Size Reduction

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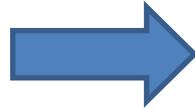
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Energy transfer to stress particles   **Reaction of particle to acting stresses**

Machine design and operation → Stress energy / Stress number → Breakage prob. / Breakage function

Two-phase flow & rheology
CFD-DEM models

Energy absorption
Stress distribution in stressed particles

Deformation
Defects
Breakage mechanism
Mechanochemistry

Mechanical particle properties

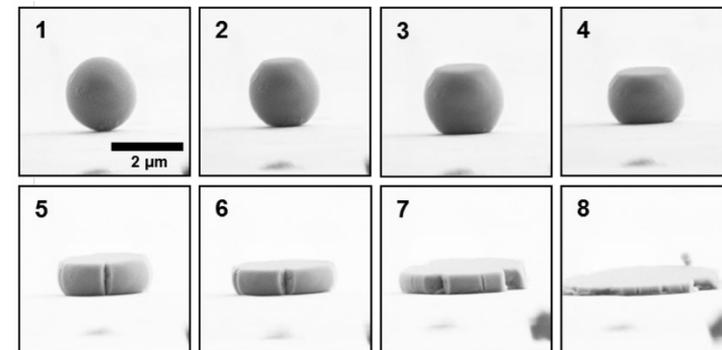**Mechanistic understanding in mills**

- Stress energy and stress number distributions

New materials and applications

- Shape control in wet stirred media mills
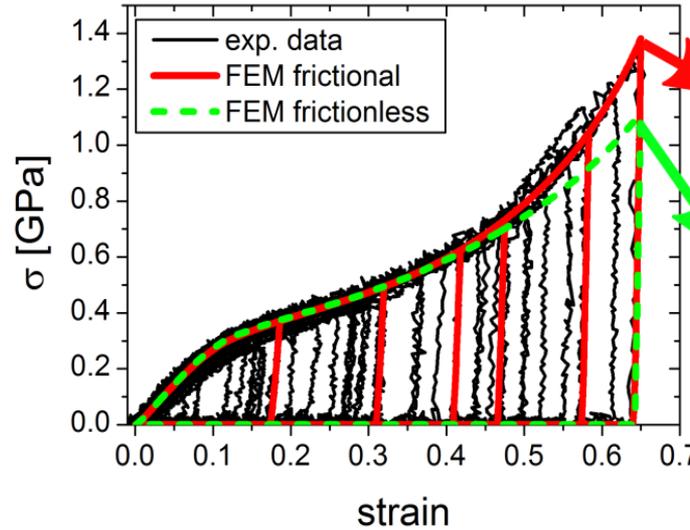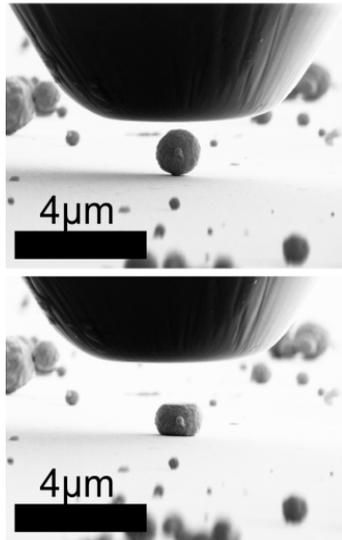
- Production of 2D materials by delamination

