

# Numerical Simulation of Open-Cell Foams

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## Outline

- Motivation and material demand
- Geometry to describe open-cell foams
- Material properties (Al-alloy)
- Basic simulation idea
- Link Hex20 with Beams (displacement and rotation)
- Global Cell Size: 3x3x3 or 9x9x9
- Element type: Hex20 – Beams
- Comparison with the observed deformation state
- Conclusion and Outlook

# Motivation

helmets



explosive liquids



impact protection  
of vehicles

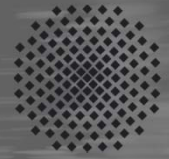


dangerous goods



space station (meteoroid)

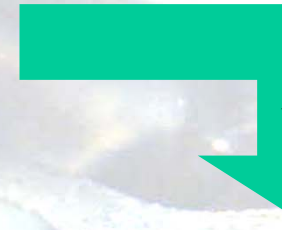




- stiffness
- hardness
- toughness
- damping and shock absorption



can we learn from nature?

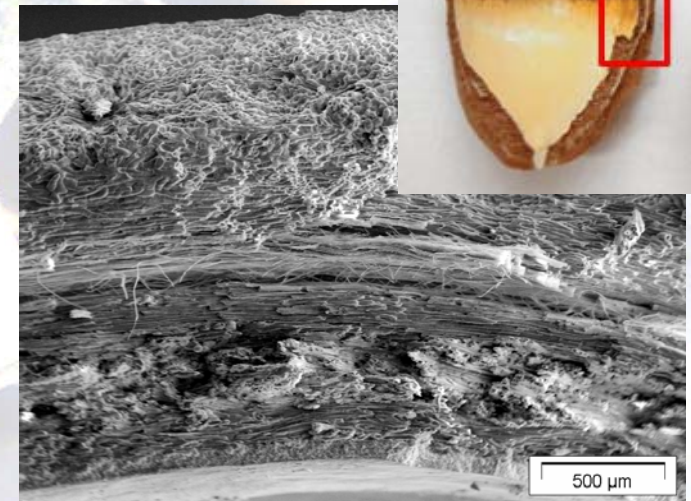


Yes we can

## Biomimetics

- Improved understanding of biological structures & functions
- Successful implementation of functional principles and development of innovative technical products inspired by nature

pericarp of Macadamia



free fall from heights up to 15 meters without any damage

## SPP 1420

### Biomimetic Materials Research: Functionality by Hierarchical Structuring of Materials



University Botanical  
Garden (Freiburg)

To understand the implications of the different hierarchical levels of fruit walls on the micro and macromechanical behaviour. The characterisation of the biological samples will be divided into the structural and mechanical part



Materials Science and  
Engineering (Berlin)

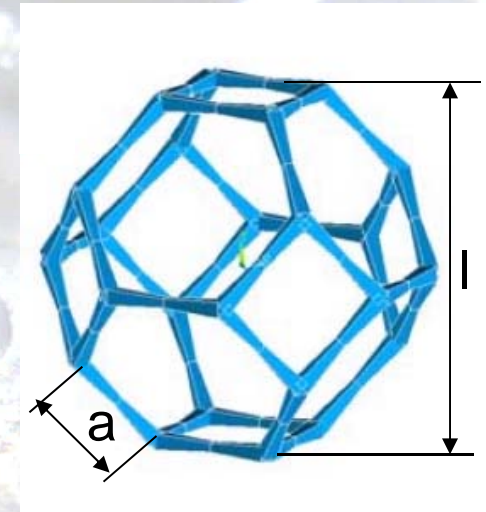
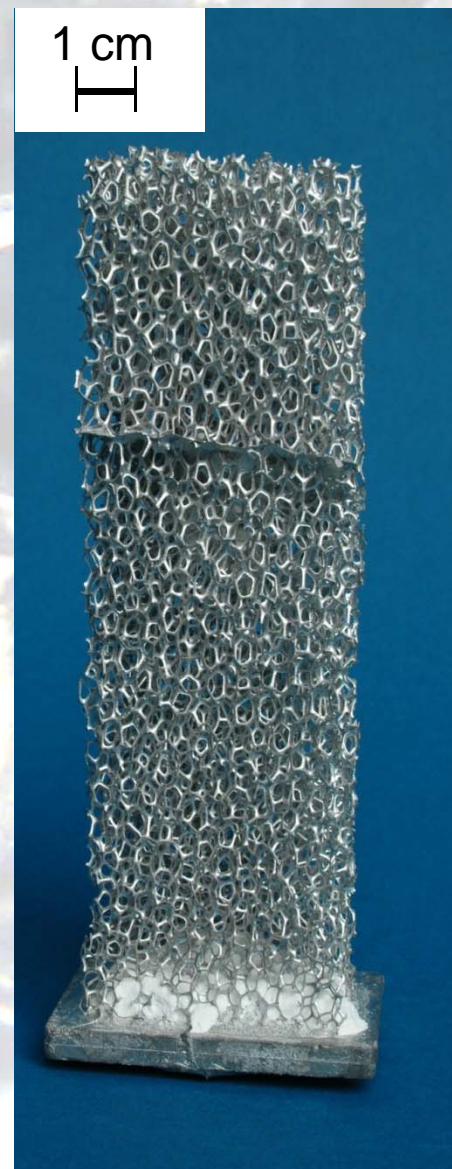
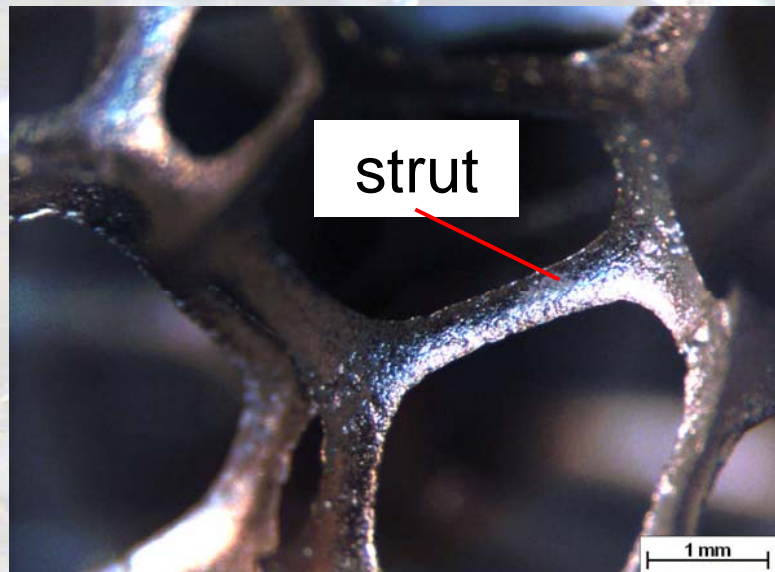
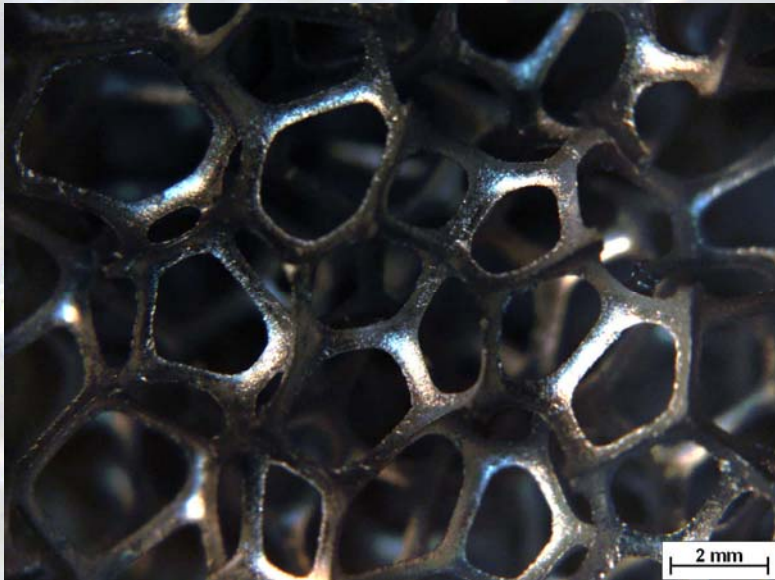
The mechanical tests on single structures. Standard specimens will be tested under quasi-static and dynamic loading conditions. (Tensile, compressive and 4-point bending tests)



Foundry Institute

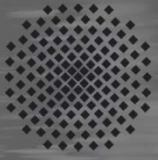
To evaluate appropriate materials (metals, models of open-pore structure). To develop process technology for casting open foam structures

