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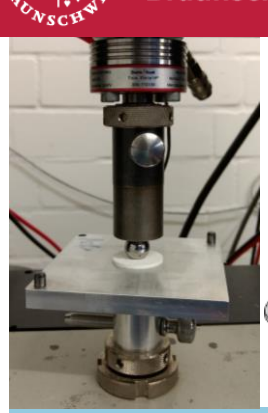
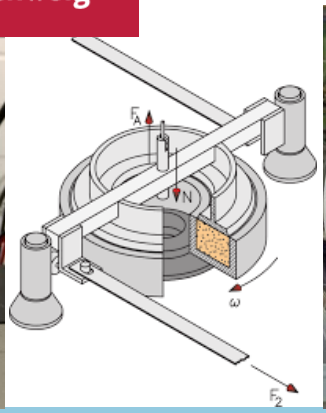
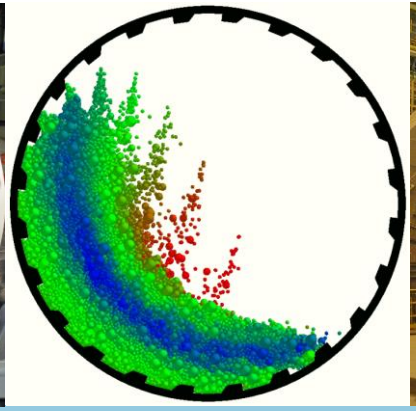





A Systems Engineering Approach to Dry-Milling with Grinding Aid Additives

2nd funding period

Anderson Chagas, Tarek Sulaiman, Arno Kwade

Project introduction

Long term objectives:

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

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

Second phase (3 years period):

I. Determine a proper powder microscopic property to represent the combination of material and GA type and dosage

II. Relate measurable microscopic particle properties with powder bulk behavior

III. Design a characterization procedure to obtain the model parameters required for axial transport simulation

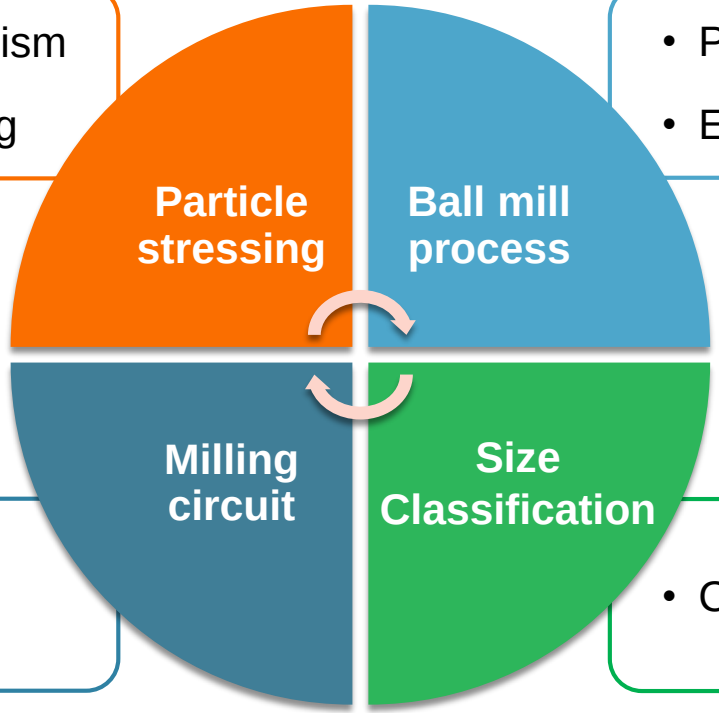
IV. Model powder internal axial transport during milling

V. Validate all developed models and flowsheet simulation with industrial data

1st phase - System engineering approach

- Grinding aid mechanism
- Powder bed stressing

- Powder transport
- Energy consumption

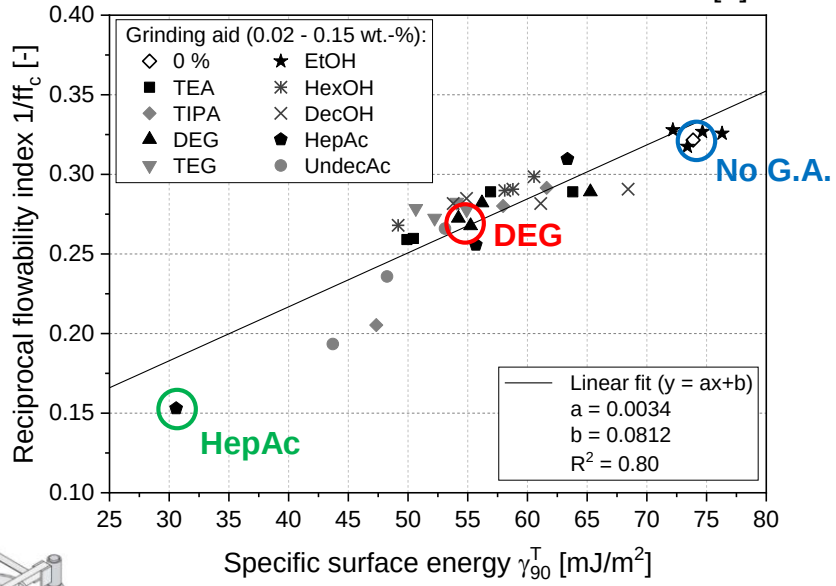


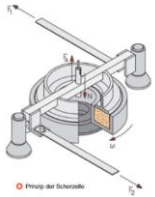
- Powder recirculation
- Plant production

