University of Twente

Multi Scale Mechanics

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University of Twente
The Netherlands

University of Twente
The Netherlands

Contents

- Introduction MSM
- Particle systems
- Some Examples
- Outlook

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MSM people 2005 (a day in Twente)

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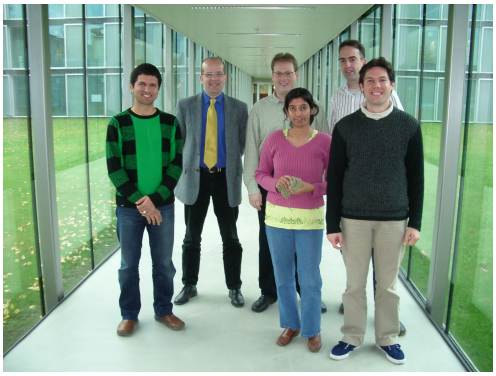
MSM people 2007



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MSM running PhD/PostDoc projects

Long range forces (DCSE+FOM)

Sound propagation (Shell/FOM)

Creep under cyclic loading (FOM)

Nano/Micro-Fluidics and Bio-Flows (μ–Ned)

Self-Healing materials (DCMat)

…

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MSM new PhD/PostDoc projects

Long range forces (DCSE+FOM)

Jamming soft matter program (FOM)

Hierarchical Multi Scale Modeling (STW)

Cont. Theory for Granular Flow (IMPACT, UT)

…

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MSM Industry contacts

Sound propagation (Shell, NL)

Sandstone+fluids (SINTEF, NO)

Particle Systems (DOW, BASF, Unilever)

Consulting (CeParTec, EDEM)

…

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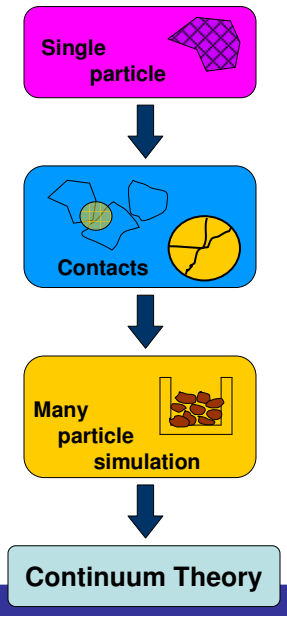
Contents

- Introduction
- Contact Models
- DEM/MD simulations
- Towards Continuum Theory
- Outlook



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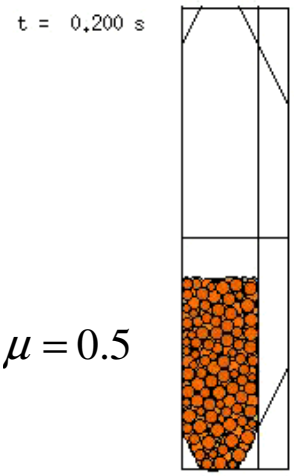
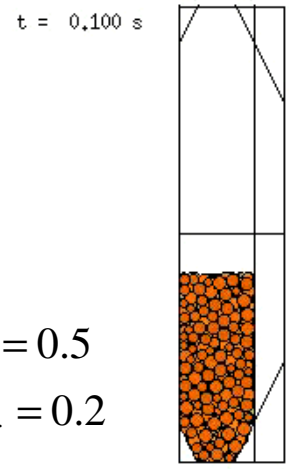
Silo Flow with friction



$\mu = 0.5$



$\mu = 0.5$

$\mu_r = 0.2$

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Impact
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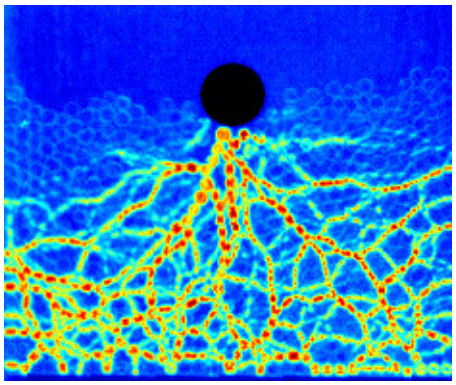
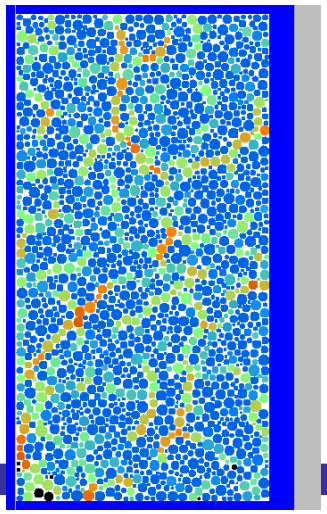
Force-chains
experiments - simulations





