Warsaw University of Technology

Faculty of Automotive and Construction Machinery Engineering

Numerical Simulations of Vacuum Packed Particles Using LS-DYNA

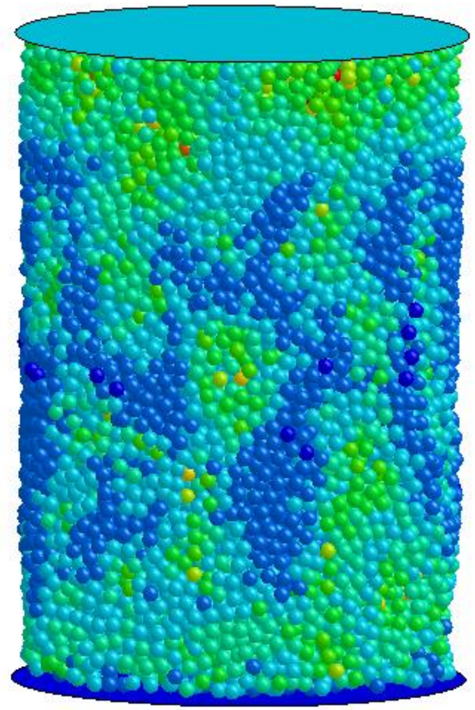
Authors: **Piotr Bartkowski**, Robert Zalewski

Agenda

- Introduction to Vacuum Packed Particles
- Experimental tests of VPP
  - Uniaxial tension and compression
  - The influence of the strain rate
  - Three point bending
- Modeling of VPP
  - DEM modeling
  - FEM modeling
- Summary

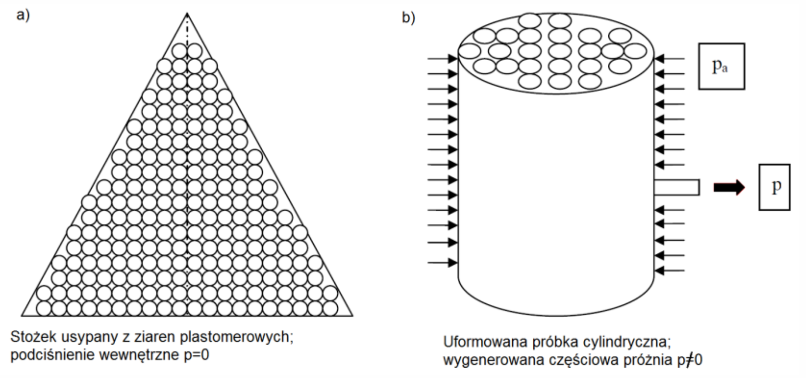
Vacuum Packed Particles (VPP)

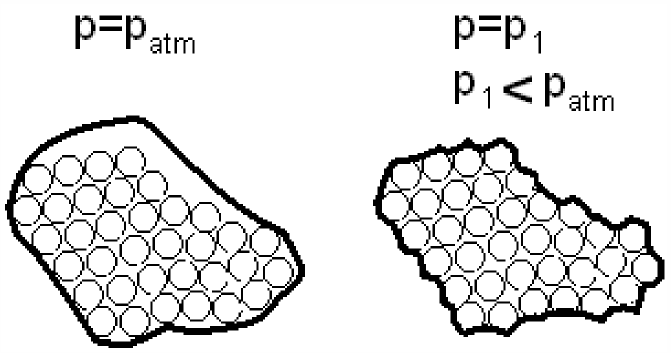
- Structure compose of granular material inside plastomer coating
- When pressure inside is equal or higher than atmospheric pressure the system behaves like liquid
- Otherwise properties are like elasto-plastic solid
- Forces between the granules are transmitted by friction



Vacuum Packed Particles (VPP)

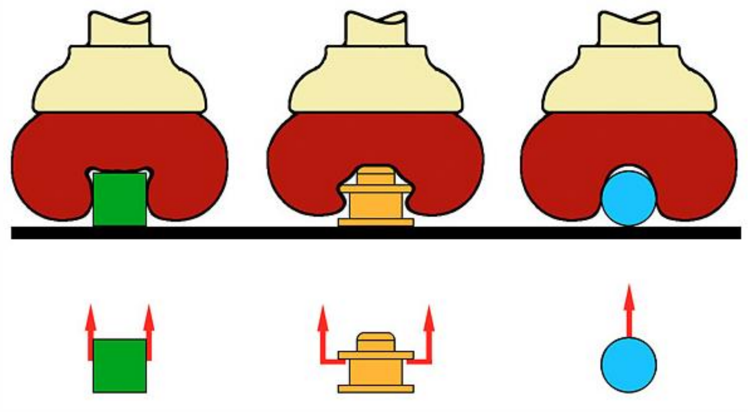
- By changing the value of underpressure the mechanical properties of the structure can be changed
- Physical properties can be changed rapidly by pulling out the pressure from the system
- Smart material with similar properties to MR fluids

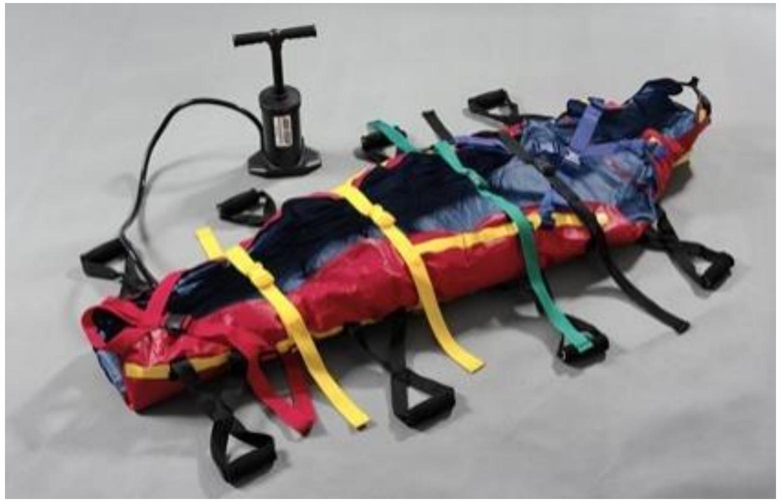




Vacuum Packed Particles (VPP)

- Application
  - Medicine
    - Endoskop with variable stiffness
    - Mattress (for people with injuries)
    - Orthesis
  - Robotics
  - Active vibration damping



