

JMC 2024

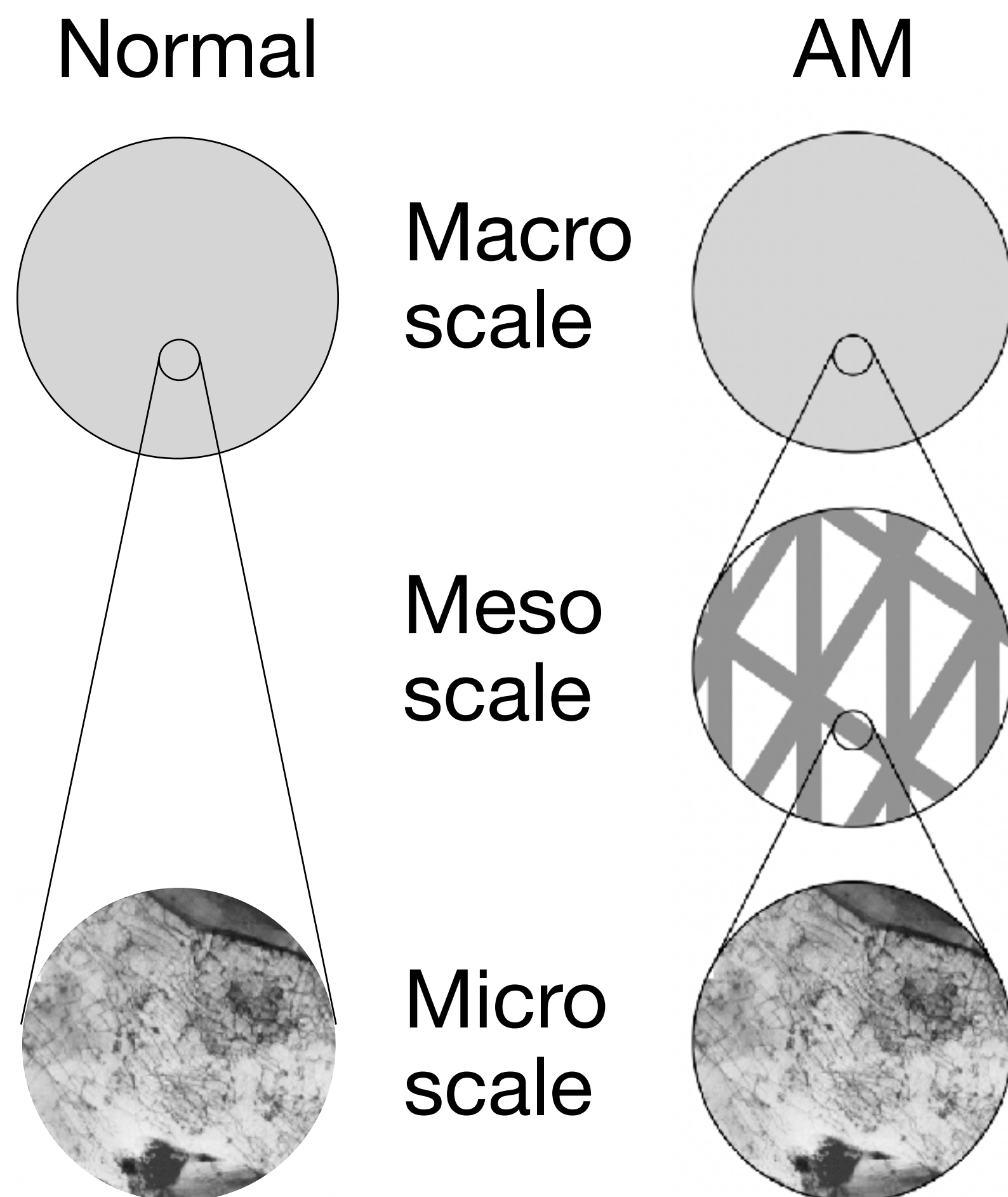
Architected materials and instabilities: a journey towards uniformity

Martin Poncelet (LMPS) et Christelle Combescure (CReC Saint-Cyr & IRDL)
Fabien Amiot (FEMTO)

Architected materials (AM)

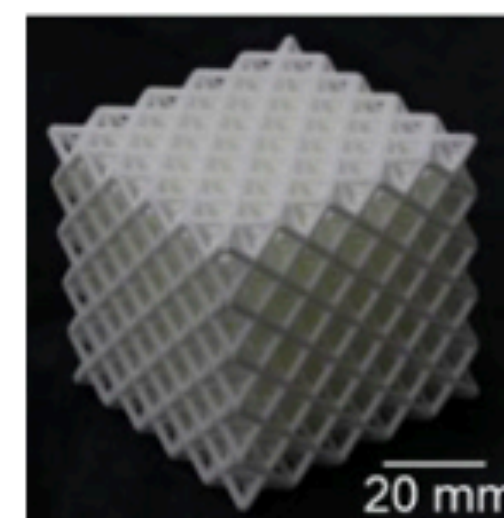
Definition: existence of mesoscopic scale

Theory

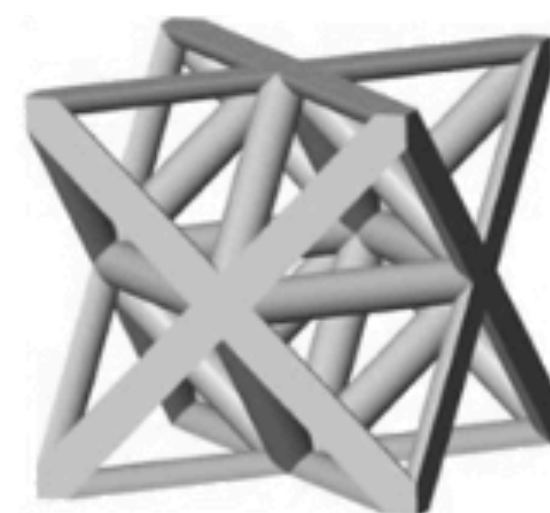


Examples in reality

Artificial AM



Structure
~ 100 mm



Cell
~ 5 mm



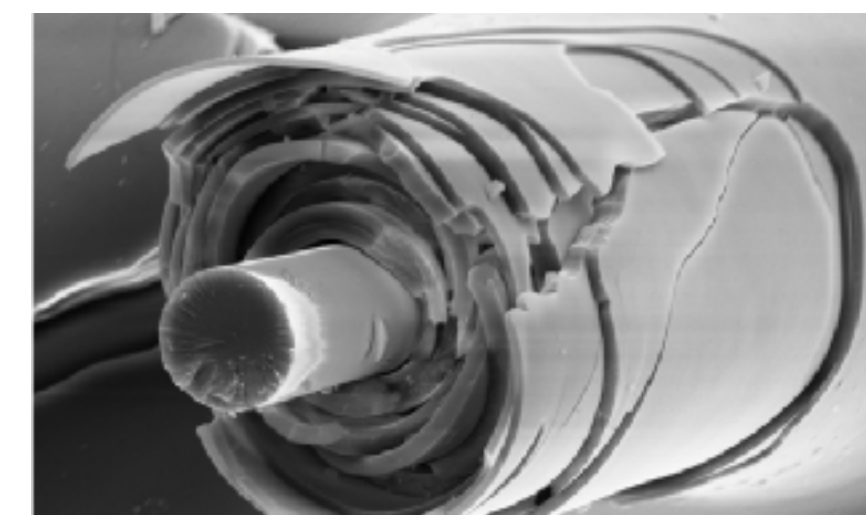
Material
~ 0.1 mm

Sponge
~ 200 mm

Cell
~ 3 mm






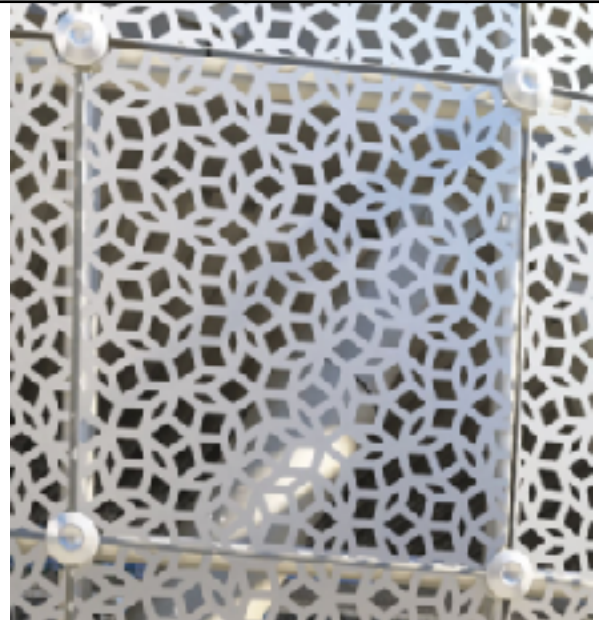
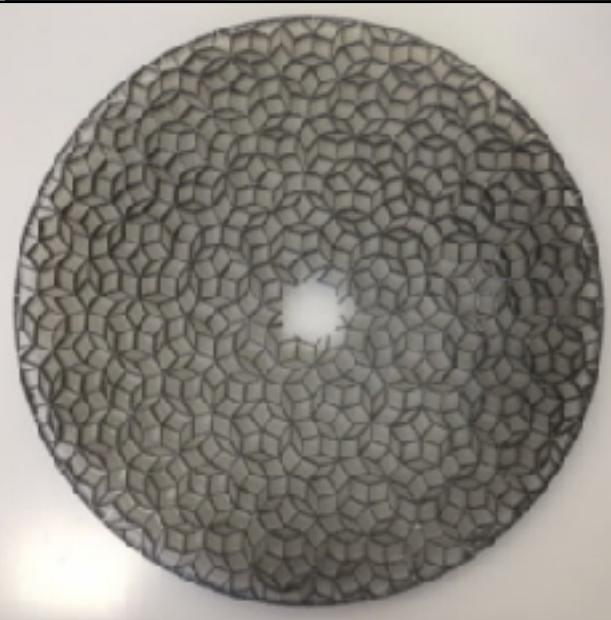

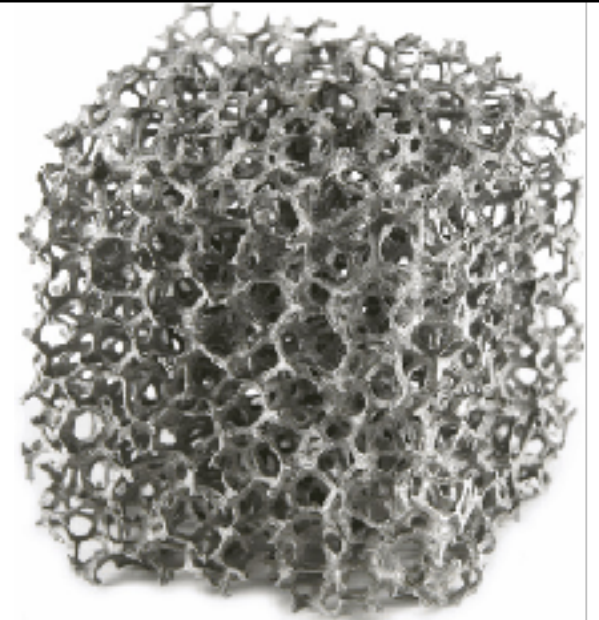
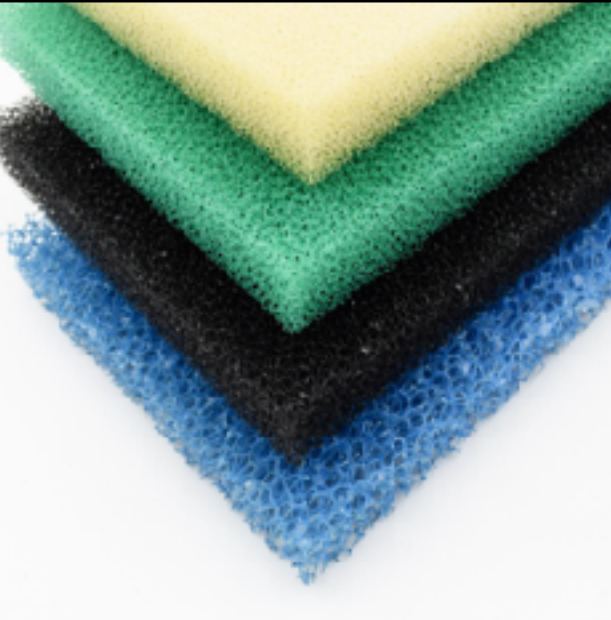
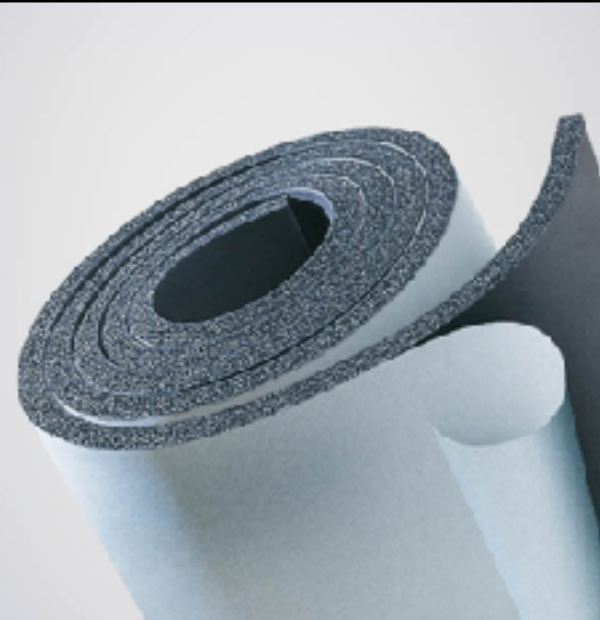
Fiber
~ 0.05 mm

Natural AM



Architected materials (AM)

Various geometry, constitutive materials, scales

	Mineral	Metal	Polymer	Elastomers
Periodic				
Quasiperiodic				
Aperiodic				

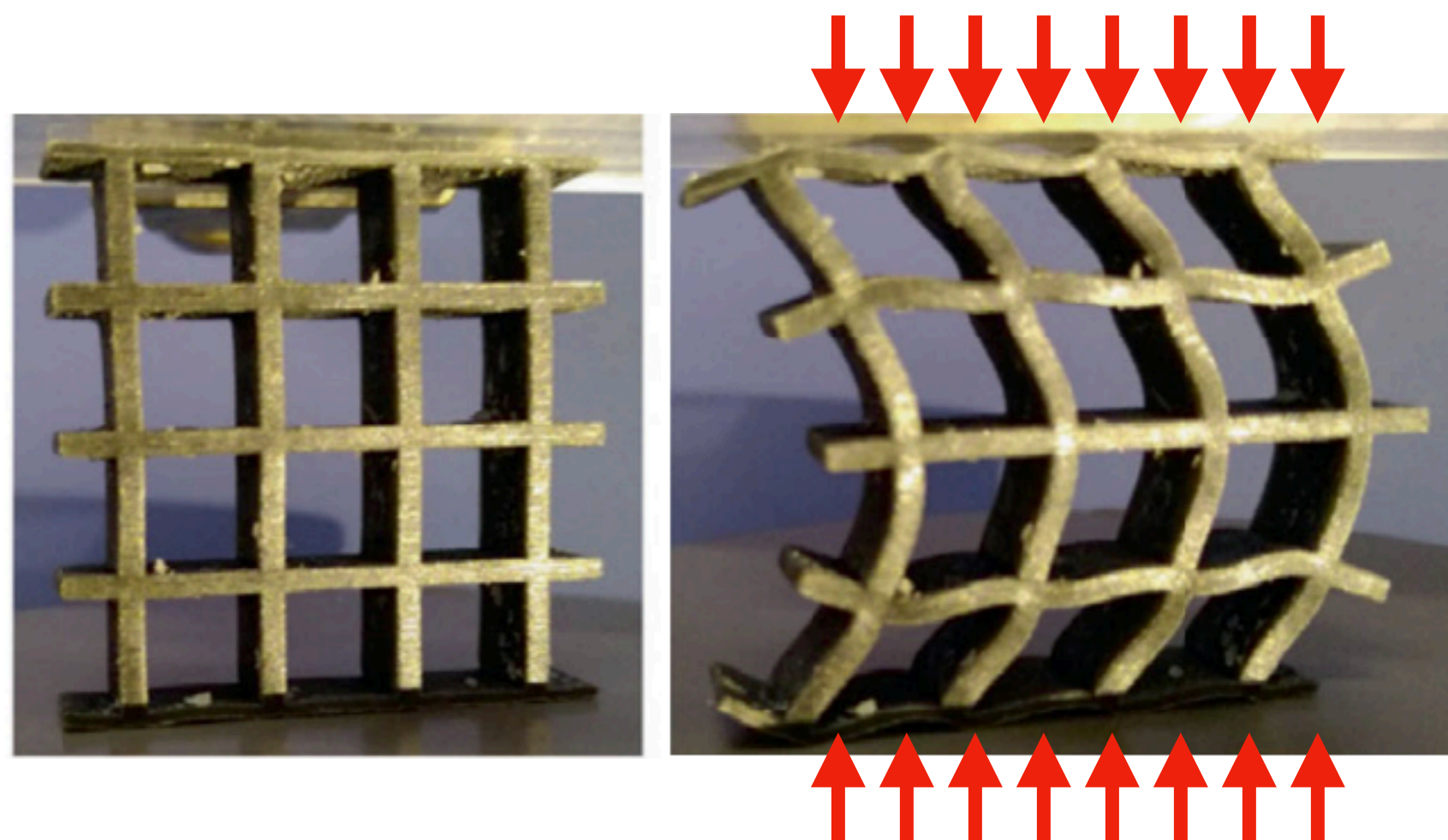
History of compaction tests on AM

Qualitative behavior appearing during buckling experiments

Global buckling

sudden softening

(periodic AM)

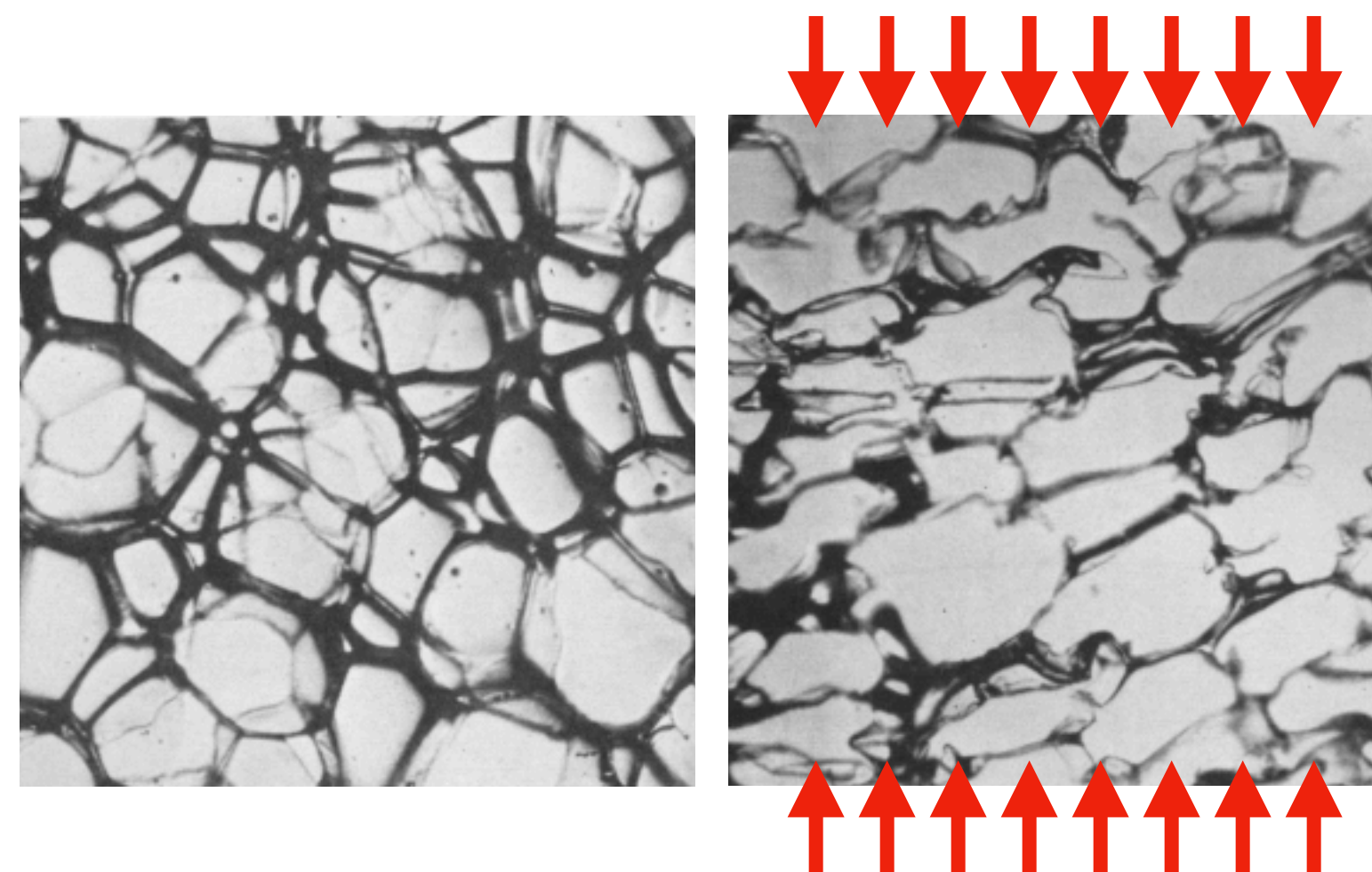


[He, Zhou et al. 2018]