# Geometrical form to describe open-cell foams

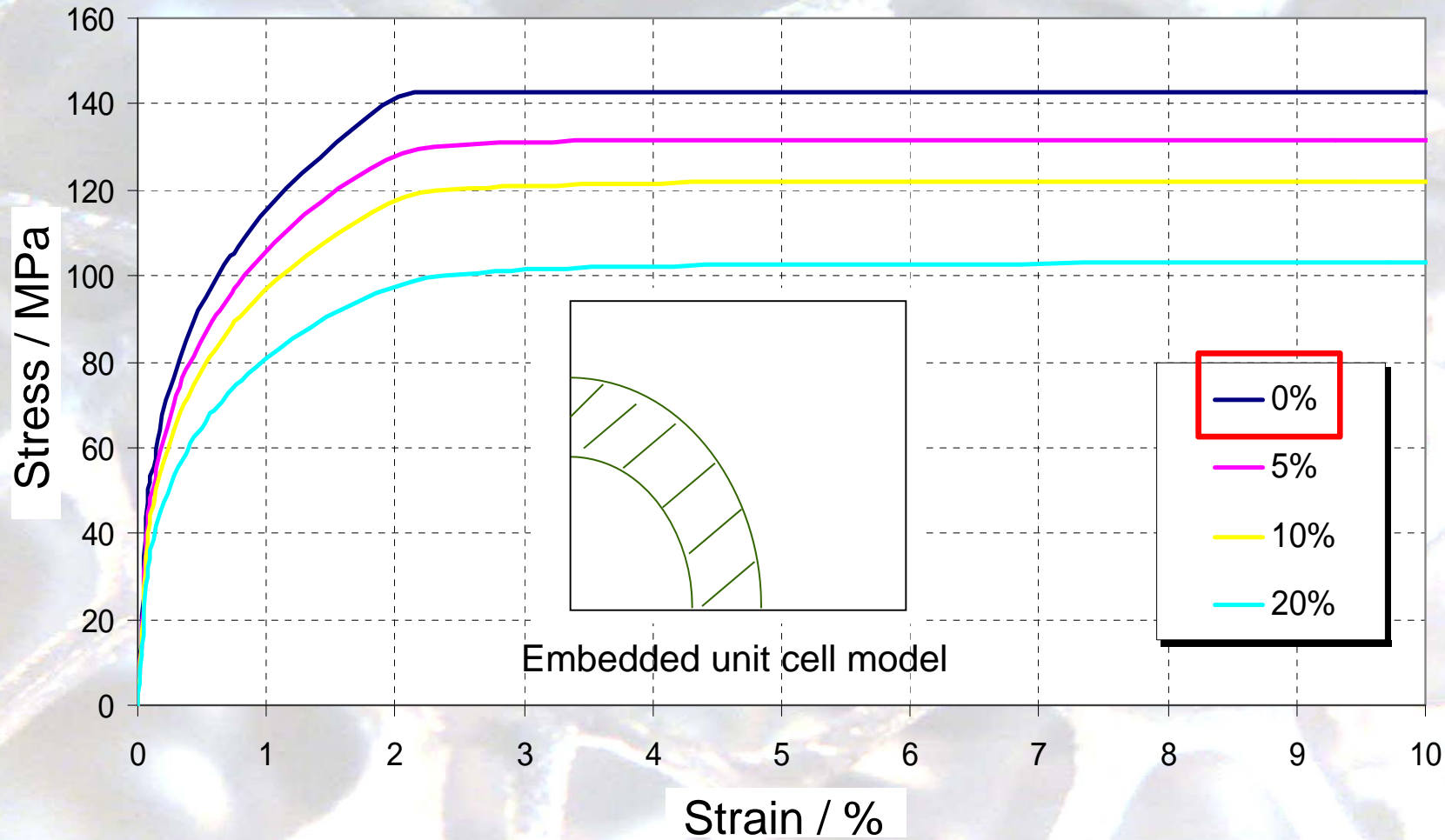


Tetrakaidecahedronal  
(Kelvin cell)

**10ppi foam:**  
 $a = 2590 \mu\text{m}$   
 $l = 7560 \mu\text{m}$



## AlSi7Mg0.3

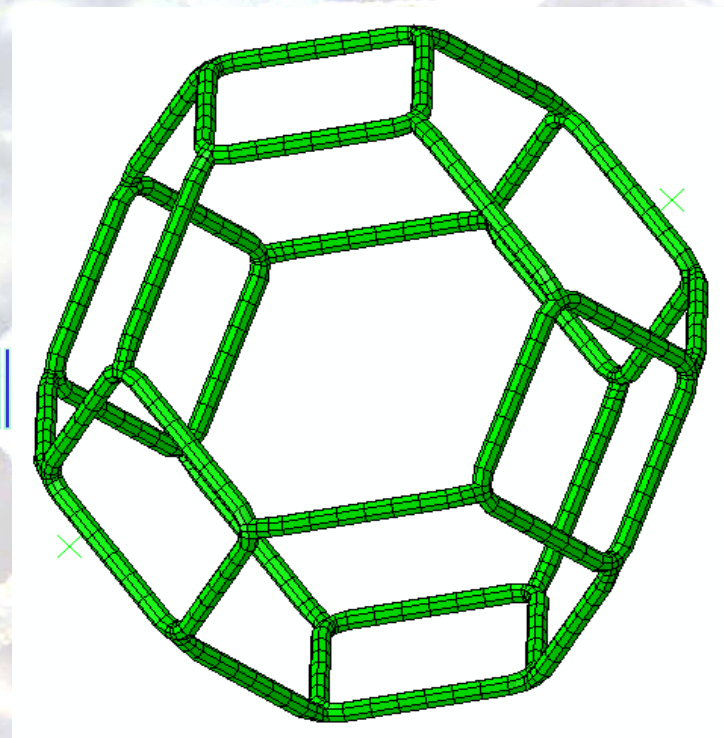
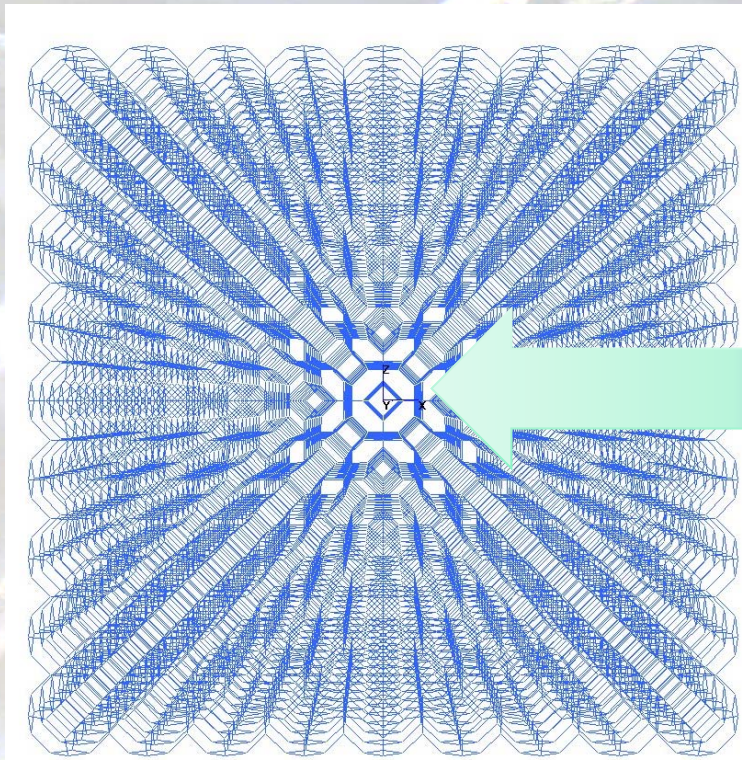


In Detail: MM-Seminar in December 2010

## Basic Idea of the simulation

Beam Structure

Include a „Super Cell“, to investigate different influences on the foam behaviour



⇒ to link beams and solids elements

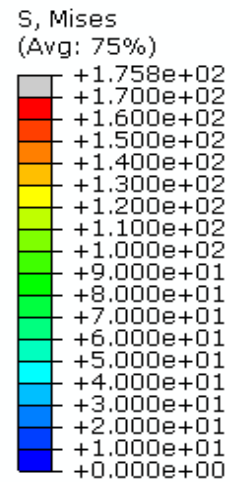
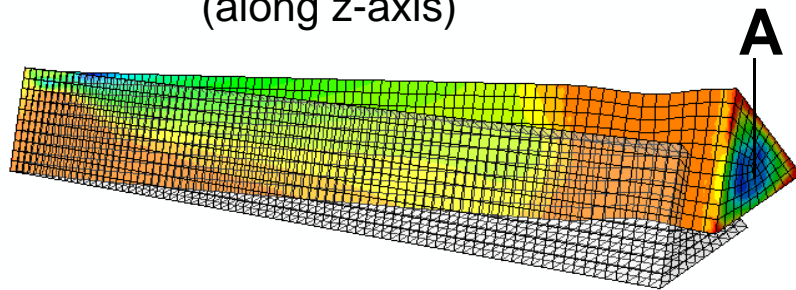


# Displacement

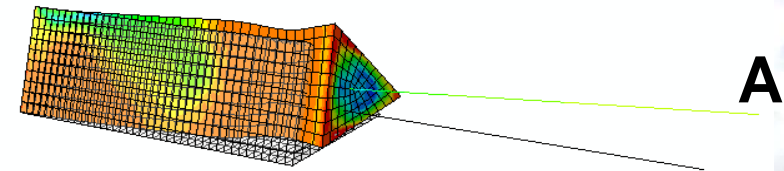
## Link Hex20 with Beam(s)

# Displacement Loading Case

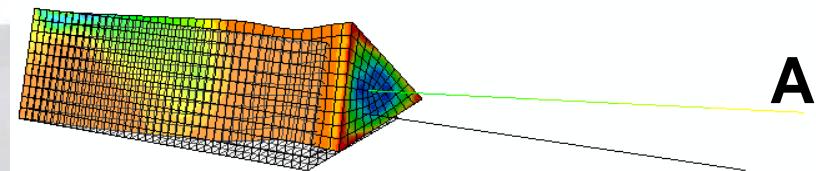
80 Hex20  
(along z-axis)