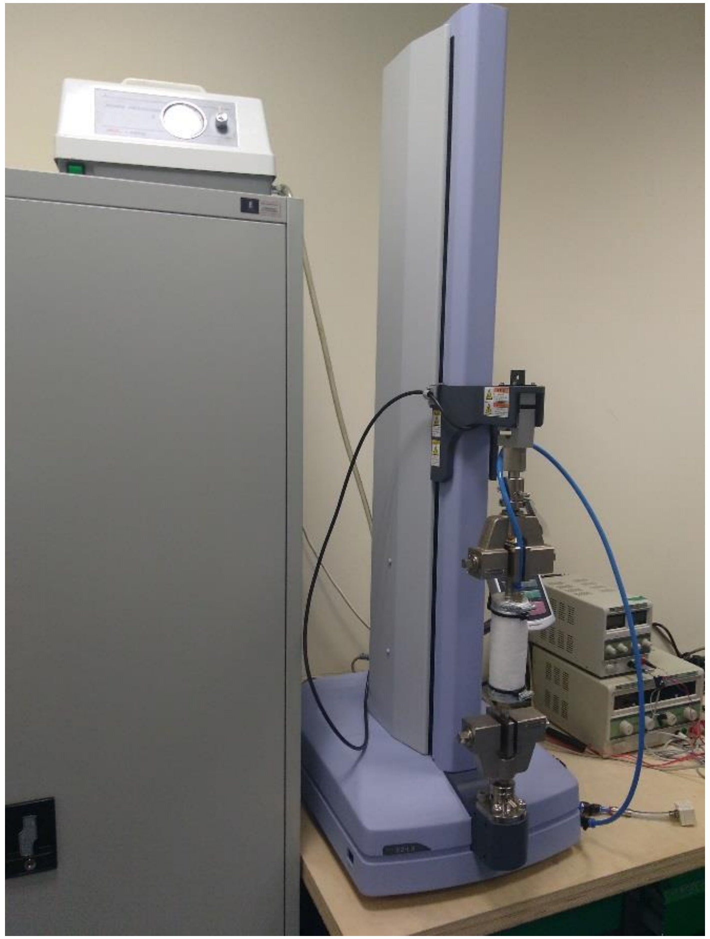


Warsaw University of Technology

Source:
http://www.bitegroup.nl/research-projects/endoscope-shaft-guidance/vacu-sl/
R.Zalewski, „MODELOWANIE I BADANIA WPŁYWU PODCIŚNIENIA NA WŁAŚCIWOŚCI MECHANICZNE SPECJALNYCH STRUKTUR GRANULOWANYCH”, 2012

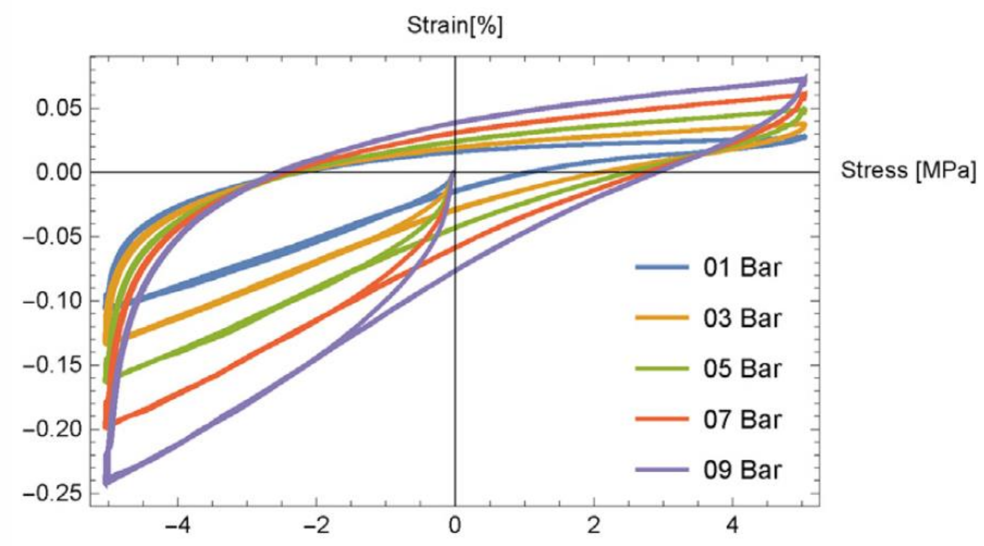
Experimental tests of VPP

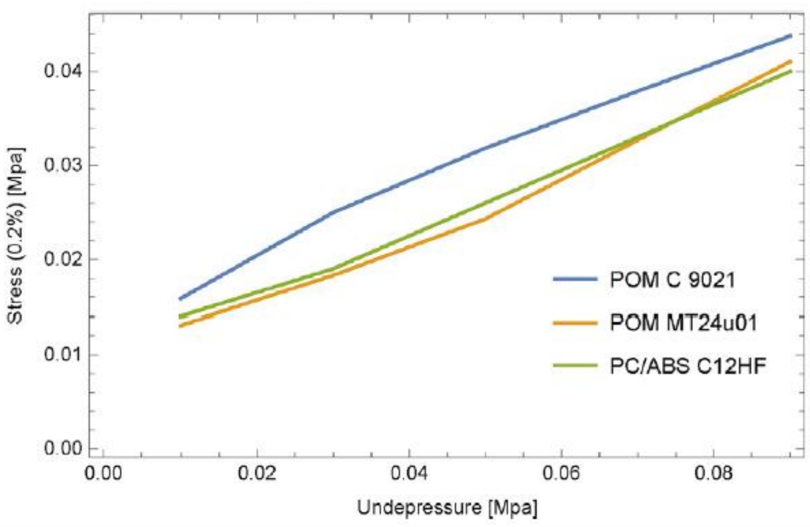
- Influence of the underpressure on the behaviour of VPP
  - Quasi static test – Shimadzu EZ-LX
  - Cylindrical samples
  - Tension, compression
  - Tests for 5 different undepressure values (0.01MPa, 0.03MPa, 0.05MPa, 0.07MPa, 0.09MPa)



Experimental tests of VPP

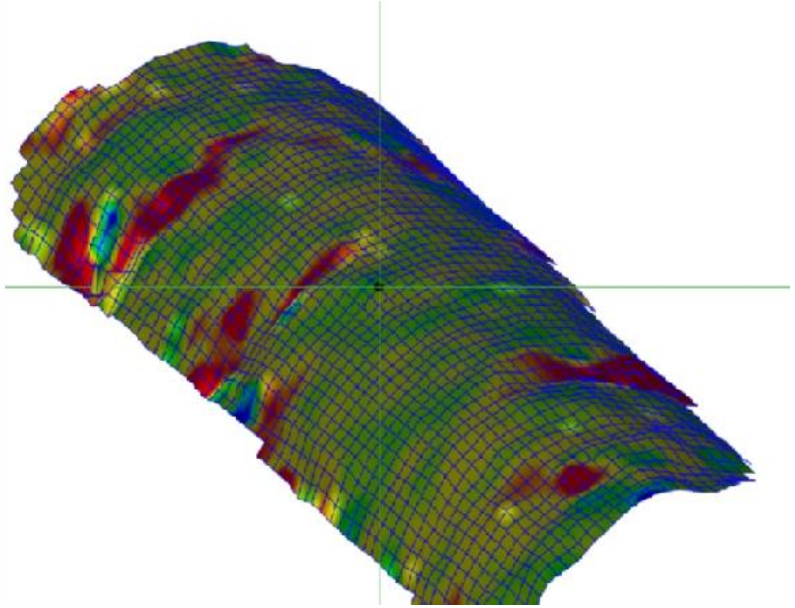
- Influence of the underpressure on the behaviour of VPP
  - Results
    - Tension
    - Compression
    - Influence of the underpressure

