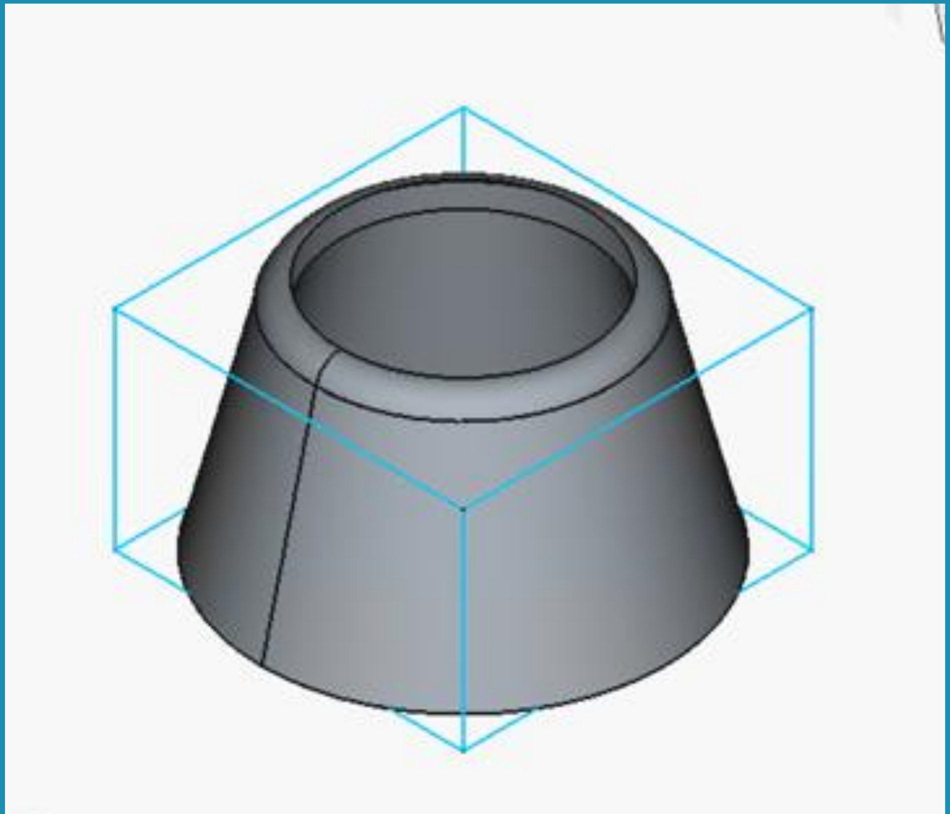
DualSPHysics Modelling of CDW-based Geopolymer Paste Flow in Mini Slump Tests



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The University of Manchester, United Kingdom

DualSPHysics Modelling of CDW-based Geopolymer Paste Flow in Mini Slump Tests

Two major problems in the construction industry for a sustainable society

1. **Cement:** 8% of global CO_2 emission

2. **Construction & Demolition Waste (CDW):** 40% of all solid waste

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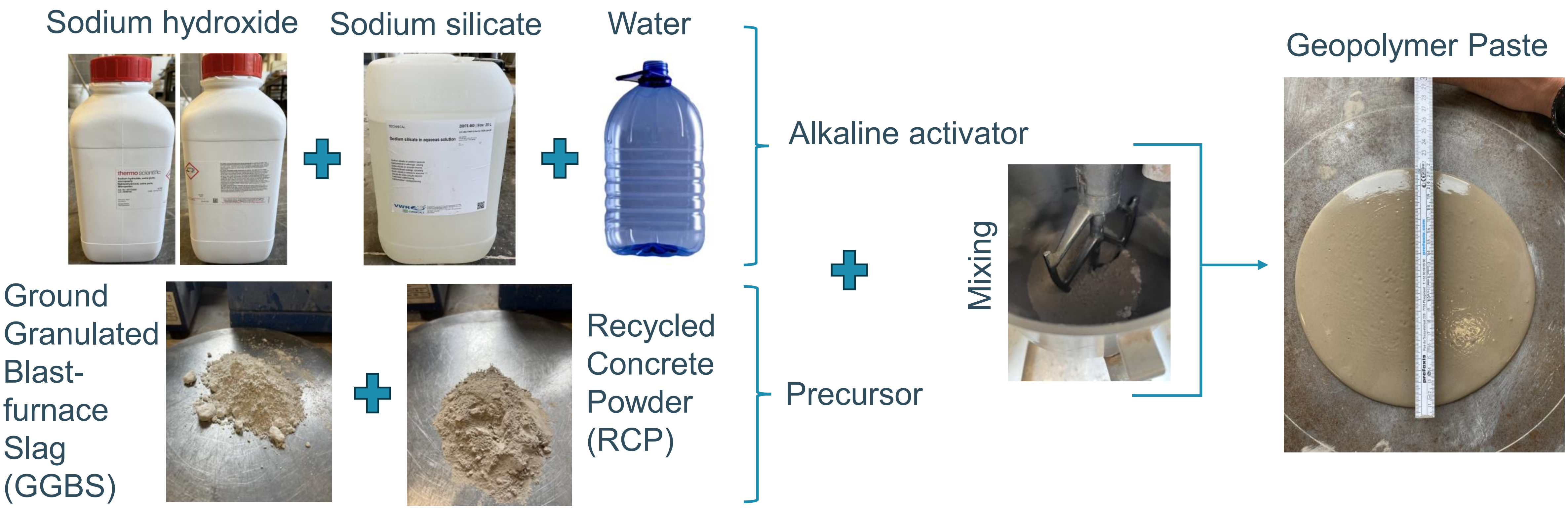

- **Geopolymers:** Sustainable, low-carbon binders
- **Made from** <u>industrial by-products</u> or/and <u>recycled materials</u>
- **Using Geopoylmer binders** → up to 80% decrease in CO_2