40 Hex20 + 40 Beams  
(along z-axis)



40 Hex20 + 1Beam  
(along z-axis)



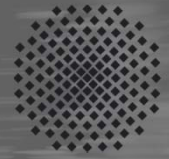
## Position A

$$\Delta x = 0.1 \text{ mm}$$

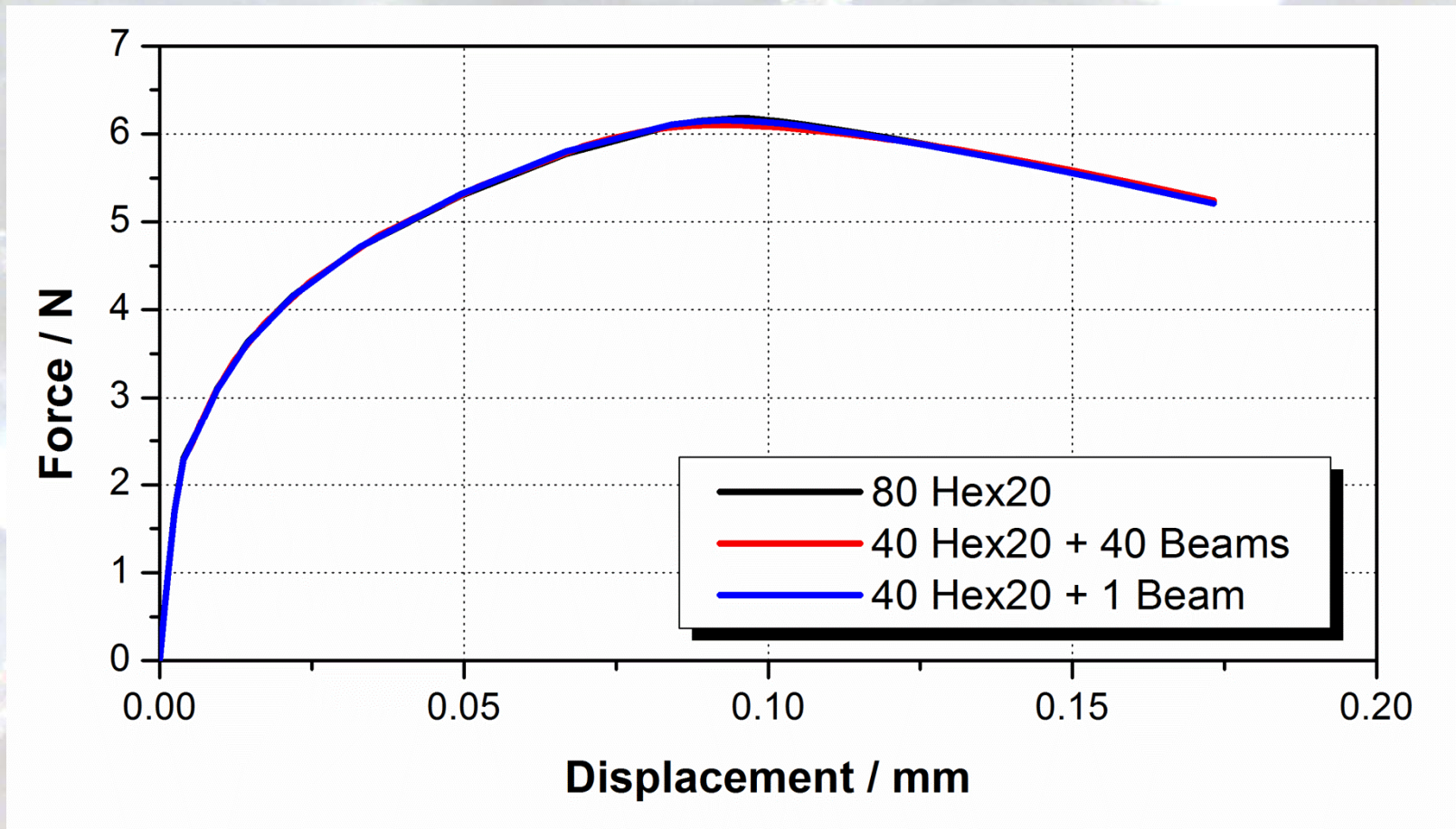
$$\Delta y = 0.1 \text{ mm}$$

$$\Delta z = 0.1 \text{ mm}$$





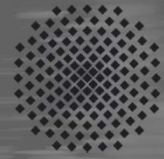
# Displacement Loading Case



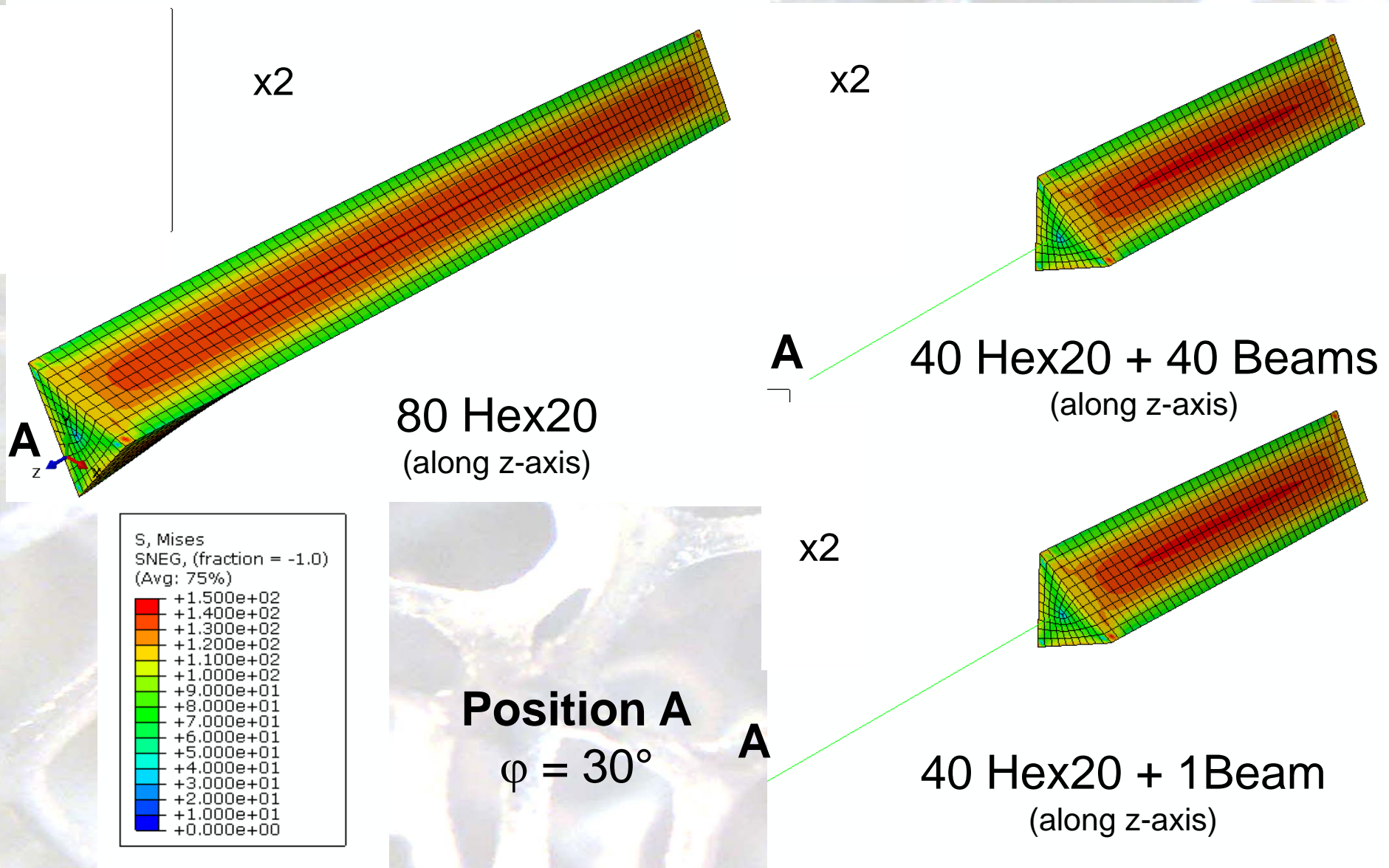


