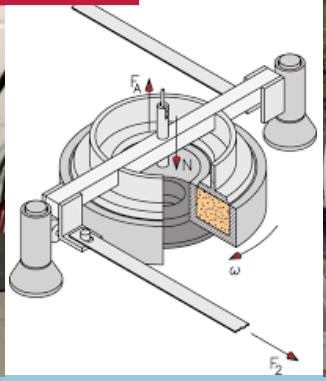
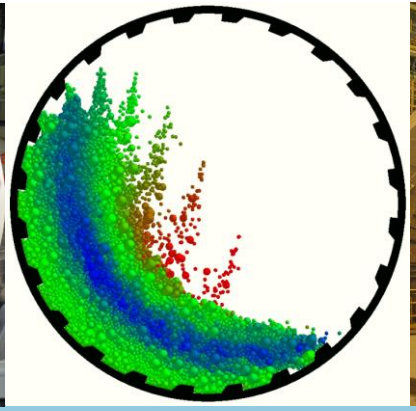
Technische Universität Braunschweig

iPAT
Institut für Partikeltechnik


IFPRI

A Systems Engineering Approach to Dry-Milling with Grinding Aid Additives

Anderson Chagas, Arno Kwade

Project introduction

Long term objectives:

I. Obtain qualitative/quantitative effects of grinding aid additives on material behaviour, process aspects and energy flows.

II. Develop a system engineering approach for optimizing and scaling industrial dry grinding processes.

First phase (3+1 years period):

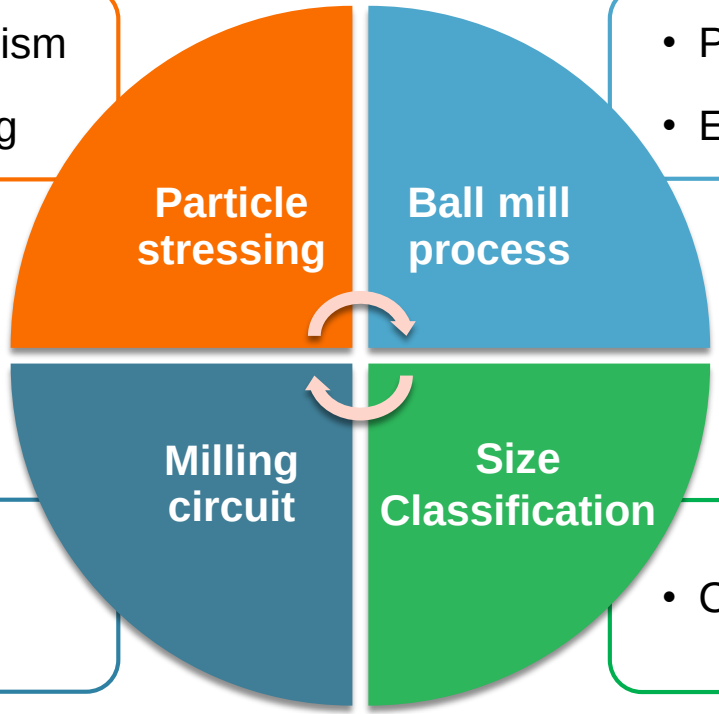
I. Focus on the grinding aid impacts on the grinding aspects during ball milling, air classification and closed circuit plants.

II. Those information is used to predict particle size distributions and energy consumptions.

System engineering approach

- Grinding aid mechanism
- Powder bed stressing

- Powder transport
- Energy consumption

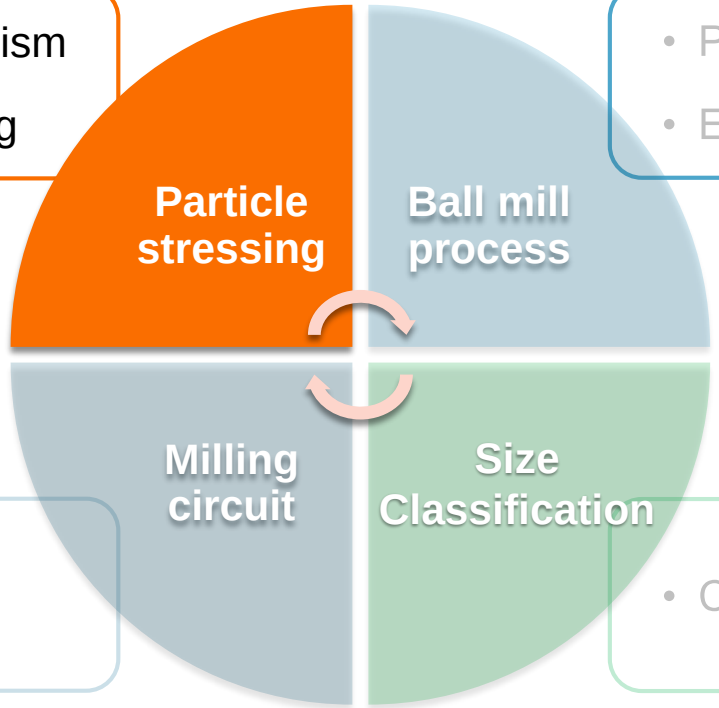


- Powder recirculation
- Plant production

- Classifier efficiency

System engineering approach

- Grinding aid mechanism
- Powder bed stressing



- Powder transport
- Energy consumption

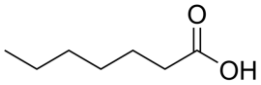
- Powder recirculation
- Plant production

- Classifier efficiency

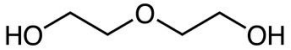
Particle stressing: Grinding aid mechanism

Grinding aid molecules:

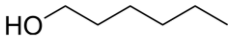
- Heptanoic acid (HepAc)
  - Chemical formula: $C_7H_{14}O_2$



- Diethylene glycol (DEG)
  - Chemical formula: $C_4H_{10}O_3$

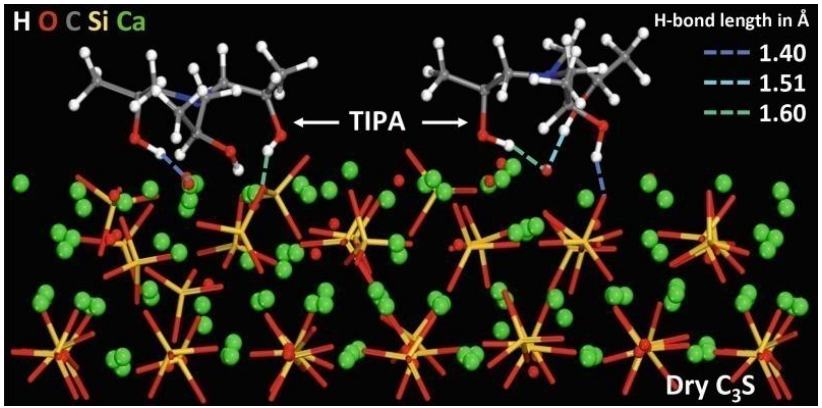


- 1-Hexanol (HexOH)
  - Chemical formula: $C_6H_{14}O$



Mechanism of action:

- Surface coverage of one molecule layer
- Organic compounds typically bonded to the surface by its polar part ($^-$OH group)

