MODELING OF THE INFLUENCE OF PORE MORPHOLOGY ON DAMAGE BEHAVIOR OF AN ALUMINUM DIE CASTING ALLOY

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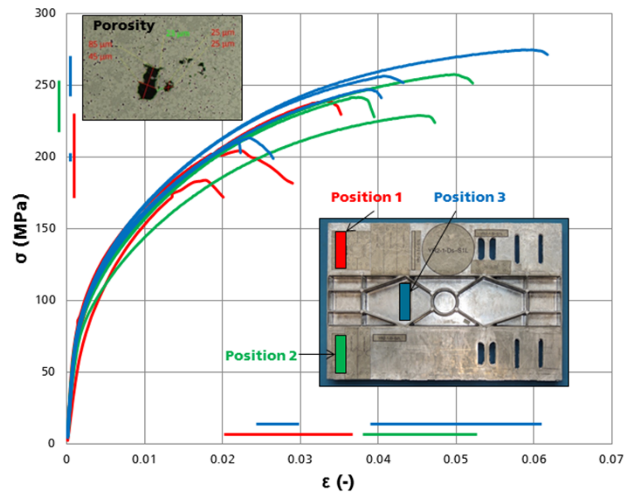
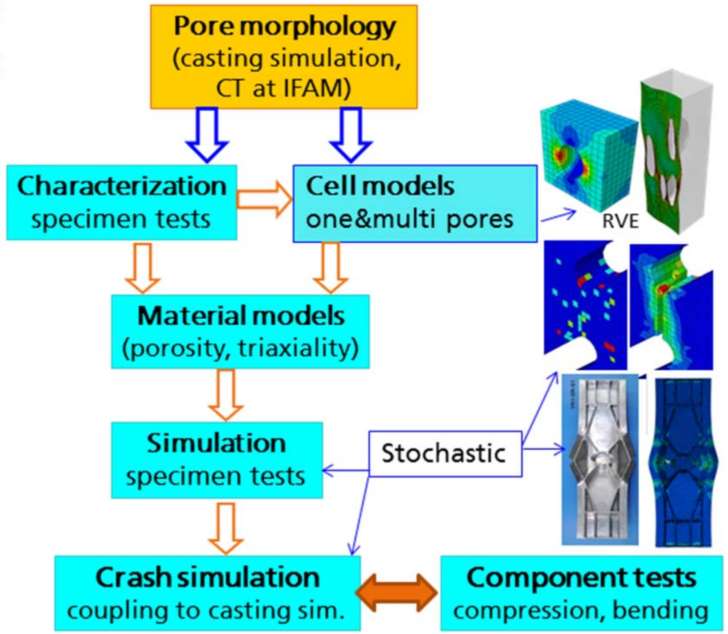
Introduction

- Inhomogeneous microstructure and porosity result in a large scatter of local properties in a casting component
- There are not reliable methods to predict damage behavior of cast components with stochastic aspect
- Coupling of casting simulation with crash simulation is a necessary step to solve the problem
- The approach used in this work:
  - characterization of influence of porosity and triaxiality
  - development of material models
  - modeling of influence of pore morphology at different loadings





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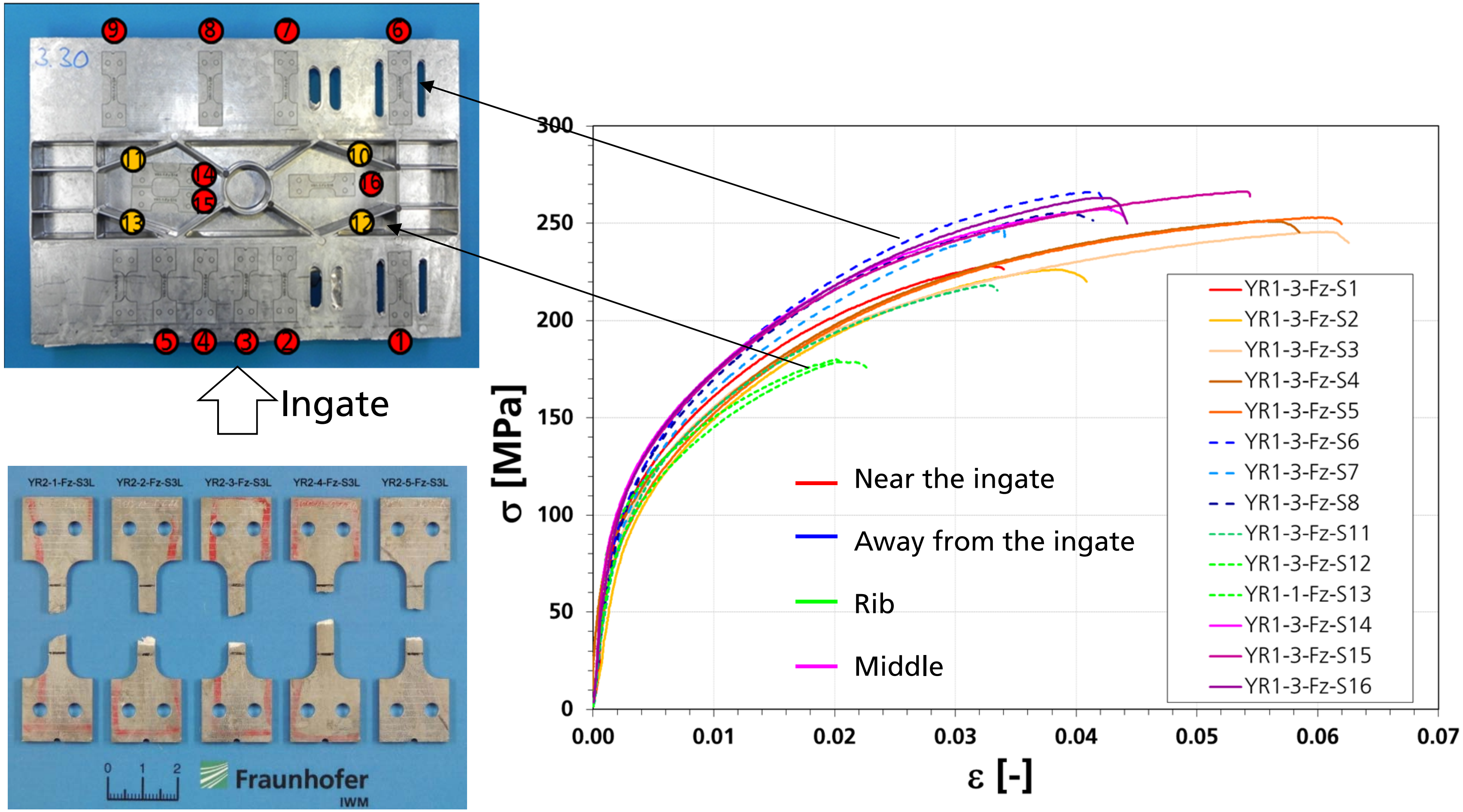
Engineering stress vs. strain curves for different positions
Aluminum die cast alloy Castasil®-37 (AlSi9Mn)



