COMSOL
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Chewing mechanisms in the elderly investigated using Finite Element Modelling (FEM) for two soft cereal foods

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Chewing: a major transformation process

- Complex mechanisms: teeth, tongue, saliva involved!
- De-structuring , particle size reduction
- From mechanical point of view:
- Compressive forces
- Deformation, damage → failure

?

Chewing

- In-mouth processing & transformation
- First step of the eating & digestion process
- Flavor & aroma release
- Perception, sensory pleasure

Importance of the mechanical behavior of the food!

- Cellular solids
- Ductile behavior
- Structure properties
- Stress vs Strain response

Soft cereal foods

Understand chewing mechanisms as a tool to develop optimized foods

Aim of the study & methodology

Aim: Predict the mechanical behavior of two ductile cereal foods under compression at high strain levels using FEM

Experimental data acquisition

- Sponge-cake & Brioche
- Mechanical behavior: uniaxial compression
- 3D Structure: X-Ray tomography (ESRF)

Model Implementation

- COMSOL® Multiphysics v. 5.3a
- Structural mechanics module
- Geometry building Meshing
- Constitutive laws + stiffening term

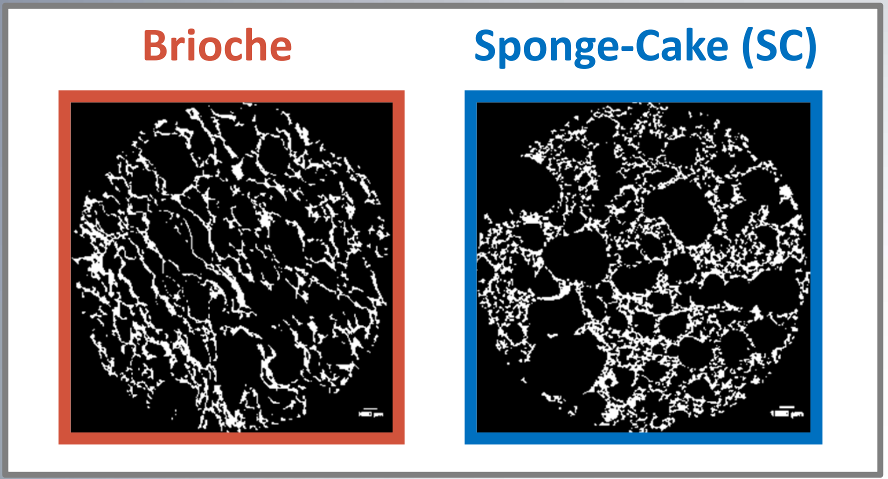
  (Guessasma & Nouri, 2015)
- Calculation

Model Validation

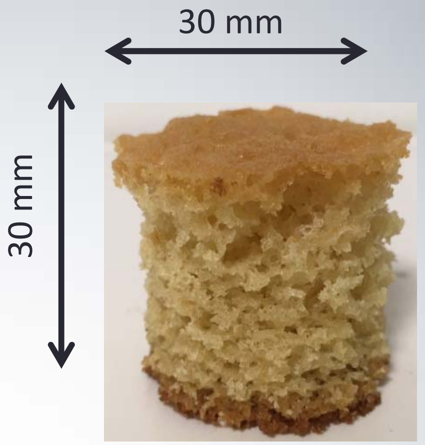
- Compare model vs. experimental results
- Optimization: Parametric sweep to find best model parameters

Experimental data acquisition

Structure (X-Ray Tomography)



Mechanical test



Sample size

Density and water content

WC (%)

30 ± 2[a] 28 ± 3[a]

ρ(g·cm^{-3})

0.33 ±0.02[a] 0.21 ±0.02[b]