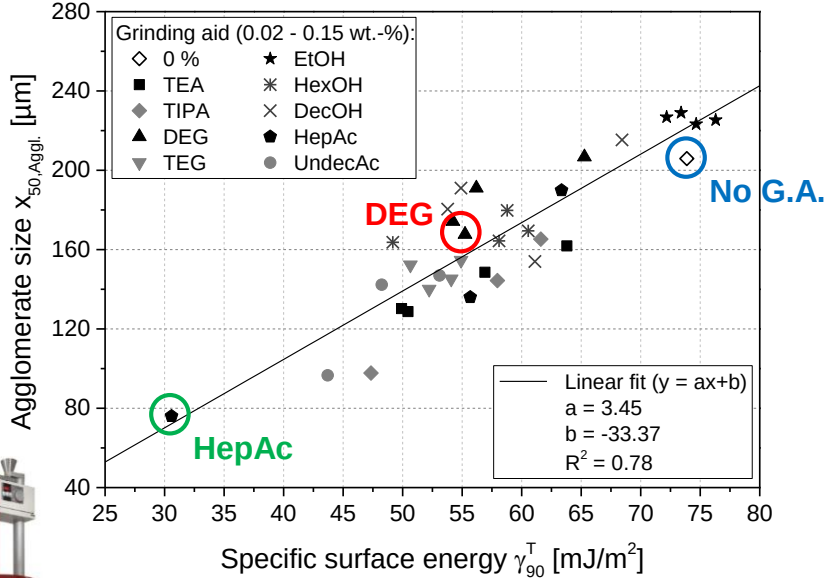


[1]

[1] Mishra, Flatt, Heinz. J. Phys. Chem. C 2013, 117, 10417−10432

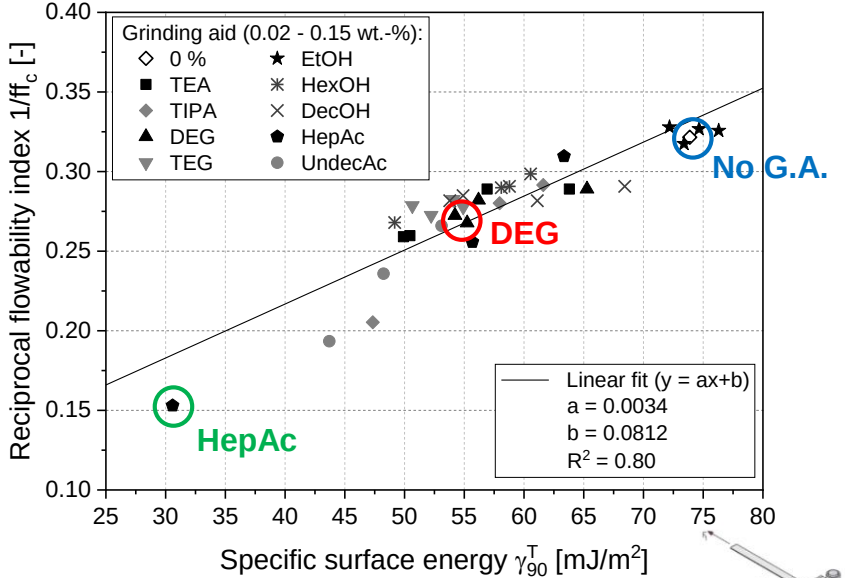
Particle stressing: Grinding aid mechanism

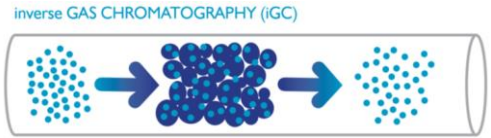
Agglomeration

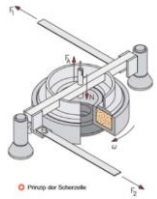


Flowability

[2]





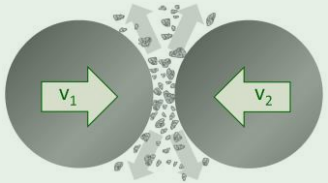


[2] Prziwara, Breitung-Faes, Kwade. Advanced Powder Technology 29 (2018) 416–425

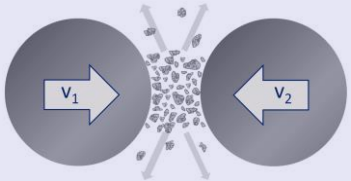
Particle stressing: Powder bed stressing

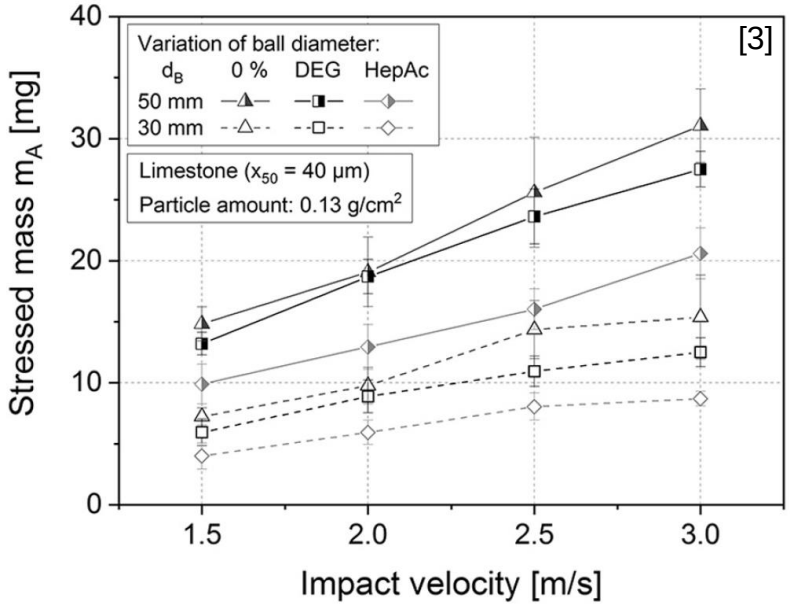
- **Mass of stressed powder** is directly influenced by flowability
- Low flowability results in **high impact energy dissipation** in particle bed between balls
- High flowability results in **low stressed mass**

High flowabilty
(↓ captured mass)



Low flowability
(↑ captured mass)



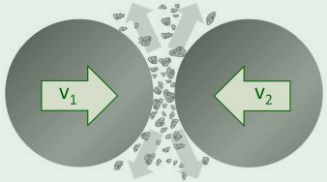


[3] Prziwara et al. Powder Technology 363 (2020) 326–336

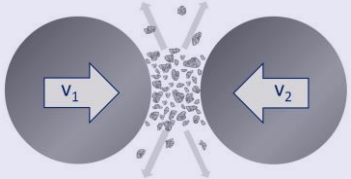
Particle stressing: Powder bed stressing