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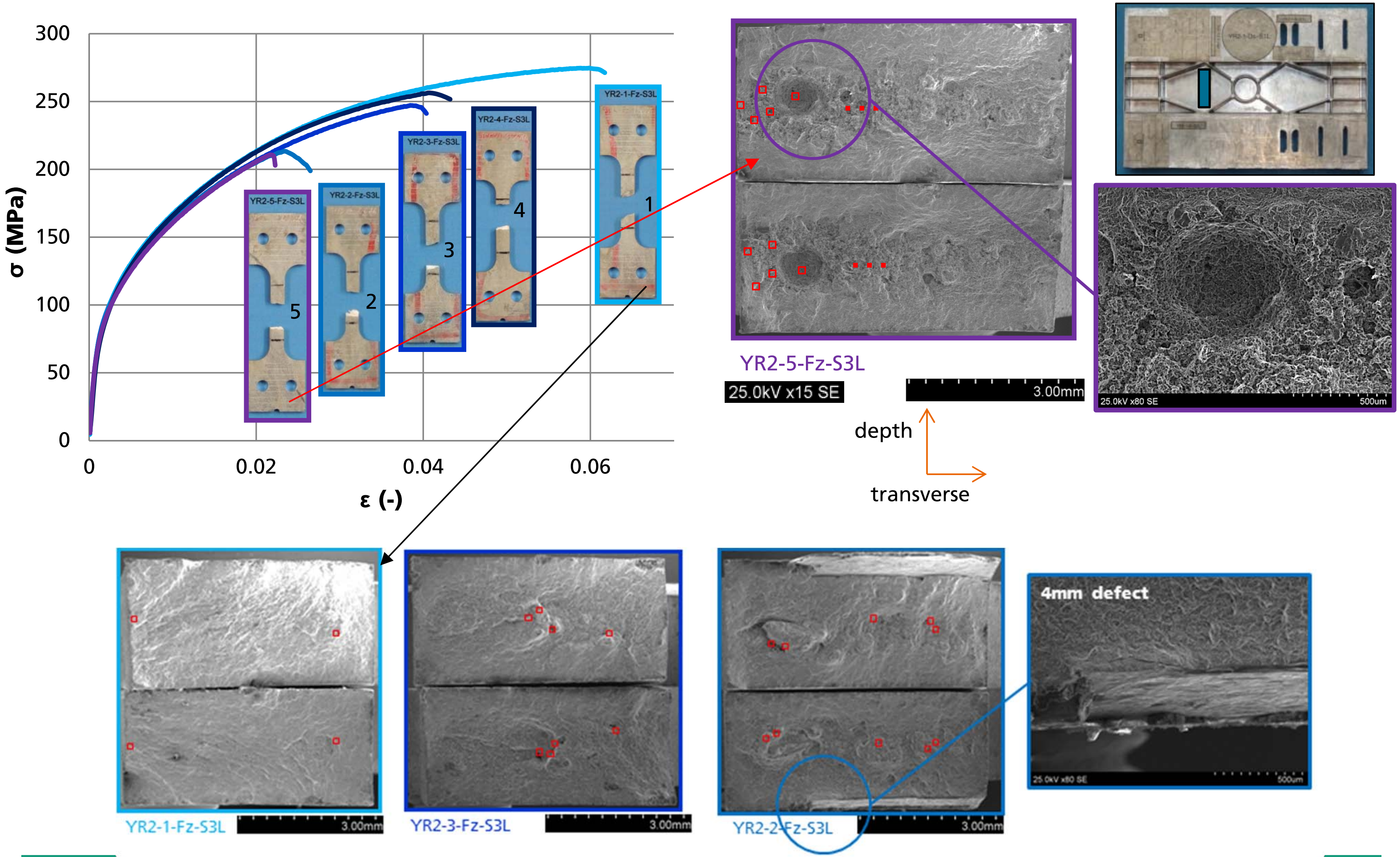
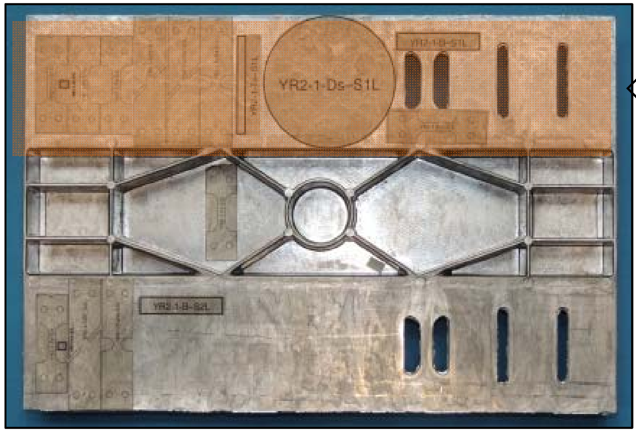
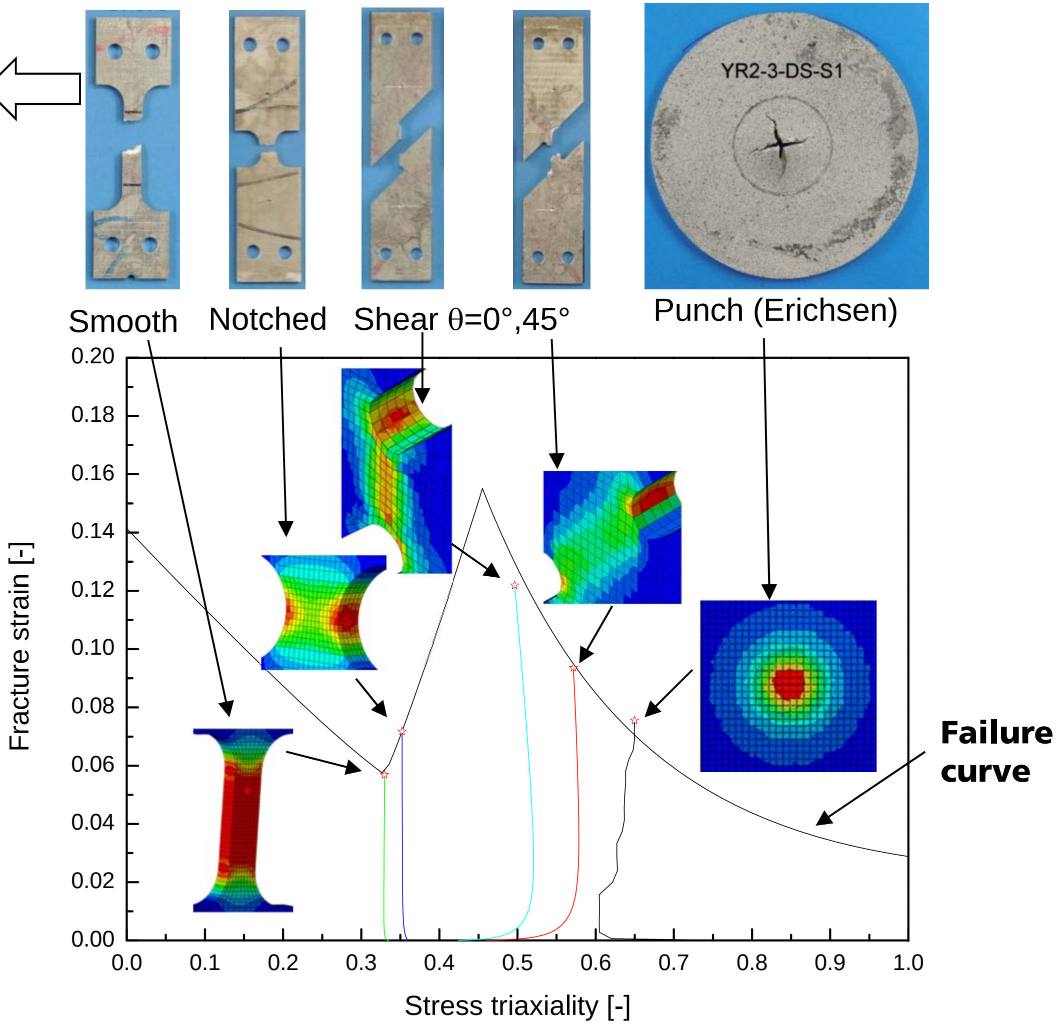
Porosity on fracture surfaces
Position 3