Mechanochemistry

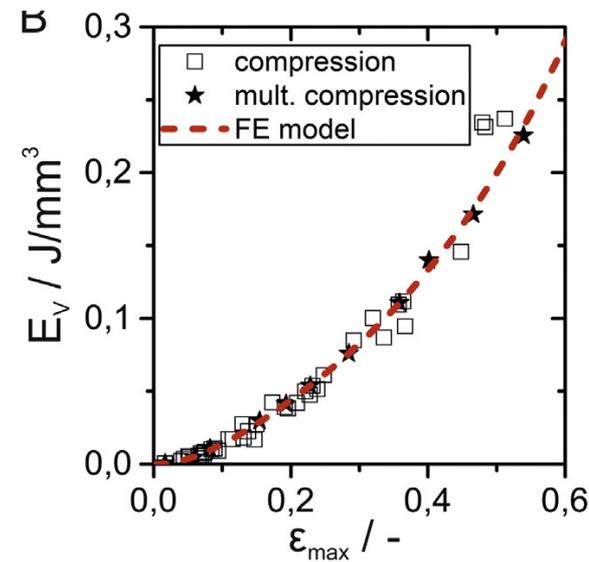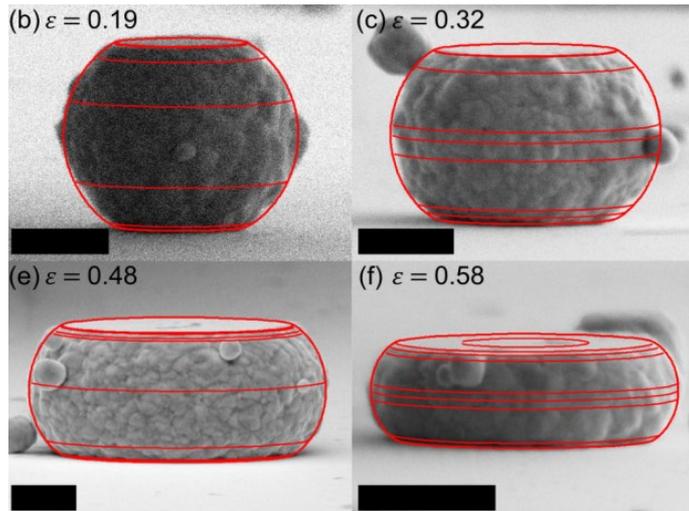Glass flake production below brittle-ductile transition
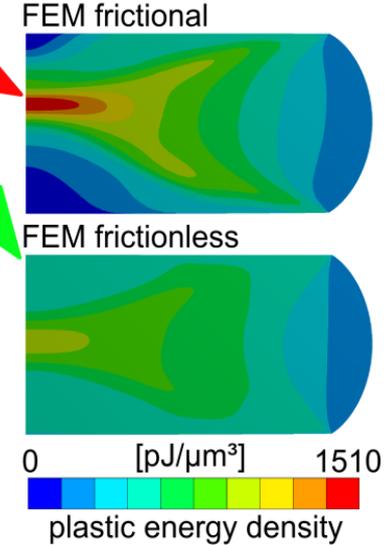