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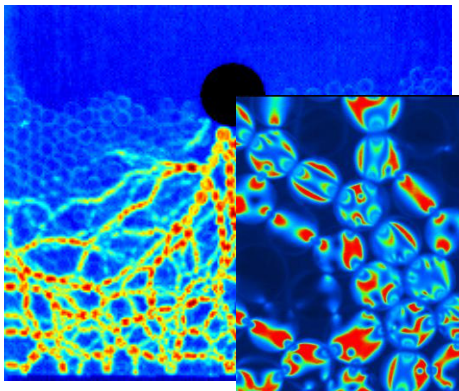
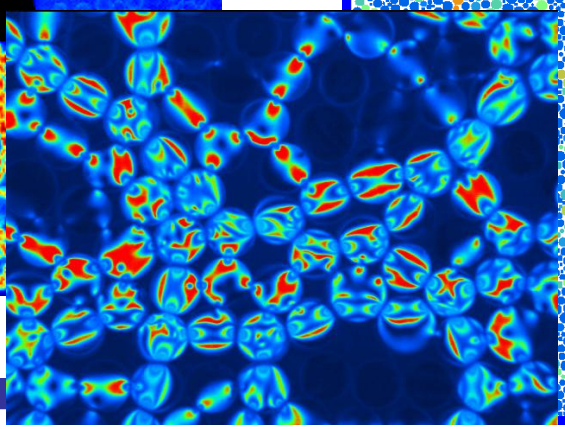
Force-chains
experiments - simulations





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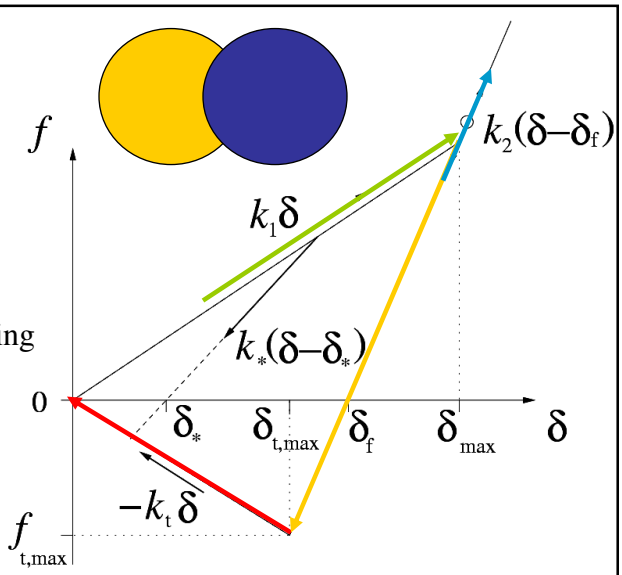
Contacts

1. loading
transition to stiffness: k_2

2. unloading

3. re-loading
elastic un/re-loading stiffness: k_2

4. tensile failure
max. tensile force



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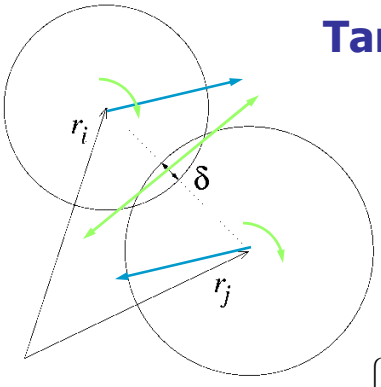

Tangential contact model

***Sliding* contact points:**
- static Coulomb friction
- dynamic Coulomb friction
- objectivity
Sliding/Rolling/Torsion

$$v_t = \begin{cases} \left(v_i - v_j\right)^t + \hat{n}\times\left(a_i\omega_i + a_j\omega_j\right) & \text{sliding} \\ a_{ij}\hat{n}\times\left(\omega_i - \omega_j\right) & \text{rolling} \\ a_{ij}\hat{n}\hat{n}\cdot\left(\omega_i - \omega_j\right) & \text{torsion} \end{cases}$$

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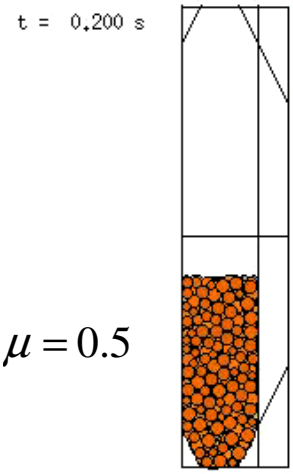
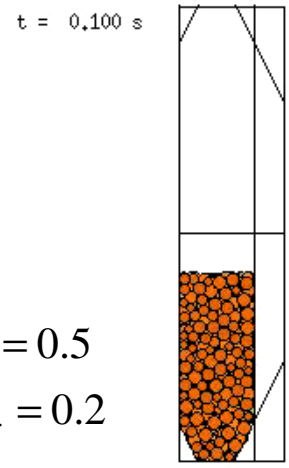
Silo Flow with friction



$\mu = 0.5$



$\mu = 0.5$

$\mu_r = 0.2$

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Biaxial box set-up

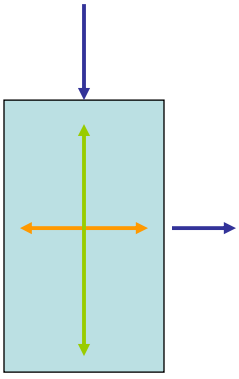
- Top wall: strain controlled

$$z(t) = z_f + \frac{z_0 - z_f}{2}(1 + \cos \omega t)$$

- Right wall: stress controlled

$$p = \text{const.}$$

- Evolution with time … ?



