Nichtlineare Simulation dreidimensionaler offenzelliger Strukturen mit regelmäßigen und gestörten Geometrien

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WORKSHOP - Simulation von Schaumstoffen
15./16. Sept. 2005, Hohenwarter Forum

OUTLINE

1 PROJECT

2 STRUCTURES / MODELING APPROACHES

3 LINEAR ELASTIC BEHAVIOR

4 NONLINEAR BEHAVIOR

5 SUMMARY

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Project

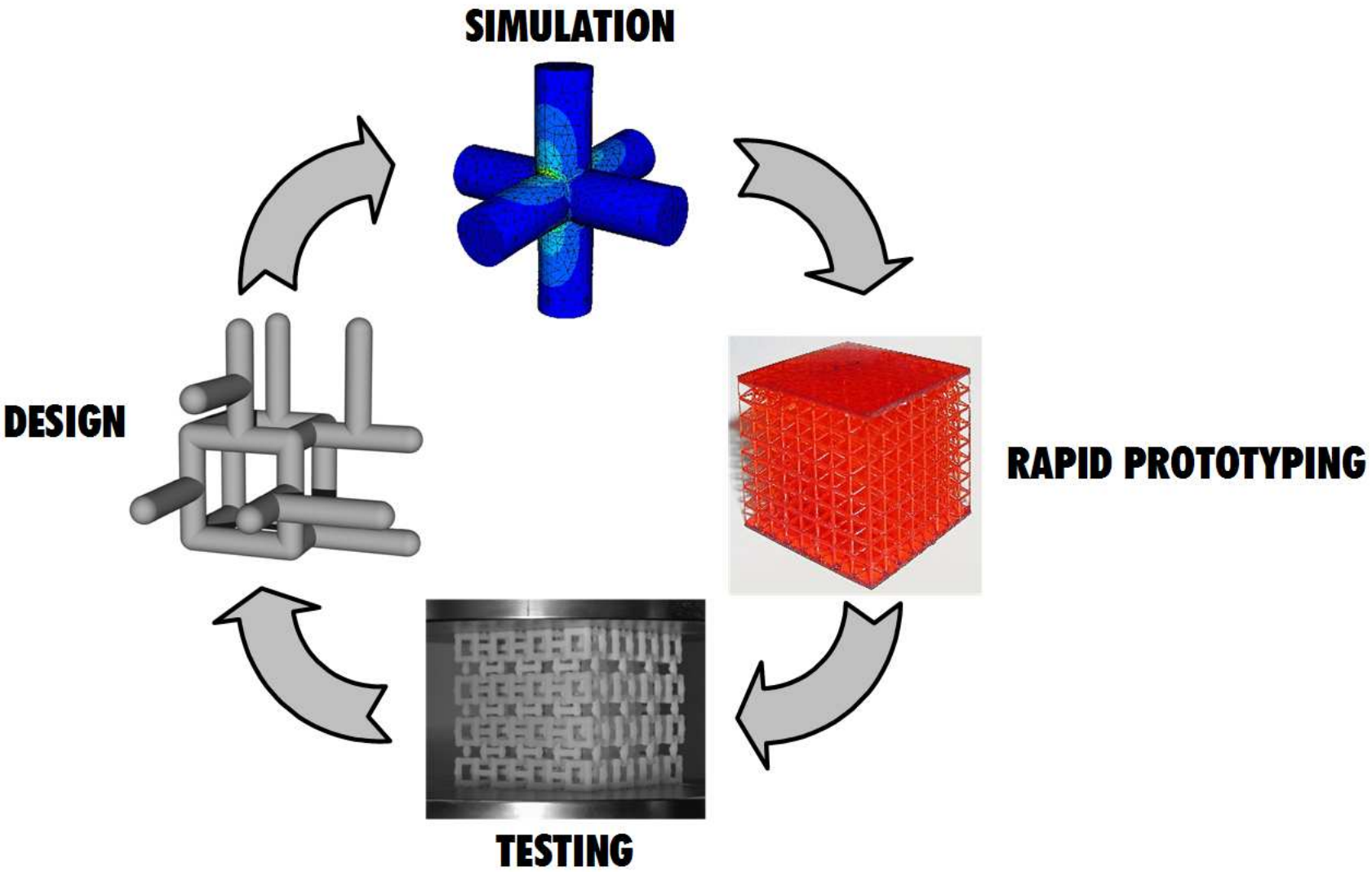
”Modeling and Rapid Prototyping of Cellular Solids“

Project partners

- Institute of Lightweight Design and Structural Biomechanics, Vienna University of Technology, Austria
- Institute of Materials Science and Technology, Vienna University of Technology, Austria
- Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Supported by the Austrian Science Fund (Grant P15852)

Project



Motivation

Mechanical behavior of cellular structures

- different generic geometries
- fully 3D
- elastic–plastic bulk material
- Finite Element Method

Regular vs. perturbed geometries

- $\rightarrow$ inspired by nature

Nonlinear behavior

- deformation localization

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Structures

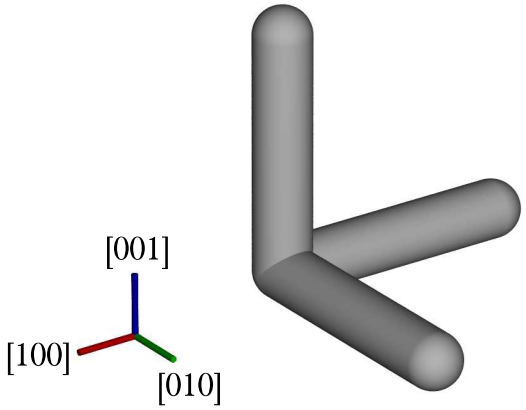
Six generic geometries — relative density 12.5%

- open cell structures

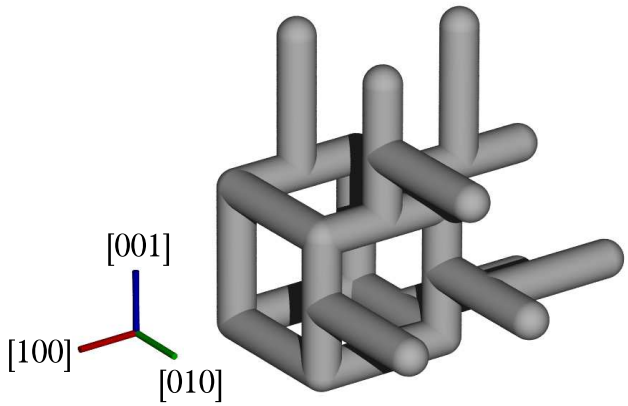
- based on regular arrangements (lattice structures)
- struts with circular cross sections

- fabricated by Rapid Prototyping (SLS & SLA)
- crosslinked photopolymer

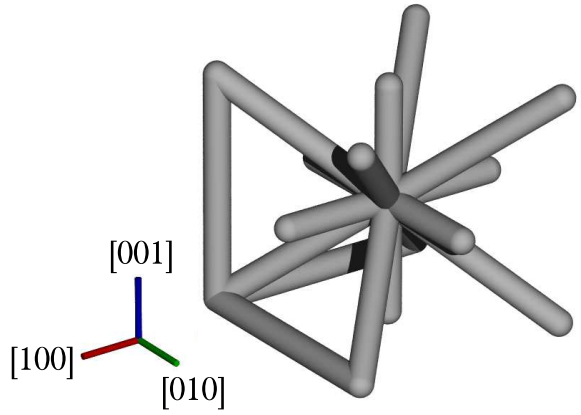
Structures — Base Cells



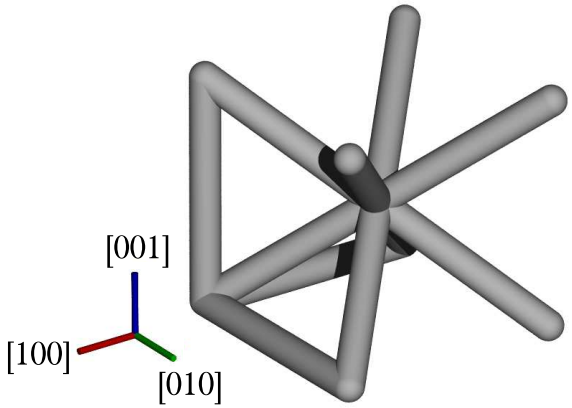
Simple Cubic (SC)



