Micro-Macro-Interactions at Stressing and Breakage of Agglomerates and Granules

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Problem Definition

- Non-uniform micro-mechanical properties throughout the structural volume of a single granule.
- Non-uniform macroscopic granular behavior even between so-called similar granules of same material.
- Insufficient knowledge of the influences of microscopic primary particle properties and of macroscopic granular properties on material behaviour.
- Insufficient knowledge of processing additives such as moisture on material behaviour.
- Insufficient knowledge of the influence of stressing conditions such as loading velocity on material behaviour.

Objectives

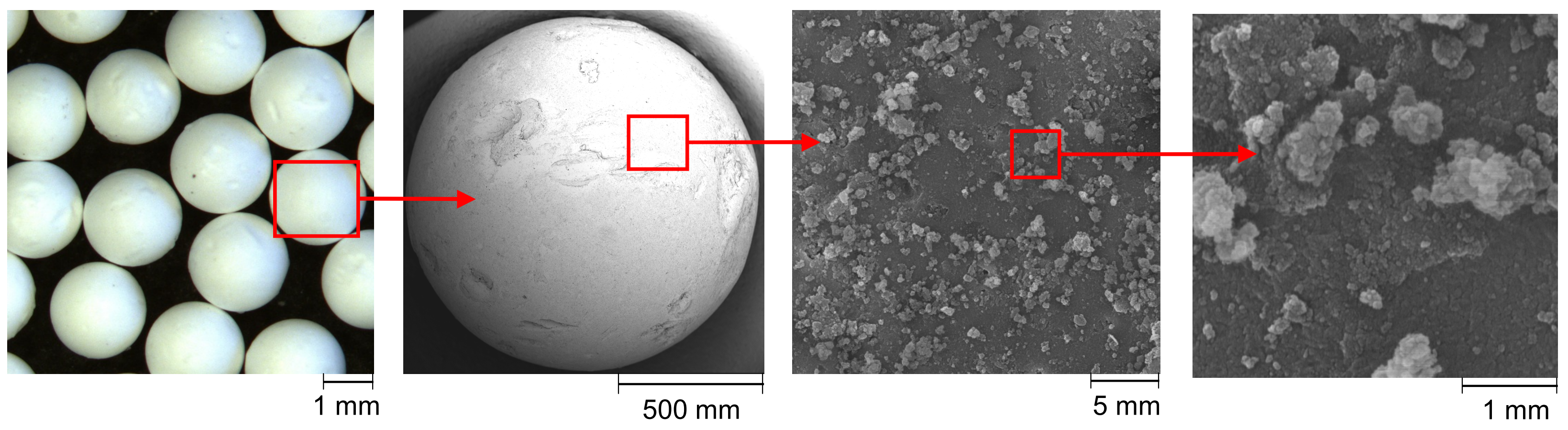
- To understand the interactions of primary particles and bonding mechanisms.
- To understand the progressive weakening of a single granule due to preloading.
- To describe the deformation in the elastic and the elastic-plastic ranges.
- To understand the influences of loading velocity, granule size and moisture content.
- To understand the breakage behaviour.
- To receive new theoretical approaches for the description of contact deformation.