Localization

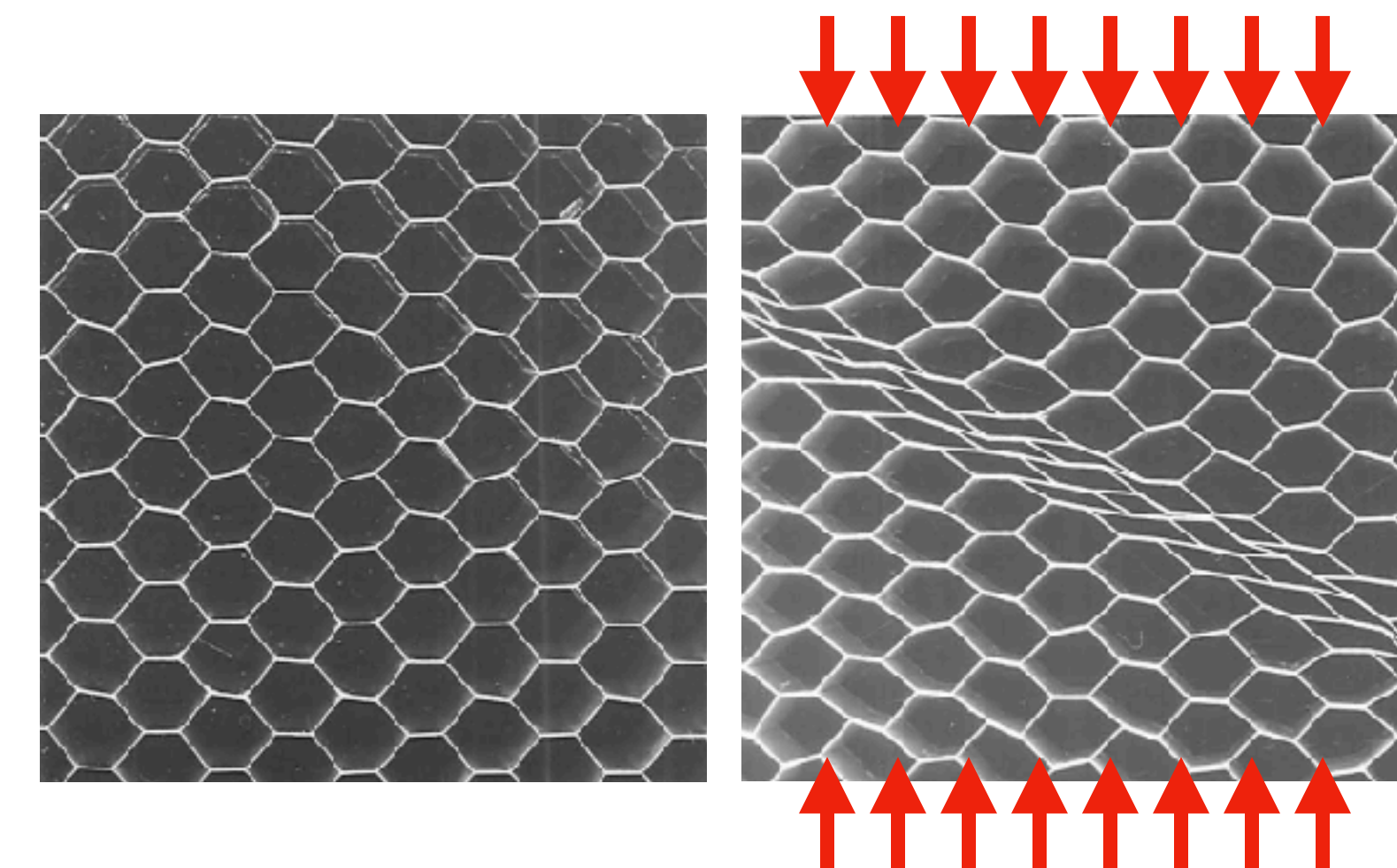
plateau force

(Aperiodic)



[Shaw & Sata 1966]

(periodic AM)

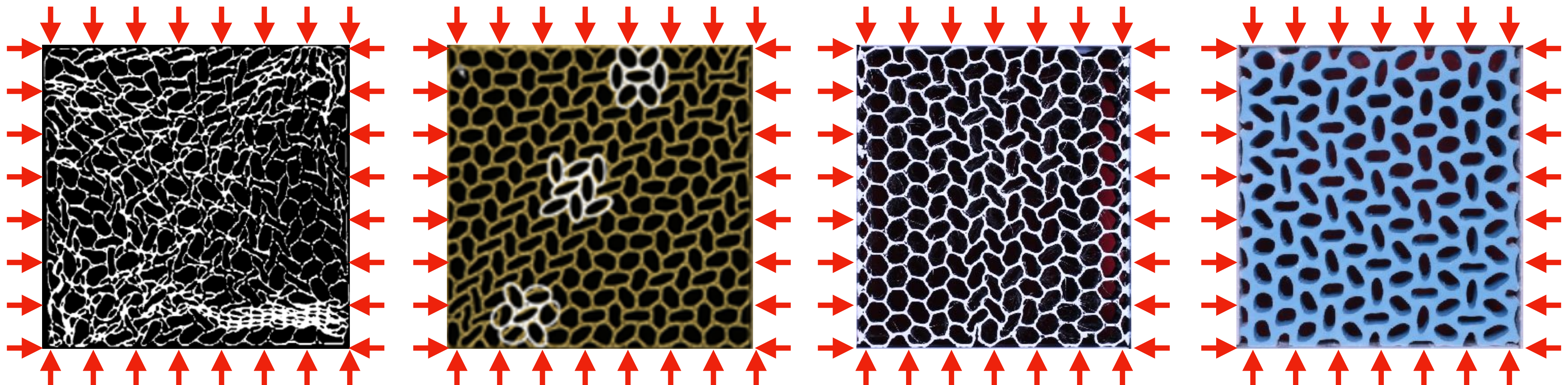


[Gibson 1981]

History of compaction tests on AM

Qualitative behavior appearing during buckling experiments

Diffuse buckling, *but* non-uniform patterns: various amplitude, various modes (Periodic AM)



[Kyriakides et al. 1999]

[Karagiosova et al. 2008]

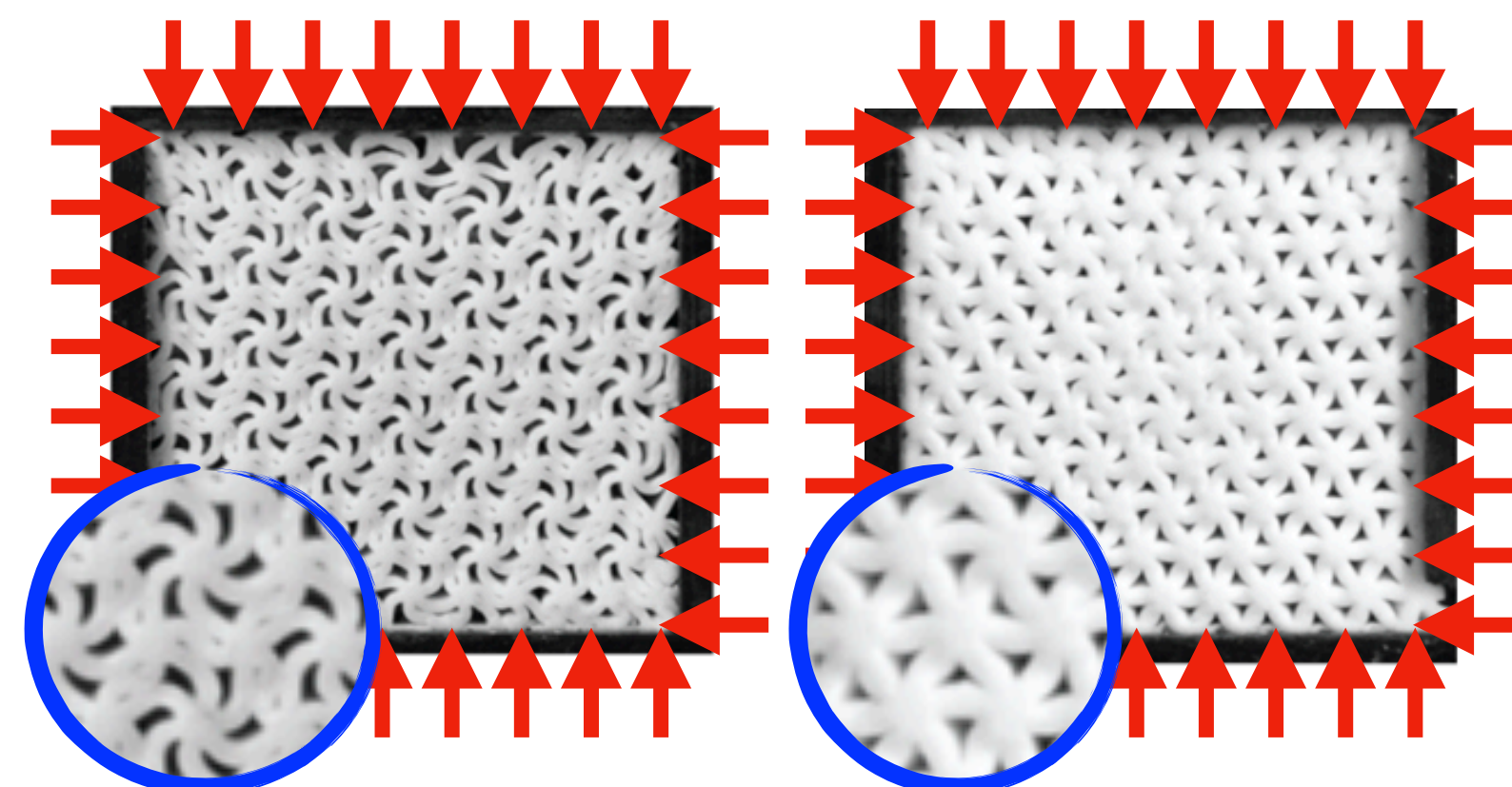
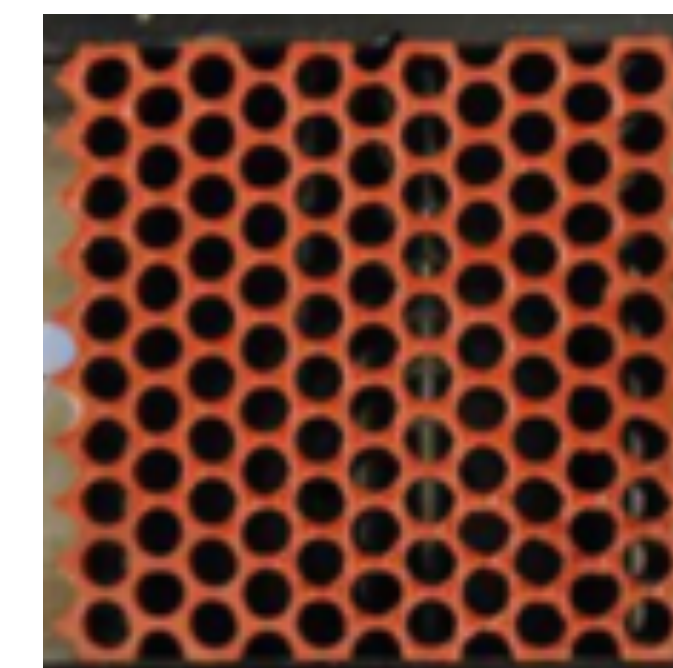
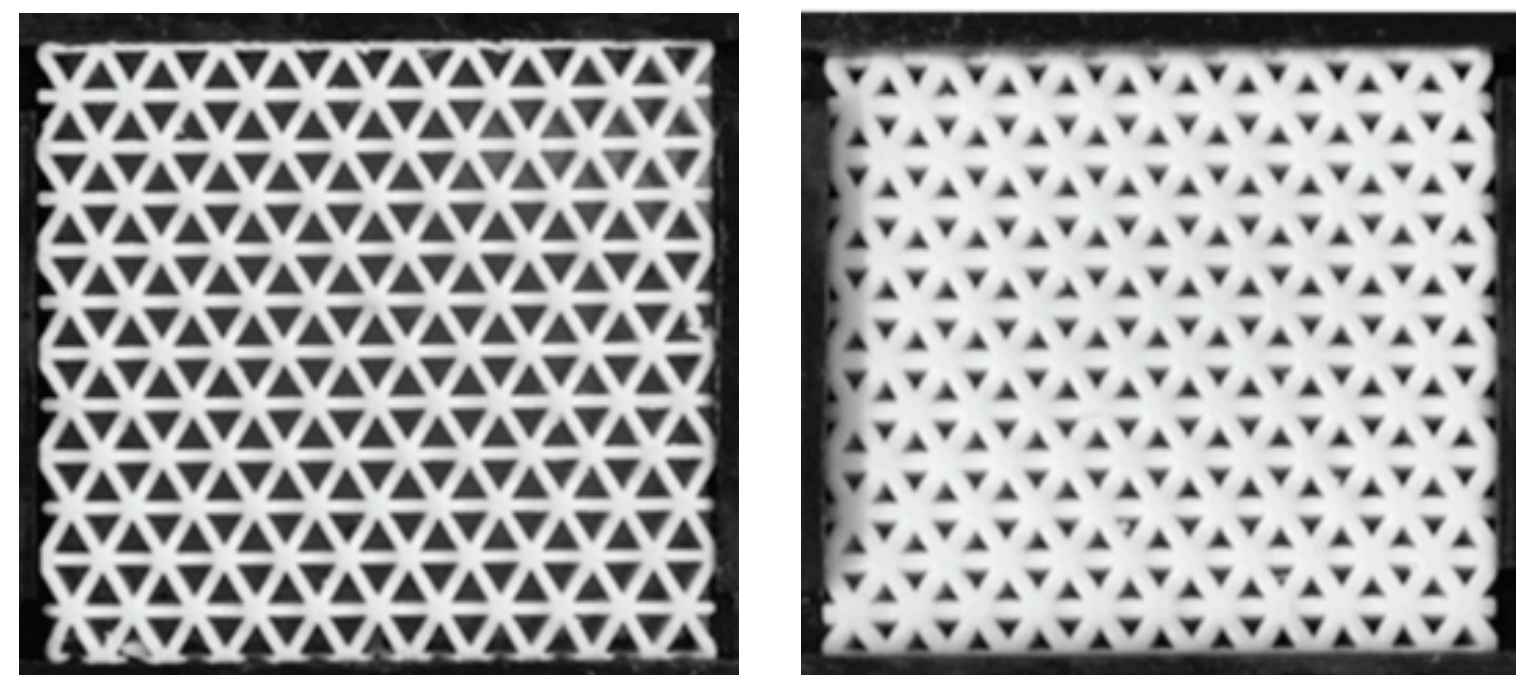
(our 1st disappointment)

(a later one 2023)

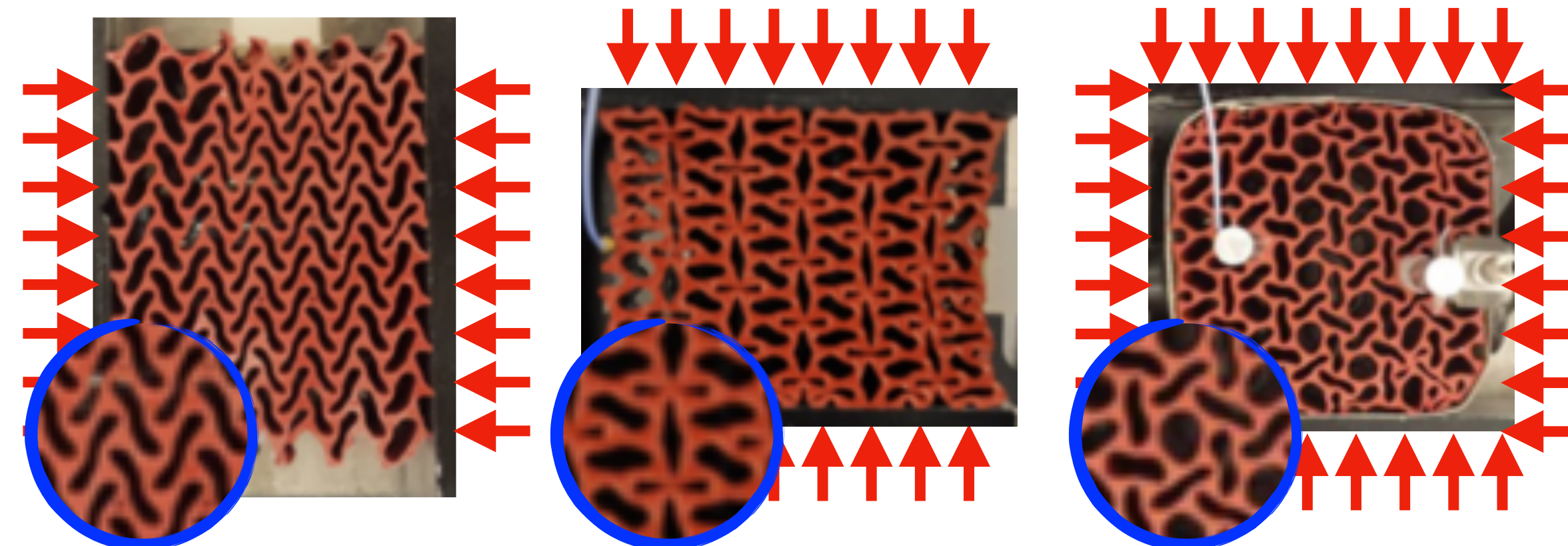
History of compaction tests on AM

Qualitative behavior appearing during buckling experiments

Diffuse buckling, with uniform patterns: same amplitude, same mode
(Periodic AM)