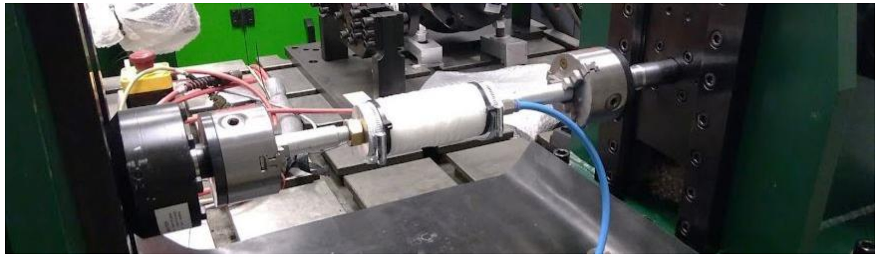




Experimental tests of VPP

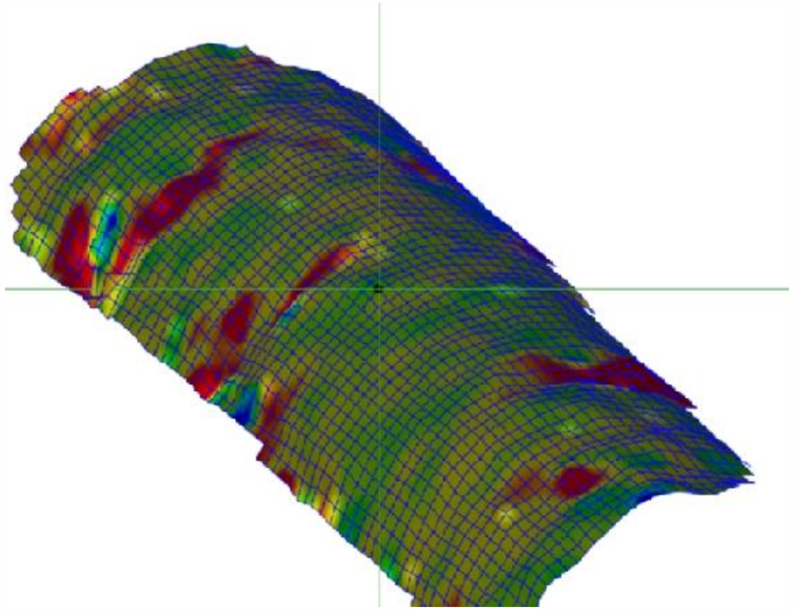
- Influence of the strain rate on the behaviour of VPP
  - Test stand MTS with ARAMIS System
  - Cylindrical samples
  - Tension, compression
  - Tests for 5 different undepressure values (0.01MPa, 0.03MPa, 0.05MPa, 0.07MPa, 0.09MPa)
  - Test for 3 different values of the strain rate

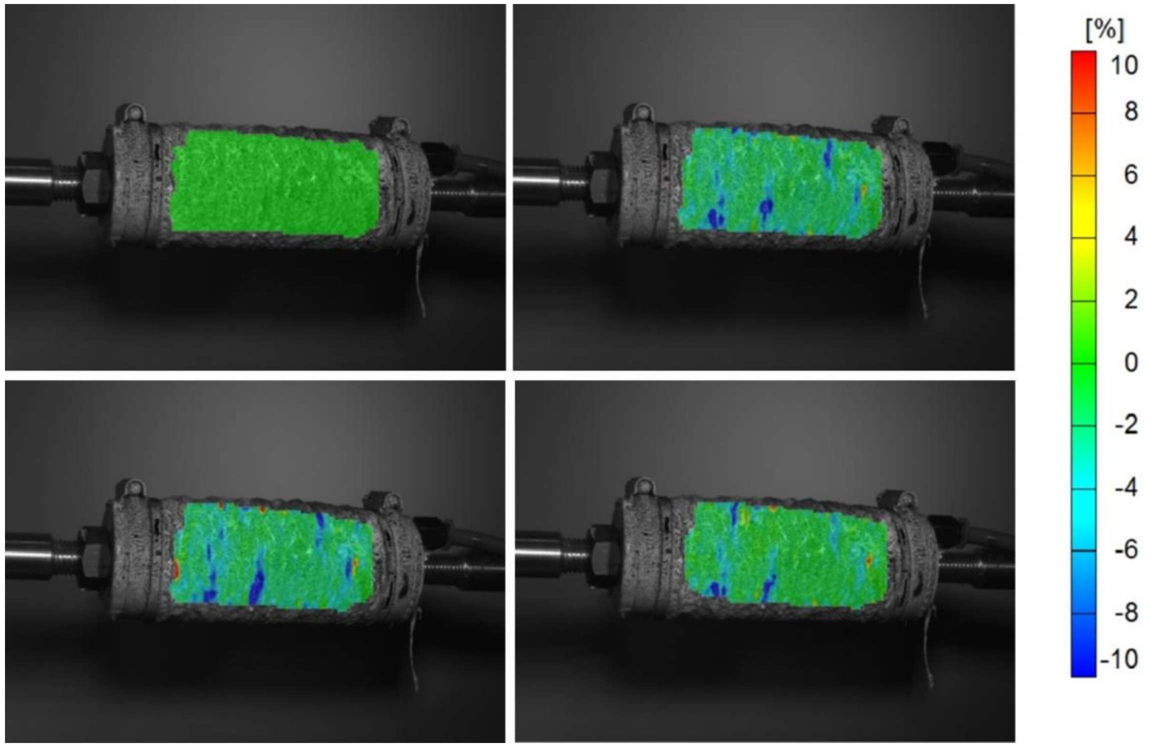




Experimental tests of VPP

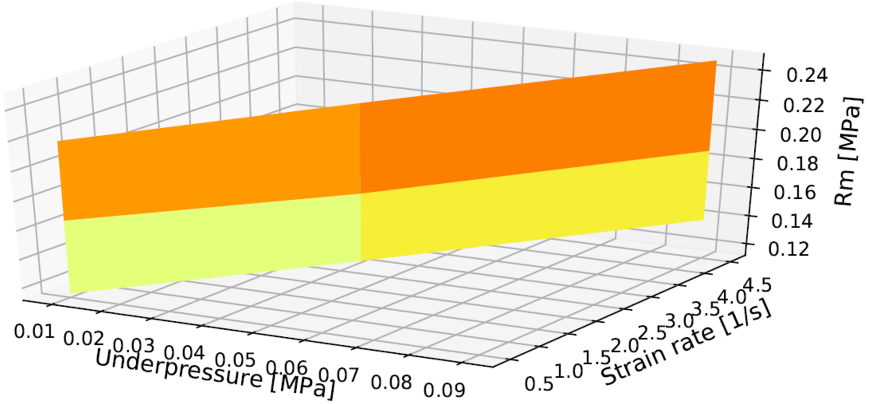
- Influence of the strain rate on the behaviour of VPP