DualSPHysics Modelling of CDW-based Geopolymer Paste Flow in Mini Slump Tests

Slump Test

Useful to quickly assess workability and placement feasibility on site

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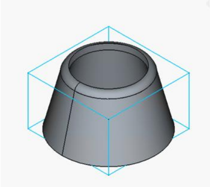
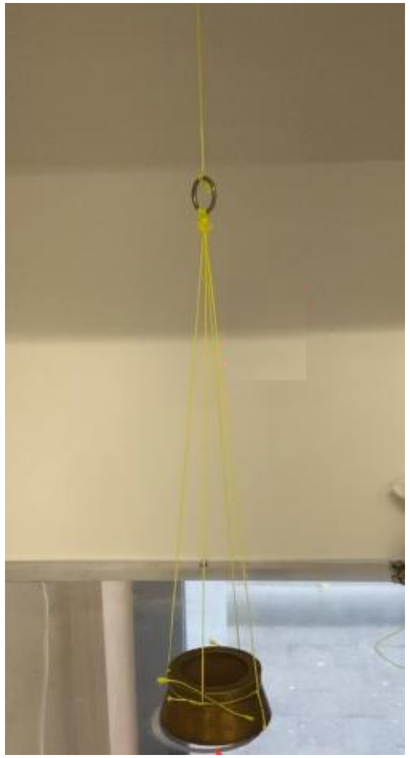


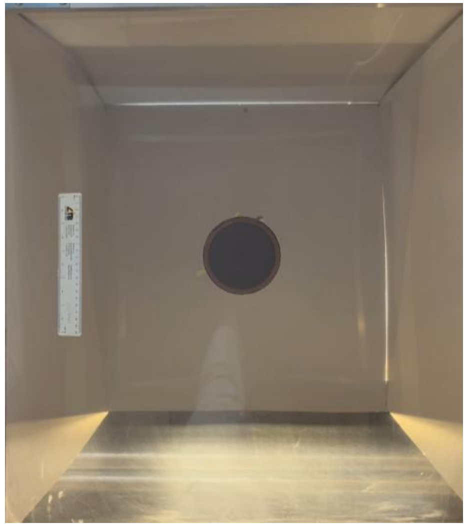
Mini Slump Test

can be regarded as a *laboratory-scale alternative* to the slump test.

Pashias et al. (1996)



Side view



'bottom' view

- Requires only small material volumes
- Highly sensitive to paste rheology (reliability is high)
- Provides time-dependent flow information

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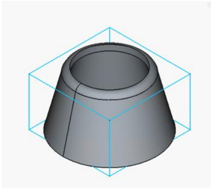
DualSPHysics Modelling of CDW-based Geopolymer Paste Flow in Mini Slump Tests



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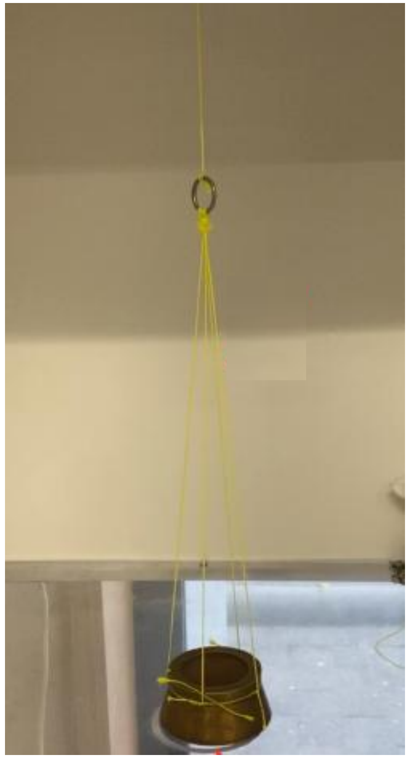
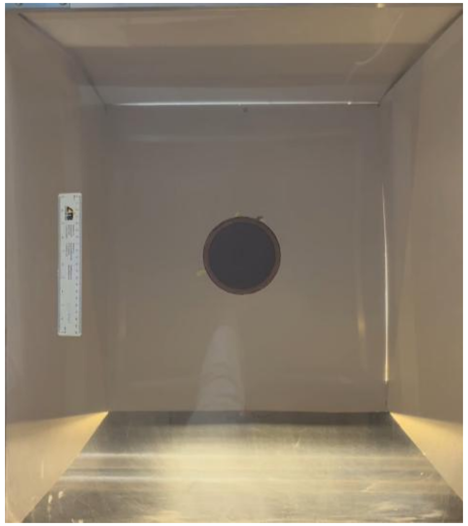


Side view



‘bottom’ view

- Requires only small material volumes
- Highly sensitive to paste rheology (reliability is high)
- Provides time-dependent flow information

DualSPHysics can be applied

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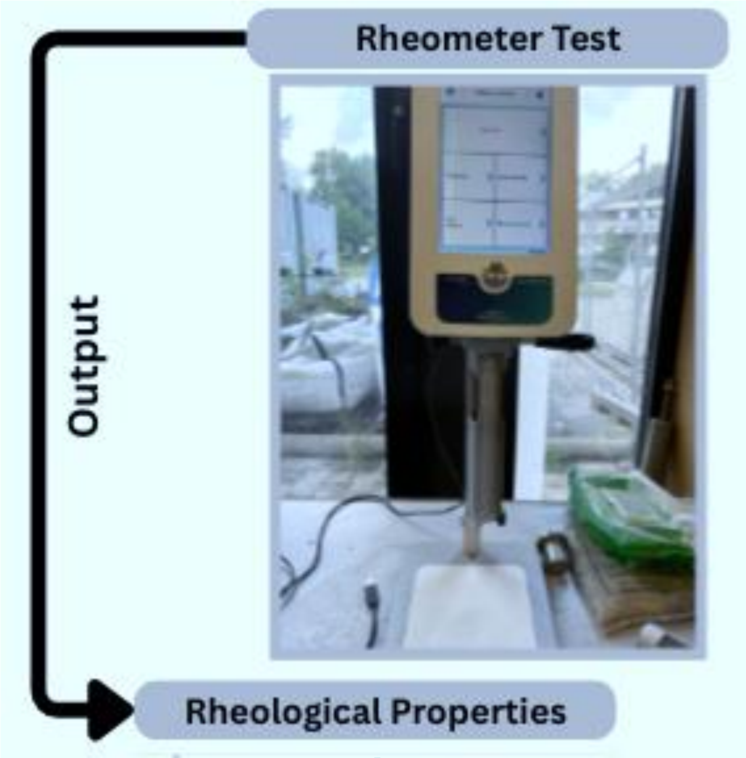
Research Methodology

1. **Materials:** GGBS + RCP, as a Geopolymer Paste
2. **Experimental:**
   - Rotational Rheometer (input fundamental properties)
   - Mini Slump Test (on-site Quality Control)
3. **Numerical:**
   - DualSPHysics v5.0
4. **Analysis:**
   - Compare DualSPHysics with Mini Slump Test



