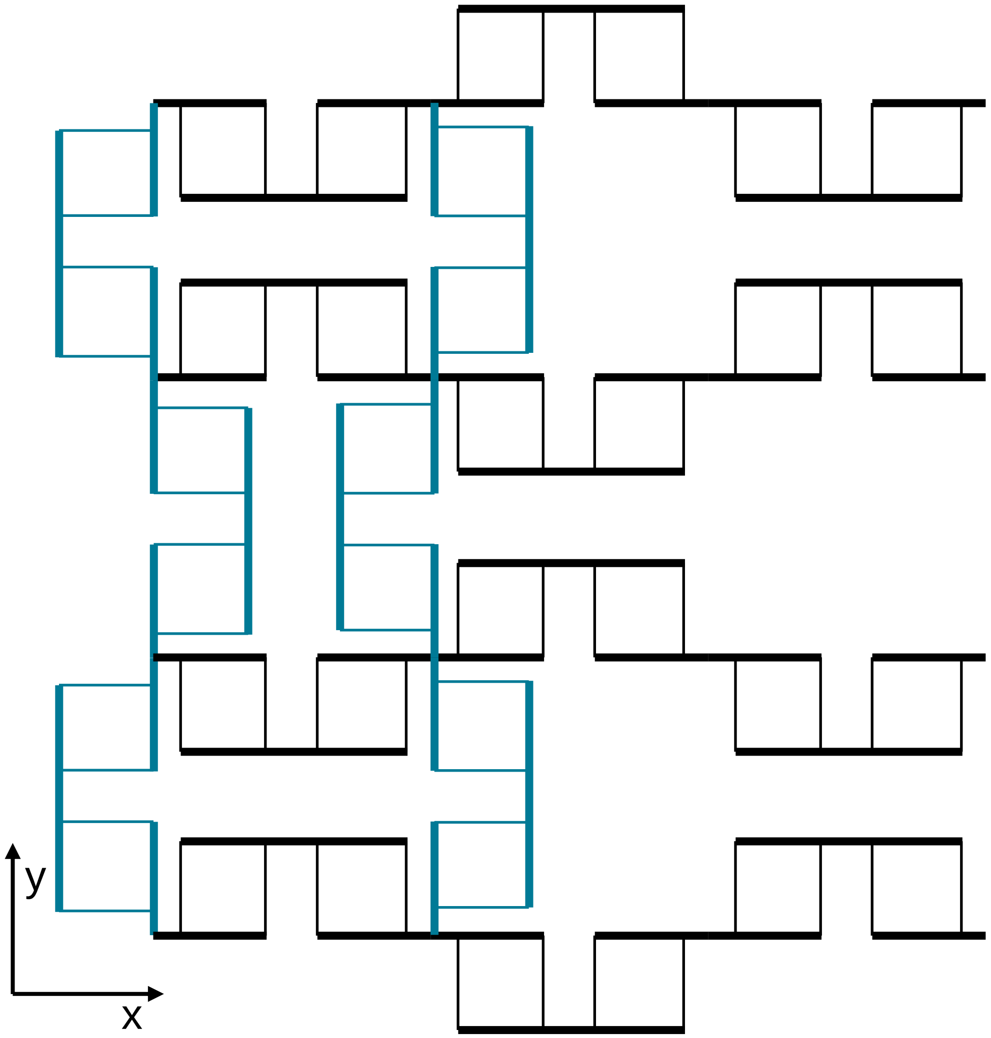
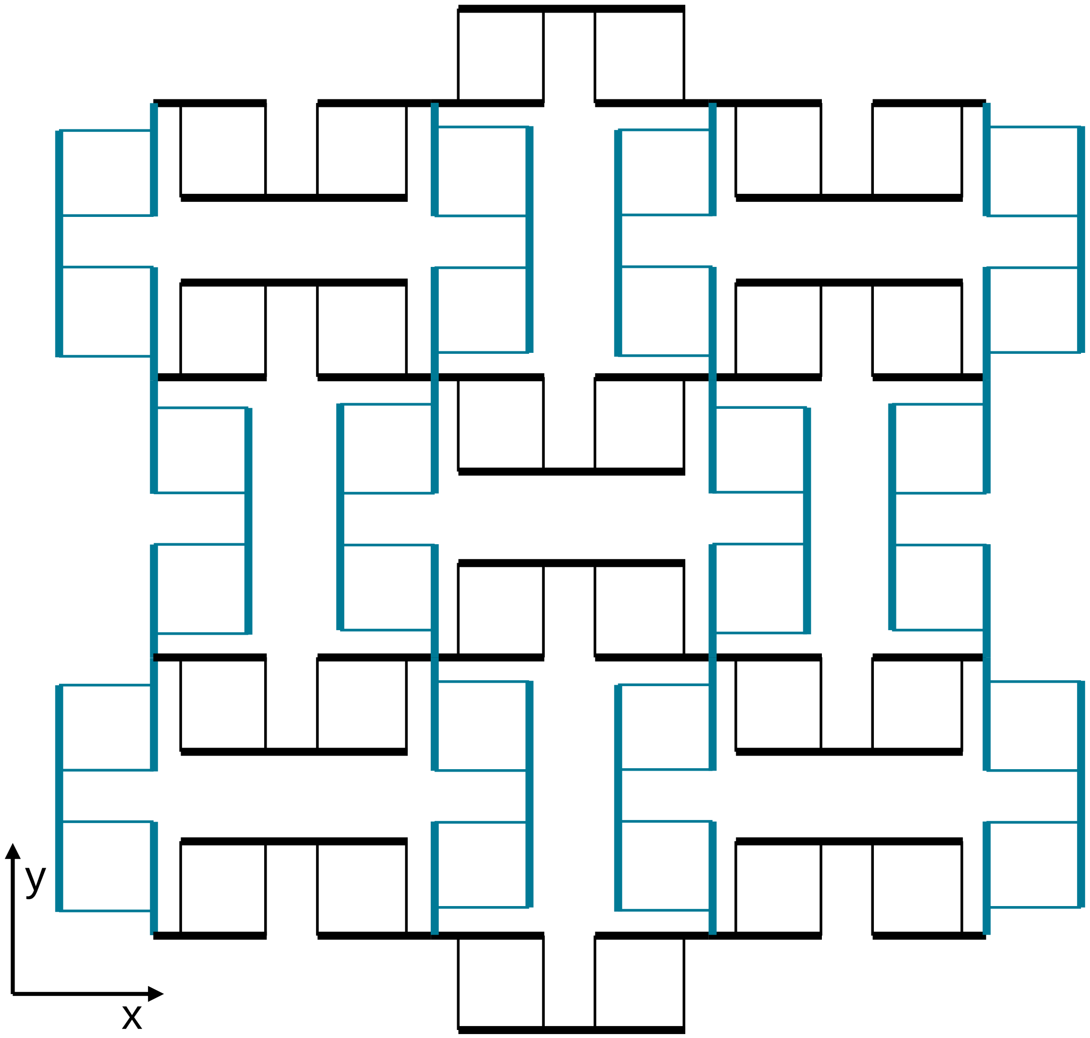
Design of metastructure



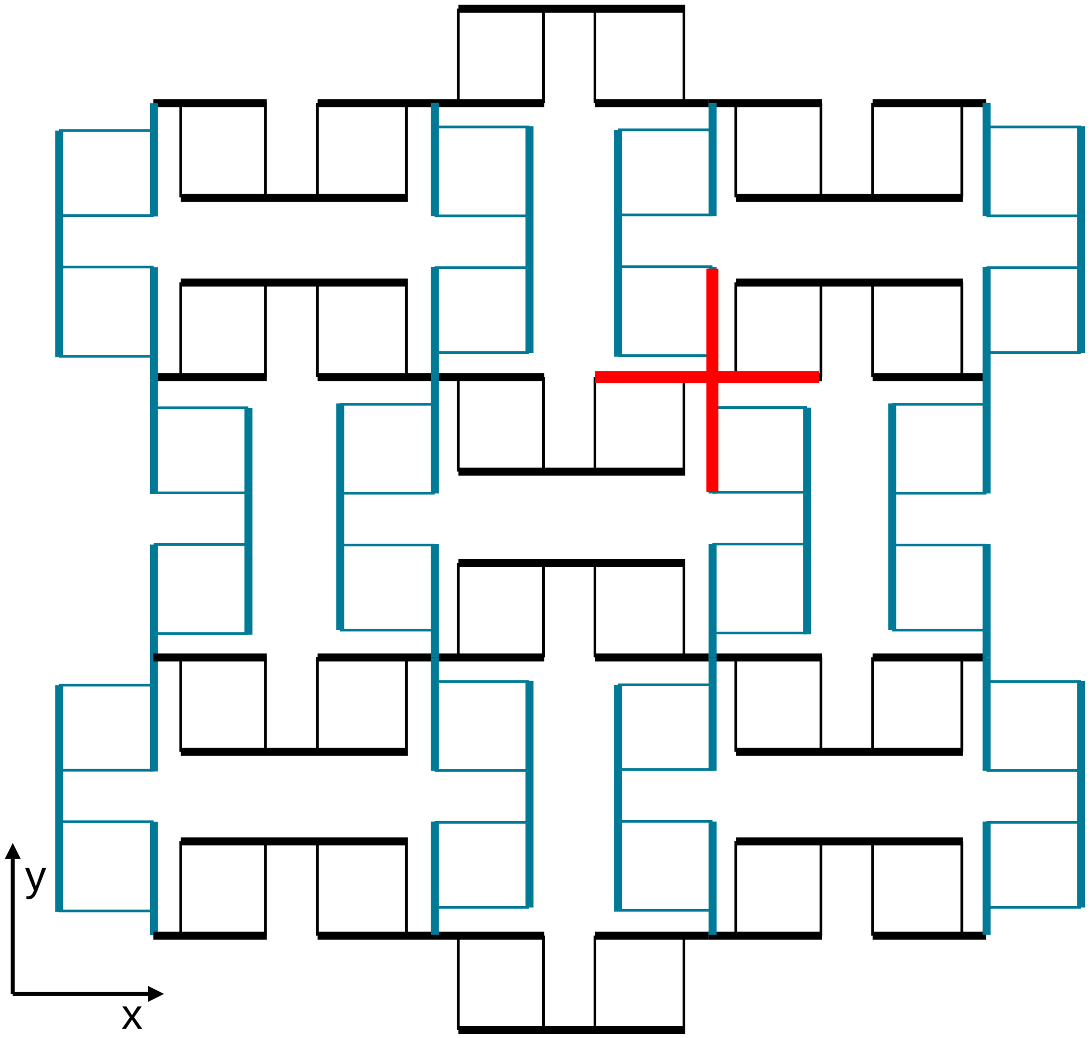
- Metastructure assembled from double corrugated strips