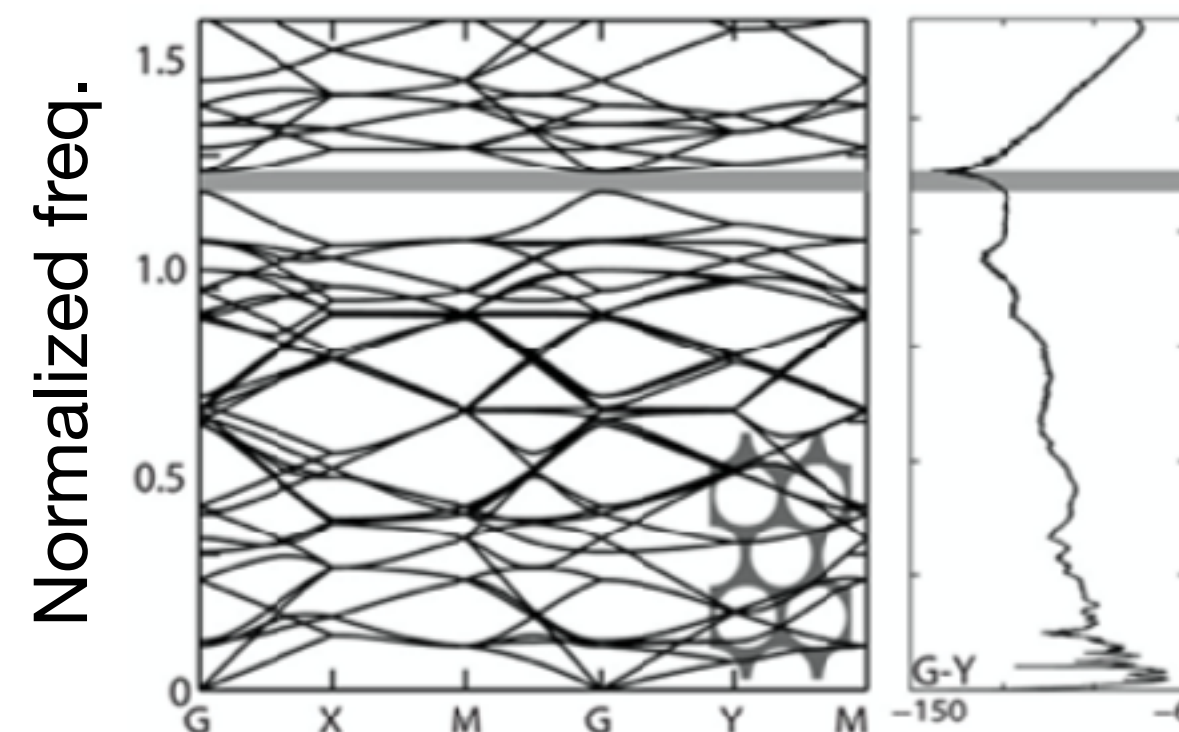
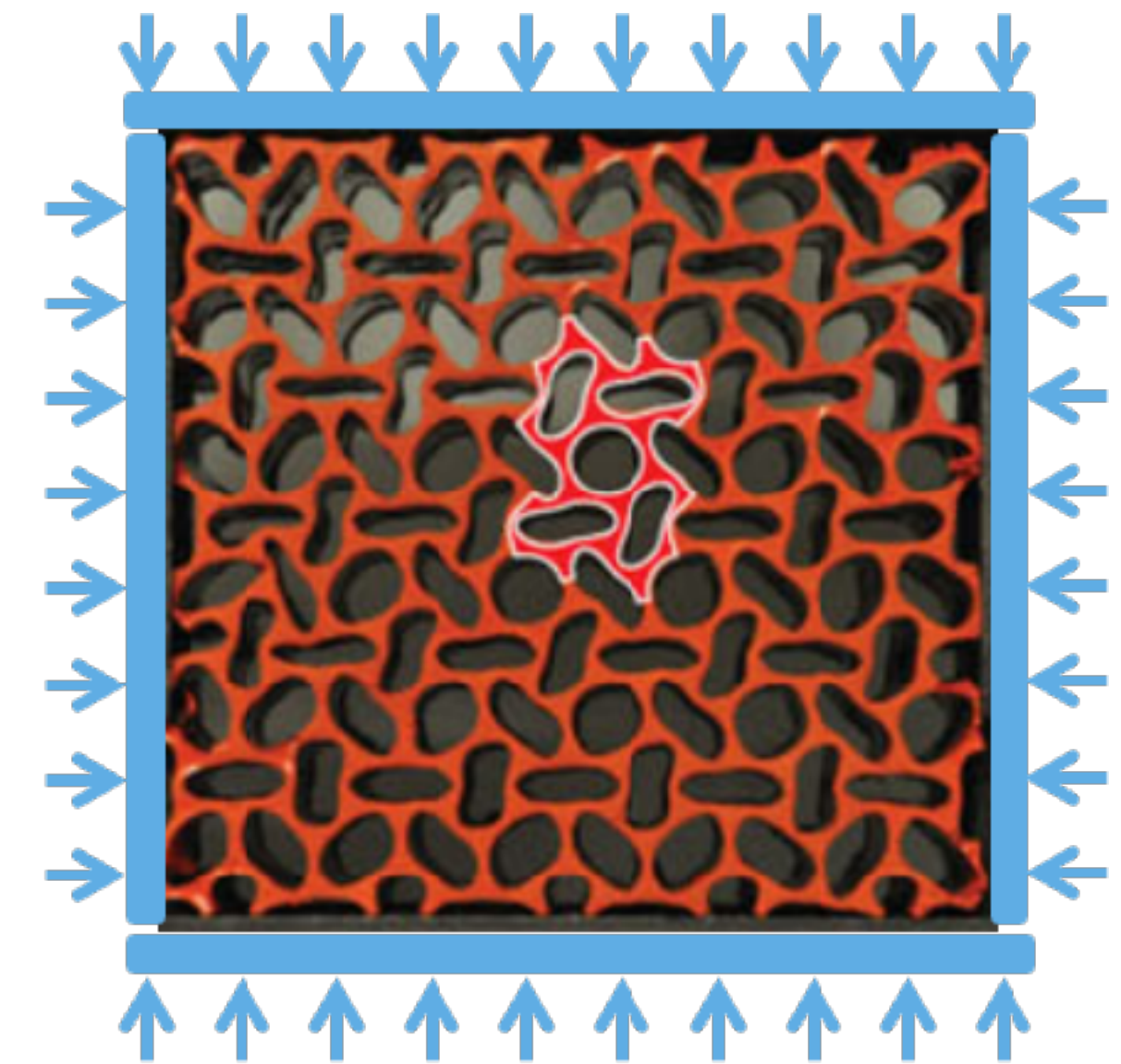
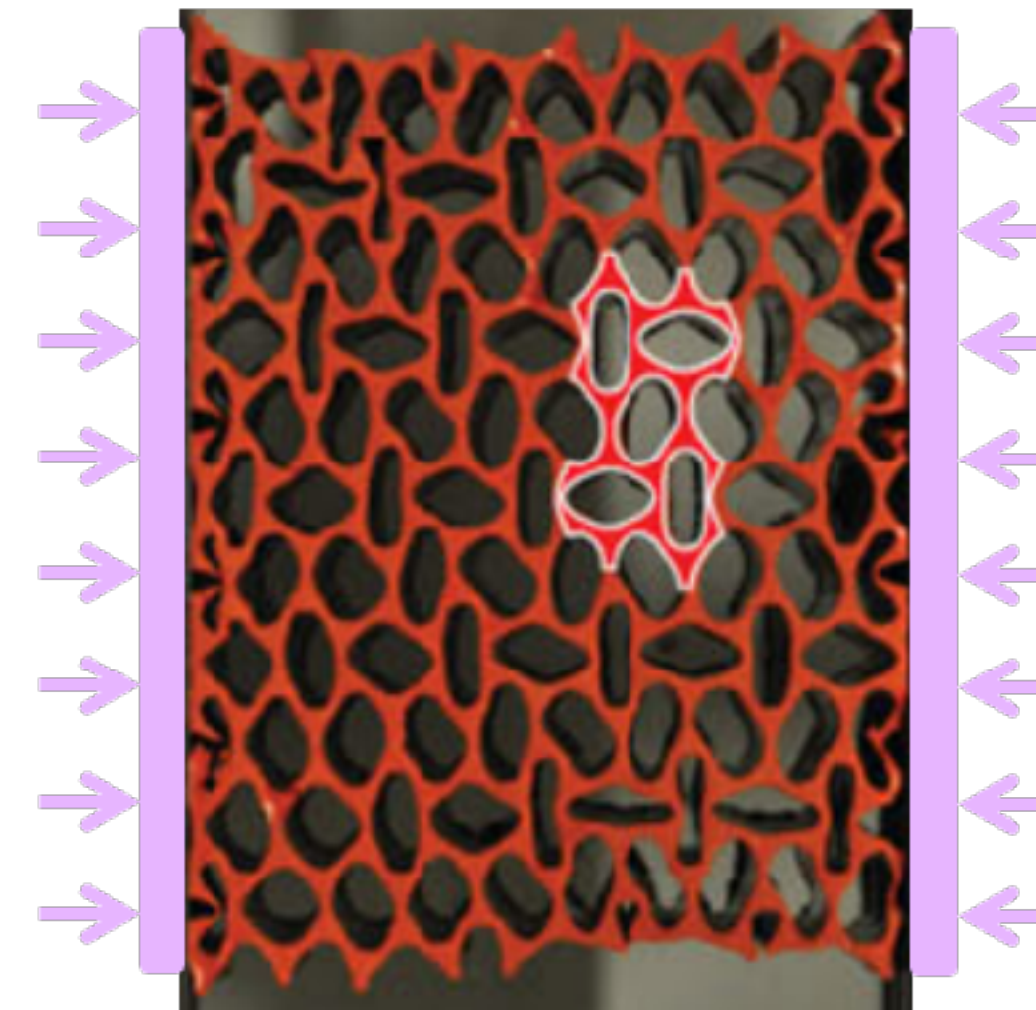
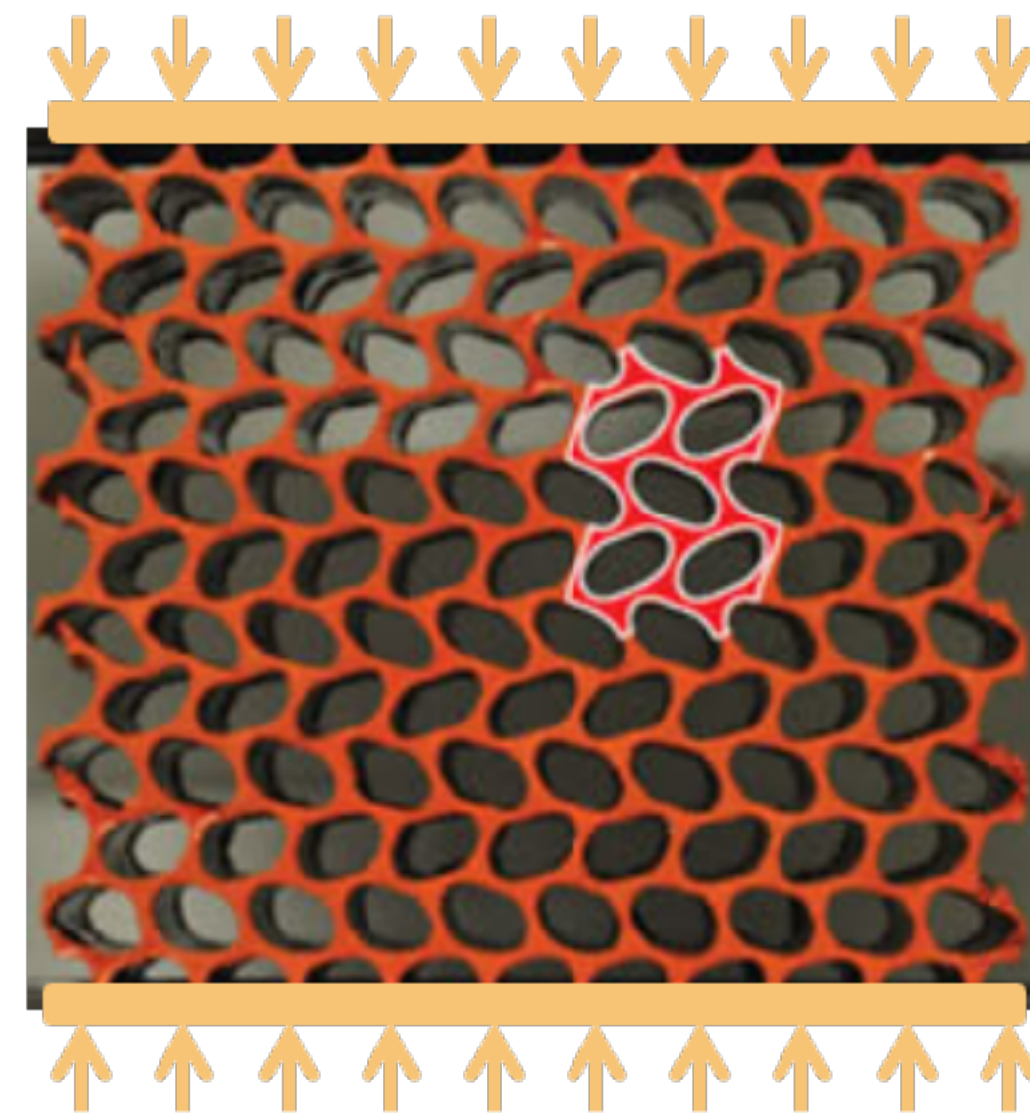
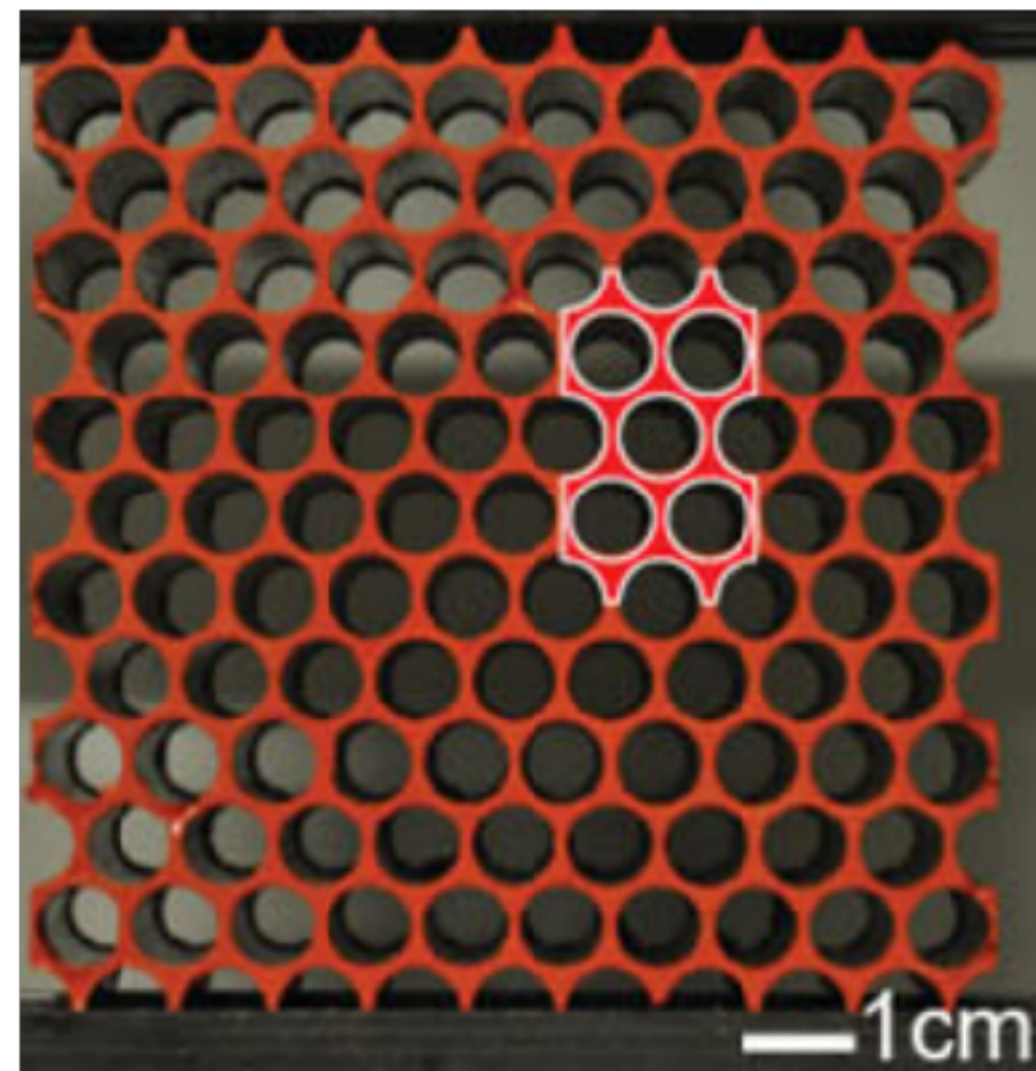
[Kang, Shan et al. 2014]



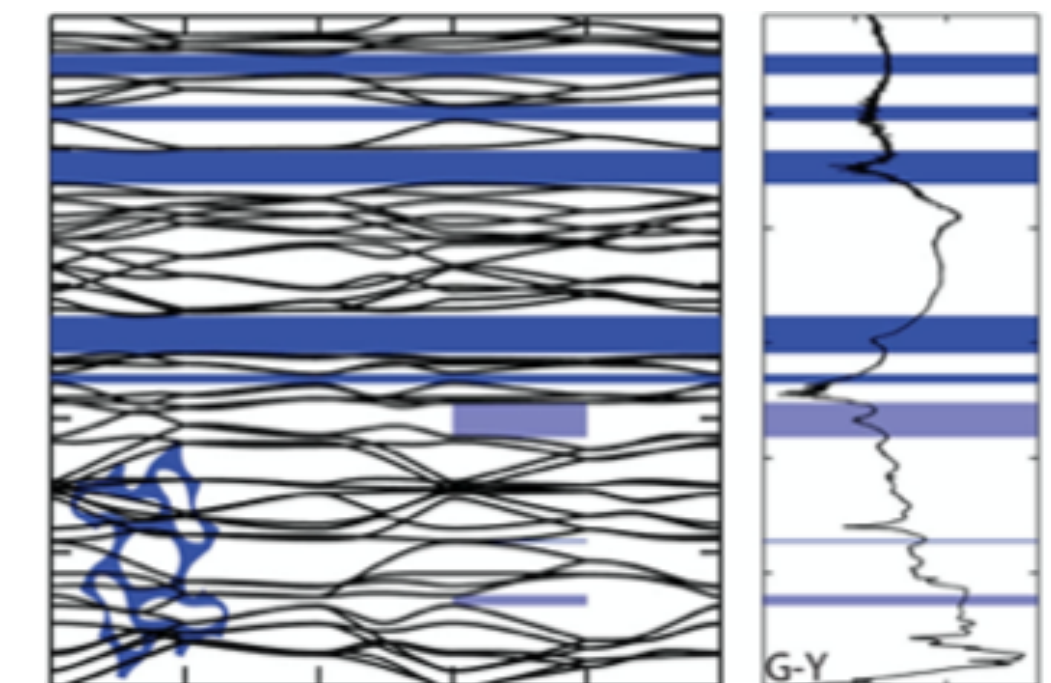
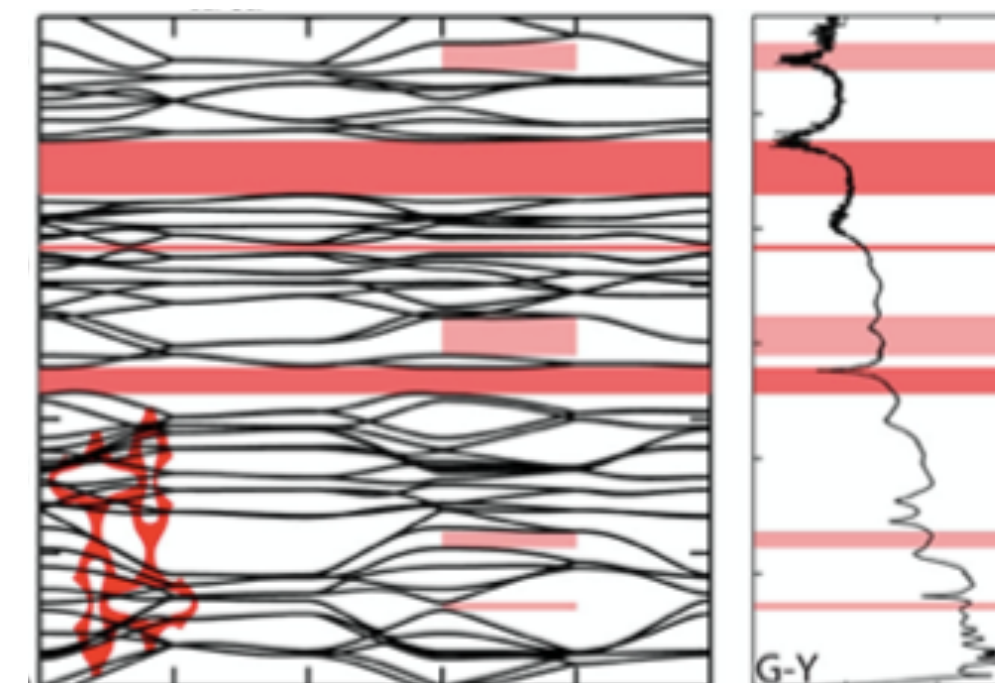
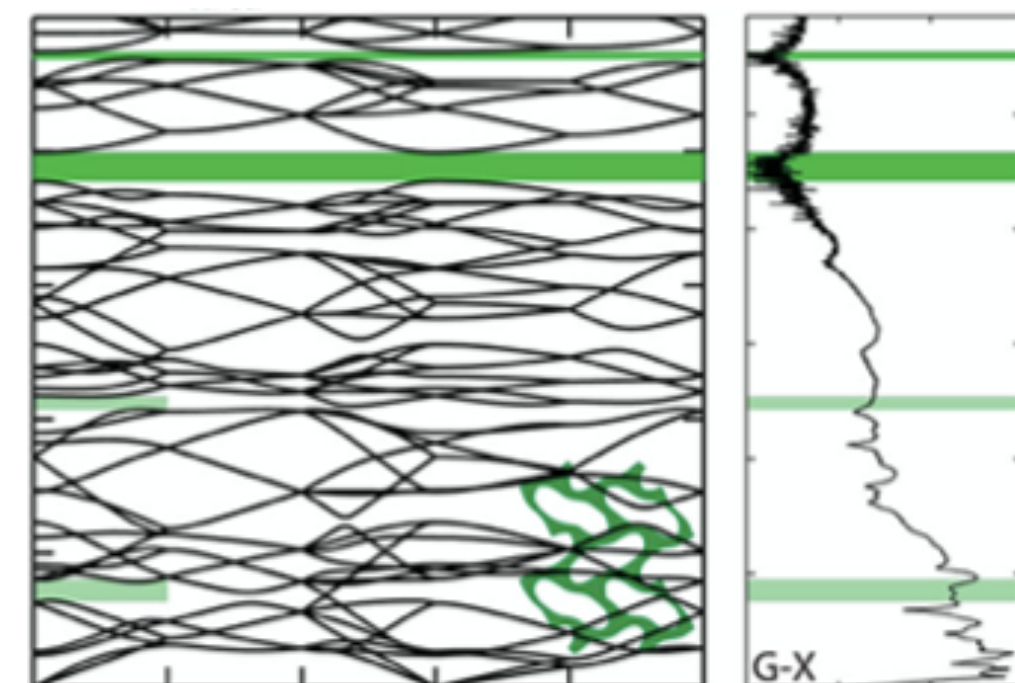
[Shan, Kang et al. 2014]

History of compaction tests on AM

Uniform buckling patterns: tunable wave propagation !



Red. wave vector. Attenuat.



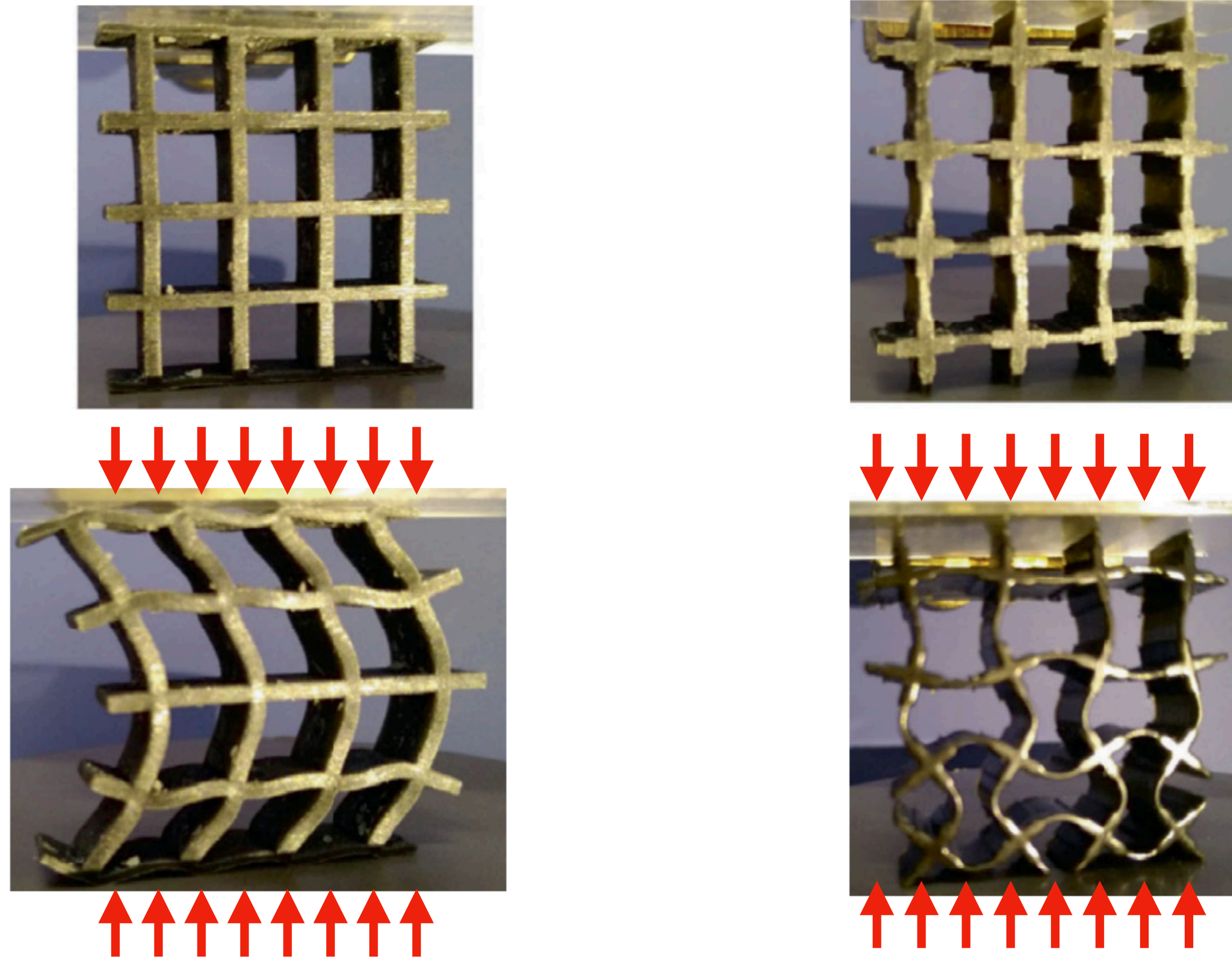
[Shan, Kang et al. 2014]

Research question

How can we obtain desired uniform patterns ?

How to obtain desired uniform patterns ?

Choice of unit-cell : from global to diffuse

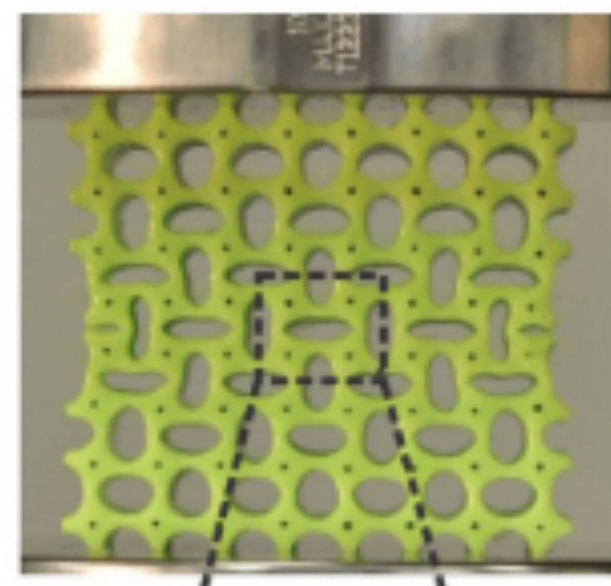
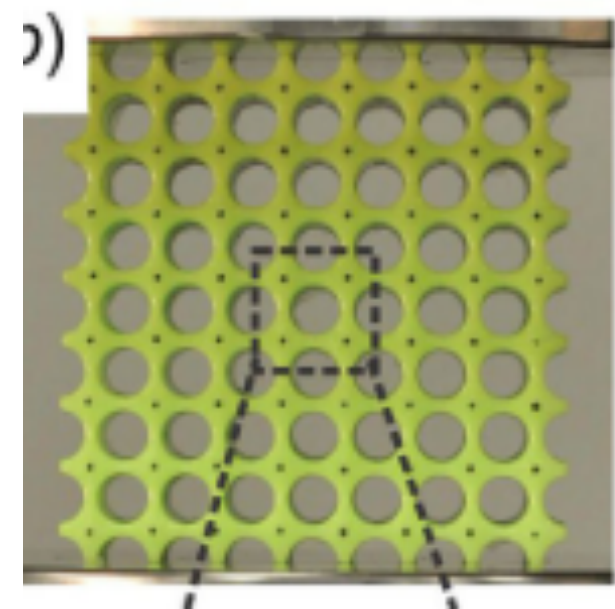


[He, Zhou et al. 2018]

How to obtain desired uniform patterns ?

