Spray-Slag: Processing of liquid blast furnace slag

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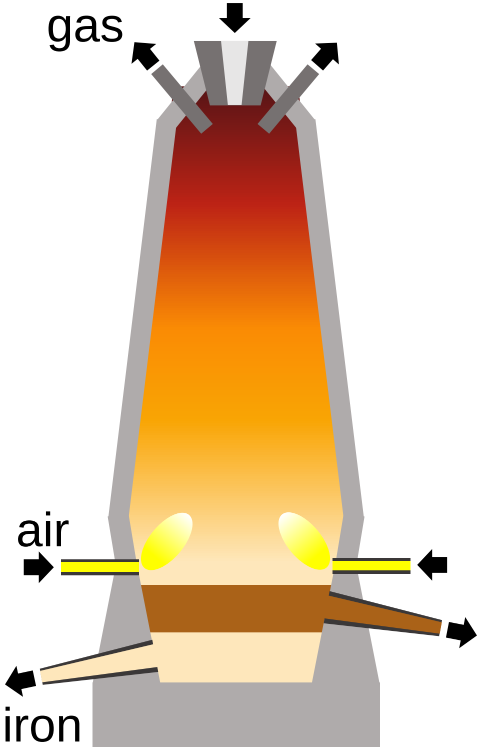
How is slag processed and used in building materials?

<u>Blast furnace</u> | <u>Processing</u> | <u>Product</u> | <u>Application</u>

ores, coke, additives

gas



air

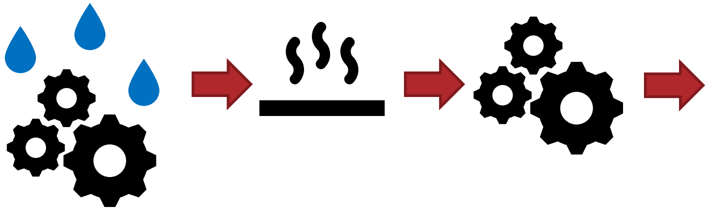
slag

iron

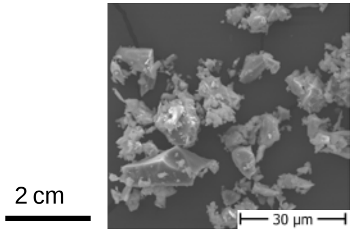
wet granulation

drying

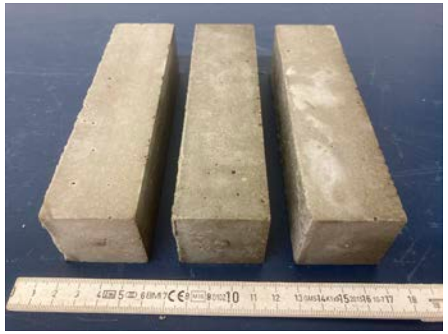
grinding



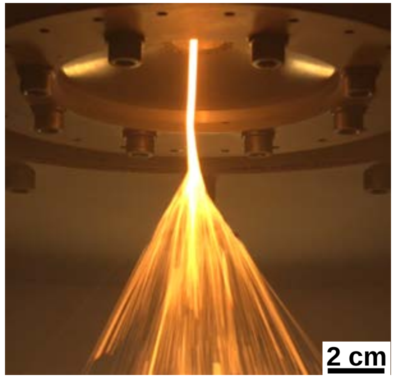
granulated slag



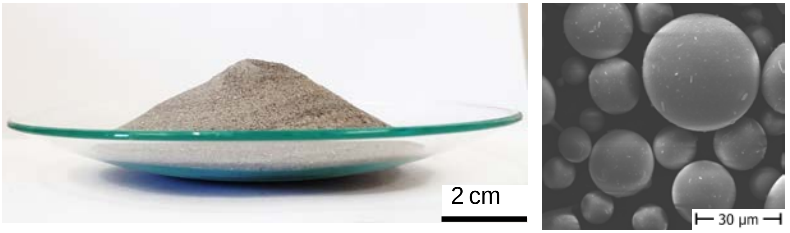
production of concrete



atomization



atomized slag



Advantages:
- Reduces mining of natural stones
- Reduces CO_2 emissions
- Reduces energy consumption

Motivation:
Resource efficient processing of slag

→ Reduction of process steps & spherical particles

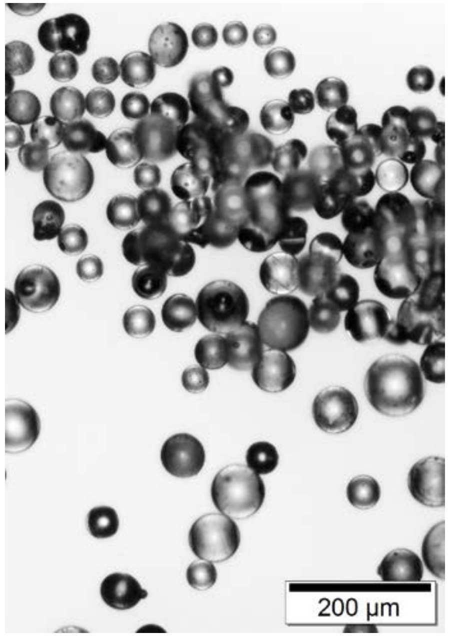
Content

Atomization of slag

Development of the atomizer

Analysis of the process and the powder

- Stability of the process
- Powder size fractions
- Flowability of the powder



Application of atomized slag

Investigation on building material properties

- Workability of binder pastes
- Reactivity of particles
- Strength properties

Difficulties in the atomization of slag

Challenges

High viscosity

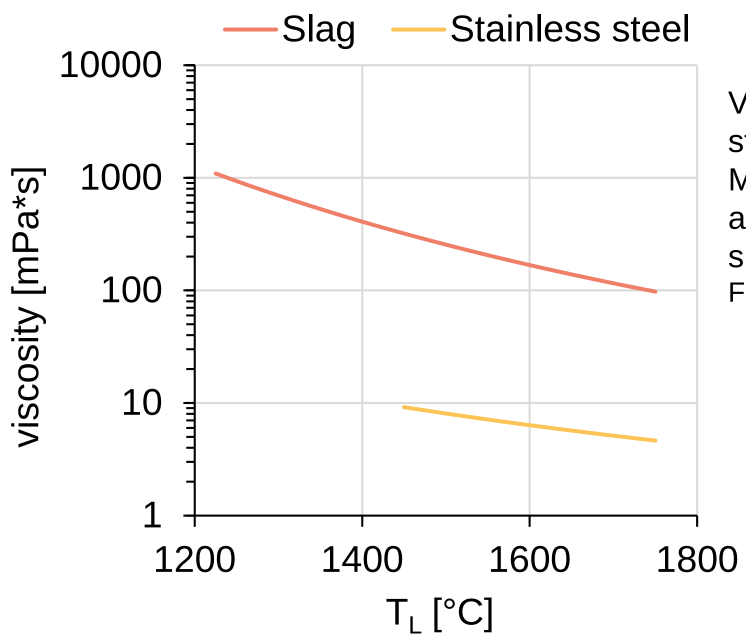
- Solidification of the melt → abortion of the process
- Incomplete formation of particles → fibers

Low density

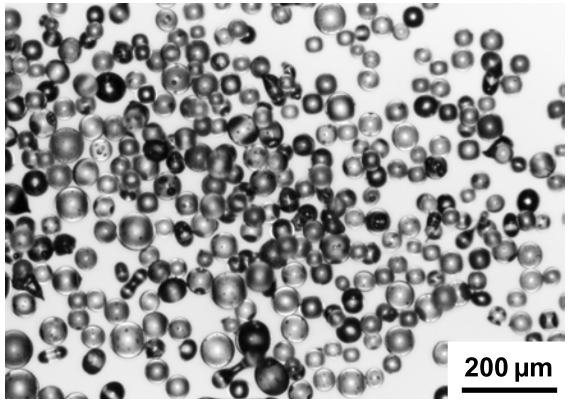
- Less liquid inertia → lower stability of the process