Granulometry

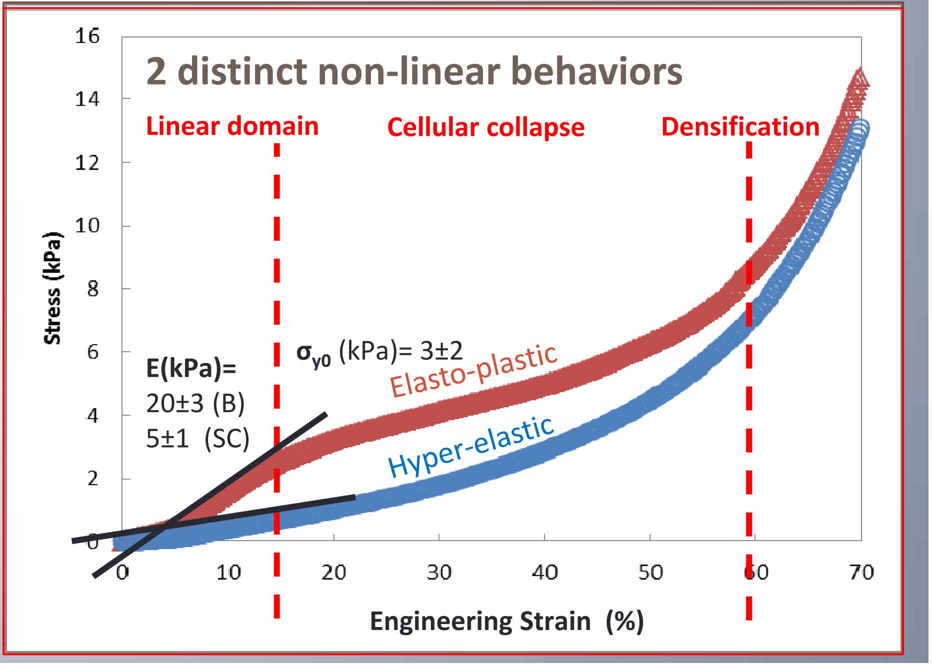
Cell D$_{50}$ (µm)

418± 79[a] 305± 14[a]

Wall D$_{50}$ (µm)

101± 1[a] 73± 3[b]

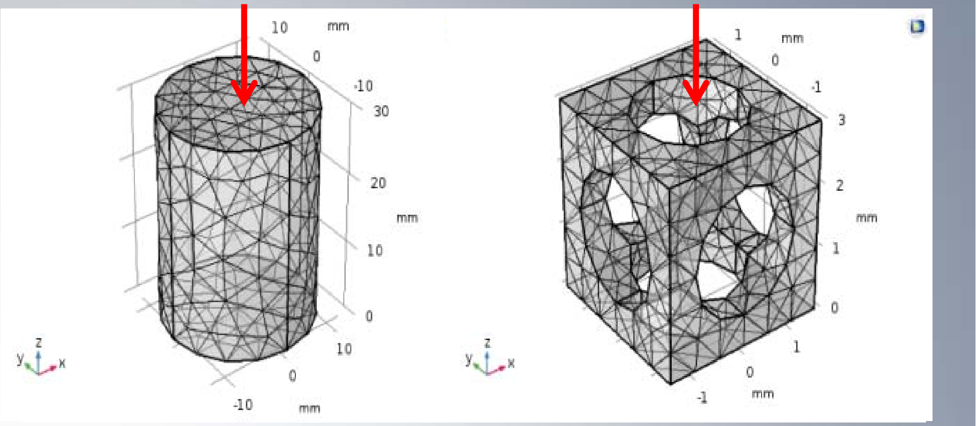
Results: Stress vs Strain response



Model Implementation

Geometry building

- Based on realistic dimensions
- **Two types of geometries: cylinder and unit cell**
- Cylinder is used to approach the large strain behavior
- **Unit cell takes porosity into account** but is restrained to linear domain due to contact non-linearity



Homogenized material **Unit cell**

Meshing

- **Tetrahedral elements**
- Number of elements: 2557 domain elements and 508 boundary elements

Boundary conditions

- **Boundary loading & fixed constraint in z direction**

Constitutive laws

- **Elasticity + Stiffening term** *(Guessasma & Nouri, 2015)*

$$E=E_0+E_D\times\left(\frac{1-\exp\left(\frac{\varepsilon}{100}\right)}{1-\exp(1)}\right)^d$$

- **Plasticity (Voce's hardening rule)**

$$\sigma_Y=\sigma_{Y0}+\sigma_S\left(1-exp\left[-\beta\varepsilon_p\right]\right)$$

Where:

E_0= Young modulus
E_D= Densification modulus
d= Stiffening coefficient
σ_{Y0}= Yield stress
σ_S= Saturation flow stress
β= Saturation exponent
ε_p=Plasticity Strain