Characterization of influence of triaxiality
Position: Away from the ingate





- Loading paths (color lines) calculated by FE
- Failure strains (symbols) calculated by fitting experimental displacements at rupture

Cell model simulation

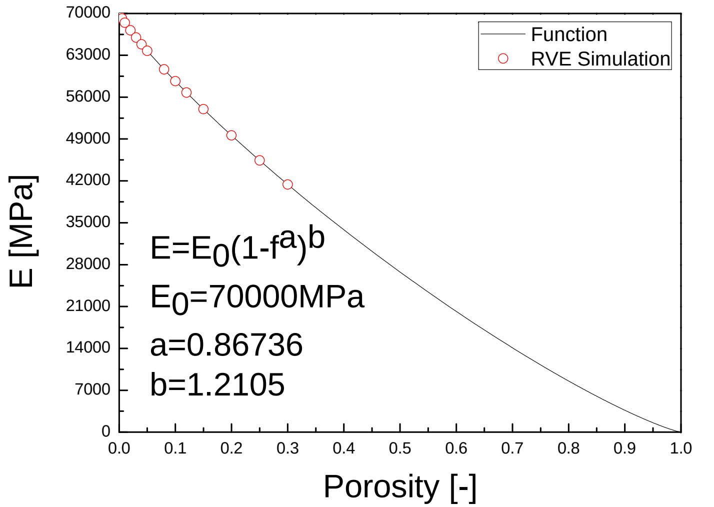
One pore in RVE

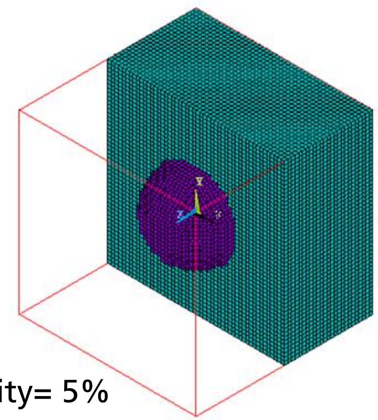
- RVE models:
    - Periodic boundary conditions
    - Controlling stress triaxiality
    - RVE size: 1mm*1mm*1mm

      Element edge length: 0.02mm

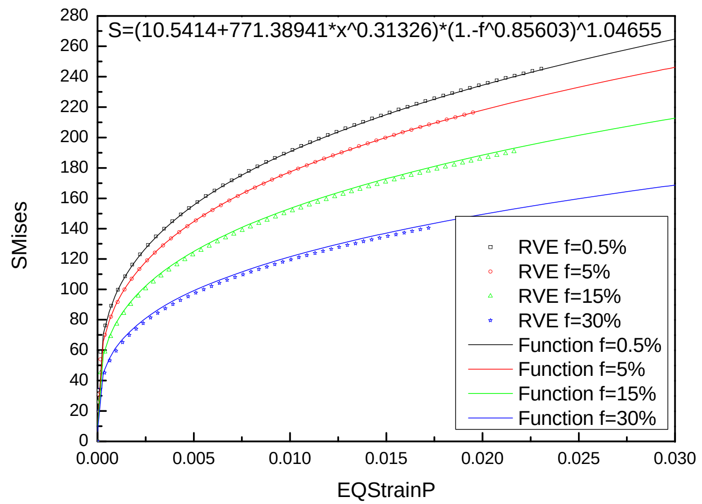
      Element number: 50*50*50
- Calculated relationships between
    - E, ν and porosity
    - σ_y and porosity
    - ε_f and porosity

      (matrix damage)





Porosity= 5%



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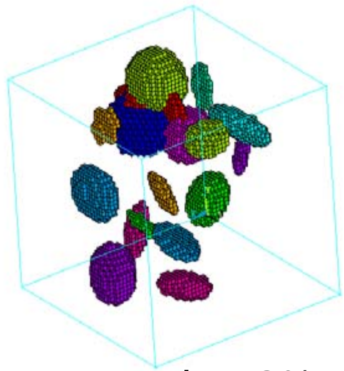
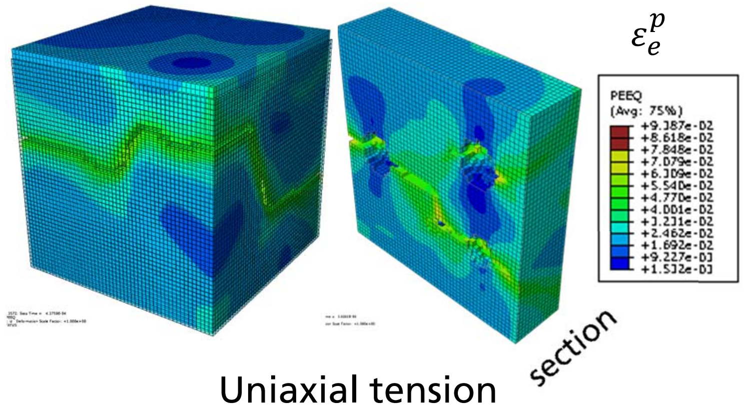
Cell model simulation
Multi pores in RVE

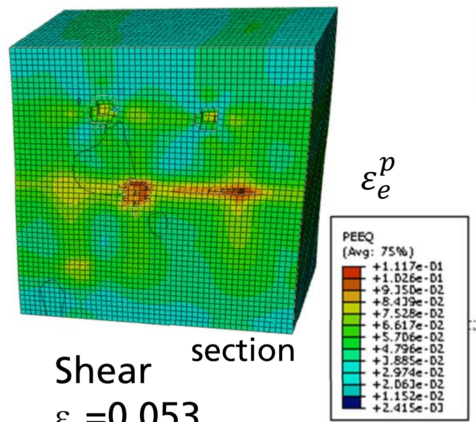
- RVE models:
  - Periodic boundary conditions
  - Controlling stress triaxiality
  - Damage criterion: triaxiality-dependent damage strains for matriax
- Calculated results about
  - effect of pore morphology on damage (ε_f)
  - Interaction between porosity and triaxiality concerning damage