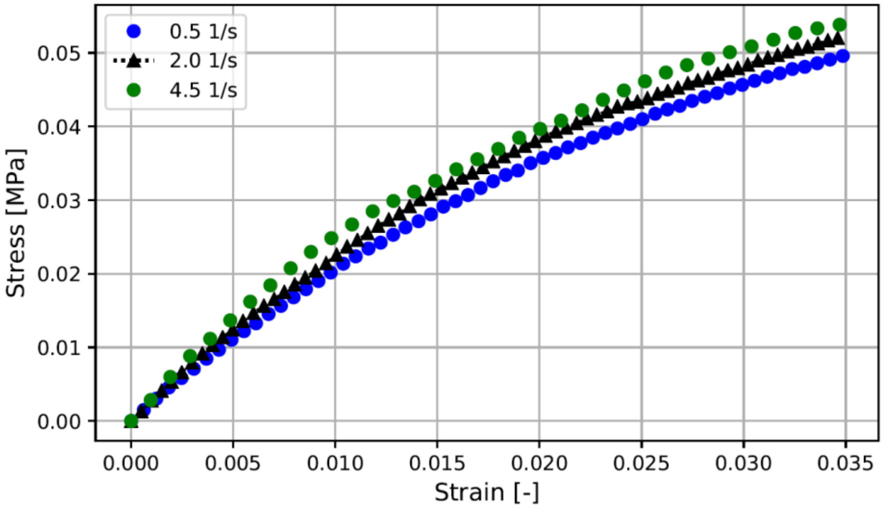


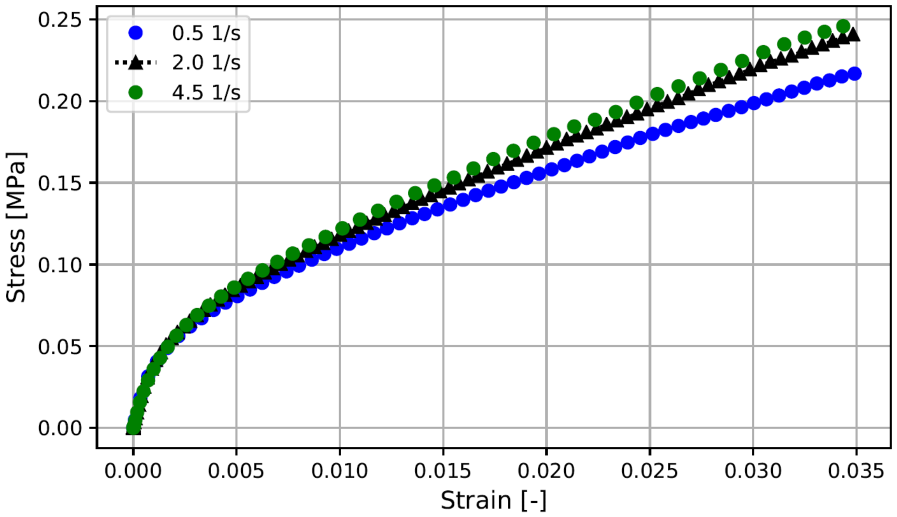


Experimental tests of VPP

- Influence of the strain rate on the behaviour of VPP
  - The influence of the strain rate for tension and compression
  - Influence of a different values of underpressure
  - Maps of strain