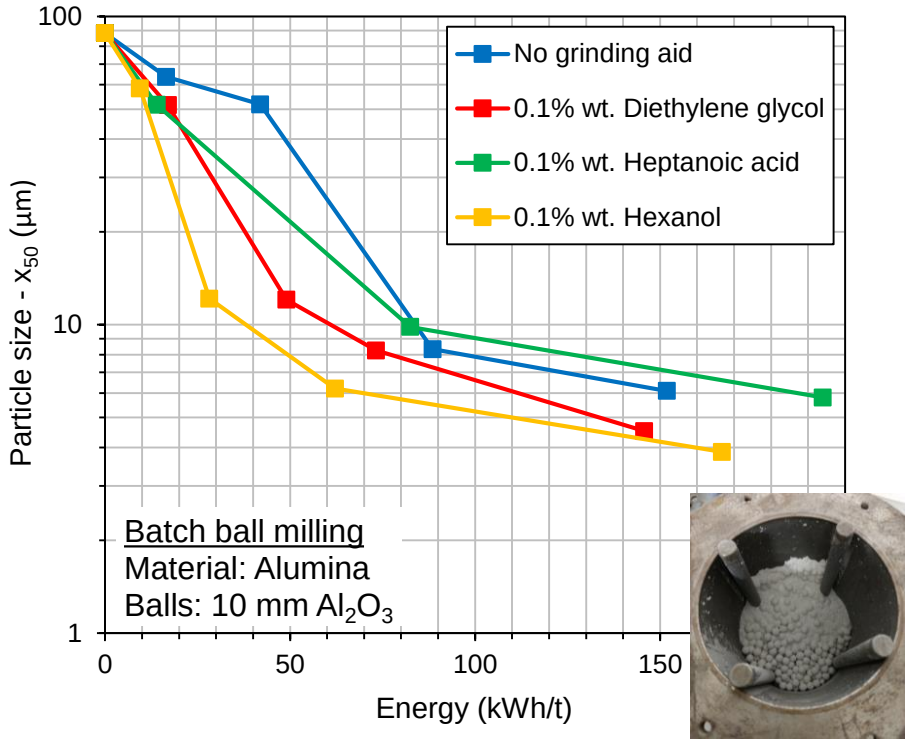
- **Mass of stressed powder** is directly influenced by flowability
- Low flowability results in **high impact energy dissipation** in particle bed between balls
- High flowability results in **low stressed mass**

High flowabilty
(↓ captured mass)



Low flowability
(↑ captured mass)

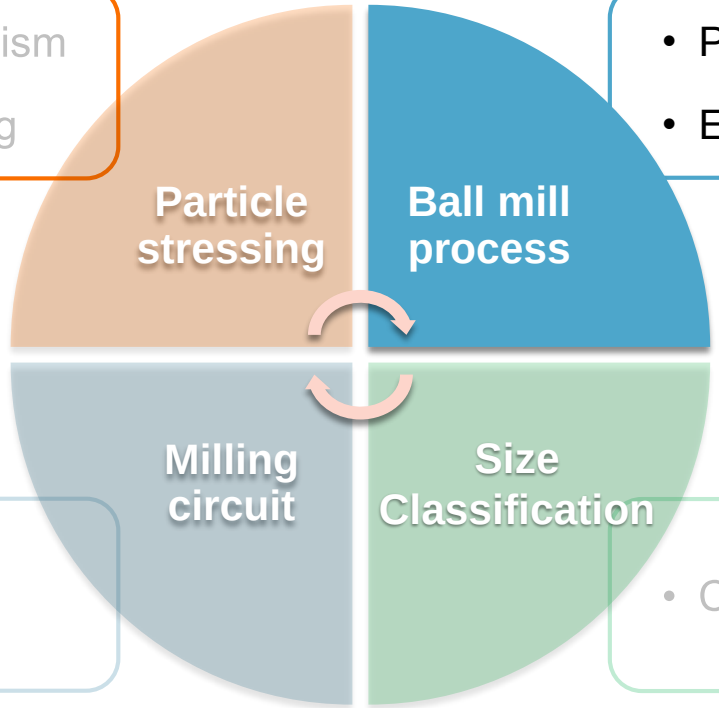




[3] Prziwara et al. Powder Technology 363 (2020) 326–336

System engineering approach

- Grinding aid mechanism
- Powder bed stressing

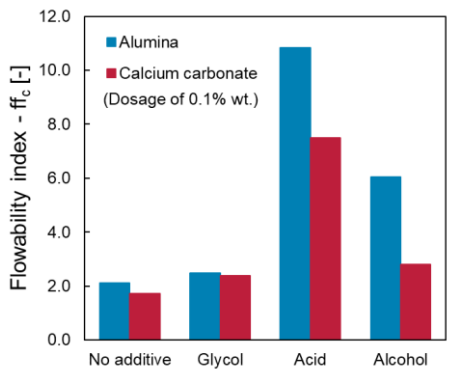


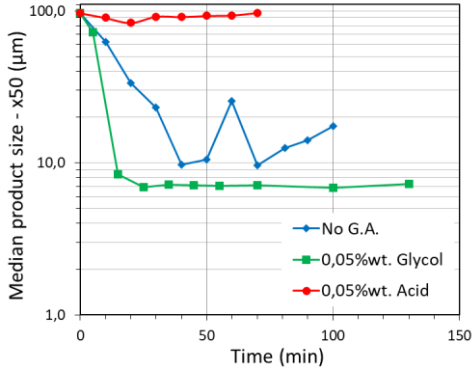
- Powder transport
- Energy consumption

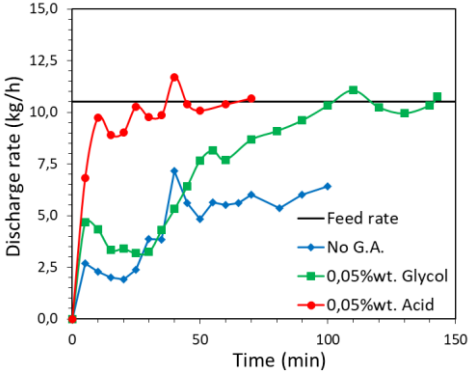
- Powder recirculation
- Plant production