Calculation

Stationary solver: ε auxiliary sweep 1 to 89 w/ step of 2

Model Validation

Parametric sweep: Model parameters

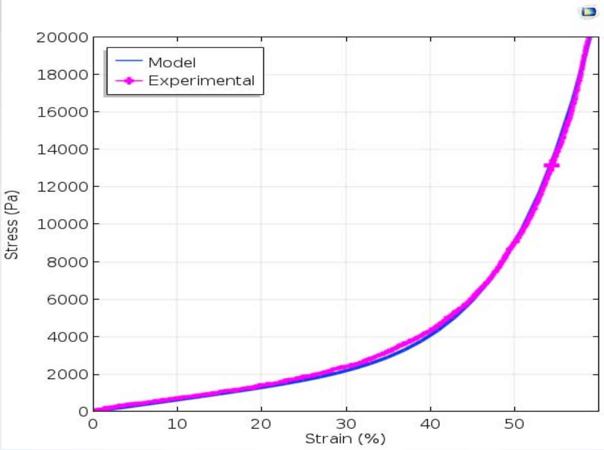
Sponge-cake

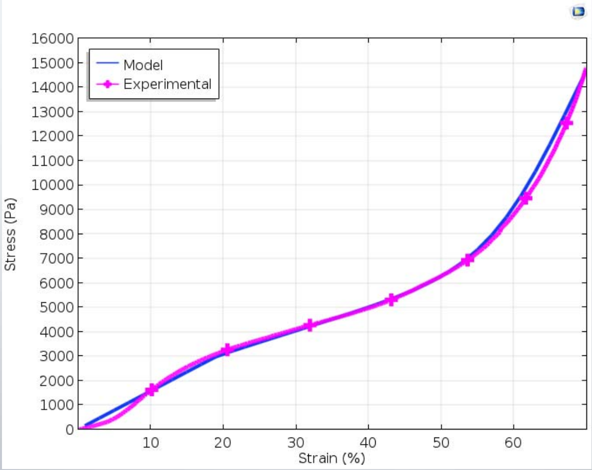
	(first, step, end)	Best value
E_0	-	5 kPa
E_D	(0.5,0.5,5)	0.5 MPa
d	(0,1,10)	4

Brioche

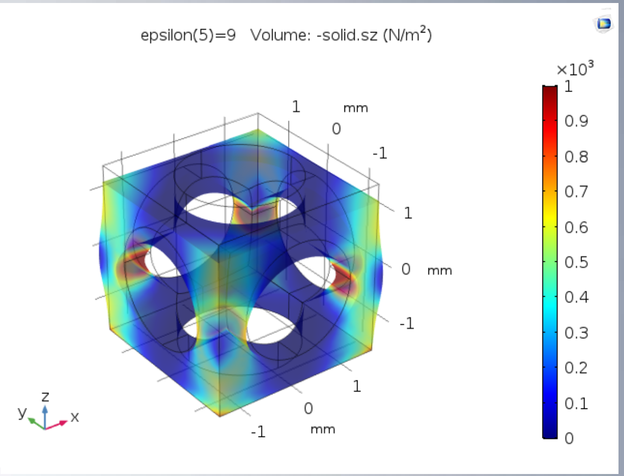
	(first, step, end)	Best value
E_0	-	20 kPa
E_D	(1,1,10)	4 MPa
d	(0,1,10)	8
β	(0, 5×10^{-4}, 1×10^{-2})	1.5×10^{-2}
σ_{y0}	-	3 kPa
σ_s	(1,1,20)	14 MPa

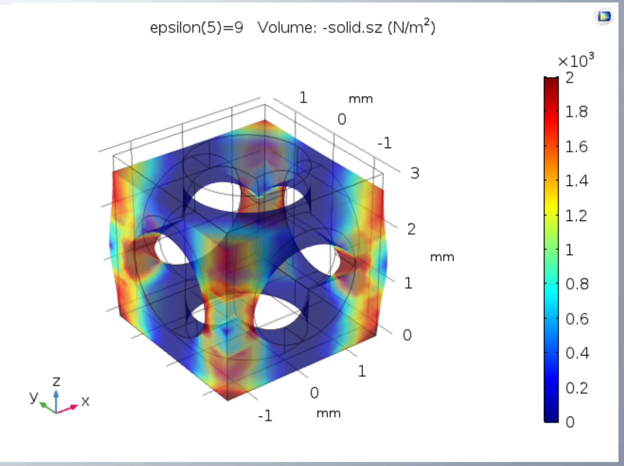
Homogenized vs. Experimental





Unit cell at 10% Strain
Stress field in z component



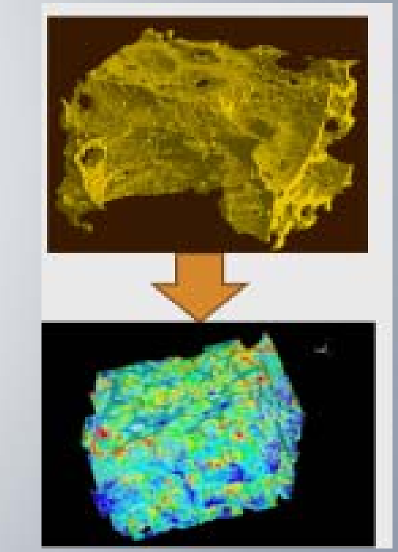


Cell-wall bending is the leading deformation mechanism

Conclusion & Perspectives

For the two studied food products:

- Use of the stiffening term was an effective way to derive the compression behavior up to the densification stage.
- The models remarkably captured all the deformation stages with a limited number of mechanical parameters.