Design of metastructure



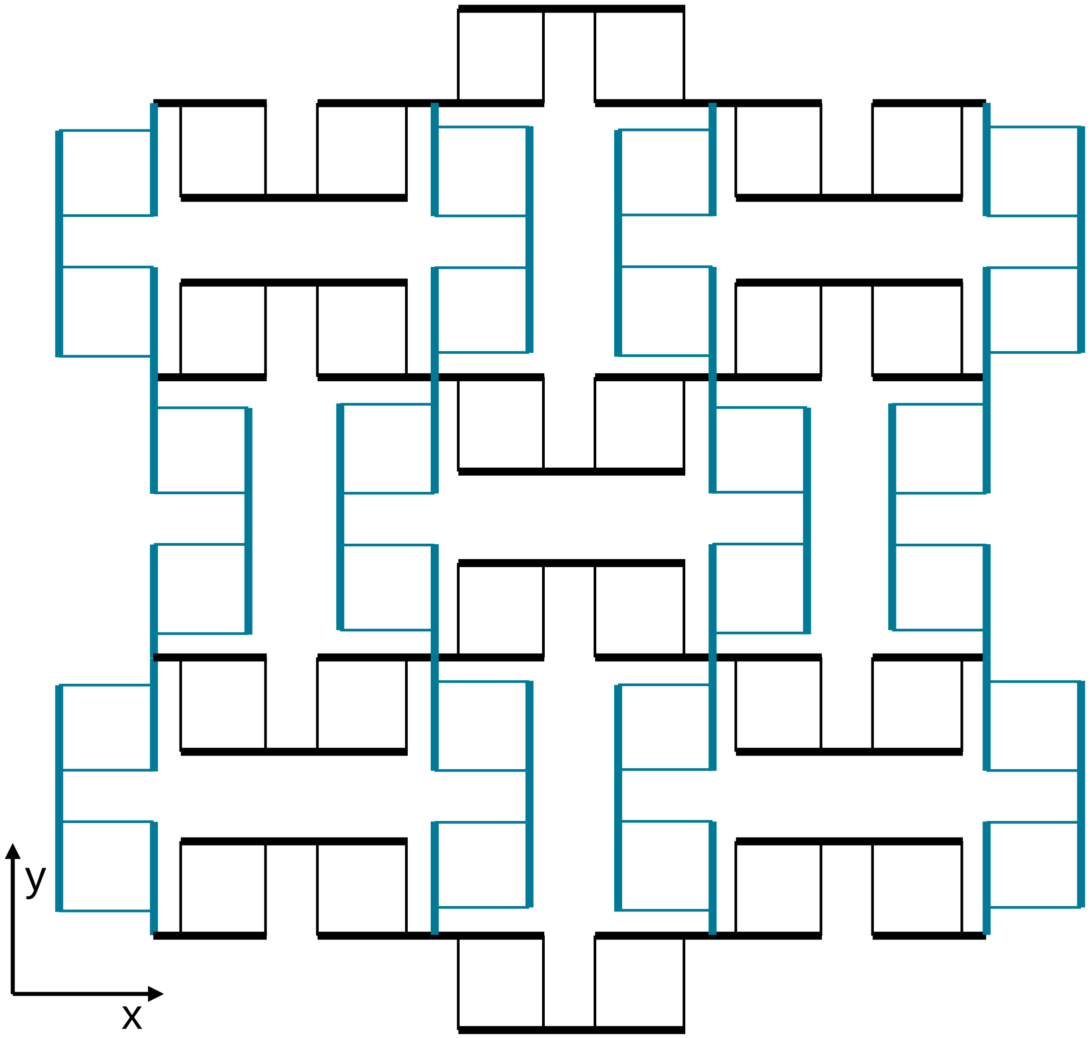
- Metastructure assembled from double corrugated strips
- Bi-axial deformation in tension and compression
- Extreme orthotropic behaviour
  - In-plane compliant
  - Out-of-plane stiff

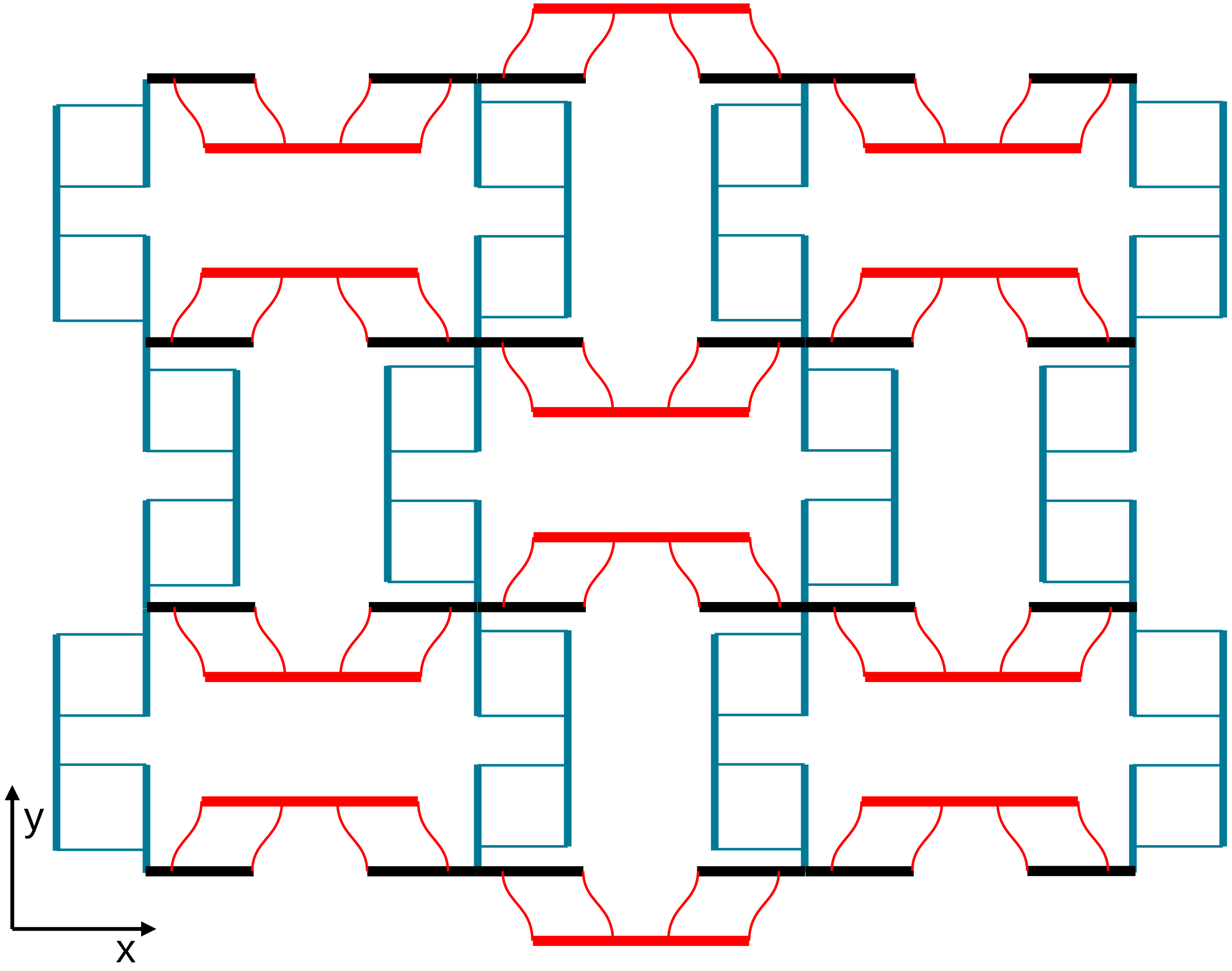
Design of metastructure



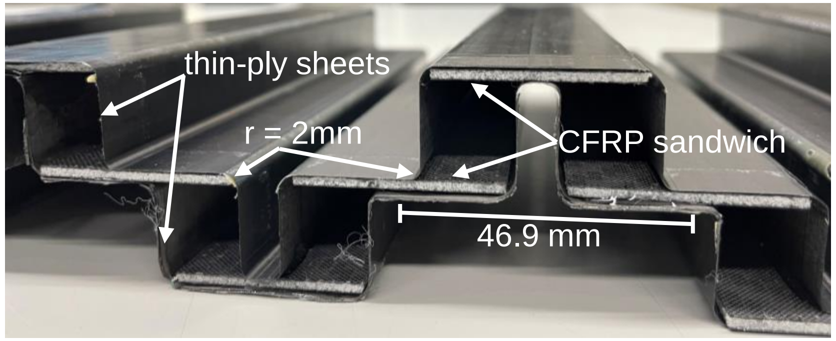
- Metastructure assembled from double corrugated strips
- Bi-axial deformation in tension and compression
- Extreme orthotropic behaviour
  - In-plane compliant
  - Out-of-plane stiff
- Platelet stacks bonded to crossing points