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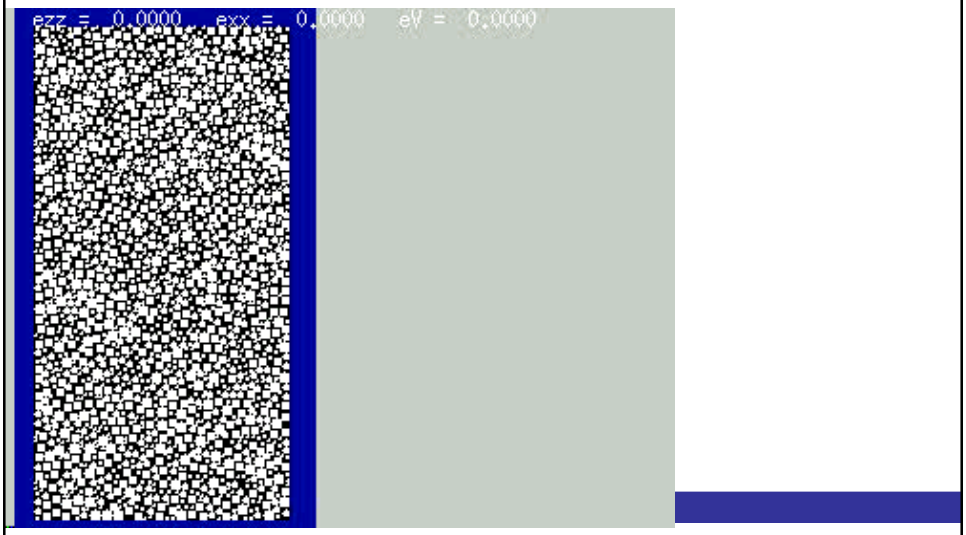
Bi-axial box (stress chains)



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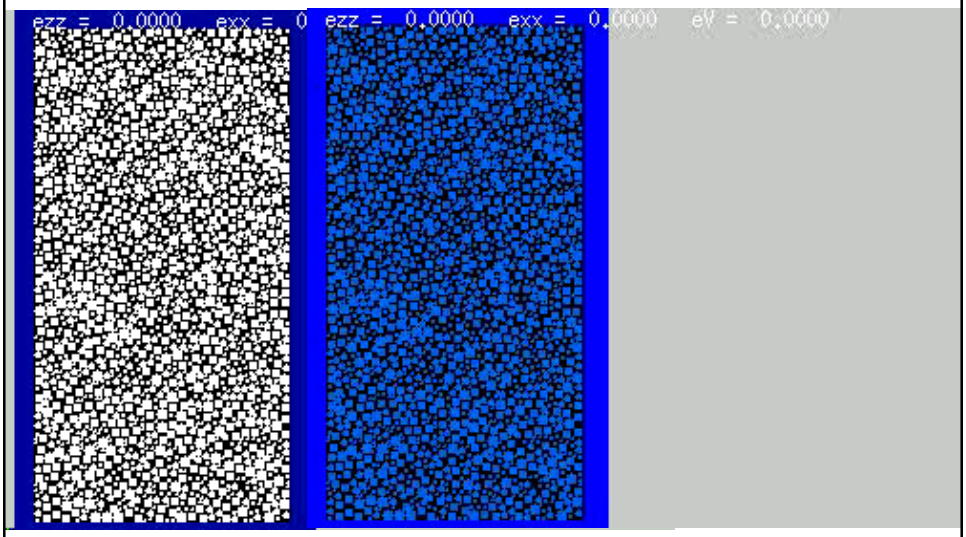
Bi-axial box (kinetic energy)



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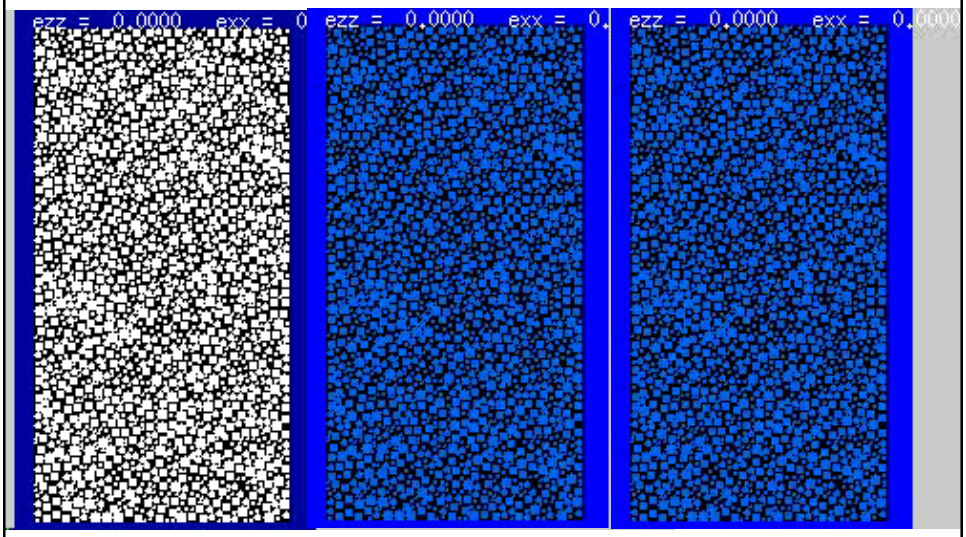
Bi-axial box (rotations)