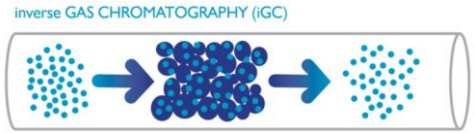
- Classifier efficiency

Particle stressing
Grinding aid mechanism and powder bed stressing

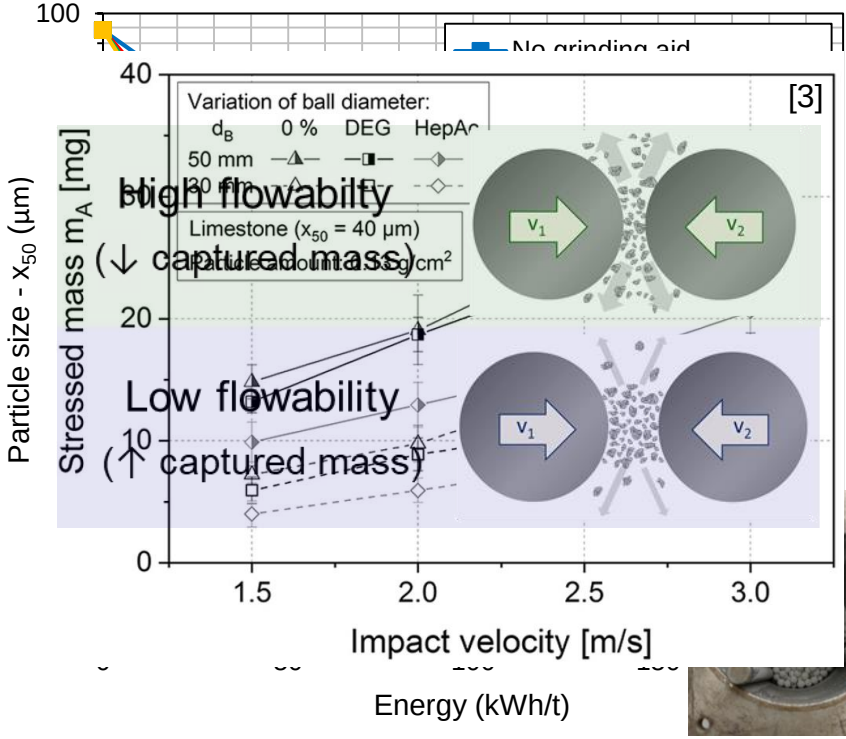
[2]

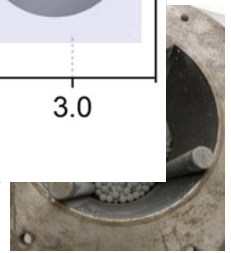






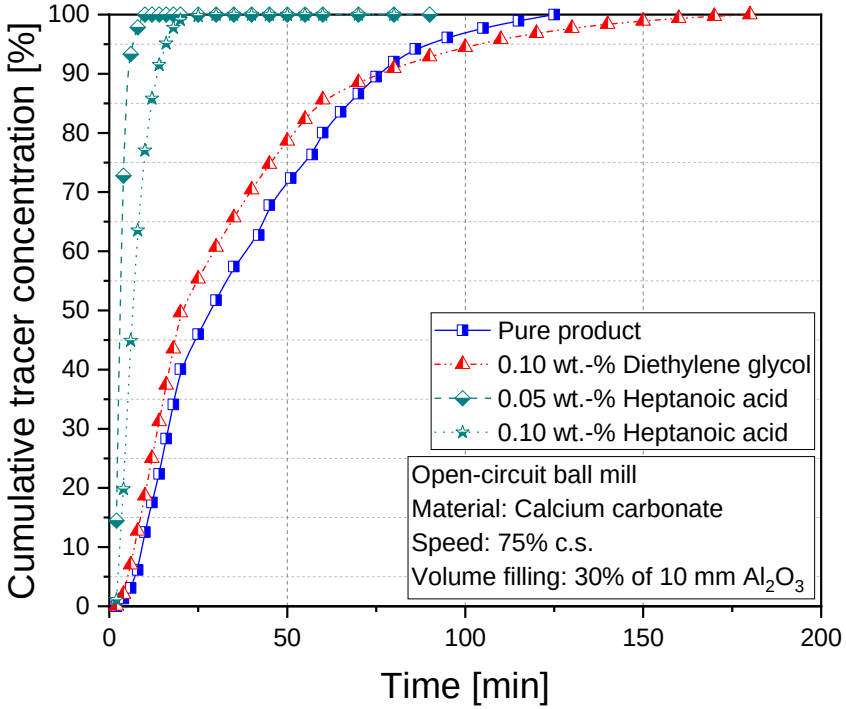
[3]





[2] Prziwara, Breitung-Faes, Kwade. Advanced Powder Technology 29 (2018) 416–425
[3] Prziwara et al. Powder Technology 363 (2020) 326–336