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Mix Design Strategy

Constants:

- Solid Precursor: 60% GGBS + 40% RCP
- Na_2O/b: 8 %

	SiO_2 / Na_2O = 1,20->1,70 met w/b = 0,4						
	G-8%-1,20-0,4	G-8%-1,30-0,4	G-8%-1,33-0,4	G-8%-1,40-0,4	G-8%-1,50-0,4	G-8%-1,60-0,4	G-8%-1,70-0,4
Binder [g]	100	100	100	100	100	100	100
GGBS [%]	60	60	60	60	60	60	60
RCP [%]	40	40	40	40	40	40	40
SiO_2 / Na_2O [%]	1,2	1,3	1,33	1,4	1,5	1,6	1,7
Na_2O/b [%]	0,08	0,08	0,08	0,08	0,08	0,08	0,08
w/b [%]	0,4	0,4	0,4	0,4	0,4	0,4	0,4
Na_2SiO_3 [g]	35,9	38,9	39,8	41,9	44,9	47,9	50,9
NaOH [g]	6,7	6,4	6,3	6,1	5,7	5,4	5,1
H_20 [g]	16,2	14,2	13,6	12,2	10,3	8,3	6,3
Activator [g]	58,8	59,5	59,7	60,2	60,9	61,6	62,3

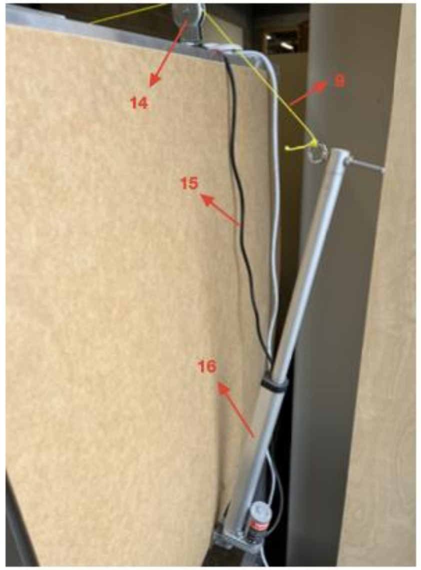
	w/b = 0,30 -> 0,60 met SiO2/Na20 = 1,33						
	G-8%-1,33-0,30	G-8%-1,33-0,35	G-8%-1,33-0,40	G-8%-1,33-0,45	G-8%-1,33-0,50	G-8%-1,33-0,55	G-8%-1,33-0,60
Binder [g]	100	100	100	100	100	100	100
GGBS [%]	60	60	60	60	60	60	60
RCP [%]	40	40	40	40	40	40	40
SiO_2 / Na_2O [%]	1,33	1,33	1,33	1,33	1,33	1,33	1,33
Na_2O/b [%]	0,08	0,08	0,08	0,08	0,08	0,08	0,08
w/b [%]	0,3	0,35	0,4	0,45	0,5	0,55	0,6
Na_2SiO_3 [g]	39,8	39,8	39,8	39,8	39,8	39,8	39,8
NaOH [g]	6,3	6,3	6,3	6,3	6,3	6,3	6,3
H_20 [g]	3,6	8,6	13,6	18,6	23,6	28,6	33,6
Activator [g]	49,7	54,7	59,7	64,7	69,7	74,7	79,7

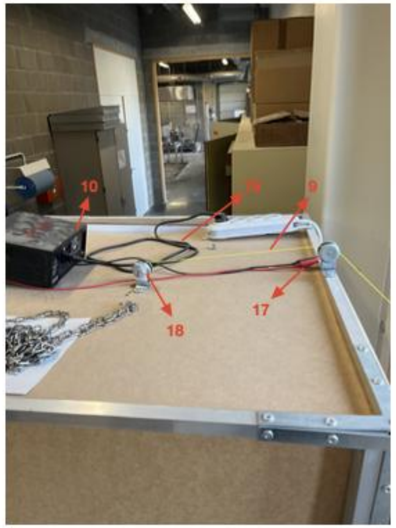
Series 1: Varied the SiO_2/Na_2O ratio while keeping the water-to-binder (w/b) ratio constant at 0,40.

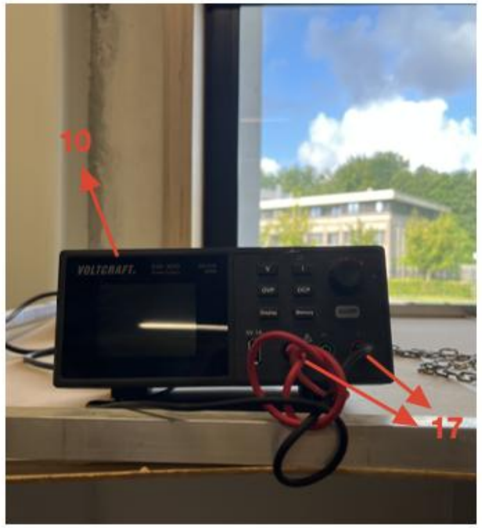
Series 2: Varied the water-to-binder (w/b) ratio while keeping the SiO_2/Na_2O ratio constant at 1,33.

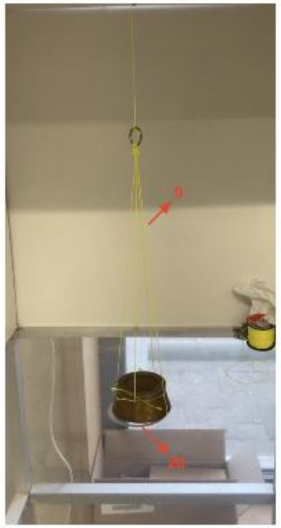
How do the Rheological Properties Change??