Cooperation

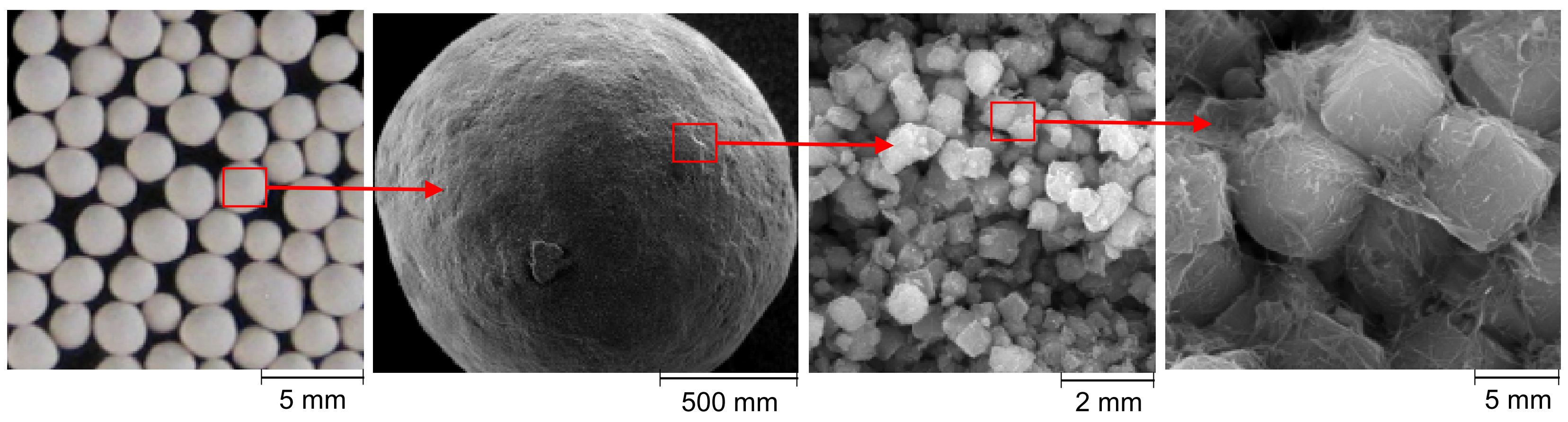
- M.Sc. Alexander Russell: „Mehrfachbeanspruchung- und Bruchverhalten feuchter kugelförmiger Granulate bei Druck- und Stoßbeanspruchung".
- Dr. Sergej Aman „Die Radiowellen- und die Lichtemission während der Kontaktdeformation und beim Partikelbruch".
- M.Sc. Zheni Radeva: "Granulation, Charakterisierung und Simulation von elastisch-plastischen Granulaten".
- Dipl.-Ing. Katja Mader „Modellierung des Kontaktverhaltens feiner adhäsiver Partikel".
- Institute of Raw Material Preparation and Environmental Processing, University Miskolc Hungary

Experimental Setup

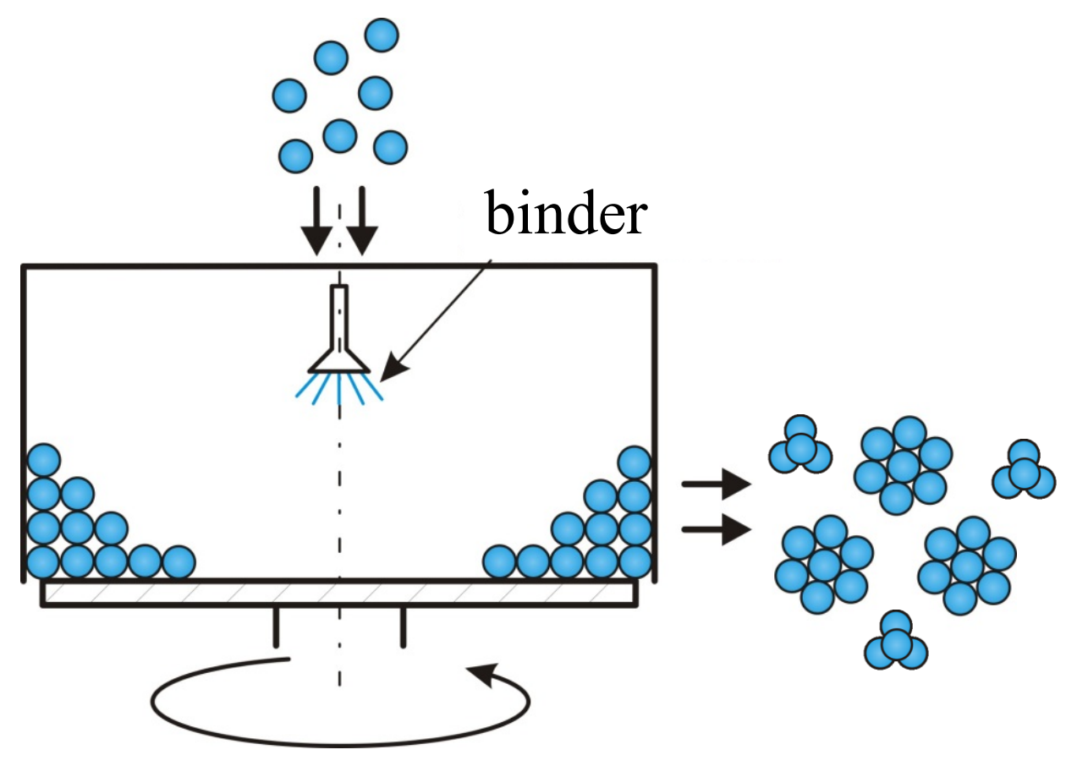
γ-Al_2O_3 – dominant elastic material behaviour