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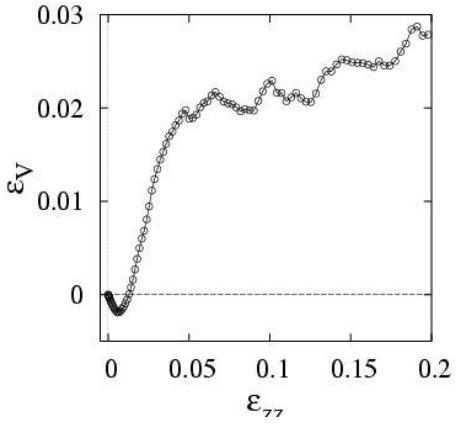
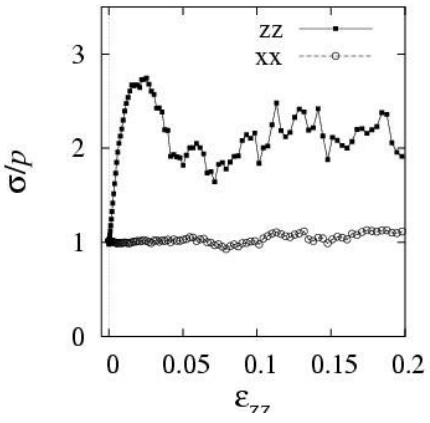
Bi-axial compression with p_x=const.





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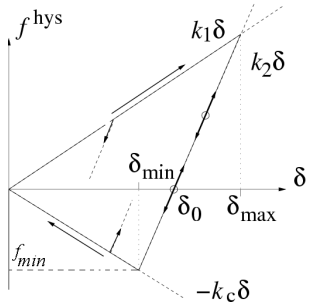
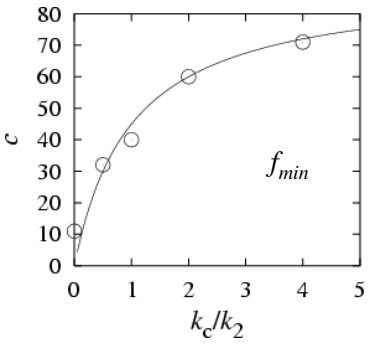
Micro-macro for cohesion



$k_c / k_2 = 0, 1/2, 1, 2, \text{and } 4$



micro adhesion: f_{min} macro cohesion $c = c_0 \dfrac{1-k_1/k_2}{1+k_2/k_c}$

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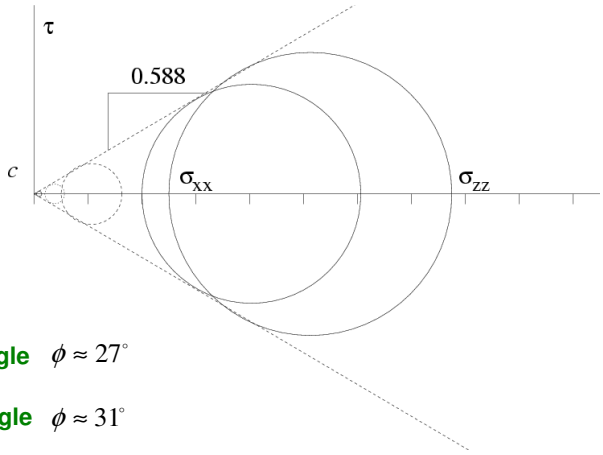
Friction – no cohesion

k_c = 0 and μ = 0.5



Internal friction angle $\phi \approx 27^\circ$

Total friction angle $\phi \approx 31^\circ$

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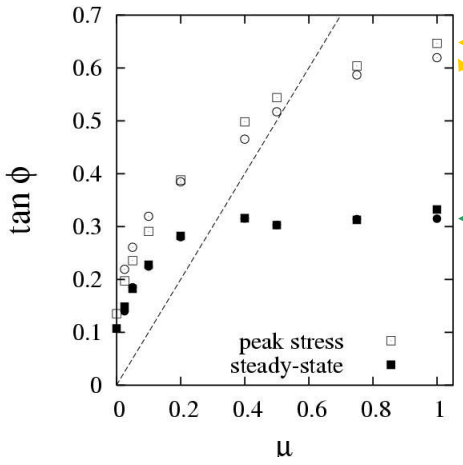
Micro-macro for friction



prepared μ=0

prepared μ=0.5

steady-state shear

micro contact-friction μ macro friction-angle ϕ

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Summary micro-macro GLOBAL

- Micro-/Macro-Flow Rheology
  - micro-adhesion … macro-cohesion
  - micro-contact-friction … macro-friction-angle
- Non-Newtonian Rheology (Anisotropy?, Micro-polar?)
- Towards solid materials

- **Does global averaging make sense anyway?**

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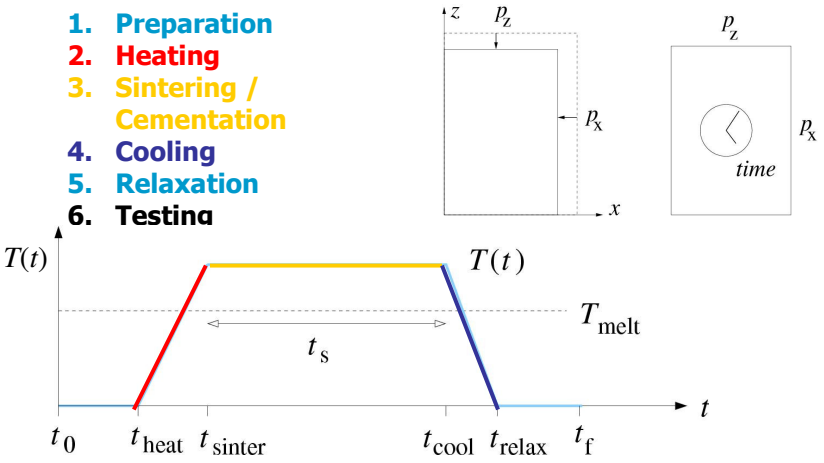
Sintering / Cementation (2D)

