Modeling of packaging behavior in closed-cell aluminum foam

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- Introduction.

The structural elements made of aluminum foams are often used in the automotive industry. Unlikely to classic materials such as steels, alloys or cast irons internal structure leads to non-usual behavior. Consistent destruction of internal cells of the material is observed on the stress-strain diagram as large plastic region with respectively low stresses. Localized to certain area such cells destruction is known in the literature as strain localization or, in the case of significant collapse of material sample, packaging.

One of the major man-made cellular solids use is packaging (Kiessling, 1961).

Problem Definition

The complete problem is including following steps:

1. Fast estimation of critical loads.
2. Determination of initial packaging location.
3. Propagation of collapsed cells domain in foams:
   a. Sharp interface approach.
   b. Phase-field approach.

Objectives

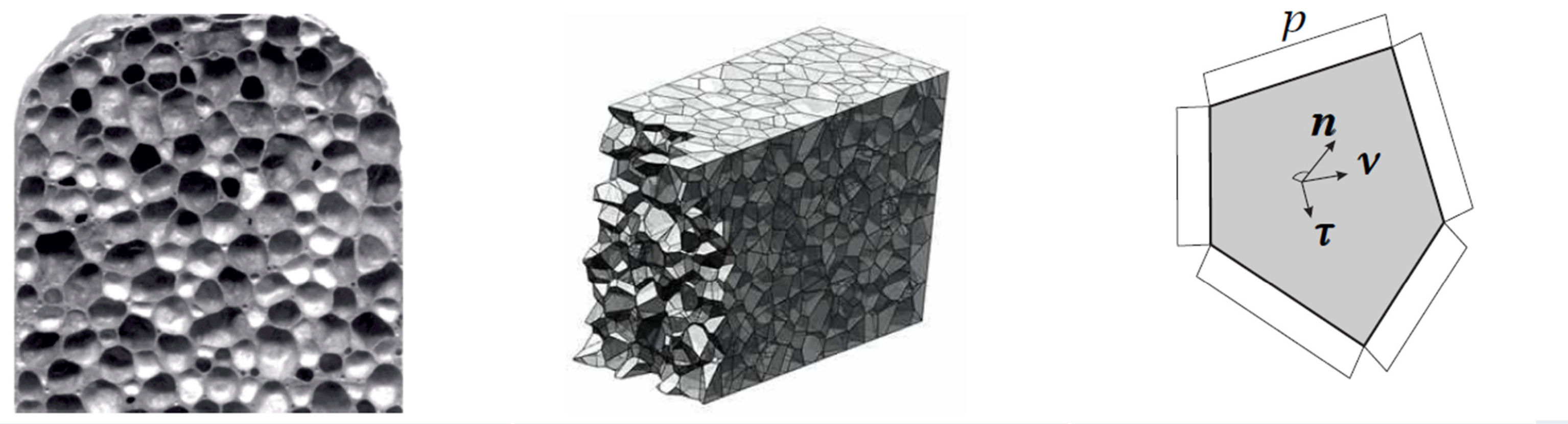
The aim of research to develop an algorithm for prediction of strain localizations arising in foams. The propagation of the collapsed cells domain through cellular structure must be predicted. The model must be simple and contain minimum material parameters.

Cooperation

Cooperation with members of the school:
K. Kovalev (IAN), K. Held (IAN), R. Glüge (IFME), S. Roy (IFME), O. Prigorniev (IFME), A. Girchenko (IFME)
Cooperation with external people:
F.Hildebrandt (IAM University of Stuttgart),
R.Schlimper (Fraunhofer IWM Halle(Saale))

Cells collapse estimation

Geometry of foam is modeled via Voronoi tessellation. Generated plates have arbitrary shape. They are used for determination of relation between the 1st critical value and geometry of the plate.