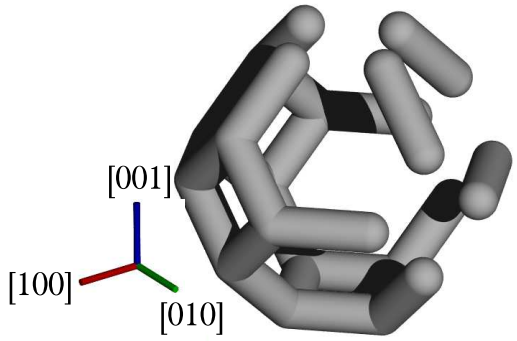
Gibson Ashby (GA)



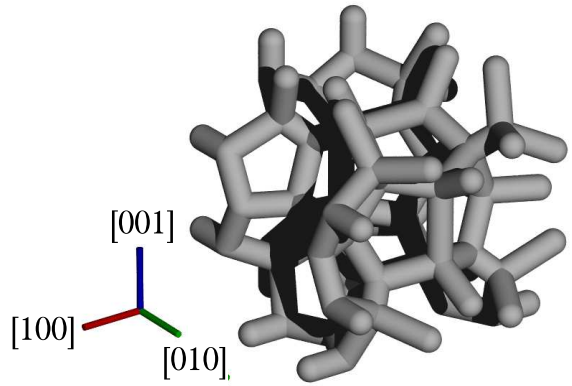
Reinforced Body Centered Cubic (RBCC)



Body Centered Cubic (BCC)



Kelvin (KV)

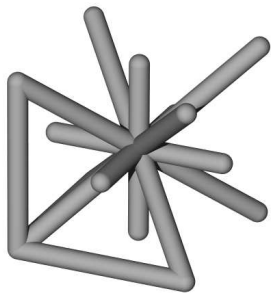


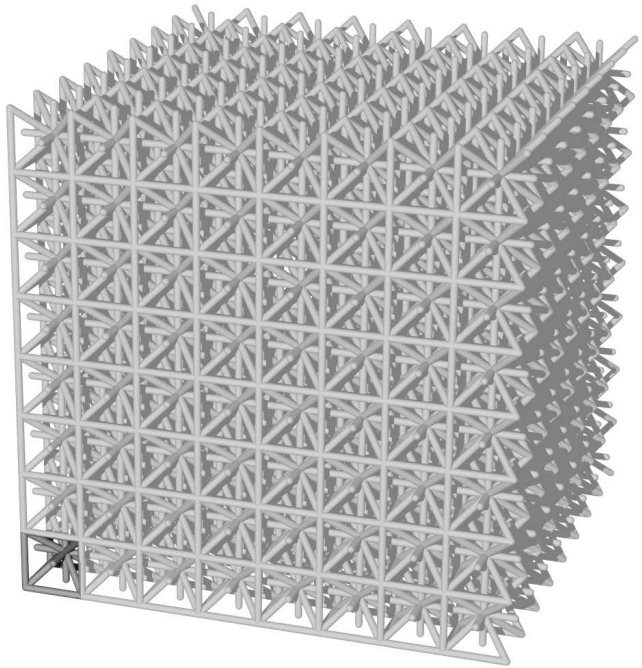
Wearie Phelan (WP)

Modeling Approaches

Two modeling approaches

- unit cell models
- finite structure models

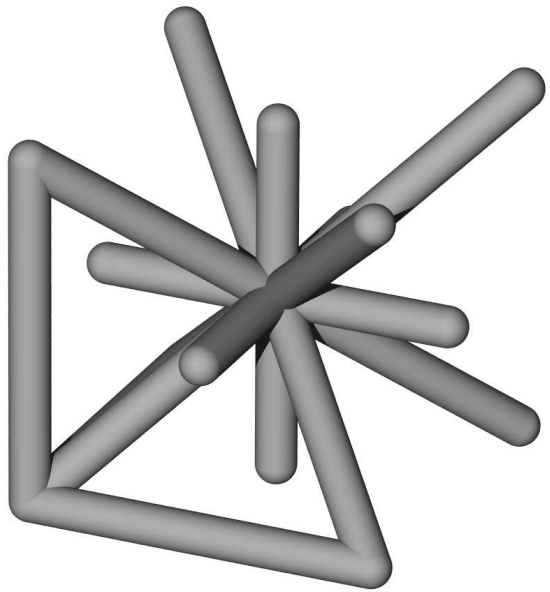




Unit Cell Models

Unit cell models

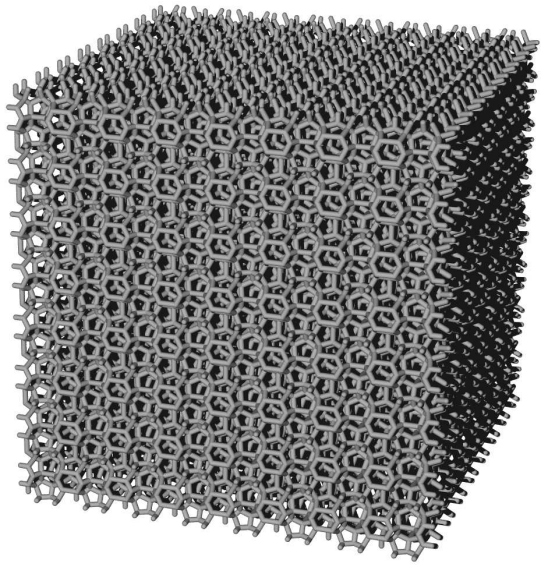
- only the periodic part is modeled
  - 1 base cell for regular structures
  - 8x8x8 base cells for perturbed structures
- periodic microfield approach
- periodic boundary conditions (also coupling of rotational DOFs)



Finite Structure Models

Finite structure models

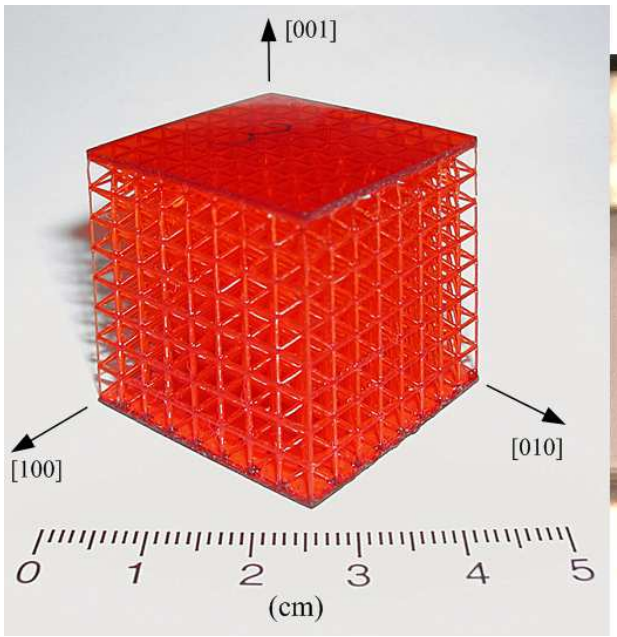
- consist of a given number of base cells
- various lattice orientations
- approx. 32mm$\times$32mm$\times$32mm
- boundary conditions correspond with experimental setup (uniaxial compression tests)
- used for nonlinear studies

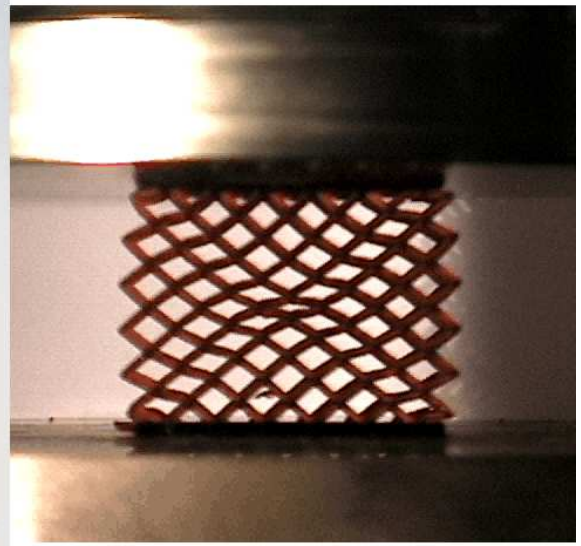


Finite Structure Models

Experimental setup / Boundary conditions

- uniaxial compression in [001] direction
- stiff top and bottom plate for load application
- bottom plate is fixed / top plate can move freely normal to [001] and rotate around [001]