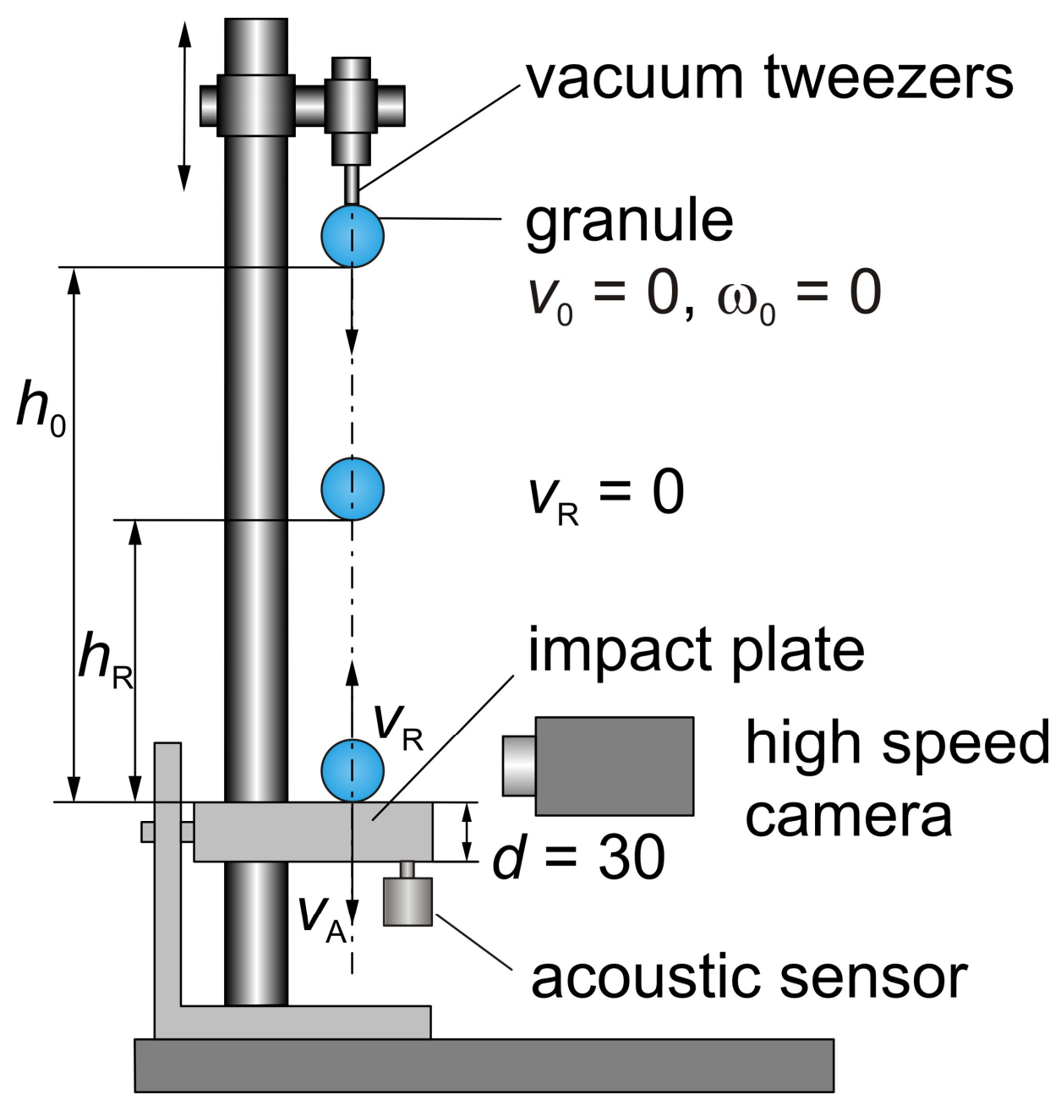
Zeolite 4A – elastic-plastic material behaviour