# Torsion

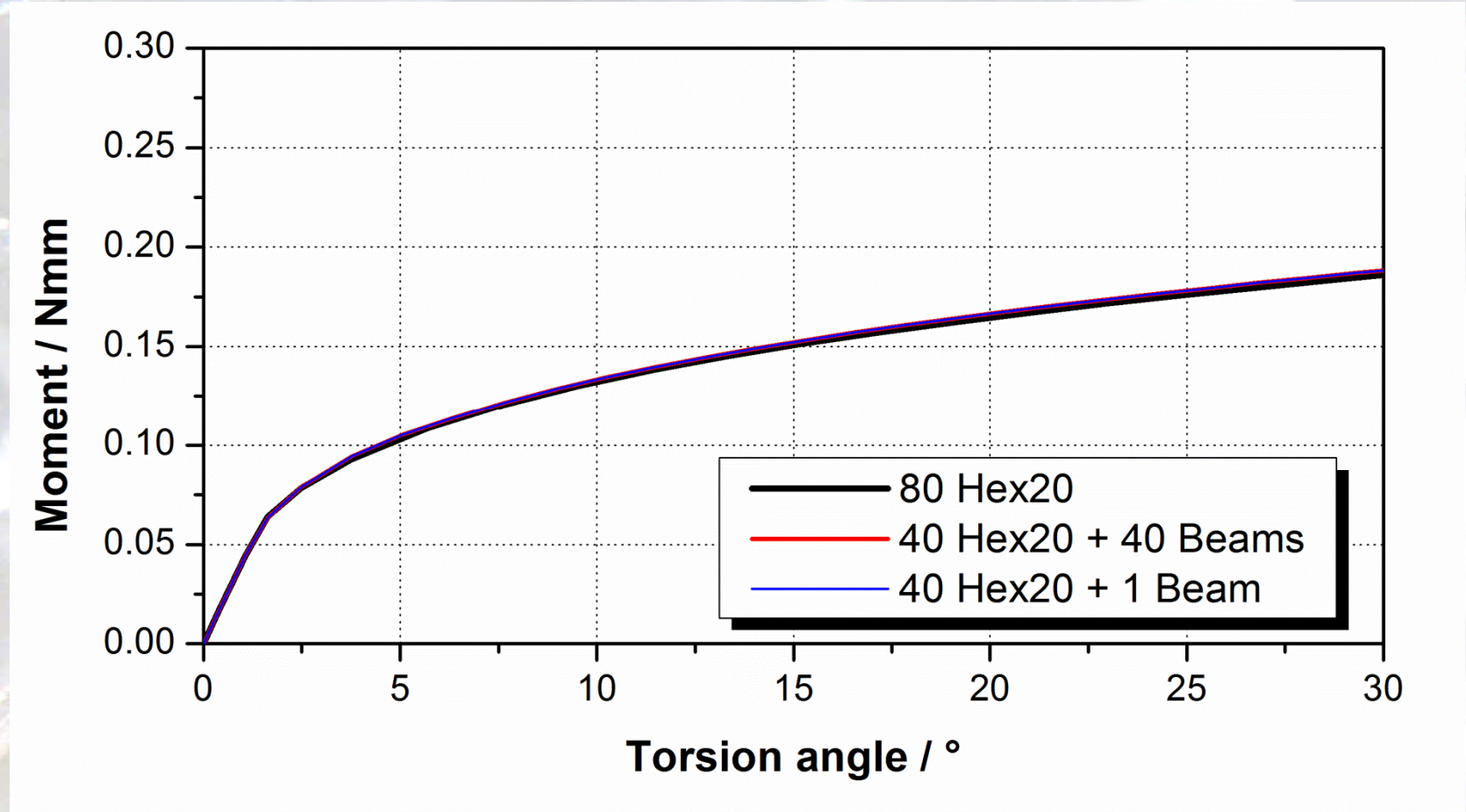
## Link Hex20 with Beam(s)



# Torsion



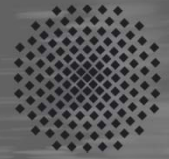
# Torsion



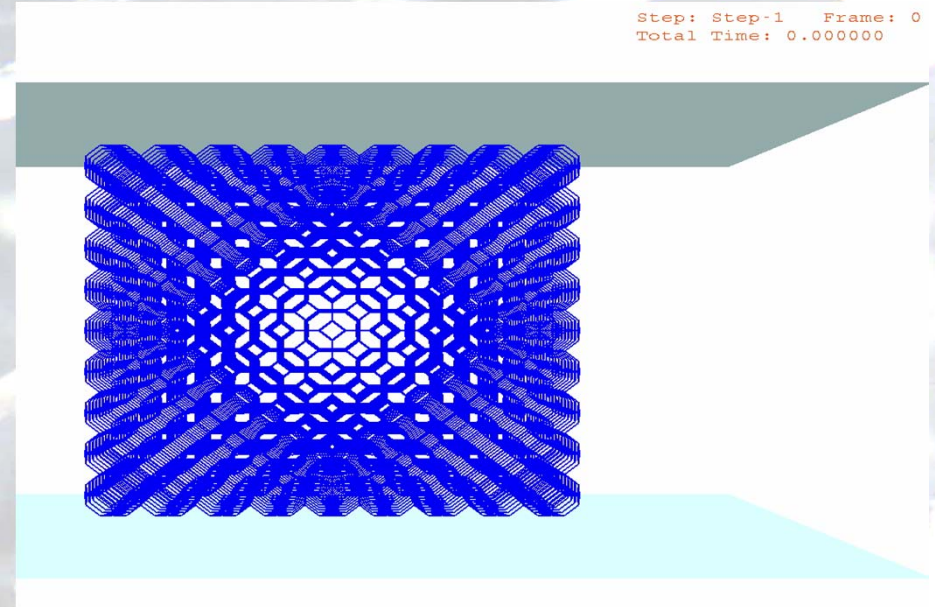
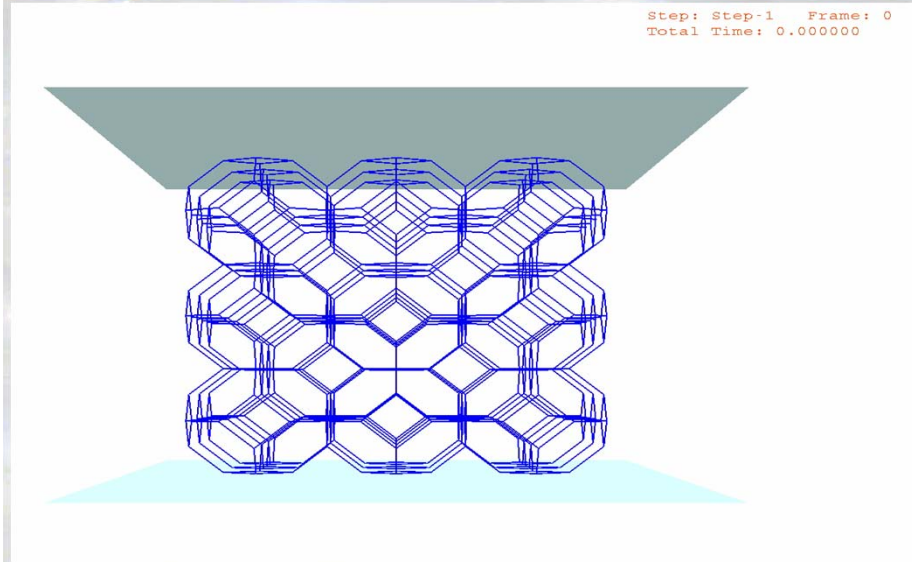


# Multiple Cells

(3x3x3 or 9x9x9 Kelvin cell)



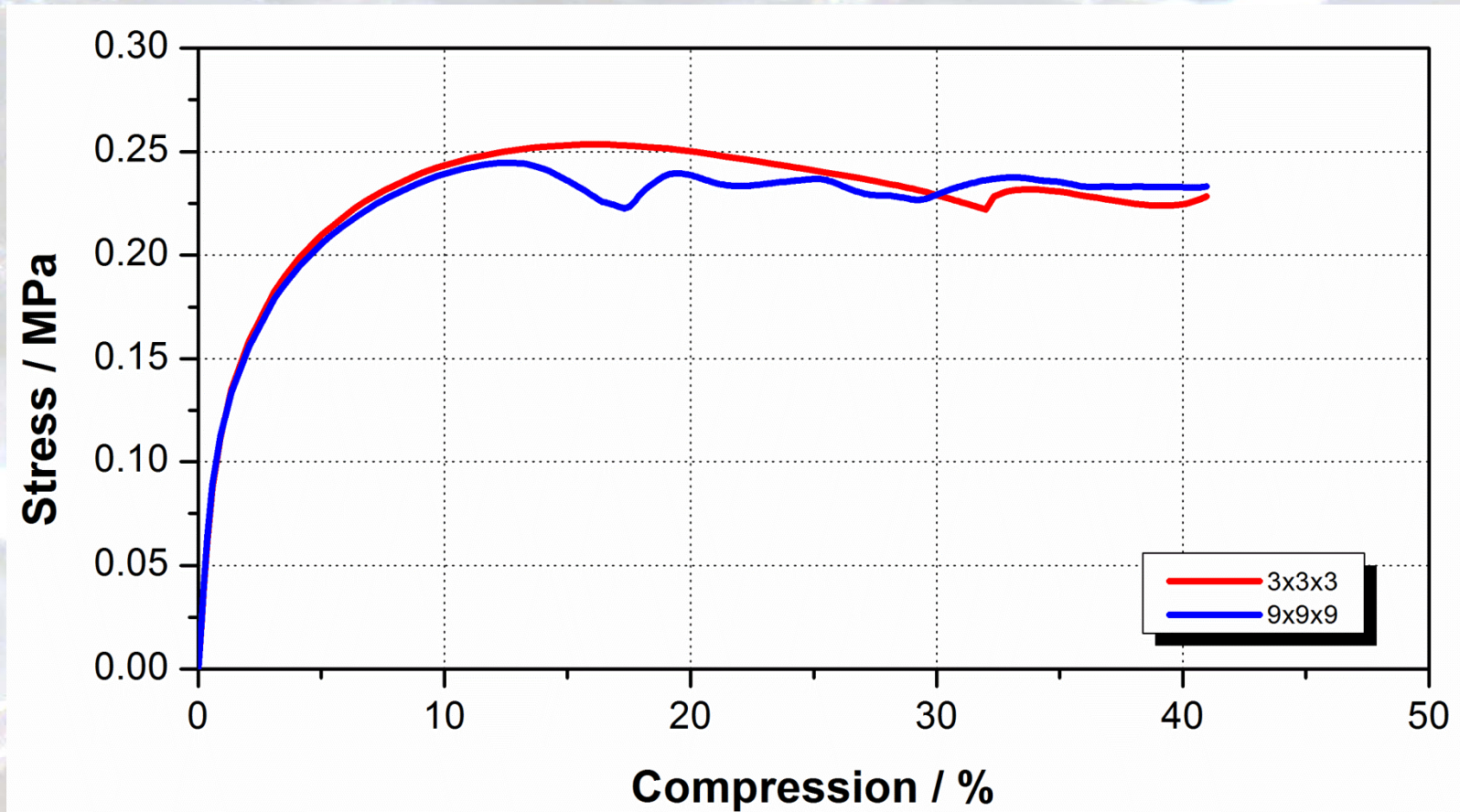
# Kelvin cell (Beams): 3x3x3 and 9x9x9



3x3x3 Cells  
2268 elementes  
CPU: 231 s (PC)