FE Models

Beam elements

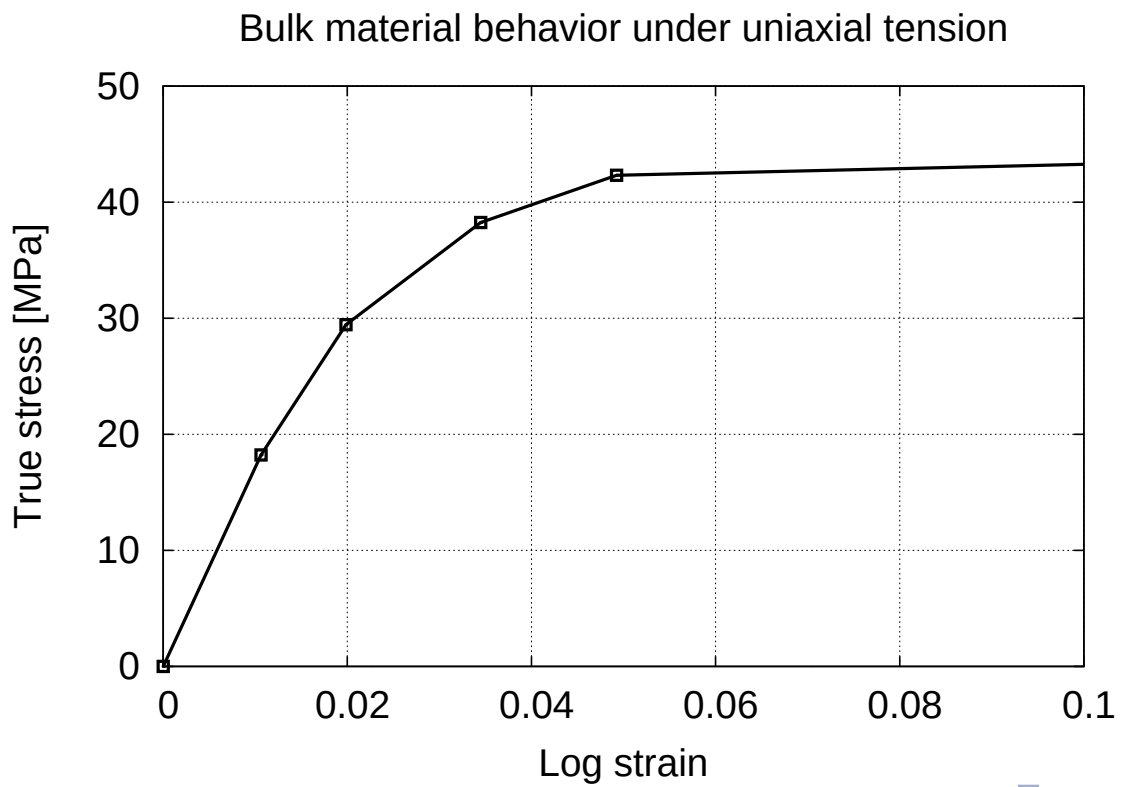
- timoshenko beams
- density approximation for determination of beam radius
- stiffness correction to account for material accumulation in the vicinity of the vertices

- previous studies

Bulk Material

Crosslinked photopolymer for rapid prototyping

- elastic-plastic behavior
- $E = 1700\text{MPa}$, $\upsilon = 0.3$, $\sigma_{\text{Y}} = 18\text{MPa}$
- no viscosity is considered



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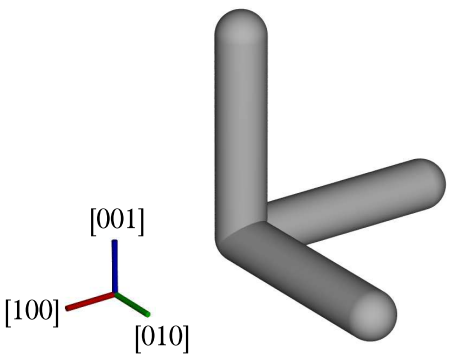
Linear Elastic Behavior



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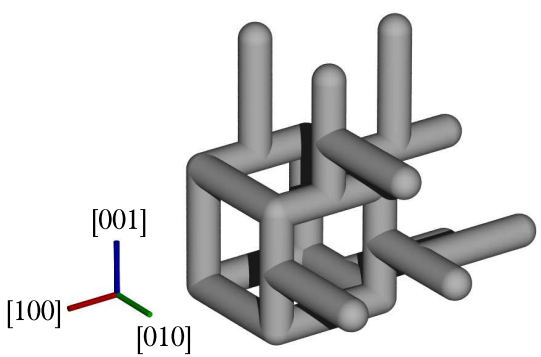

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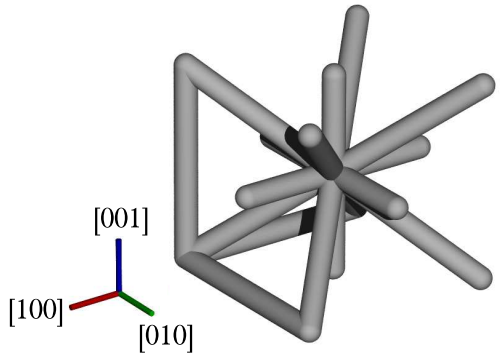

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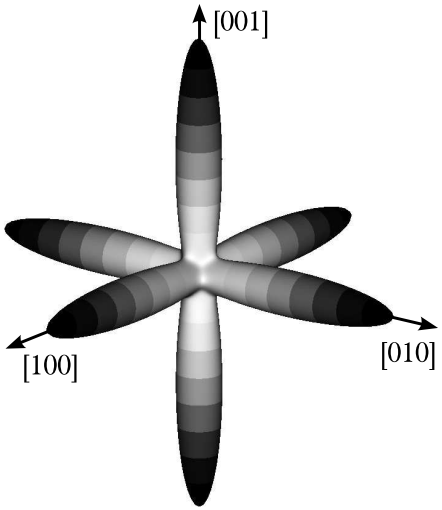

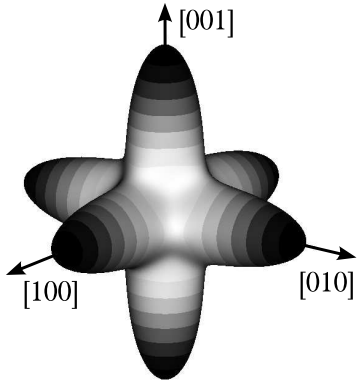

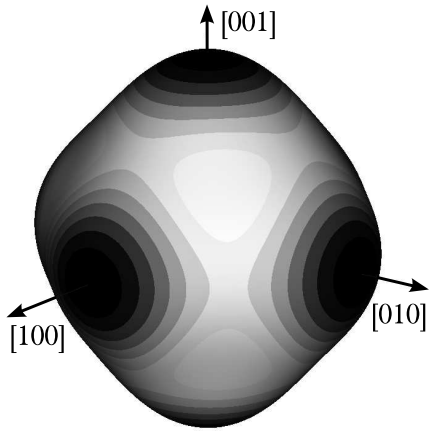

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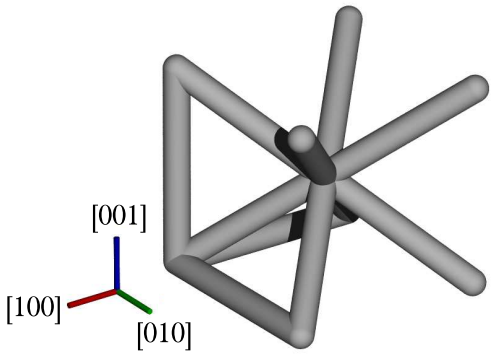
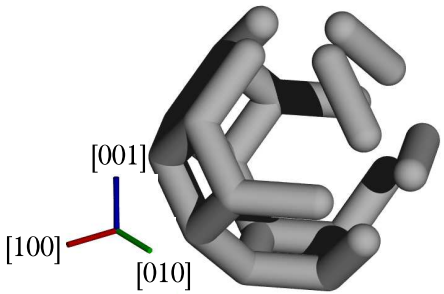