The Automated Mini Slump Test







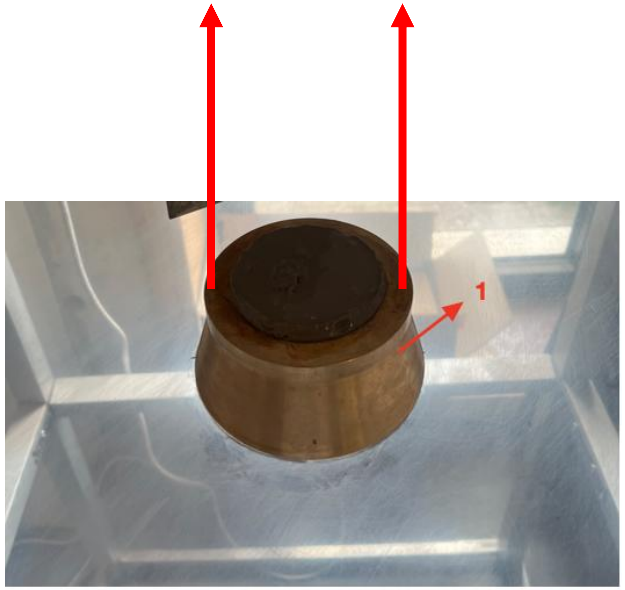


Custom-built, automated apparatus:

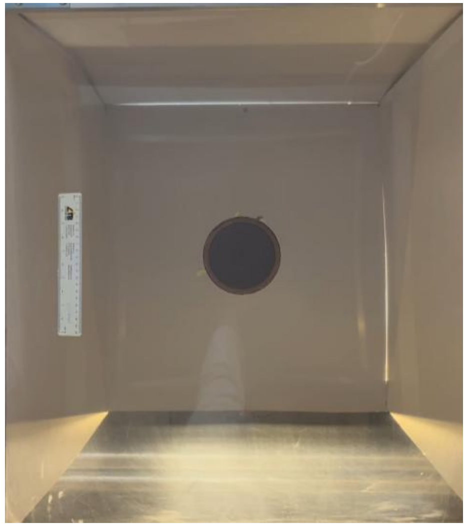
- **Advantage:**
  - Cost-effective
  - Ensures a consistent, repeatable test
- **Components:**
  - VEVOR Linear Actuator (controlled lift)
  - DC Power Supply
  - Adjustable legs
  - Transparent Acrylic Table
  - Video recording