Zero Poisson's ratio deformation pattern



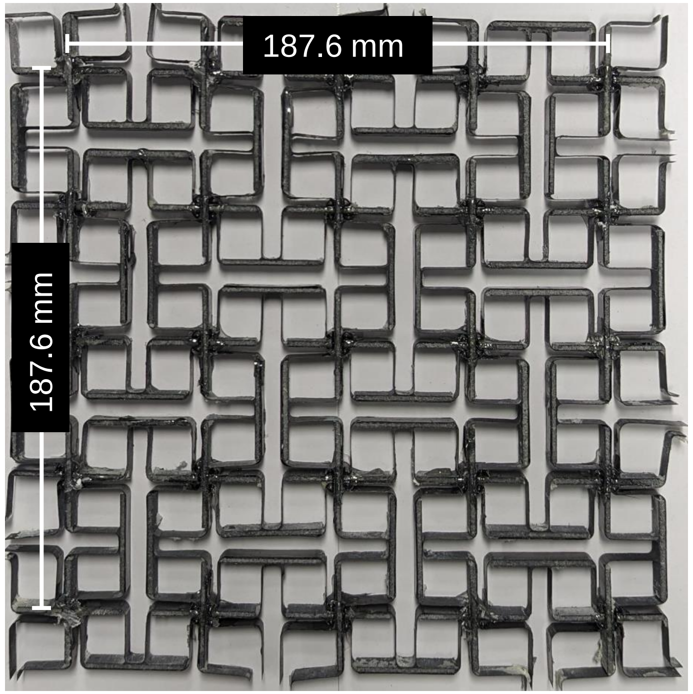


Manufacturing process metastructure



Double corrugated plates

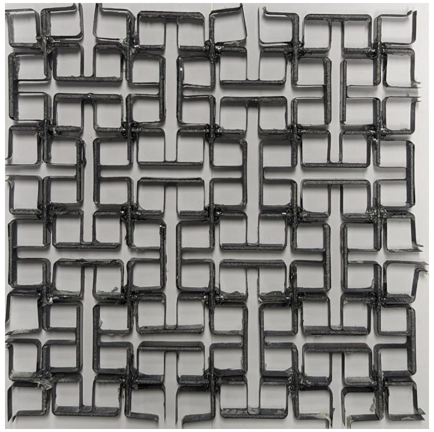
Corrugated strips



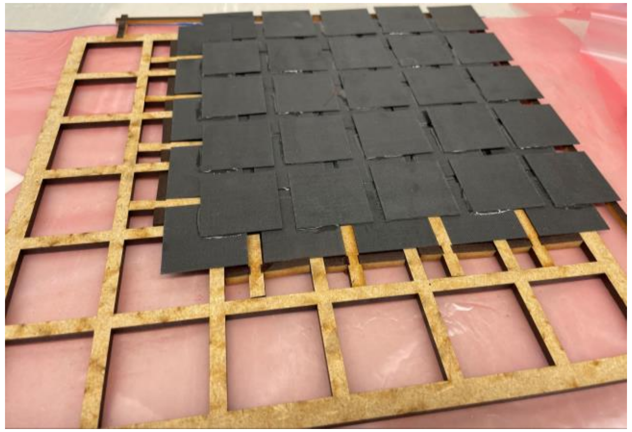
Metastructure

- Thin-ply sheets
  - NTPT T800/402, 40 g/m^2
  - Layup [0°, 90°, 0°]
  - Total thickness 165 μm
- CFRP sandwich
  - 2 mm PET foam core
  - 160 g/m^2 CF/epoxy weave
- Bonding of sandwich and thin-ply sheets with epoxy resin
- Cutting strips (10 mm wide)
- Assembly with bonded cross-lap joints
- Approximately 2 kg/m^2

Manufacturing process skin system

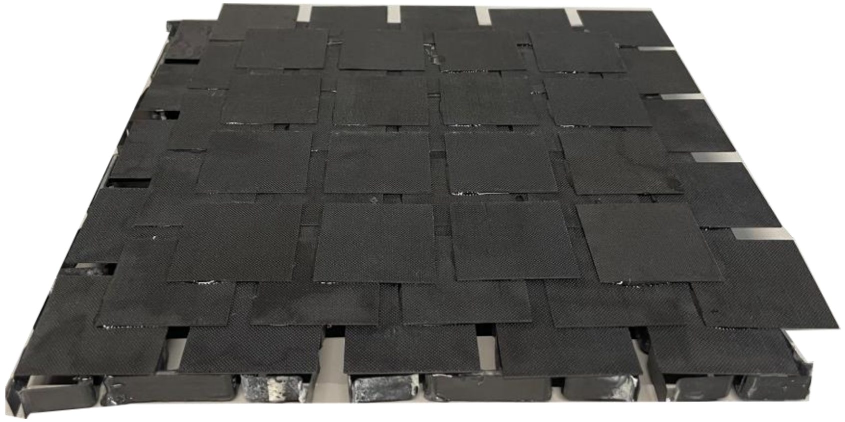


Metastructure



Platelet stack assembly

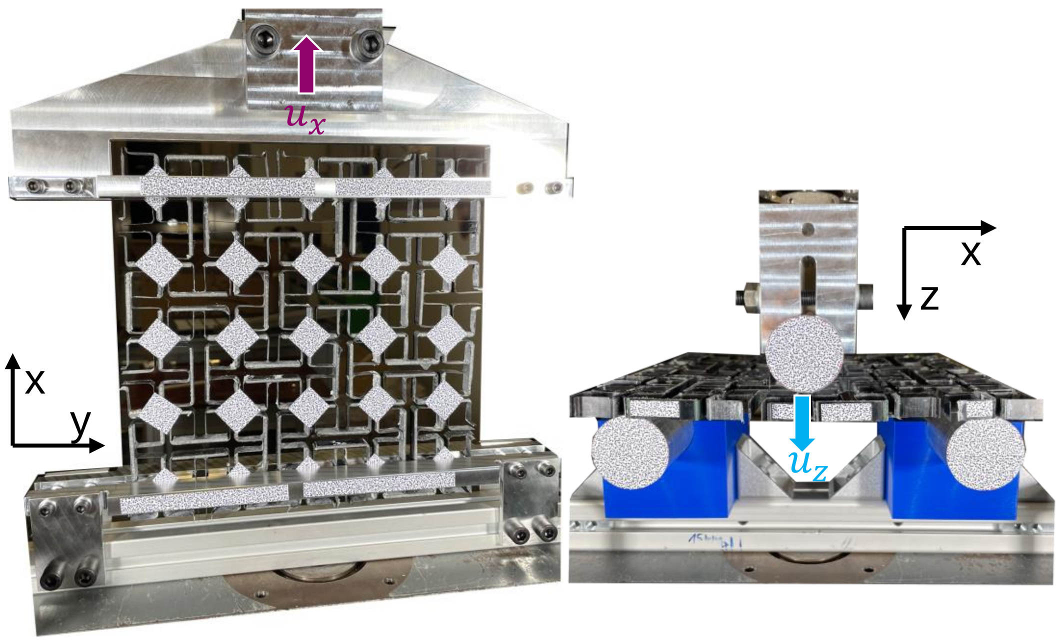
Bonding stacks and metastructure

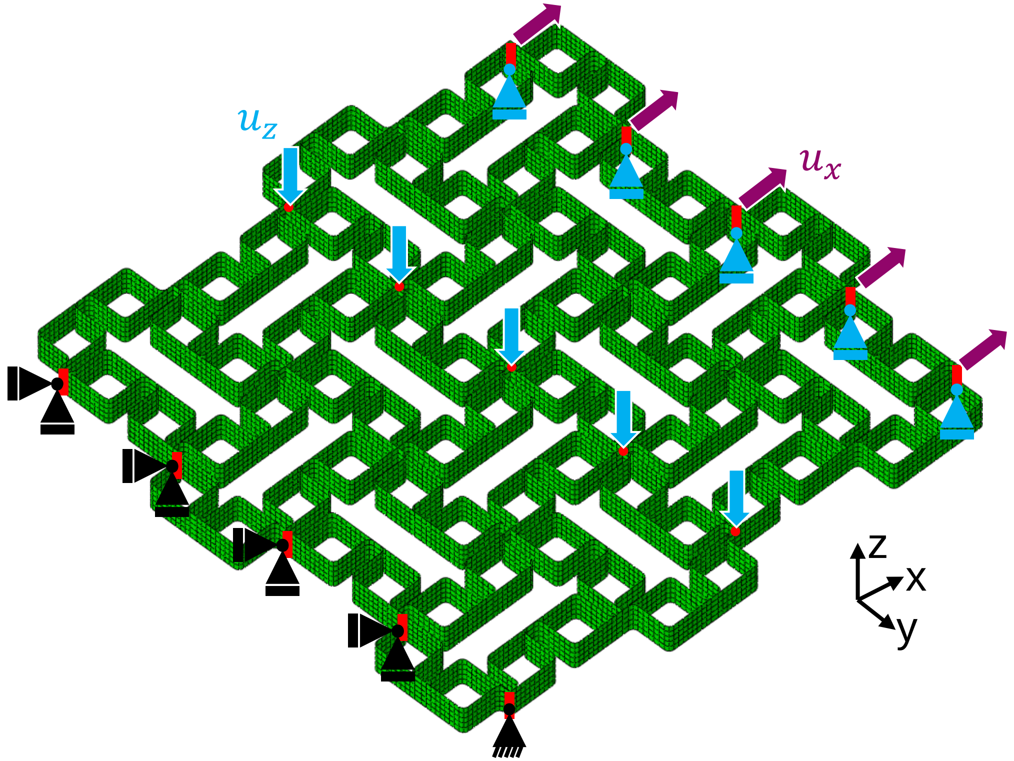


Skin system

- Platelets
  - $[0°, 90°]_s$
  - 150 g/m^2 TC250/HTS40
- Platelet stacks
  - Assembly with rig
  - Bonded with epoxy resin
- Skin system
  - Bonded with epoxy resin
  - Approximately 5 kg/m^2