Body Centered Cubic (BCC)



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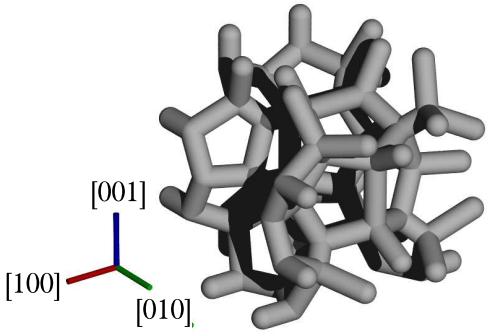

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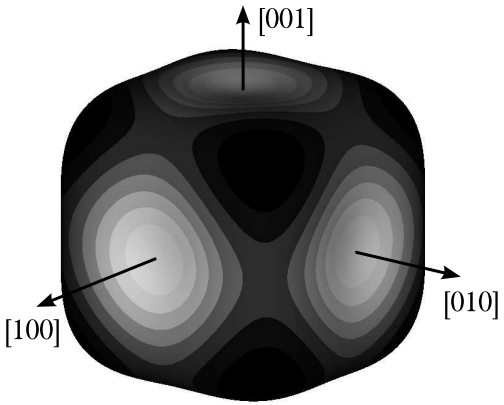
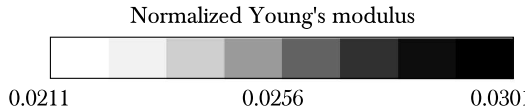
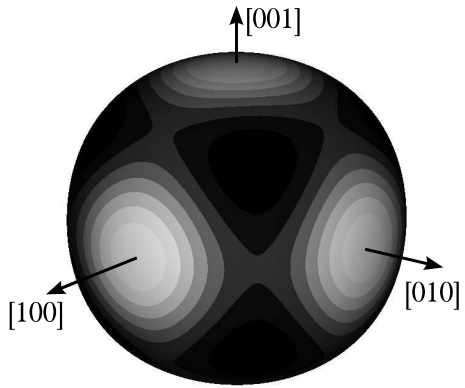
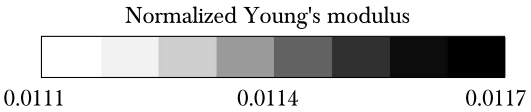
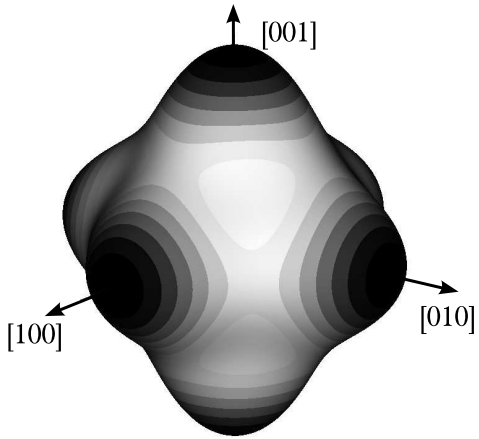
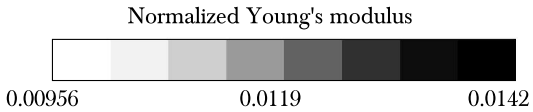












Perturbations

For the two structures with lowest and highest anisotropy:

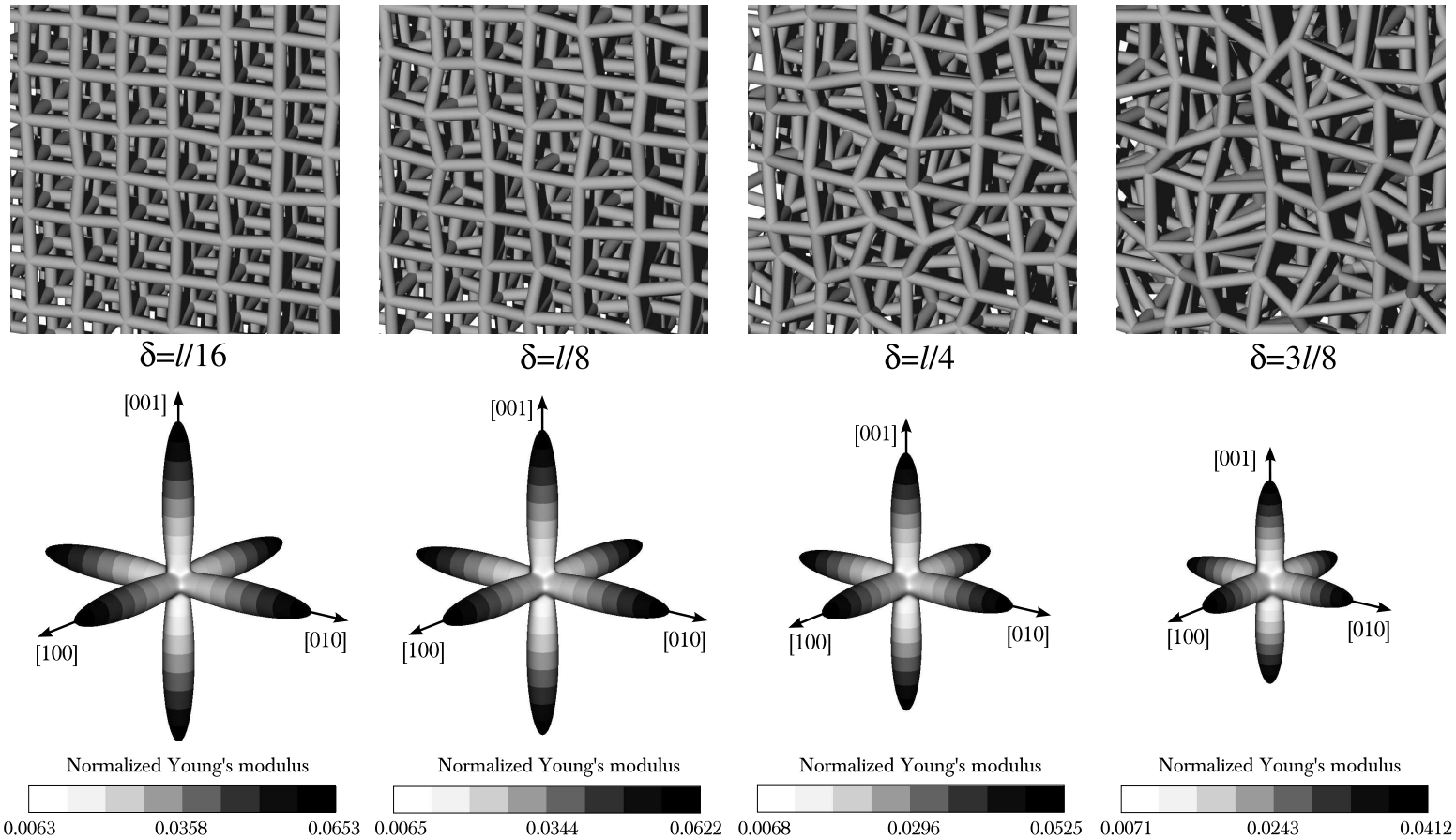
8x8x8 base cells as unit cell

Random shift of vertices

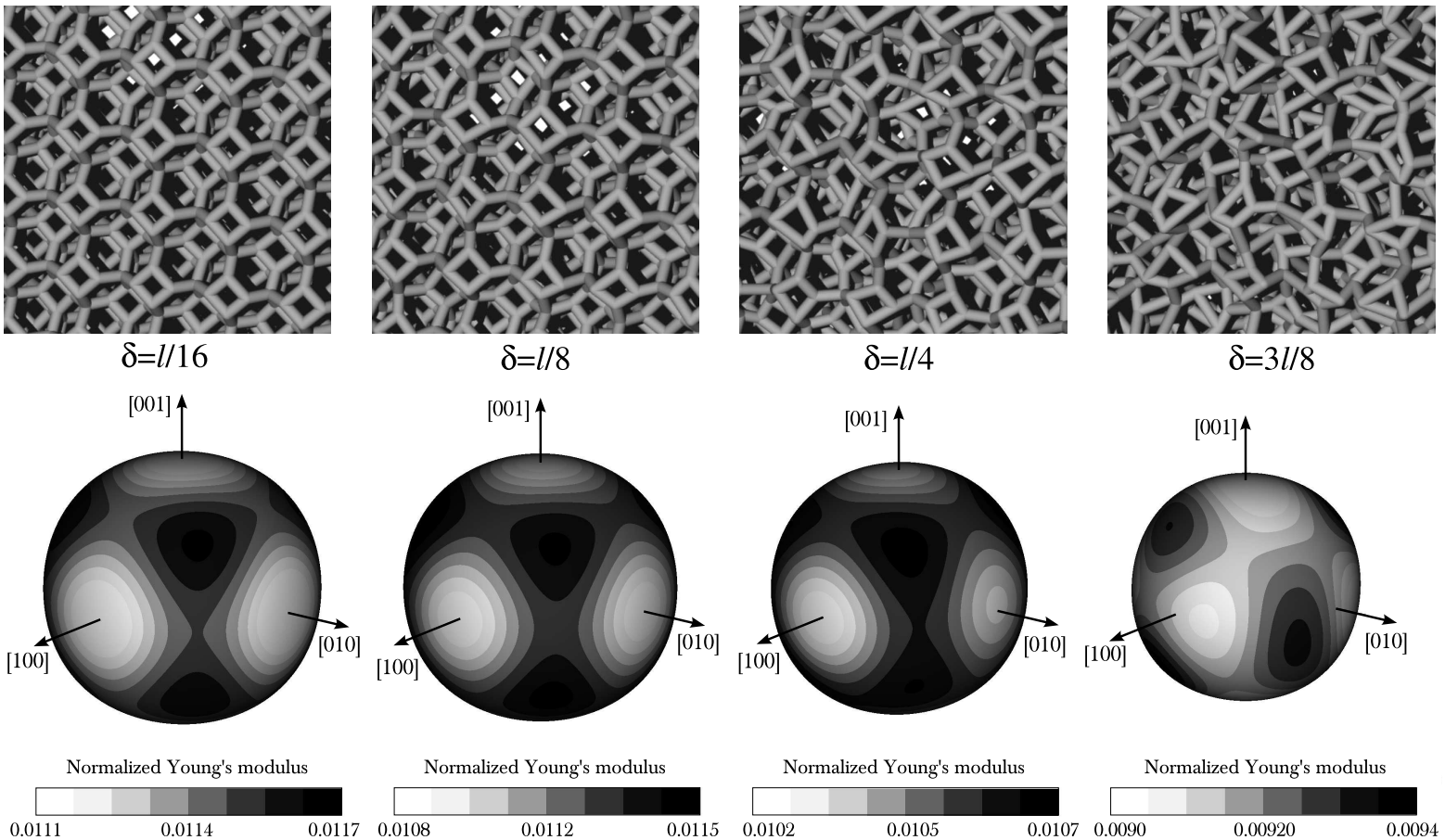
- direction 3D random
- distance fixed as $\delta/l = 1/16; 1/8; 1/4; 3/8$

Correction for density of 12.5%

Perturbations — Simple Cubic structure



Perturbations — Kelvin structure



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Nonlinear Behavior

Deformation localization

- . . . no longer with periodic unit cells

Finite samples

- uniaxial compression
- four lattice orientations

BCs in accordance with experiments

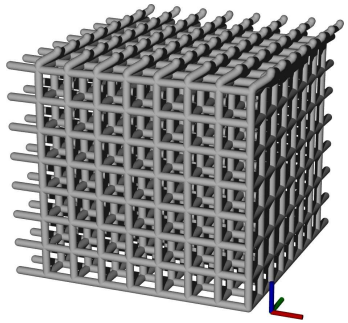
- top, bottom with rigid plate — no tilting, but twisting
- free side faces

Elastic–plastic bulk material

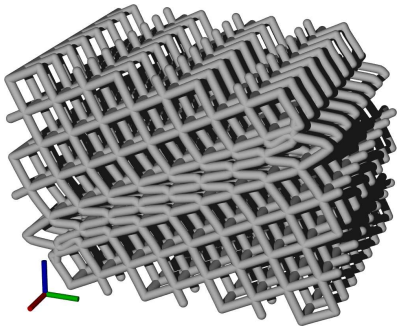
No contact

Simple Cubic — Perfect Geometry

Deformation localization



[001]



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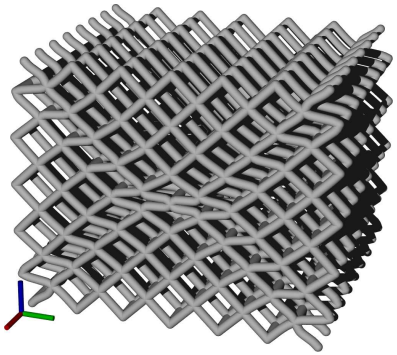

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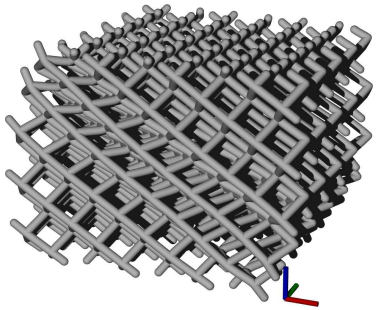