1. **Preparation**
2. **Heating**
3. **Sintering / Cementation**
4. **Cooling**
5. **Relaxation**
6. **Testing**



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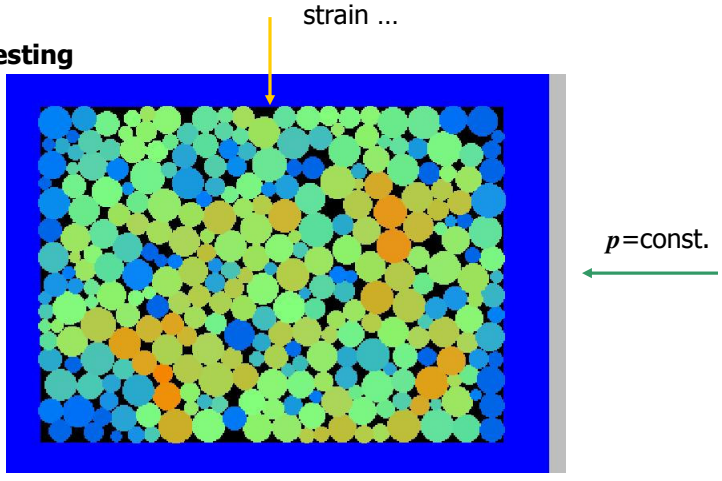
Sintering / Cementation

6. **Testing**



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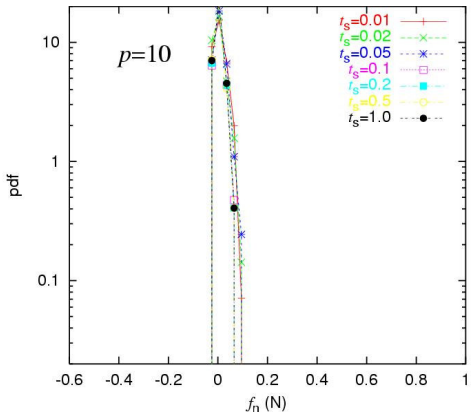
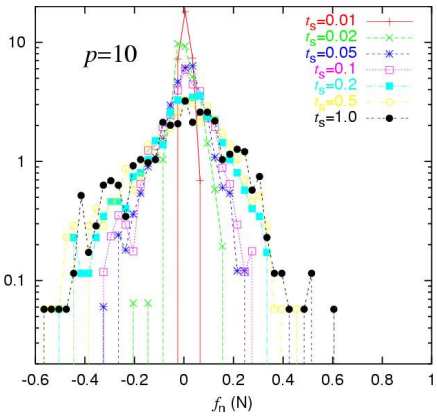
Contact forces

after Sintering



after Relaxation



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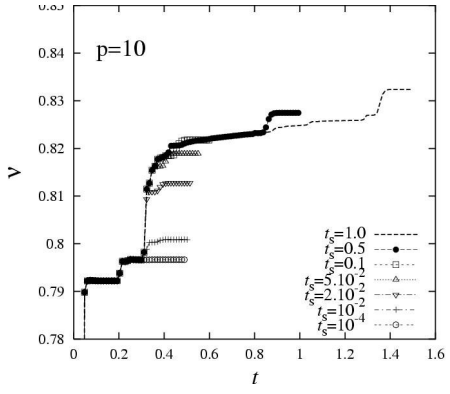
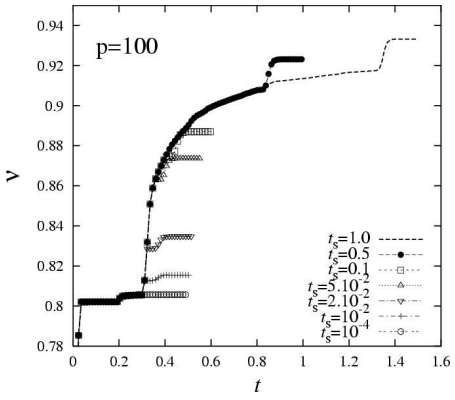
Sintering / Cementation

Density – Shrinkage!





