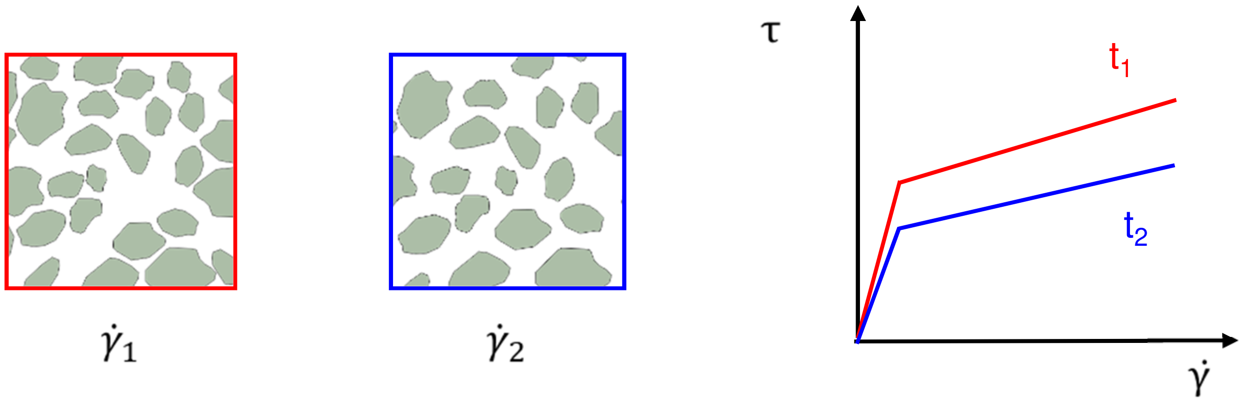
Effect of Different Shear Rates on Particle Microstructure of Cementitious Materials in a Wide Gap Vane-in-Cup Rheometer



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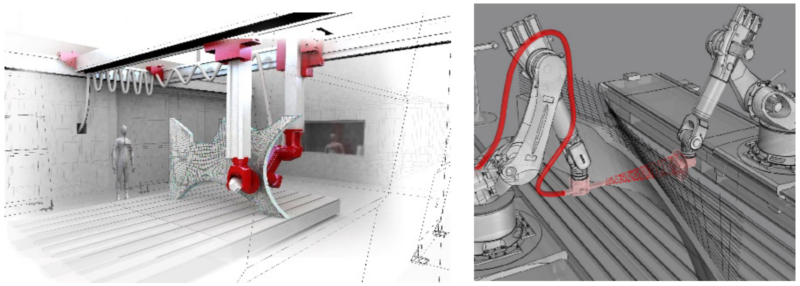
Overview

- **Concept**
- **Materials and sample preparation**
- **Experimental investigations**
  - Focused Beam Reflectance Measurement (FBRM)-Rheometer coupled setup
  - Shear profile
- **Computational Fluid Dynamics (CFD) Simulations**
- **Results and discussion**
  - Effect of shear rates on Median Chord Length (MCL)
  - Effect of shear rates on variation of small particles