Mini Slump Test Procedure & Data

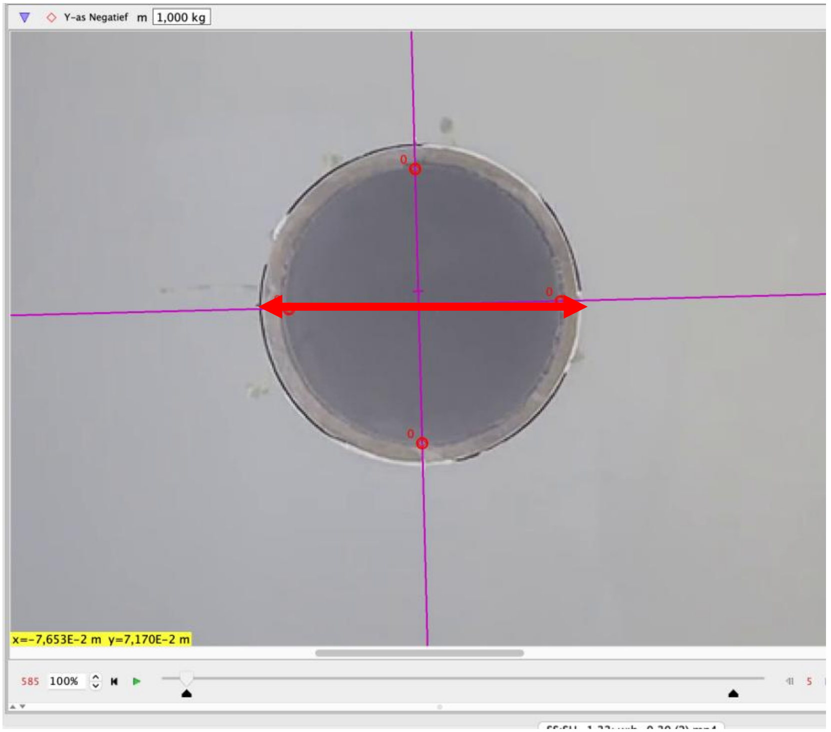
Lift at 10 mm/s



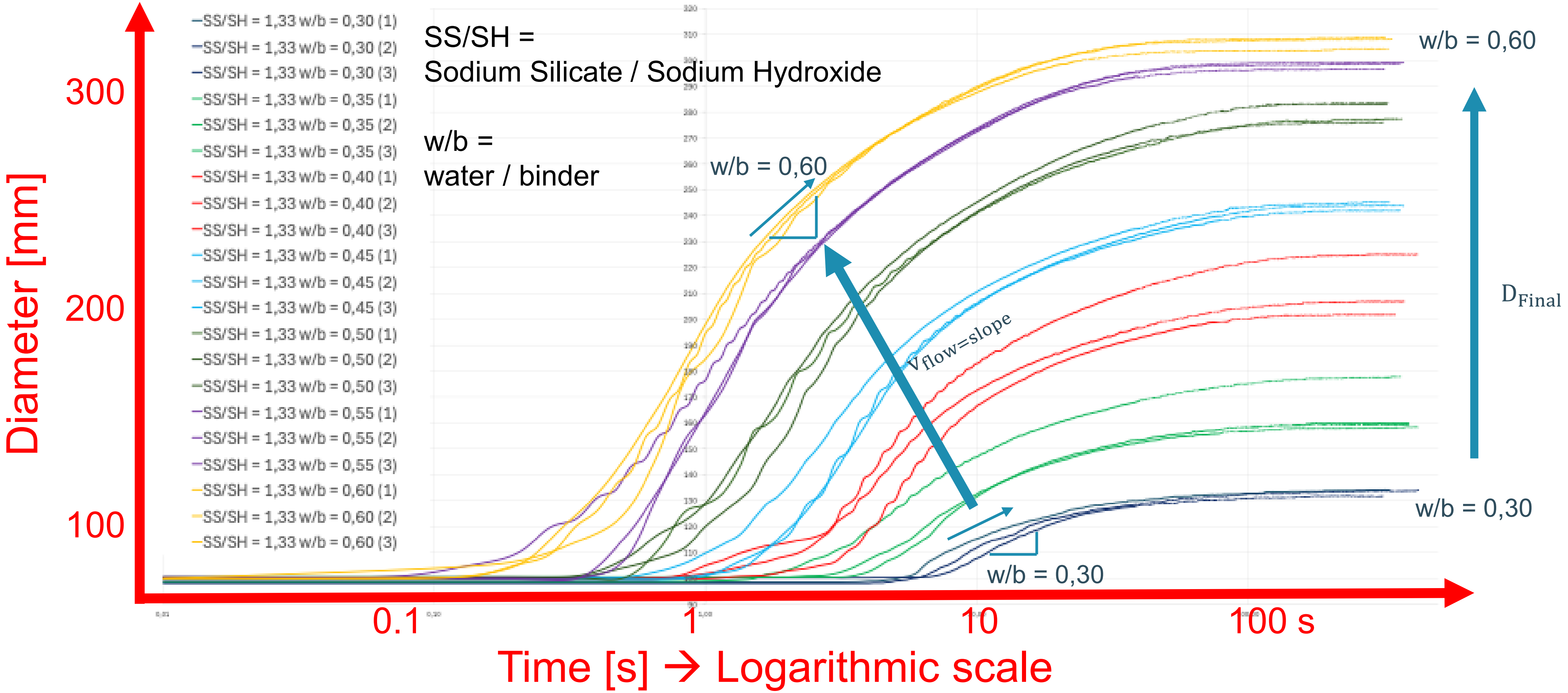
View from bottom



Digitize diameter in time



Experimental Results: Mini Slump Test



Conclusion: The mini slump test is a highly sensitive and reliable tool that can be used for on-site quality control.

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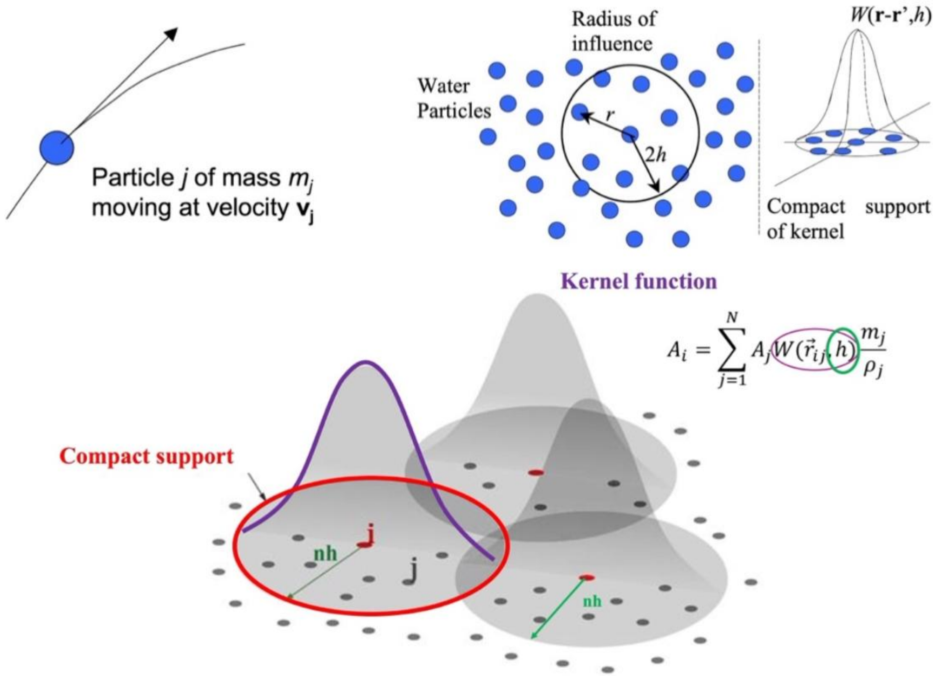
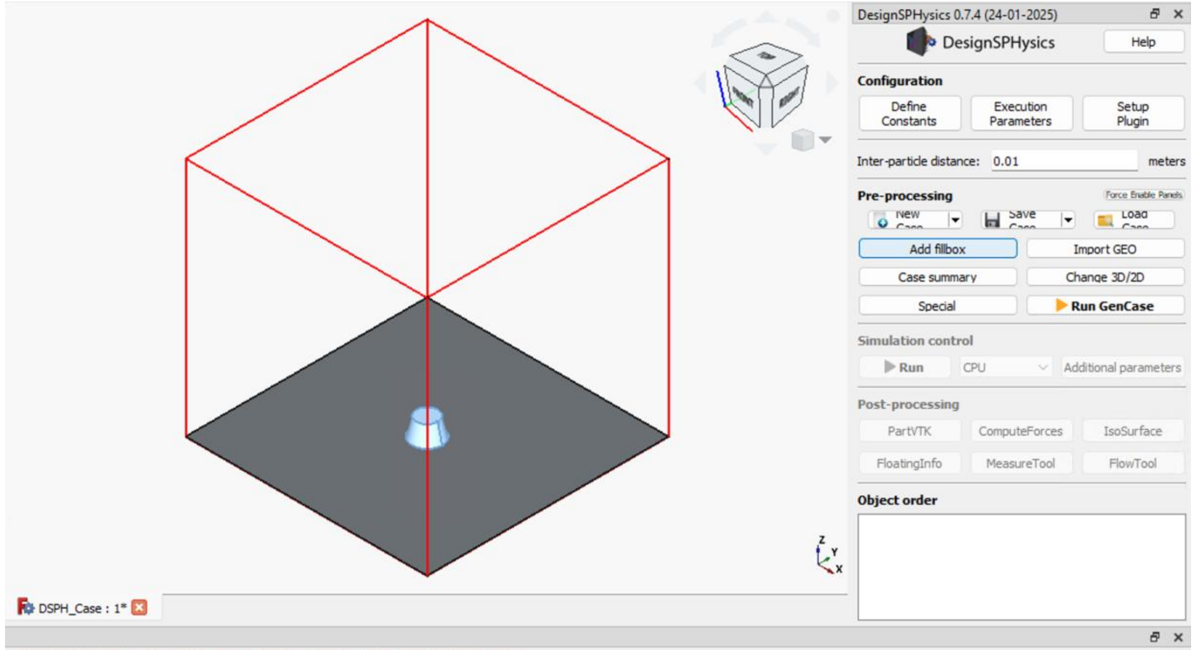
Numerical Approach with SPH

$$F(r) \approx \sum_{j=1}^{N} F(r_j) W(r - r_j, h) \frac{m_j}{\rho_j} = \sum_{j=1}^{N} F(r_j) W(r - r_j, h) V_j$$