1st phase
Ball milling process

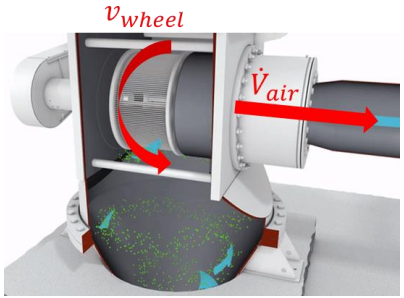


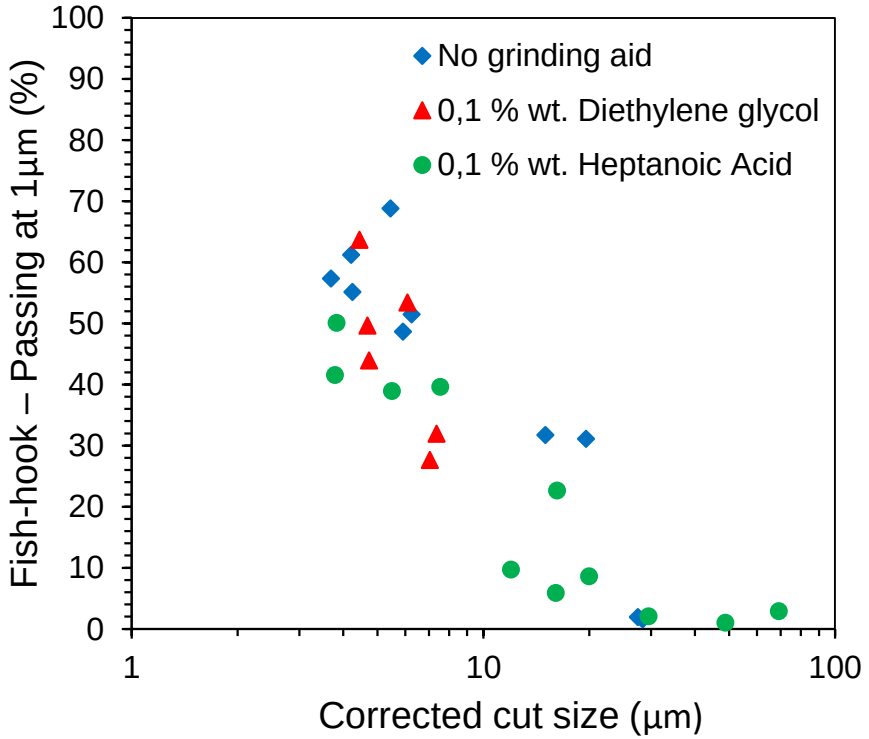
- On continuous ball milling, the main impact of grinding aids is on flow accross the mill
- G.A. such as glycol, presents minimal impact on flowability. However, finer products to be achieved without mill clogging
- G.A. such as carboxylic acids, retards the loss in flowabilty with product size reduction. Allowing the product to flush throught the mill with less size reduction.

1st phase
Size classification

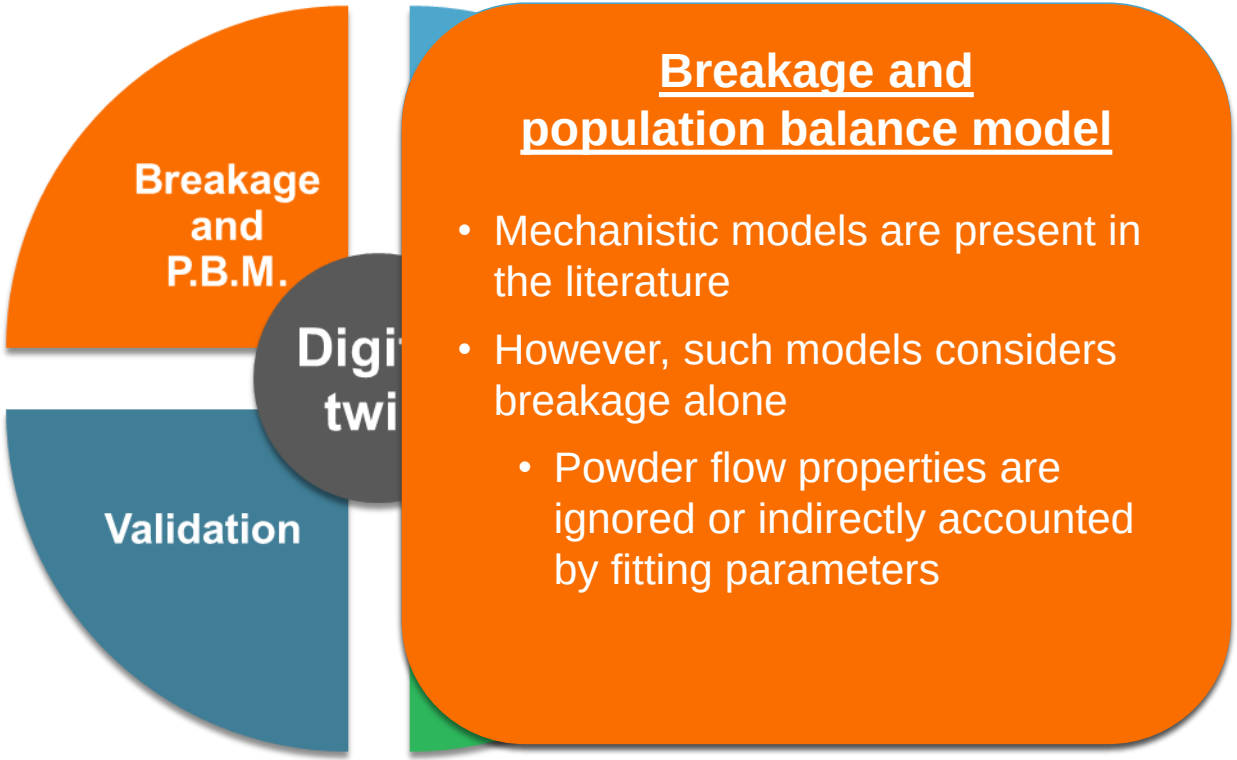
Impact of G.A. on the tromp curve:

- Corrected cut size is independent of formulation for relavant operation points
- 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.