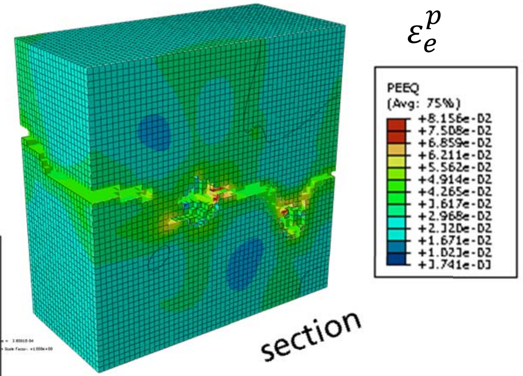
Porosity= 3%



Uniaxial tension
ε_e=0.034



Shear
ε_e=0.053



Biaxial tension
ε_e=0.035

Constitutive equations about porosity effects
Deformation and damage

- Elastic properties

$$\begin{cases} E = E_0(1 - f^{E_a})^{E_b} \\ \nu = \nu_0(1 - f^{\nu_a})^{\nu_b} \end{cases}$$

E_0 and ν_0: Young's modulus and Poisson's ratio of matrix
f: porosity
E_a, E_b, ν_a, ν_b: parameters

- Yield and hardening

$$\sigma_y = \sigma_{y_0}(1 - f^{s_a})^{s_b}$$

$$\sigma_{y_0} = A + B\left(\bar{\varepsilon}_m^{pl}\right)^n$$

σ_{y_0}: yield stress of matrix
$\bar{\varepsilon}_m^{pl}$: equivalent plastic strain of matrix
s_a, s_b, A, B, n: parameters

- Damage

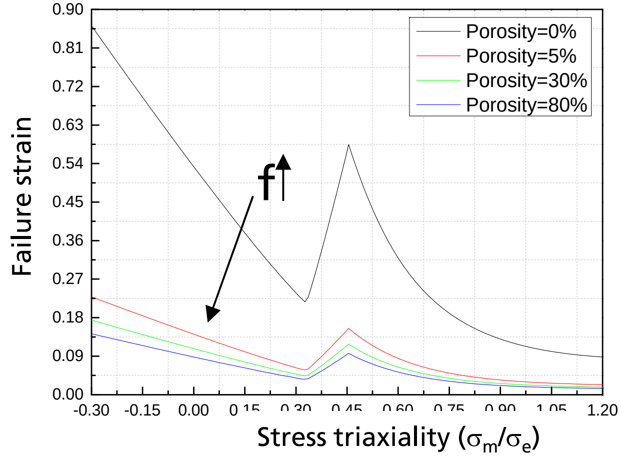
$$\bar{\varepsilon}_f^{pl} = (1 - F_a f^{F_b})^{F_c} \bar{\varepsilon}_{f\ 0}^{pl}$$

$\bar{\varepsilon}_{f\ 0}^{pl}$: failure strain of matrix
F_a, F_b, F_c: parameters

$$\bar{\varepsilon}_{f\ 0}^{pl} = d_{shear1} + d_{shear2}\left|\left(\frac{\sigma_m}{\sigma_e} - T_0\right)\right|^{m_2} + d_{shear3}\left\langle -\left(\frac{\sigma_m}{\sigma_e} - T_0\right)\right\rangle^{m_3}$$ for $1/3 \geq \sigma_m/\sigma_e - T_0 > -1/3$

$$\bar{\varepsilon}_{f\ 0}^{pl} = \left(d_1 + d_2 exp(-d_3 \frac{\sigma_m}{\sigma_e})\right)$$ for $\sigma_m/\sigma_e - T_0 \geq 1/3$

Damage curves: $\bar{\varepsilon}_f^{pl}(f, \sigma_m/\sigma_e)$



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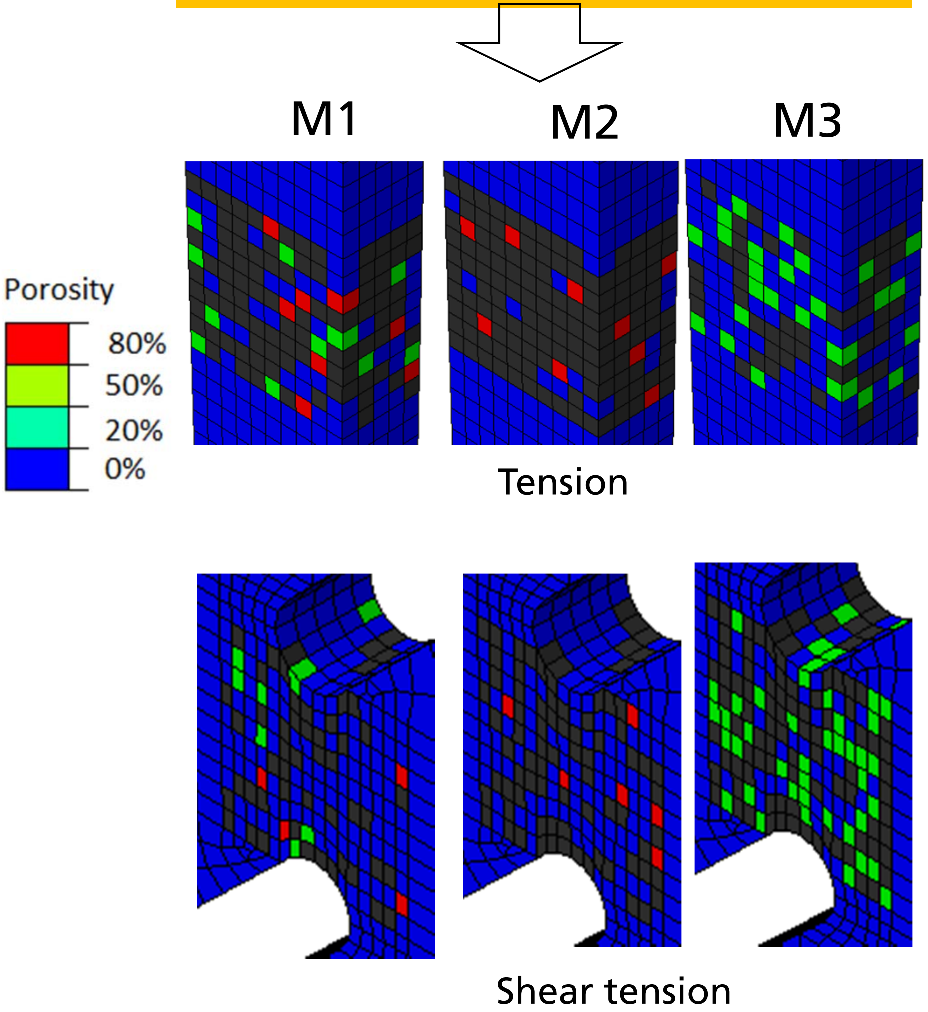
Modeling of different pore morphologies (f=5%)
under different loadings