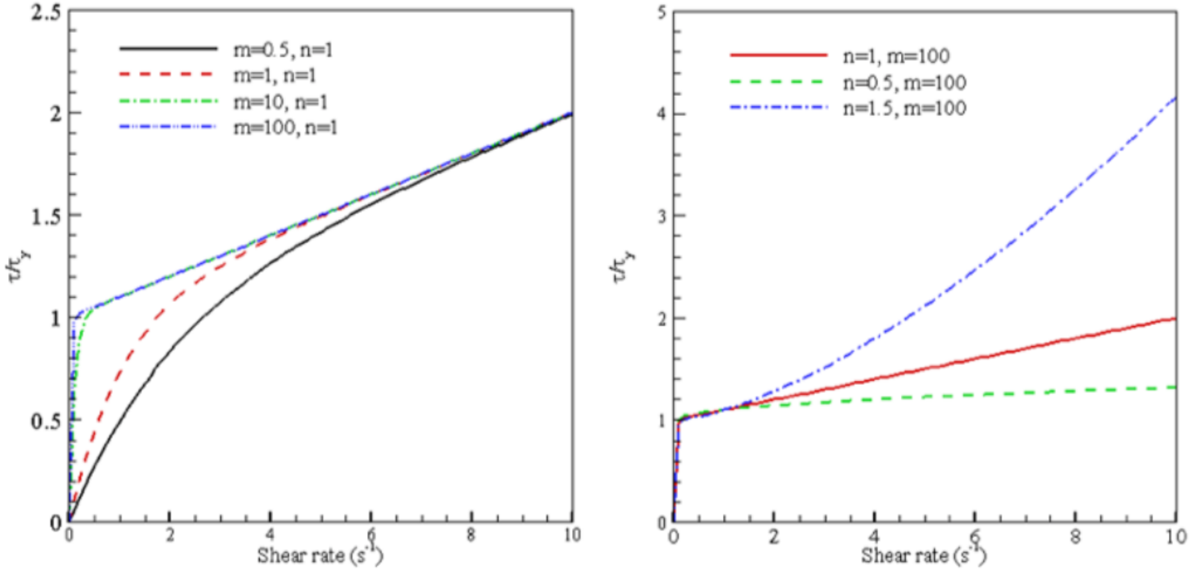
rheometer data (τ_y and μ_p) as inputs to the SPH simulation
=> to see if it replicates mini-slump test results.

SPH Simulation Setup



$$\vec{\tau} = \eta_{app} \cdot \dot{\vec{\gamma}}$$

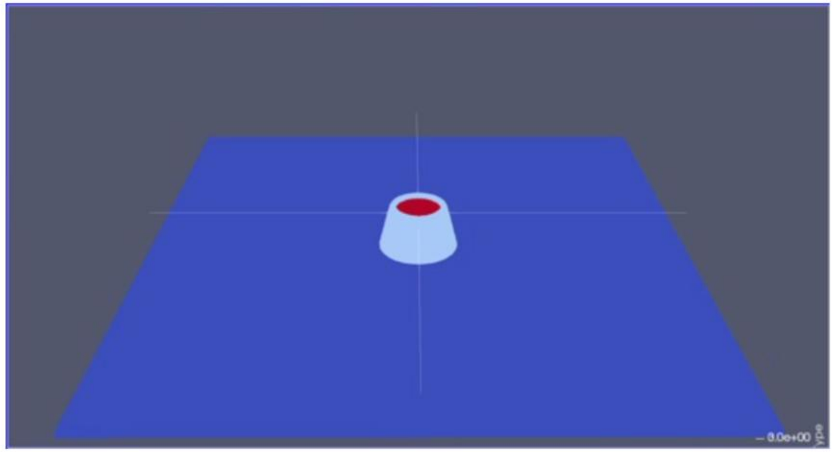
$$\eta_{app} = \mu\left|\dot{\vec{\gamma}}\right|^{n-1} + \frac{\tau_y}{\left|\dot{\vec{\gamma}}\right|}\left[1 - e^{-m\left|\dot{\vec{\gamma}}\right|}\right]$$

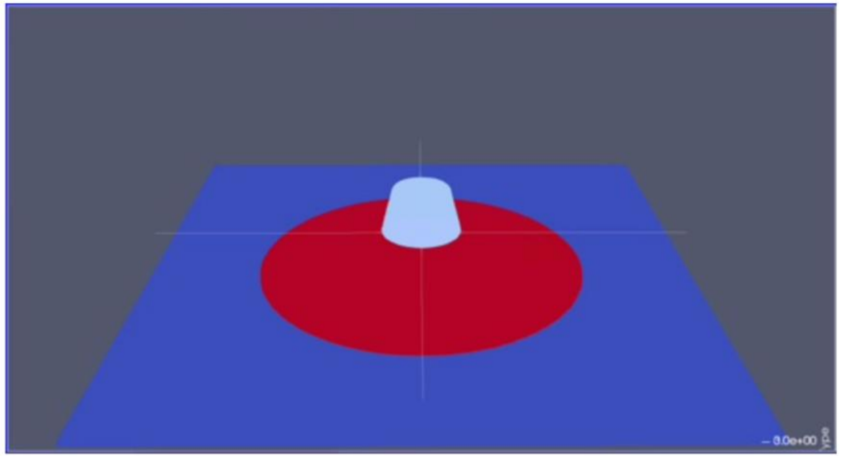


Geometry: The cone lift and the dimensions
Model: Herhsel-Bulkley-Papanastasiou modified Bingham fluid m=100, n=1
Parameters: a ‘standard’ set of SPH parameters (personal communication with Foutakas, 2025)
Inputs: τ_y and μ_p from my rheometer tests

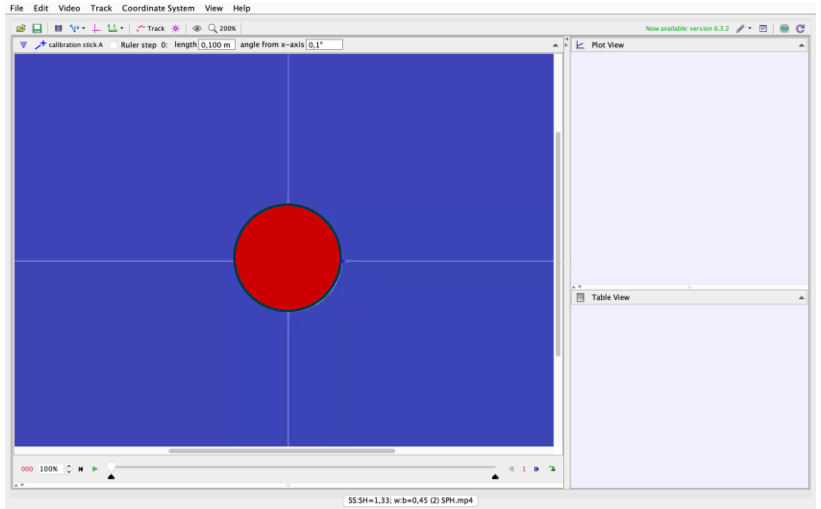
Simulation and post-processing with ‘Tracker’