Challenges

- Reduction of fibers & smaller particle size (< 200 µm)
  → Preheated atomization gas
- Stable atomization process (no recirculation of melt)
  → Optimized atomizer



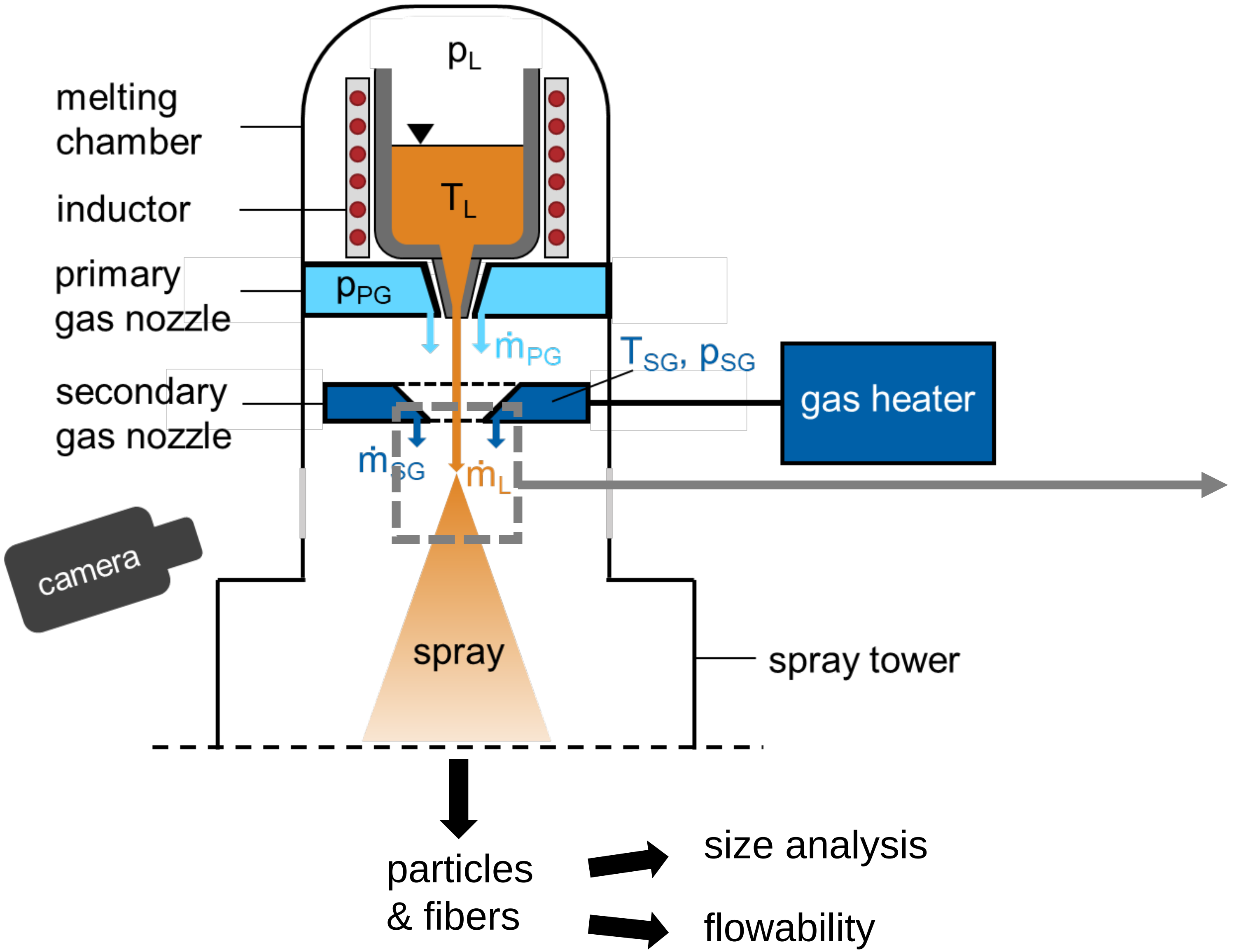
Viscosity of stainless steel [calculated after Mills et al. (2004)] and blast furnace slag [calculated by FEhS]



FEhS – Institut für Baustoffforschung e.V., Duisburg, Germany
Mills, K. C., Su, Y., Li, Z., & Brooks, R. F. (2004). Equations for the calculation of the thermo-physical properties of stainless steel. ISIJ international, 44(10), 1661-1668.

Atomizaton of slag: free-fall atomizer

Experimental setup, T_L = 1700°C



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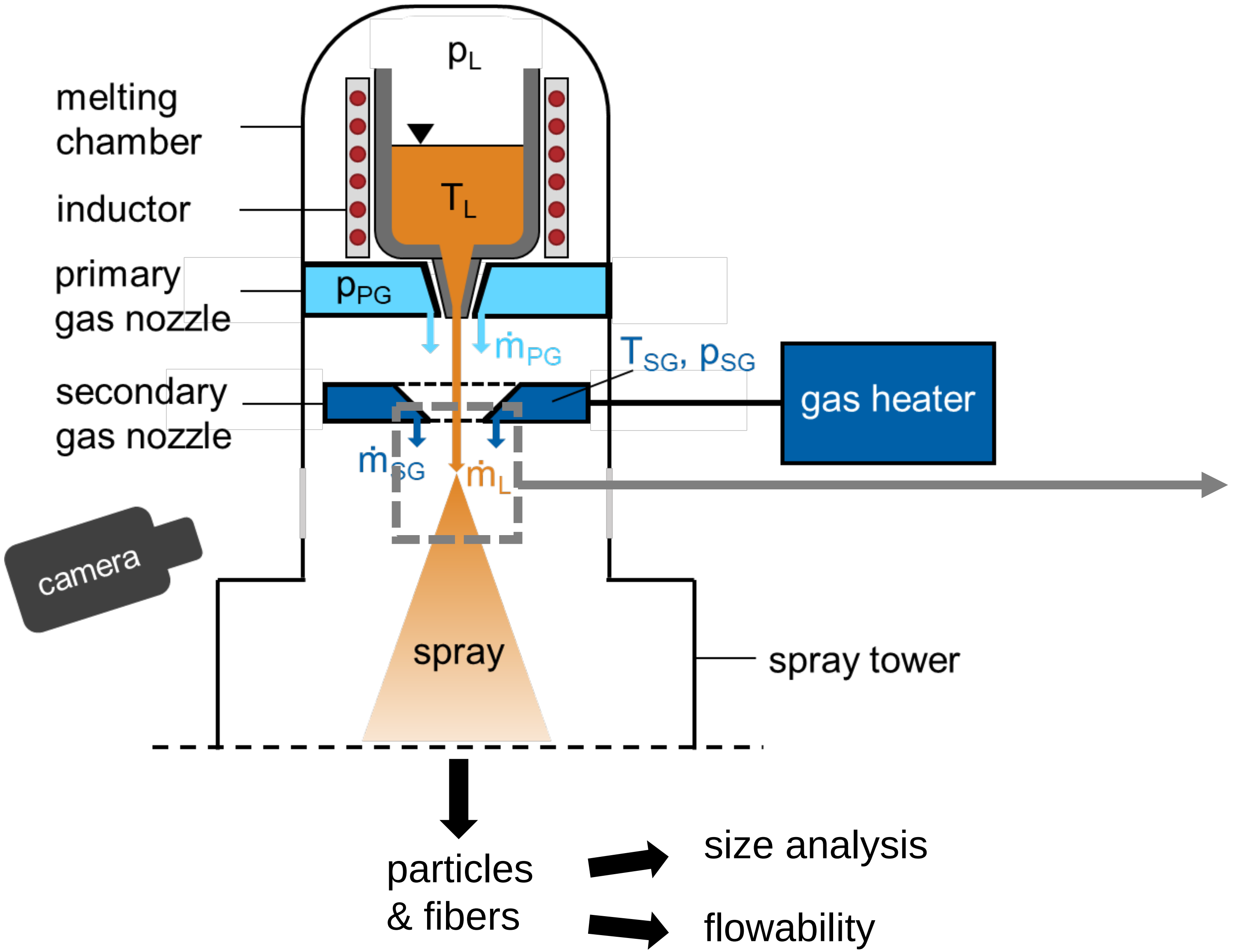