Testing and simulation set-up metastructure

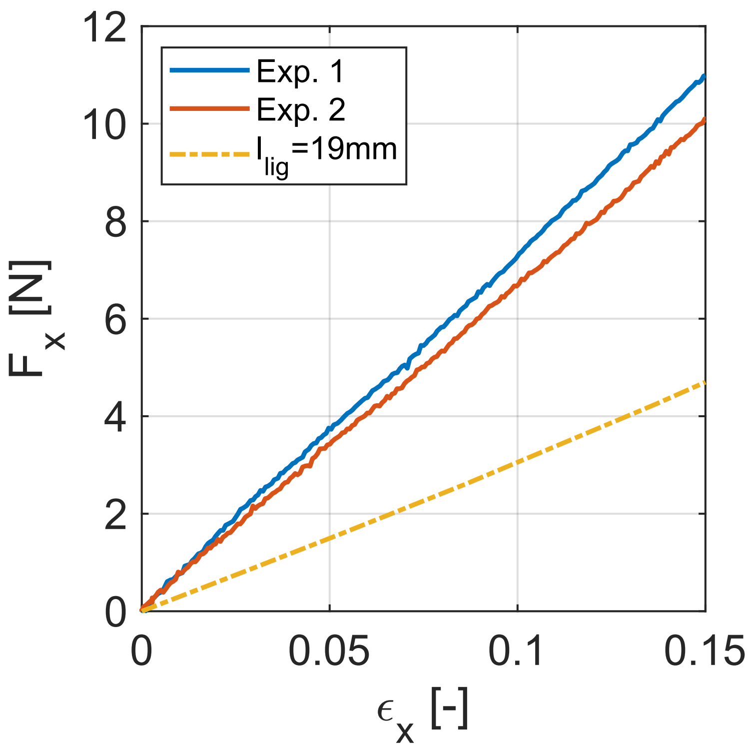


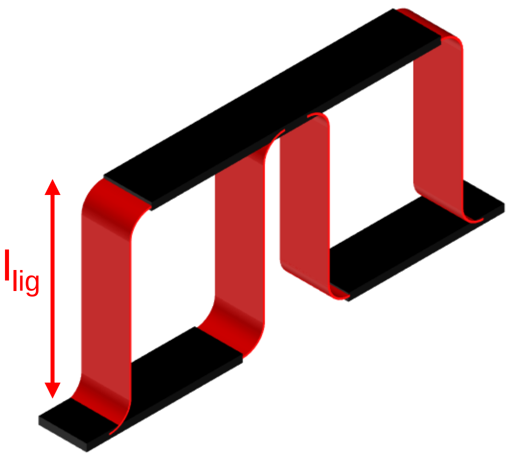


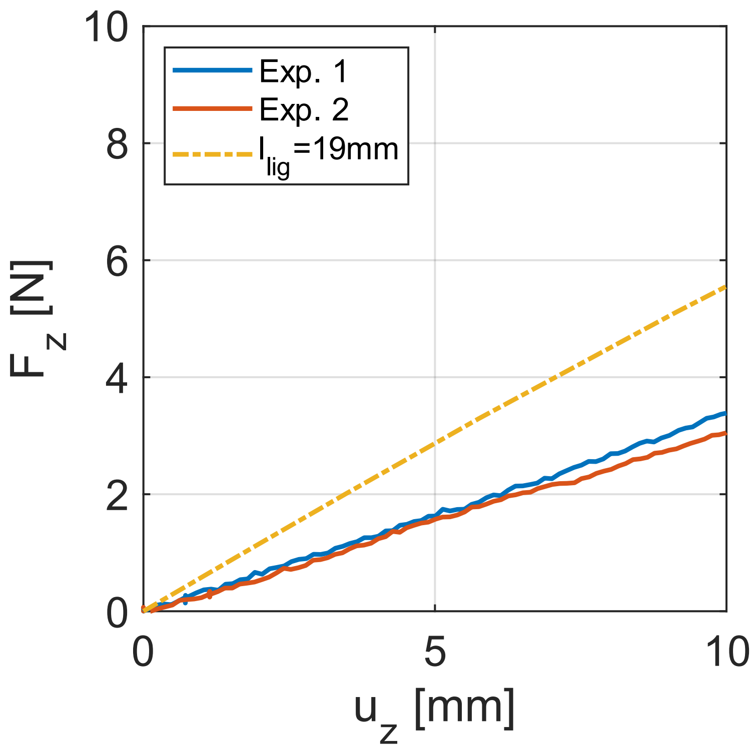
- Experimental set-up
  - In-plane tensile test up to $\varepsilon_x = 15\%$
  - 3-point bending test, $u_z = 10mm$ deflection

- Finite Element model
  - Quadratic shell elements
  - Boundary conditions tensile test
  - Boundary conditions 3-point bending test

Validation of Finite Element model for metastructure



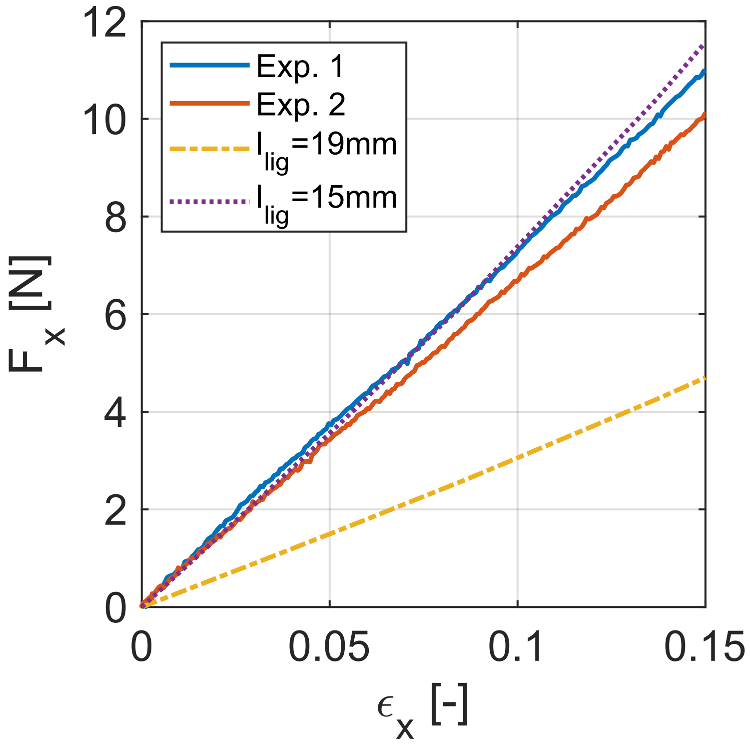


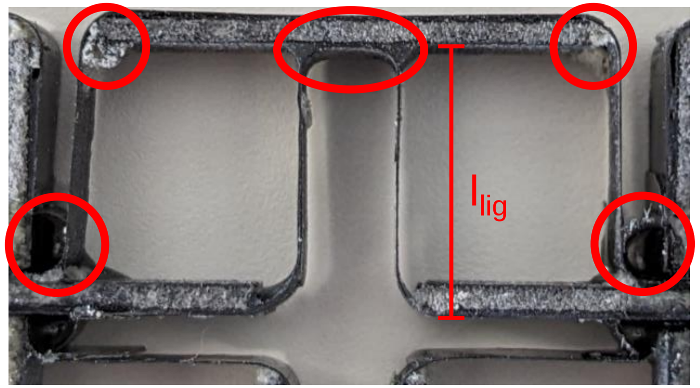


- Tensile response
  - Experiments twice as stiff

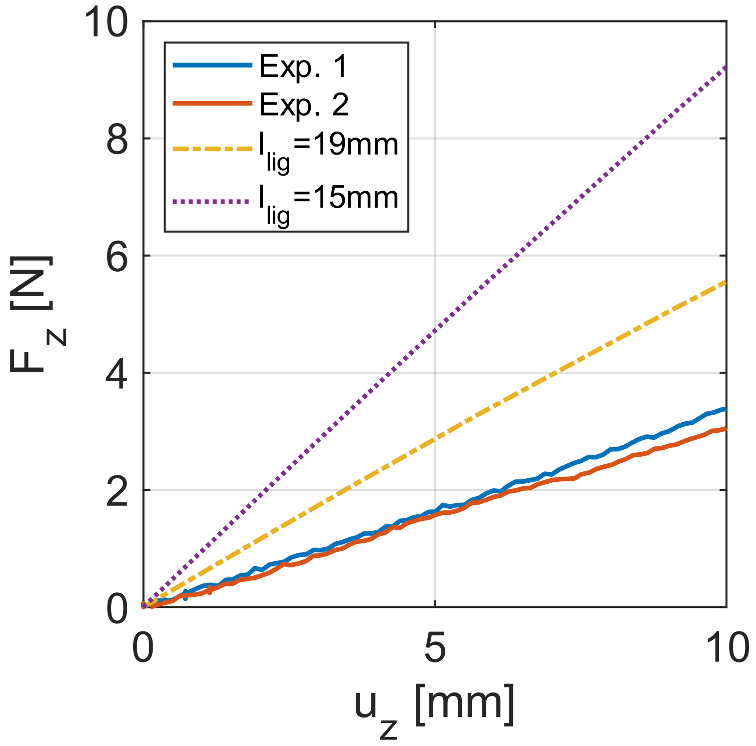
- Bending response
  - Simulation nearly twice as stiff