9x9x9 Cells  
55404 elements  
CPU: 7h (PC)

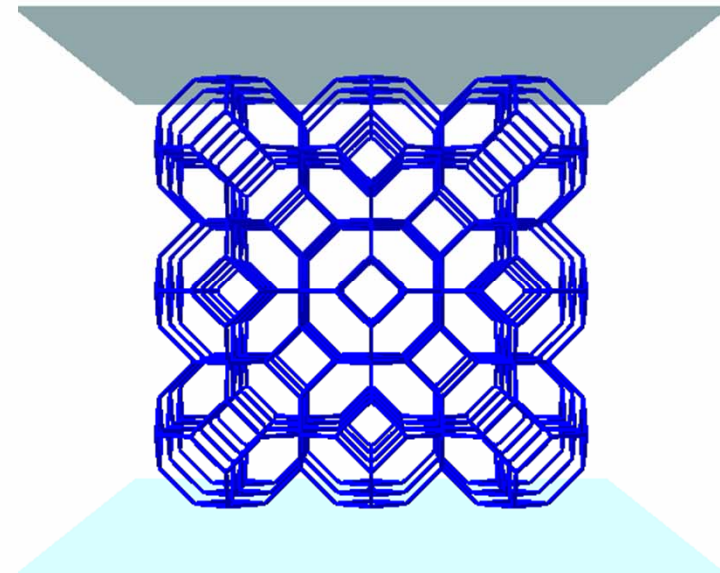
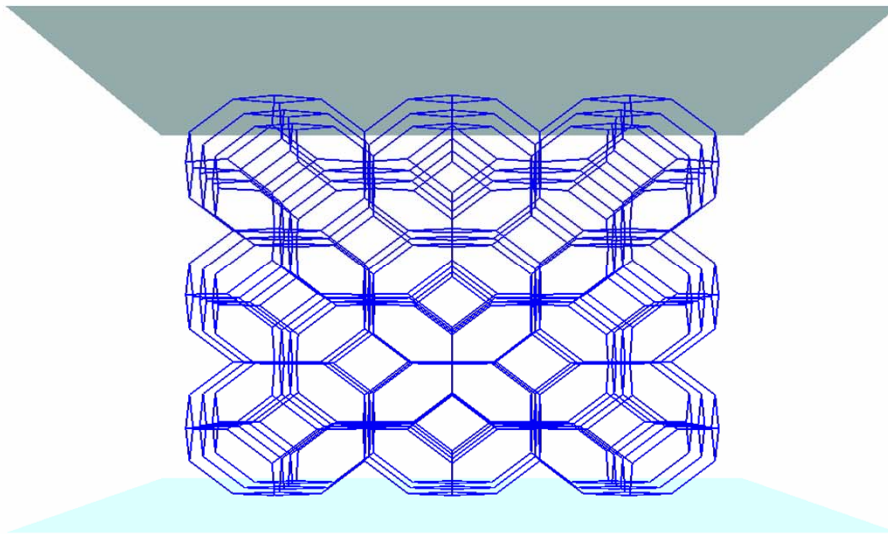
# Kelvin cell (Beams): 3x3x3 and 9x9x9



## 3x3x3 Kelvin cell: Hex20 and Beams

Step: Step-1 Frame:  
Total Time: 0.000000

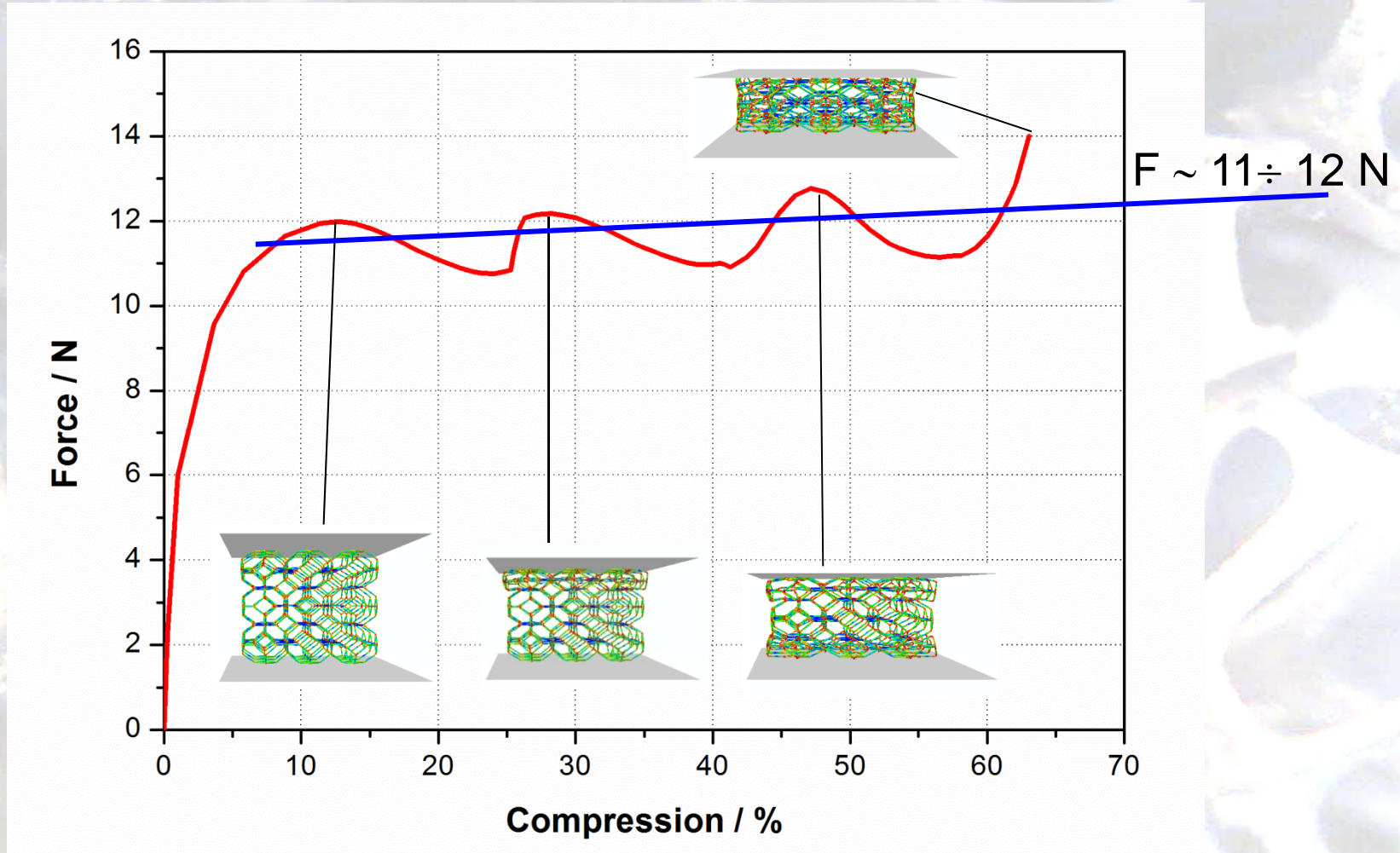
Step: Step-1 Frame: 0  
Total Time: 0.000000

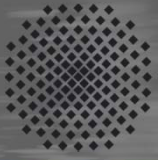


Beam model:  
2268 elements  
CPU: 231 s (PC)

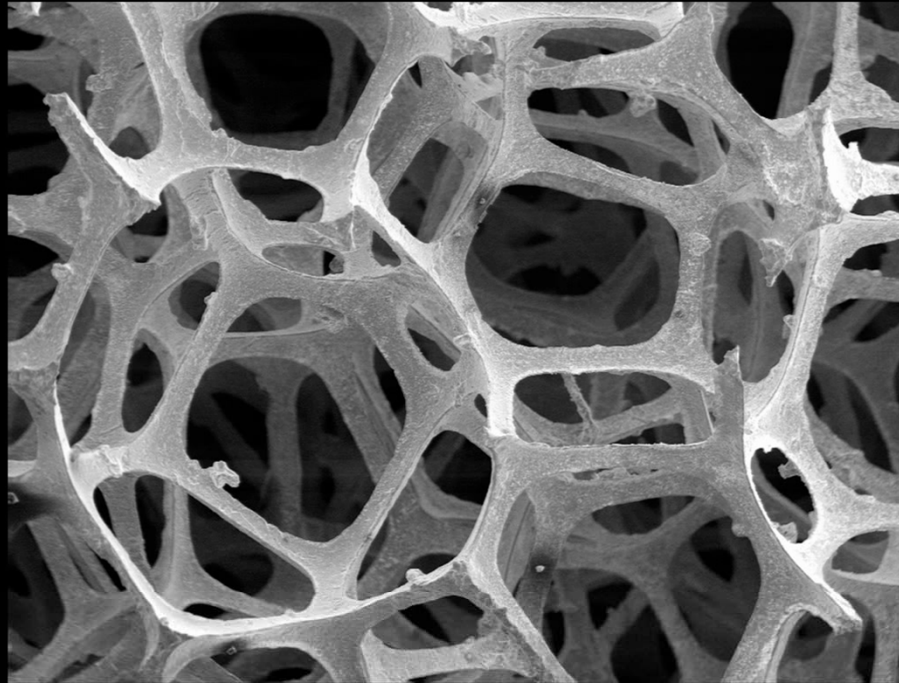
Hex20 model:  
101952 elements  
CPU: 84 h (HLRS)