Influence of the atomization gas temperature

Control parameters: primary gas pressure [p_{PG}], secondary gas pressure [p_{SG}], secondary gas temperature [T_{SG}]

	snapshots of the atomizations		
	initial	middle	end
T_{SG} = 300°C p_{SG} = 1.55 MPa p_{PG} = 0			
T_{SG} = 750°C p_{SG} = 1.55 MPa p_{PG} = 0			

Unstable atomization & upward transportation of melt

→ Gas recirculation

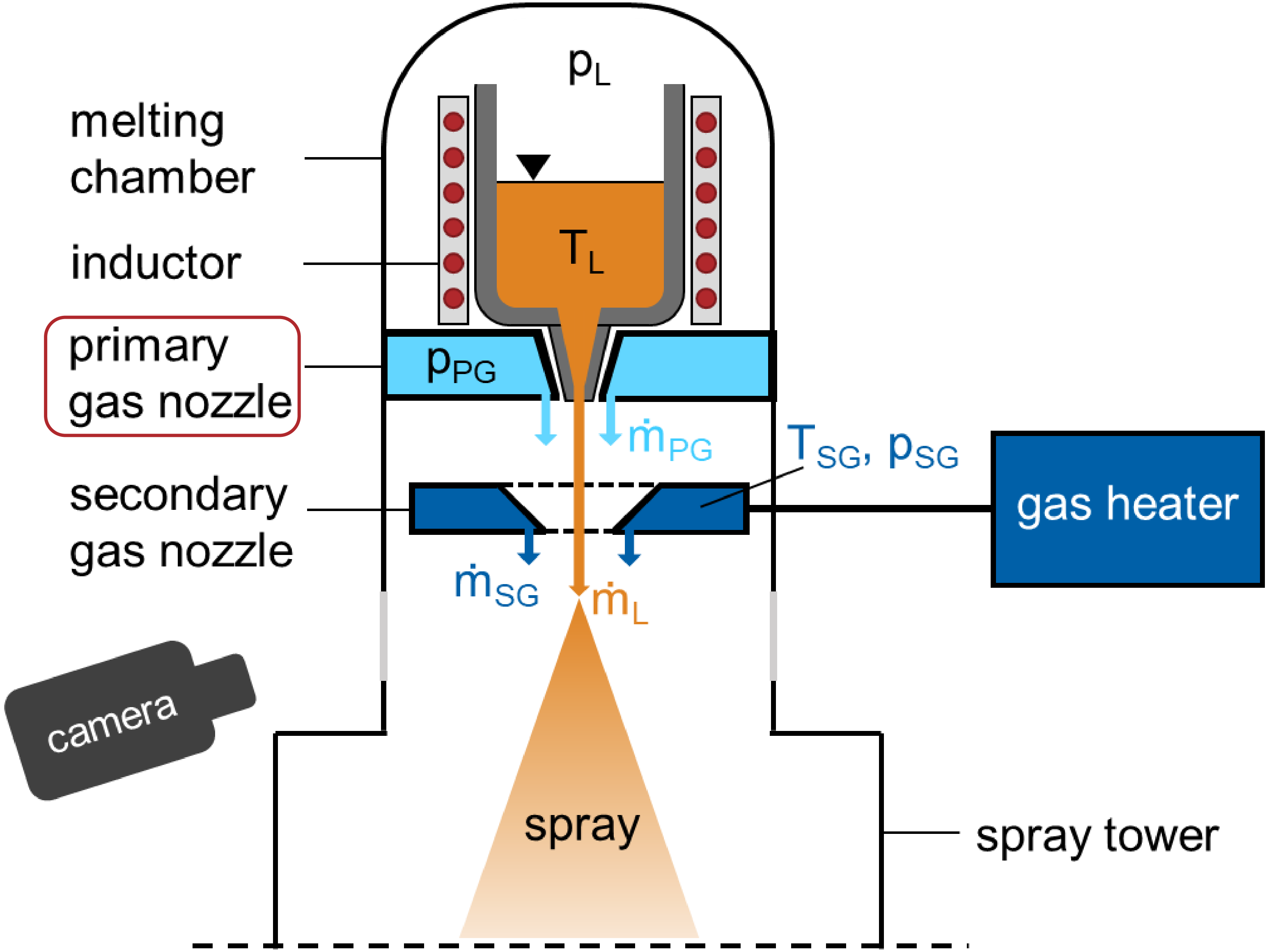
→ Increases with higher gas pressures

Adhesion of recirculating melt at the gas nozzle

→ Could lead to an abortion of the process

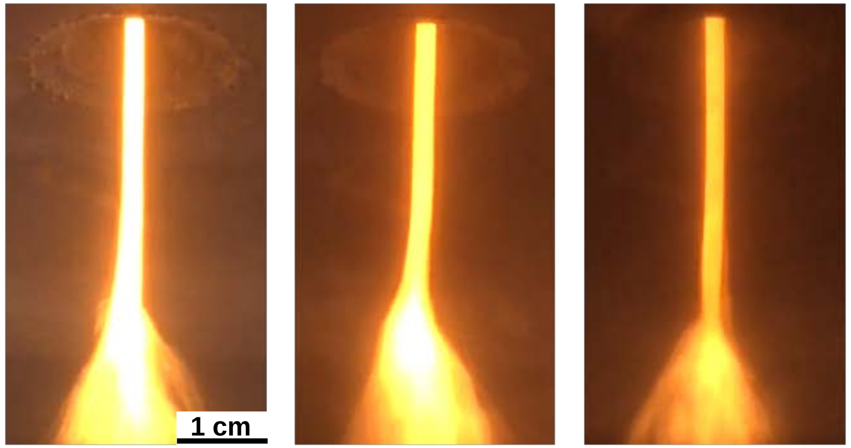
Atomizaton of slag: free-fall atomizer

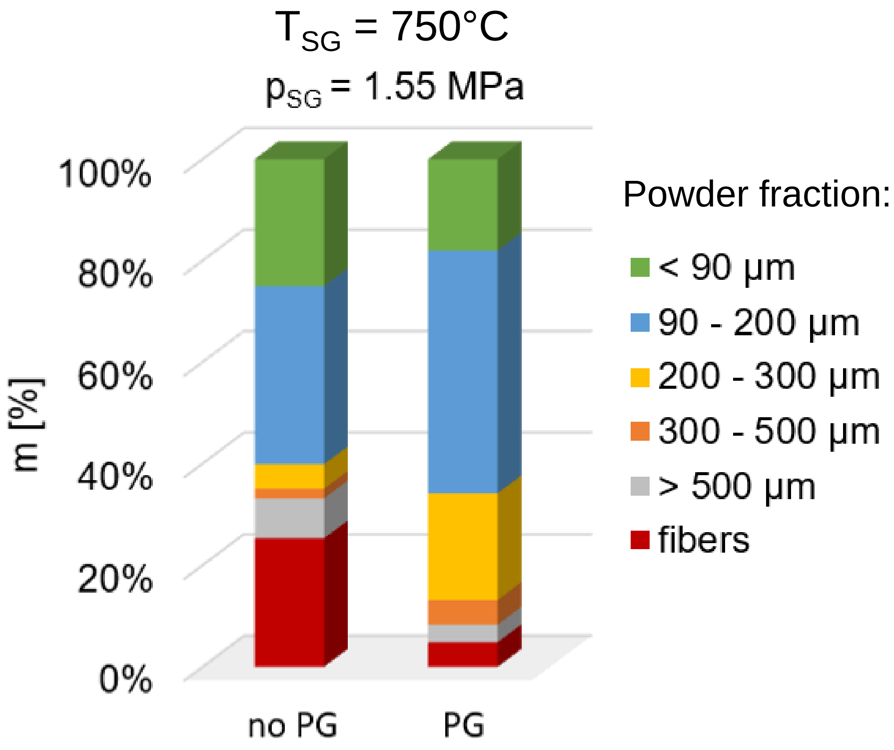
Experimental setup, T_L = 1700°C



Influence of the primary gas

Control parameters: primary gas pressure [p_{PG}], secondary gas pressure [p_{SG}], secondary gas temperature [T_{SG}]

	snapshots of the atomizations		
	initial	middle	end
T_{SG} = 750°C p_{SG} = 1.55 MPa p_{PG} = 0			
T_{SG} = 750°C p_{SG} = 1.55 MPa p_{PG} = 0.1 MPa			