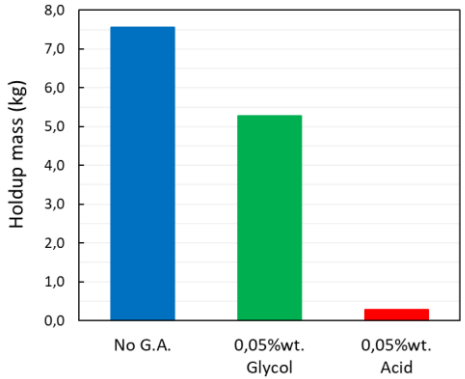
- Classifier efficiency

Ball mill process: Internal powder transport









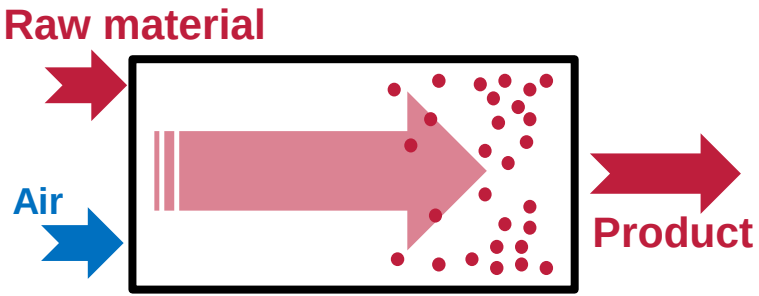
No additive

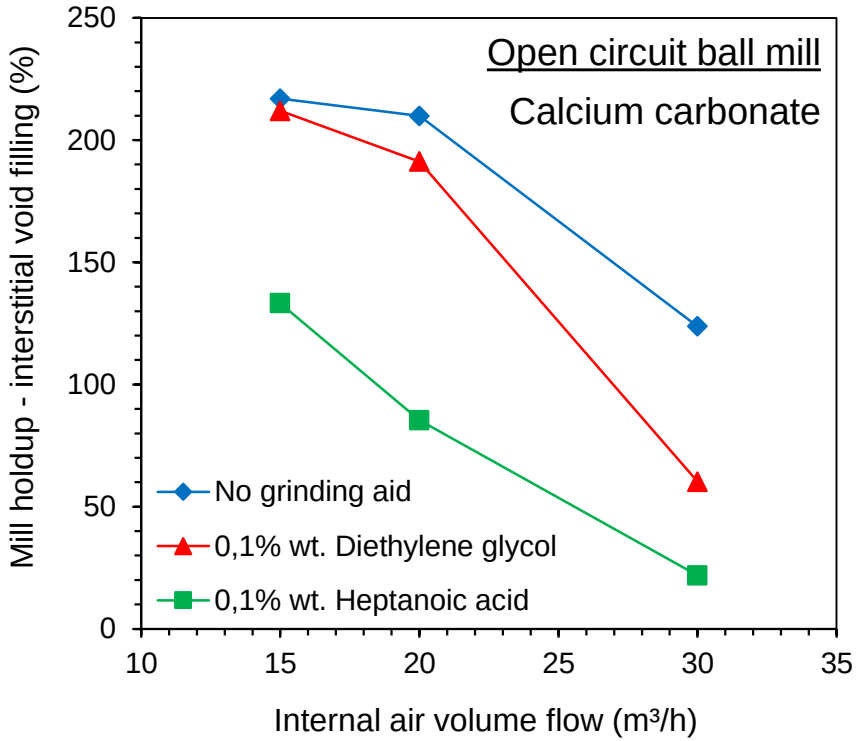
Glycol

Acid

Ball mill process: Mill holdup

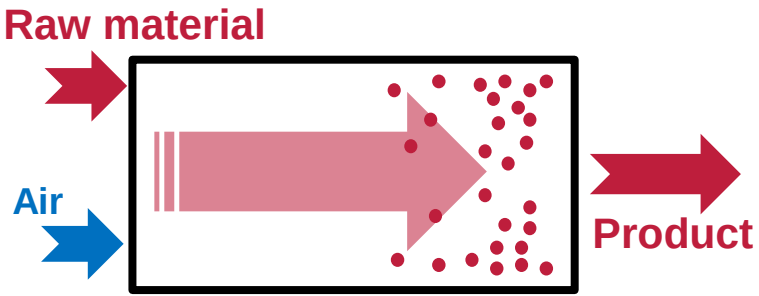
- Depending on the compound, G.A. can impact not only flowability, but also dispersion on air
- In passage mode milling, G.A. influence directly the mill internal holdup.