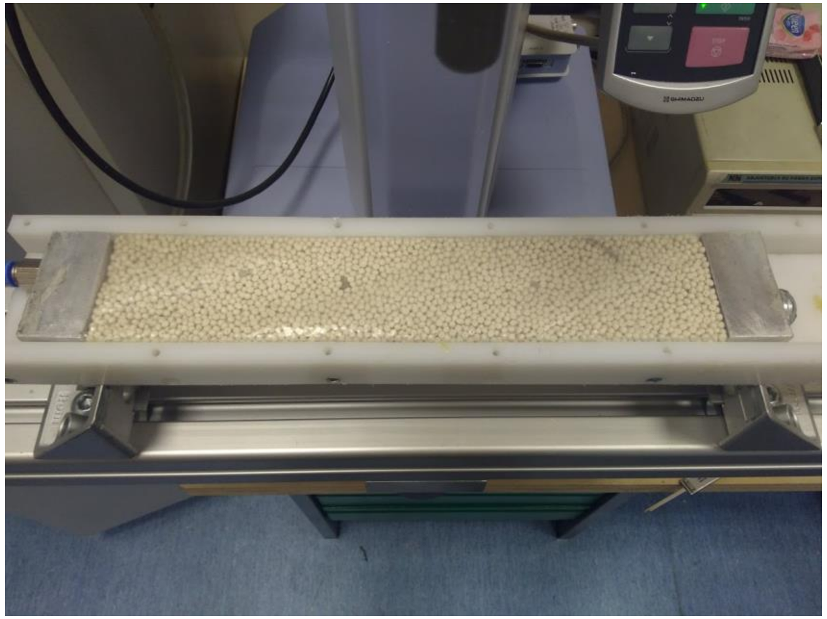


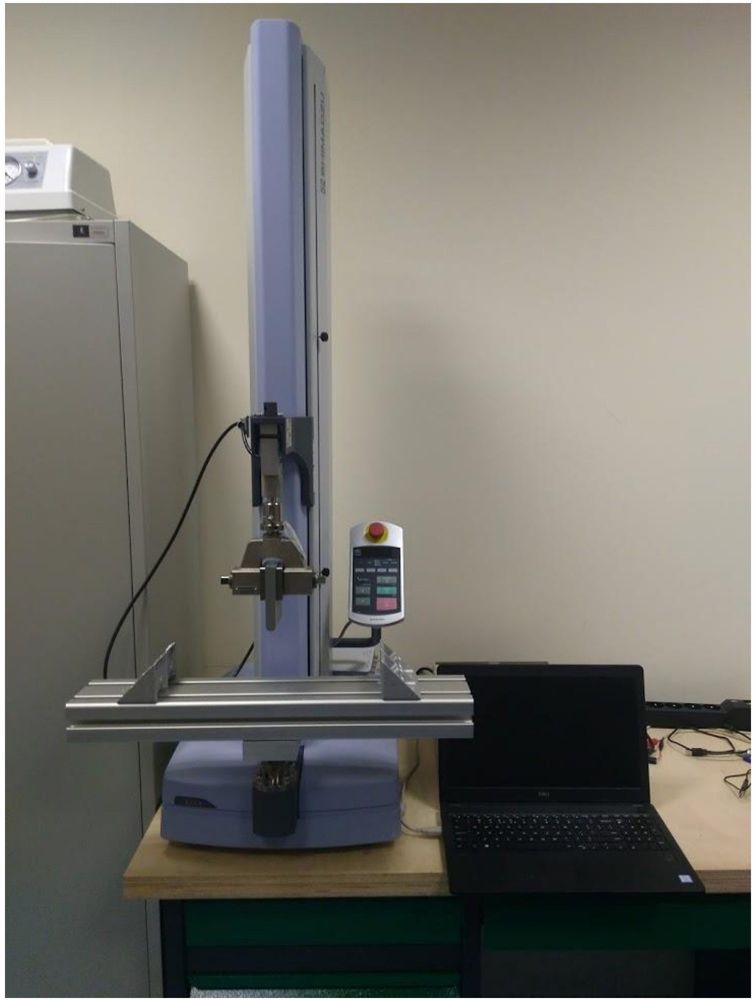




Experimental tests of VPP

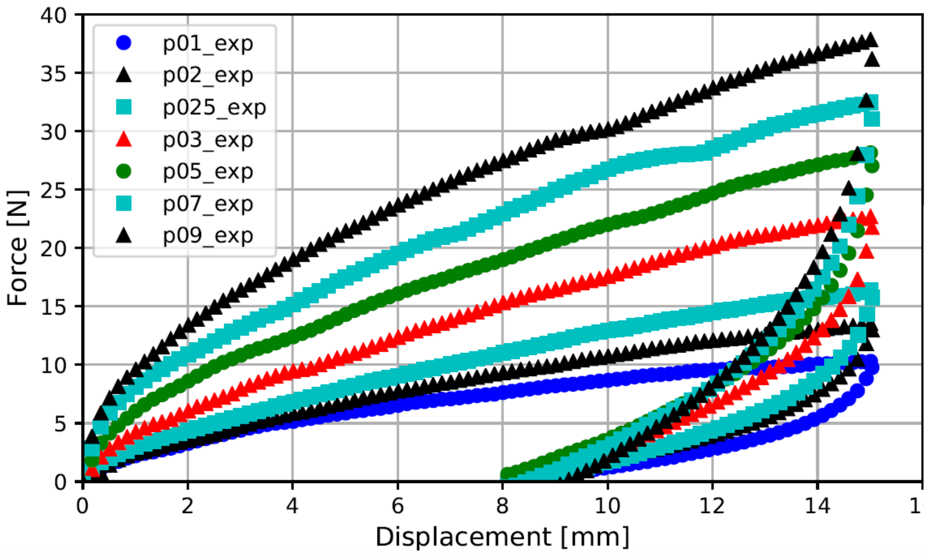
- Three point bending
  - Quasi static test – Shimadzu EZ-LX
  - Beam 20x60x330mm
  - Beam formed in a special tool
  - Tests for a different underpressure values

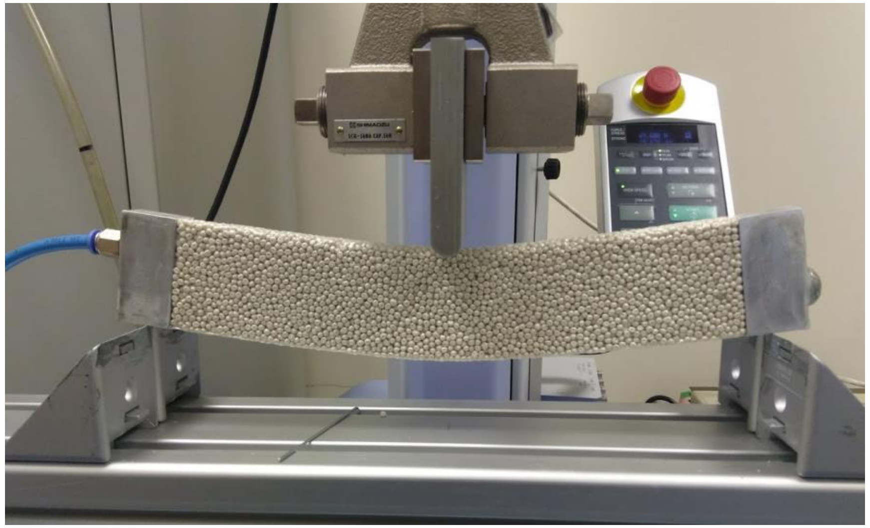


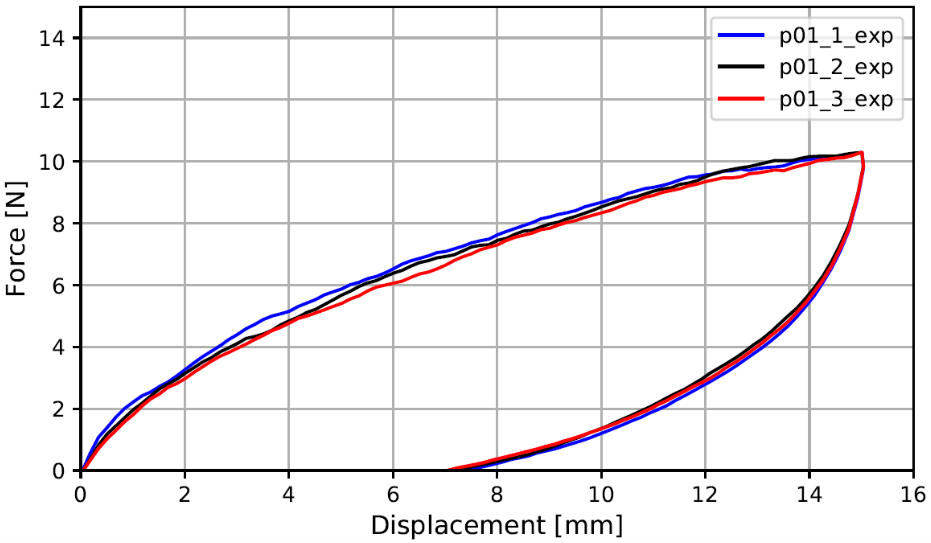


Experimental tests of VPP

- Three point bending
  - The influence of the undepressure on the behaviour ov VPP
  - Repeatable results