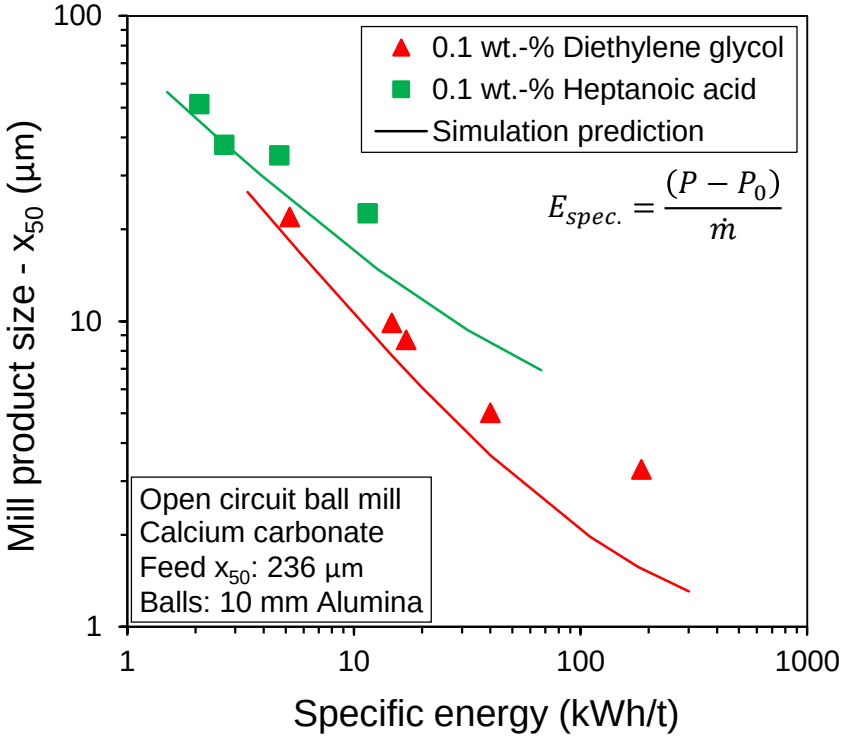
2nd phase - System engineering approach



Breakage and population balance model

- Mechanistic models are present in the literature
- However, such models considers breakage alone
  - Powder flow properties are ignored or indirectly accounted by fitting parameters

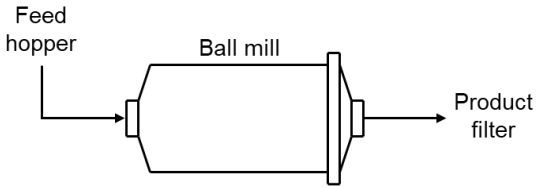
2st phase
Current model capability – Open-circuit milling



- **Flowsheet inputs:**
  - Feed rate
  - mill holdup and residence time
  - Material flow parameters

G.A.

- **Current limitations:**
  - Increase in cohesion is not simulated
  - Material flowability is assumed to be constant

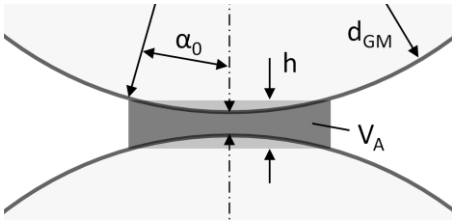


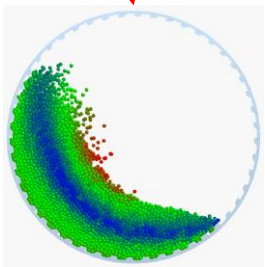
2st phase
Flow dependent breakage rate

- The product breakage will account for powder flow properties

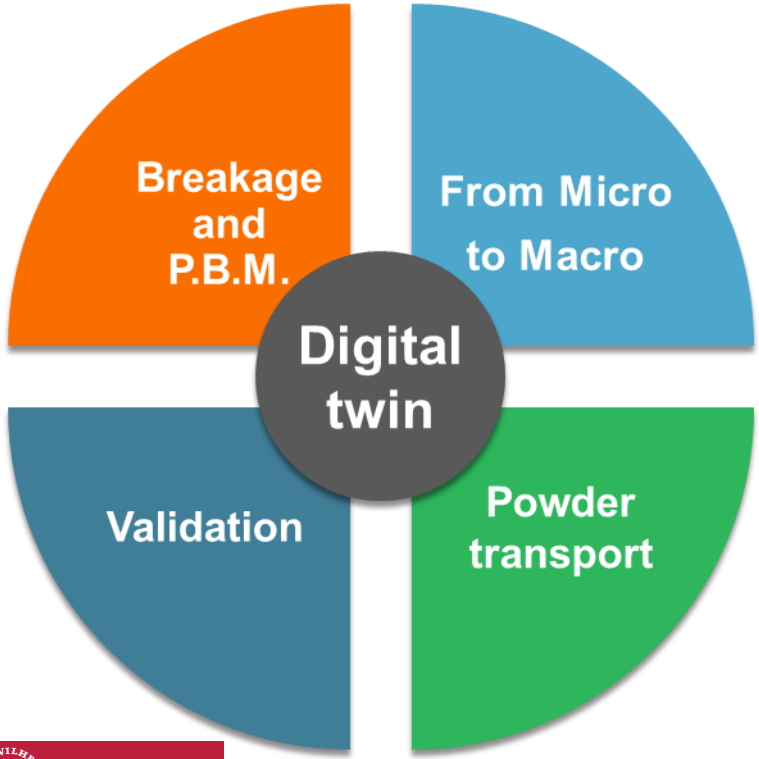
$$\begin{bmatrix} Breakage\ rate \\ \text{for } energy\ E \end{bmatrix} = \begin{bmatrix} Amount\ of\ material \\ captured\ by\ energy\ E \end{bmatrix} \cdot \begin{bmatrix} N^{o}\ of\ \text{stresses.} \\ of\ energy\ E \end{bmatrix} \cdot \begin{bmatrix} fraction\ of\ material \\ thats\ breaks\ with\ E \end{bmatrix}$$

$$S_i(t) = \int_0^{\infty} \frac{m_{capt}}{m_{holdup}} \cdot N_{col}(E,t) \cdot \left[\int_0^{1} F_i(E) \cdot p(e)\, de \right] \cdot dE$$