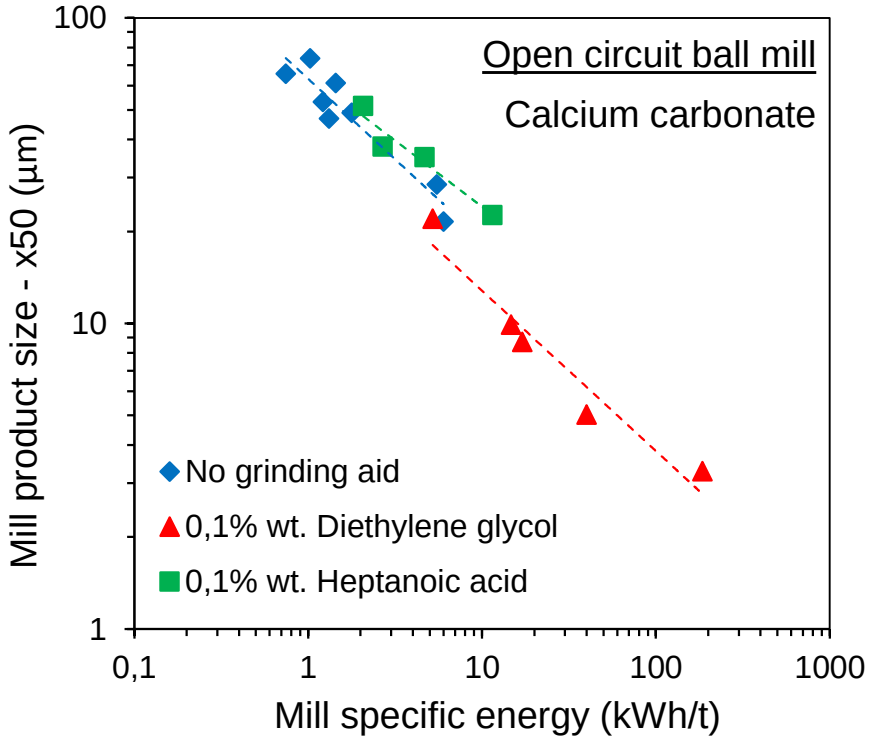




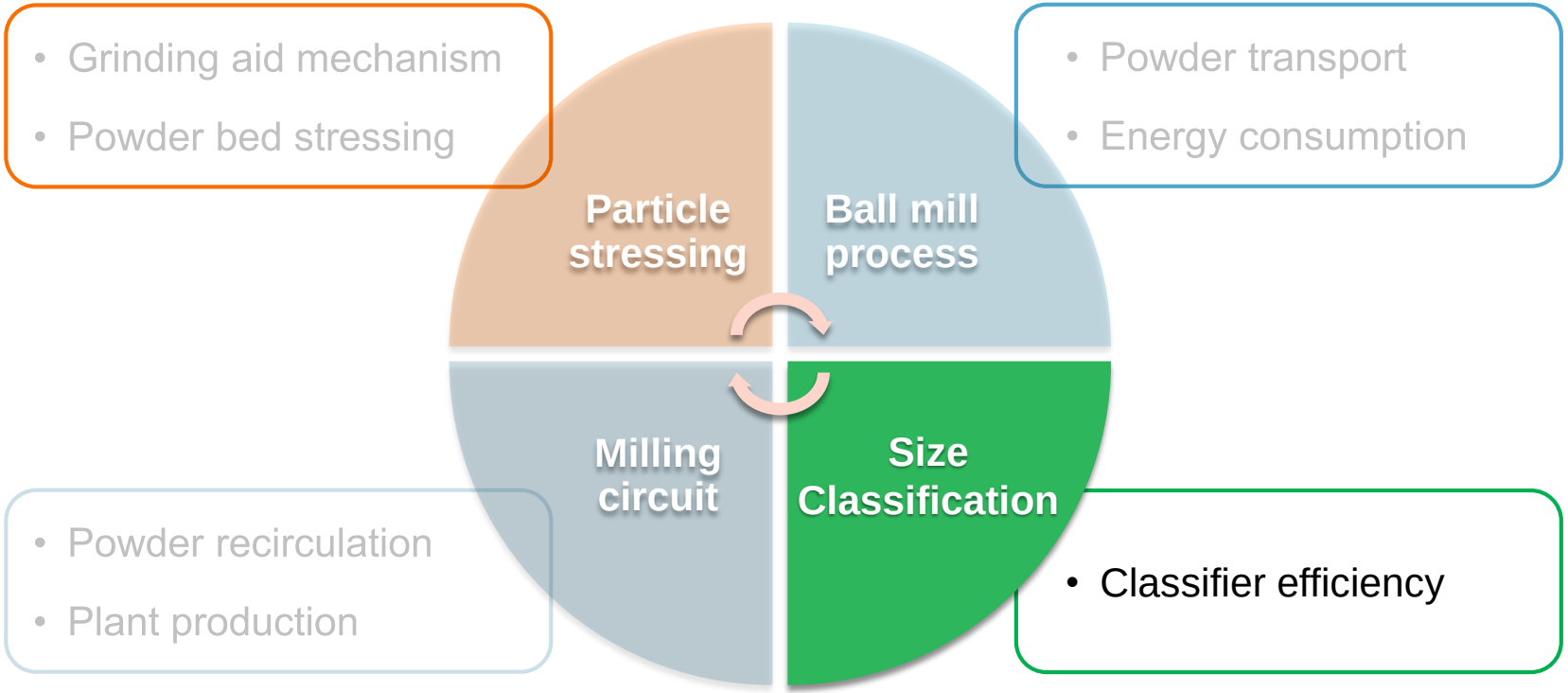
Ball mill process: Process efficiency

- Influence of G.A. on flowability, powder bed stressing and holdup effects process efficiency
- High flowability (with heptanoic acid) was slightly detrimental for process efficiency
- G.A. allow much finer product sizes to be achieved in passage mode





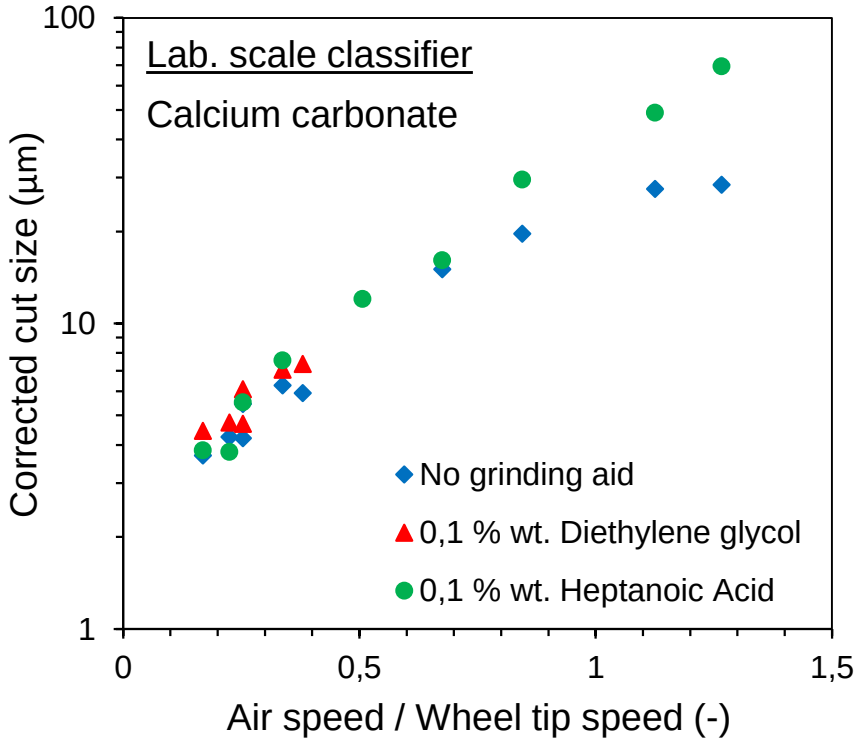
System engineering approach



Size classification: classifiers efficiency

Impact of G.A. on the tromp curve:

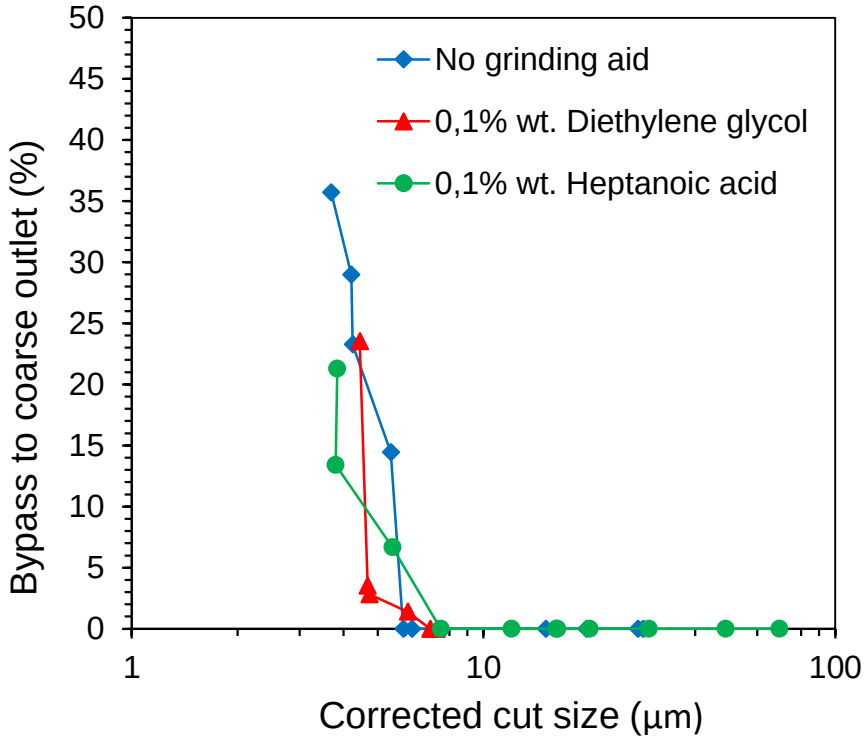
- Corrected cut size is independent of formulation
- The Bypass to coarse outlet is only slightly reduced by G.A.
- The fish-hook effect (smaller then 1 µm) was also slightly reduced by G.A.



Size classification: classifiers efficiency

Impact of G.A. on the tromp curve:

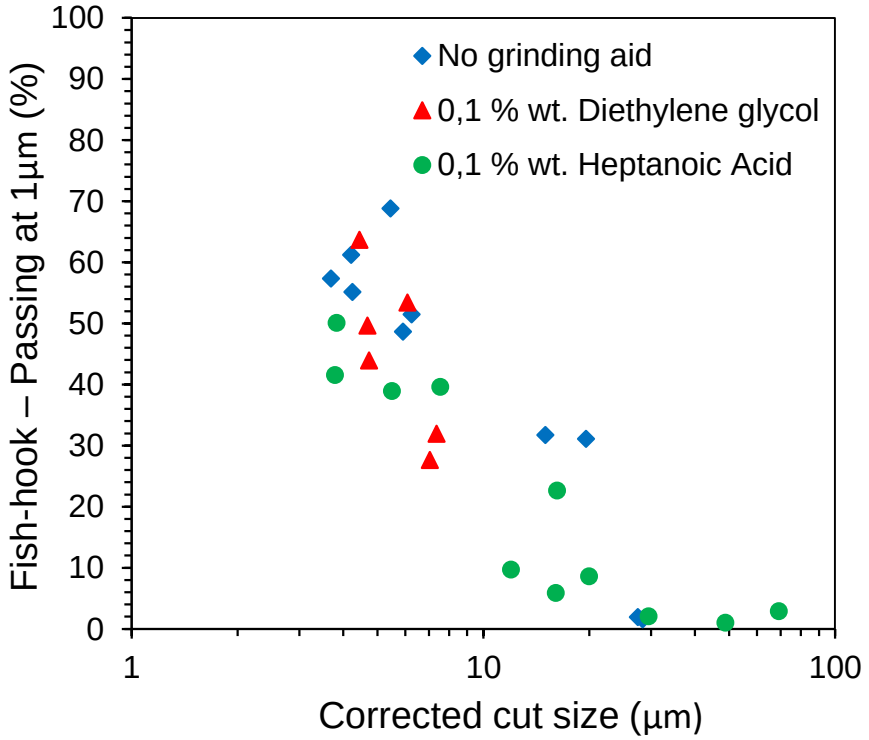
- Corrected cut size is independent of formulation
- The Bypass to coarse outlet is only slightly reduced by G.A.
- The fish-hook effect (smaller then 1 µm) was also slightly reduced by G.A.