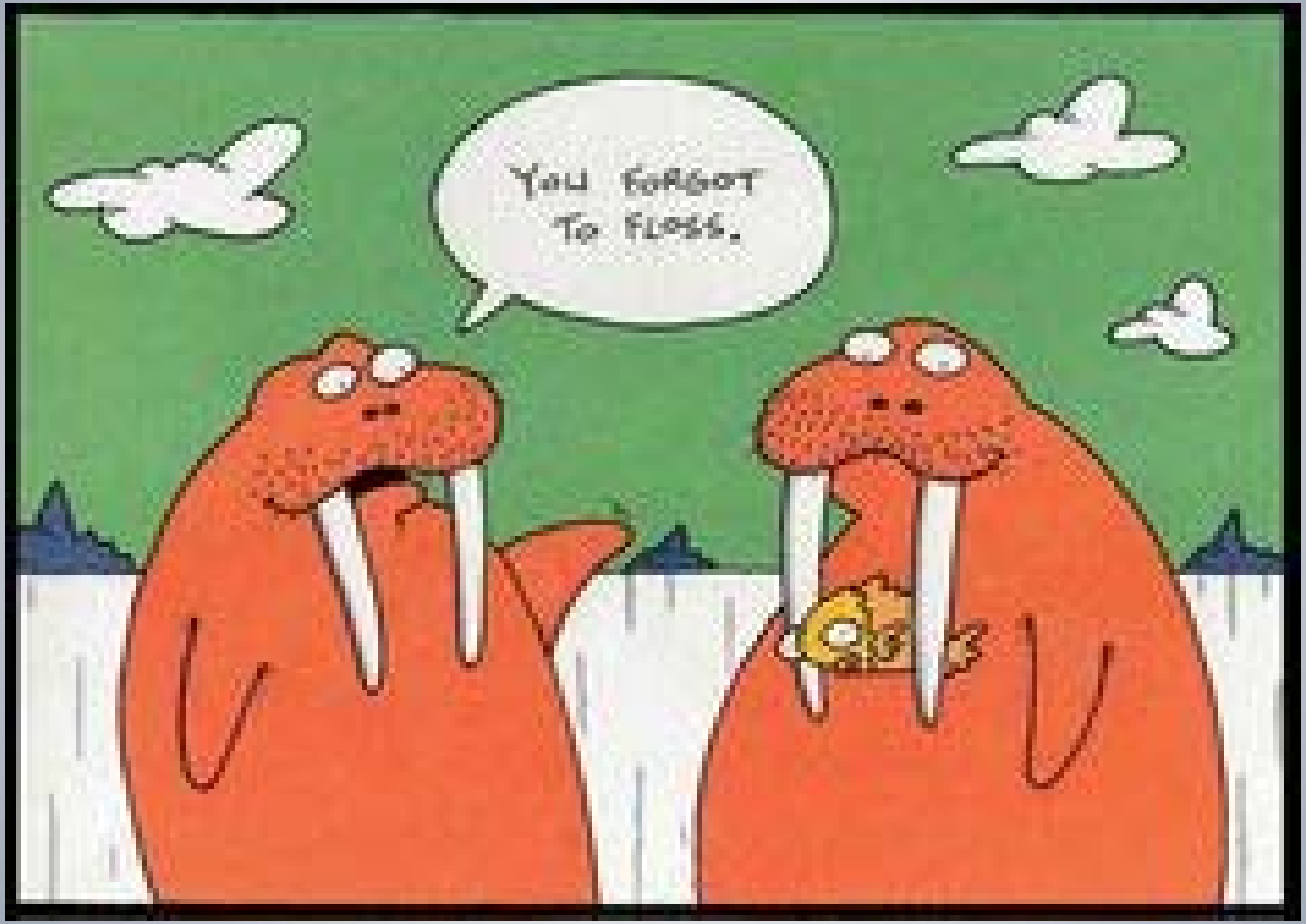


What is next?

- Modelling of mechanical response of the two foods from the 3D cellular structure
- Include physiology criteria
- Take account for viscous effects

✓ **First step towards a more accurate description of the mechanical and structural changes that occur during chewing in cereal soft foods.**

Thank you for your attention!



Any questions?