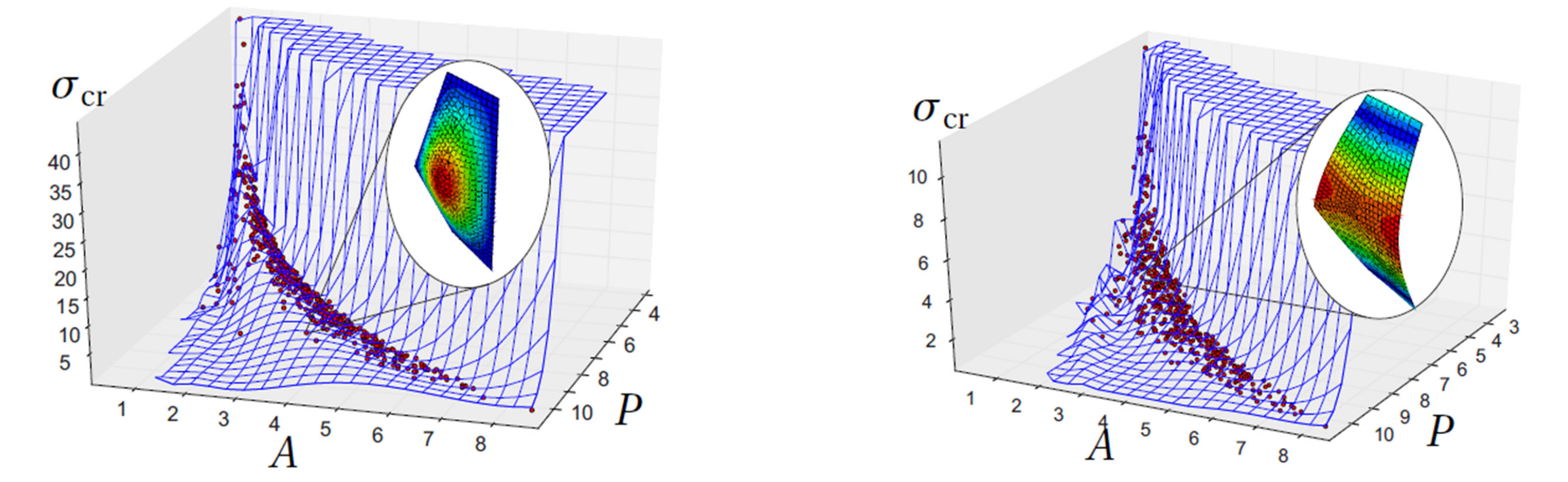
(a) Alulight® foam trademark | (b) Voronoi tessellation | (c) One of the plates

Fig.1 Modeling of closed-cell foam

Obtained results are approximated by the basic shape functions:

$$F = \left(\frac{1}{x^2}, \frac{1}{y^2}, \frac{1}{xy}, \frac{1}{x^2}\frac{y}{x}, \frac{1}{y^2}\frac{x}{y}, \frac{1}{x^2}\frac{y^2}{x^2}, \frac{1}{y^2}\frac{x^2}{y^2}\right)$$