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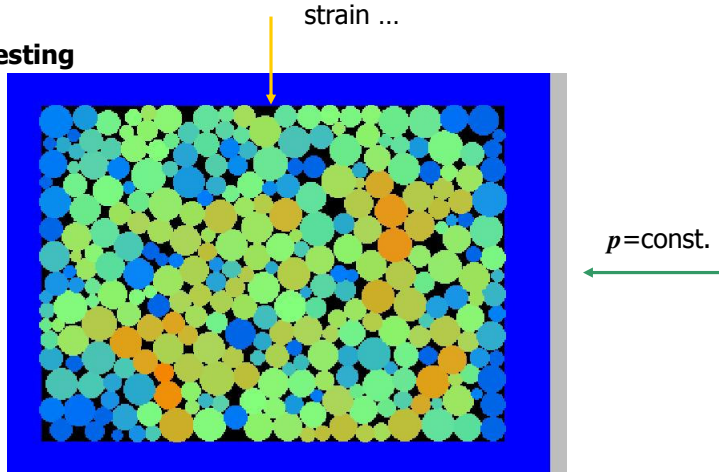
Sintering / Cementation

6. **Testing**



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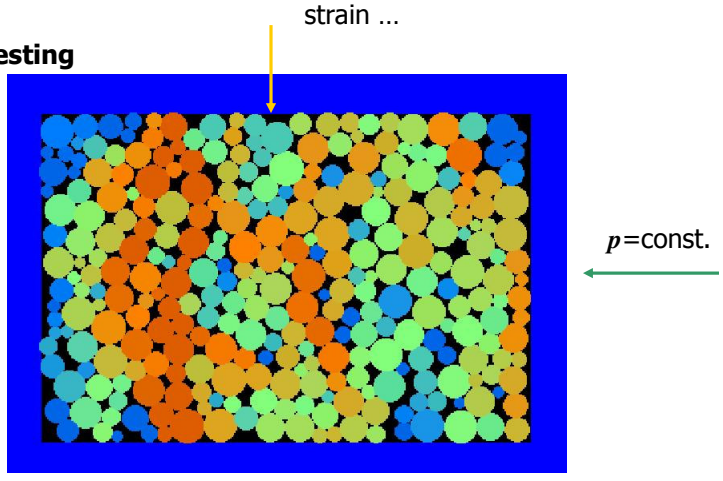
Sintering / Cementation

6. **Testing**



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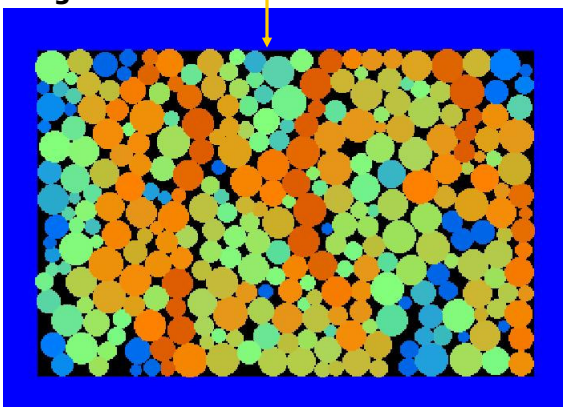
Sintering / Cementation

6. **Testing**

strain ...



p=const.

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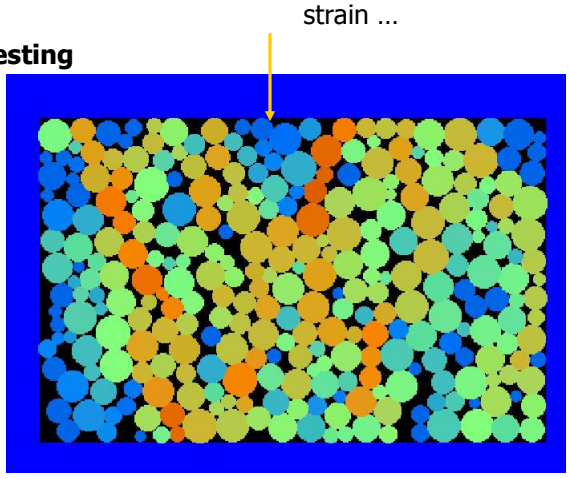
Sintering / Cementation

6. **Testing**

strain ...

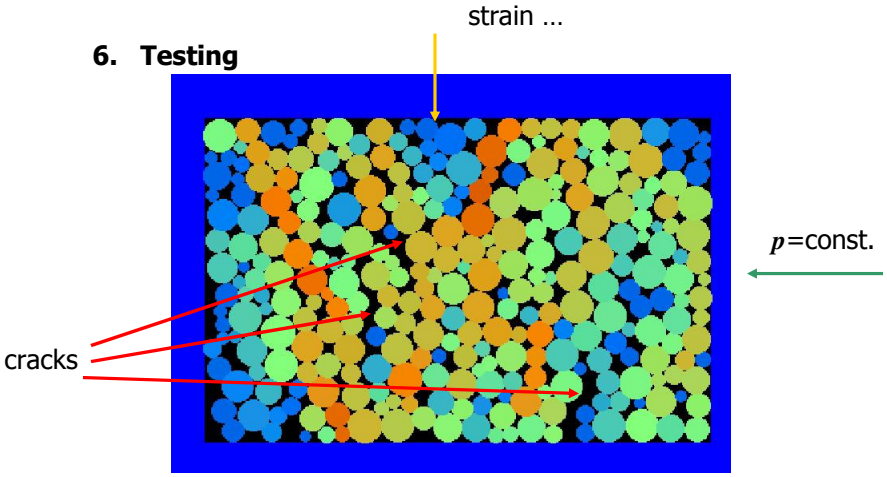


p=const.