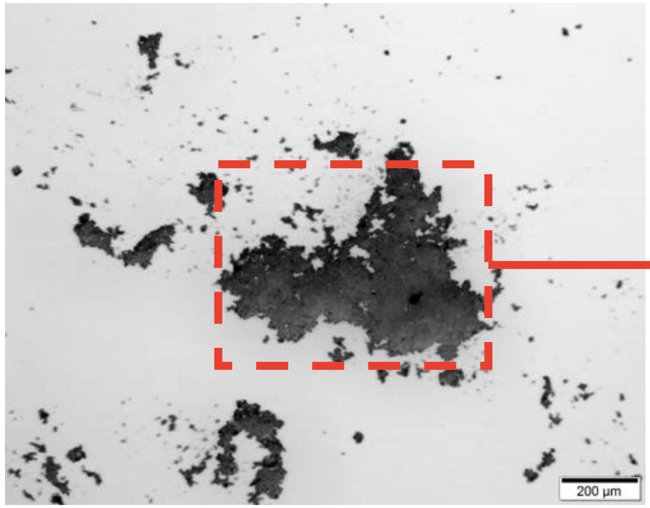
Primary gas reduces the recirculation of the melt and the atomization gas

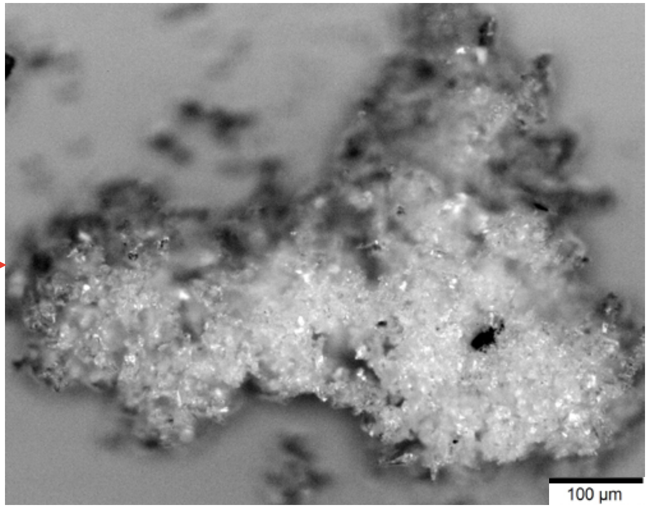
→ Stable process without melt adhesions at the gas nozzle

Particle shape

Granulated slag

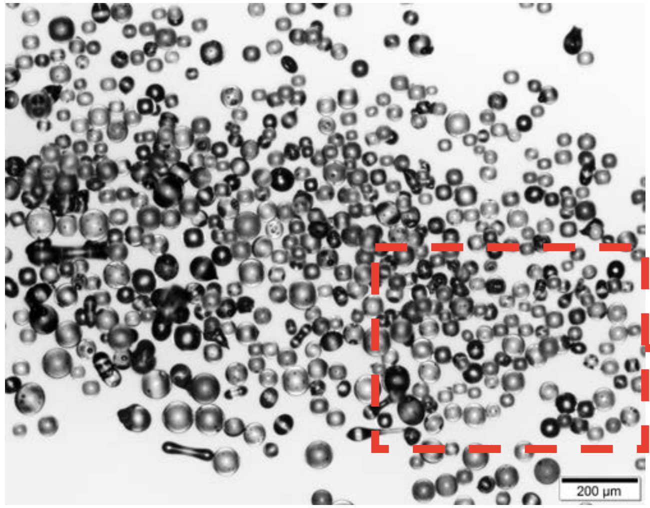
2 cm

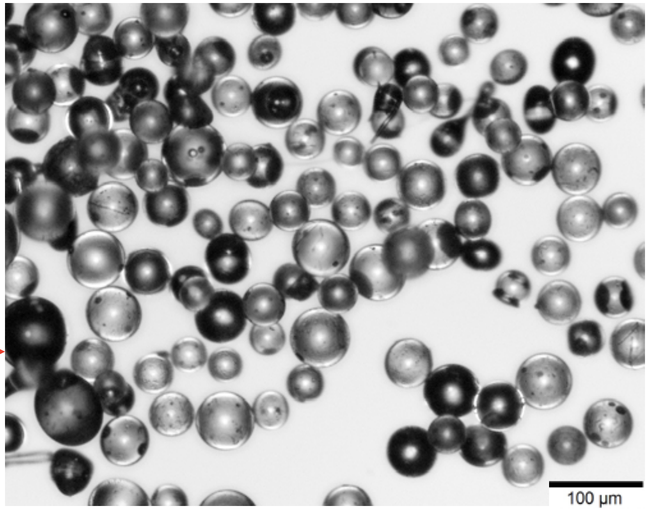




Atomized slag

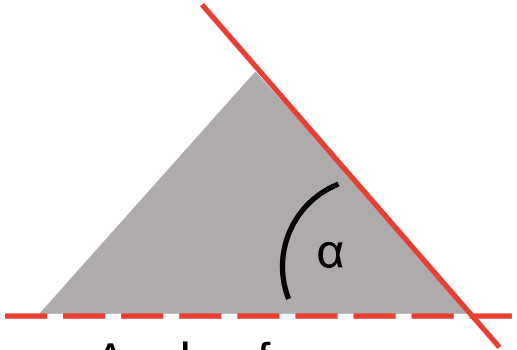
2 cm





Flowability

Dynamic angle of repose

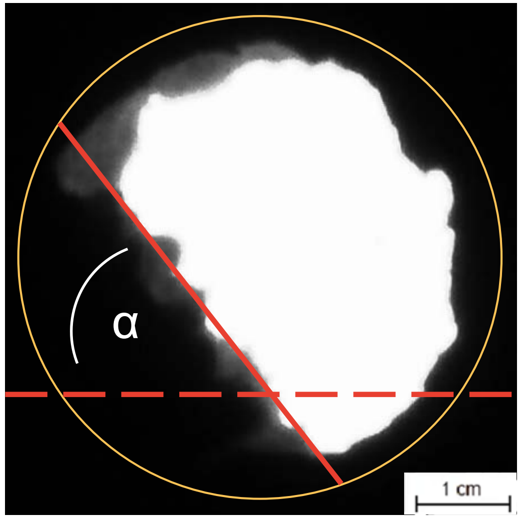


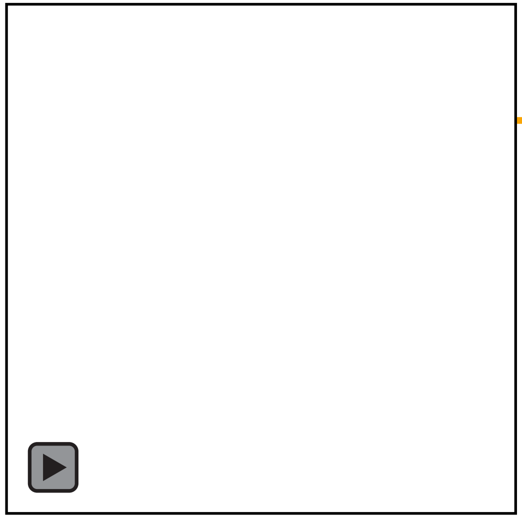
Angle of repose

Steepest angle of the surface of the stacked material with respect to the horizontal plane