Esper, WP et al, Adv. Powder Tech 2020

Example: Compression of metallic spheres in SEM

In situ compression

4µm

4µm

FEM modelling

FEM frictional

FEM frictionless

0   [pJ/µm³]   1510

plastic energy density

(b) $\varepsilon = 0.19$

(c) $\varepsilon = 0.32$
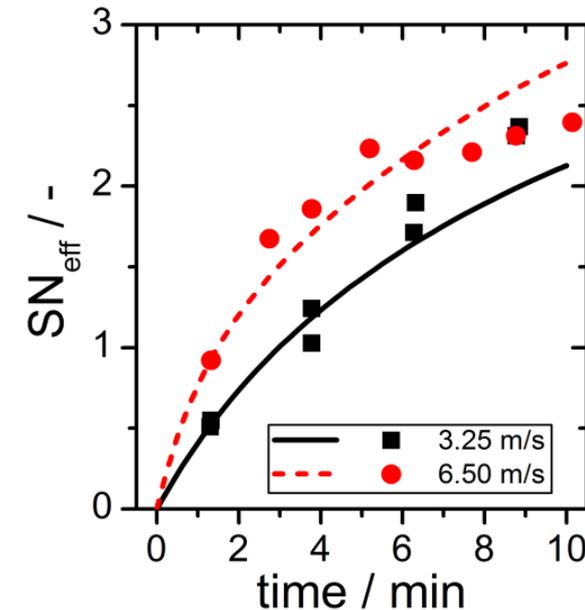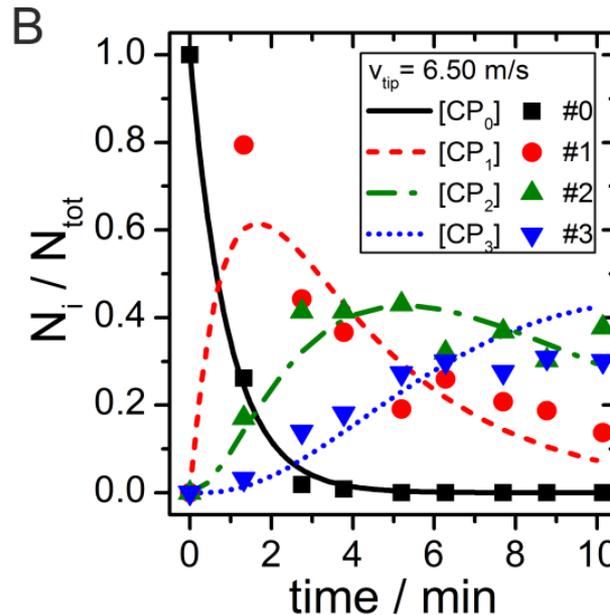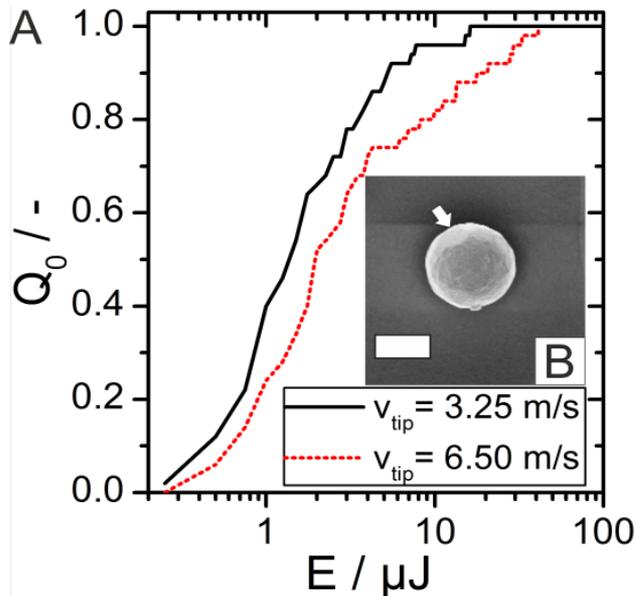
(e) $\varepsilon = 0.48$