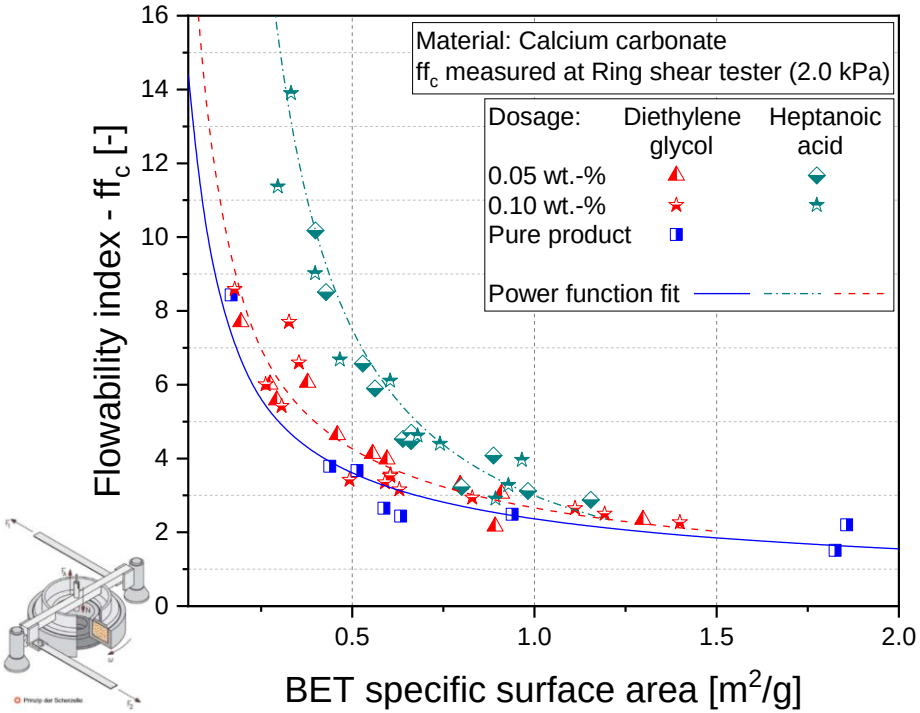
2nd phase - System engineering approach



From Micro to Macro

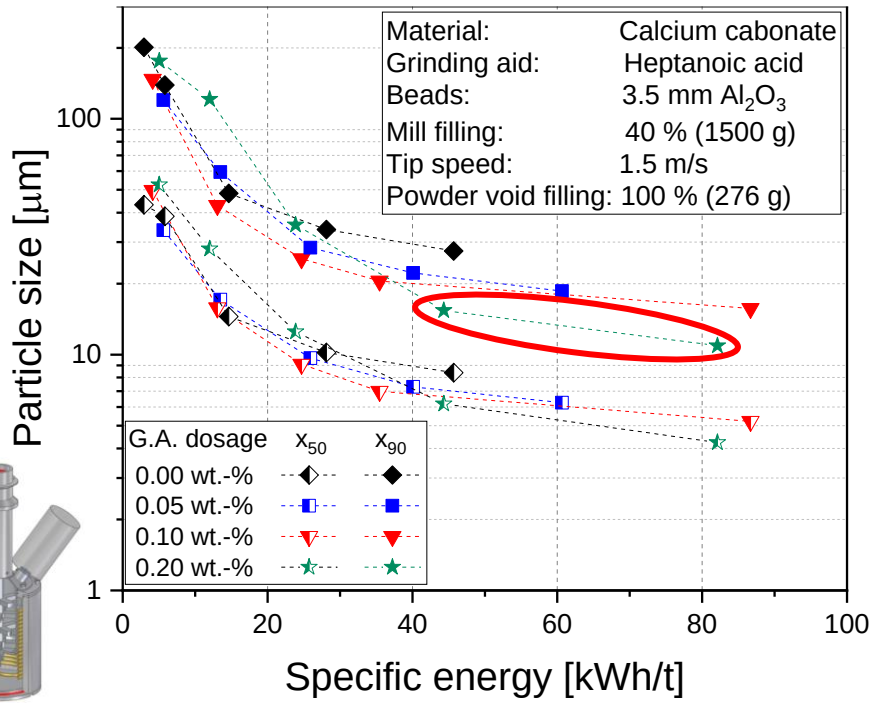
- Relation between microscopic particle properties to macroscopic flow behavior
- Selection of proper microscopic property to represent the combination of material and GA type and dosage
- Design a characterization procedure to obtain the model parameters