Granulated slag
α = 49°

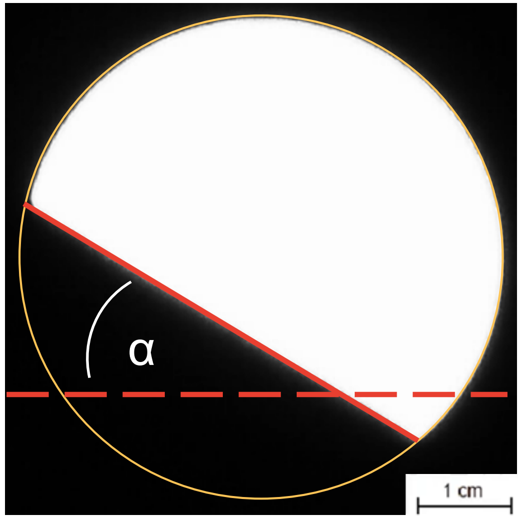
2 cm

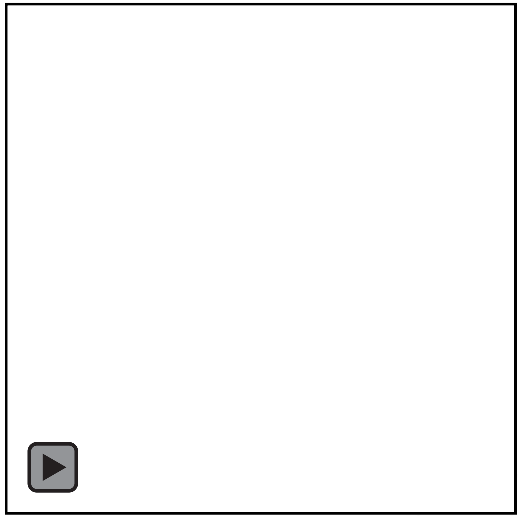




Rotating cylinder

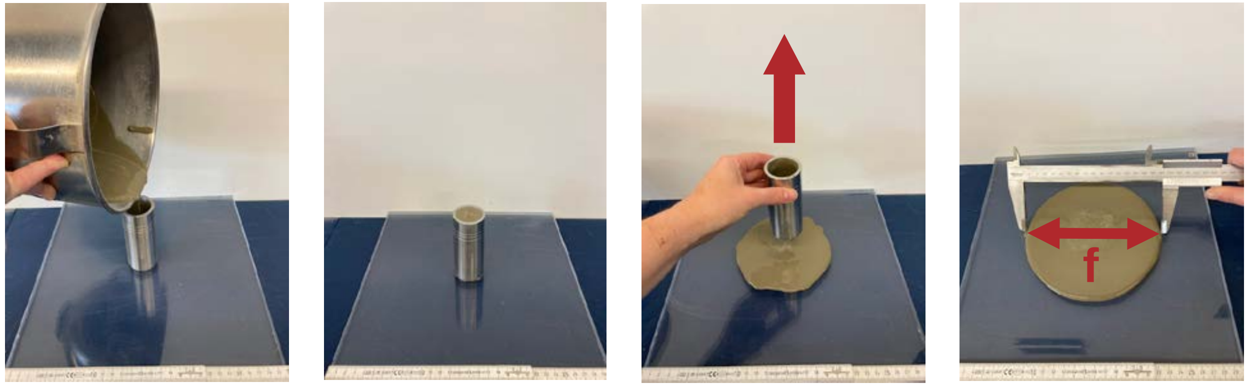
Atomized slag
α = 32°



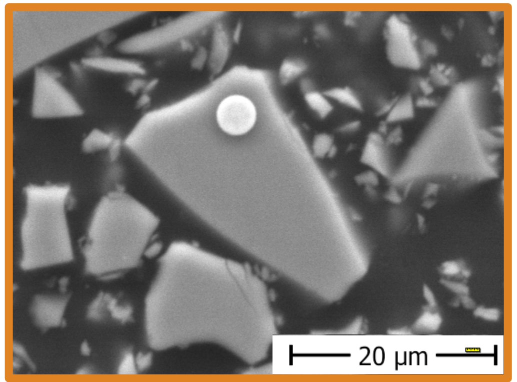


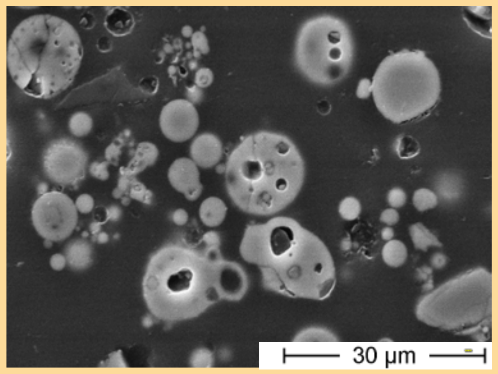
Influence on the workability of binder paste