Size classification: classifiers efficiency

Impact of G.A. on the tromp curve:

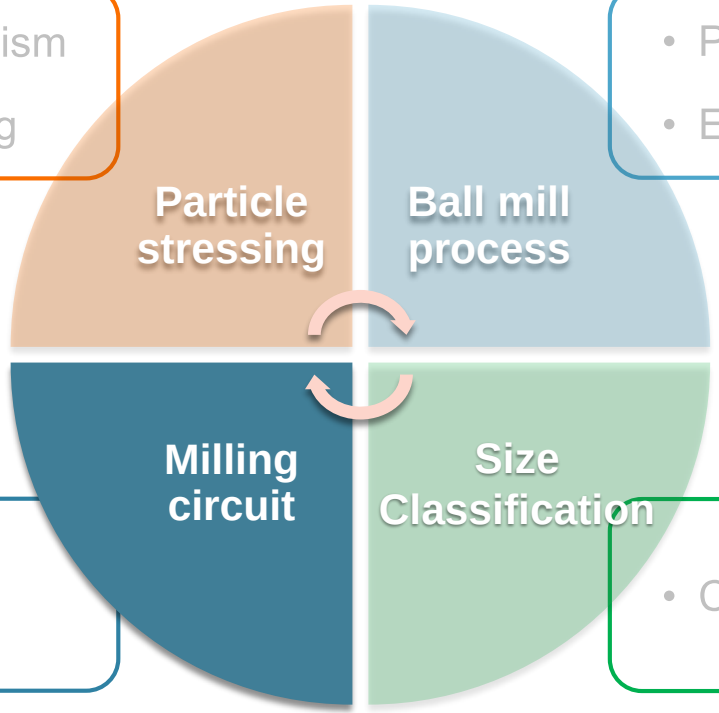
- Corrected cut size is independent of formulation
- The Bypass to coarse outlet is only slightly reduced by G.A.
- The fish-hook effect (smaller then 1 µm) was also slightly reduced by G.A.



System engineering approach

- Grinding aid mechanism
- Powder bed stressing

- Powder transport
- Energy consumption



- Powder recirculation
- Production

- Classifier efficiency

Effects of grinding aids GA
Summary

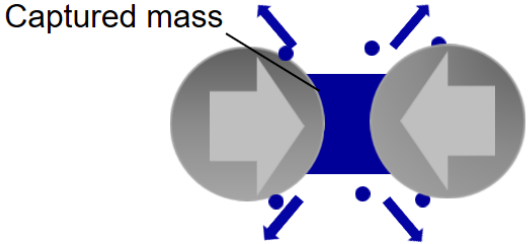
Micro scale

Stabilization against agglomeration

- As thickness of liquid GA < 1 nm, Van der Waals forces are only slightly affected
- GA decrease **surface energy** & adhesion forces
- Agglomeration state affects **classifier performance**

Meso scale

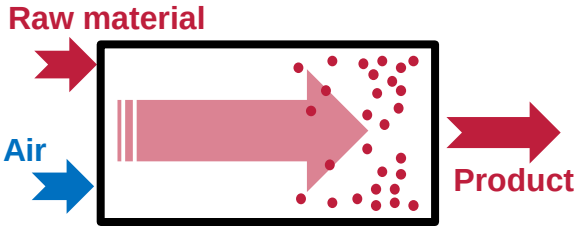
Particle capturing between balls



- **Flowability** and **captured mass** determines stress energy and by that energy efficiency and particle size distribution

Macro scale

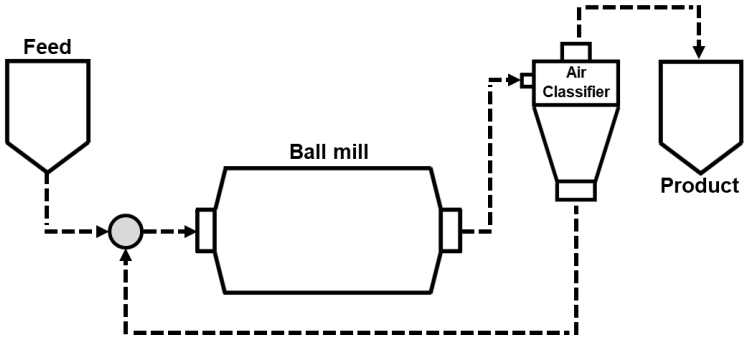
Material transport and mill hold-up

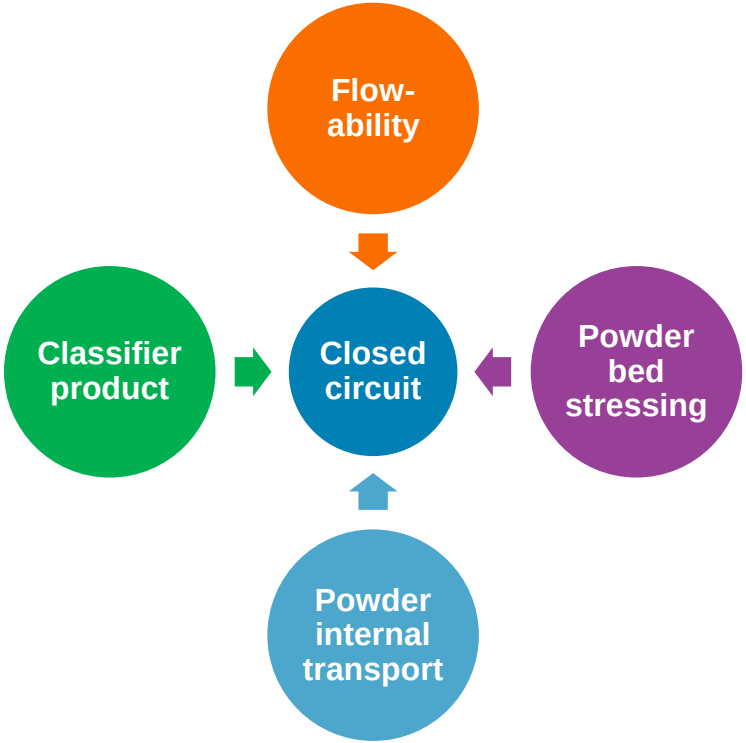


- Flow velocity and by that **hold-up** and **mean residence time** depends strongly on flowability