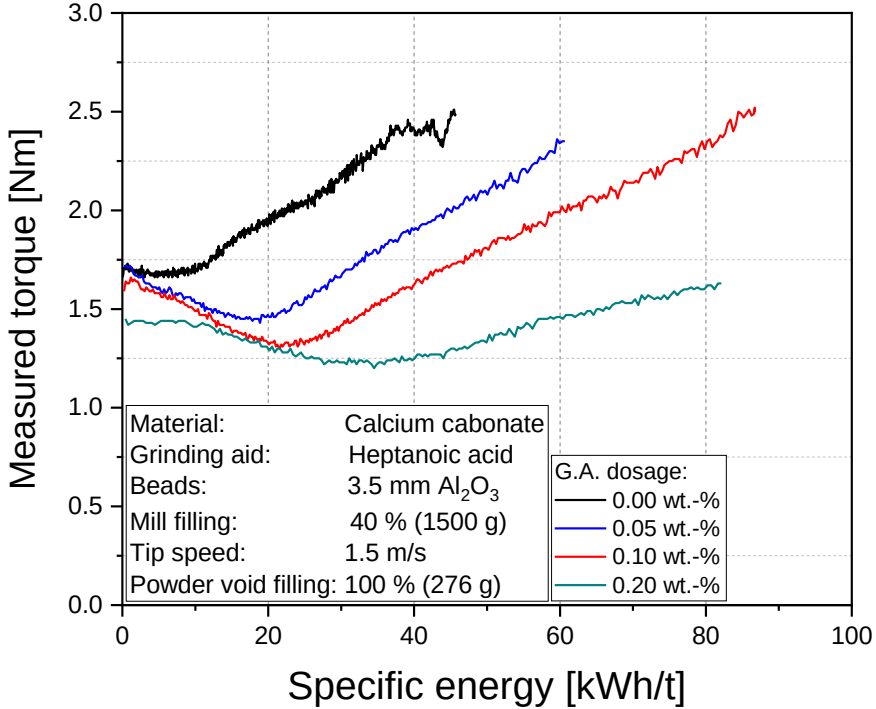
2nd phase – From Micro to Macro
Preliminary results



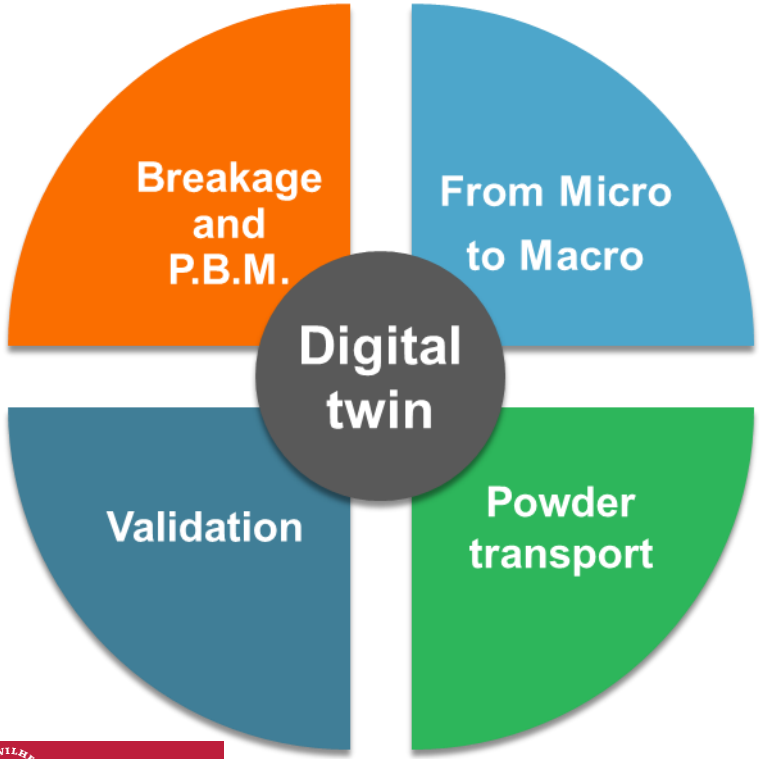
- As expected, flowability is a function of both particle size (or surface area) and grinding aids
- A power law relates flowability to the combination of powder surface area and class of grinding aid
- Once pre-characterized, a size population balance model can dynamically estimates the changes in flow during grinding

2nd phase – From Micro to Macro
Preliminary results





2nd phase - System engineering approach

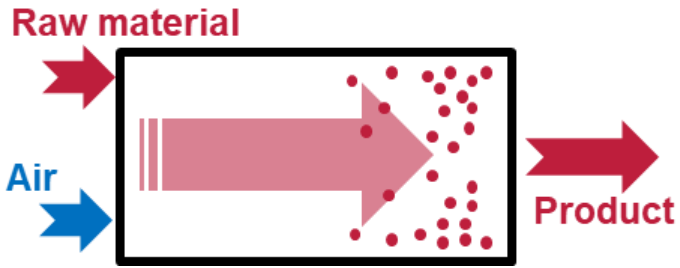


Powder transport model

- A transport model would allow dynamical flowsheet simulation of a dry grinding plant
- The outcome of the previous WP will be used to model the powder axial flow, mill holdup and discharge
- CFD-DEM coupled simulations will also be done describe air conveying

2nd phase – From Micro to Macro
Transport model

- **Main goal:** Implementation of transport model to allow flowsheet simulations
- Outcome of the previous WP will be used to model the powder axial flow, mill holdup and discharge rate
- A one-dimension transport model will be adopted:

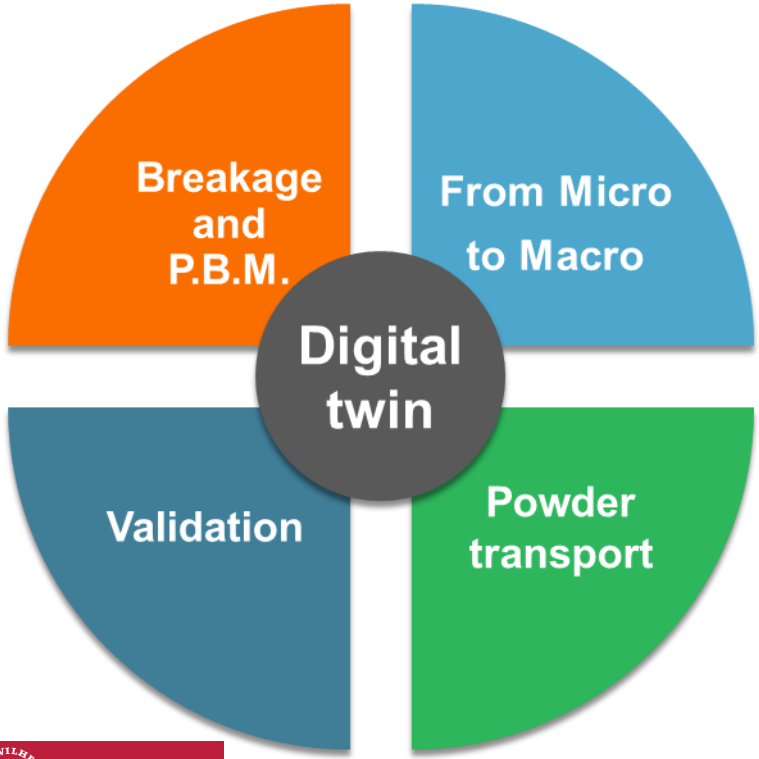


$$\frac{\partial Q}{\partial t} = D_x \frac{\partial^2 Q}{\partial x^2} - u_x \frac{\partial Q}{\partial x} \qquad Pe = L \frac{u_x}{D_x}$$

$$Q(t) = \frac{1/\theta}{2\sqrt{\pi \cdot Pe \cdot \left(t/\theta\right)^3}} exp\left[-\frac{\left(1 - t/\theta\right)^2}{4 \cdot Pe \cdot \left(t/\theta\right)}\right]$$

$$w_{i,cont.}(t) = \int_0^\infty w_{i,batch}(t) \cdot Q(t) \cdot dt$$

2nd phase - System engineering approach



Digital twin validation

- A industrial plant is being search for this task
- Product sampling rounds would be conducted to obtain,
  - Product size and flow rates
  - Energy consumptions
- Product samples will be characterized and the process simulated in a flowsheet tool

Acknowledgements

iPAT
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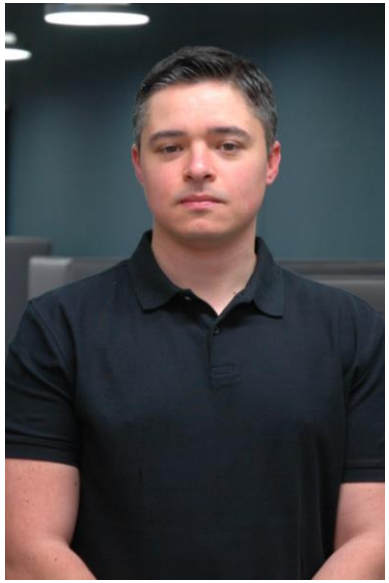
IFPRI
International Fine Particle Research Institute

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

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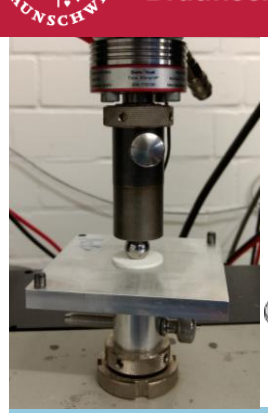
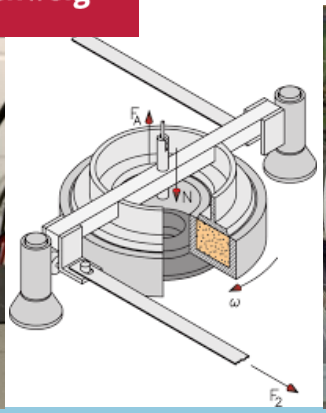