# 3x3x3 Kelvin cell: Hex20

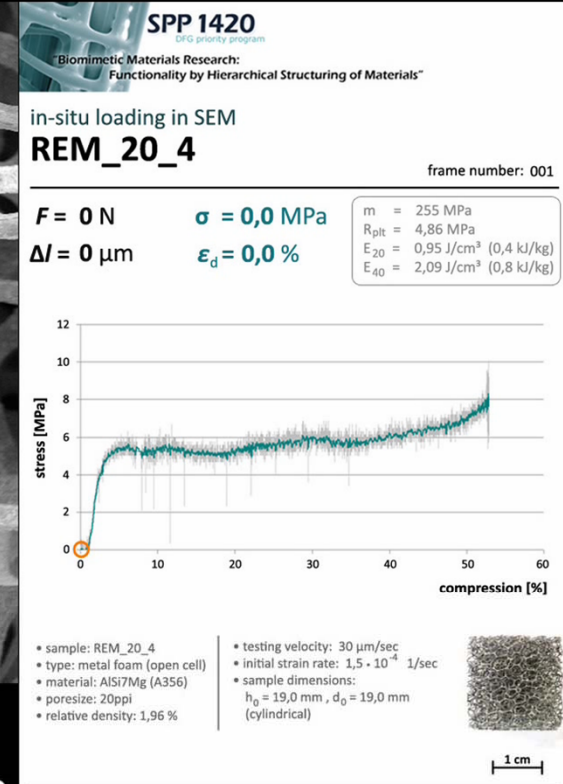




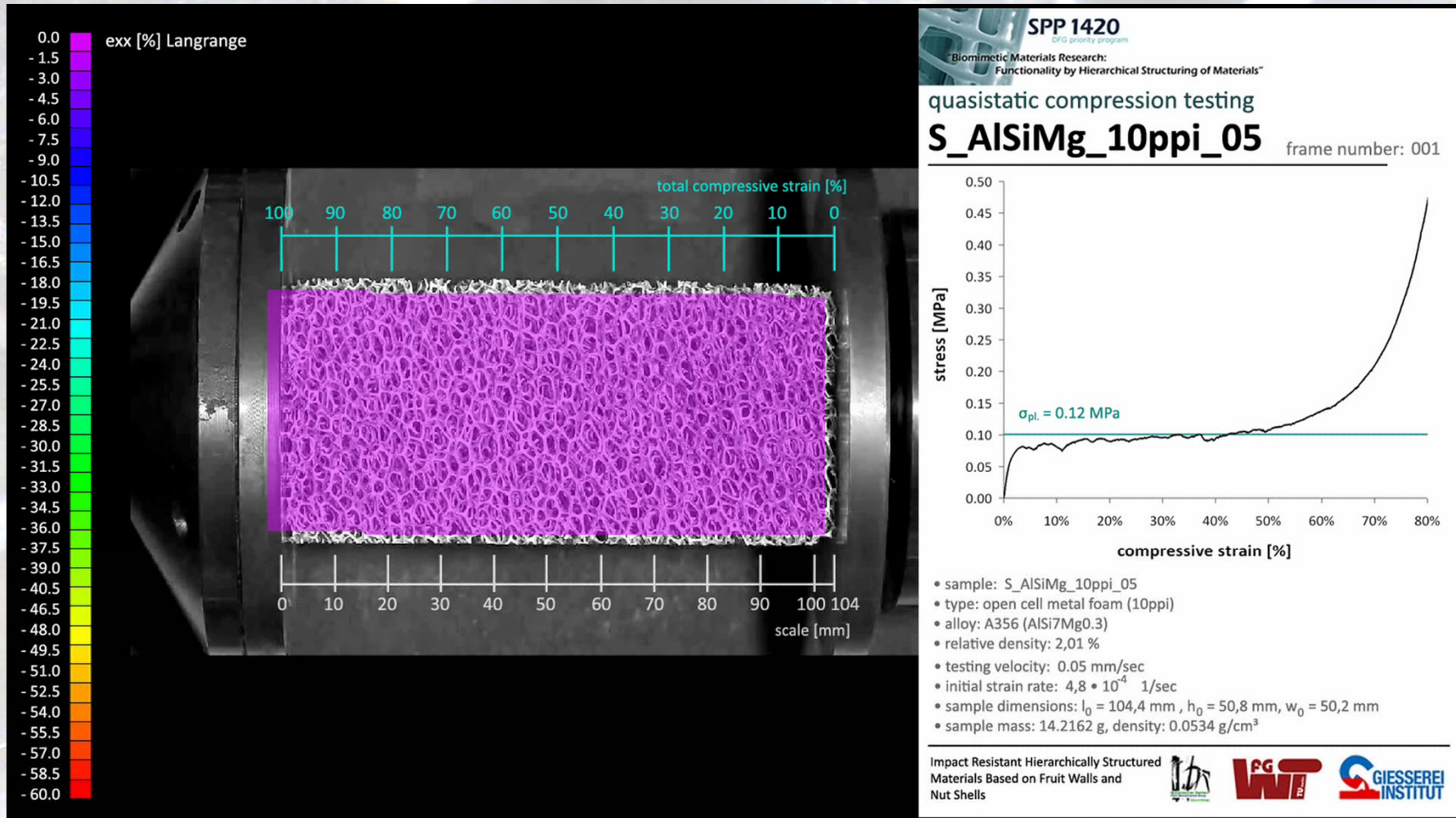
# Open-cell foam (20ppi) Experiment

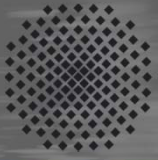


1000  $\mu\text{m}$

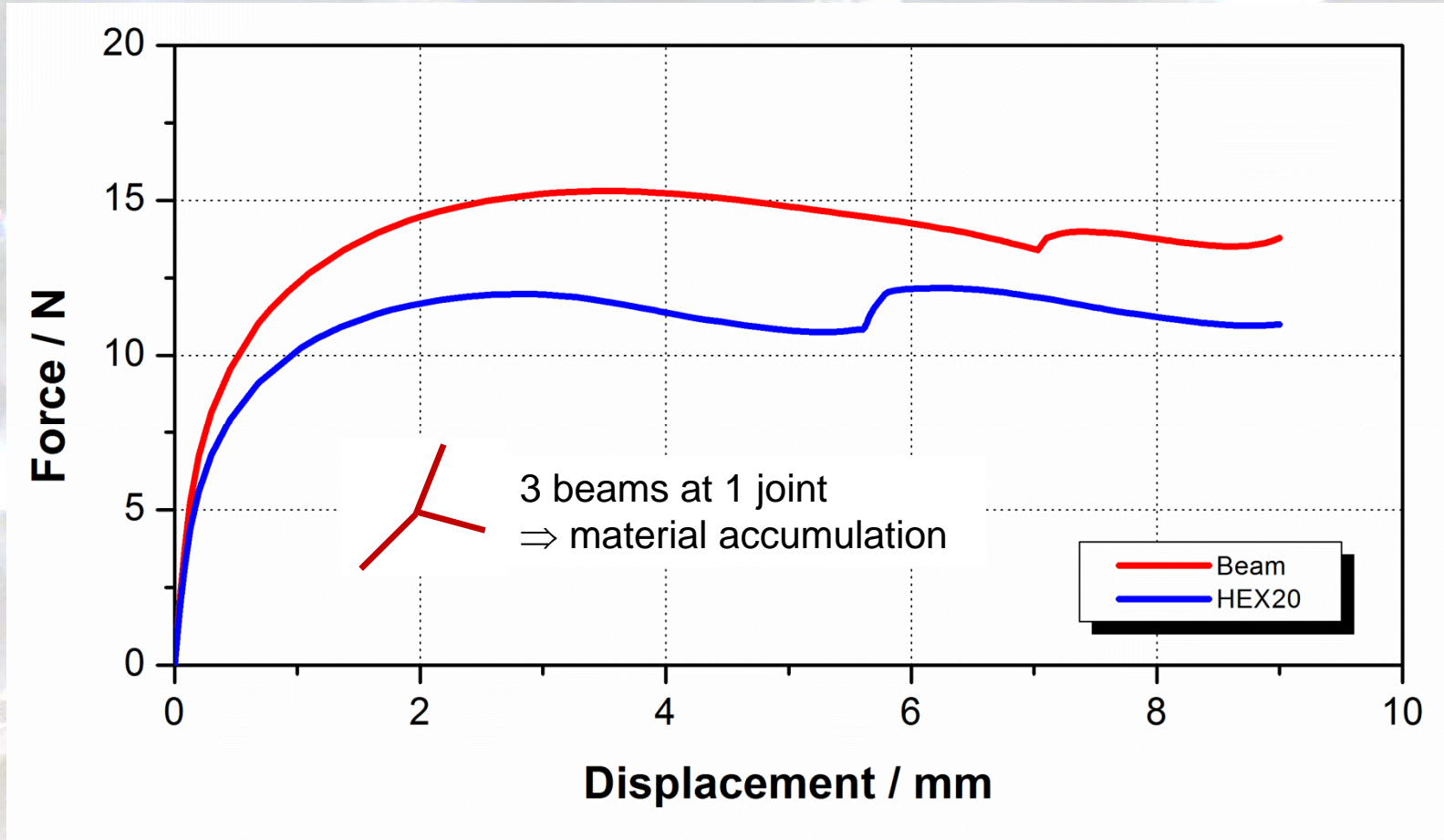


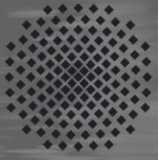
# Open-cell foam (10ppi) Experiment





# 3x3x3 Kelvin cell: Hex20 and Beams





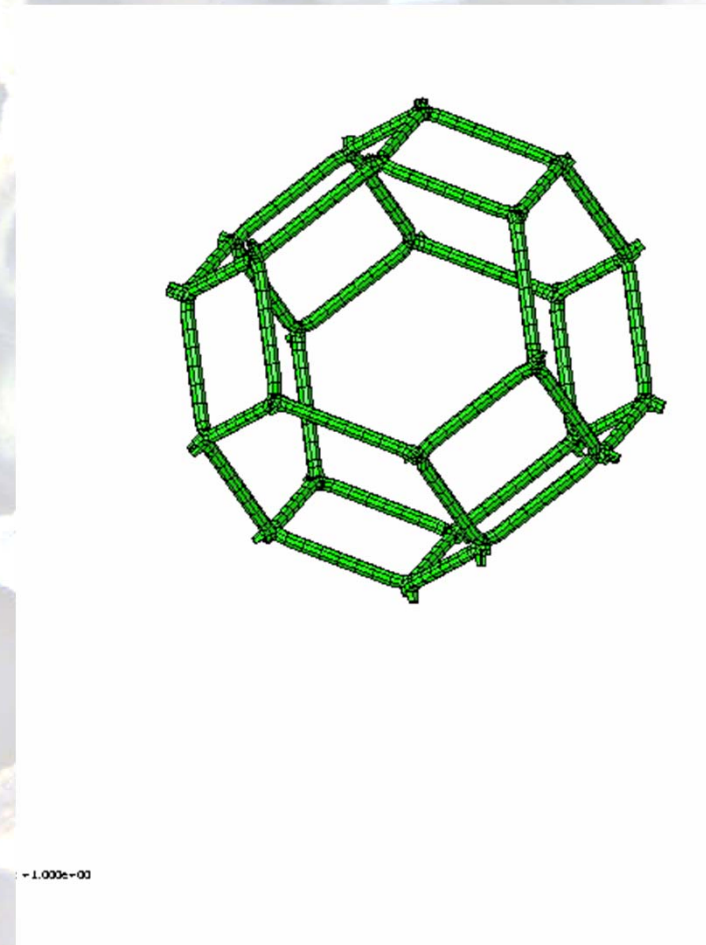
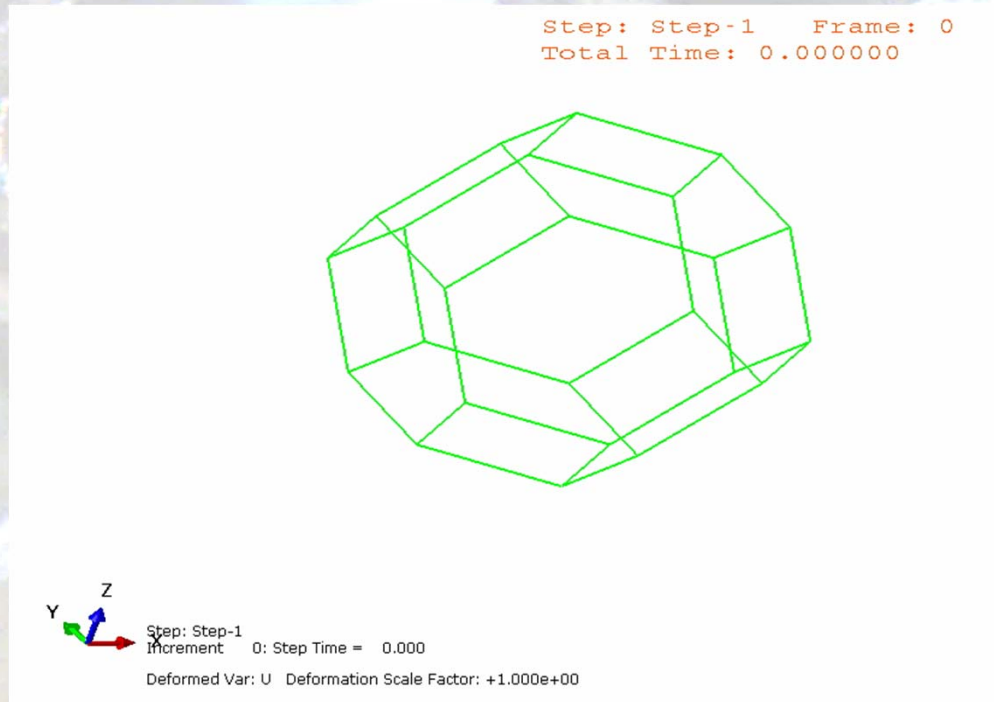
# 3x3x3 Kelvin cell: Hex20 and Beams

## Deformation of the central cell

Beam model

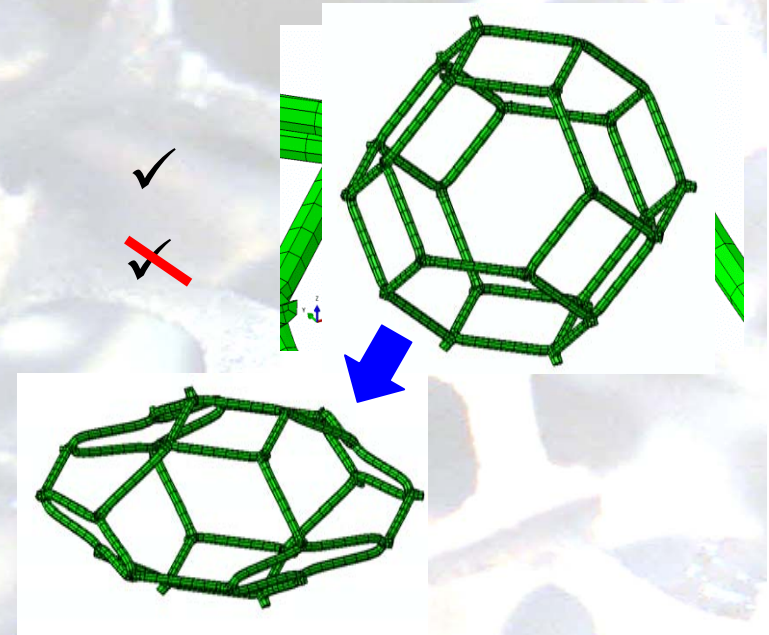


