Multi Scale Mechanics

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Materials with microstructure:

Interacting phases on multiple scales

Holger Steeb

UTwente, 22 September 2008

h.steeb@utwente.nl

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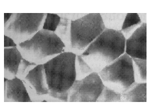
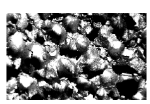
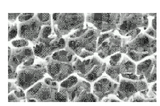
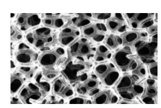
porous solids with microstructure





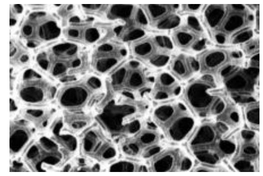




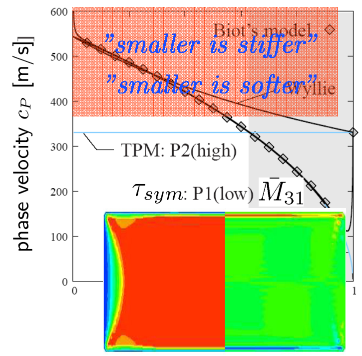
Solids with microstructure

- **cellular materials**
  - ∗ polymer & metal foams
  - ∗ biological tissues
    (hard tissues: bones, e. g. spongiosa)
- **mechanical response**
  - ∗ boundary layer effects
    under shear, tension & bending
  - ∗ size effects
- **acoustic behaviour**
  - ∗ viscous vs. scattering attenuation
  - ∗ dispersion & higher order waves modes

standard Boltzmann-continua are not suitable



polymer foam



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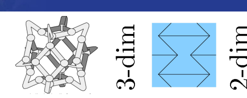
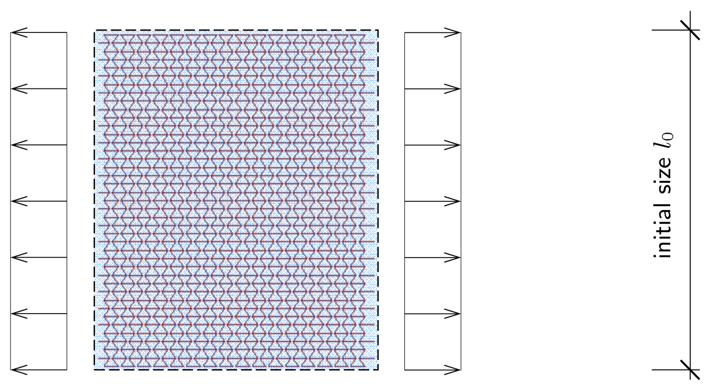
- foams: re-entrant foam





LAKES [1987, 1993]

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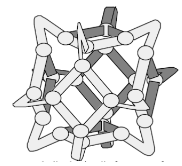

- foams: re-entrant foam
- **mechanical & acoustical behaviour:**
  - large deformations?
  - low vs. high frequency range?
  - coupling with pore fluid - multiphase problem:
    analogy trabecular bones

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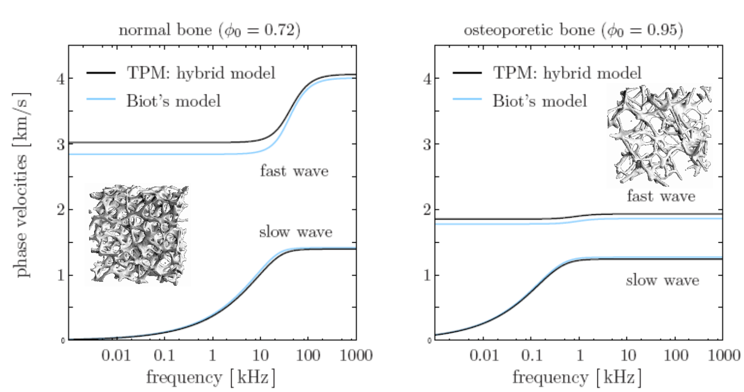
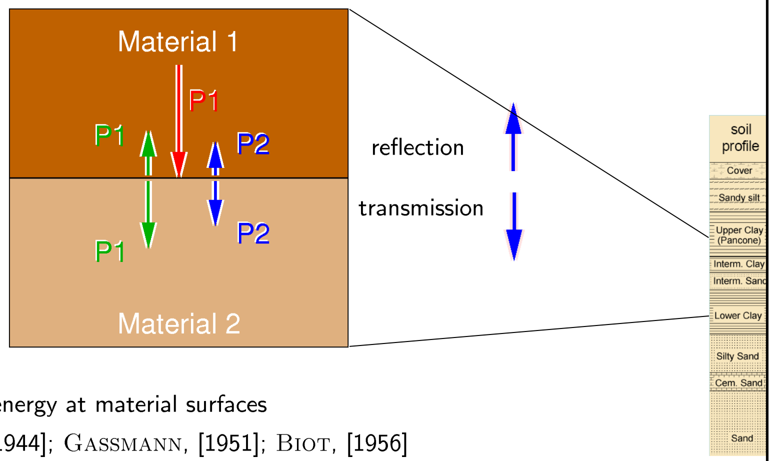
- **trabecular bone - dispersion relation**
  material parameters: GIBSON [1985]