msm

Sintering / Cementation

6. Testing



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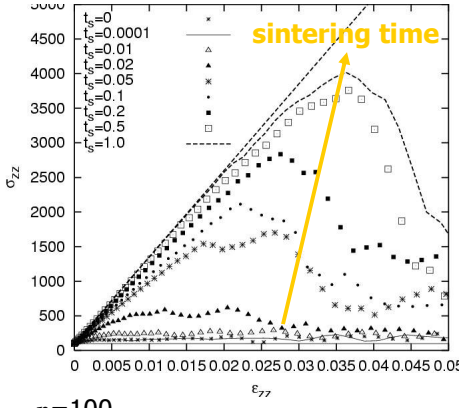
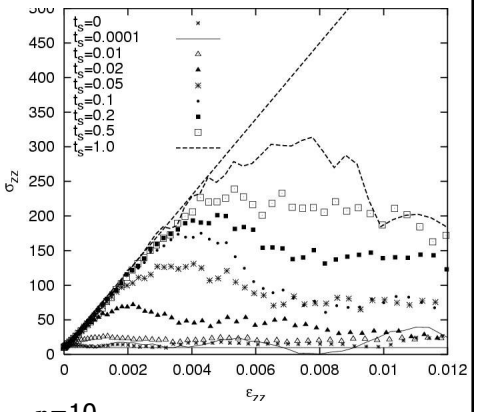
Sintering / Cementation

Stiffness …



p=100



p=10

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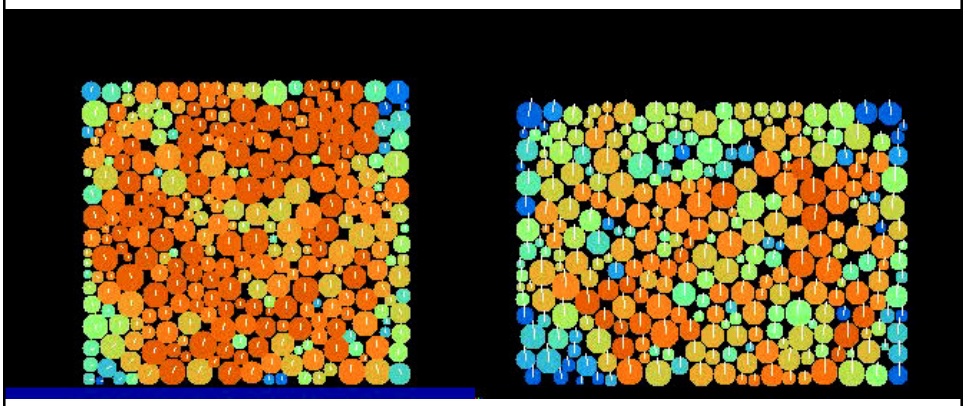
Sintering 7

7. **Vibration test**



p=100 p=10

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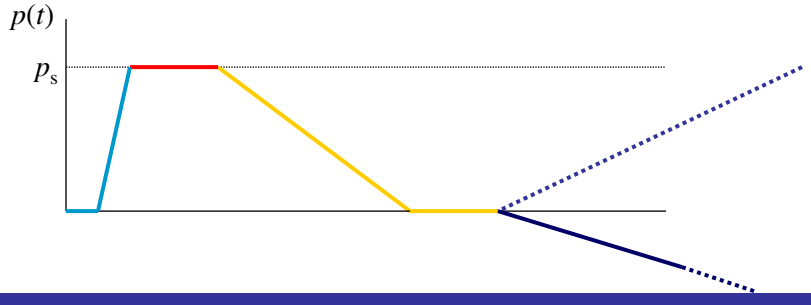
PCT (pressure-compression-tension)

1. **Preparation**
2. **HIGH pressure**
3. **Relaxation**
4. **Compression**
5. **Tension**



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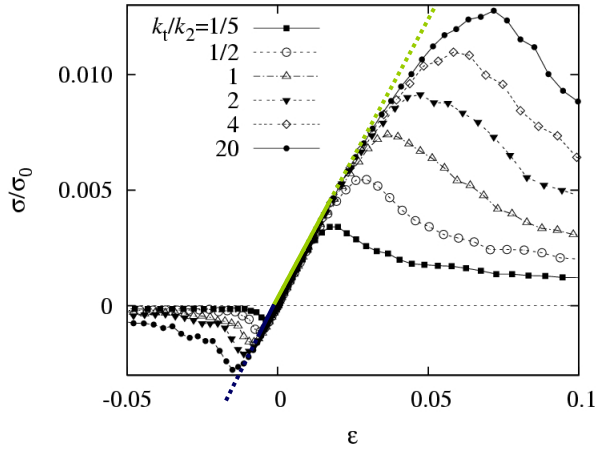
uni-axial compression-tension

- Compression
- Tension



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compression - uni-axial

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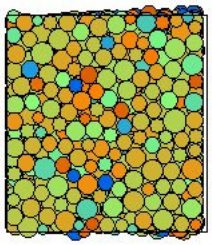
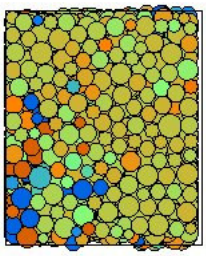
k_t/k_2=1/2