Milling circuit: Product recirculation

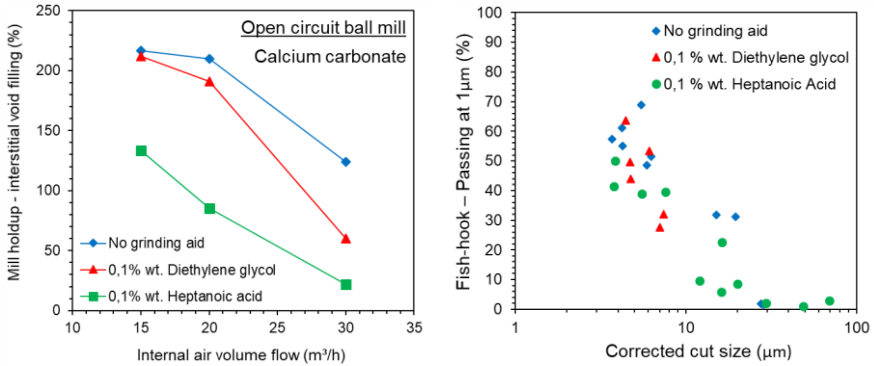
- Closed circuit results are the combination of all discussed mechanisms and the individual units operation

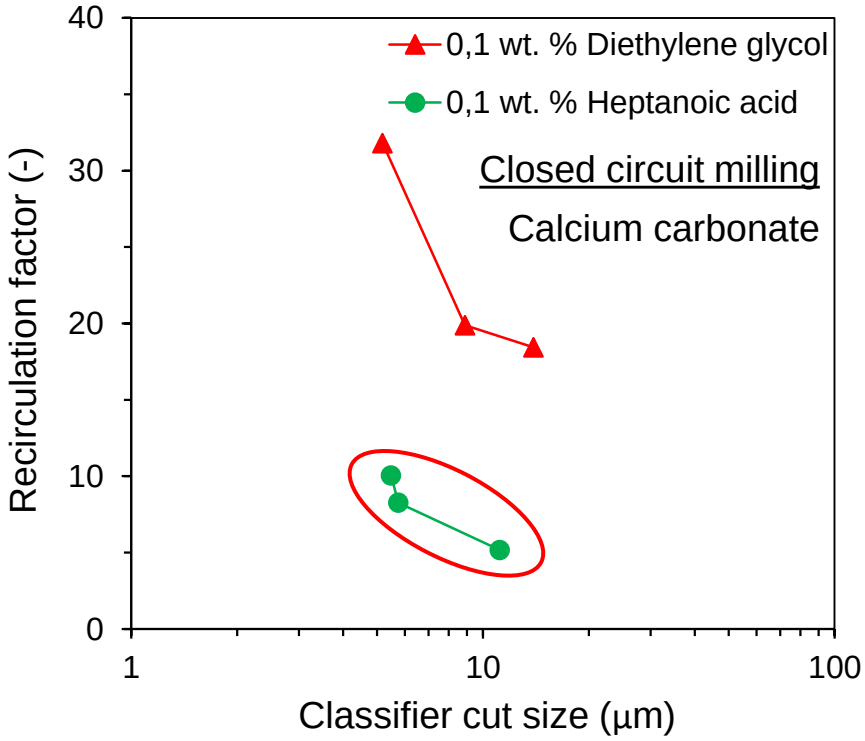




Milling circuit: Product recirculation

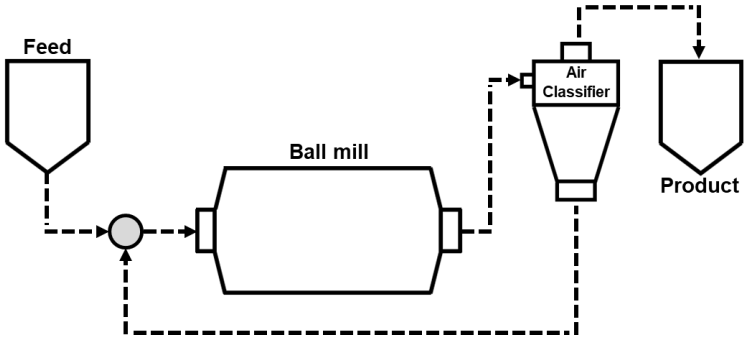
- Closed circuit results are the combination of all discussed mechanisms and individual units operation
- As expected G.A. presents a massive impact on product recirculation