- Three pore morphologies
  (840 elements in specimen center)
  - M1:
    30*80%+30*20%+600*2%+180*0%
  - M2: 50*80%+100*2%+690*0%
  - M3: 200*20%+100*2%+540*0%
  - Ref: Homogeneous pore distribution 840*5%
- Material model
  - User model
- Loading
  - Tension, compression
  - Shear tension (θ=0°, 45°)
  - Punch

Casting simulation (stochastic)



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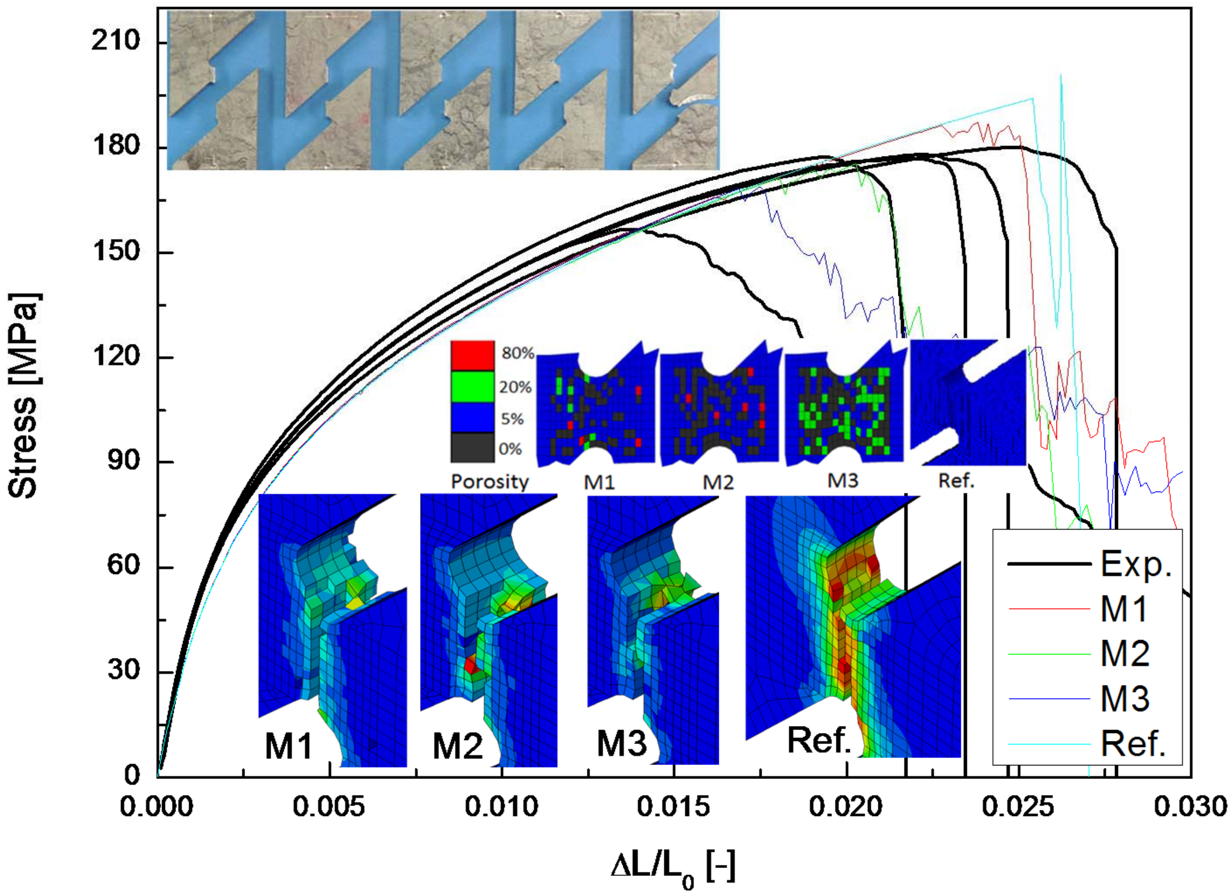
Modeling of effect of pore morphologies (f=5%)
under shear tension (θ=0)

- Simulation of 3+1 assumed pore morphologies
- Comparison with five shear tension tests
- Scatter in simulation is similar to that in experiment



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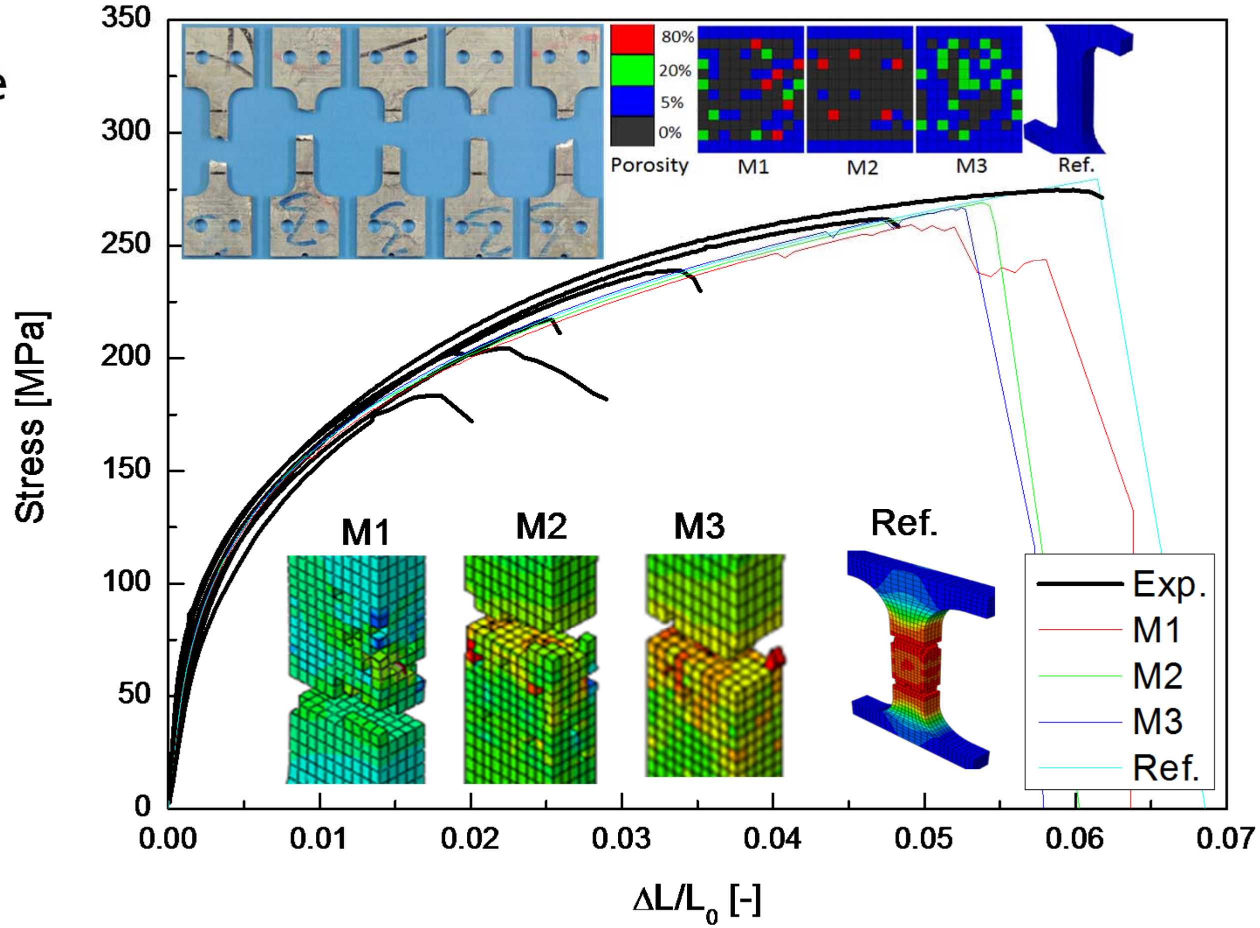
Modeling of effect of pore morphologies (f=5%)
under uniaxial tension