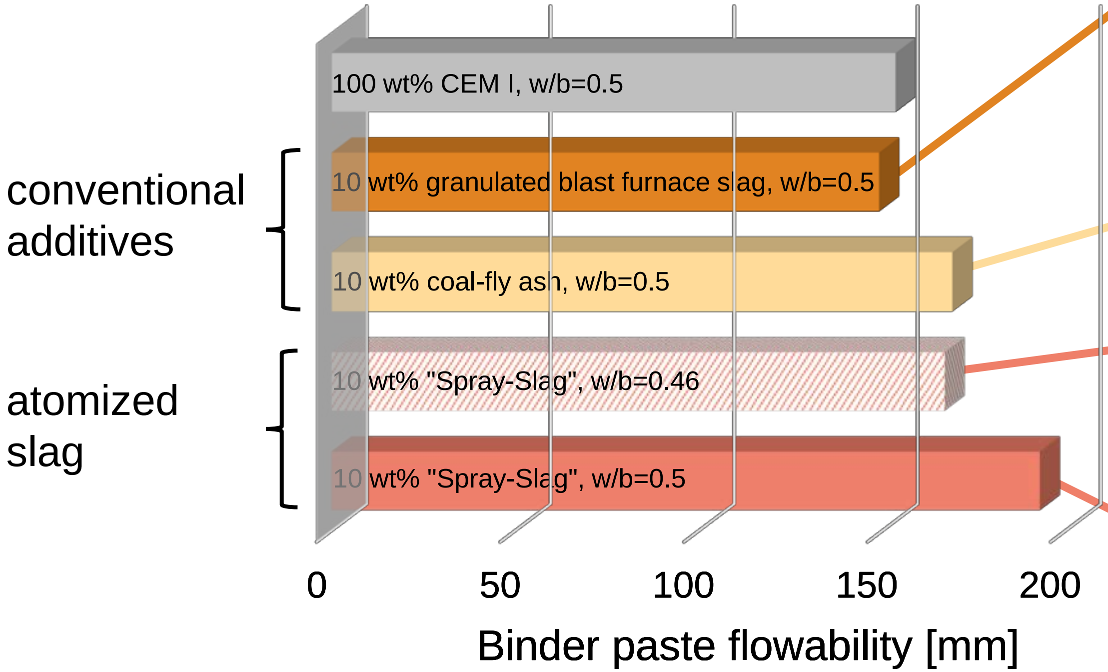
Binder paste flowability

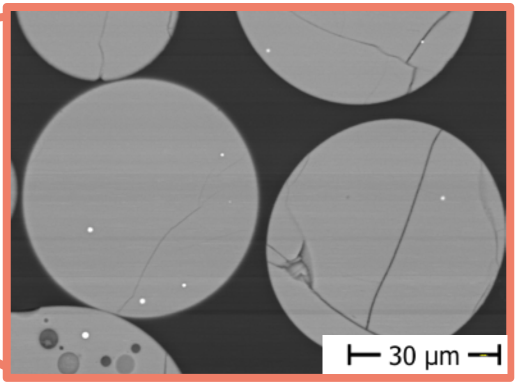


Measuring method: binder paste flowability f









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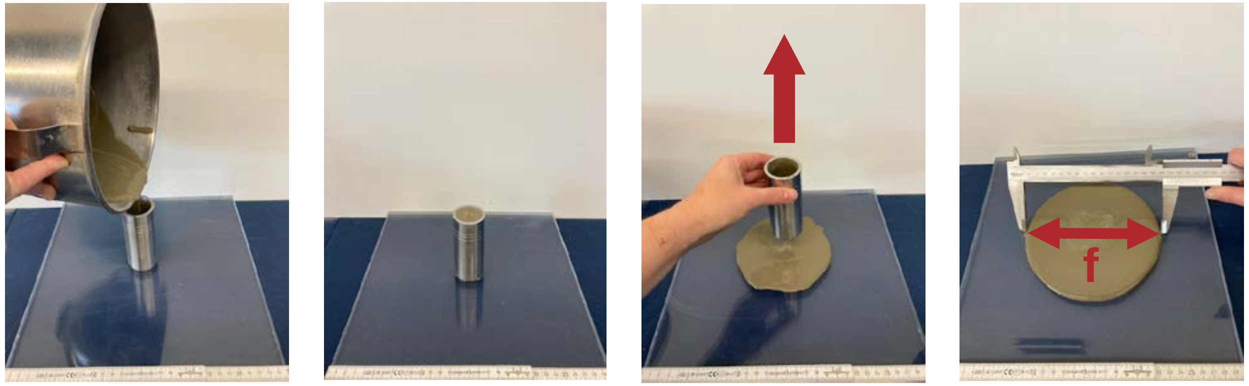
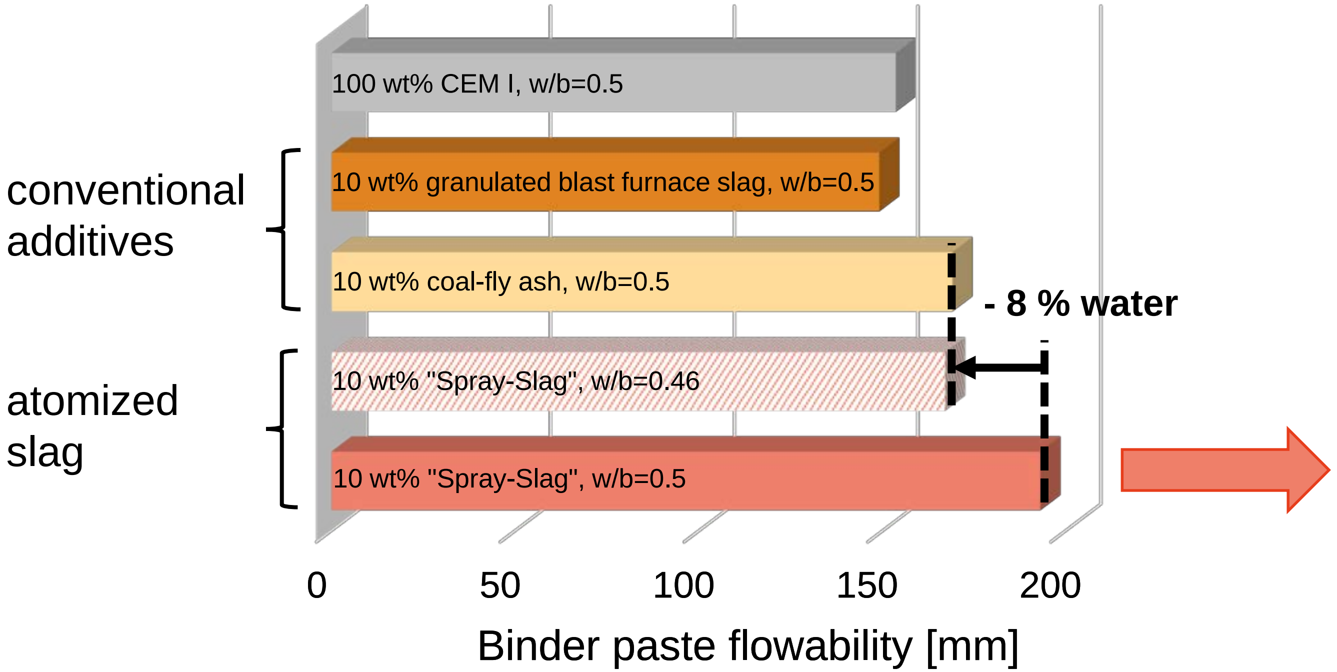
Binder paste flowability



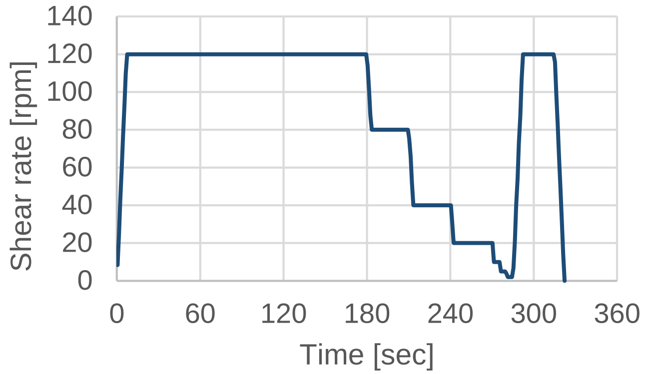
Measuring method: binder paste flowability f

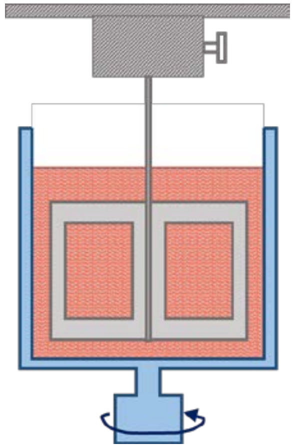


- „ball bearing effect“
- less wetted surface area

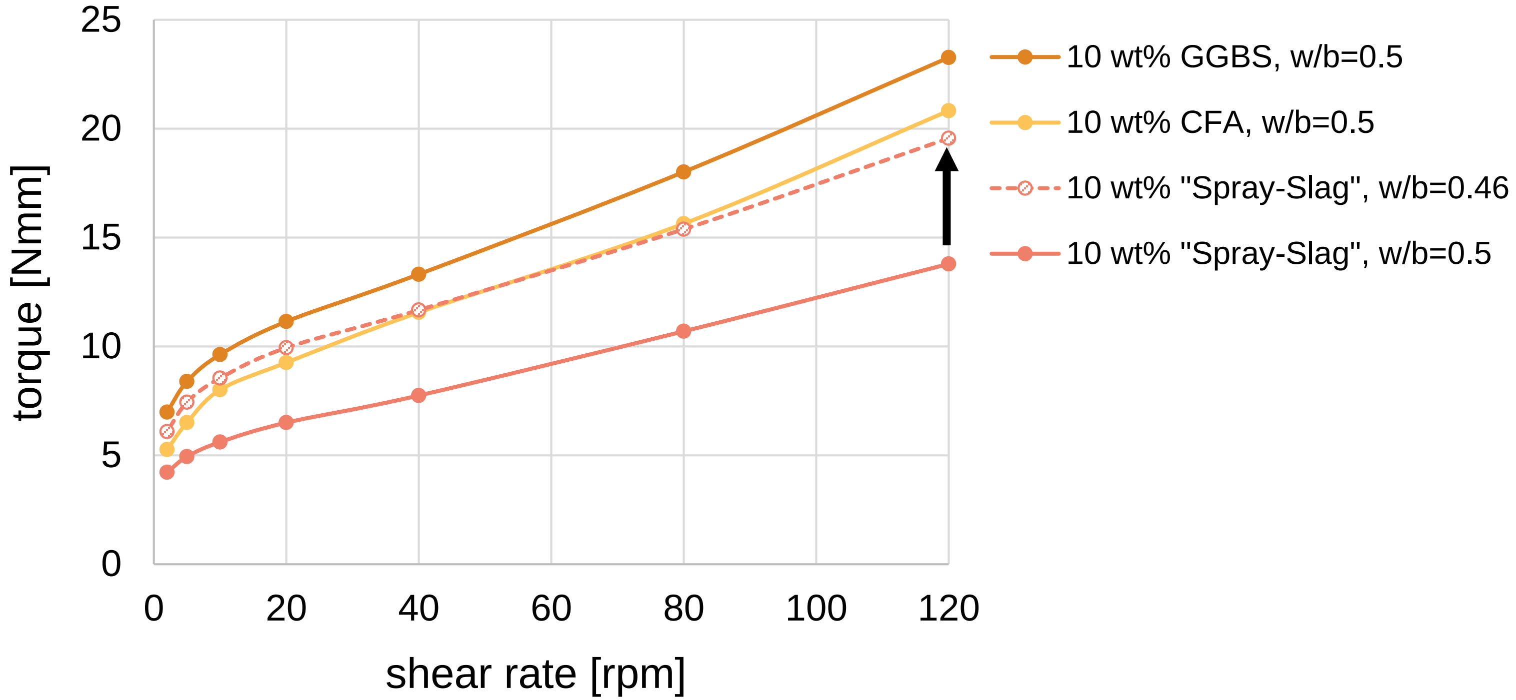
Influence on the workability of binder paste