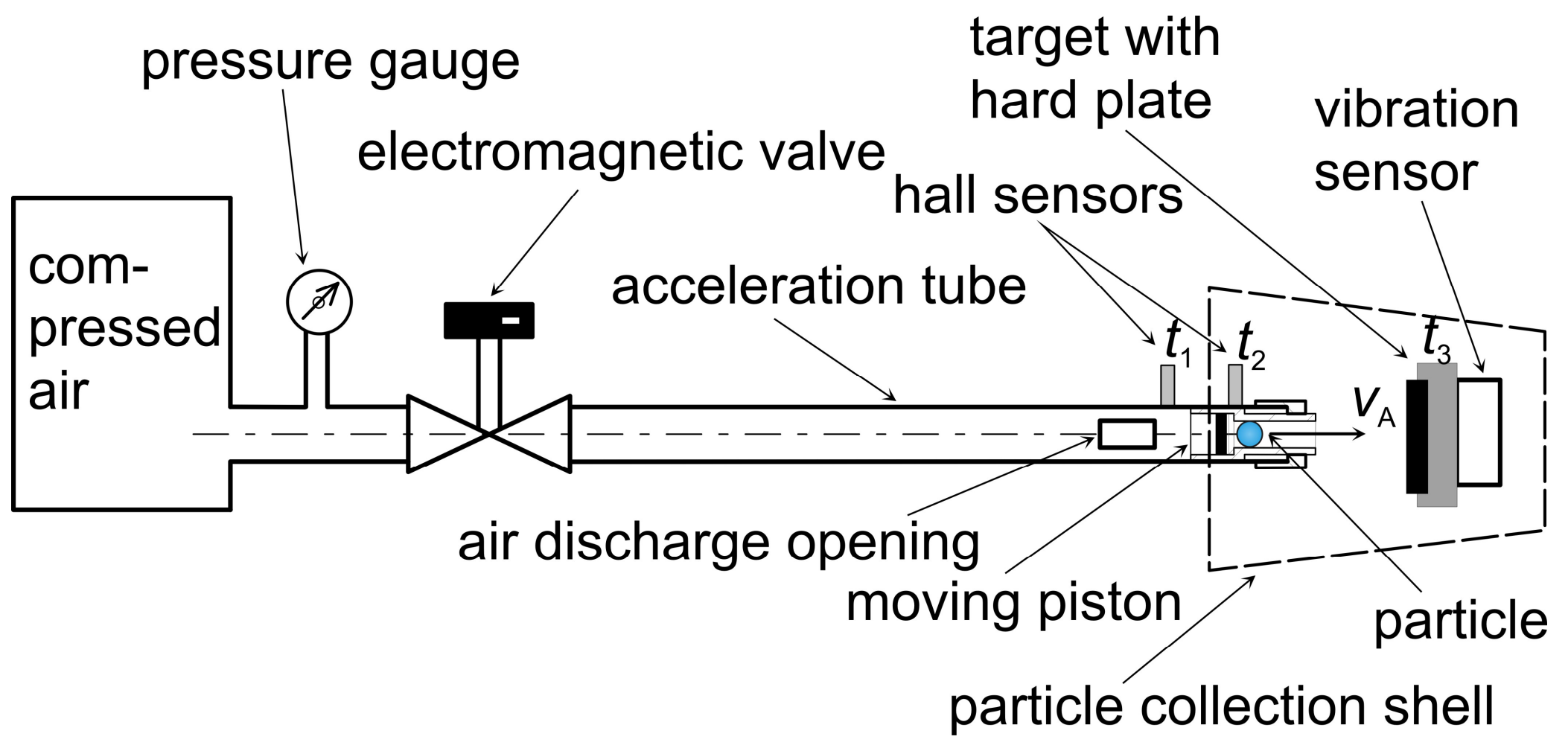
Pan pelletizer



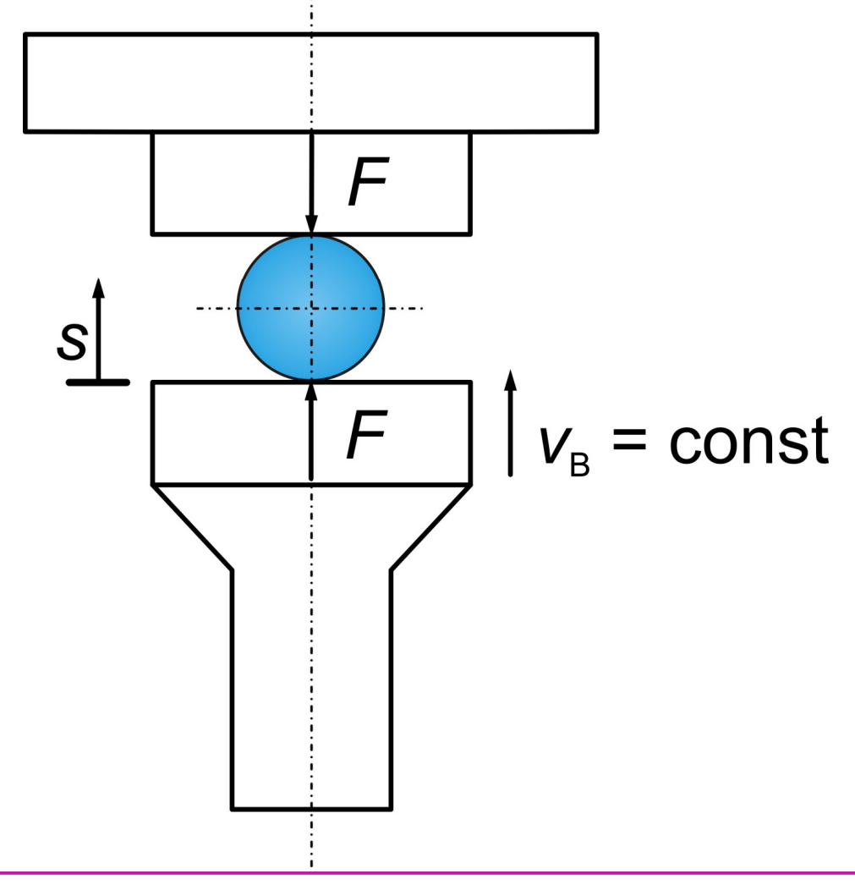
Free fall apparatus



Pneumatic impact canon



Compression tester



Analytical Description

Contact mechanics