Validation of Finite Element model
Effect of excessive resin



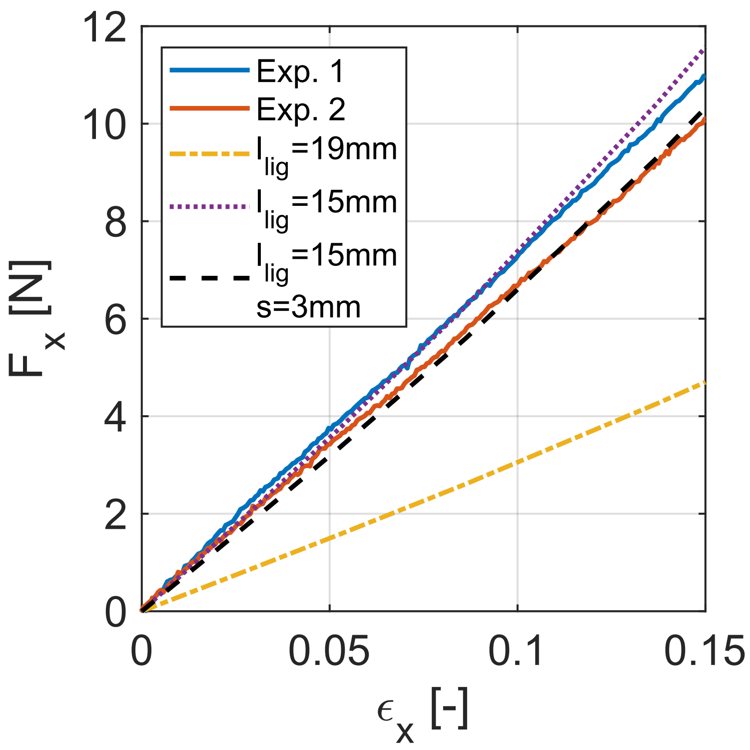


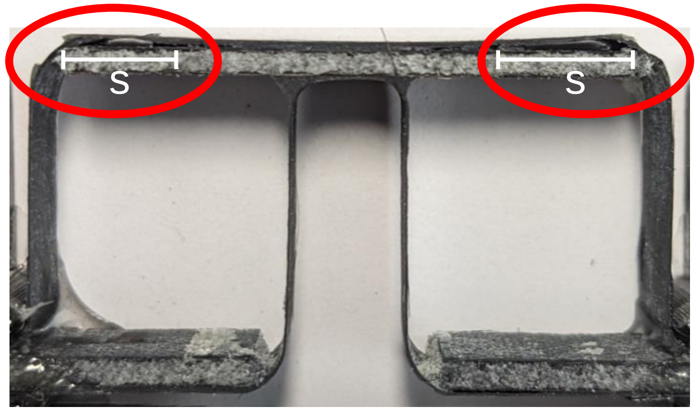
Excessive resin in ligament radii



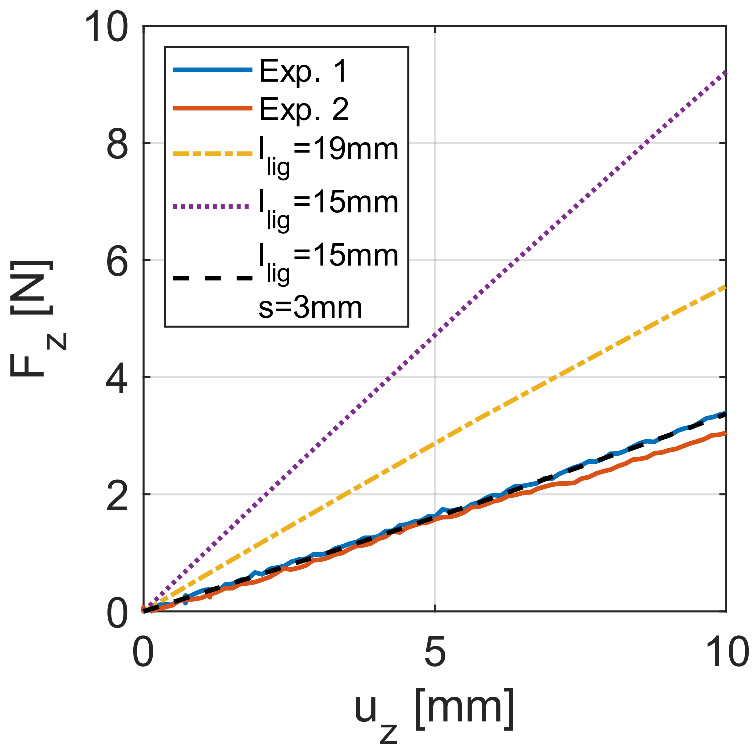
- Tensile response
  - Excessive resin effectively shortens ligaments
  - FEM agrees with experiments
- Bending response
  - Further increased bending stiffness
  - FEM results far off

Validation of Finite Element model
Effect of sandwich ligament interface





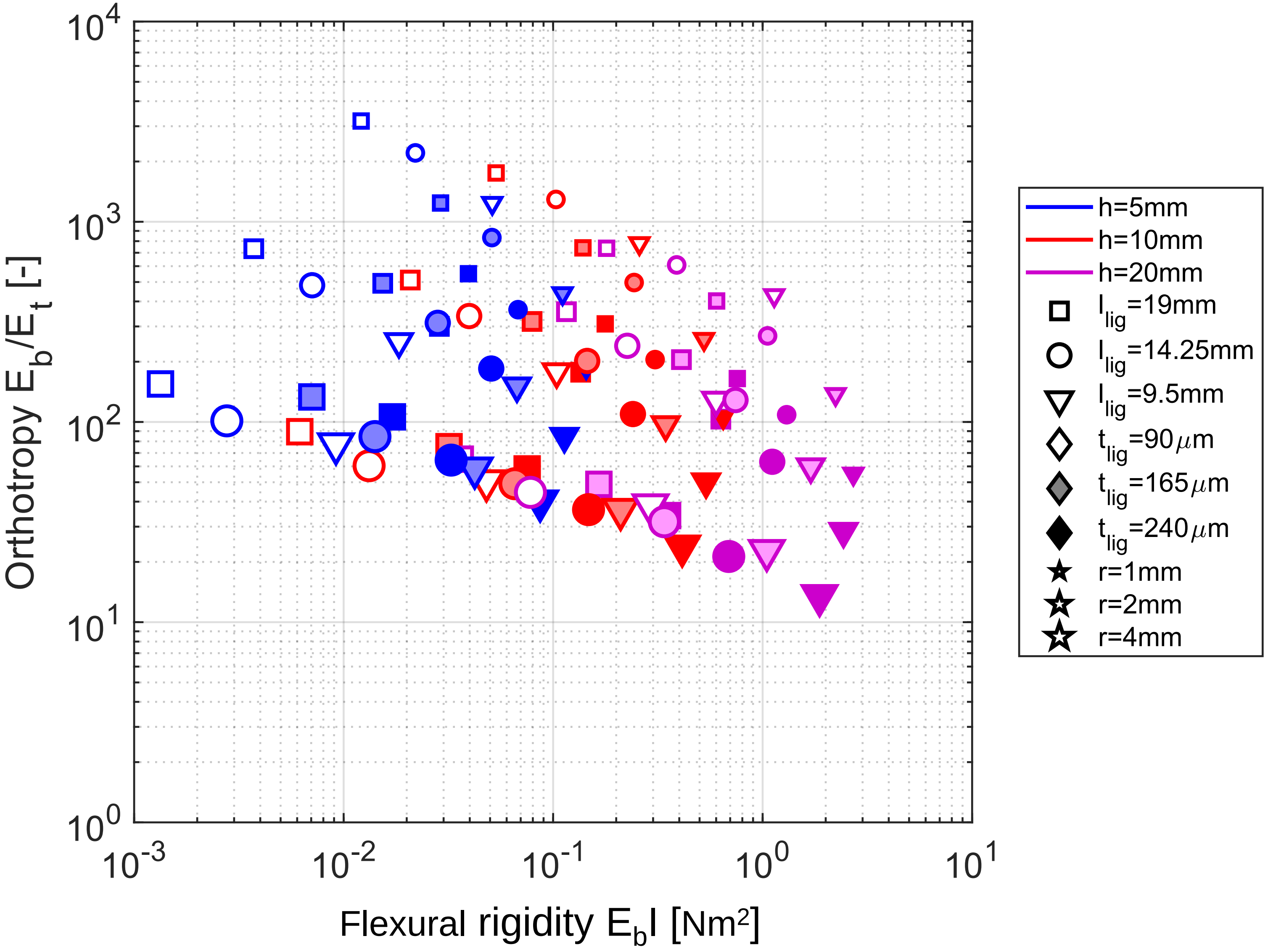
Debonding due to saw cutting

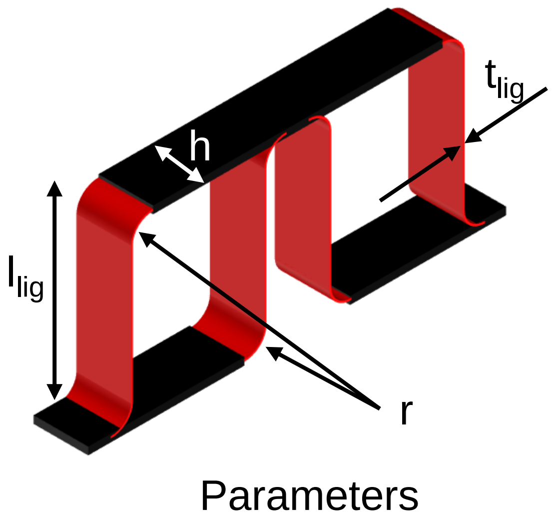


- Tensile response hardly influenced by sandwich – thin-ply sheet interface
- Poisson's ratio: -0.05 (experiments), -0.02 (FEM)