STEEB [2007]

- fully-saturated binary mixture



⇝ transfer of energy at material surfaces

Frenkel, [1944]; Gassmann, [1951]; Biot, [1956]

motivation – slow compressional wave
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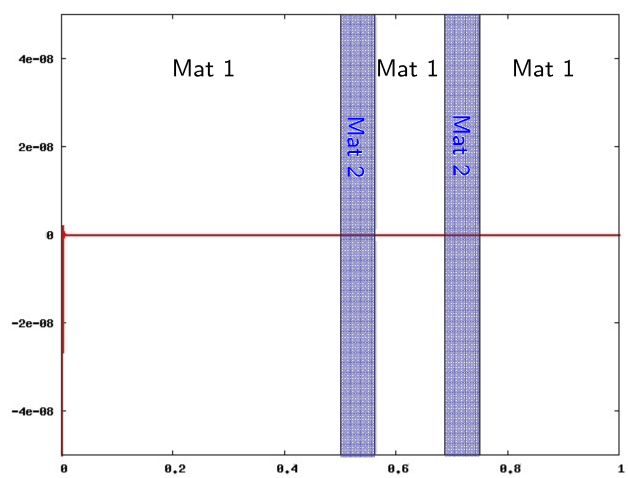
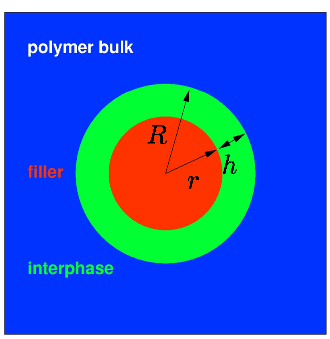


solids with microstructure: (nano-)composites

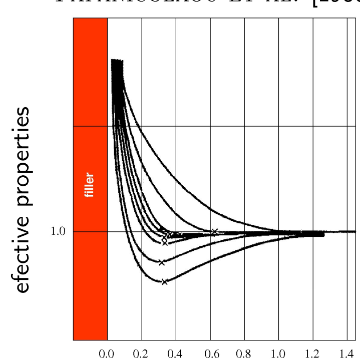
size effects in (nano-)filled polymers

- size effect: smaller is stiffer



unit cell (REV) $\mathcal{R}$

PAPANICOLAOU ET AL. [1980]



filler distance l

- modeling of interphases on continuum scale: concept of order parameters

- **extended model – multi scale continuum mechanics**
  - ∗ balance equations

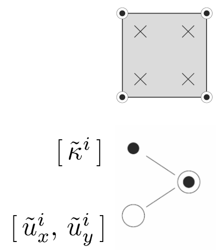
$$\operatorname{div} \mathbf{T} = \mathbf{0}, \qquad \operatorname{div} \mathbf{S} + \hat{\kappa} = 0,$$

  - ∗ hyperelasticity (extended Neo-Hookean)

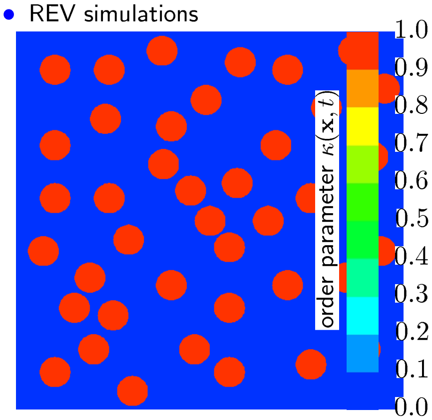
$$\begin{aligned} \mathbf{T} &= -p\,\mathbf{I} + [(1-\kappa)\,\mu_B + \kappa\,\mu_I]\,\mathbf{B}, \\ \mathbf{S} &= \beta \operatorname{grad} \kappa, \\ -\hat{\kappa} &= \alpha\,\kappa + \tfrac{1}{2}\,(\mu_I - \mu_B)\,(\mathrm{I}_{\mathbf{B}} - 3)\,. \end{aligned}$$