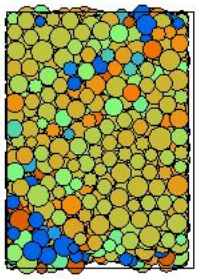
compression - uni-axial

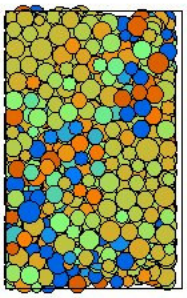




$k_1/k_2 = 1/2$

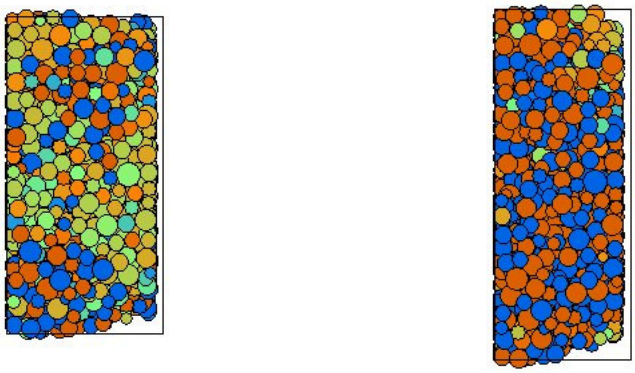
compression - uni-axial





$k_1/k_2 = 1/2$

compression - uni-axial



$k_t/k_2 = 1/2$

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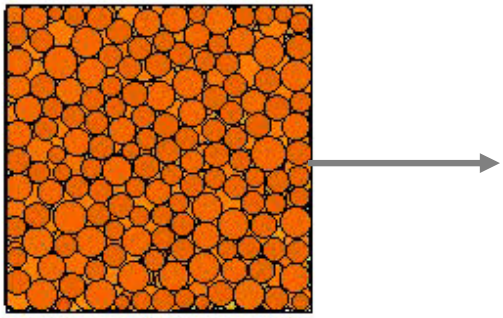
tension - uni-axial

$k_t/k_2 = 1/2$



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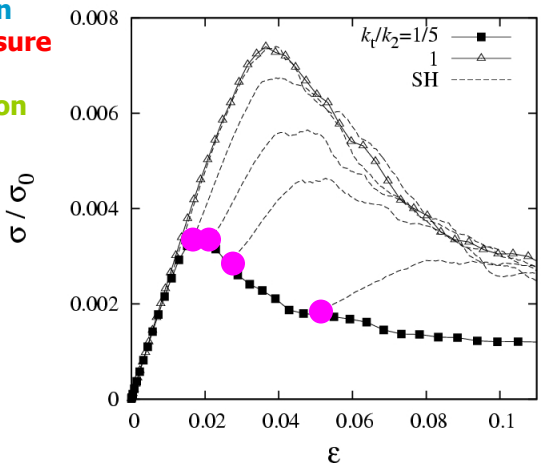
healing (compression)

1. Preparation
2. HIGH pressure
3. Relaxation
4. Compression
5. Tension
6. Healing



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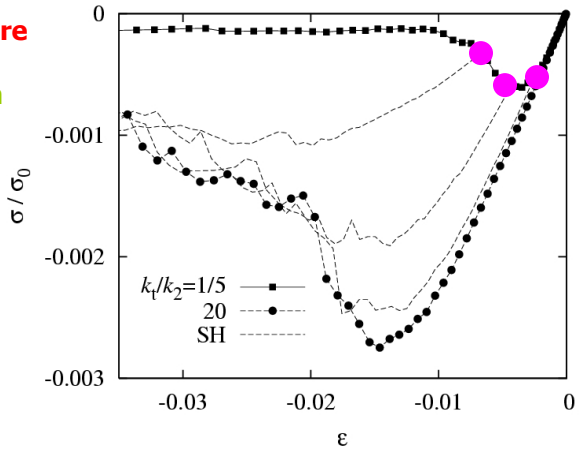
healing (tension)

1. Preparation
2. HIGH pressure
3. Relaxation
4. Compression
5. Tension
6. Healing



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Summary

- Slow deformation - compression & tension
  (sintering/cementation) tabletting …
  damage … failure … healing …
- Fast deformation - small amplitude
  sound propagation - effect of disorder?
- Slow deformation - large amplitude - 100 cycles
  strain accumulation vs. sliding contacts

Perspective:

Micro-parameters and structure **->Macro** continuum
& validation experiments

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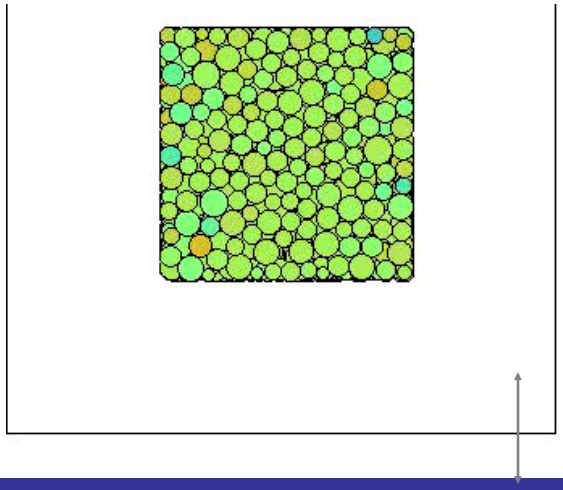
FAST deformation, LARGE amplitude, CYCLIC



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