Hertzian elastic diametrical loading of a sphere:

$$\left(\frac{p_{el}}{p_{max}}\right)^2 = 1 - \left(\frac{r_k}{r_{k,el}}\right)^2$$

Force-displacement approach:

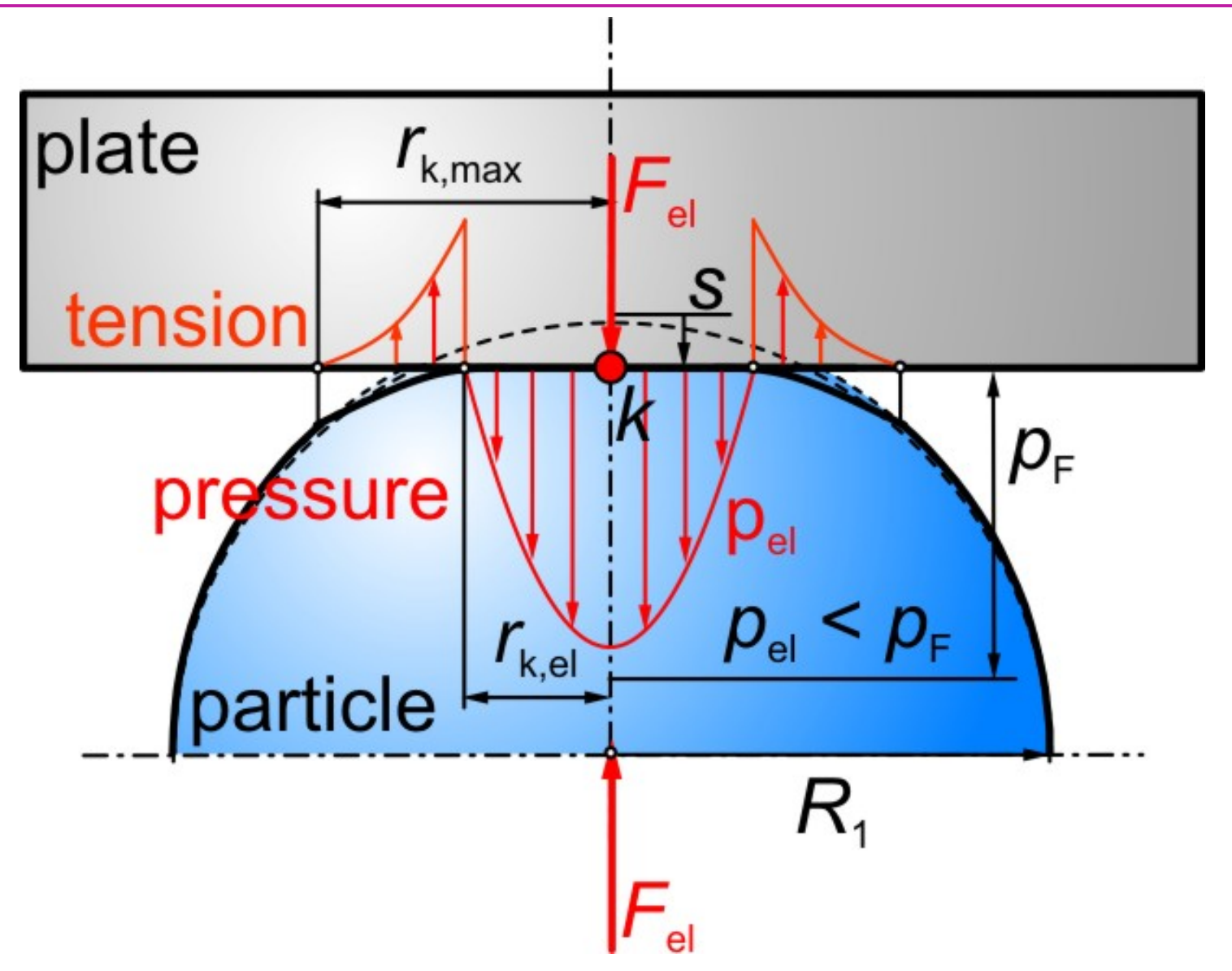
$$F_{el} = \frac{2}{3} E^* \sqrt{R_1 s^3}$$