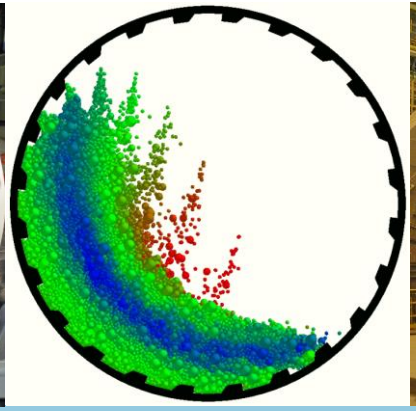

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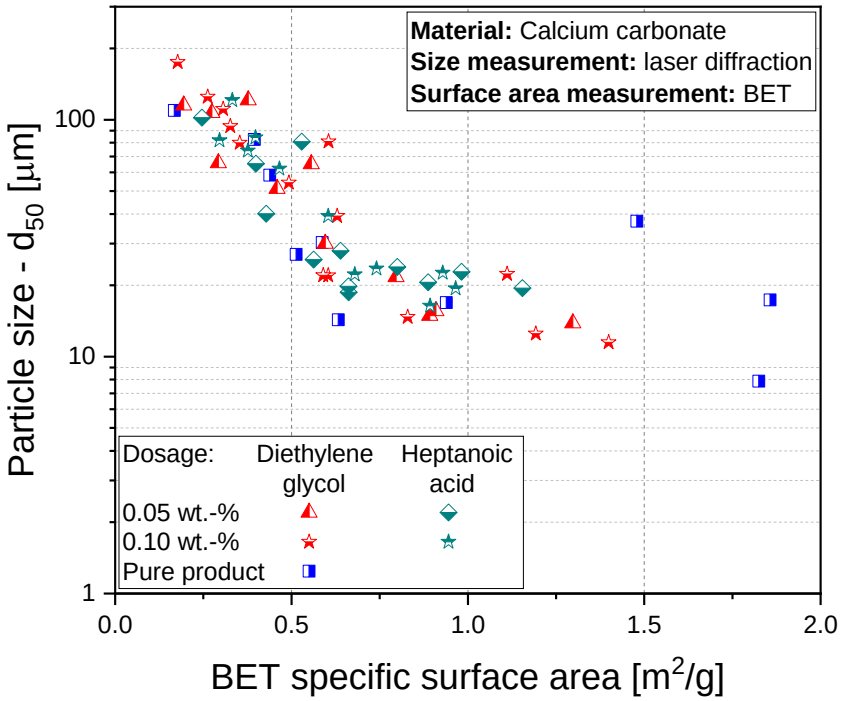
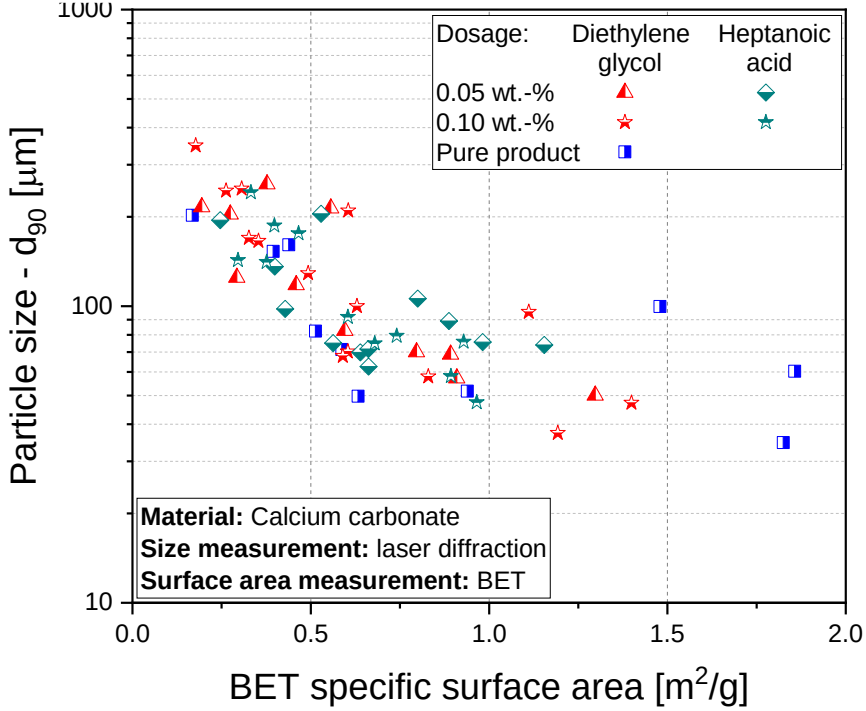
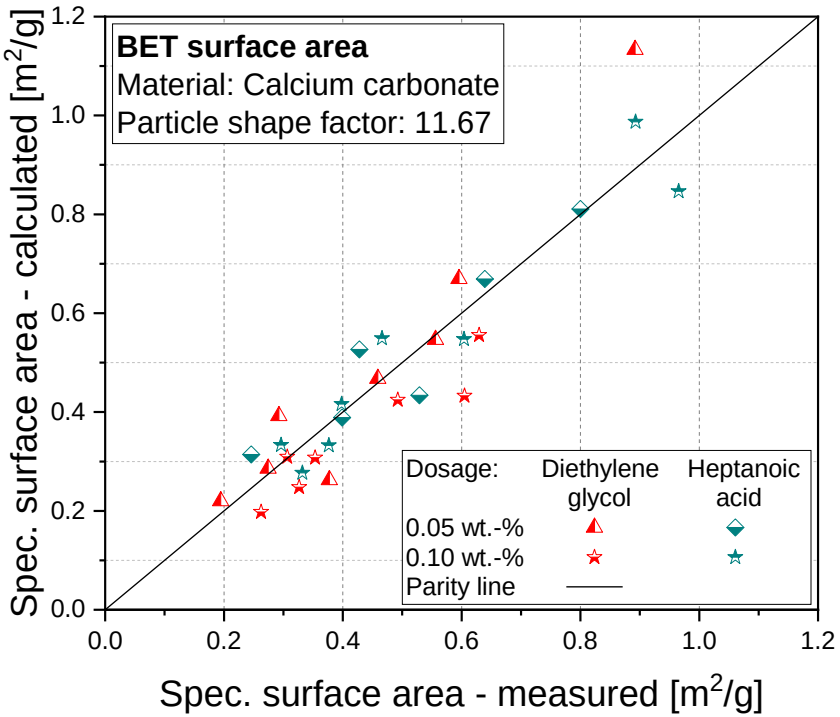
Surface area vs particle size





Specific surface area



- Specific surface area calculated from measured size distribution and the material solid density. Spherical particles were assumed and multiplied by a shape factor

$$Shape\ factor = \frac{\left(Surface\ area\ measured\ by\ BET\right)}{\left(Surface\ area\ for\ spherical\ particles\right)}$$