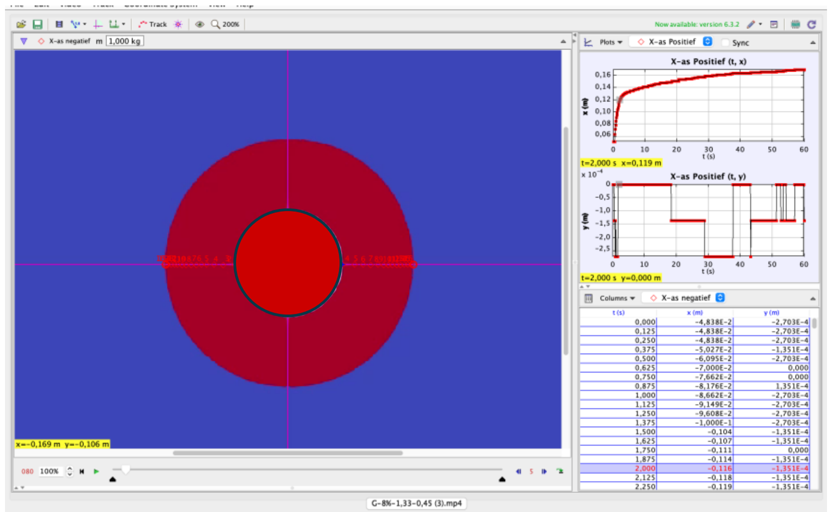
Simulation





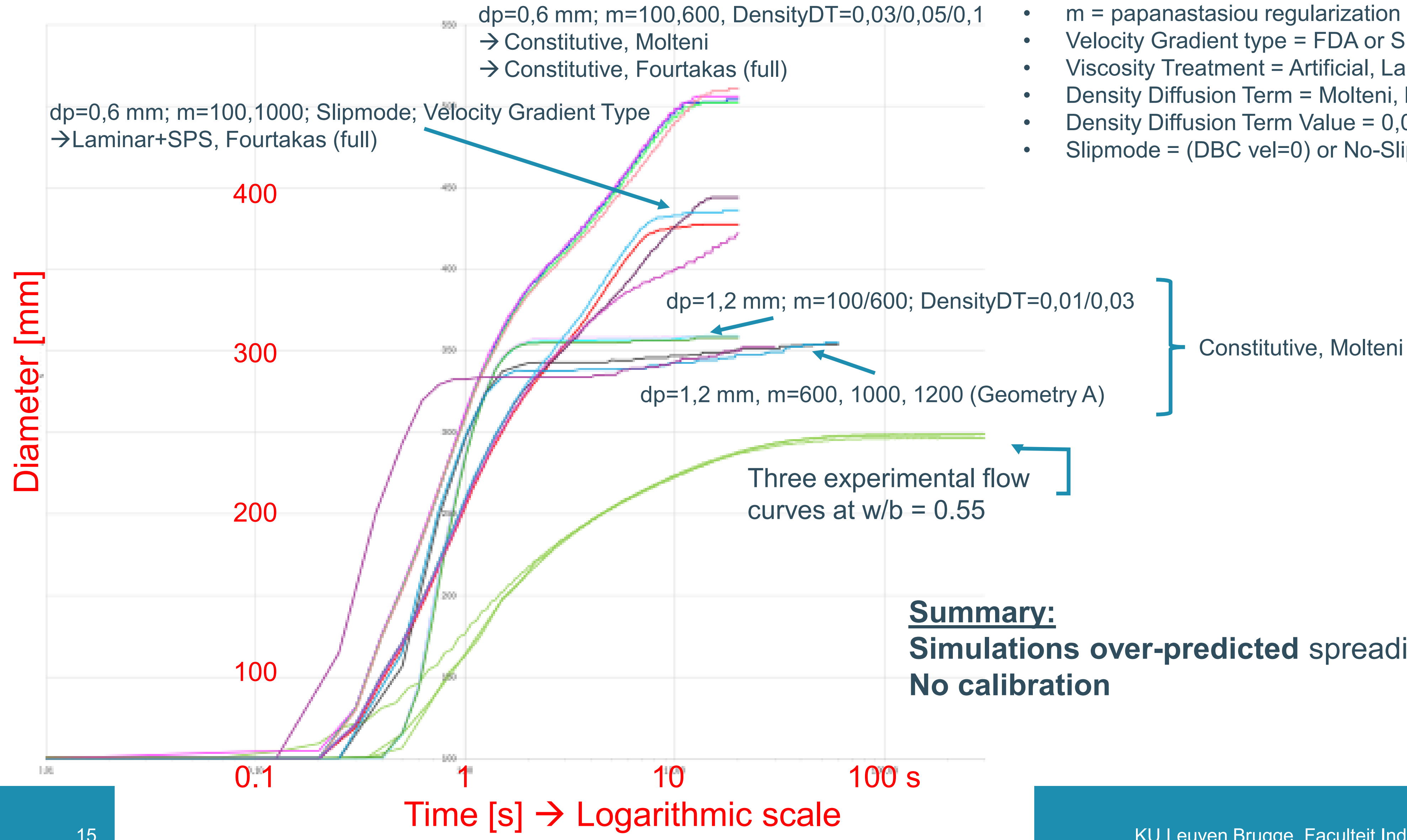
Tracker





SPH Results

Calibration Mix: w/b = 0.55
Parameters:
- dp = 1,2 mm or 0,6 mm
- m = papanastasiou regularization parameter = 100, 600, 1000, 1200
- Velocity Gradient type = FDA or SPH
- Viscosity Treatment = Artificial, Laminar+SPS, Constitutive
- Density Diffusion Term = Molteni, Fourtakas (full)
- Density Diffusion Term Value = 0,01; 0,03; 0,05; 0,1
- Slipmode = (DBC vel=0) or No-Slip