Concept

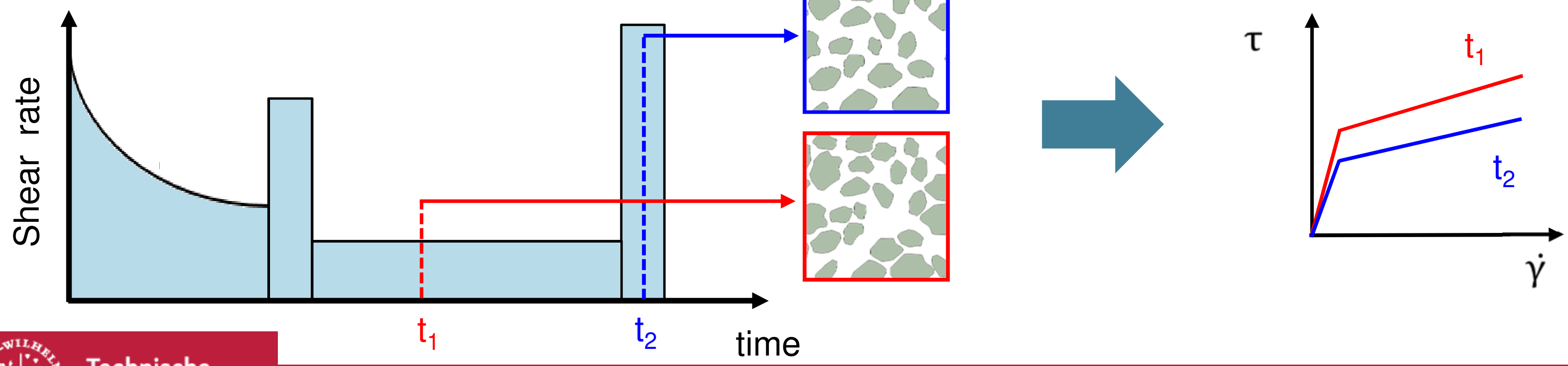
Motivation: Modelling of rheological characteristics in case of complex processes

Example: 3D Printing by concrete spraying process



[Digital Building Fabrication Laboratory, TU Braunschweig]

Shear history (example) → **Microstructure** (particle agglomeration) → **Rheological properties** as a function of shear history



Materials and sample preparation

Materials

- Ordinary Portland Cement CEM I 42.5 R (OPC; HeidelbergCement)
  - Mean particle size d_{50}: 14.8 µm
  - Density: 3.12 g/cm³
- Demineralized water

→ cement paste with a volumetric solid fraction Φ_v: 0.42 (-)

Sample preparation

- 1698 g cement
- 754 g demineralized water
- mixed in a mortar mixer (according to DIN EN 196-1)

Table 1: Mixing procedure to prepare cement paste

Process	Mixing Intensity	Duration
Dry homogenization of raw material	Level 1 (140 min^{-1})	60 s
Addition of water during mixing	Level 1 (140 min^{-1})	15 s
Mixing at lower speed	Level 1 (140 min^{-1})	45 s
Rest, manual homogenization	–	90 s
Mixing at higher speed	Level 2 (285 min^{-1})	60 s
Rest, manual homogenization	–	30 s
Mixing at higher speed	Level 2 (285 min^{-1})	120 s

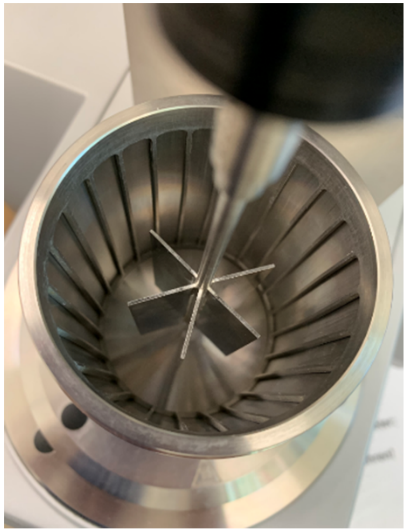
Experimental investigations
FBRM-Rheometer coupled setup

In-situ particle agglomeration monitoring during rheometer test

Focused Beam Reflectance Measurement (FBRM)
- 19 mm probe diameter
- 4.83 mm scan circle diameter

Vane-in-cup rheometer
- Anton Paar MCR 502
- Wide gap rheometer
- Searle principle
- Wall boundary conditions (vane probe, blades)