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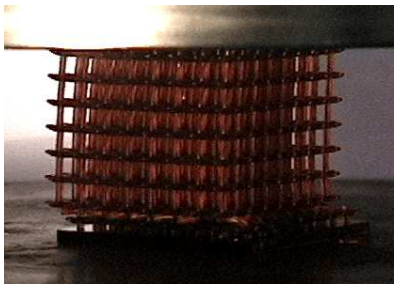
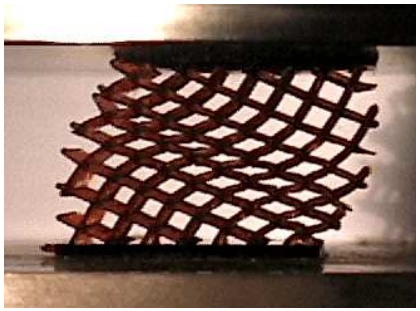
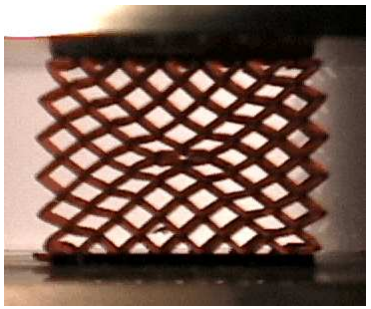
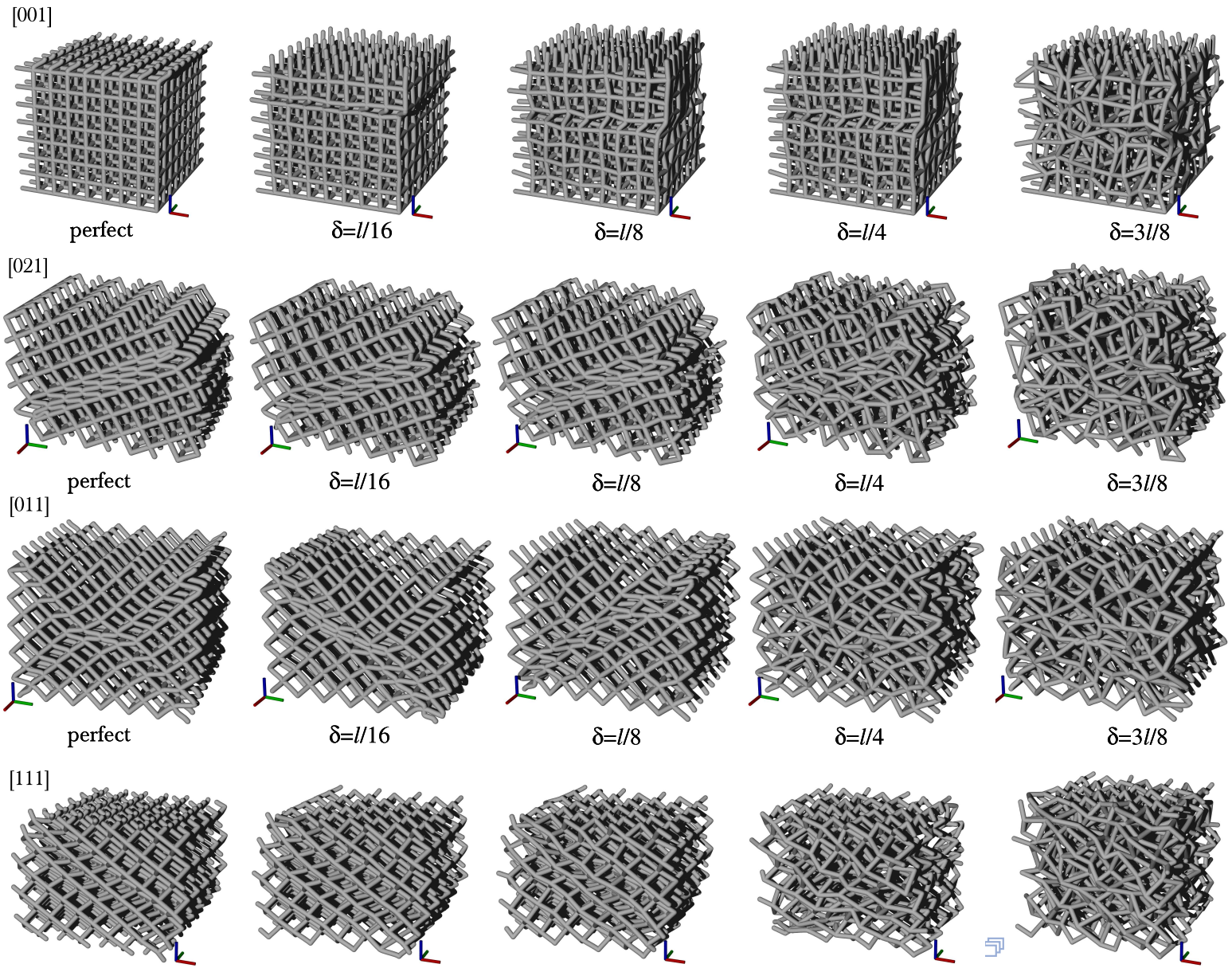