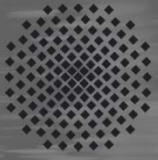
Hex20 model



## Real deformation states

- Reality:
  - “Zig-zag”-deformation of struts has been observed
  - Rotation of cells has been observed
- How can we realise more realistic deformation and rotation states?
  - Reinforcement of the Kelvin cell squares
  - Partial reduction of the stiffness (on the left or on the right hand side) of the the 3x3x3 multiple cell structure
  - External loading with additional rotation



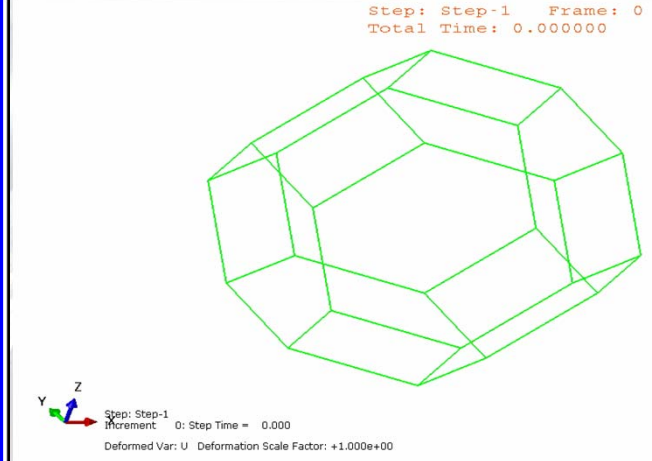
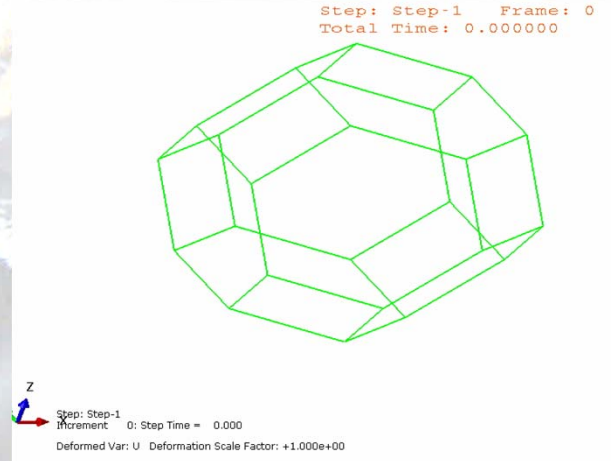
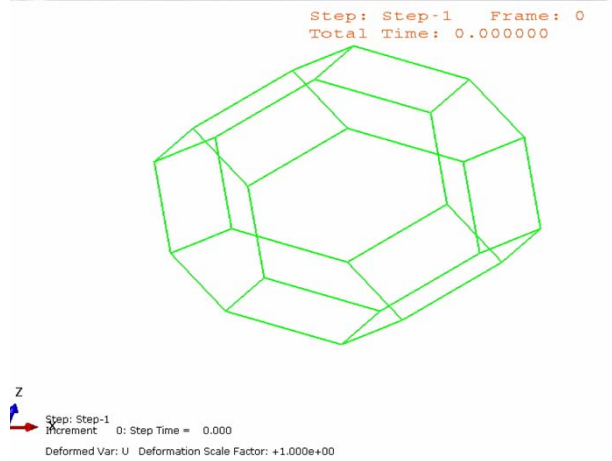