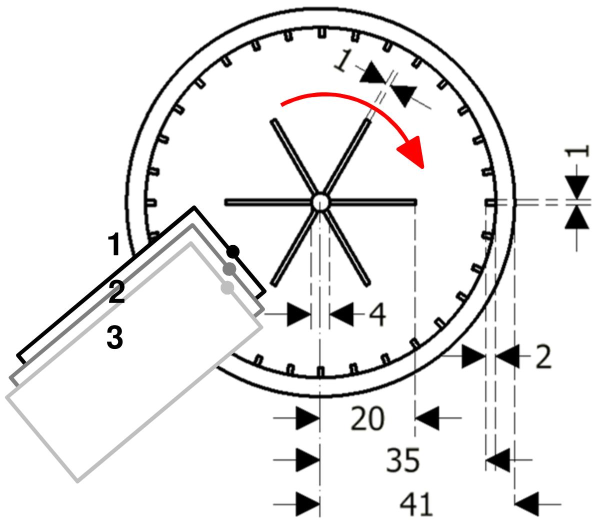
Coupling



Experimental investigations
FBRM-Rheometer setup development

Integrated FBRM into vane-in-cup rheometer in 3 different radial directions

Horizontal cross section | **Vertical cross section**



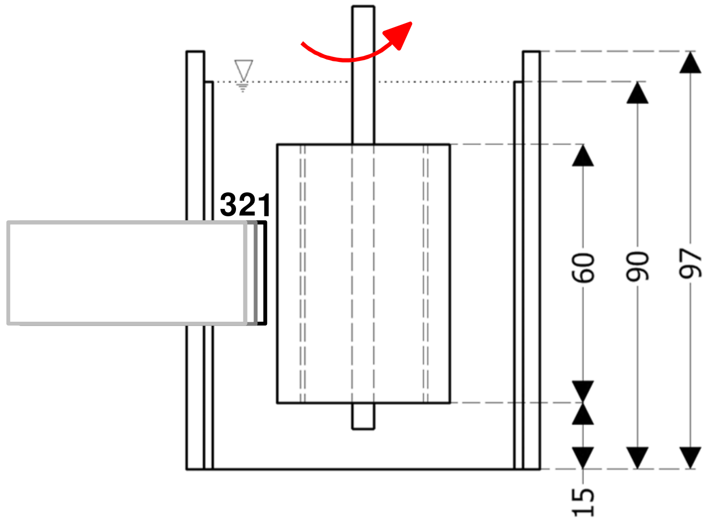


Figure 1. Scheme of the FBRM probe integrated into the rheometer at three different radial positions (the distance of each position from the middle point until the tips of the vane probe ; (a) vertical cut, (b) top view; all dimensions in mm.

Distance of FBRM system (middle point) from tip of vane probe

- Position 1: 3.5 mm
- Position 2: 5.5 mm
- Position 3: 7.5 mm

Experimental investigations
Shear profile

The rotational speed increased from 0 rpm to 700 rpm within 15 s (ramp)