(f) $\varepsilon = 0.58$

3

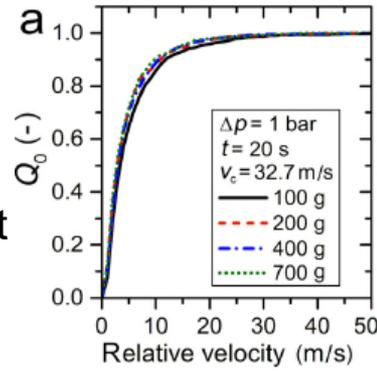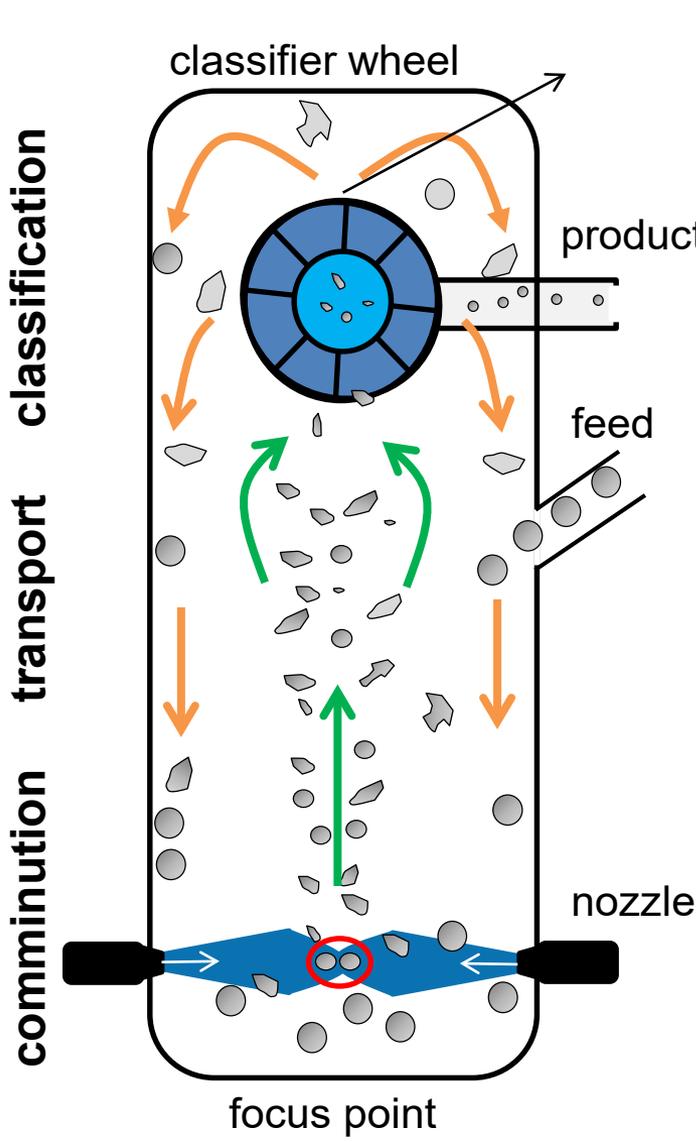Statistical image analysis of stressed particles (here: 80 µm Cu particles)
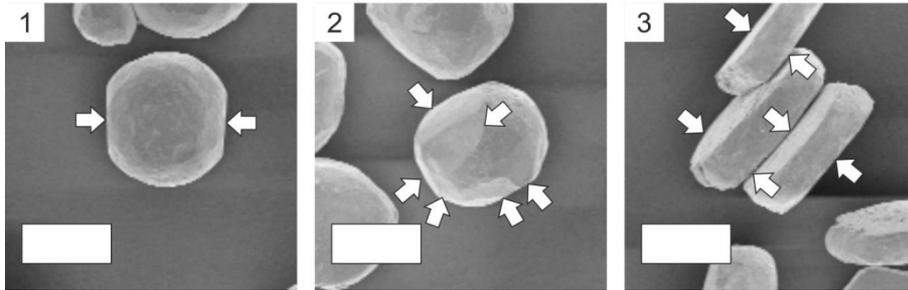
Number of indents: stress number
Degree of compression: acting energy

Experimental determination of
- ➤ **Stress energy distribution SE** (calibrated through single particle compression)
- ➤ **Stress number distribution SN** (number of indents)
- ➤ Consumed energy ~ SE ˣ SN

Romeis, WP et al, Powder Technology 2017, Chem. Eng. Res. Des. 2018

Distributions of SE and SN

Particle velocities (PIV)