# 3x3x3 Kelvin cell: Beams Deformation of the central cell

Reinforcement of the  
Kelvin cell squares

Partial reduction

External loading with  
additional rotation



„Zig-zag“-deformation  
of struts, no rotation  
of the cell

„Zig-zag“-deformation  
of struts, no rotation  
of the cell

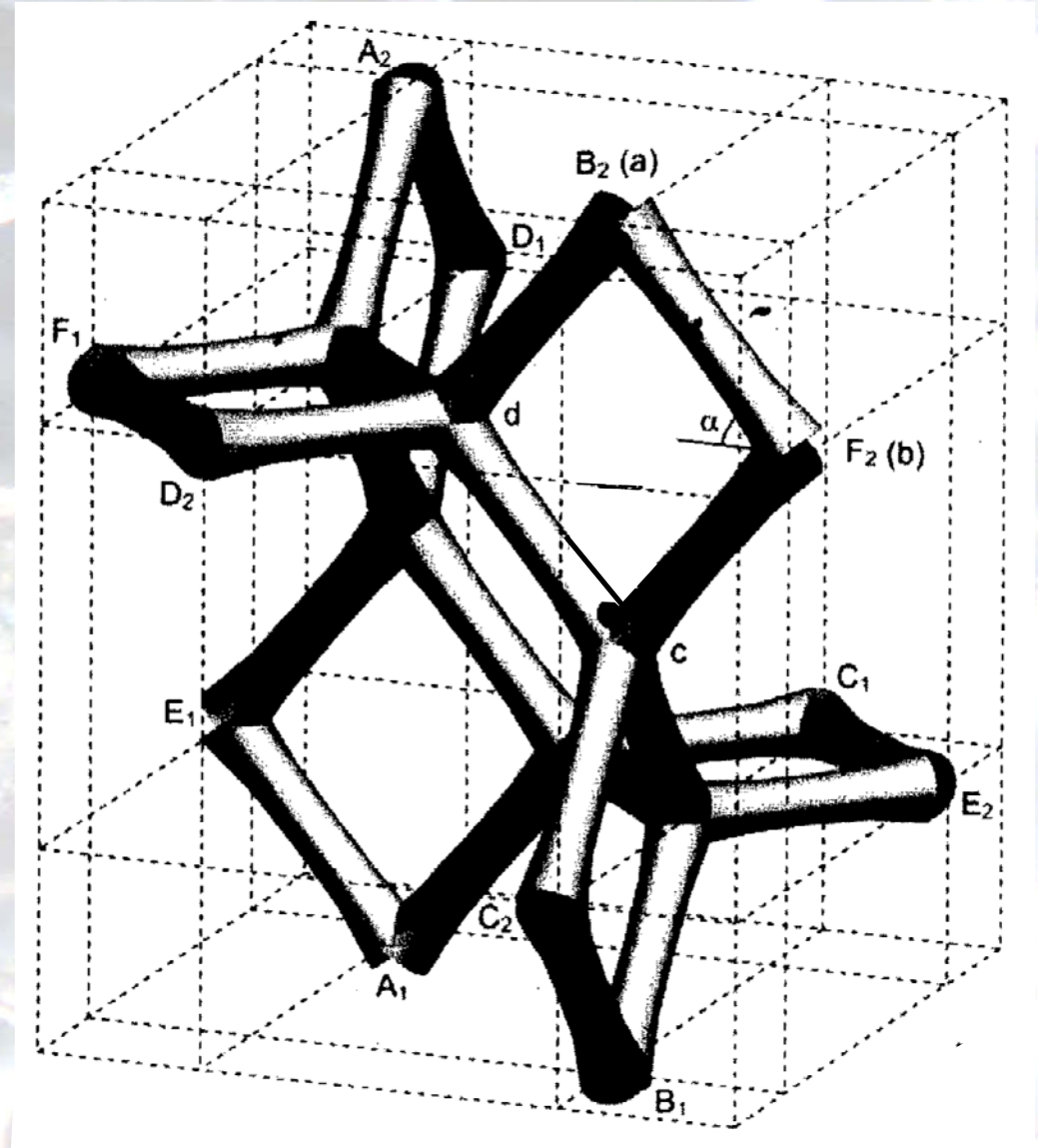
„Zig-zag“-deformation  
of struts + rotation  
of the cell

⇒ **BCs for the „super“ Kelvin cell**

# Unit cell modelling

## Alternative: Unit Cell

- Application of periodic BCs (deformation + rotation)
- Consider Damage by removing single struts

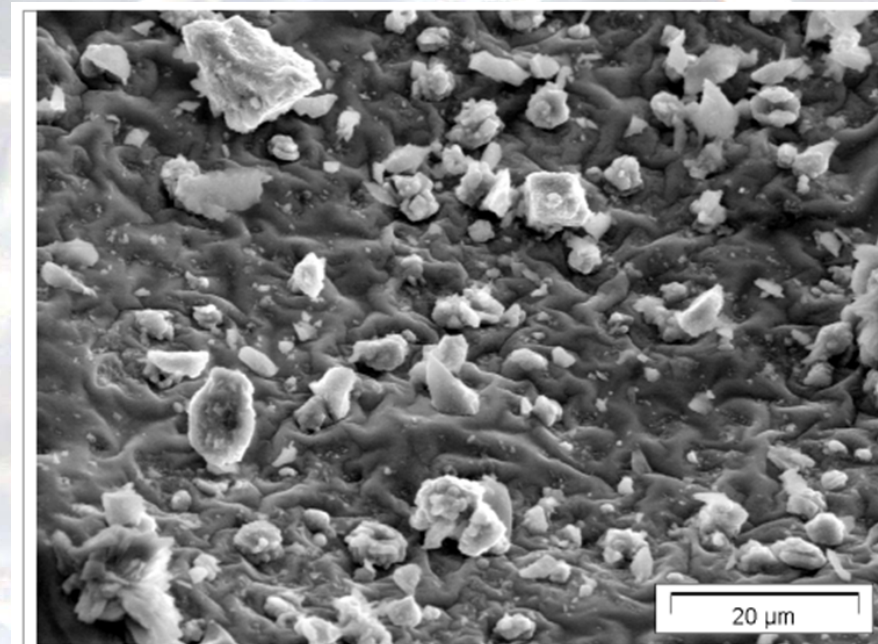
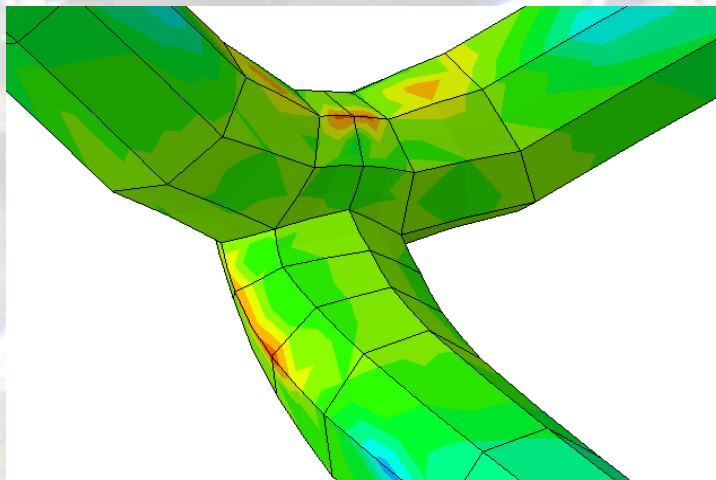


## Conclusion

- Link of Hex20 with Beams:
  - No influence on the deformation state under external displacement and torsion loading
- 3x3x3 cell structure is sufficient as global foam structure
- 3x3x3 Hex20 cell structure:
  - Good (qualitative) agreement between simulation and experiment (global deformation behaviour)
- 3x3x3 cell structure: Hex20 – Beams:
  - Beams: Material accumulation in the strut nodes  
⇒ stiffer behaviour of the beam cell
  - Single cell rotations, observed in the experiment, are not reproduced (external loading with additional rotation)

## Next steps

- „Super“ Kelvin cell with
  - cement particles
  - removed cement particles
  - .....to investigate local stress and strain concentrations



Anzahl/Fläche	1 bis 4 Partikel/100 $\mu\text{m}^2$
Mittlere Größe	3 – 5 $\mu\text{m}$
Mittlerer Abstand	2 – 5 $\mu\text{m}$