The rotational speed decreased **stepwise**, each step lasting for 90 s

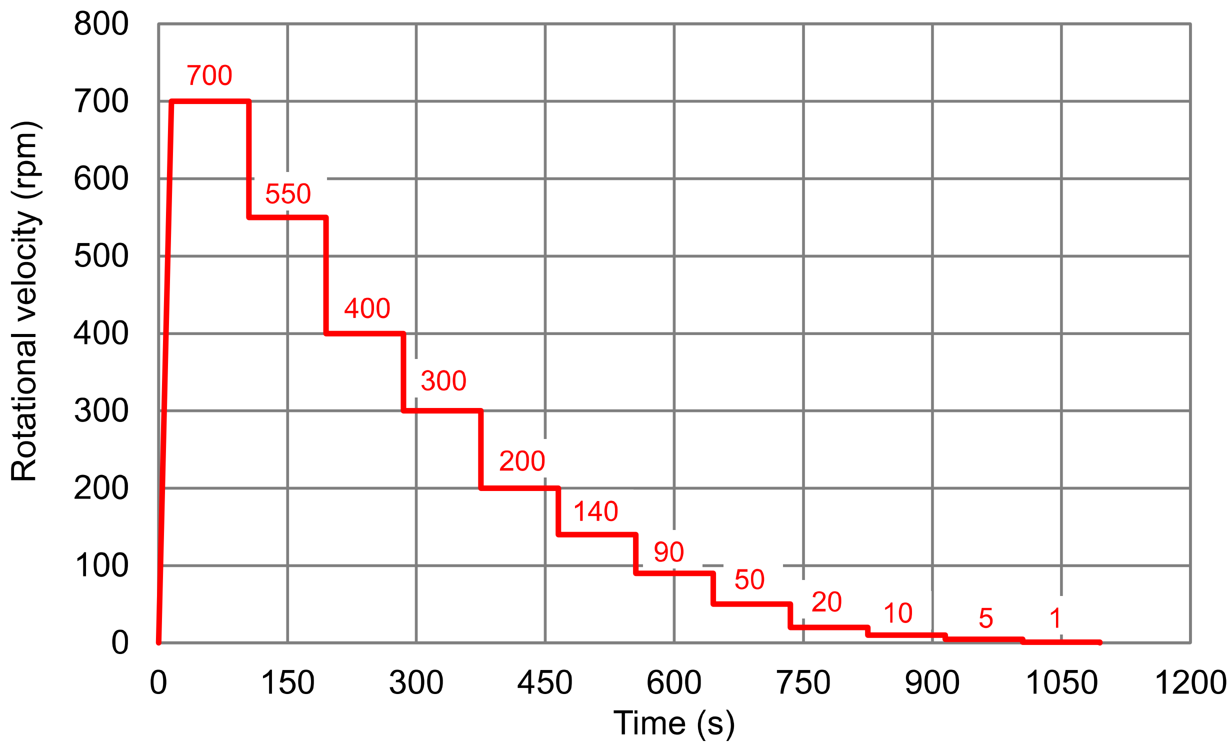


Figure 2. Rotational rheometer profile consisting of different steps of rotational velocity

Computational Fluid Dynamics (CFD) Simulations

Investigation the material flow behavior in a complex wide gap rheometer

Determination of the **non-linear shear rate distribution over gap** taking into account **stress peaks** in a vane-in-cup wide gap rheometer using **CFD simulations**