K.E. Wirth et al, Powder Technology 2018, WP et al, Particuology 2020, A. Bück et al, Processes 2021
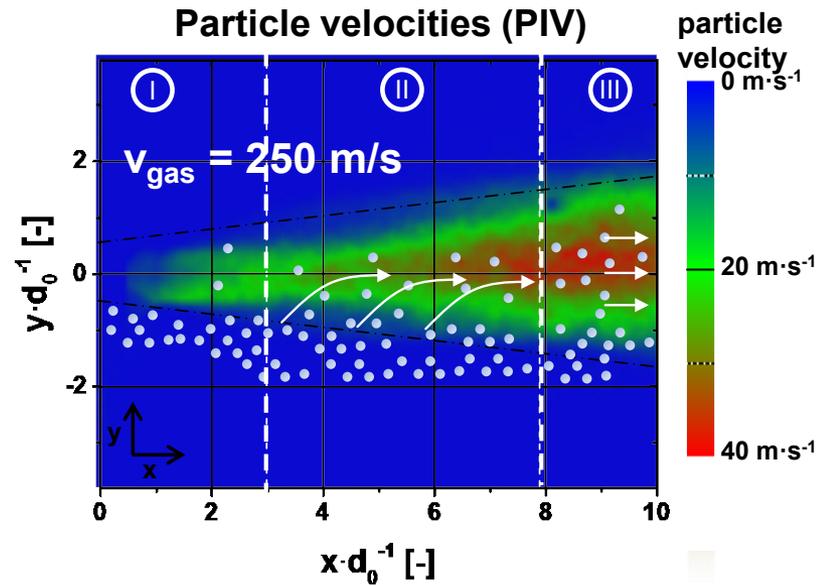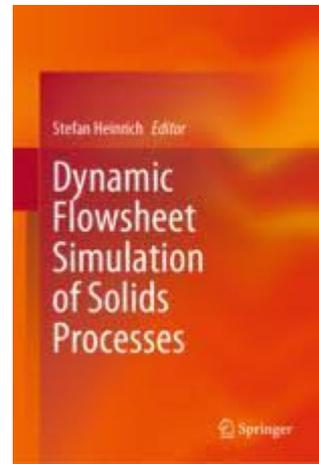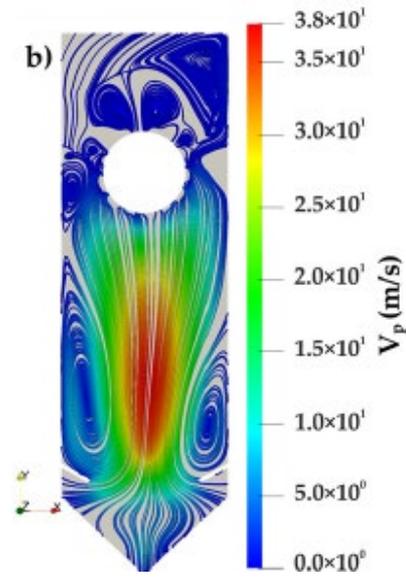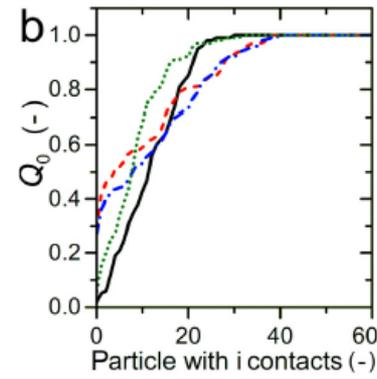
$$dF = -SdT - pdV + \sum_{i}^{n} \mu_i dn_i + \gamma dA + V\sum_{l,m=1}^{3} E_{l,m} de_{l,m}$$

chemical potential

surface energy

stress tensor

Rusanov, Surface Sci. Rep. 2005

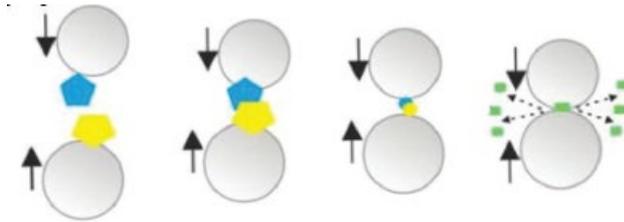*Mechanochemistry boosts perovskites Bolink et al, Adv. Energy Materials 2021*