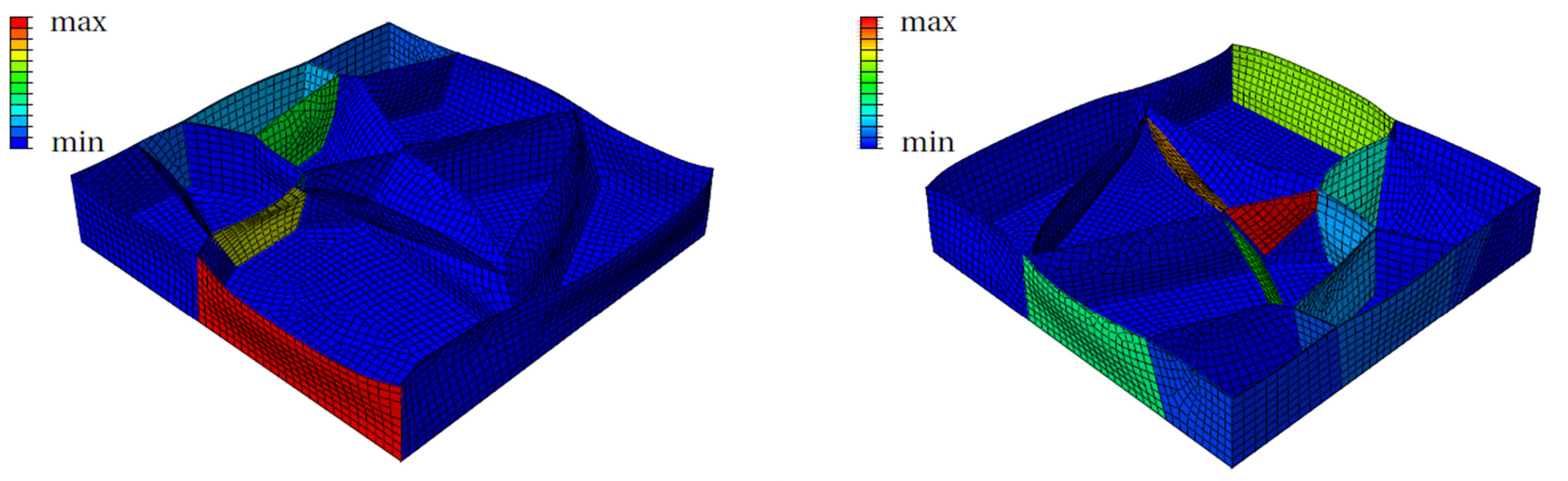
Approximation results:



(a) Clamped edge solutions | (b) Free edge solutions

Fig.2 Estimation of critical forces for plates with different boundary conditions

Estimation results:



(a) Overestimation | (b) Underestimation

Fig.3 Estimation of plates subjected to buckling

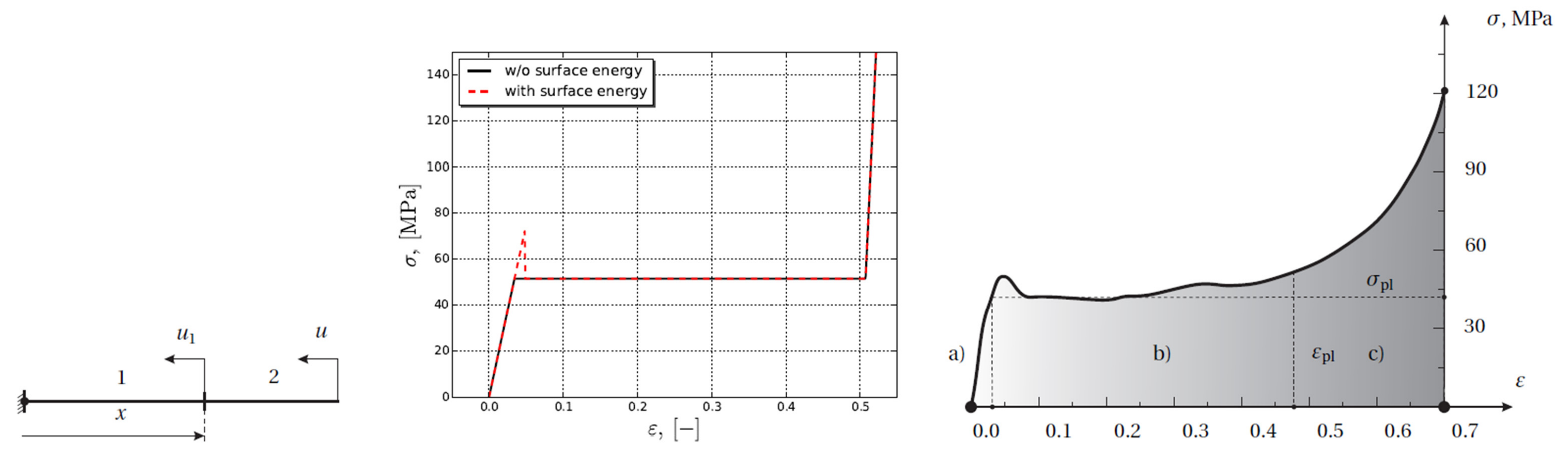
Phase transformation treatment

Assumptions:

- Packaging is similar to 1st order phase transformation
- Interface is coherent
- Only linear elastic behavior of material take place

Sharp interface approach

$$W(X,\boldsymbol{u}) = W_1 + W_2 + W_{\text{int}}$$
$$W \rightarrow \min$$



(a) Problem scheme | (b) Obtained solution | (c) Experimental results

Fig.4 Packaging at uni-axial compression test

Phase-field approach

$$W = W(\phi, \boldsymbol{u}) \qquad W \rightarrow \min$$

Equilibrium:

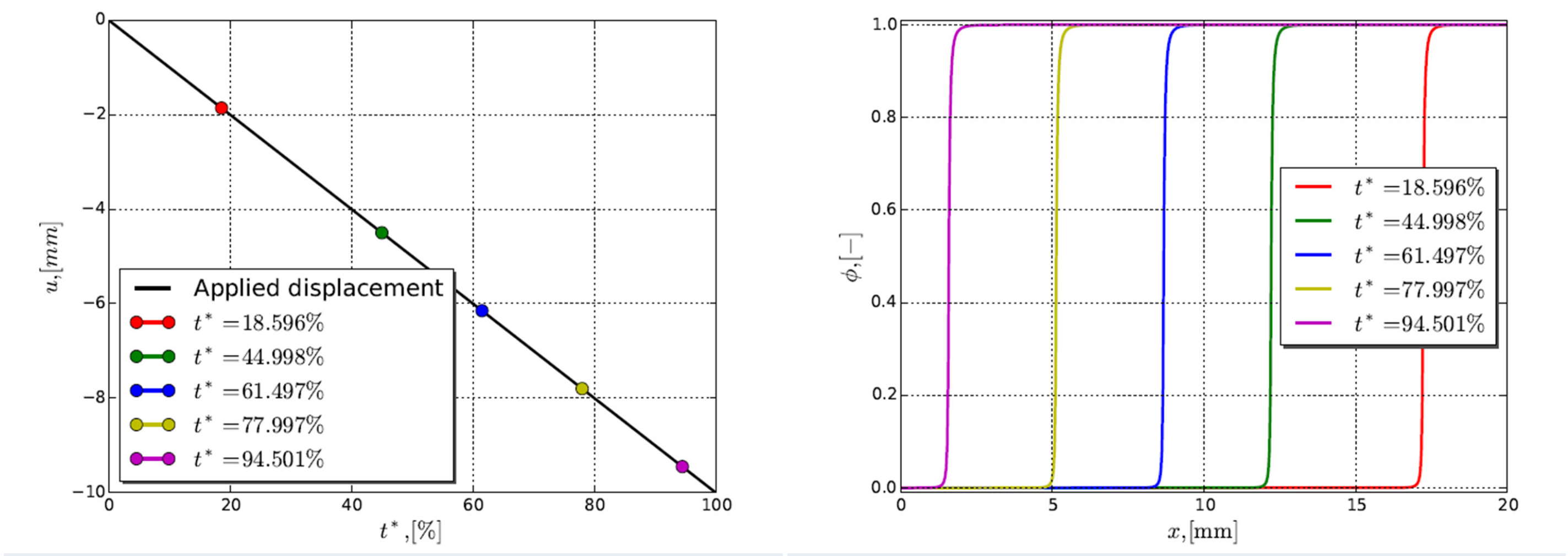
$$\frac{\delta W}{\delta \boldsymbol{u}} = 0 \quad \Downarrow \quad \nabla \cdot \boldsymbol{\sigma} = 0$$

Evolutional:

$$\frac{\delta W}{\delta \phi} = 0 \quad \Downarrow \quad \dot{\phi} = -L\frac{\delta W}{\delta \phi}$$

Constitutive:

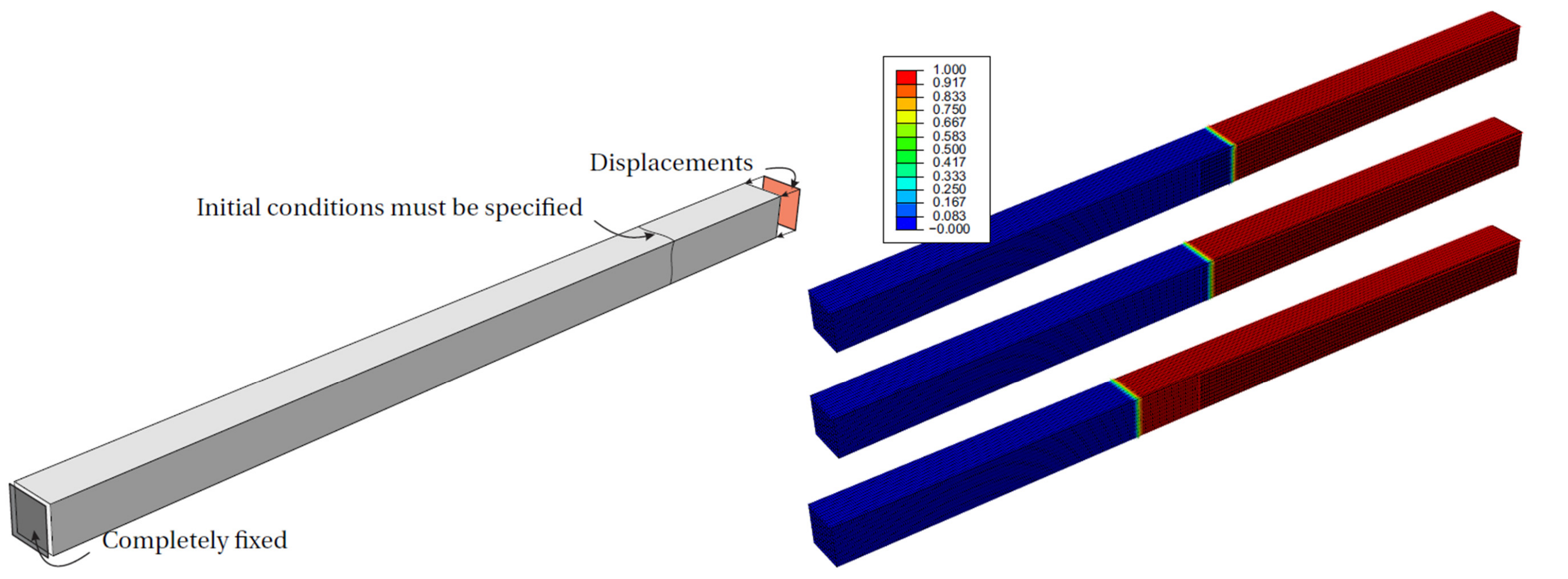
$$W = (1-h)W_1 + hW_2 + W_{\text{int}}$$
$$h = h(\phi)$$
$$\boldsymbol{\sigma} = \frac{\partial W}{\partial \boldsymbol{\varepsilon}}$$



(a) Applied displacement | (b) Interface movement

Fig.5 Simulation of uniaxial rod compression test

Implementation into Abaqus



(a) Initial and boundary conditions | (b) Phase distribution

Fig.6 Abaqus simulation of uniaxial rod compression (3D)

Results and Discussion

Results

- Geometry generation scheme based on the Voronoi tessellation is developed
- The nucleation criteria by means of the semi-analytic approach is proposed
- Material parameters are determined with application of sharp interface approach
- Phase-field approach within the framework of current research is developed
- Phase-field approach for uniaxial problem is realized in Python scripting language
- Three-dimensional model is implemented in Abaqus

Conclusions

Linear elastic material properties defined by double-well elastic potential **is sufficient** for modeling of strain localizations and packaging behavior in foams.

Only **few material parameters** are necessary for application of proposed approach.

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