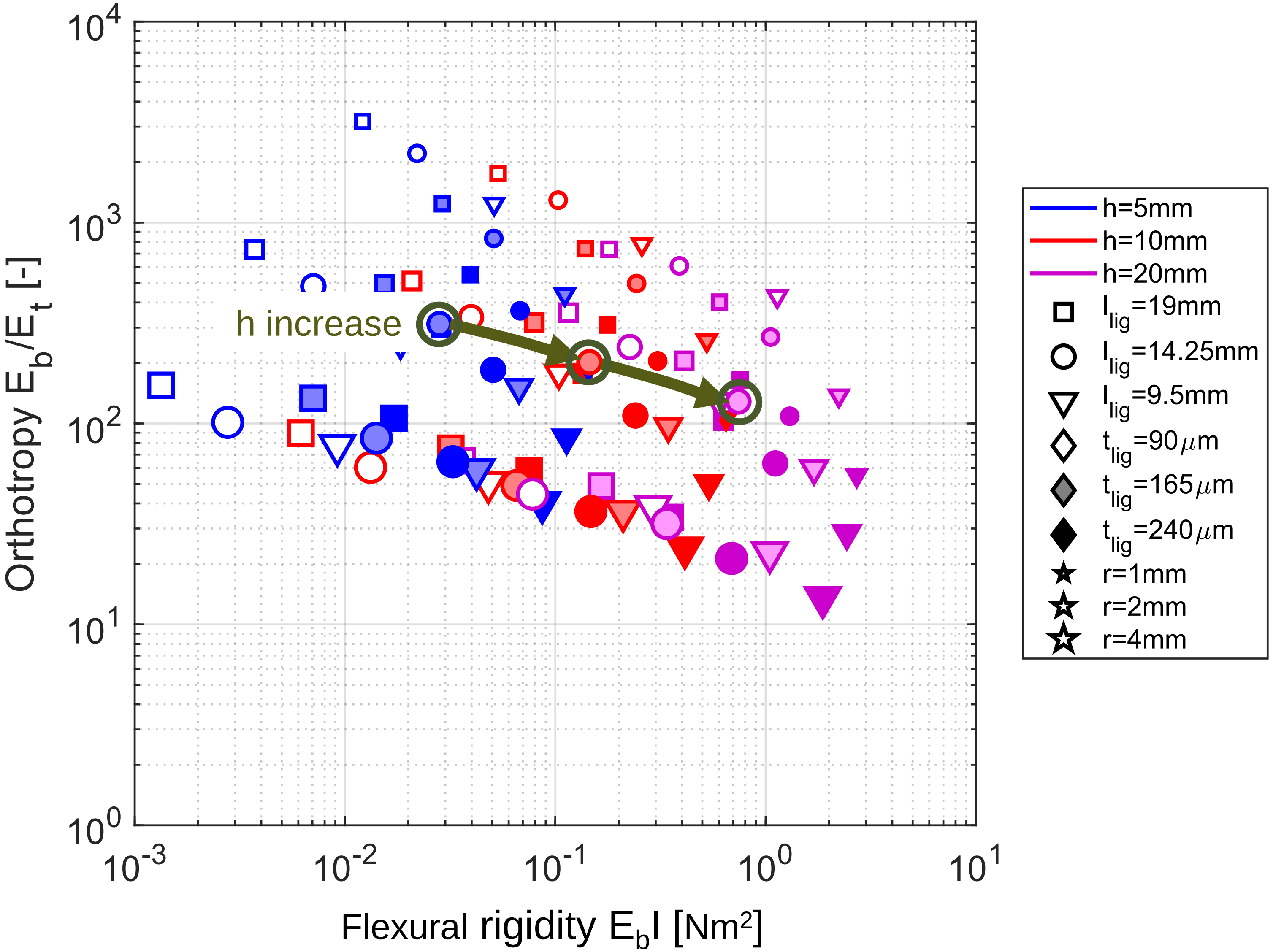
- Bending response highly sensitive to sandwich – thin-ply sheet interface
- Sandwich support crucial

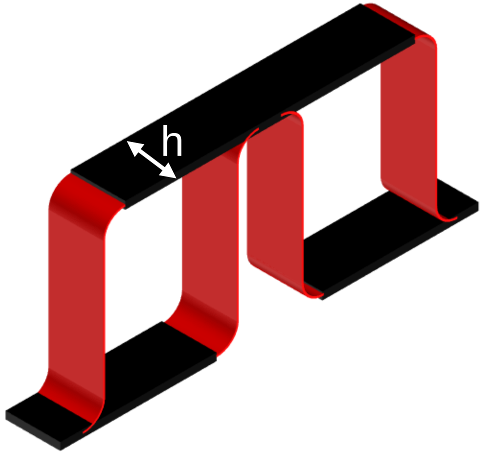
Parametric study of metastructure





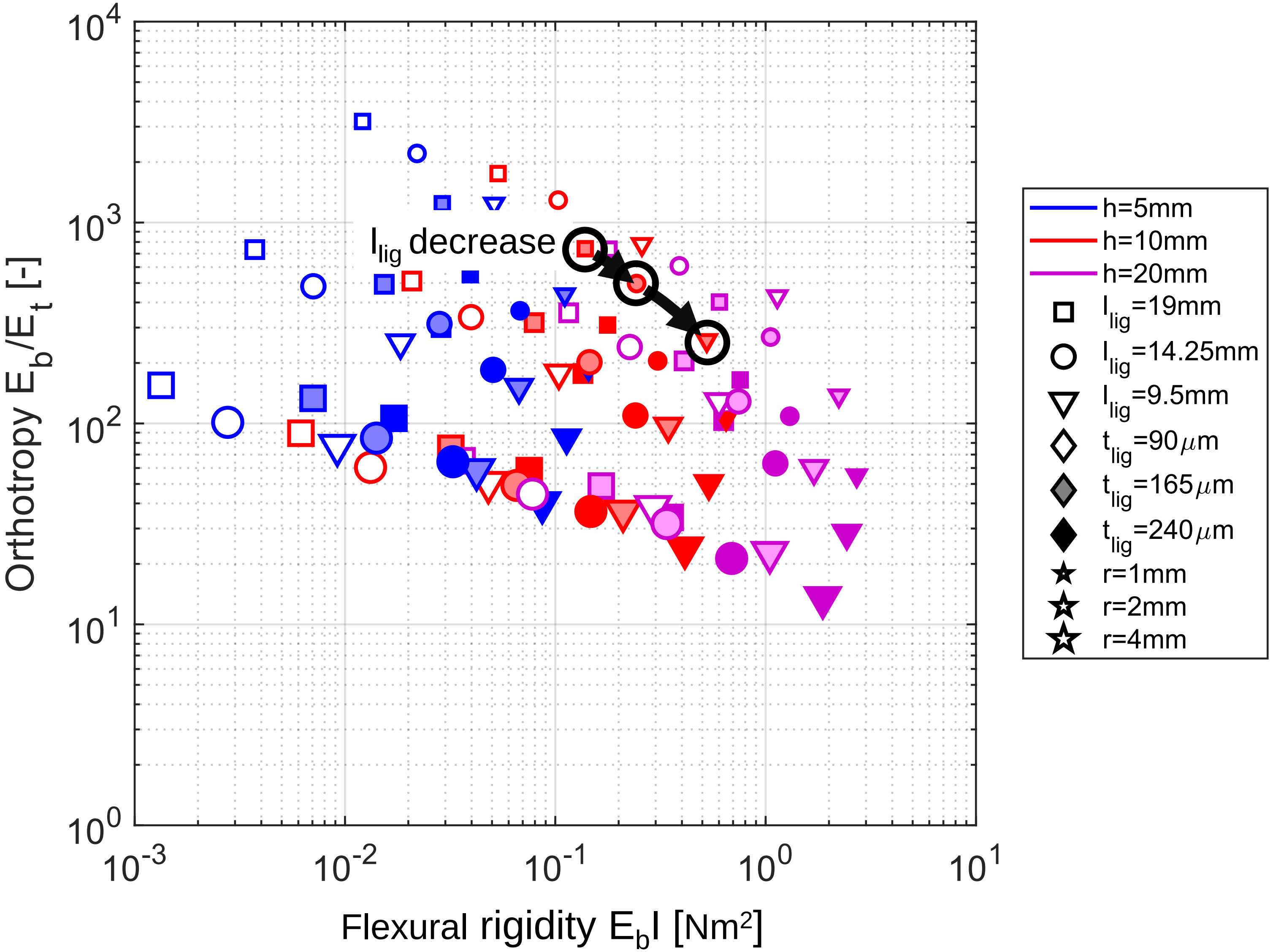
Parametric study of metastructure
Metastructure height