Rheology of binder paste





Measuring method: Rheology



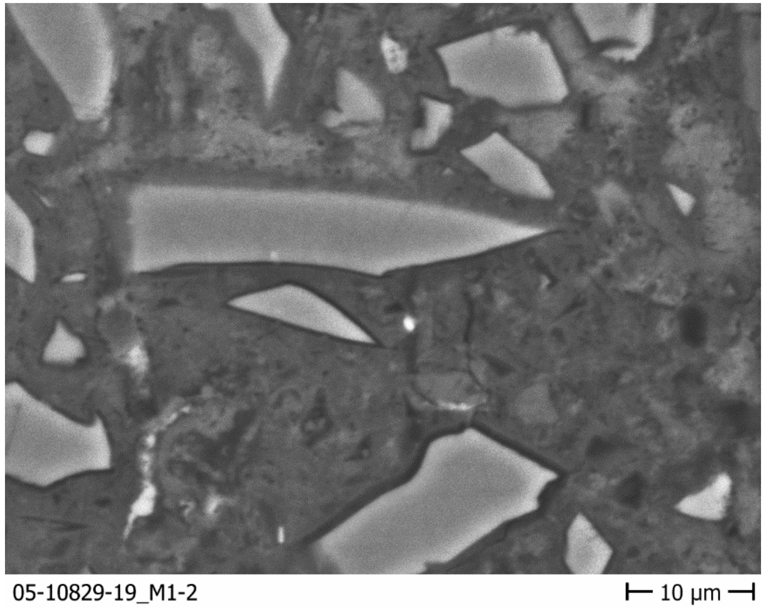
Investigations on the reactivity of the particles

Scanning electron microscopy on the thin sections

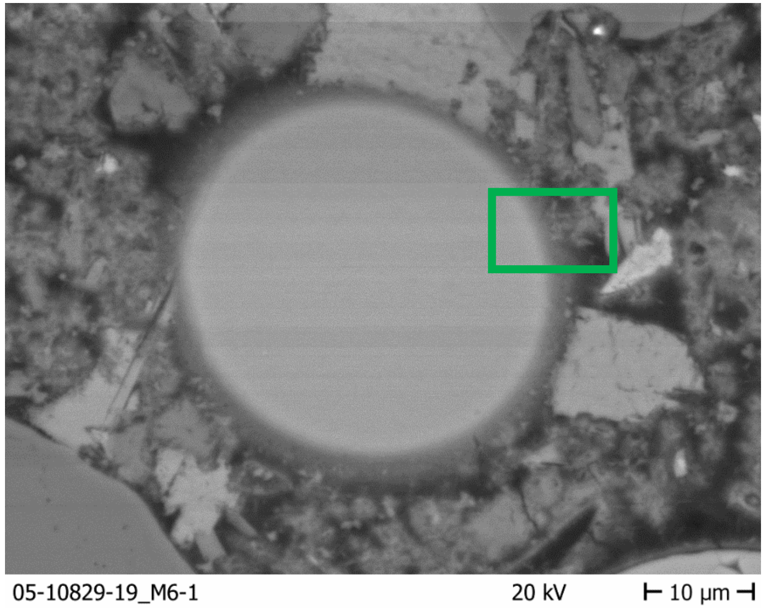
Treatment:
Mortar, 50 wt% GGBS resp. atomized slag
50 wt% cement
water/binder-ratio = 0.5
28 days hydration at 20°C, under water

Treatment:
Alkaline solution
NaOH + KOH pH ~ 14

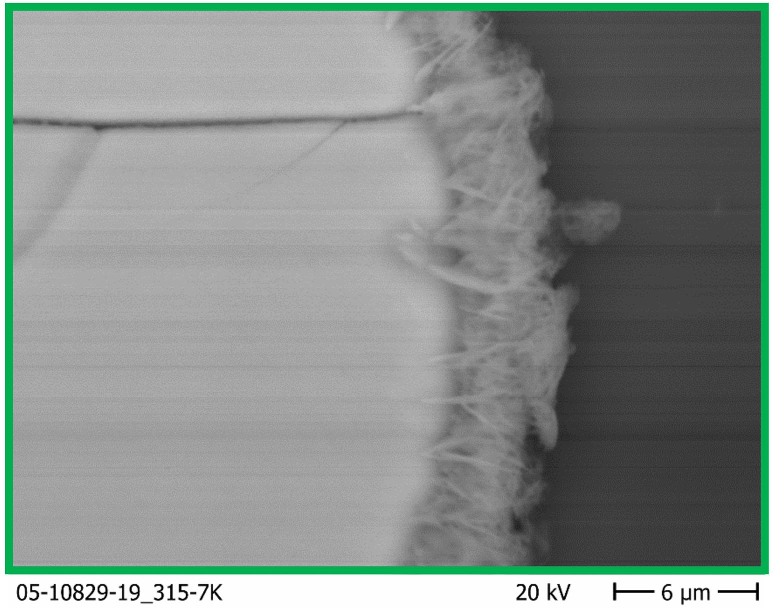
7 days hydration at 40°C
corresponds nearly 28 days at 20°C



Granulated blast furnace slag



Atomized slag



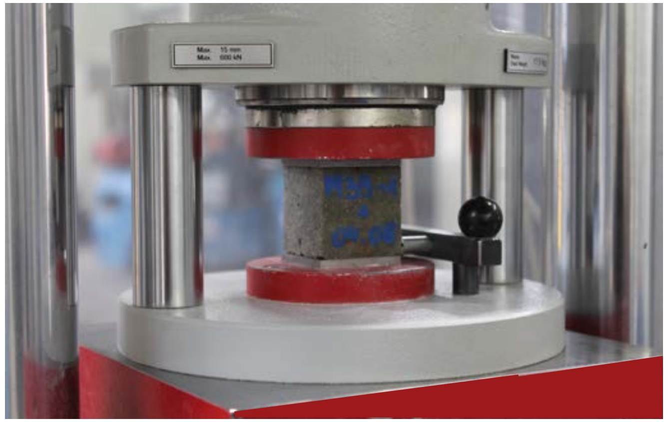
Atomized slag

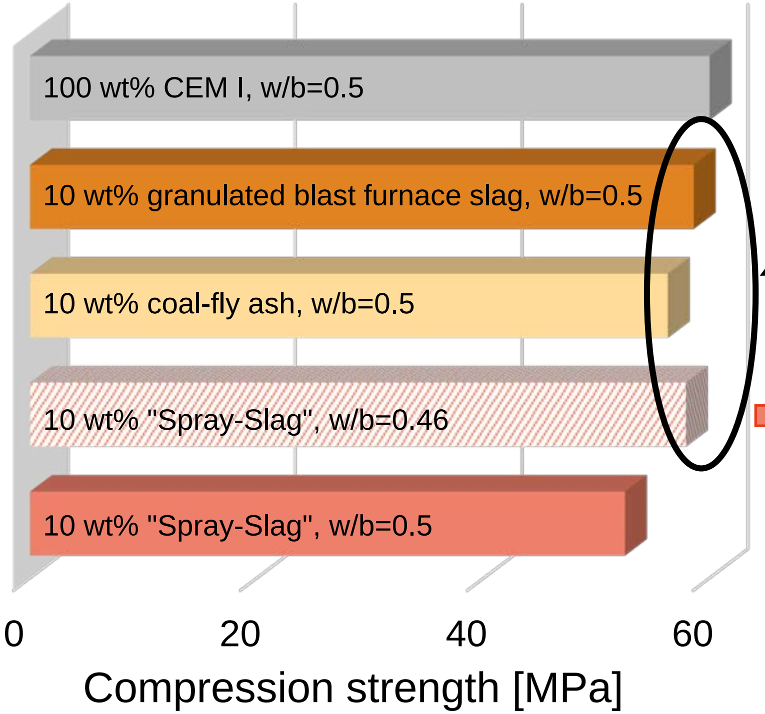
Hydration of atomized blast furnace slag