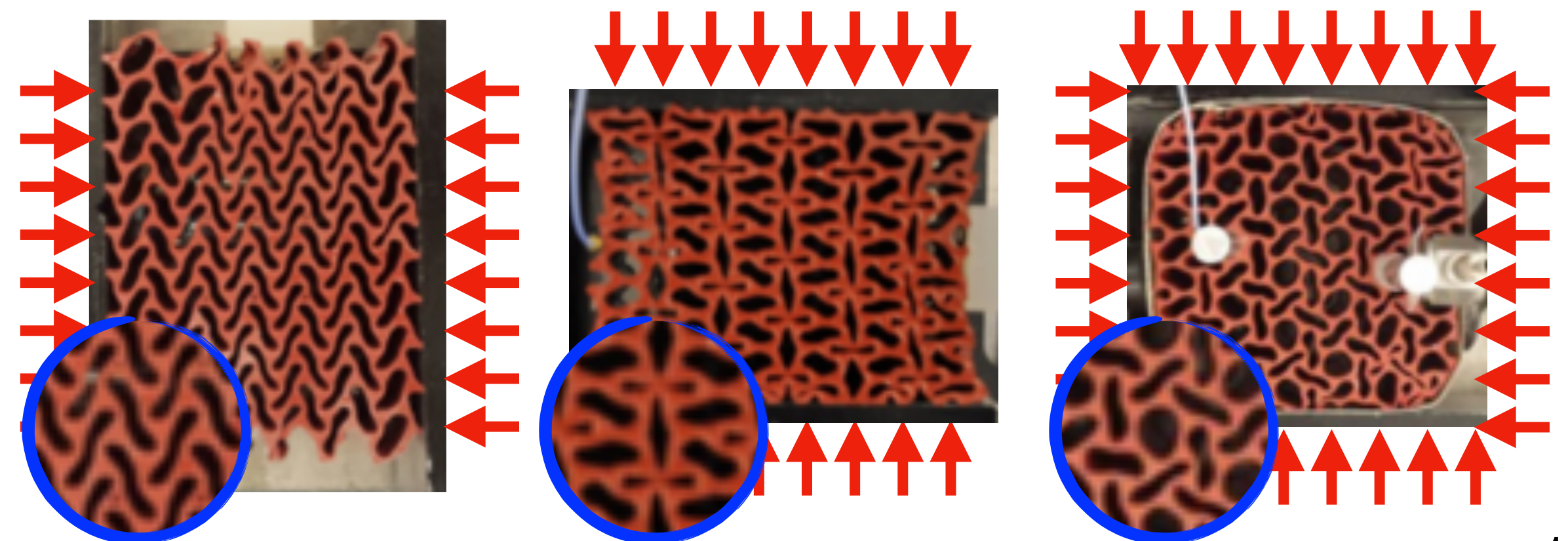
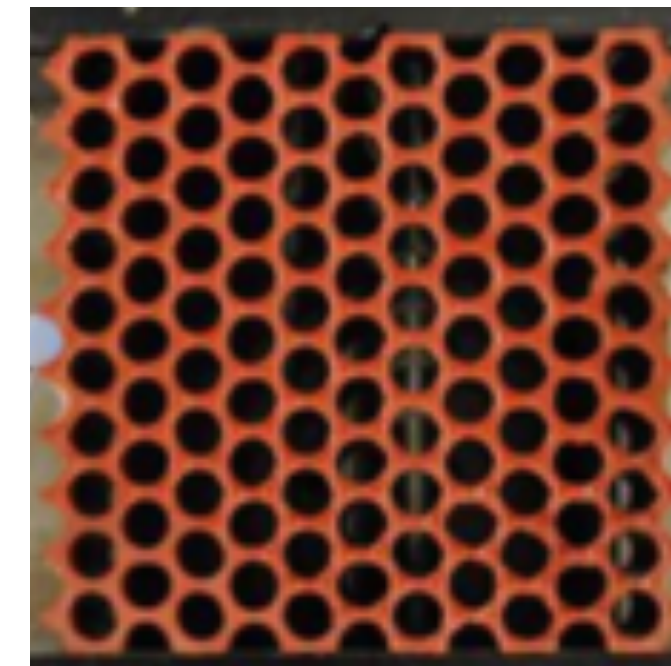
Choice of unit-cell : from single to multiple modes

Some unit-cell geometries only have a single bifurcation mode



Not very interesting
for tuning wave
propagation

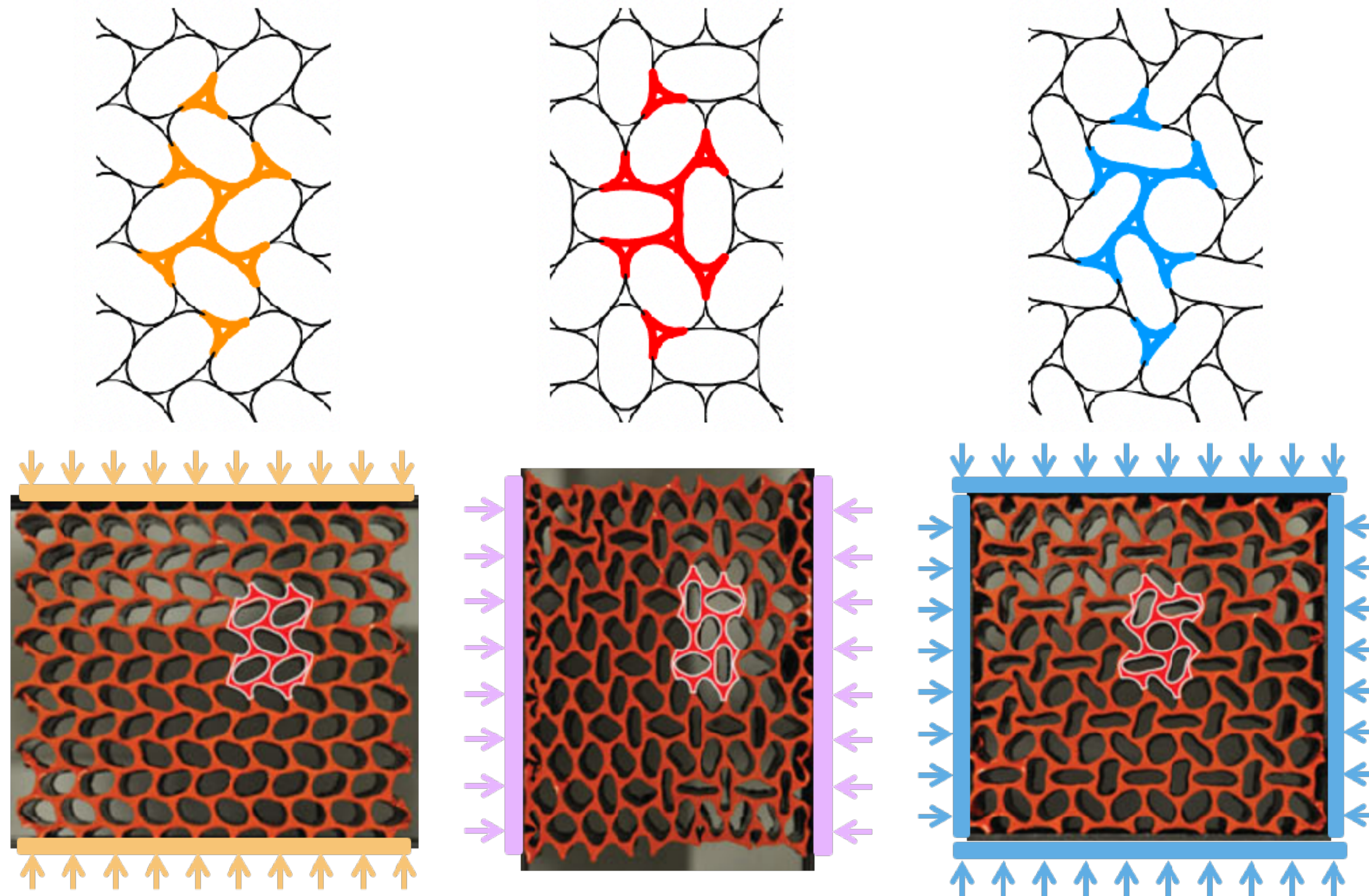
Some unit-cell geometries have multiple
bifurcation modes



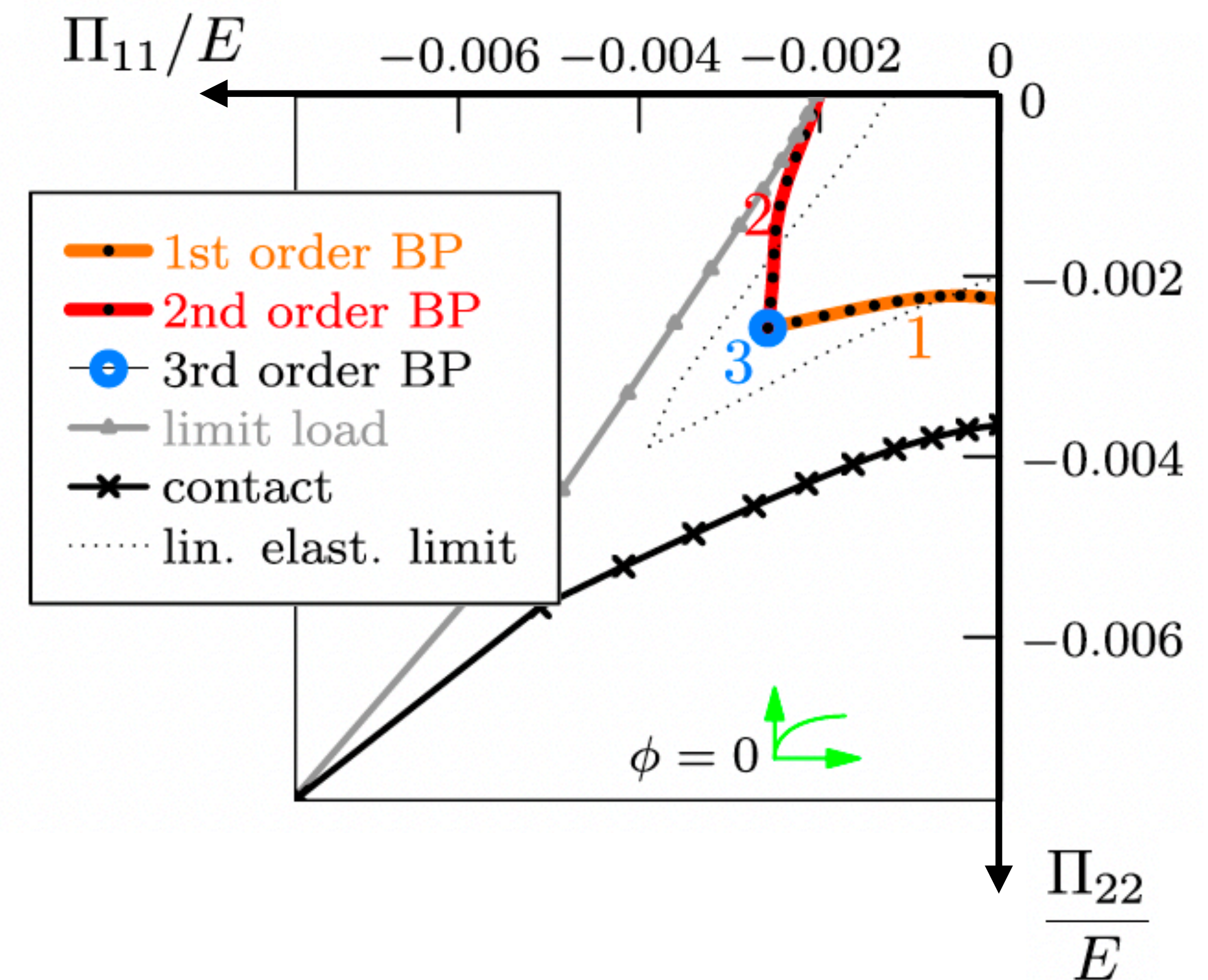
[Shan, Kang et al. 2014]

How to obtain desired uniform patterns ?

Numerical simulations assuming uniformity



[Combescure et al. 2020]

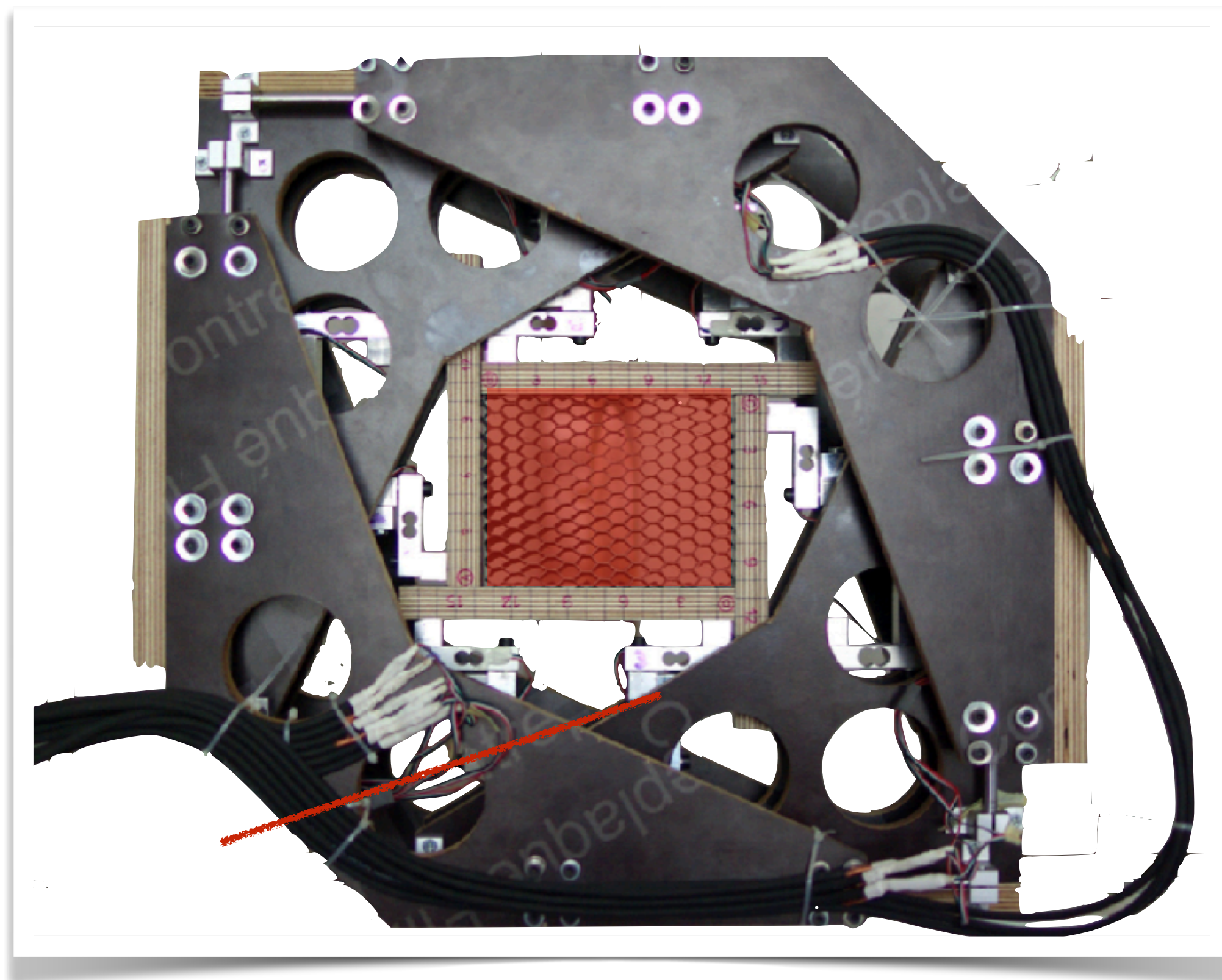


Satisfying buckling modes predictions
Overestimation of buckling loads due to flawless mesostucture

How to obtain desired uniform patterns ?

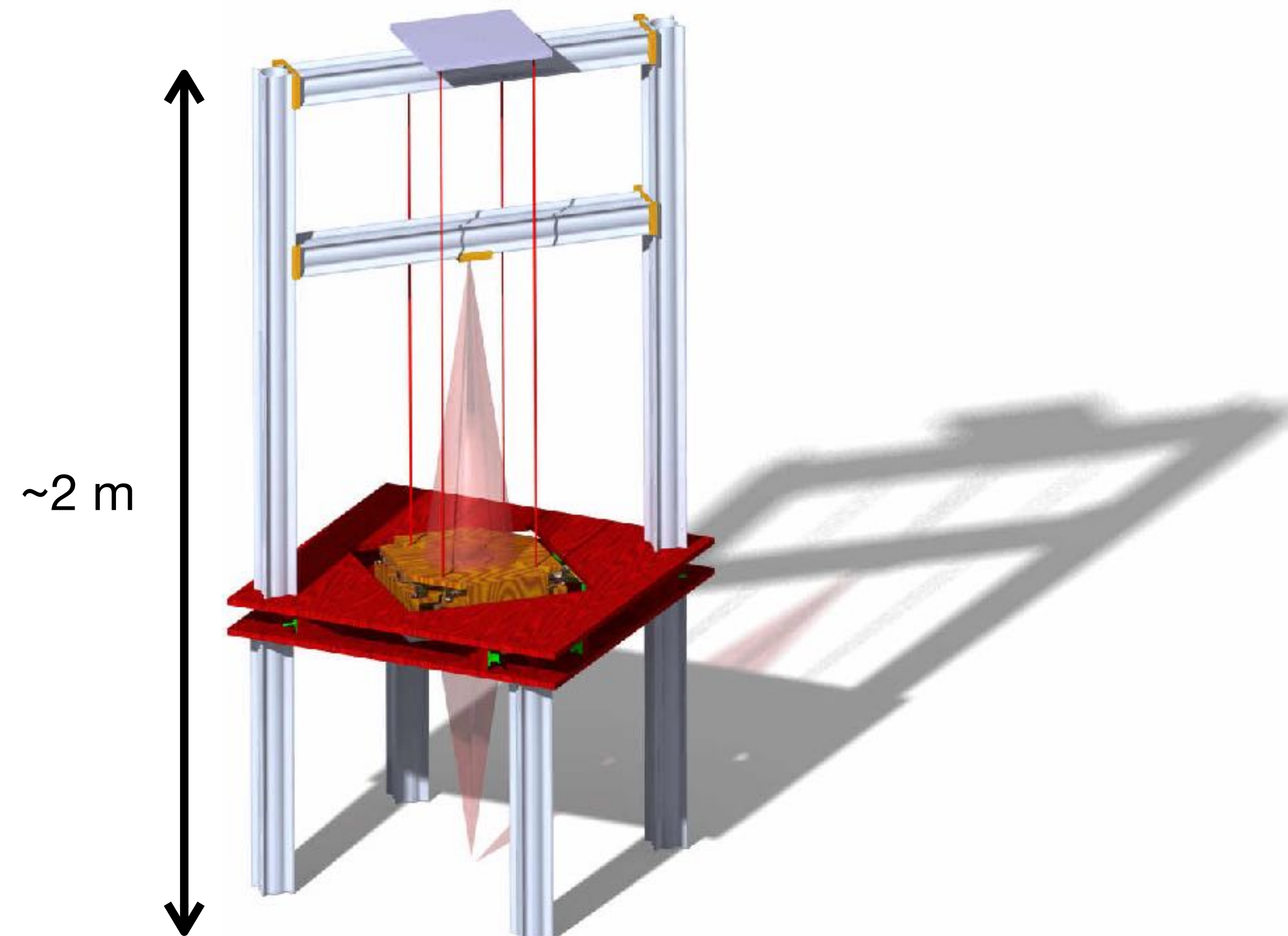
Dedicated setup for buckling detection

Forces and torque measurement on each side



[Poncelet et al. 2023]

Possible single/double camera setup



How to obtain desired uniform patterns ?