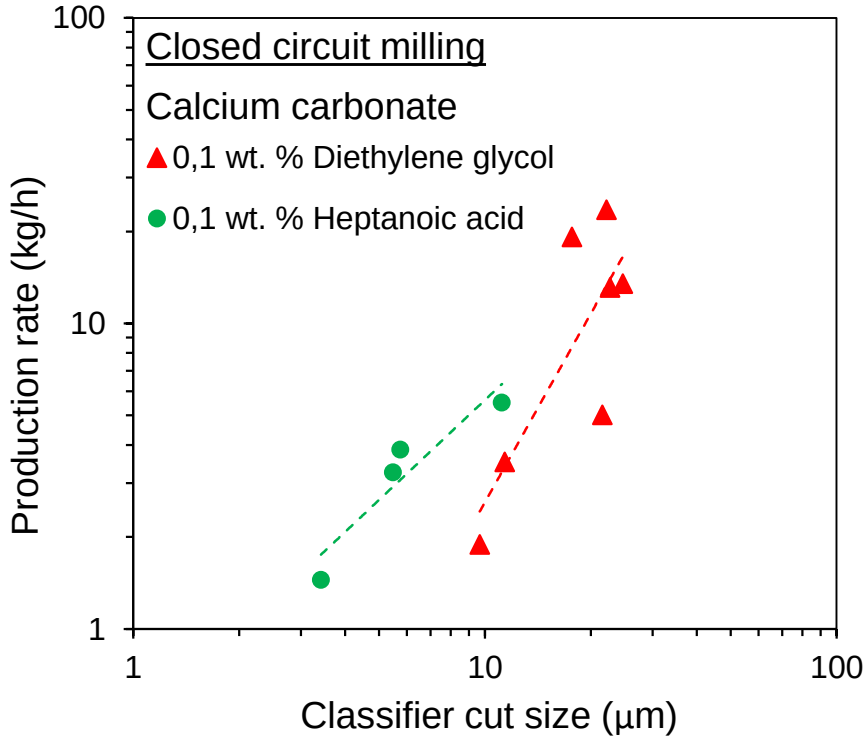




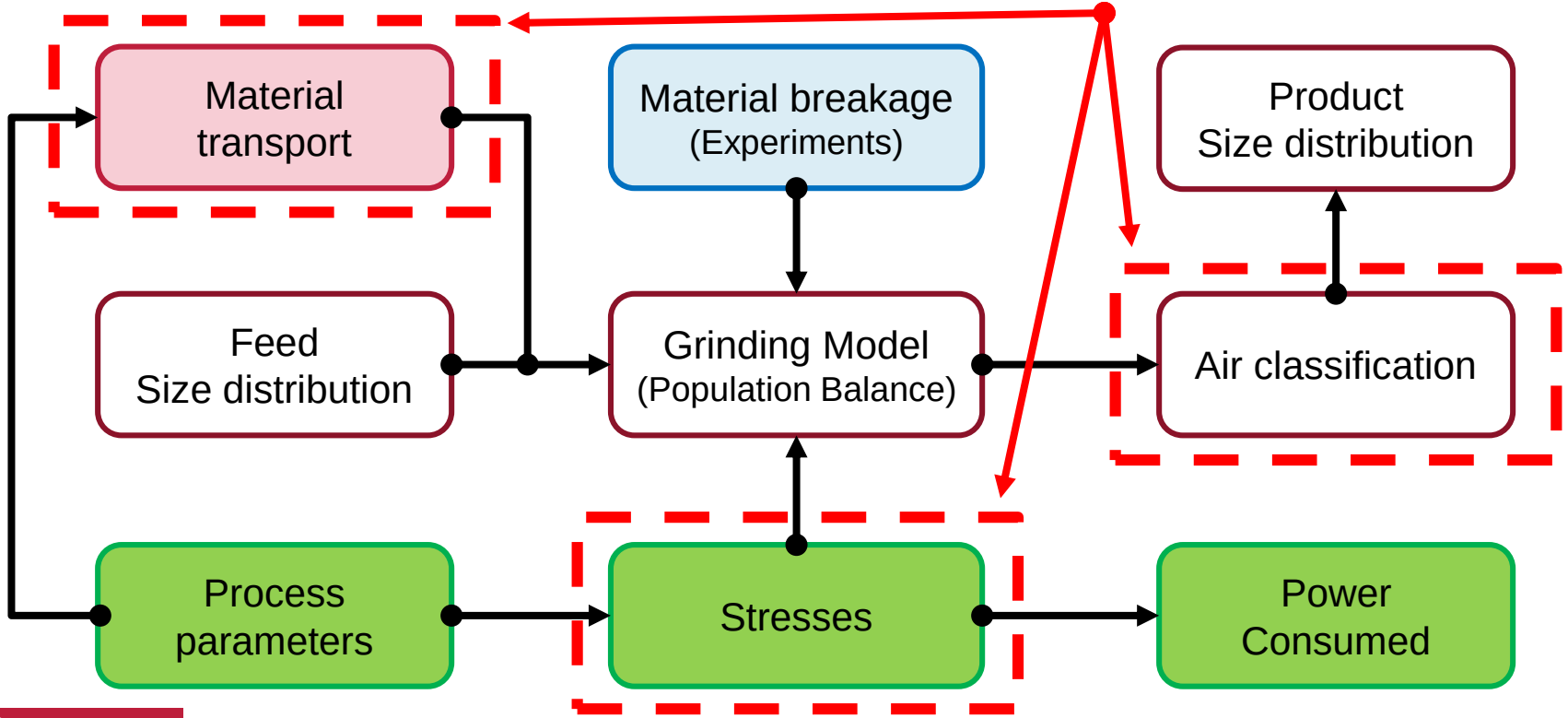
Milling circuit: Product recirculation

- Closed circuit results are the combination of all discussed mechanisms and individual units operation
- As expected G.A. presents a massive impact on product recirculation
- The selection of G.A. can also improve the plant production





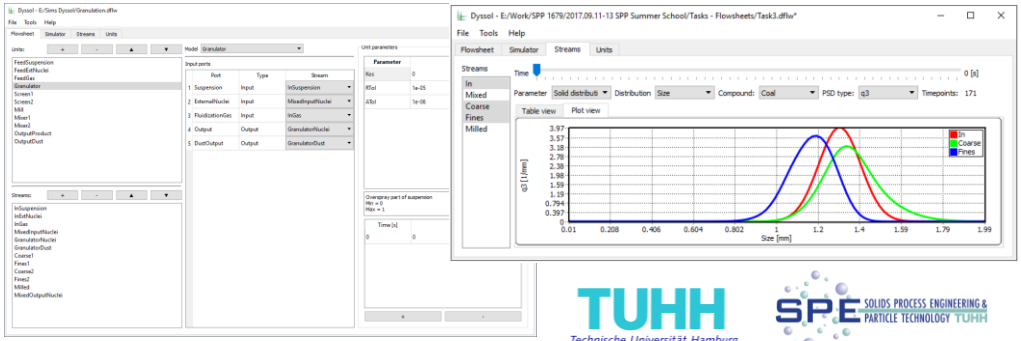
Simulation model structure based on systems engineering approach



Flowsheet simulation tool – Dyssol

Main features:

- Dynamic simulation of complex process
- Consideration of solid, liquid and gas phases and their mixtures
- Open source:
  - Free for use
  - Allow implementation of new unit and models



Ball mill model

- Input:
  - Stresses [from DEM simulations]
  - Powder material and bulk properties
  - Mill mass holdup
- Output:
  - Product size distribution
  - Estimation of power consumption

Air classifier tromp curve

- Input:
  - Tromp curve parameters
- Output:
  - Product size distribution

Project renew proposal

From Micro to Macro

- Relation between microscopic particle properties to macroscopic powder behavior
- Microscopic particle properties: Particle size, surface area and surface energy
- Macroscopic powder properties: Ring shear test, powder rheometer, heap angle, dynamic angle of repose
- Design of a characterization procedure to obtain required model parameters

Modelling of axial powder transport during milling

- Based on milling data combined with macroscopic powder properties

Validation of flowsheet tool with industrial data

- Collection of industrial plant data (either provided or by a sampling at the plant)
- Characterization of material and flowsheet simulation of circuit for validation

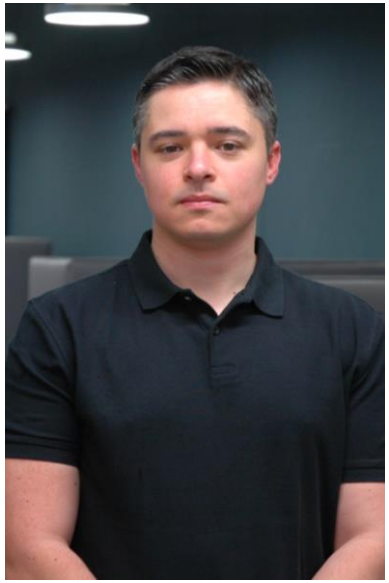
Acknowledgements

iPAT
Institut für Partikeltechnik

IFPRI
International Fine Particle Research Institute

Advisory board:

- Jarrod Hart (Imerys)
- Eric Gulliver (Lincoln Electric)
- Frits van der Westerlaken (Imerys)
- Oliver Gutsche (FMC)

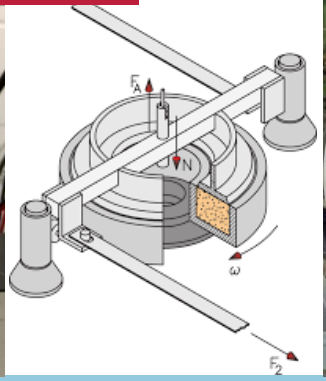


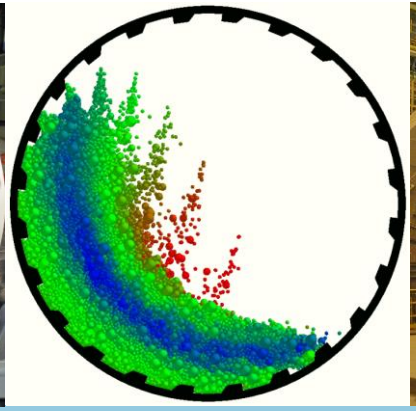
M.Sc. Anderson Chagas

Prof. Dr. -Ing. Arno Kwade

Technische Universität Braunschweig

iPAT
Institut für Partikeltechnik


IFPRI

A Systems Engineering Approach to Dry-Milling with Grinding Aid Additives

Anderson Chagas, Sandra Breitung-Faes, Arno Kwade