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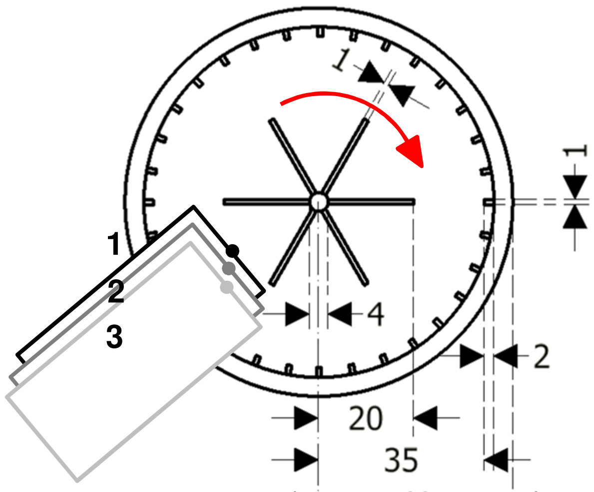
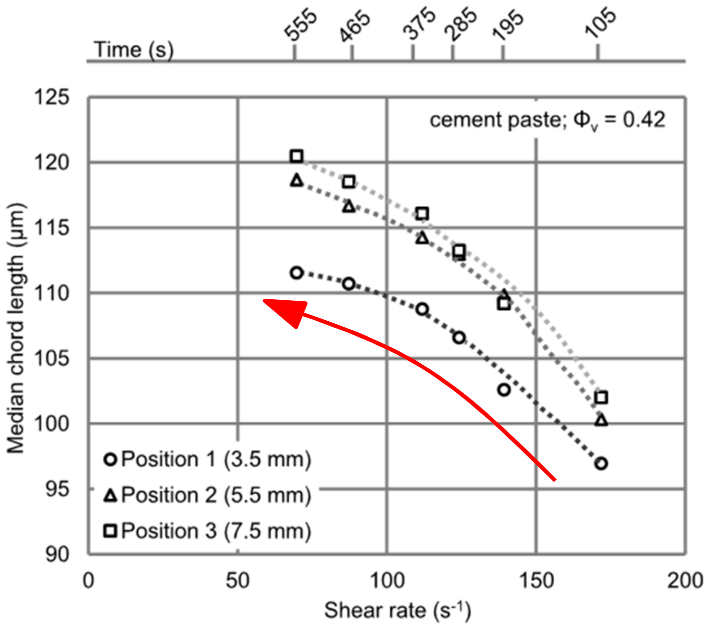
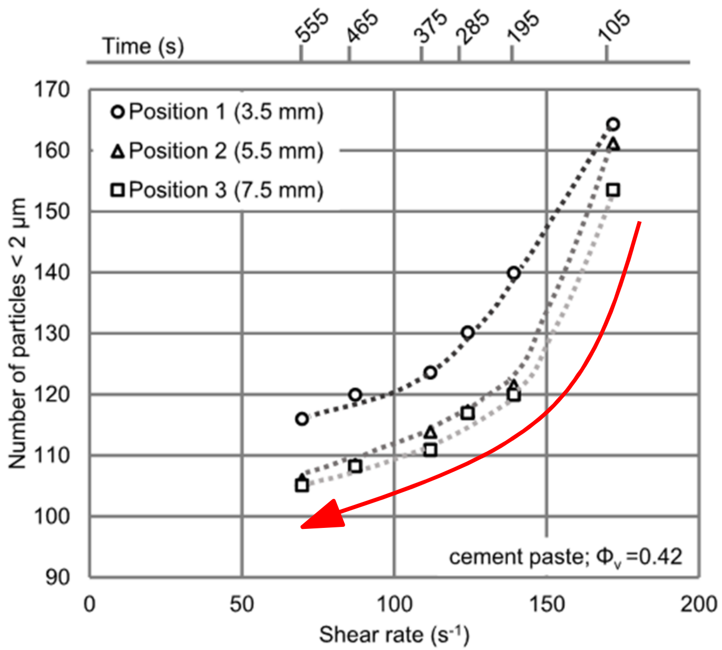


Results & Discussion

- The mean chord length (MCL) increases in all three positions as the **average shear rate** increases → increasing particle agglomeration with decreasing **average shear rates**
- Decreasing the number of particles < 2 µm about 31% in all radial positions with decreasing **average shear rate**



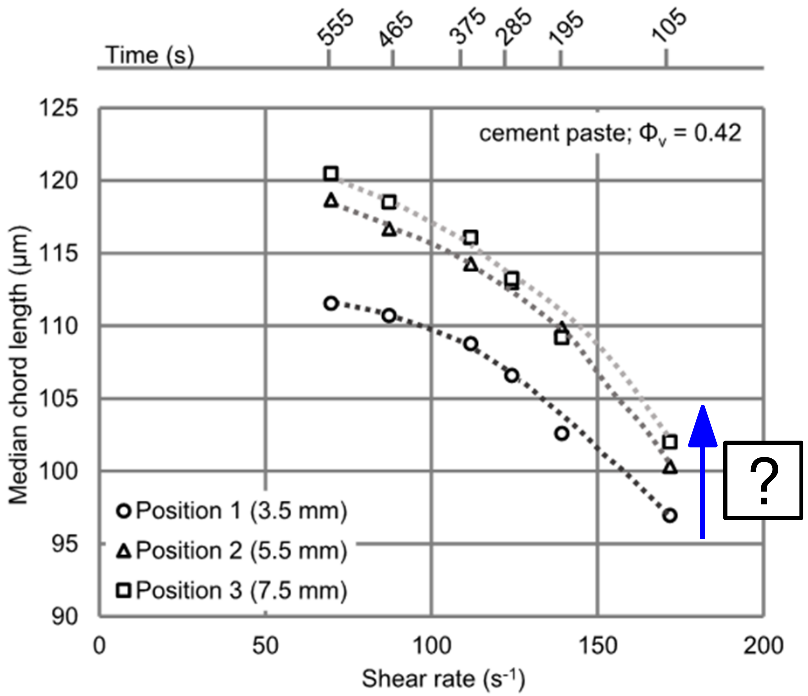
Averaged median chord length for different average shear rates in three different radial positions over the gap [1]