- Simulation of 3+1 assumed pore morphologies
- Comparison with five tension tests
- Scatter in simulation is smaller than in experiment
- Modeling of pore morphologies scanned by CT is necessary



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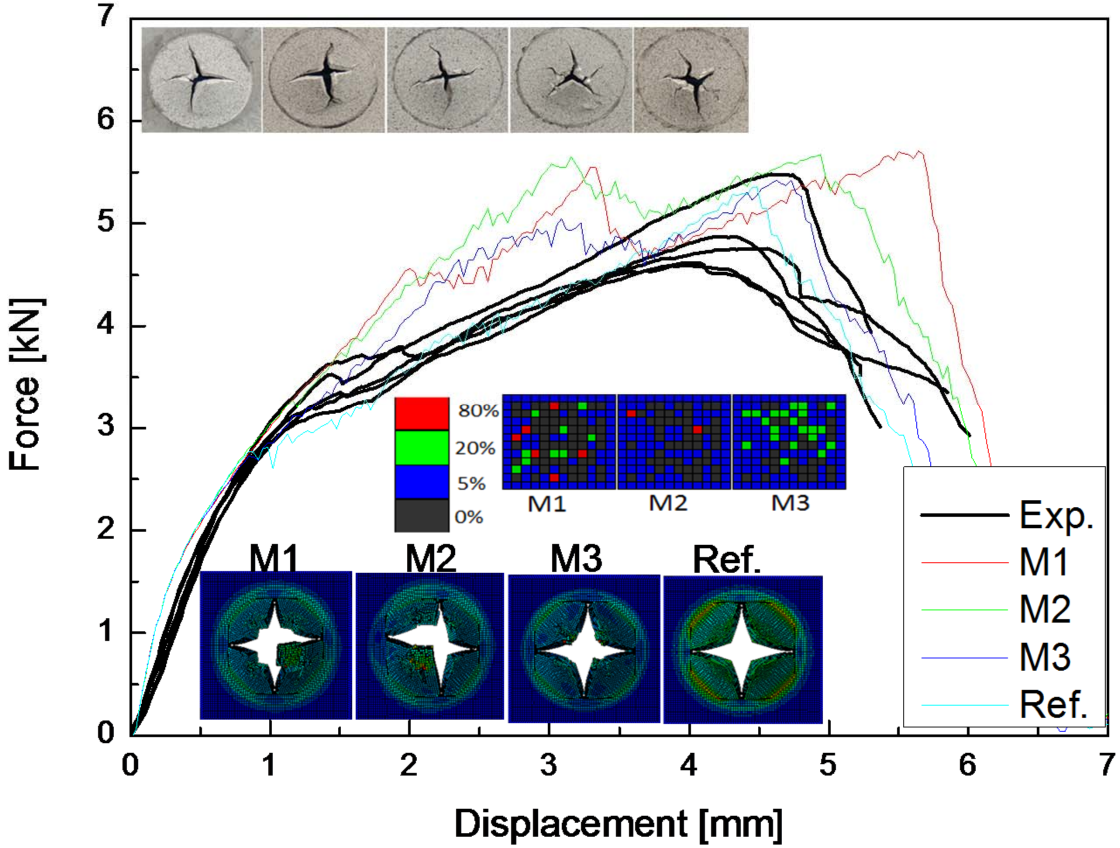
Modeling of effect of pore morphologies (f=5%)
under biaxial tension (punch tests)

- Simulation of 3+1 assumed pore morphologies
- Comparison with five punch tests
- Scatter in simulation is similar to that in experiment



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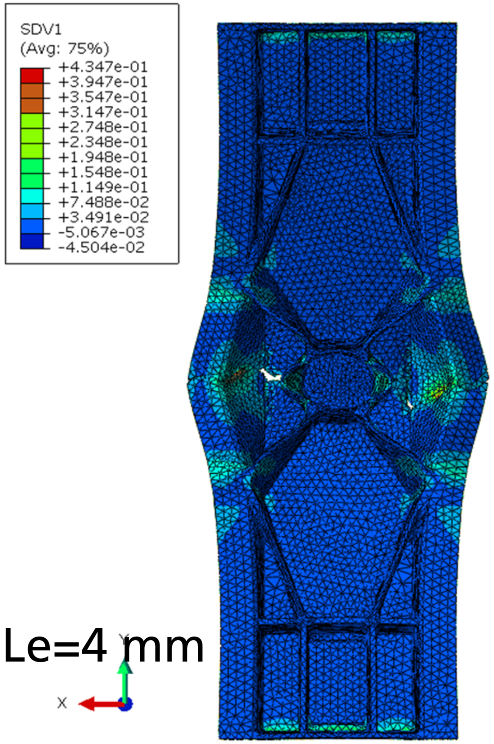
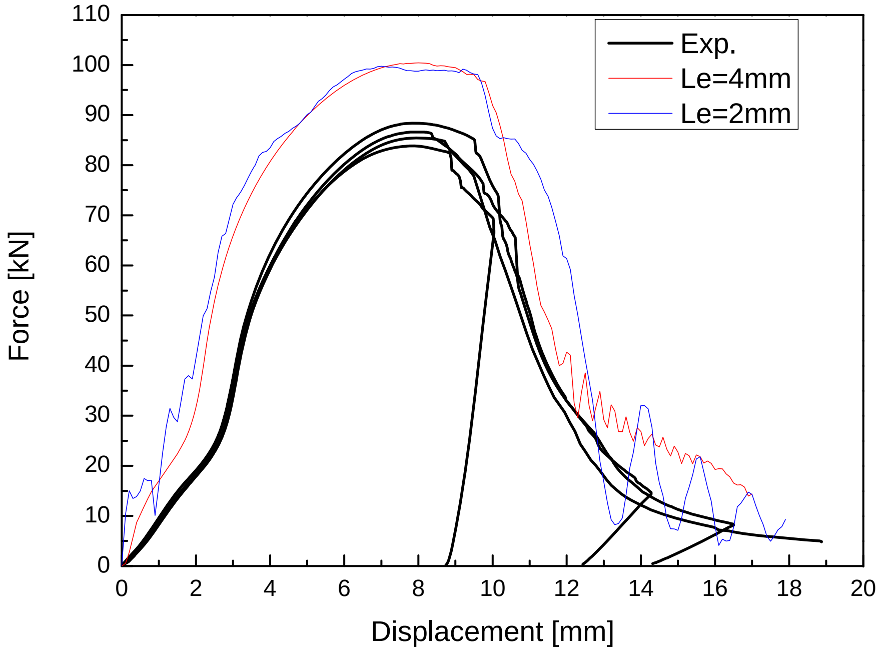
Compression tests on Y-box and simulation