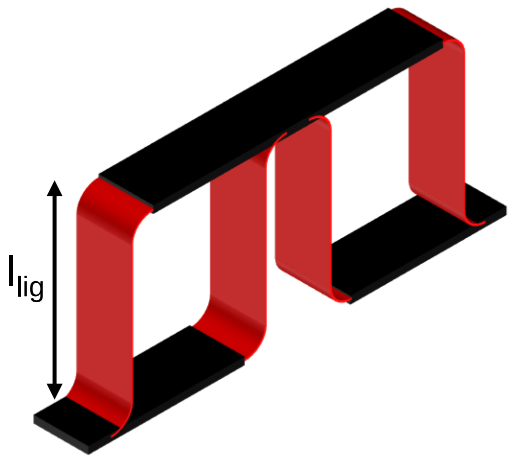




Parameter

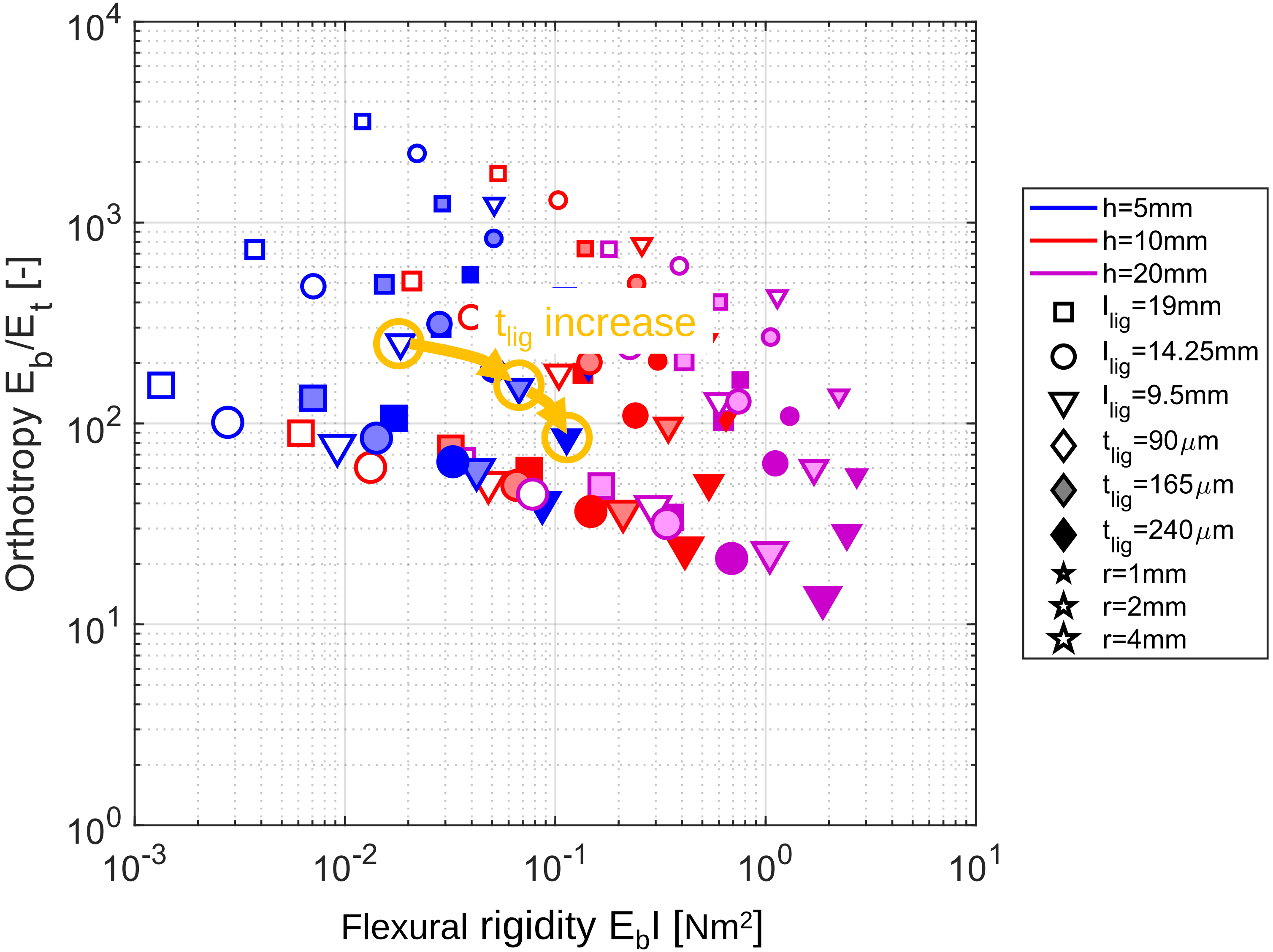
Parametric study of metastructure
Ligament length

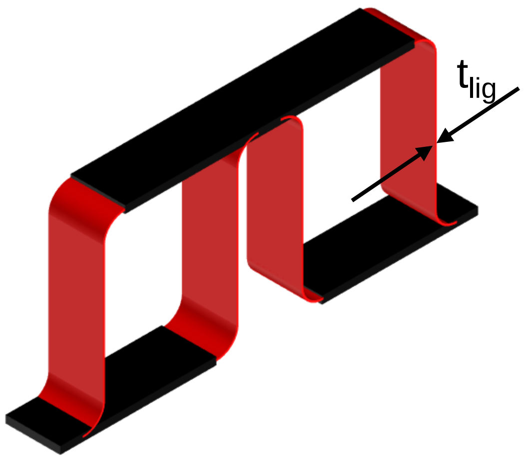




Parameter

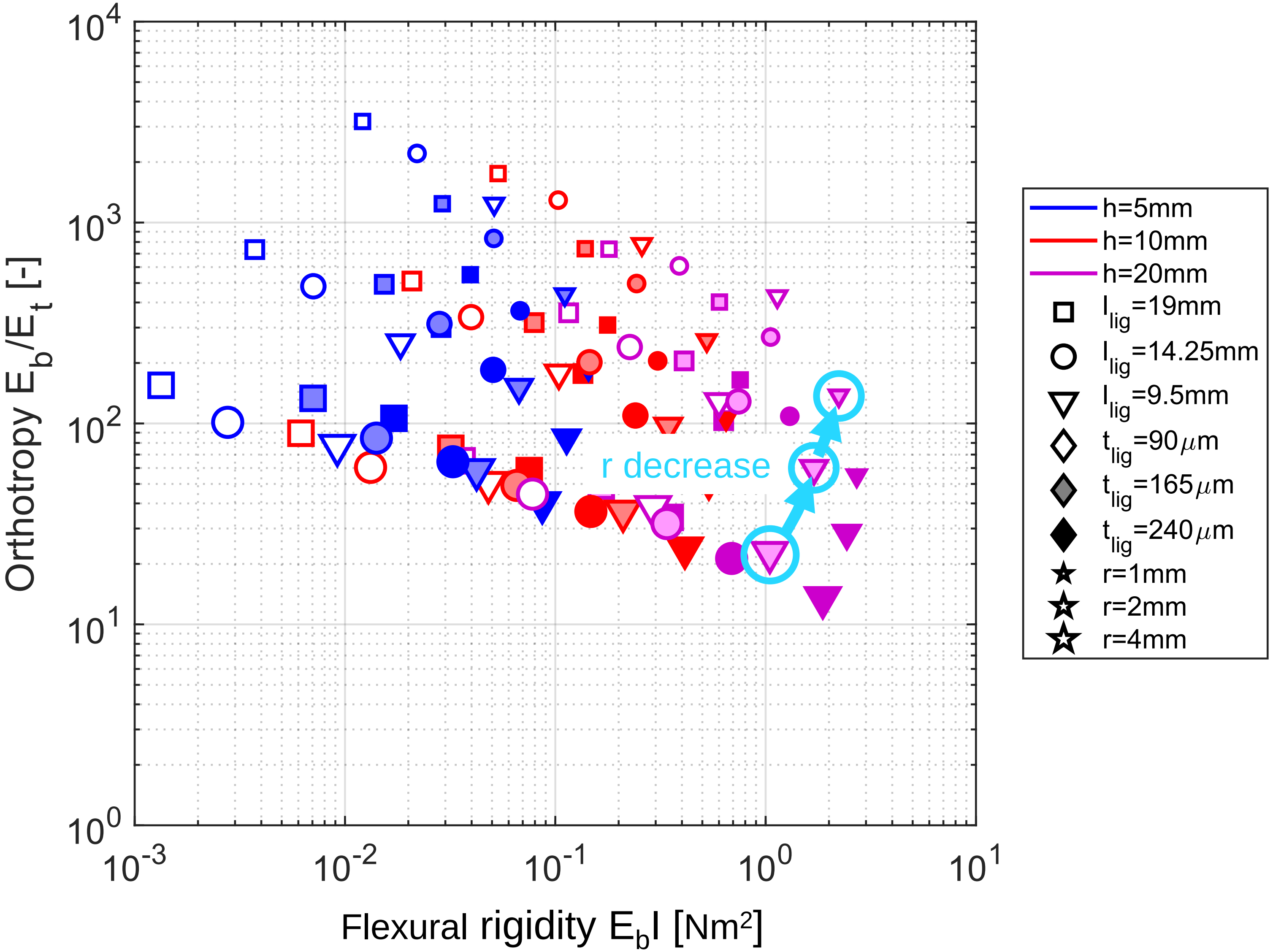
Parametric study of metastructure
Ligament thickness