Dedicated setup for buckling detection

Multiple loadcells \neq existing setups

[Poncelet, Wangermez, Combescure 2022]

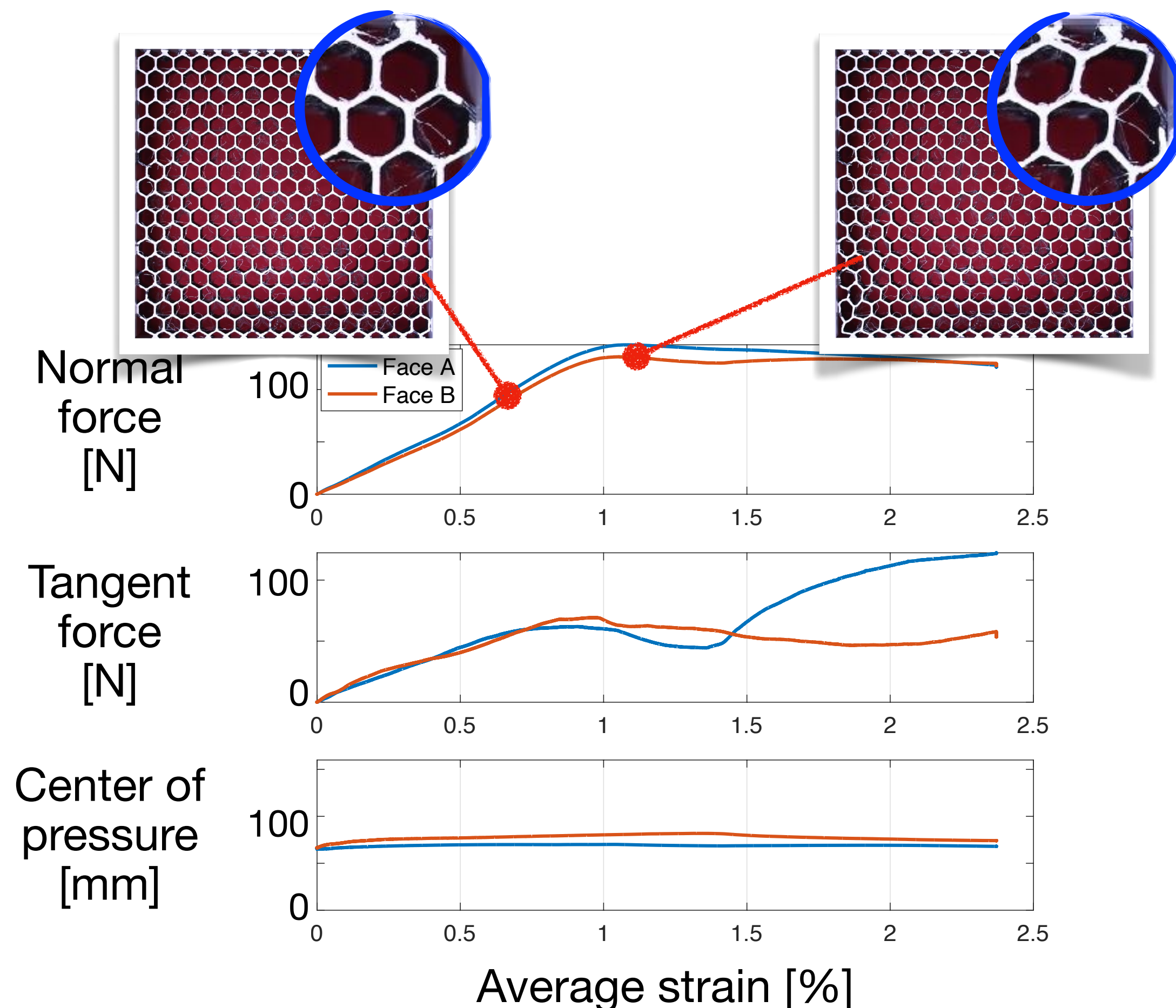
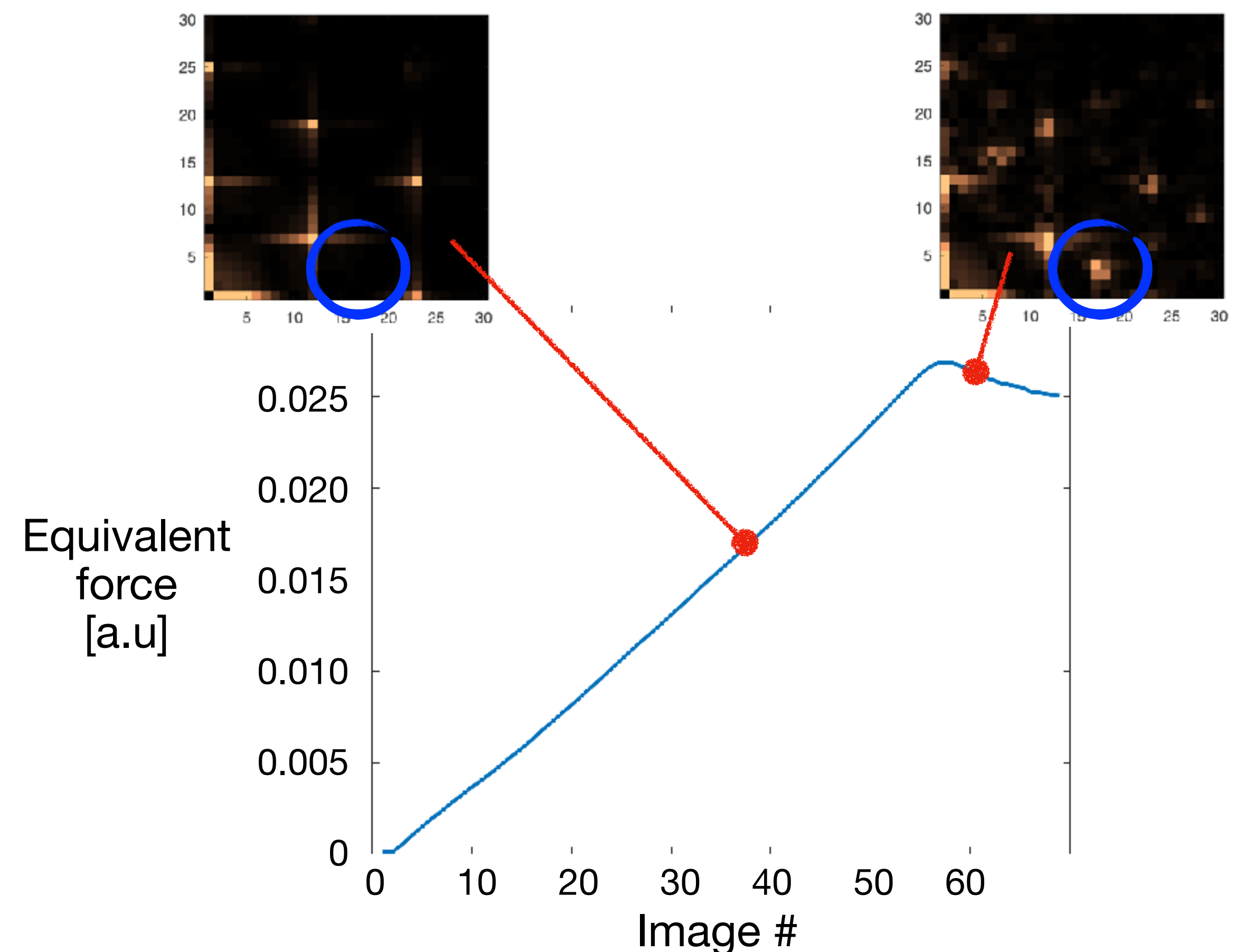


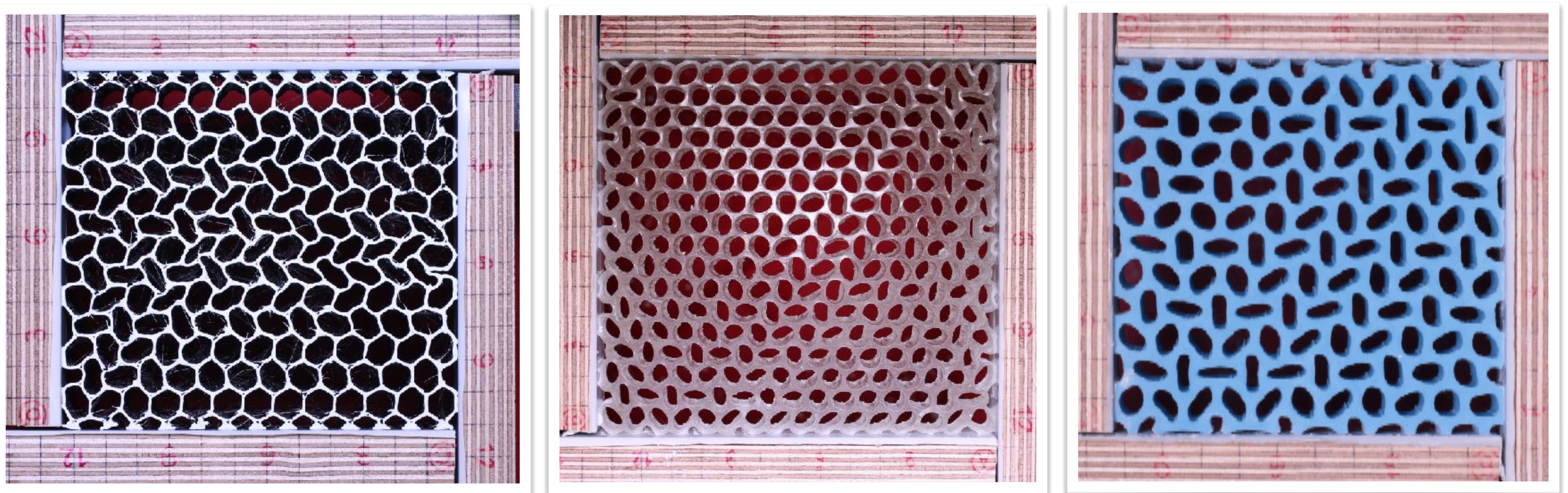
Image FFT analysis \neq existing setups

[Poncelet, Combescure, Amiot 2023]



How to obtain desired uniform patterns ?

But ...



Non-uniform pattern !

Despite similar geometries as in published experimental results

Subsidiary Research question

What causes non-uniform pattern ?

Sample geometry

Boundary conditions

Sample base material

Sample fabrication process

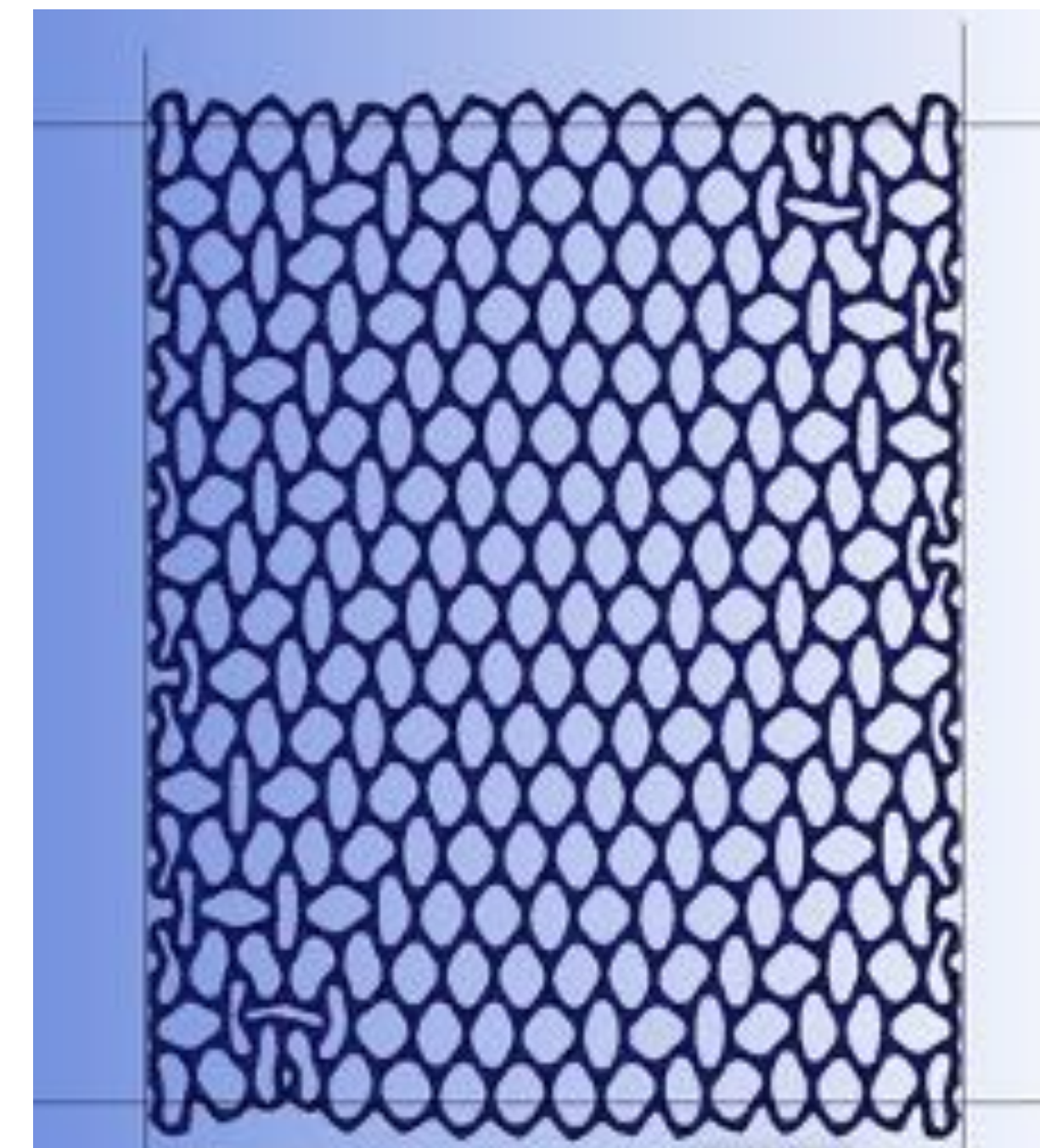
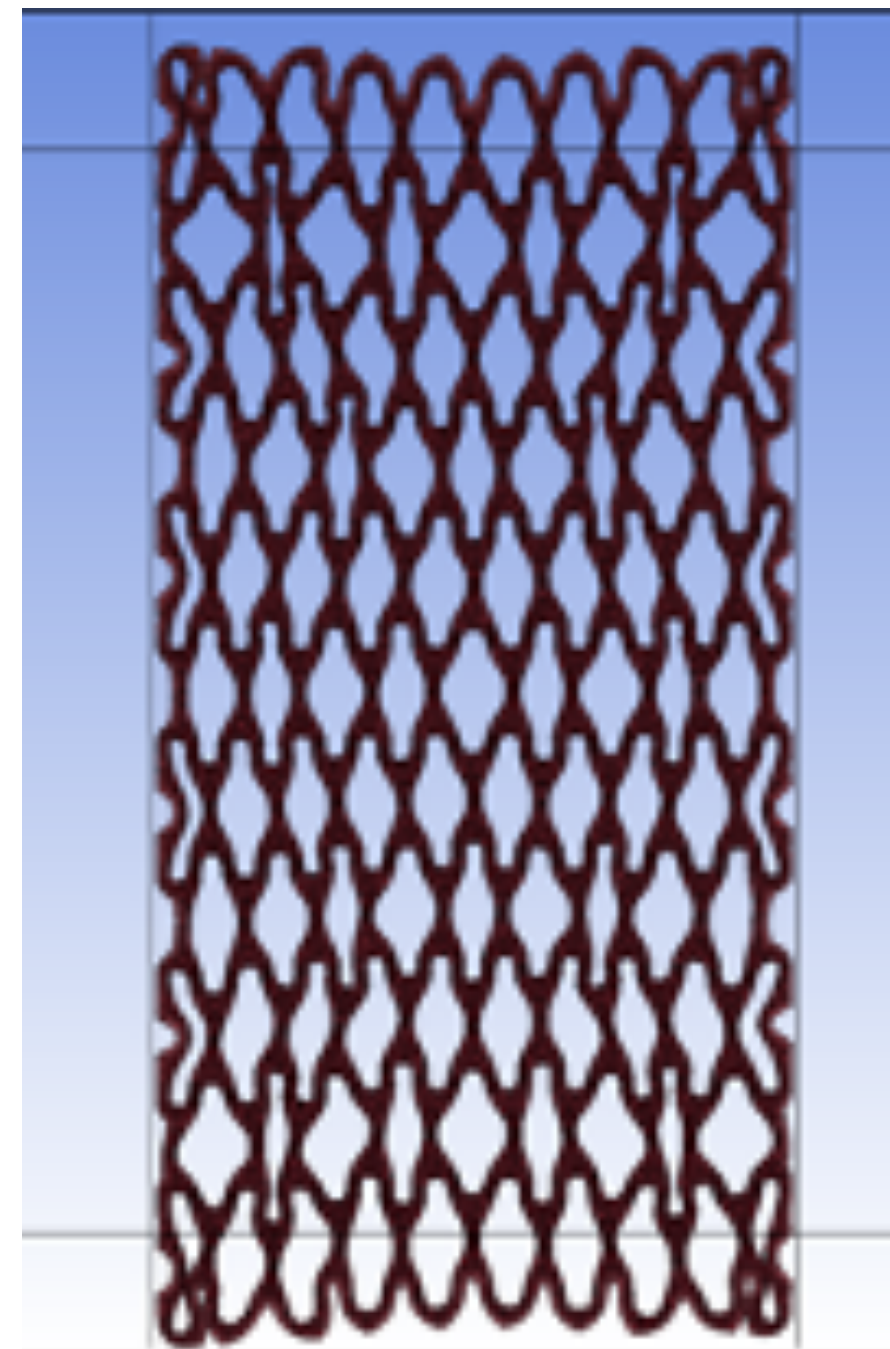
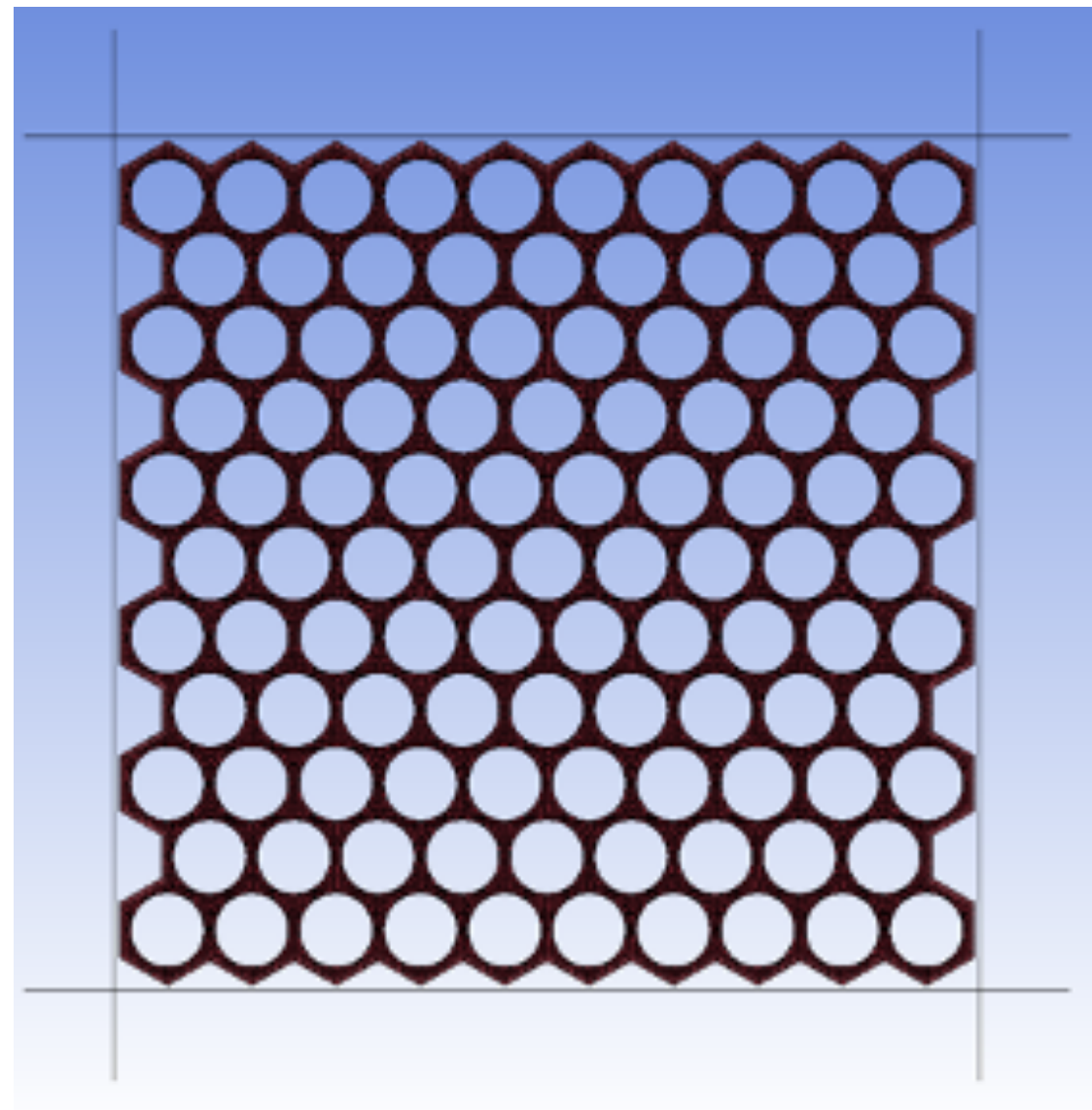
Cause of non-uniformity