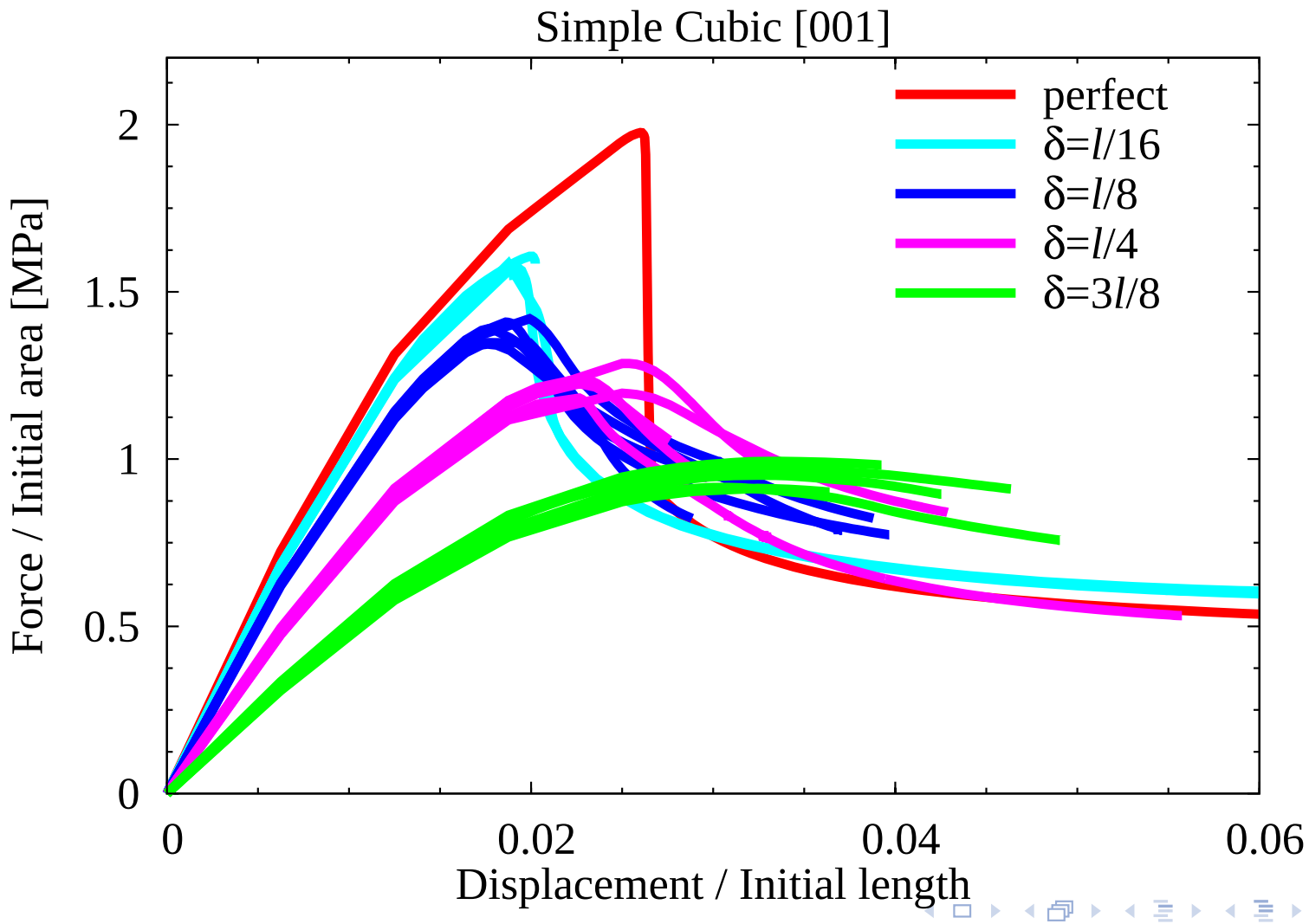




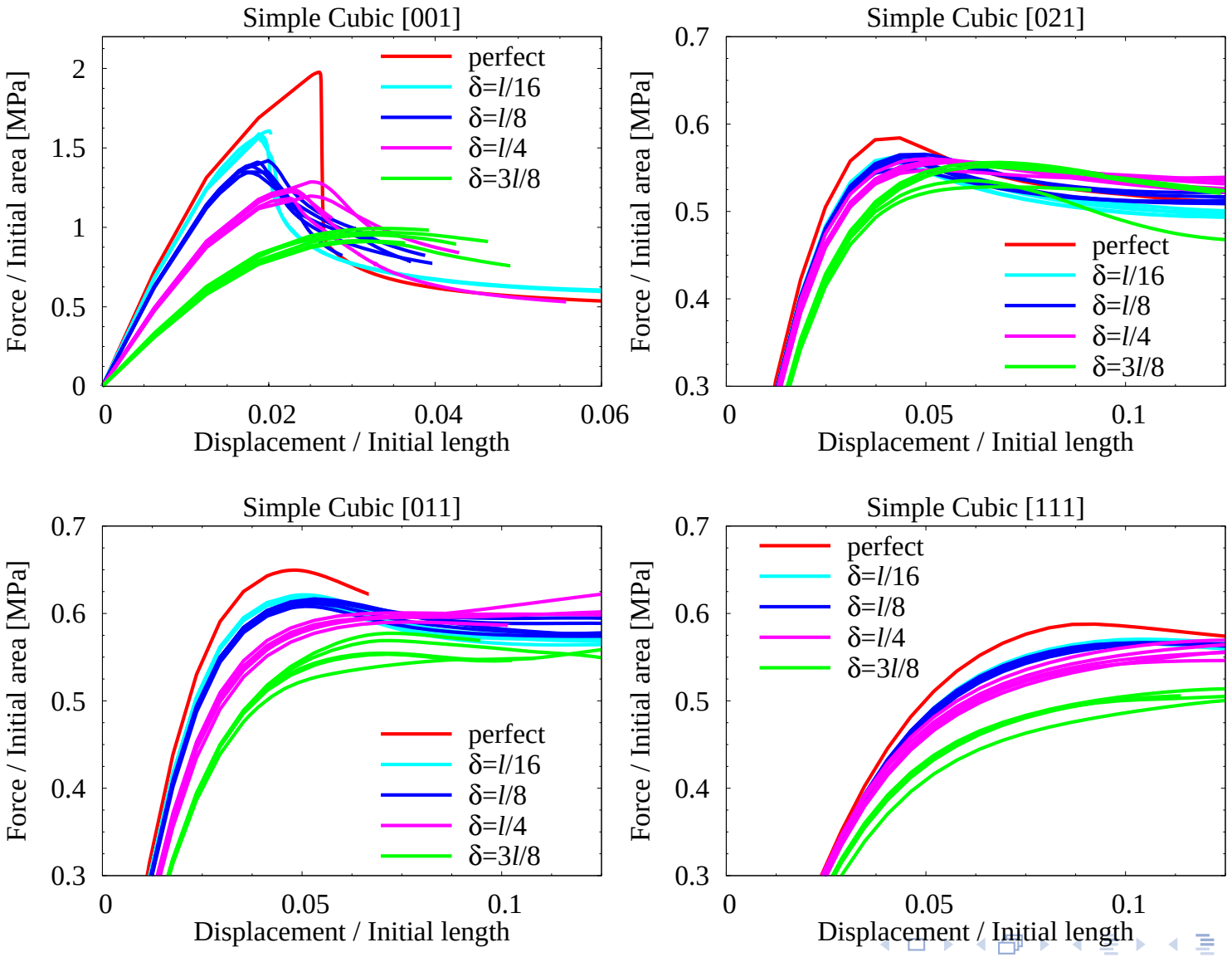
Simple Cubic — Perturbations



Simple Cubic — Load–Displacement

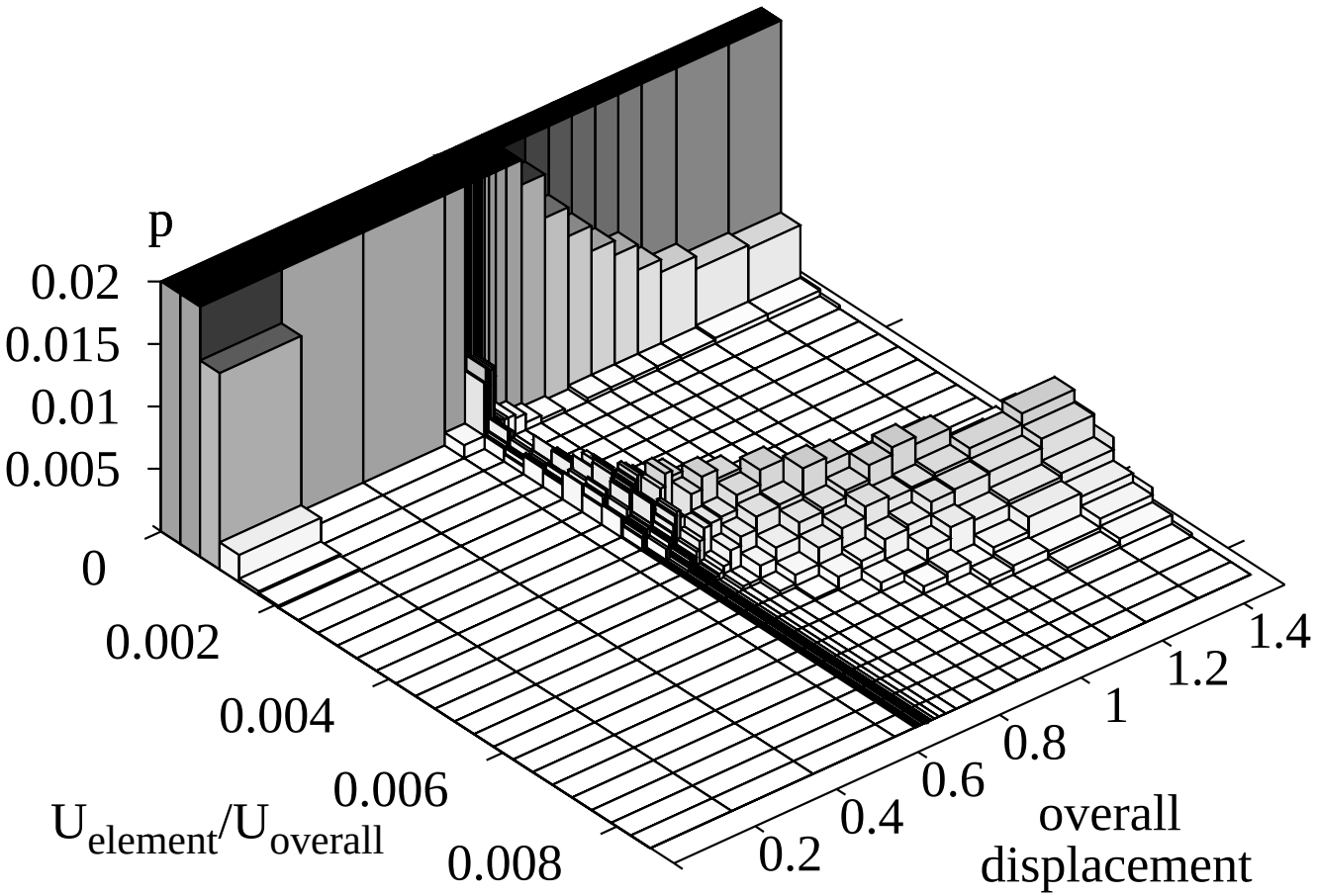


Simple Cubic — Load–Displacement



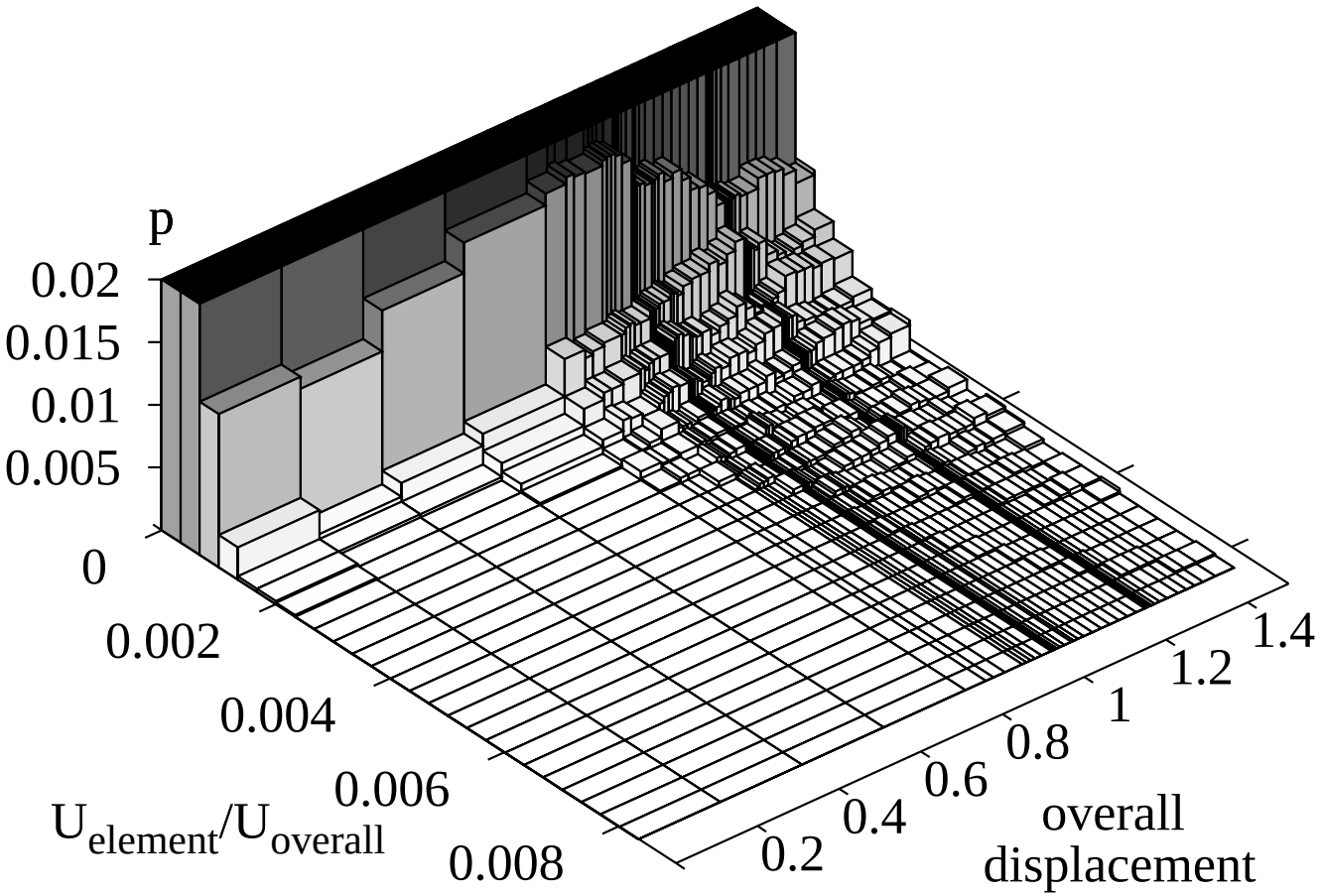
Energy Distribution

Simple Cubic [001] — $\delta/l = 1/16$

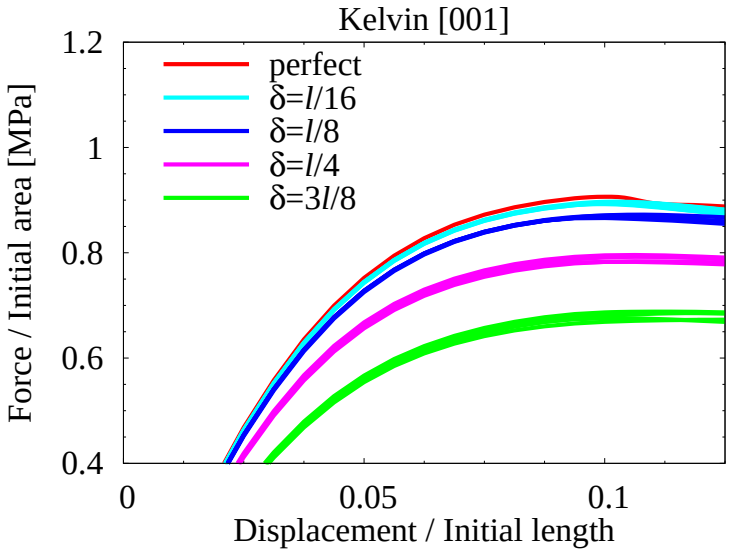


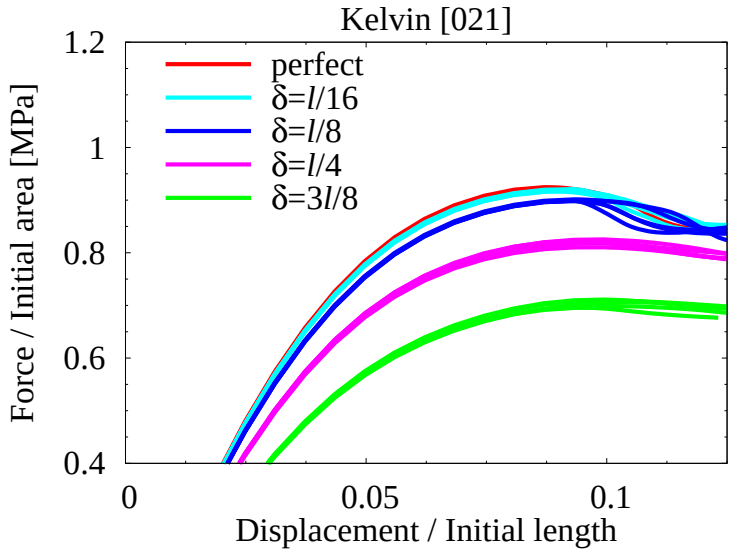
Energy Distribution

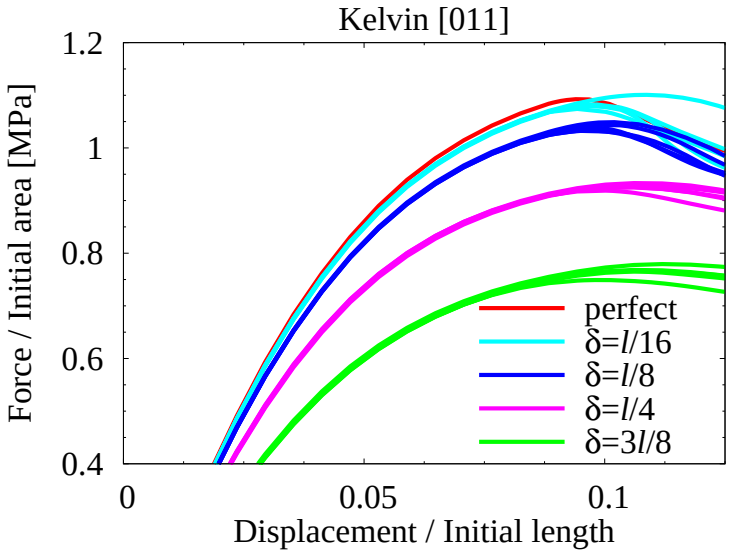
Simple Cubic [001] — $\delta/l = 3/8$

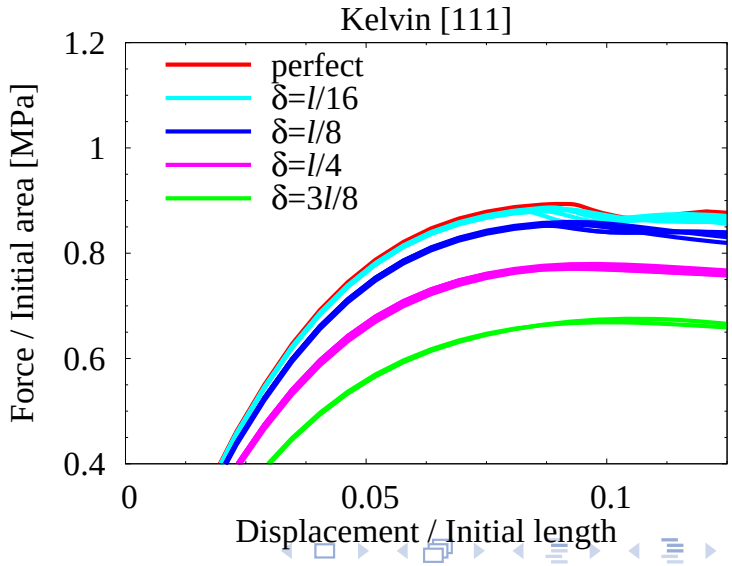


Kelvin — Load Displacement Curves









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3D open cell structures

Regular geometries

Influence of structural perturbations

Linear elastic behavior — unit cells

Nonlinear behavior — finite samples

- deformation localization
- force displacement curves
- energy distribution

Young's moduli — Perfect Structures

	$E^*/E_s \cdot 10^{-2}$			
	[001]	[021]	[011]	[111]
SC	6.630	1.193	0.816	0.631
GA	1.080	0.551	0.432	0.360
RBCC	2.906	2.632	2.499	2.389
BCC	2.106	2.460	2.716	3.007
KV	1.109	1.140	1.158	1.174
WP	1.421	1.152	1.041	0.956