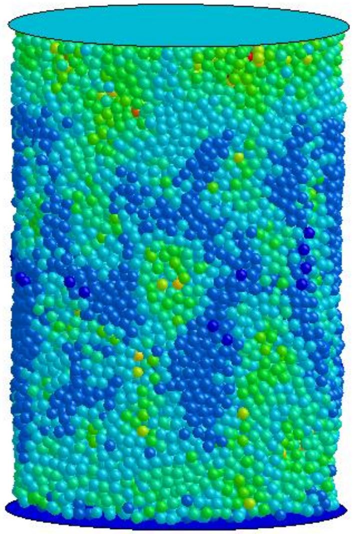


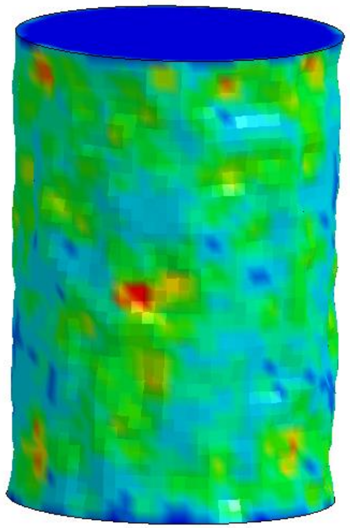


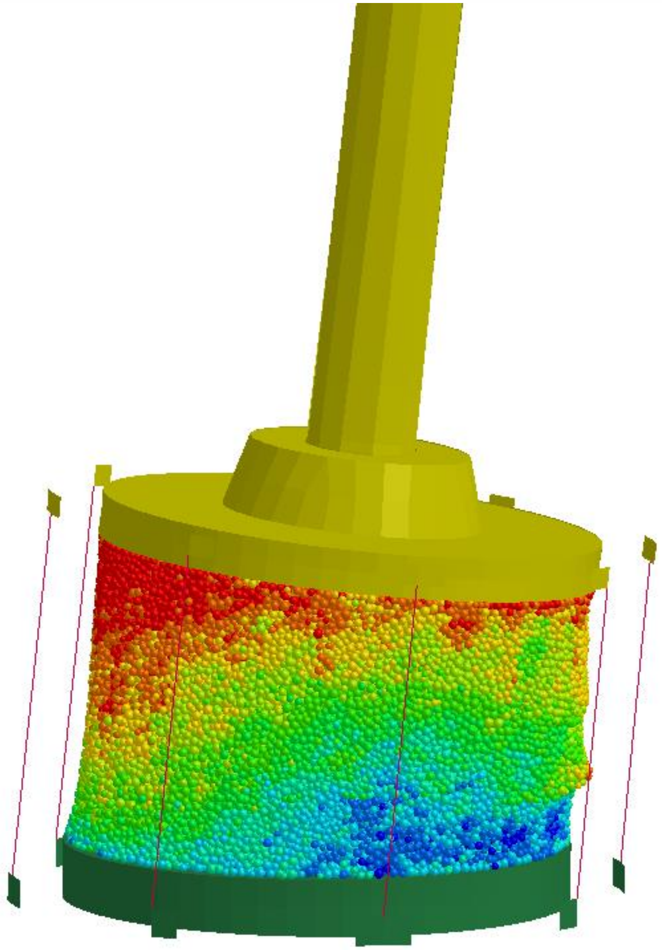


Modeling of VPP

- DEM modeling
  - Plastomer coating is modeled by shell elements – FEM
  - Grains model as a rigid ball (DEM)
  - Model identification base on the simple uniaxial test
  - CPU consuming
  - Problems with contact between grains and outer shell







Modeling of VPP

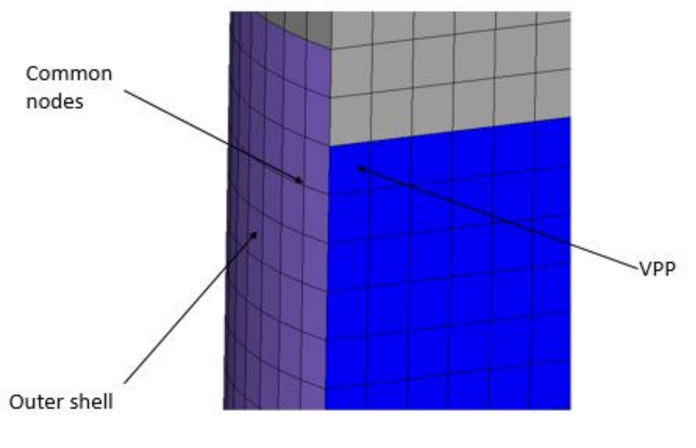
- FEM modeling
  - Mat_124 was chosen
  - Yield function described by HMH rules
  - Incremental plastic strain is computed
  - Different yield function for tension and compression
  - Modification of the model – JC-p
  - Outer shell modeled by shell elements

$$\phi = \frac{1}{2}s_{ij}s_{ij} - \frac{{\sigma_{up}}^2}{3} \leq 0 \tag{4.1}$$

$$\sigma_{up} = \beta[R_e + f_{c,t}(\epsilon_p)] \tag{4.2}$$

$$I_\sigma = tr\sigma = \sigma_{kk} \tag{4.3}$$

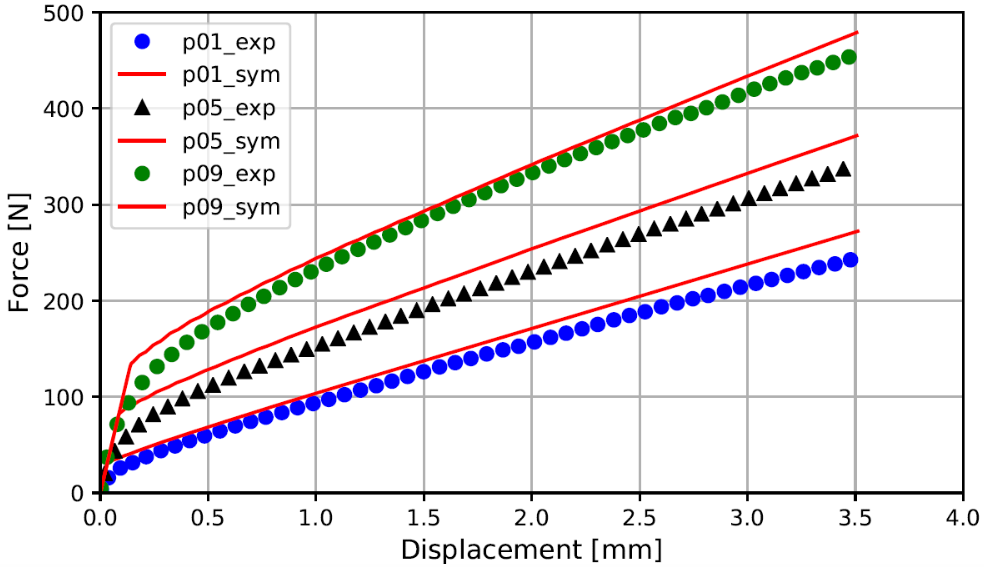
$$\Delta\epsilon_p = \frac{(\frac{3}{2}s^*_{ij}s^*_{ij})^{0.5} - \sigma_{up}}{3G + E_p} \tag{4.4}$$

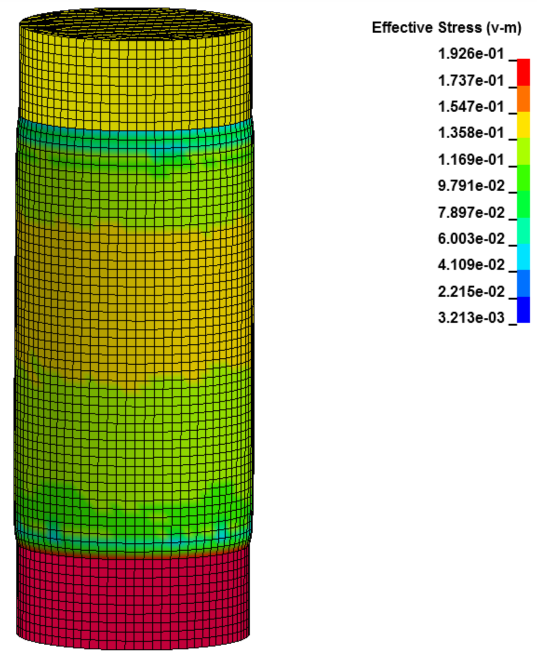


$$(\epsilon, \dot{\epsilon}, p) = (\alpha + \beta p + (\Psi + \gamma p)\epsilon^{\Upsilon - \chi p})(1 + (\Xi - \mu p)ln\left(\frac{\dot{\epsilon}}{\dot{\epsilon}_0}\right)) \tag{4.5}$$