Compression strength of mortar

Mortar prisms

- binder content according to water/binder-ratio
- 28 days hydration





Same binder paste consistency

Similar strength!

reduced water content = reduced binder paste content

Advantages of atomization in slag processing

Comparison

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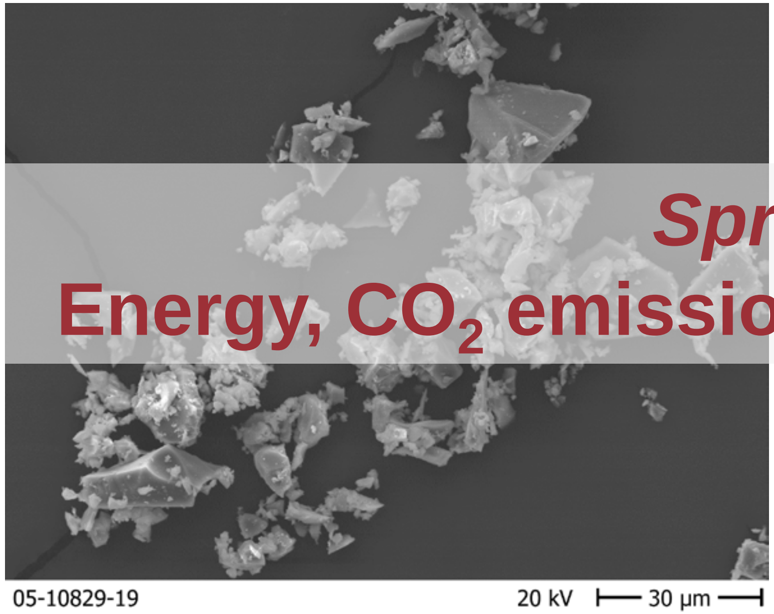
	Conventional process	Atomization
Process steps	3 (wet granulation, drying & grinding)	1 (atomization)
Resources	High consumption on energy and water, high CO_2 emission	Utilization of the heat energy and liquid state of the blast furnace slag
Particle shape	Angular	Spherical
Flowability	Poor	Improved
Reaction potential	Given	Given

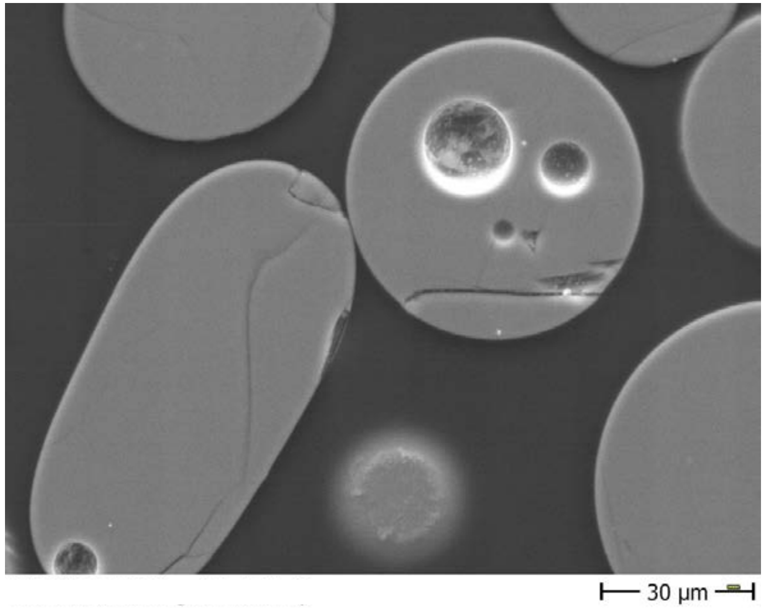
granulated slag particles



atomized slag particles

Spray-Slag

Energy, CO_2 emissions, workability improved



Thank you for your attention!

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European Union
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Die Senatorin für Klimaschutz, Umwelt, Mobilität, Stadtentwicklung und Wohnungsbau

Freie Hansestadt Bremen

Influence of the primary gas

Melt flow behaviour

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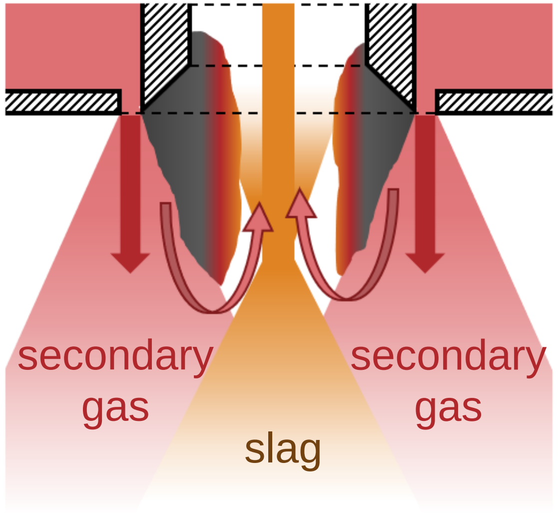
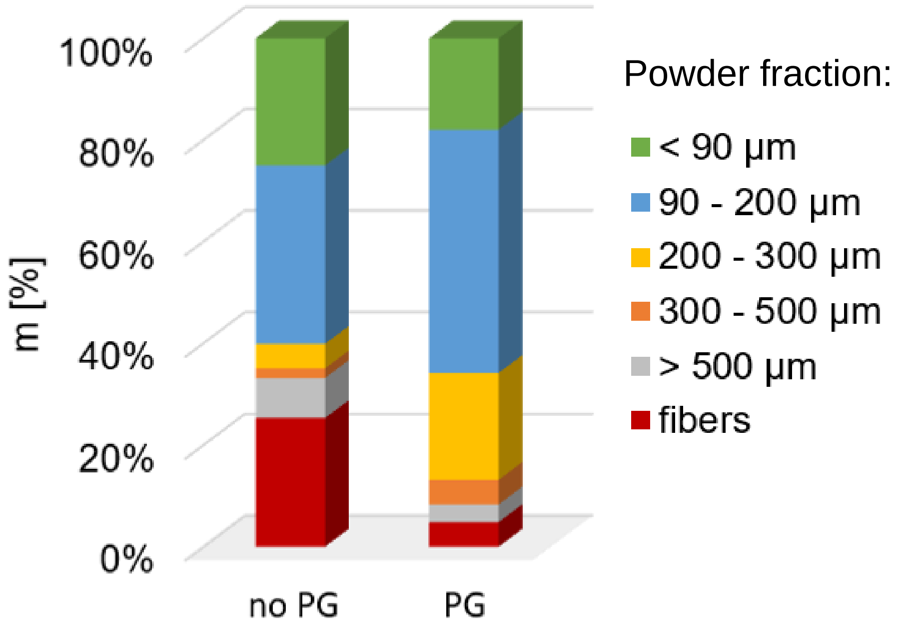


T_G = 750°C

p_{SG} = 1.55 MPa



Shorter distance between gas nozzle & atomization area

→ Higher impact between gas & melt

→ More powder < 90 µm