Sample geometry: specimen number of cells

10x11

vs

16x17

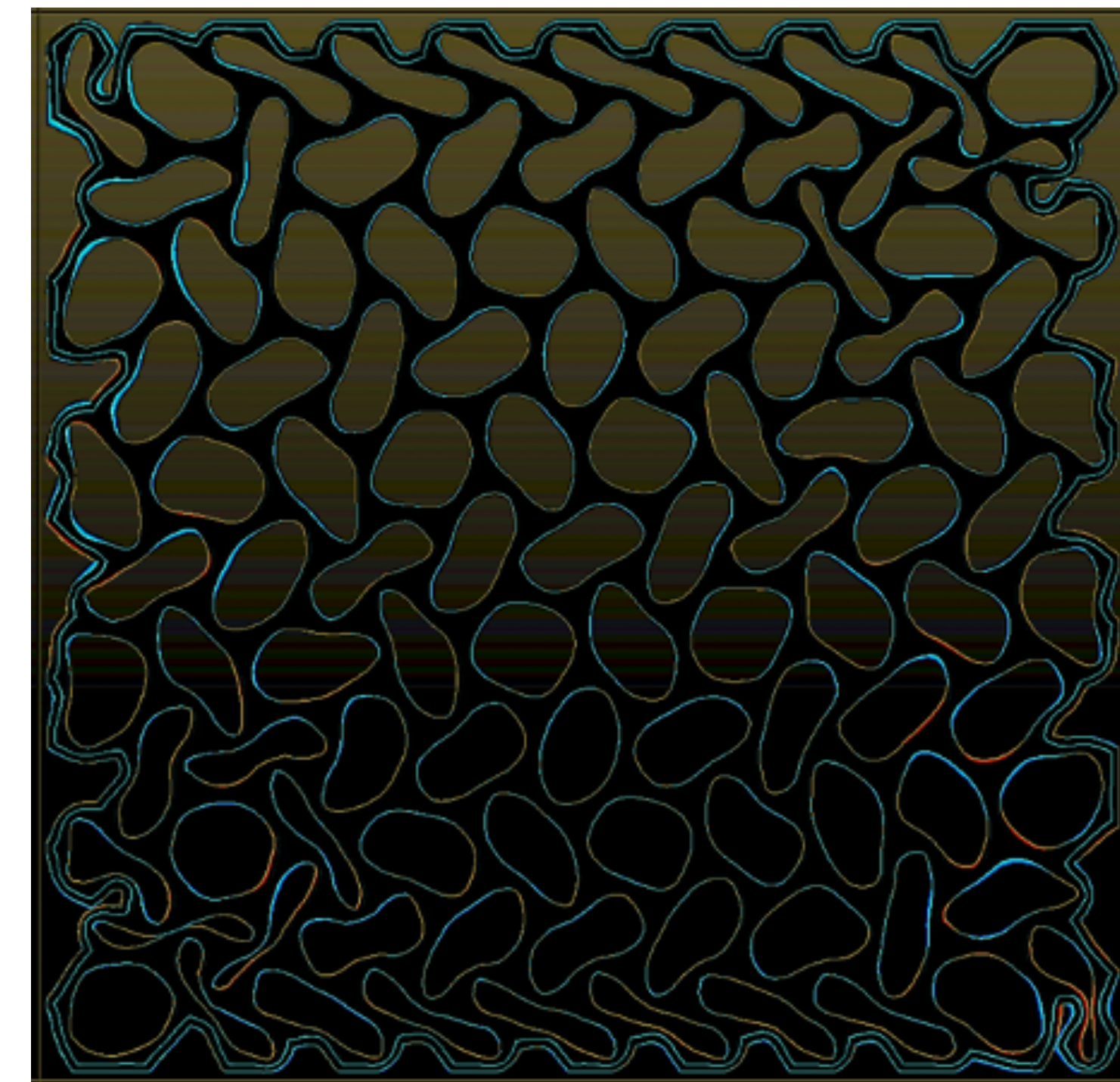
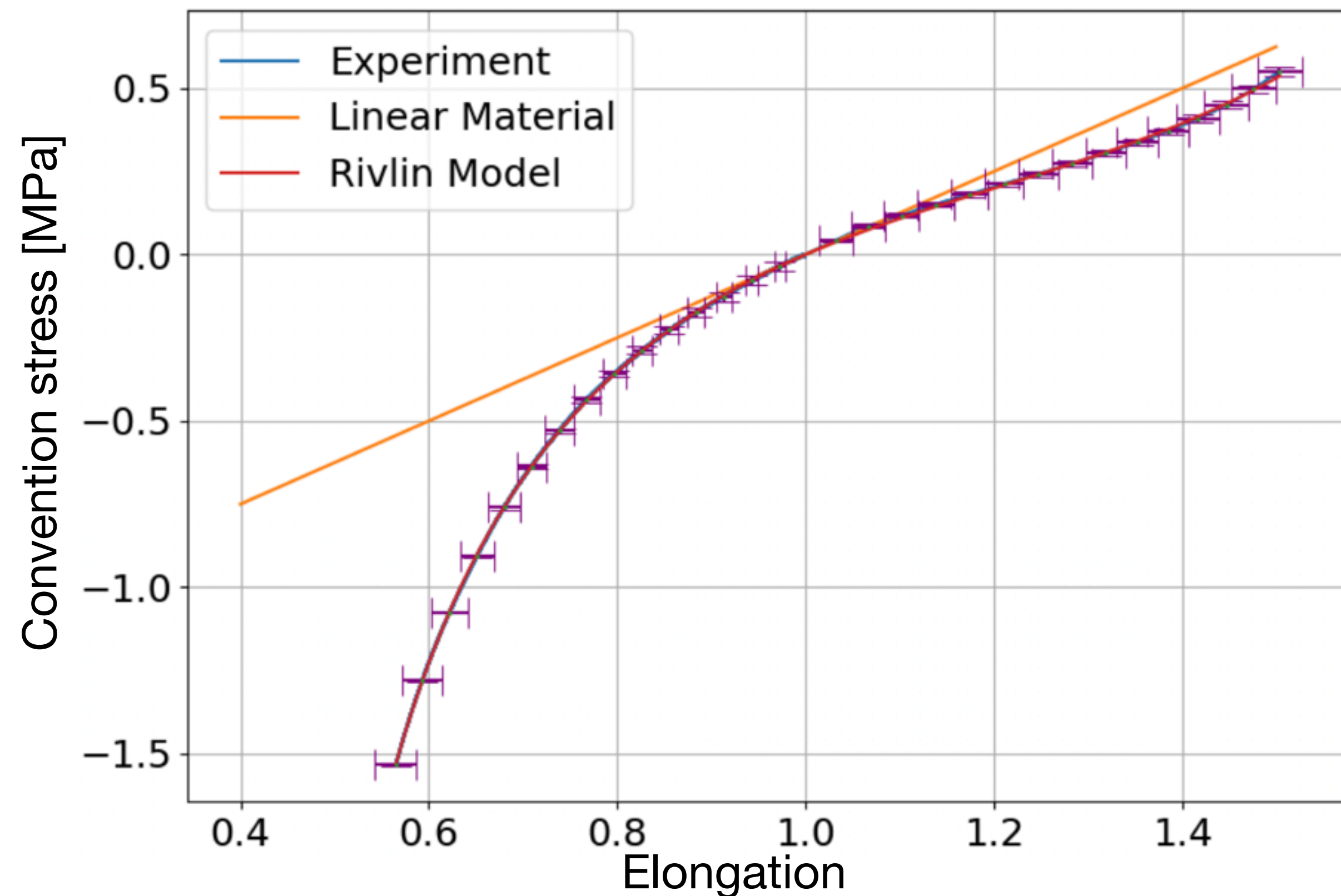


No noticeable effect of cell number

Cause of non-uniformity

Sample material

Comparison between a theoretical linear material and our real non-linear one



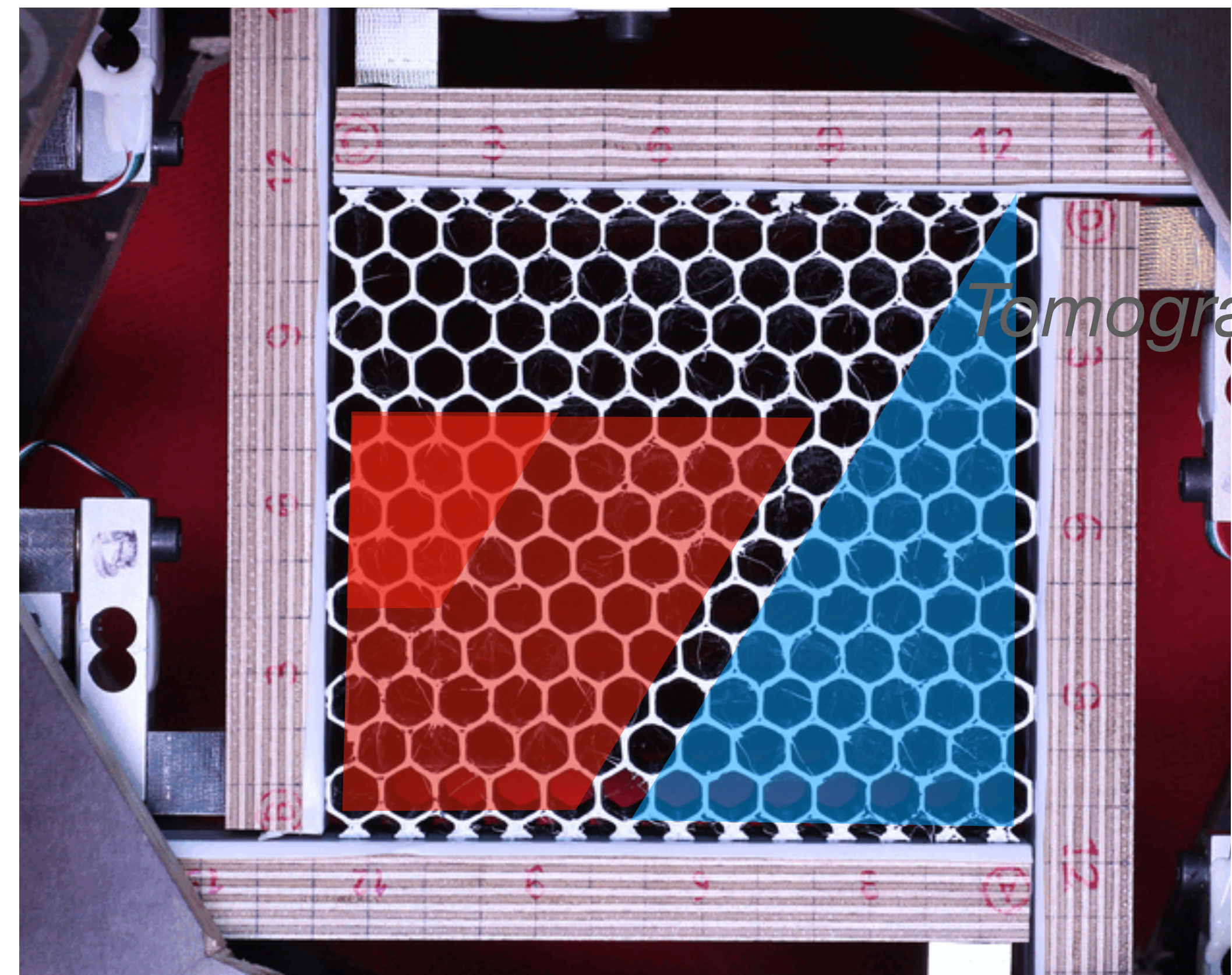
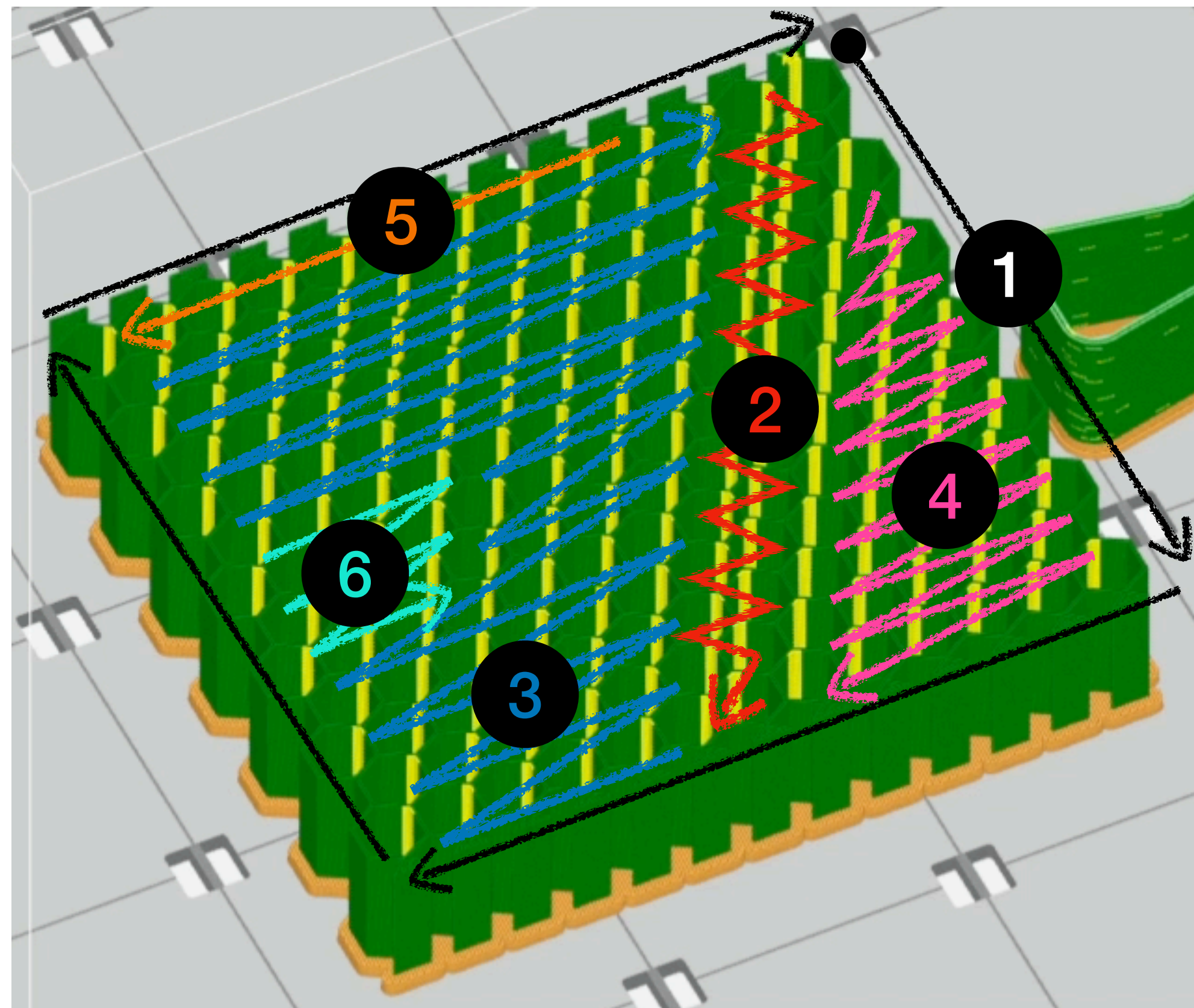
Difference between linear and N-linear material results