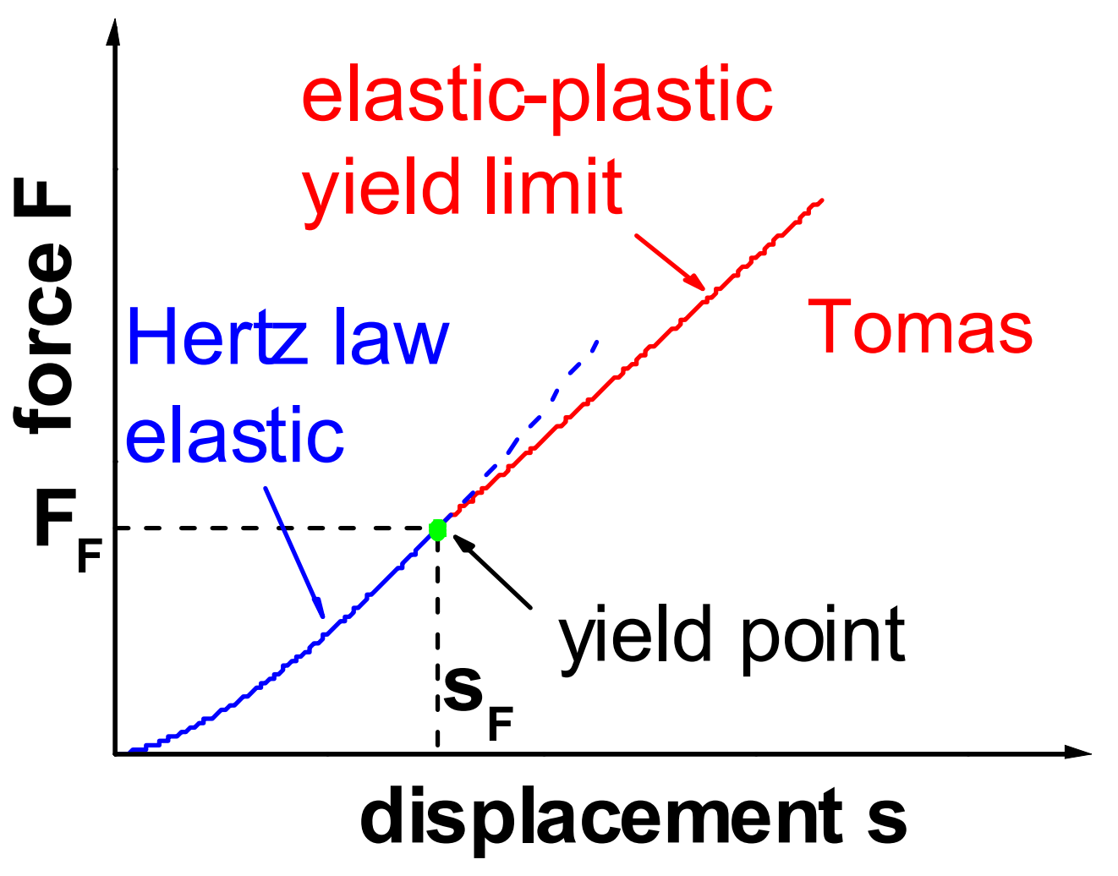
Tomas's elastic-plastic diametrical loading of a sphere:
Force-displacement approach:

$$F_{el\text{-}pl} = A_k p_F \kappa_A = \pi R_1 p_F \left(1 - \frac{1}{3}\sqrt[3]{\frac{s_F}{s}}\right) s$$