Particle numbers < 2 µm as a function of the average shear rate on the vane probe at different radial positions of the FBRM probe [1]

Results & Discussion

- **First source:** Higher **local shear rate** at position 1 → particle dispersion more pronounced as compared to the other two radial positions, resulting in lower MCL.
- **Second source:** Shear-induced particle migration



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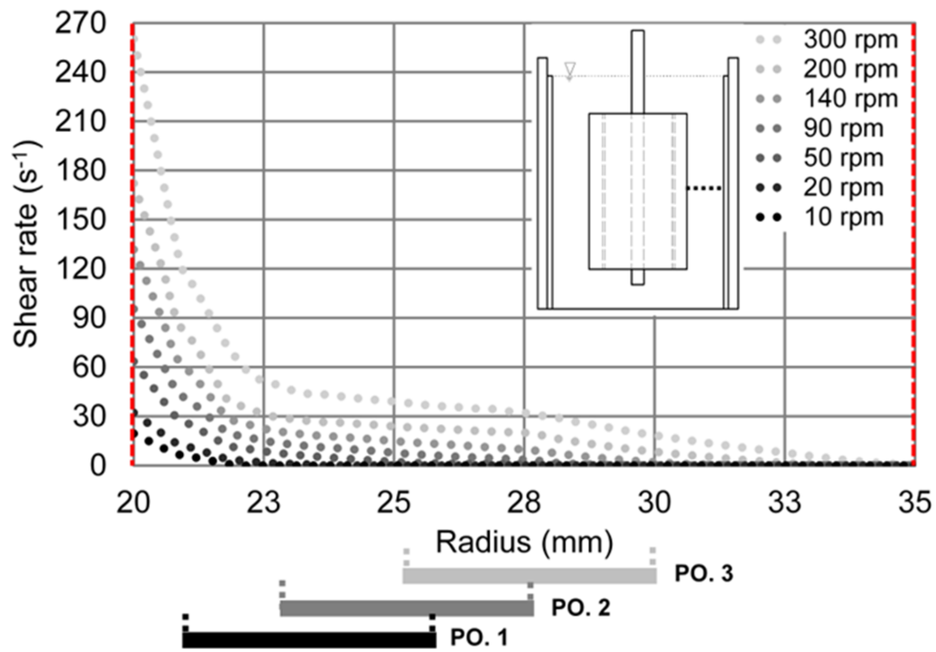

Different local shear rates due to various positions of the FBRM system within the gap from CFD simulations [1,2]

References

1) **Eslami Pirharati, M.; Krauss, H.-W.; Schilde, C.; Lowke, D.** Effect of Different Shear Rates on Particle Microstructure of Cementitious Materials in a Wide Gap Vane-in-cup Rheometer. Materials 2020, 13, 2035.

2) **Eslami Pirharati, M.; Ivanov, D.; Krauss, H.-W.; Schilde, C.; Lowke, D.** Numerical Simulation of the Flow Behavior of Newtonian Fluids in a Wide Gap Rheometer by CFD. In: Mechtcherine V., Khayat K., Secrieru E. (eds) Rheology and Processing of Construction Materials. RheoCon 2019, SCC 2019. RILEM Bookseries, vol 23. Springer, Cham.

Thank you for your attention

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