Modeling of VPP

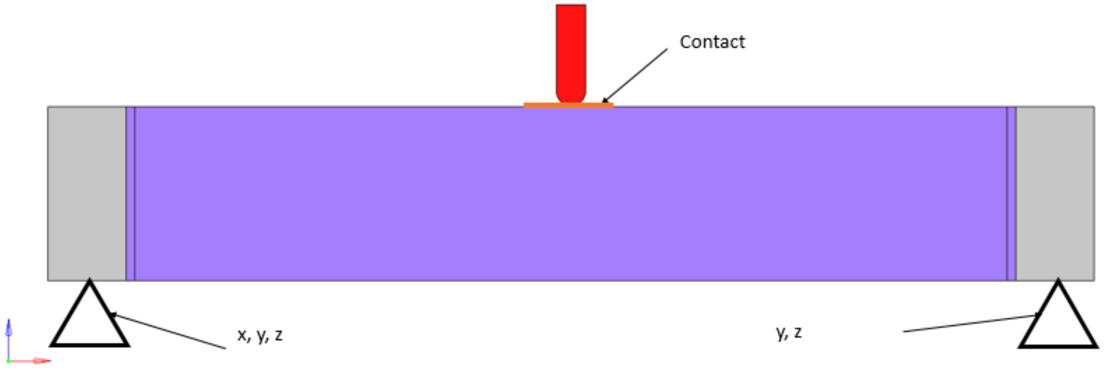
- Model validation
  - Uniaxial tension – compression
    - Only the undepressure parameter was changed
    - Model works correctly for tension and compression
    - Very good correlation for a higher strain rate

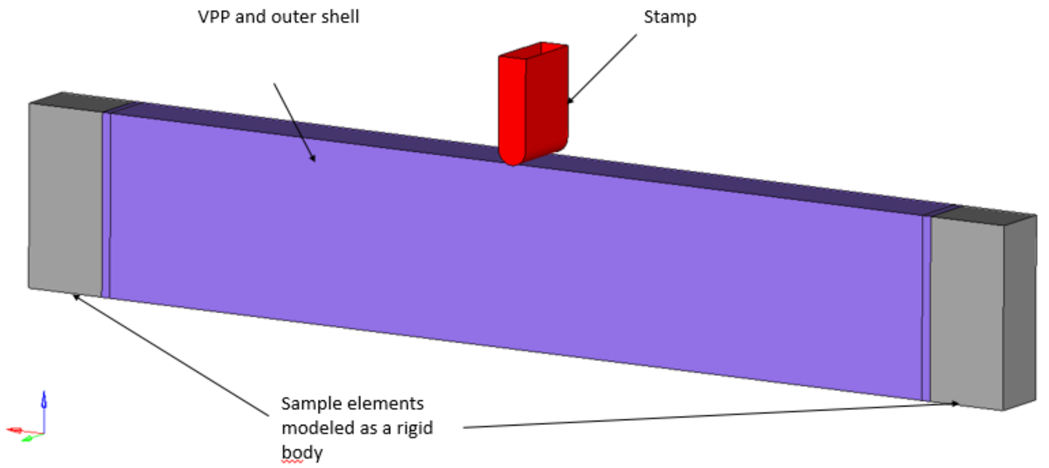




Modeling of VPP

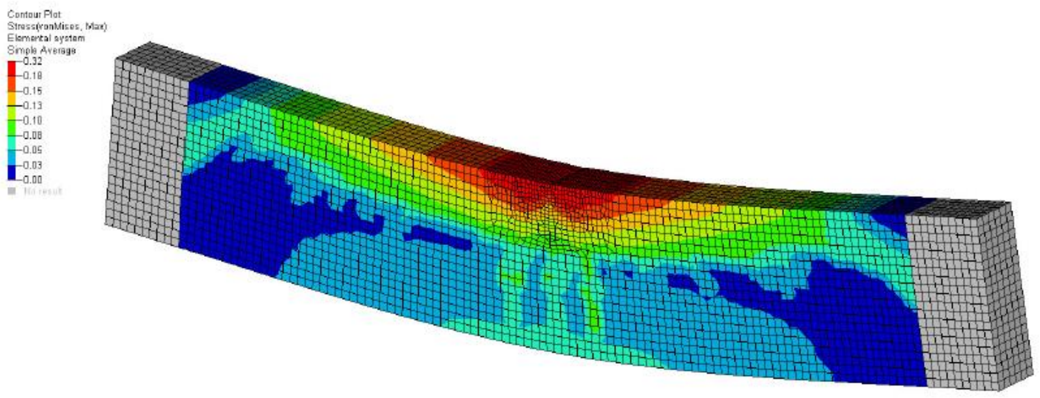
- Model validation
  - Three point bending
    - Boundary condition analogous to the test
    - Contact beetween beam and stamp