Yield pressure:

$$p_F = \frac{E^*}{\pi}\sqrt{\frac{s_F}{R_1}}$$





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[1] H. Hertz: Ueber die Berührung fester elastischer Körper, J. reine u. angew. Math. 1881, 92, 156-171; [2] J. Tomas: Zur Mechanik trockener kohäsiver Schüttgüter, Schüttgut 2002, 8 (6), 522-537

Numerical Description

Discrete Element Method (DEM)

Contact Models

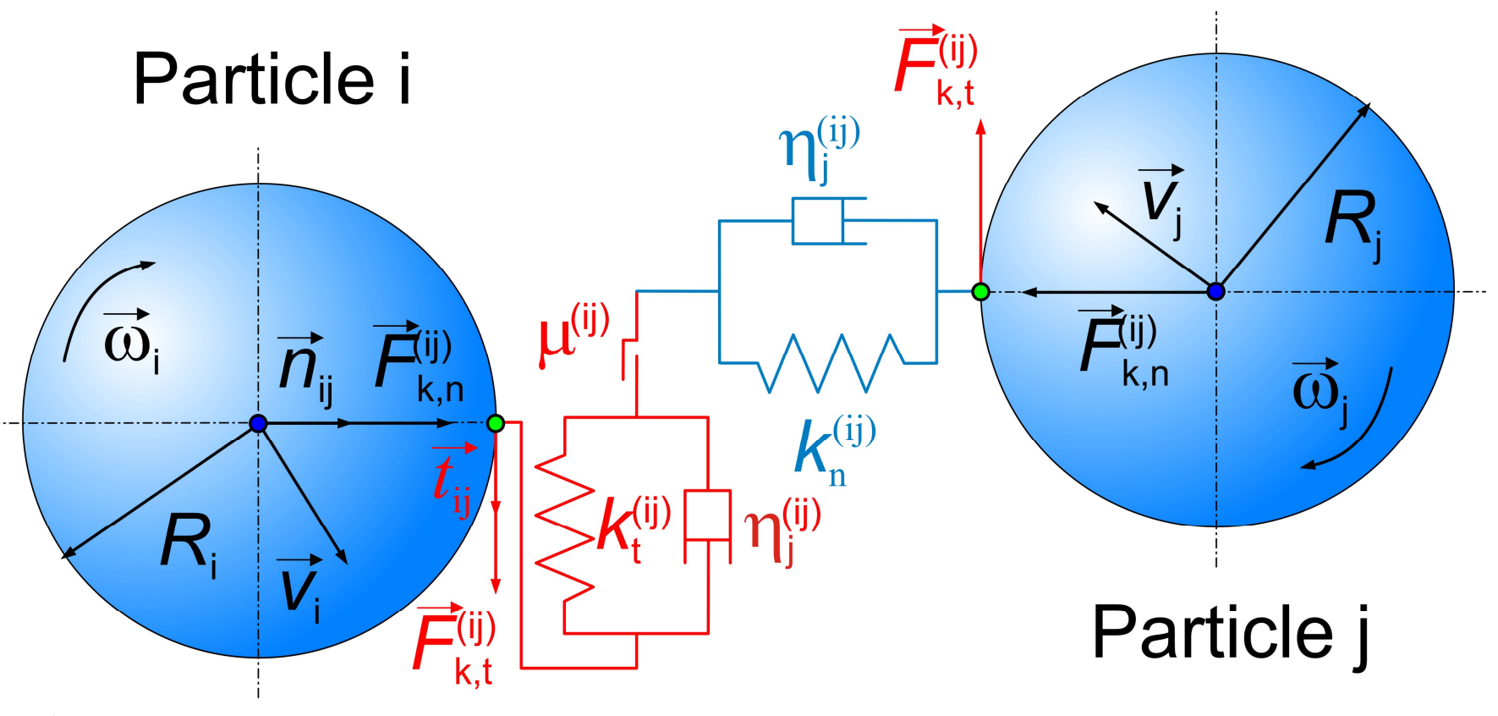
- Linear spring dashpot model & slider
- Hertz model & slider

normal direction:

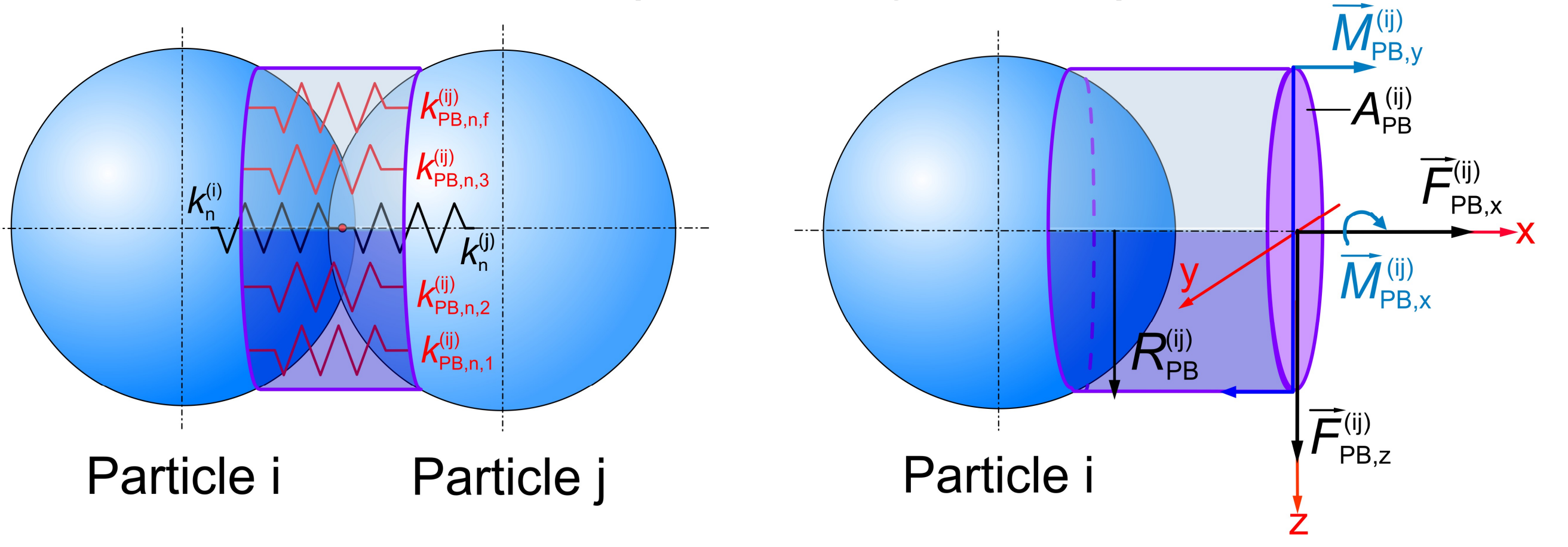
$$\vec{F}^{(ij)}_{k,n} = \left(k^{(ij)}_n s^{(ij)}_n + \eta^{(ij)}_n \dot{s}^{(ij)}_n\right)\vec{n}_{ij}$$

tangential direction:

$$\vec{F}^{(ij)}_{k,t,max} = \left(\left[k^{(ij)}_t s^{(ij)}_t + \eta^{(ij)}_t \dot{s}^{(ij)}_t\right], \mu_{ij}\vec{F}^{(ij)}_{k,n}\right)\vec{t}_{ij}$$



Parallel bonds (solid bridge bonds)



Results and Discussion

Material	Diameter d_{50} [mm]	Moisture content X_w [kg_{H2O}/kg_{TS}]	Modulus of elast. E_1 [GPa]	Contact stiffness $k_{n,el\text{-}pl}(s=s_B)$ [N/mm]	Yield pressure p_F [MPa]	Fracture strength σ_B [MPa]	Coefficient of restitution e
γ-Al_2O_3	1.8	0.00	16.44 ± 5.51	1295 ± 375	1432 ± 406	43.95 ± 9.30	0.73
		0.85	9.82 ± 2.48	784 ± 178	876 ± 163	34.36 ± 10.31	0.71
Zeolith 4A	2.1	0.00	2.45 ± 0.64	834.4 ± 150.4	288 ± 53	8.34 ± 1.75	0.66
	2.1	0.43	1.54 ± 0.79	521.3 ± 81.2	166 ± 36	3.59 ± 0.63	0.61

Outlook

- Influence of different binders and binding mechanisms?
- Improvement of the force-displacement approaches.
- Contact model for agglomerates consisting of macroscopic primary particles.
- Influence of liquid and powder layers on the impact behaviour.
- Simulation of the material behaviour of granules and agglomerates using DEM.

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