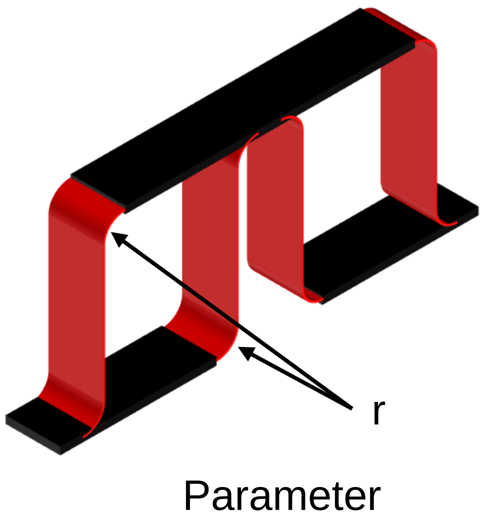




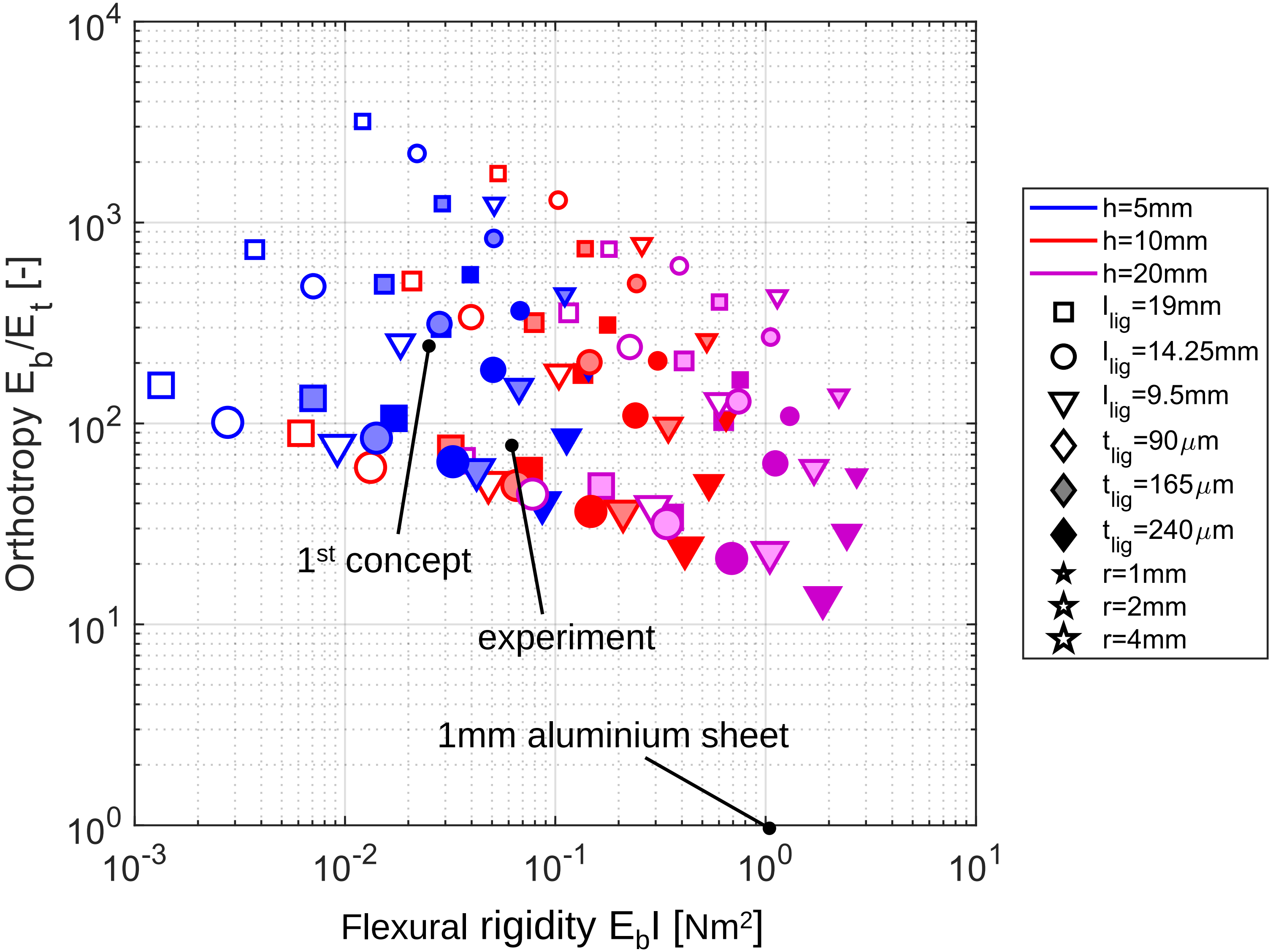
Parameter

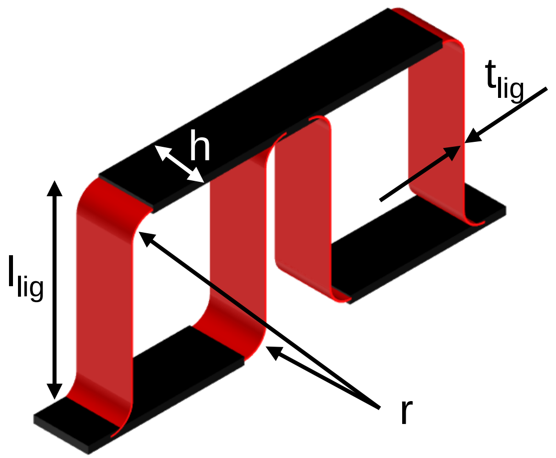
Parametric study of metastructure
Radius of ligaments





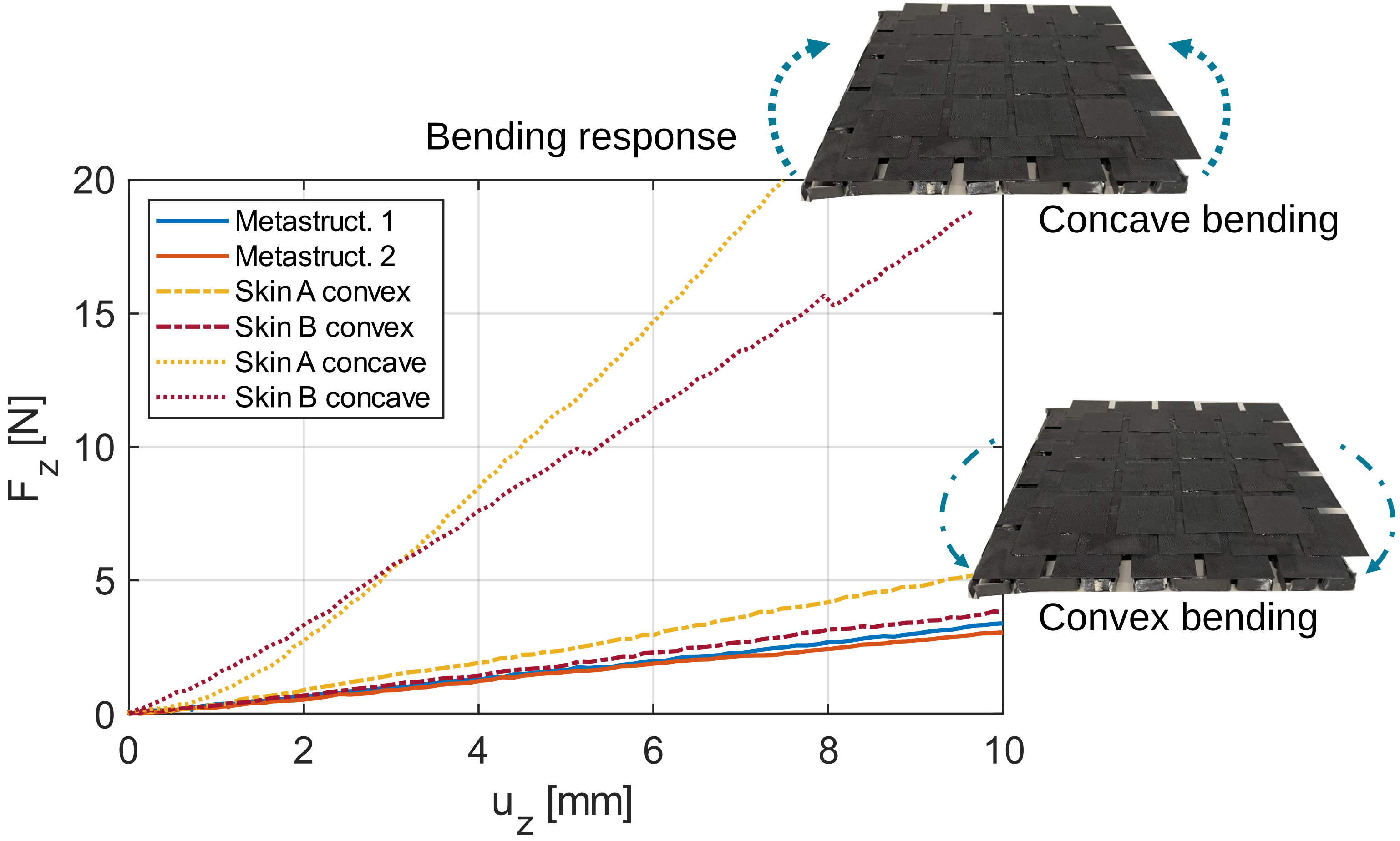
Parametric study of metastructure
Comparison





Parameters

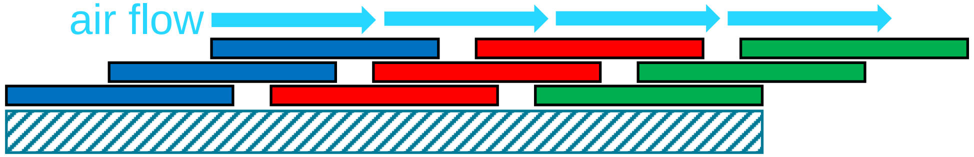
Experimental results skin system



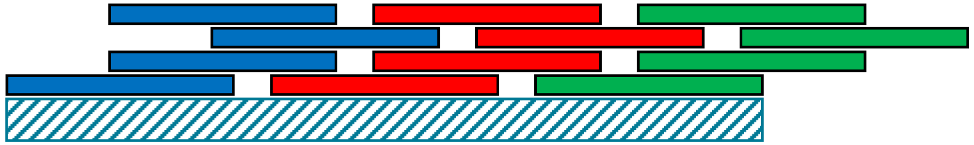
- Tensile response not influenced by platelet stacks
- Convex curvature
  - Hardly influences bending response
  - Protrusion of platelet stacks
- Concave curvature
  - Significantly increased bending stiffness (and orthotropy)
  - No protrusion of platelet stacks

Outlook

- Mechanical effect of platelet stacks on morphing skin system



- Aerodynamic study
  - How does the platelet surface influence drag



- Stacking sequence of platelets to prevent protrusion

- Manufacturing quality

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