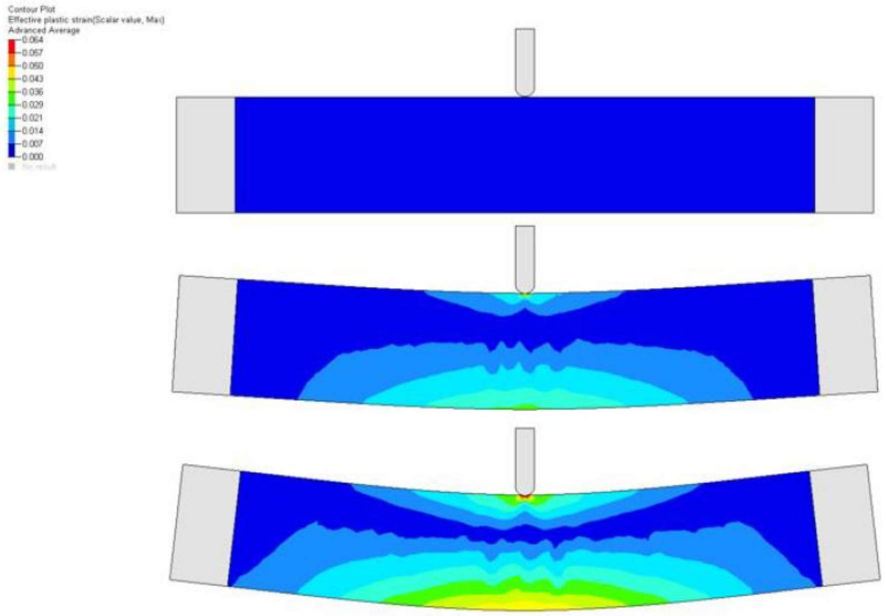


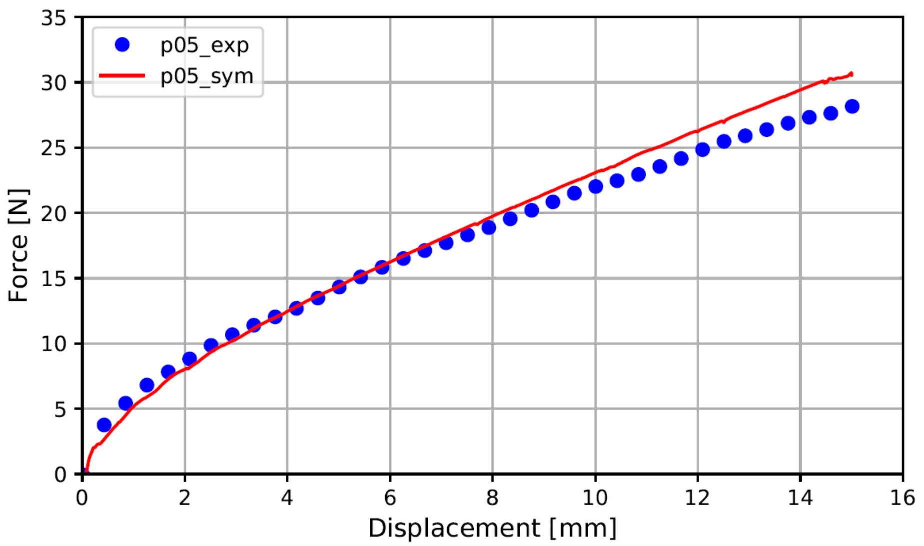


Modeling of VPP

- Model validation
  - Three point bending
    - Results

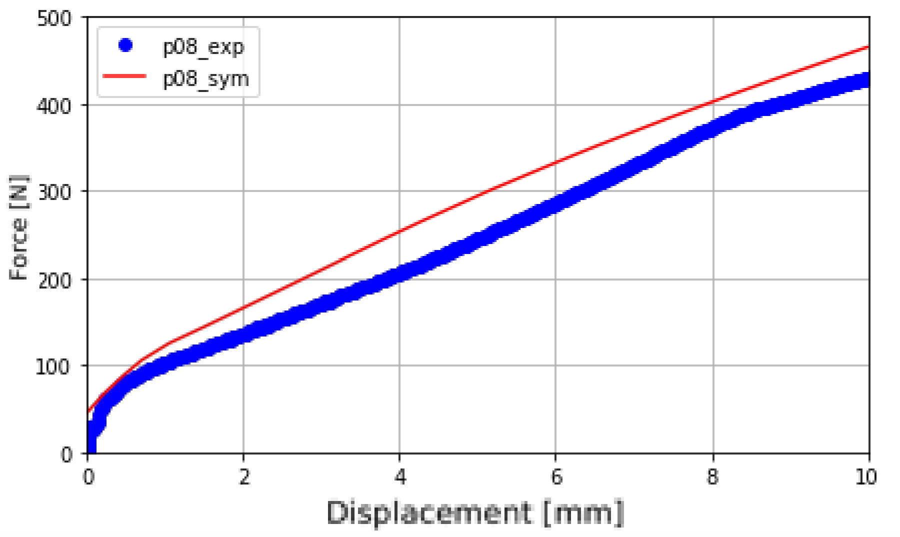


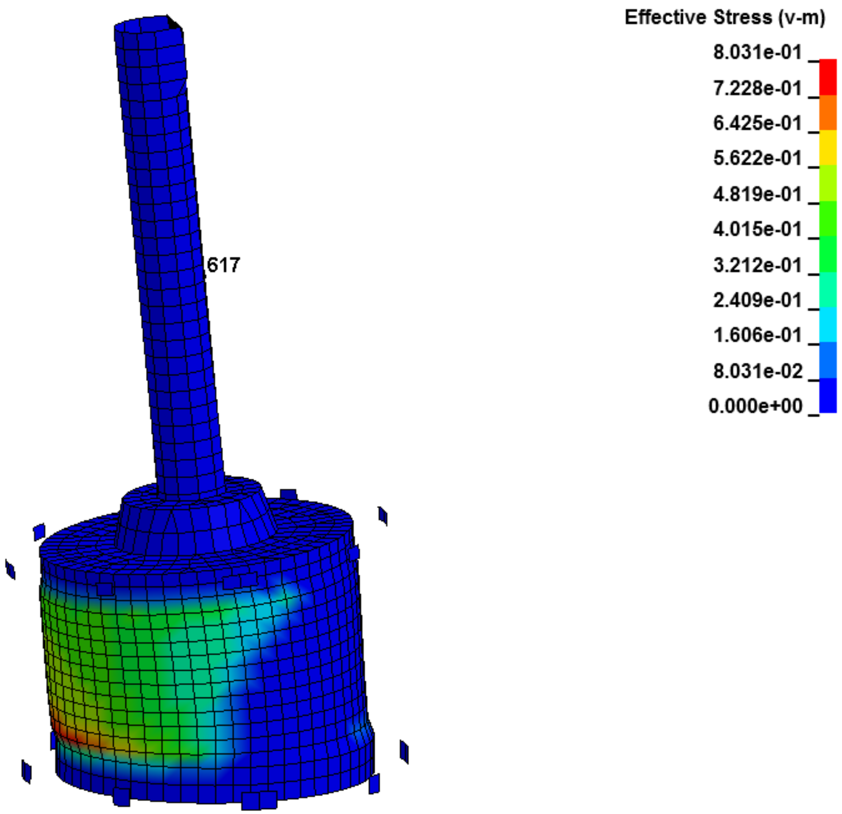




Modeling of VPP

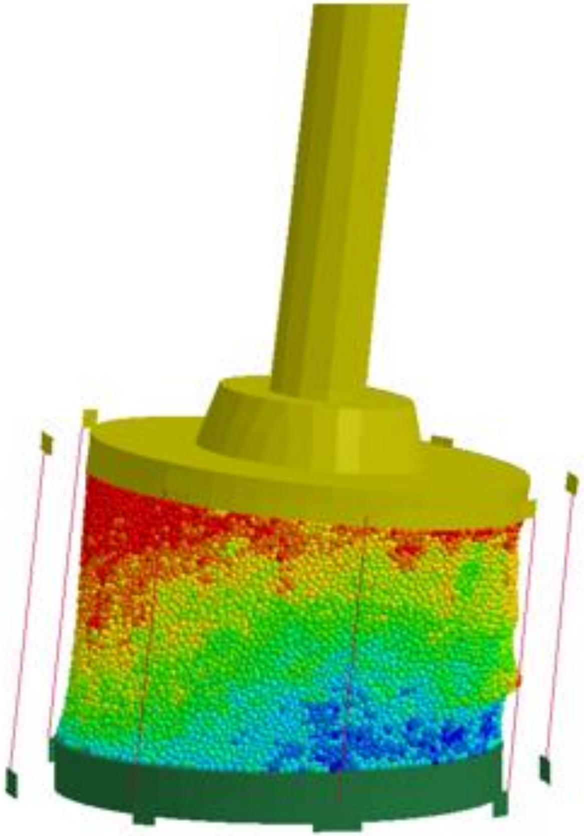
- Crash Energy absorber made of VPP
  - Adaptive crash Energy absorber
  - Possibility to change the stiffeness characteristic





Summary

- The experimental research showed the influence of the undepressure on the behaviour of VPP
- VPP is strain rate dependent
- Proposed modeling methodology gives good correlation beetwen experiments and simulation



Warsaw University of Technology

Thank you for your attention!

This work was carried out within the project no. 2016/23/N/ST8/02056 founded by National Science Centre, Poland.