- Static compression tests
- Simulation with homogeneous porosity of 5%
- Simulation with inhomogeneous porosity in near future





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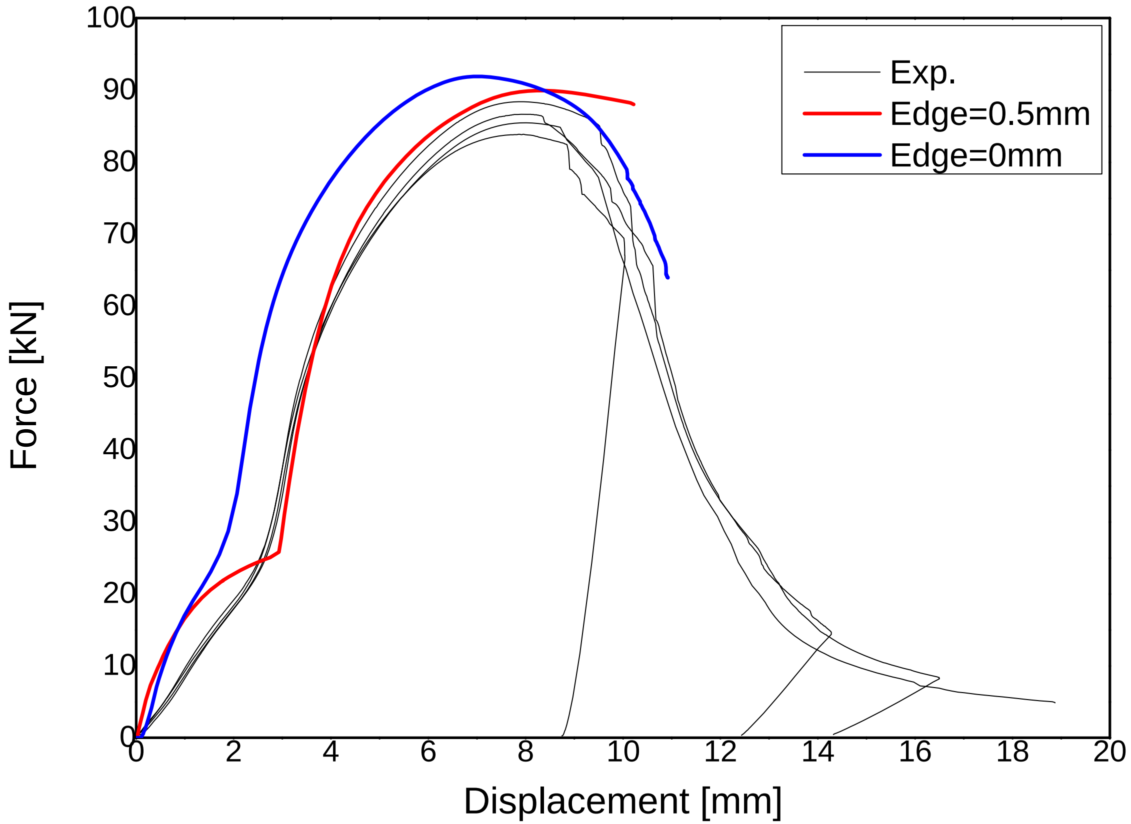
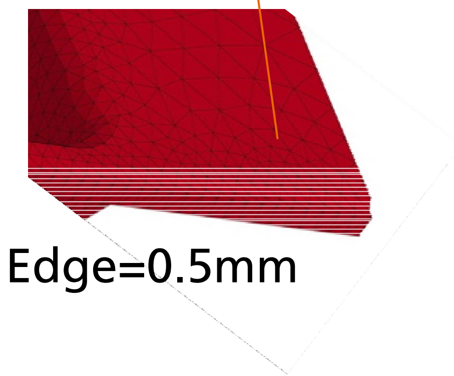
Compression tests on Y-box and simulation

- Geometry difference
- Stress vs. strain curve from compression test





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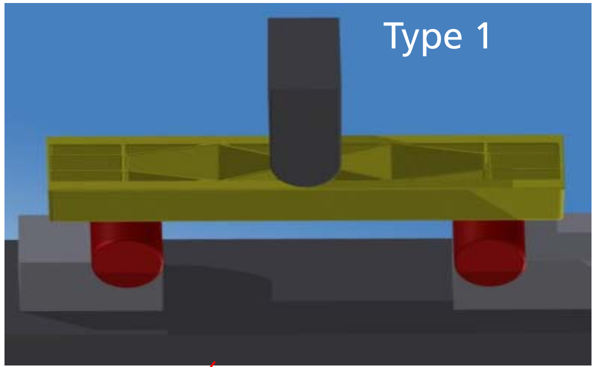
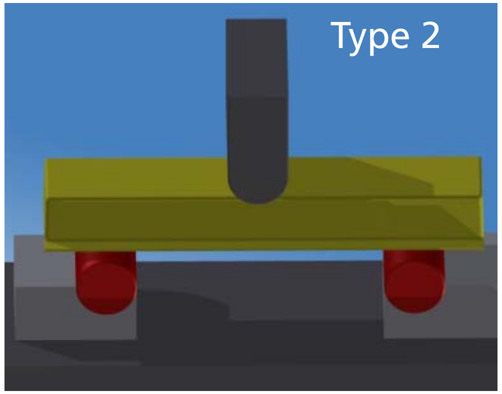
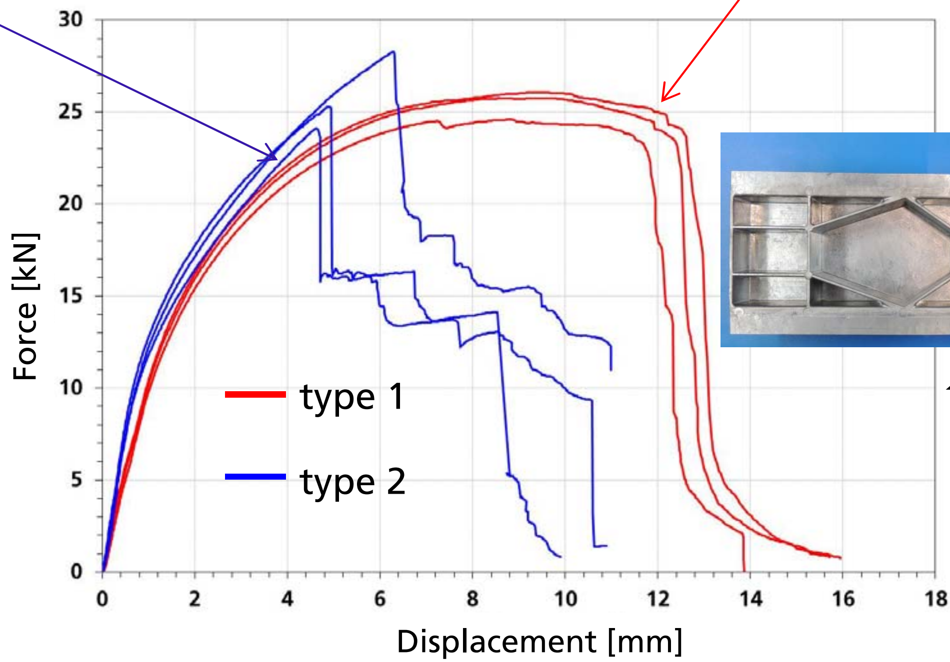
Two types of bending tests on Y-box
Static loading