No effect of material behaviour

Cause of non-uniformity

Sample fabrication process

Case of a 3D FDM printed sample

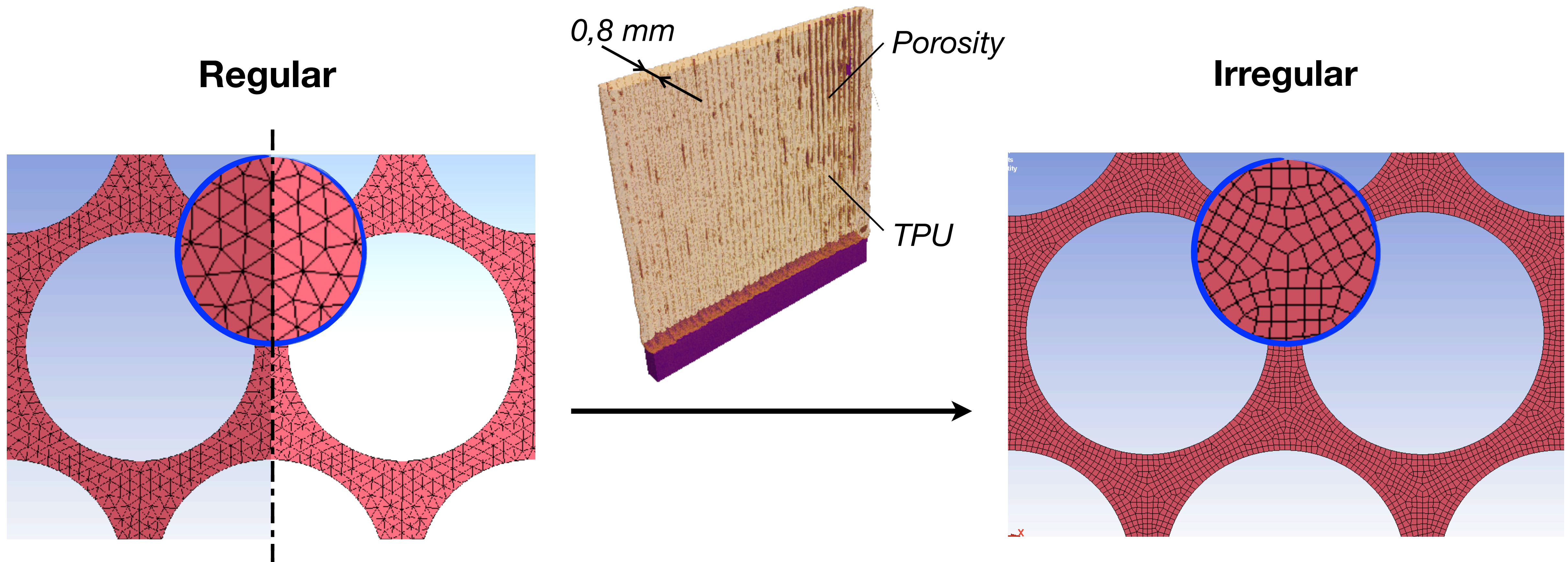


Clear effect of large scale defects

Cause of non-uniformity

Sample fabrication process

Material inhomogeneity modeled by mesh irregularity

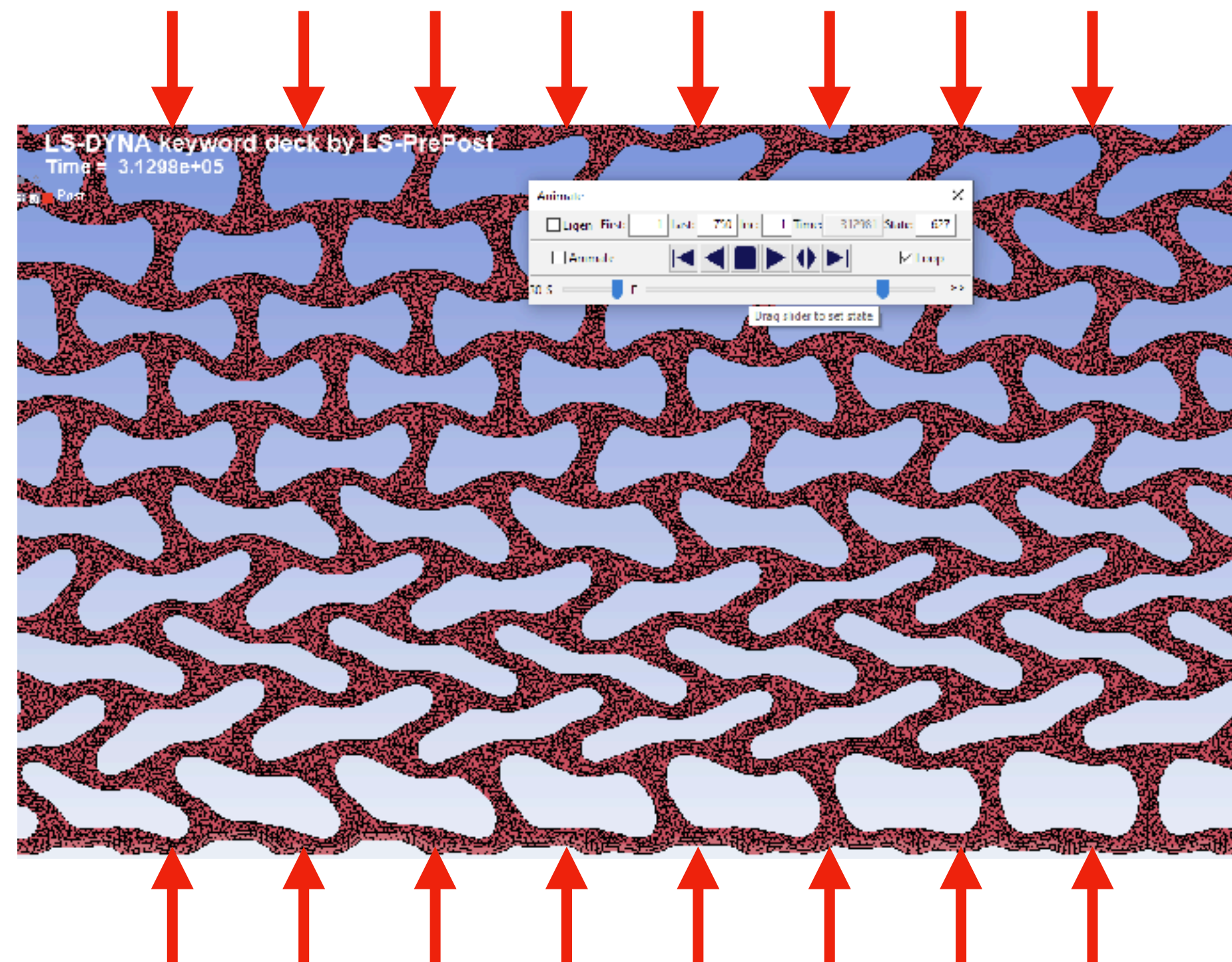


Cause of non-uniformity

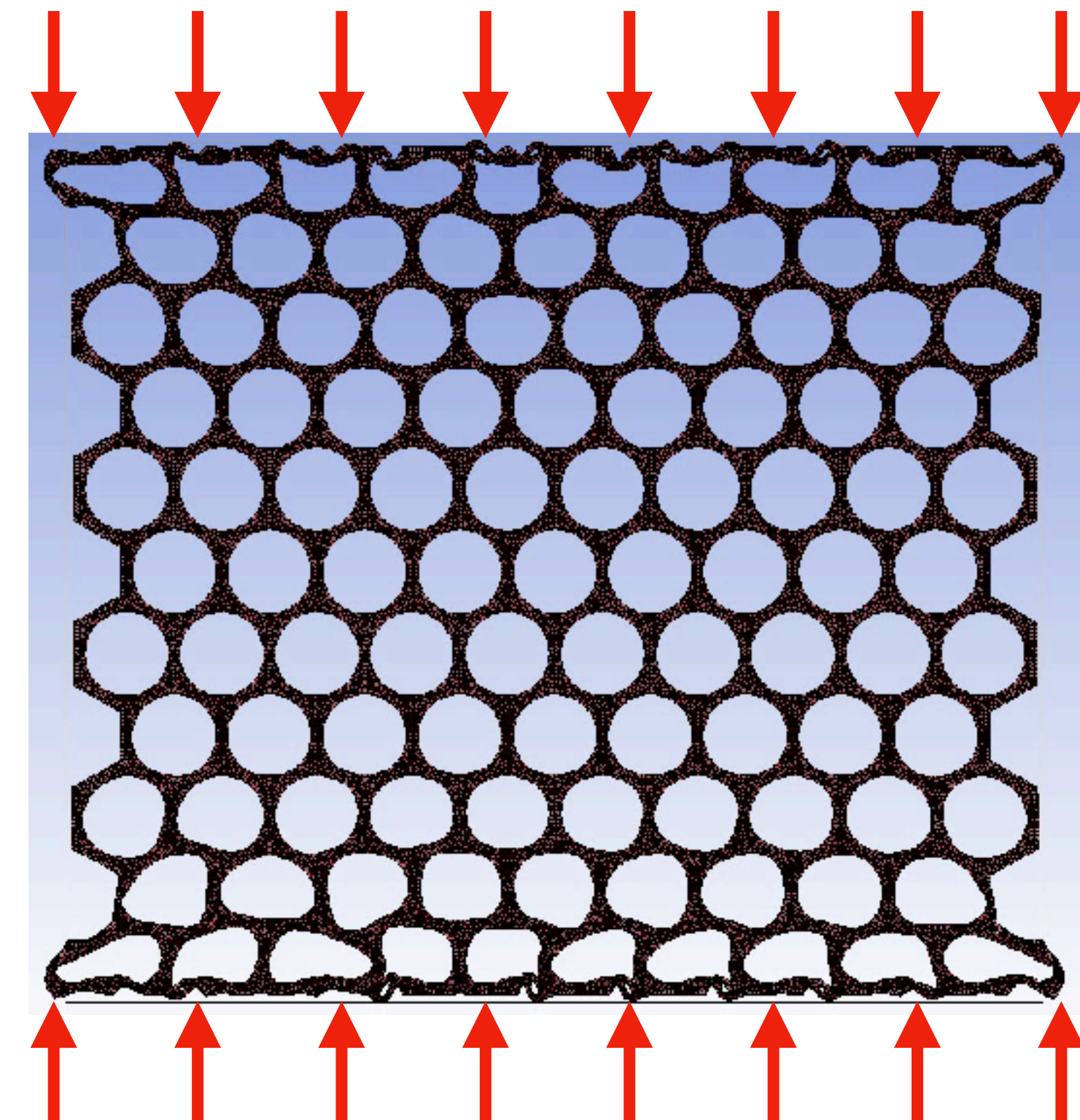
Sample fabrication process

Material inhomogeneity modeled by mesh irregularity

Regular



Irregular



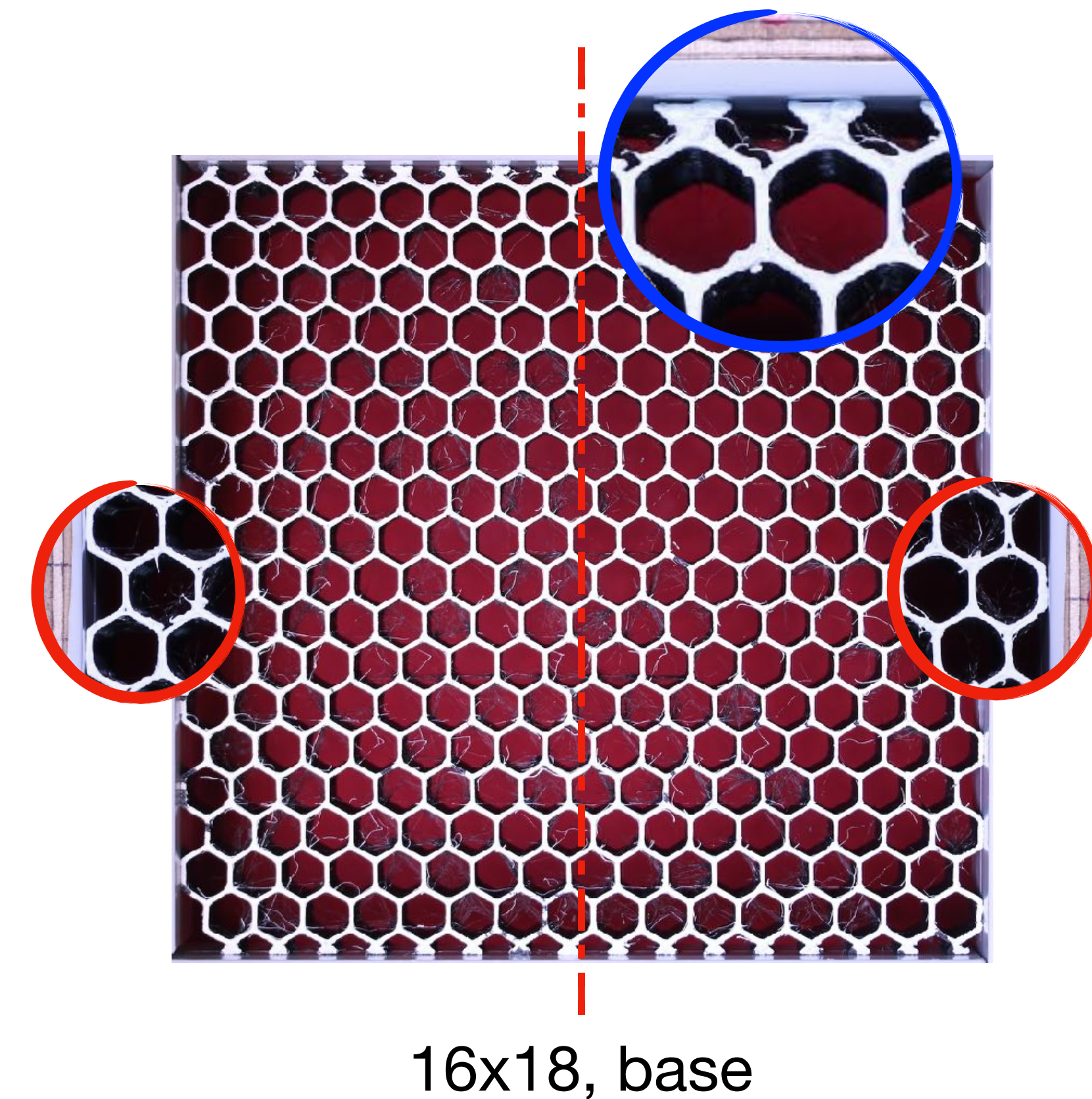
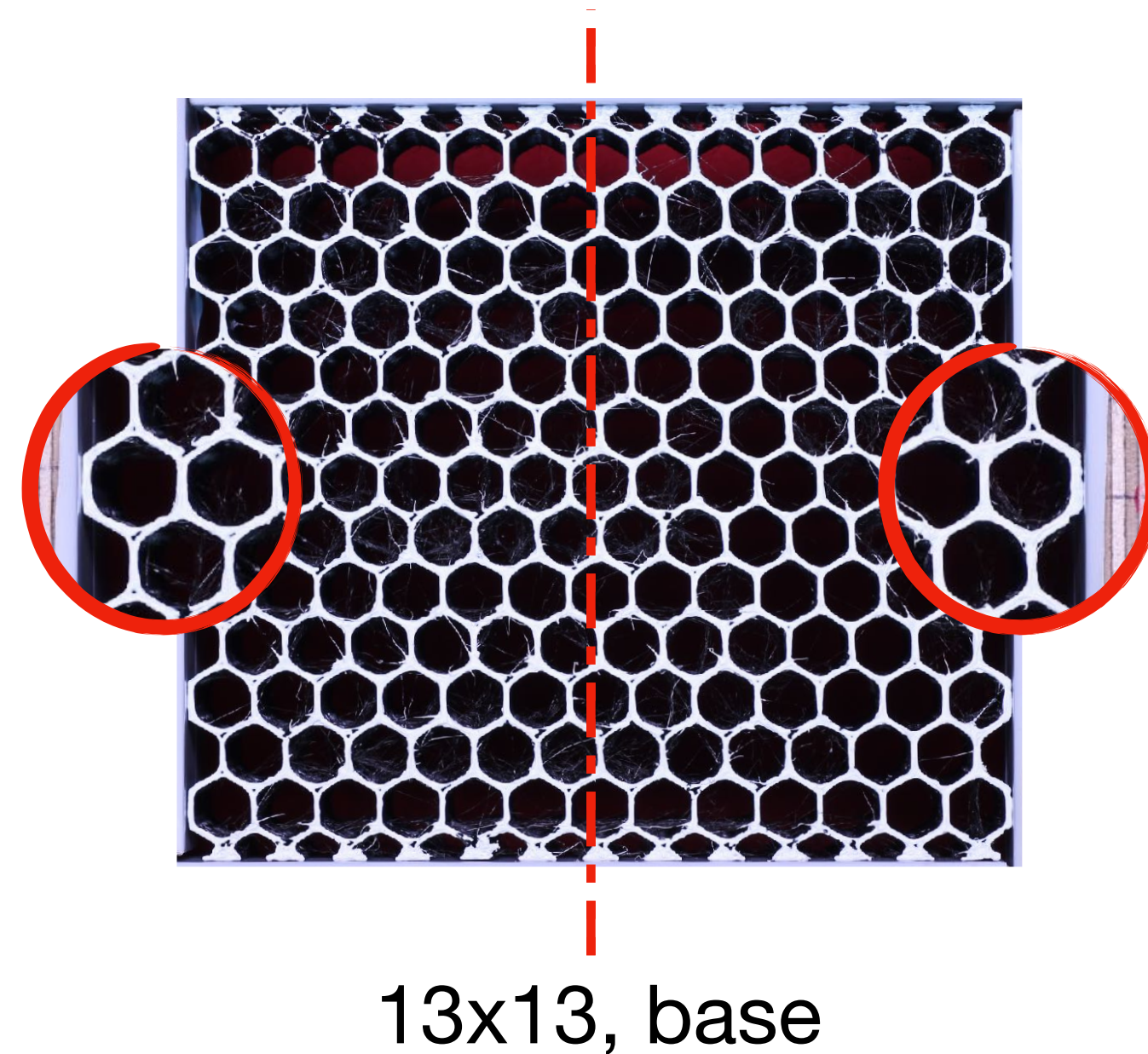
Clear effect of small scale defects (mat. heterogeneity)

Cause of non-uniformity

Boundary conditions: specimen external shape

Some examples:

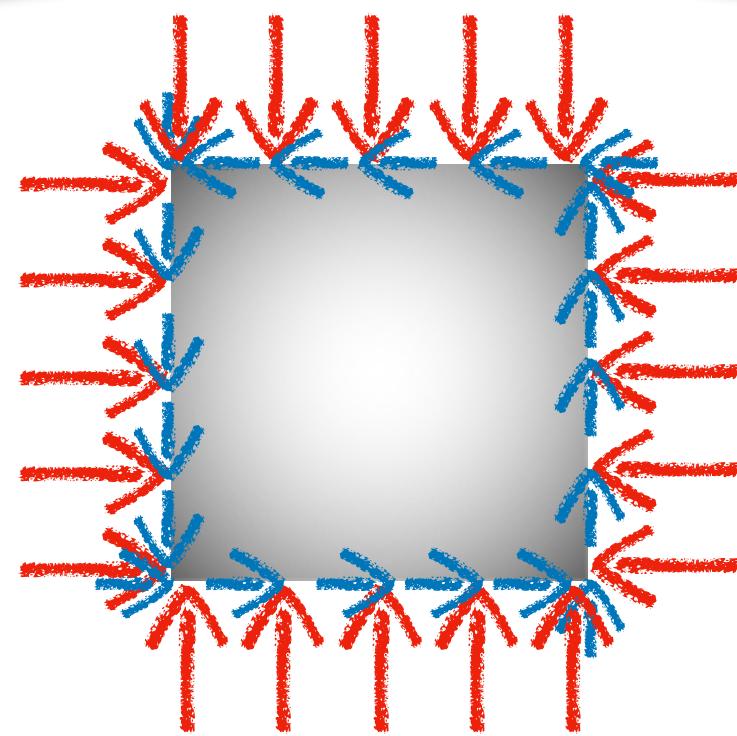
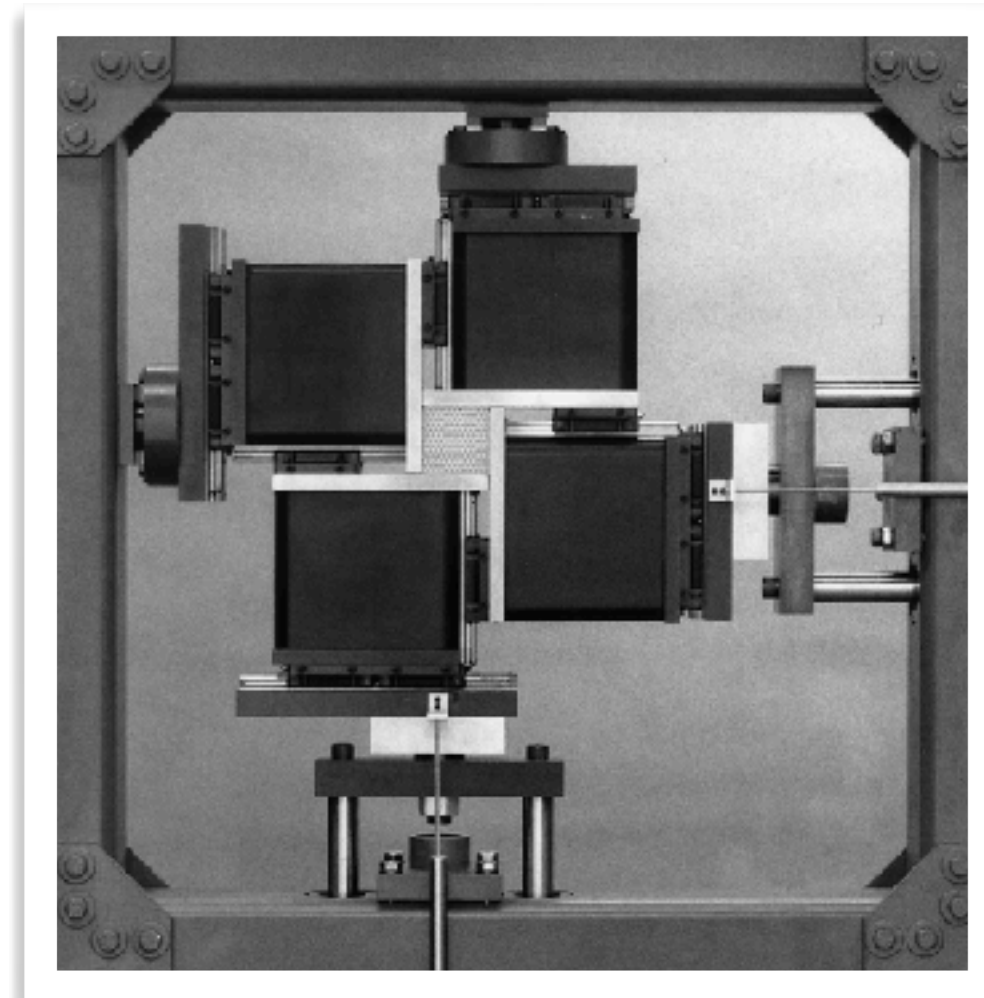
- symmetric/asymmetric BC,
- preventing rotation with sliders



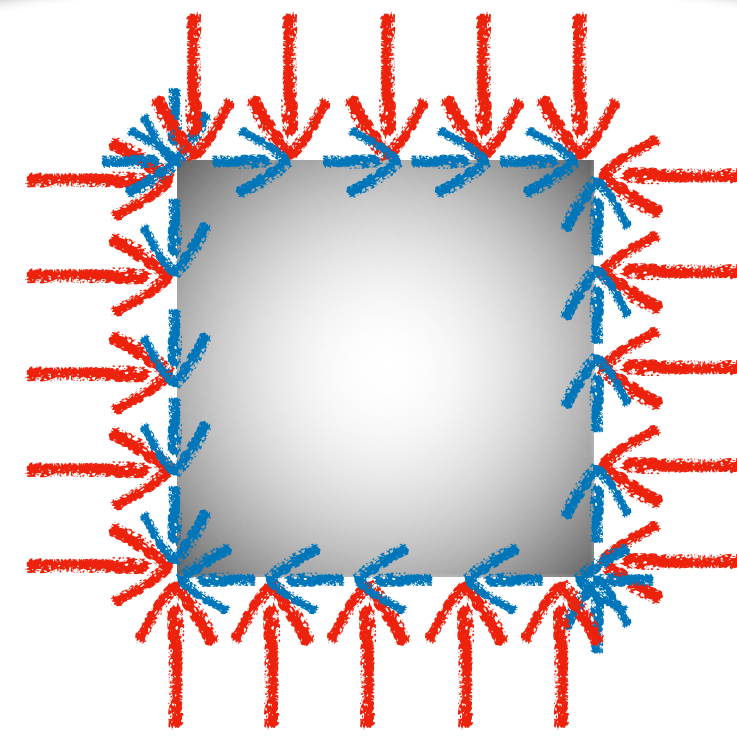
No noticeable effect of external shape

Cause of non-uniformity

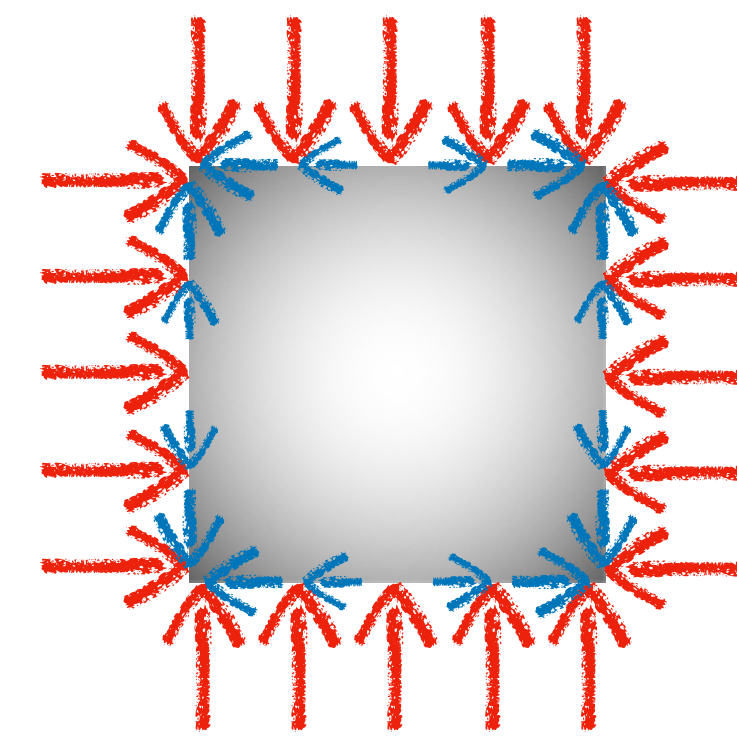
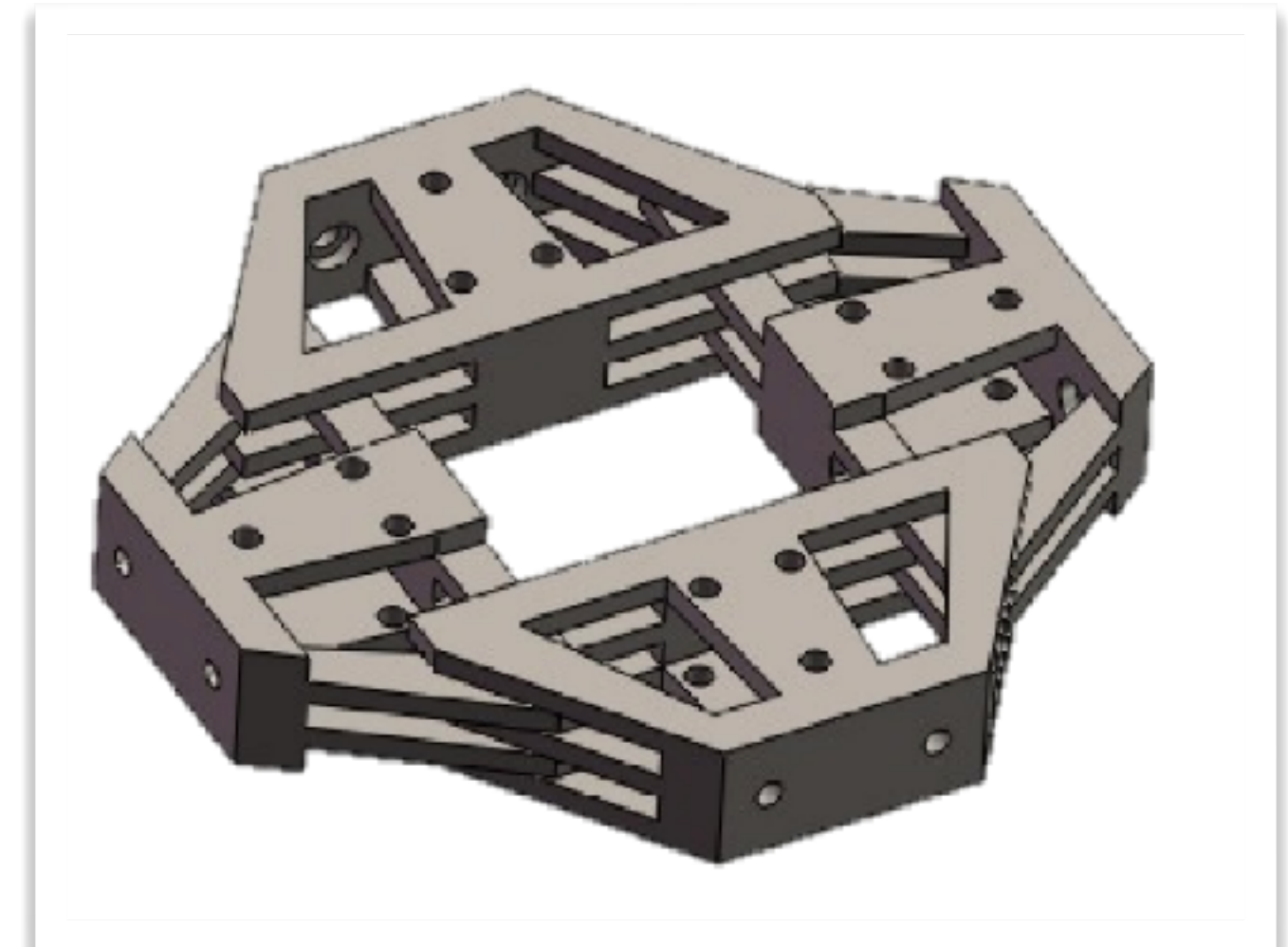
Boundary conditions: setup ?