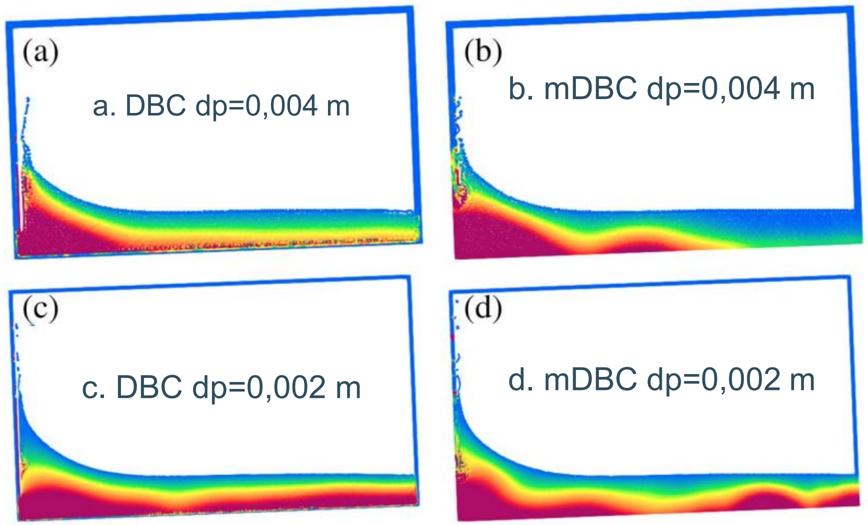


Summary:
Simulations over-predicted spreading rate & final diameter
No calibration

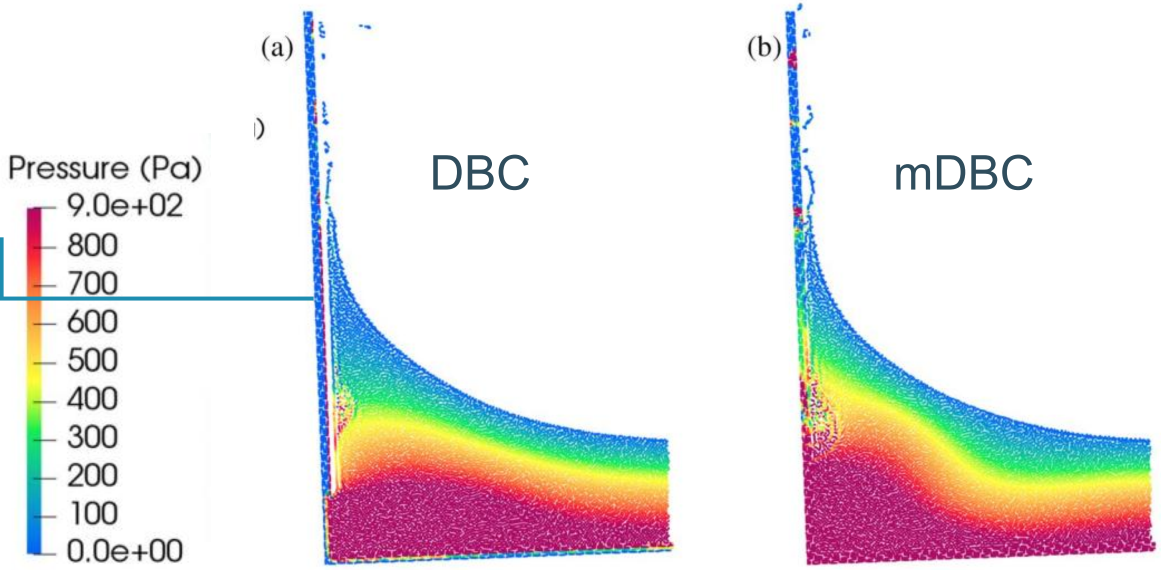
Limitation 1

- **Boundary condition:**
  - **DBC:** Simple & stable, but creates a gap → inaccurate boundary pressures
  - **mDBC:** Ghost nodes + interpolation → closes the gap, improves accuracy at walls & corners
- **Issue:** mDBC is not yet supported for non-Newtonian solver in DualSPHysics v5.0

Sloshing Tank



small unphysical gap (≈ the smoothing length *h*)



Limitation 2

- **Wall friction model**
- **issue: Viscoboundfactor** cannot be activated with a correct non-Newtonian constitutive model or Laminar+SPS model

XML file

EXECUTION-PARAMETERS

Viscosity treatment

```
<parameter  key="ViscoTreatment" value="1"
            comment="Viscosity formulation 1:Artificial, 2:Laminar+SPS (default=1)" />
<parameter  key="Visco" value="0.02" comment="Viscosity value" />
<parameter  key="ViscoBoundFactor" value="1"
            comment="Multiply viscosity value with boundary (default=1)" />
```

$$\frac{d\boldsymbol{v}_a}{dt} = -\sum_b m_b \left(\frac{P_b + P_a}{\rho_b \cdot \rho_a} + \Pi_{ab} \right) \nabla_a W_{ab} + \boldsymbol{g}$$

$$\Pi_{ab} = \begin{cases} \dfrac{-\alpha \overline{c_{ab}} \mu_{ab}}{\overline{\rho_{ab}}} & \boldsymbol{v}_{ab} \cdot \boldsymbol{r}_{ab} < 0 \\ 0 & \boldsymbol{v}_{ab} \cdot \boldsymbol{r}_{ab} > 0 \end{cases}$$

α_{FF} for interaction fluid-fluid

α_{FB} for interaction fluid-boundary

α_{FB}= ViscoBoundFactor · α_{FF}

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Conclusion

- **Experiments for validation**
- **DualSPHysics v5.0 is applied to the Mini Slump Test**
- **Overestimation of the spreading rate & final diameter**
- **Detected some potential improvement points**

Thanks for your kind attention!

Future Prospects

<u>Phase 1: Addressing Software Deficiencies</u>
Action 1: Implement & validate wall-friction model for non-Newtonian fluids
Action 2: Make mDBC fully compatible with non-Newtonian solver
Expected Result:
Physically capable tool for boundary-dominated viscoplastic flows

<u>Phase 2: Build Predictive model</u>
Action: Large parametric study → hundreds of SPH runs (vary τ_y and μ_p)
Action: Record full diameter–time curves
Expected Result: Database linking rheology ↔ flow behaviour

<u>Phase 3: Derive final mathematical model</u>
Action: Use SPH database → equations linking D(t) to τ_y & μ_p
Model Form: Generalized, tailored to CDW-based geopolymers
Expected Result: Validated framework converting field mini slump data → rheological properties

$$D = \alpha + 29.8\ln(t+\gamma) - \lambda\left(\frac{t^{0.842}}{13.5 + t^{0.842}}\right)$$