  - ∗ weak form – FEM for 2 fields $\{\mathbf{u}, \kappa\}$

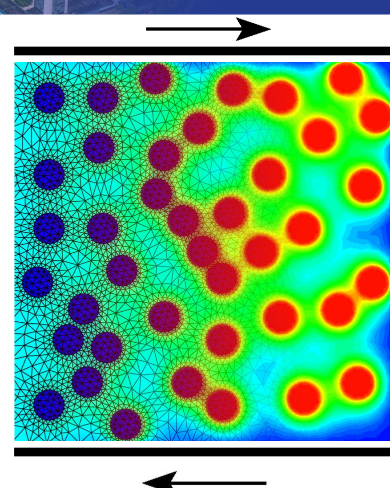
$$\begin{aligned} \int_{\mathcal{B}} \mathbf{T} : \operatorname{grad} \delta\mathbf{u}\, \mathrm{d}v &= \int_{\partial\mathcal{B}} \bar{\mathbf{t}} \cdot \delta\mathbf{u}\, \mathrm{d}a \\ \int_{\mathcal{B}} \mathbf{S} \cdot \operatorname{grad} \delta\kappa\, \mathrm{d}v &= \int_{\partial\mathcal{B}} \bar{s}\, \delta\kappa\, \mathrm{d}a \int_{\mathcal{B}} \hat{\kappa}\, \delta\kappa\, \mathrm{d}v \end{aligned}$$



- REV simulations



carbon black-filled polymer



- details: Steeb & Diebels, *Int. J. Solids Struct.*, **41**, (2004) 5071–5085
  Johlitz et al., *J. Phys. Conf. Ser.*, **62**, (2007) 34–42
  Johlitz et al., *J. Mat. Sci.*, (2008) in press, *Gamm Mitt.*, (2008) subm.

size effects in (nano-)filled polymers

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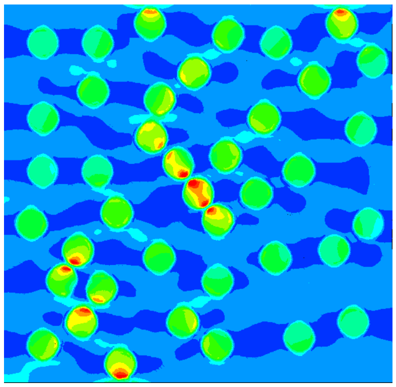
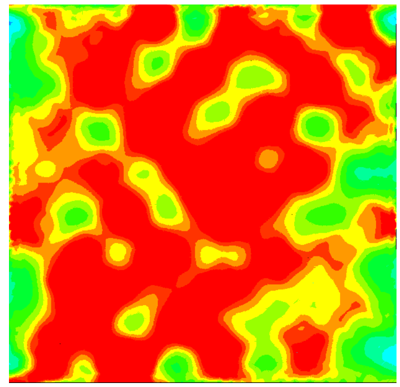
- REV simulations (simple shear, uniaxial tension, . . .)

shear stresses T_{12}



standard one-phase model

shear stresses T_{12}



extended model incl. order parameter

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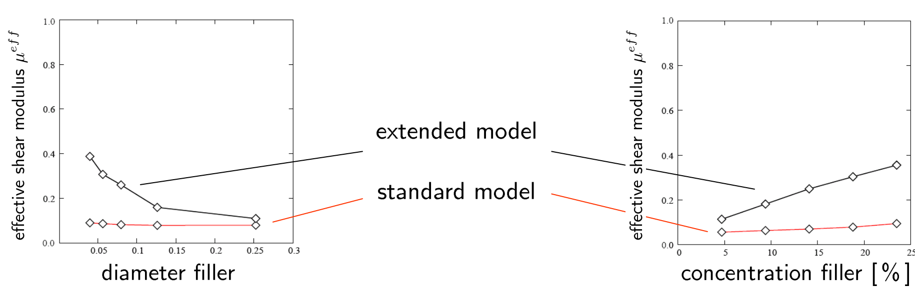
- **standard model:** effective properties depending on volume fraction
- **extended model:** additional dependency on specific surface of filler

volume fraction of filler = const.