[Kyriakides et al. 1999]



[Kossa et al. 2015]



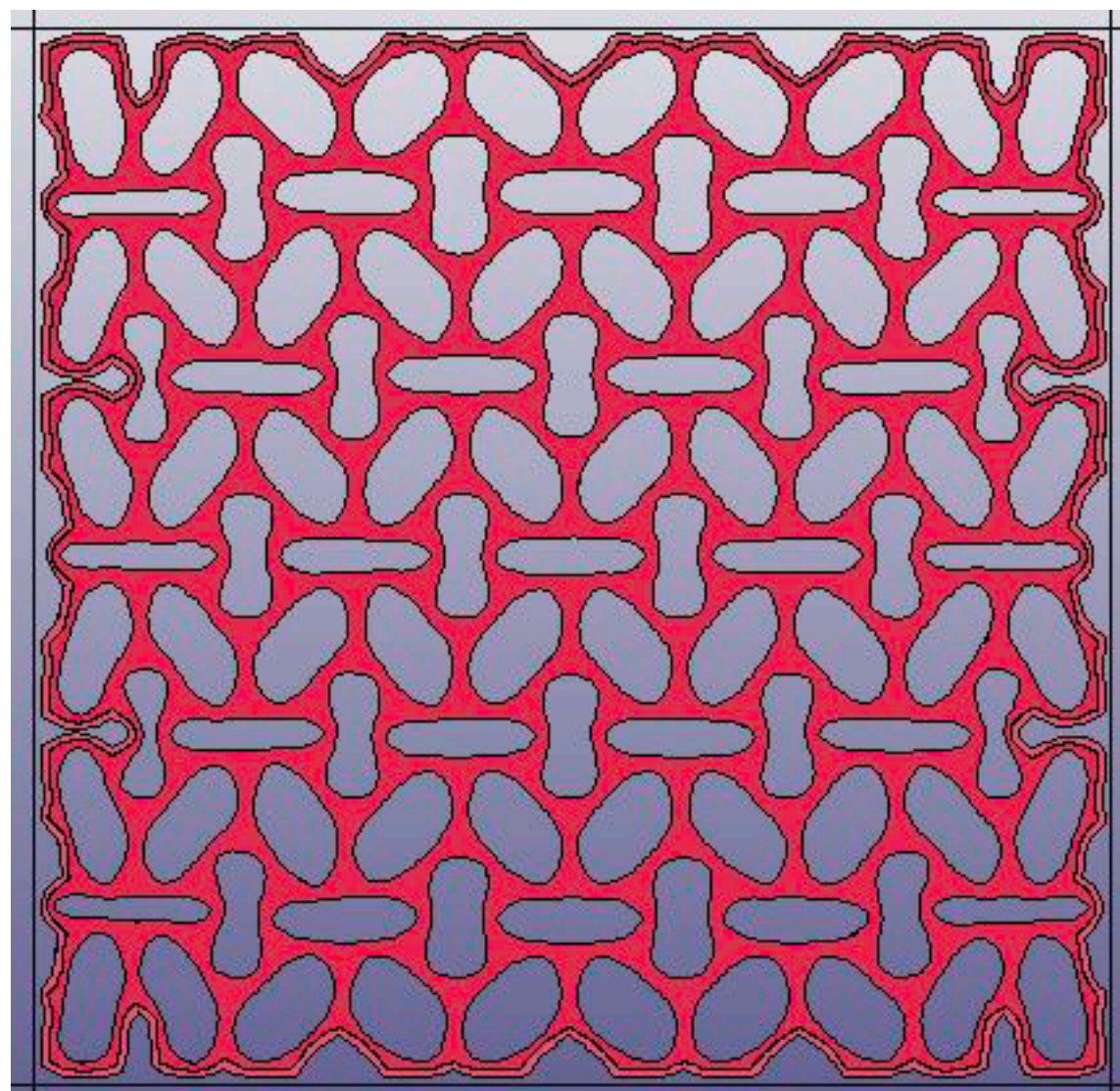
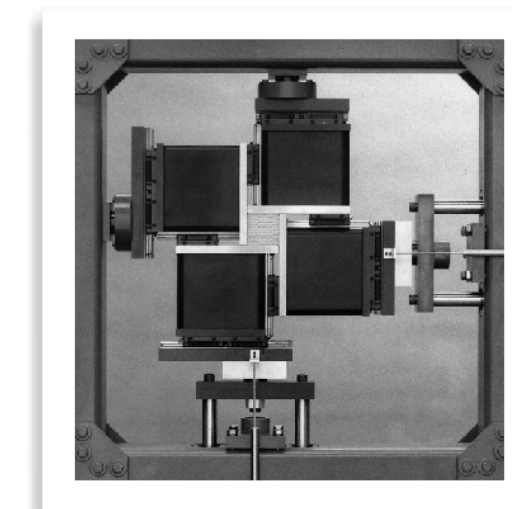
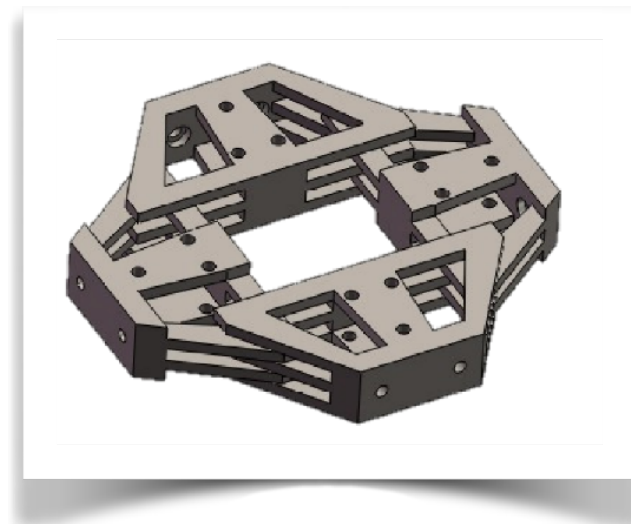
[Shan et al. 2014]

No perfect method because of friction

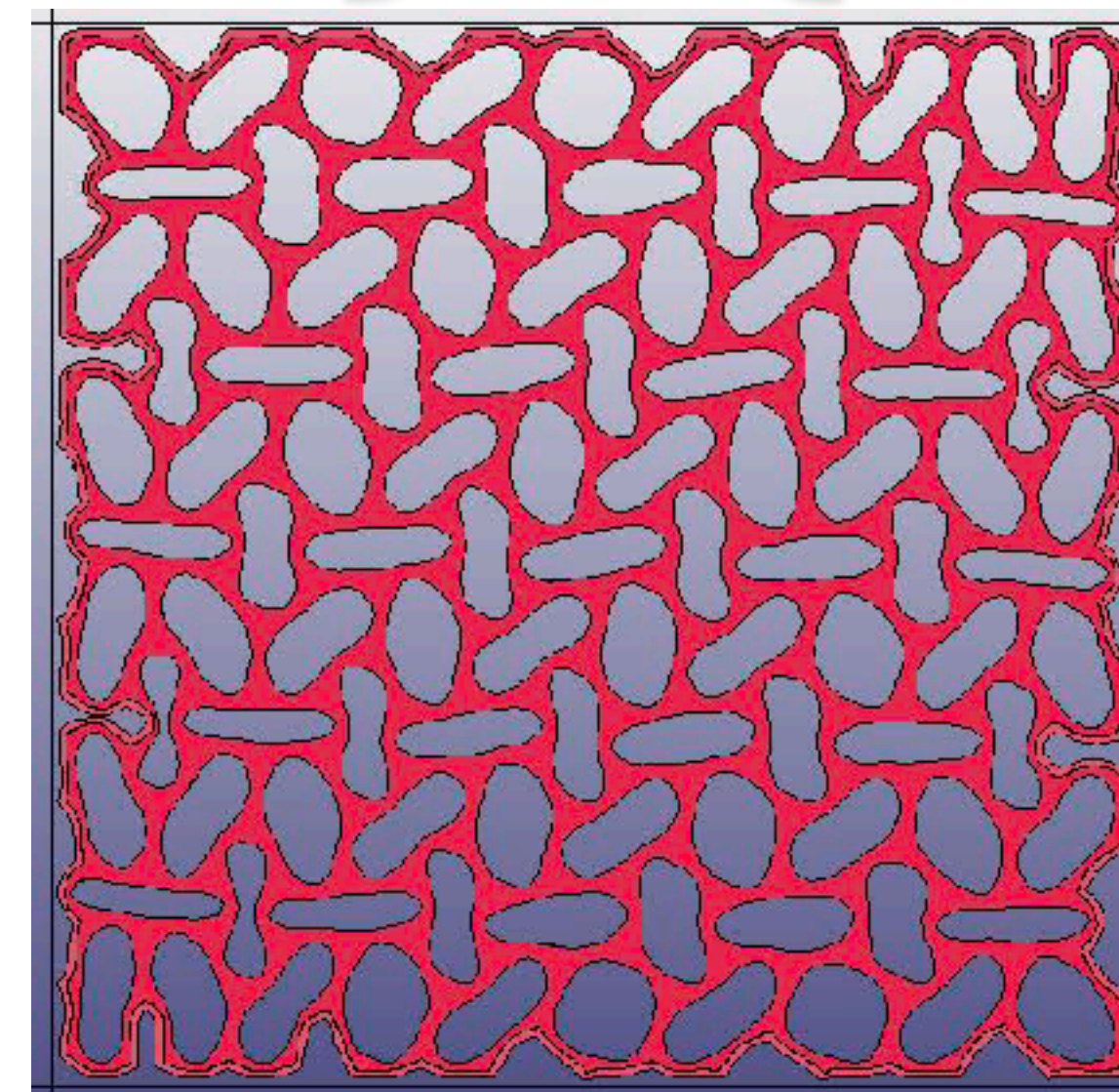
Cause of non-uniformity

Boundary conditions: setup ?

Equibiaxial compression : comparison Shan vs Kyriakides



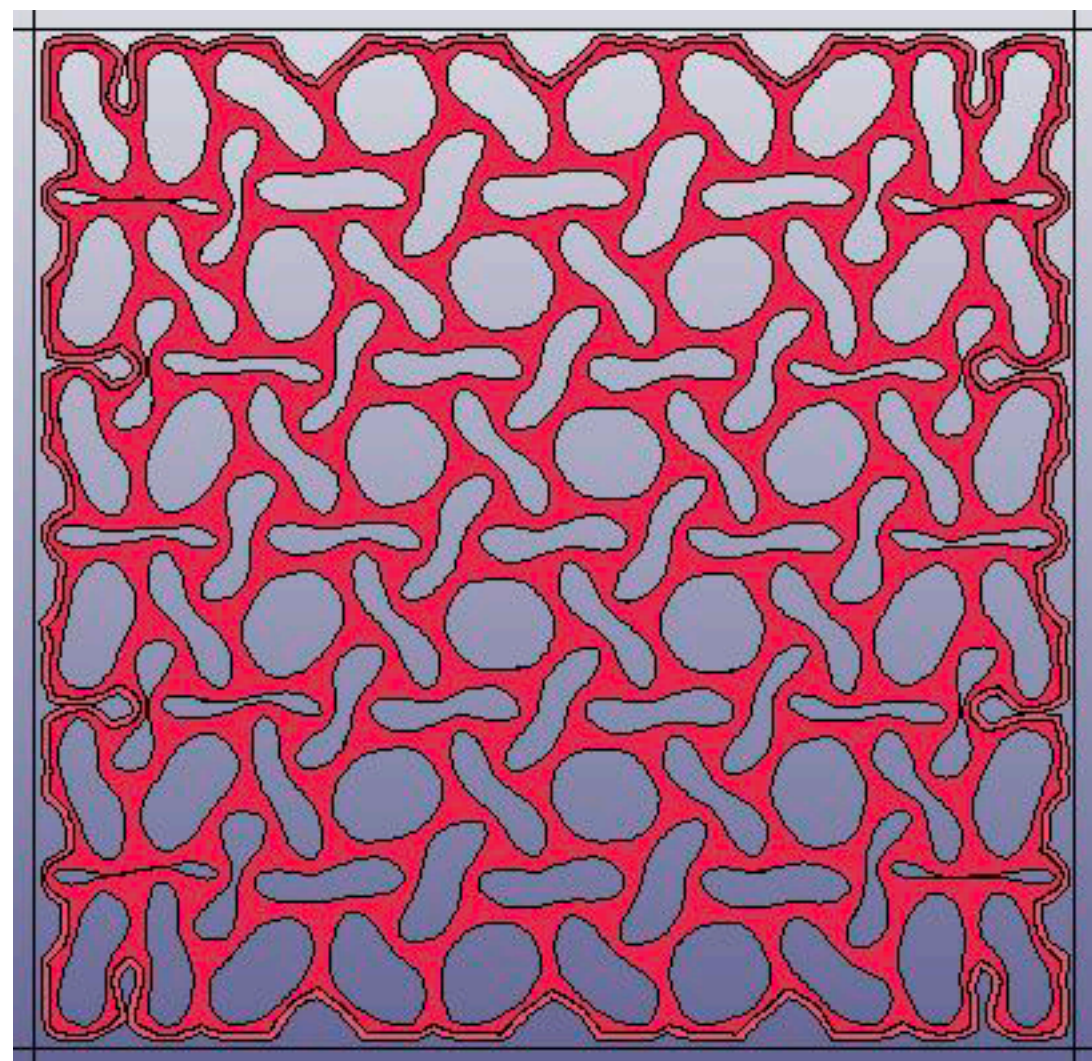
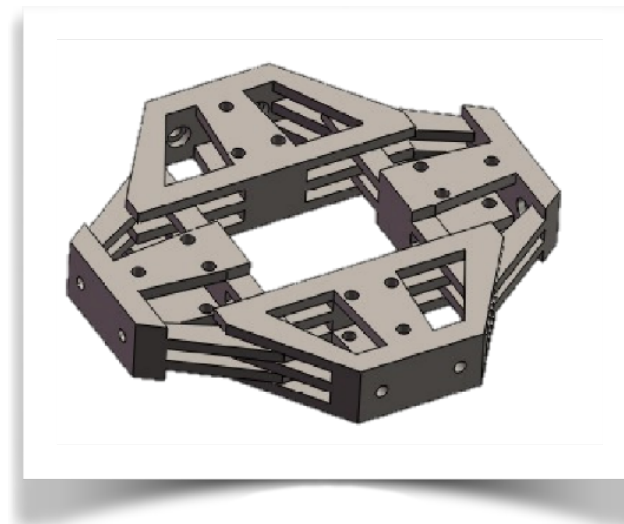
$$\varepsilon_{xx} = \varepsilon_{yy} = 9 \%$$



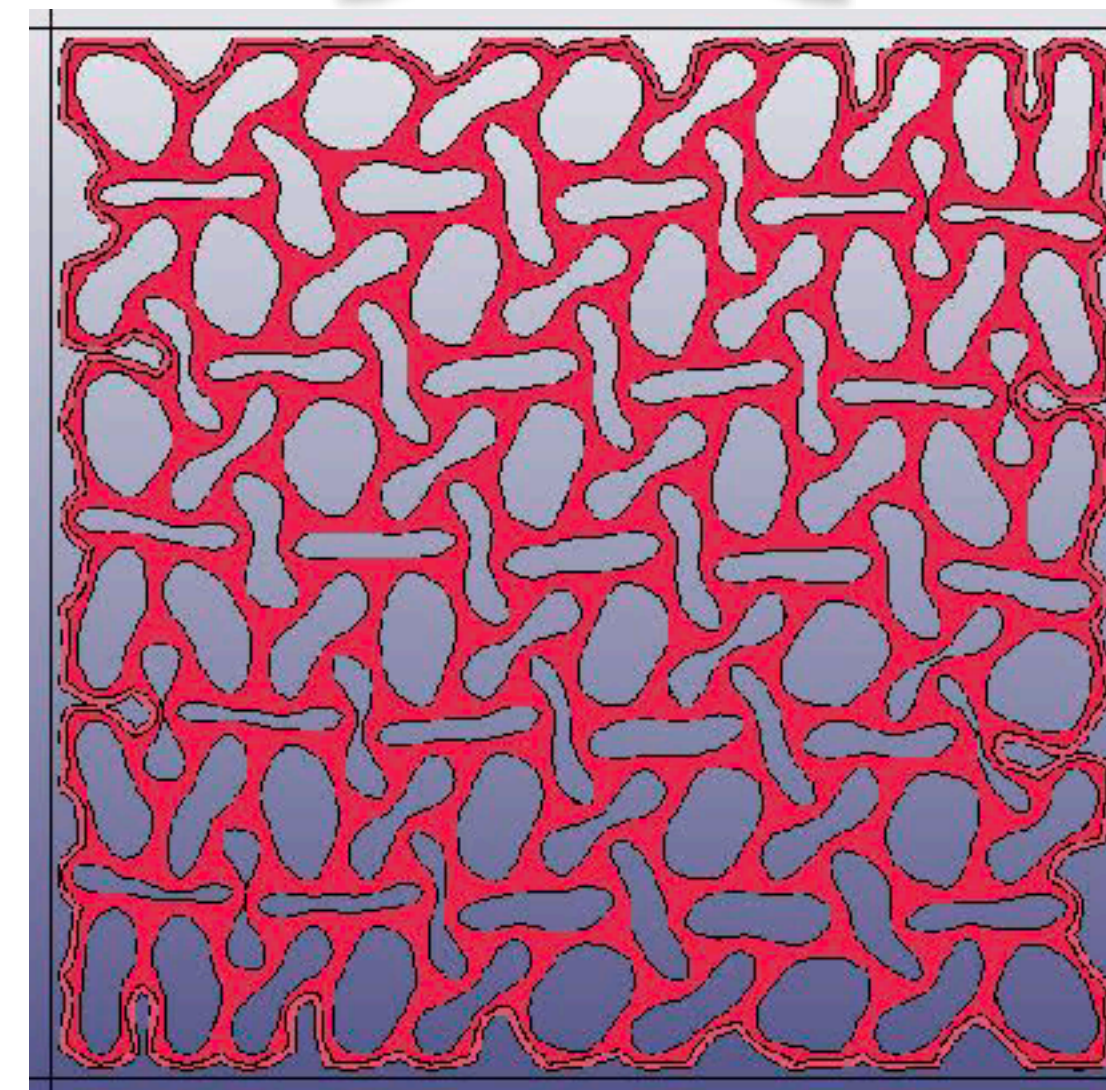
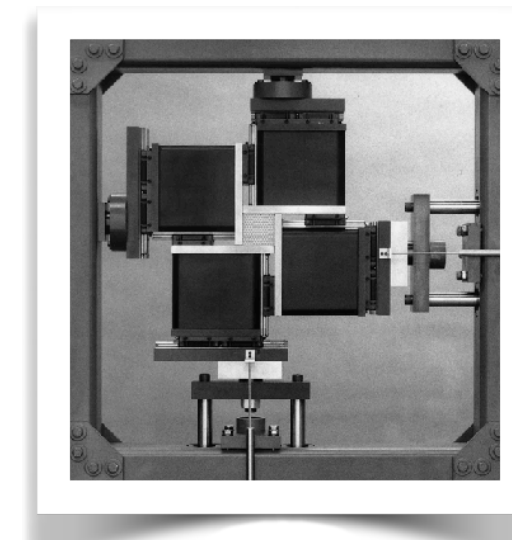
Cause of non-uniformity

Boundary conditions: setup ?

Equibiaxial compression : comparison Shan vs Kyriakides



$$\epsilon_{xx} = \epsilon_{yy} = 12 \%$$



Clear effect of setup kinematics

How to cheat ?

Increase loading amplitude to its maximum

Compact the sample, then partially unload it !

Loading path ?



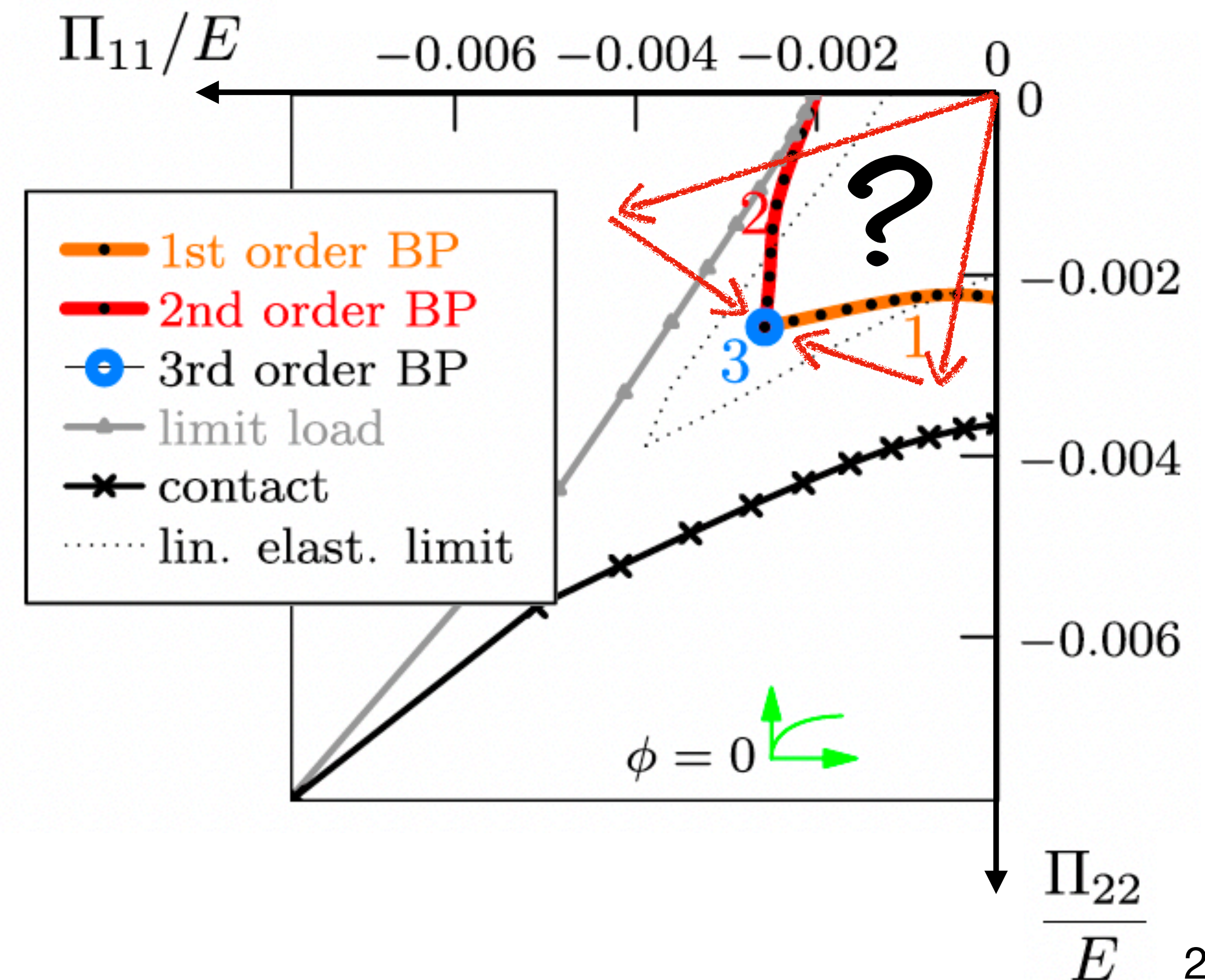
Result obtained by loading *carelessly by hand*

How to cheat load in a clever way ?

Increase loading amplitude

What about:

- non-monotonous ?
- non-proportional loadings ?



Subsidiary Research question

What causes non-uniform pattern ?

~~Sample geometry:
Effect of cell number~~

Loading path ?

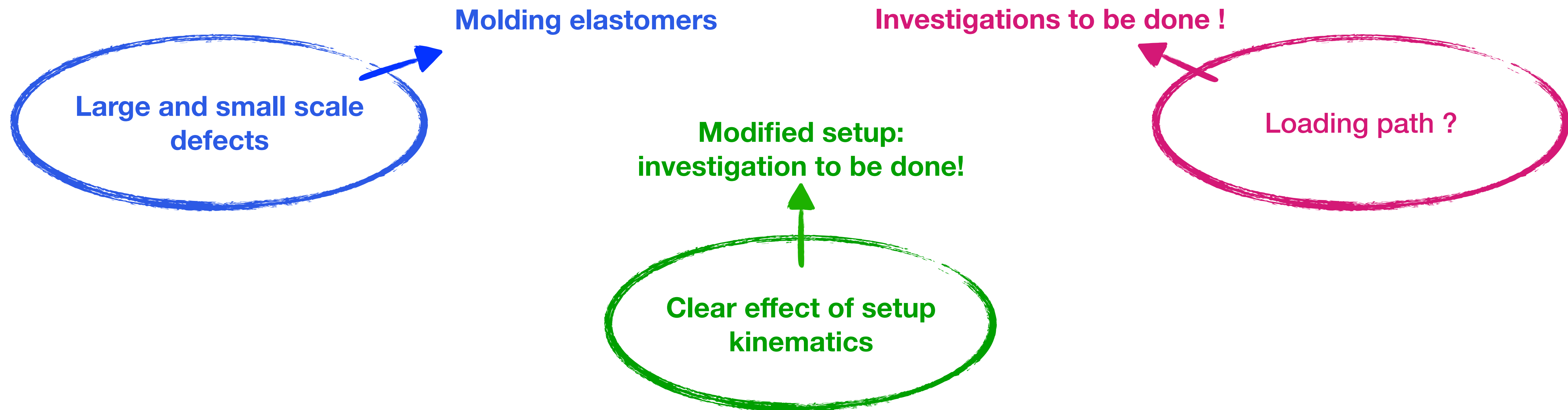
Boundary conditions:
Clear effect of setup kinematics
~~Effect of external shape~~

~~Sample base material:
Material non-linearity~~

Sample fabrication process:
Effect of large and small scale defects

(Partial) Conclusion

What causes non-uniform pattern ?



We should have everything ready for success !!