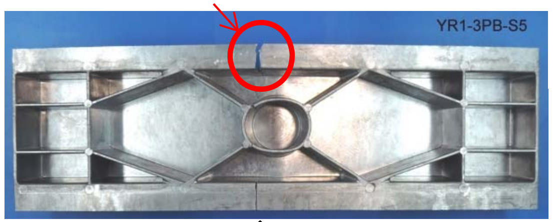
- Damage begins always at the side "away from ingate"





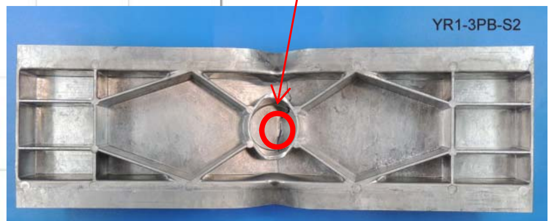


First crack



Ingate

First crack



Ingate

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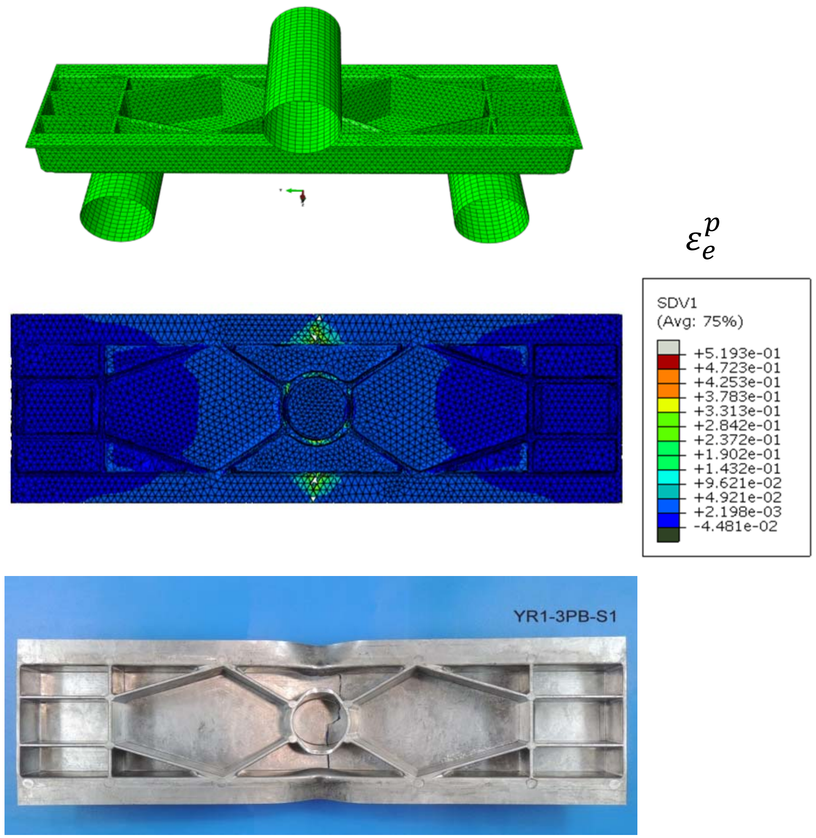
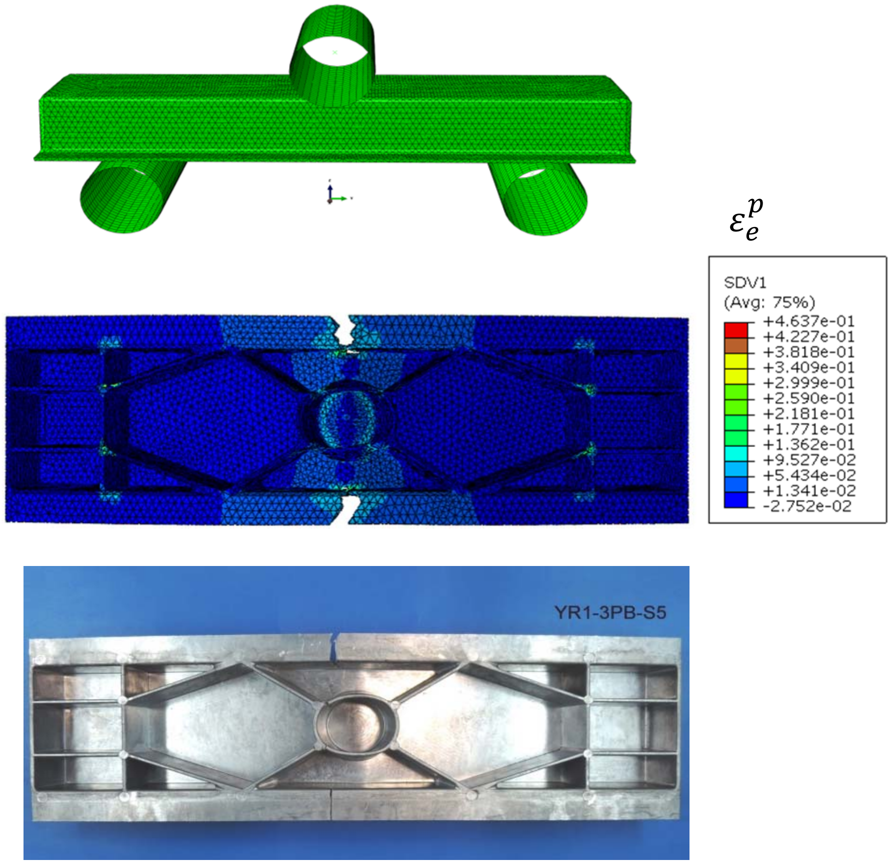
Simulation of bending tests on Y-Box

Two test set ups





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Conclusions

- The deformation and damage behavior of the casting component Y-Box from the aluminum alloy AlSi9Mn was characterized under different loading situations. A large scatter of the mechanical properties was determined.
- To investigate the influence of pore morphology on the material properties damage modeling was performed with three methods e.g. RVE with a single pore and multiple pores and continuum mechanical simulations.
- Material models were derived and calibrated based on the RVE calculations. The scatter of the material data can be predicted by using the approach of the continuum mechanical simulation applied in this work.
- The real distribution of porosity in the component will be determined by casting simulation and CT-measurement. The damage modeling will be repeated using the date for real pore morphology.

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