diameter of filler = const.



experimental validation: size effects in polymer bonds

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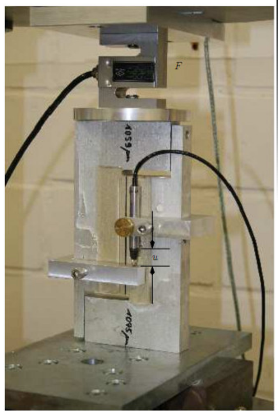
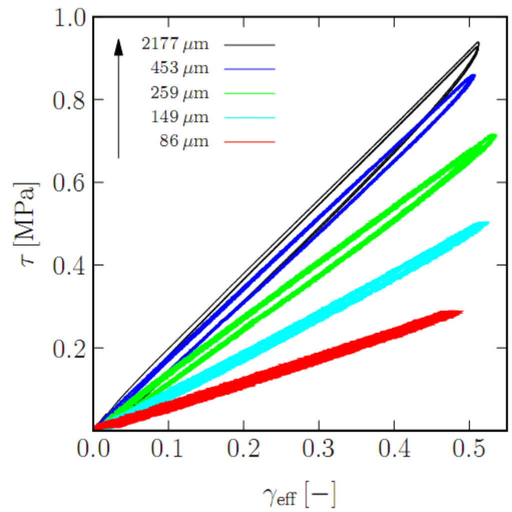
- size effects in polymer bonds

"smaller is softer"



shear experiments



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size effects in polymer bonds

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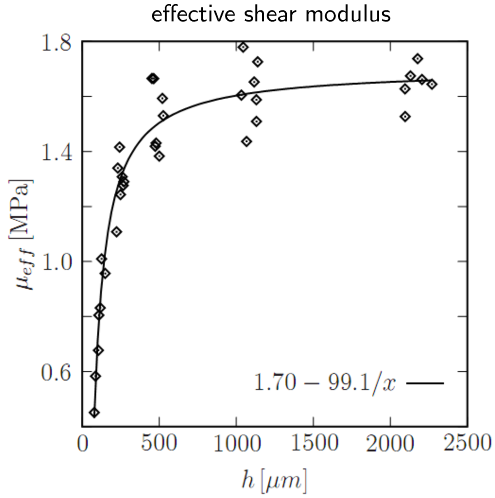
effective shear modulus



Johlitz et al., *J. Mat. Sci.*, **43**, (2008) 4768–4779, *Tech. Mech.*, **28**, (2008) 3–12

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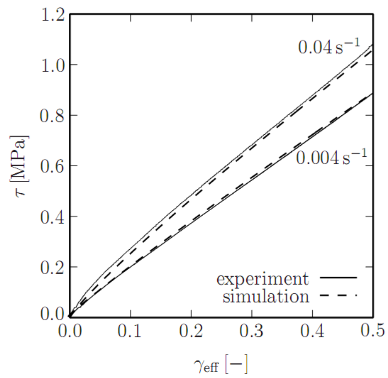
size effects in polymer bonds

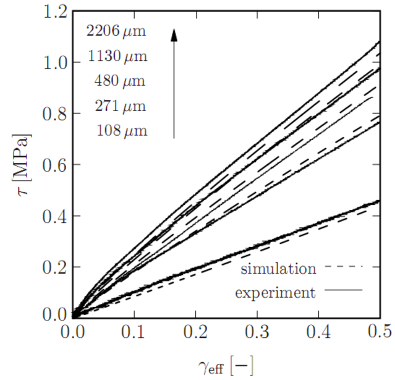
- rate dependency - viscoelasticity

thickness: 2206 μm



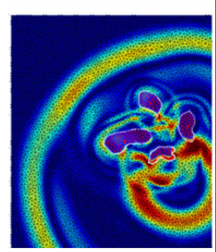
bulk behaviour

shear rate: 0.04 s^{-1}



further activities

- **continuum-based modeling**
  - ∗ artificial materials (tunable devices, nano-composites, cellular materials)
  - ∗ modeling of complex processes
  - ∗ porous materials (geothermal energy, seismic, phase transition)
- **numerical methods**
  - ∗ space-time Galerkin FEM
  - ∗ multi-scale methods (numerical homogenization, FE^2)
  - ∗ multi-phase problems
- **experminetal investigations**
  - ∗ parameter identification of microstructured materials
  - ∗ multi-axial experiments with entropy-elastic materials



fluid-saturated porous rock
scattering fast and slow P-waves