Thermodynamics of mixed phases plus
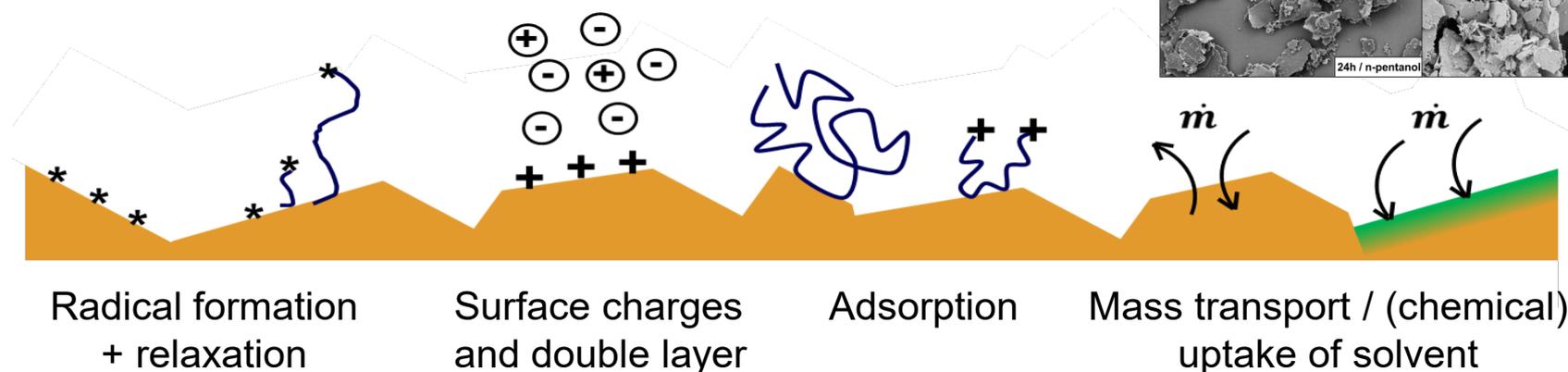**Effects of surface**, e.g.
- Stress-dependent solubility
- Radical formation
- Grafting of molecules

Effects of stresses, e.g.
- Crack growth in dependence of chemical surrounding: Joint effect of acting stress and chemical interactions
- Stress-induced phase transformations
- Growth rate dispersion of stressed crystals

Bioglass in different solvents

Radical formation
+ relaxation

Surface charges
and double layer

Adsorption

$\dot{m}$ $\dot{m}$

Mass transport / (chemical)
uptake of solvent
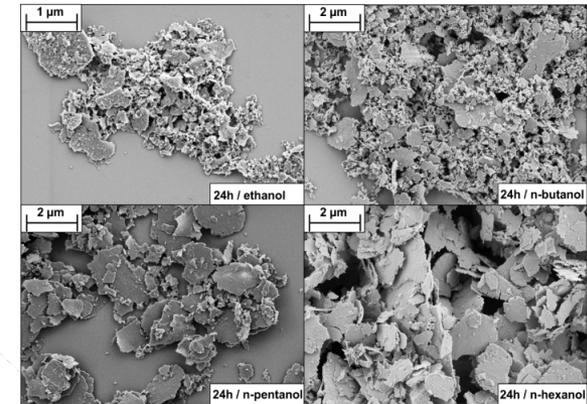
Reviews:
Difficult to grind materials, scope and focus
Temperature, stickiness, soft, shape (platelets, fibers), humidity
Might include of grindability tests

Mill-classification with superimposed drying
From dry to completely wet
Drying kinetics vs grinding/dispersion, residence time adepted between milling – drying

Research projects:
Effect of surface moisture to control electrostatics, flowability (surface, adsorption, adhesion)
Entrapped capillary water in agglomerated particles, absorbed pore water in polymers carbohydrates, for instance

Effect of drying on particle-particle bonds
Redispersion of dried products, depending on previous drying step
(flash or spray dying, granulation): hard skins, solid bridges,
possibly without added chemistry