Improved Extrusion Technology for the Production of Batteries – Enhancing Performance and Reducing Costs. A Current and Future Perspective

Eike Wiegmann, Laura Helmers, Arno Kwade 13.11.2018

Extrusion in LIB-Production

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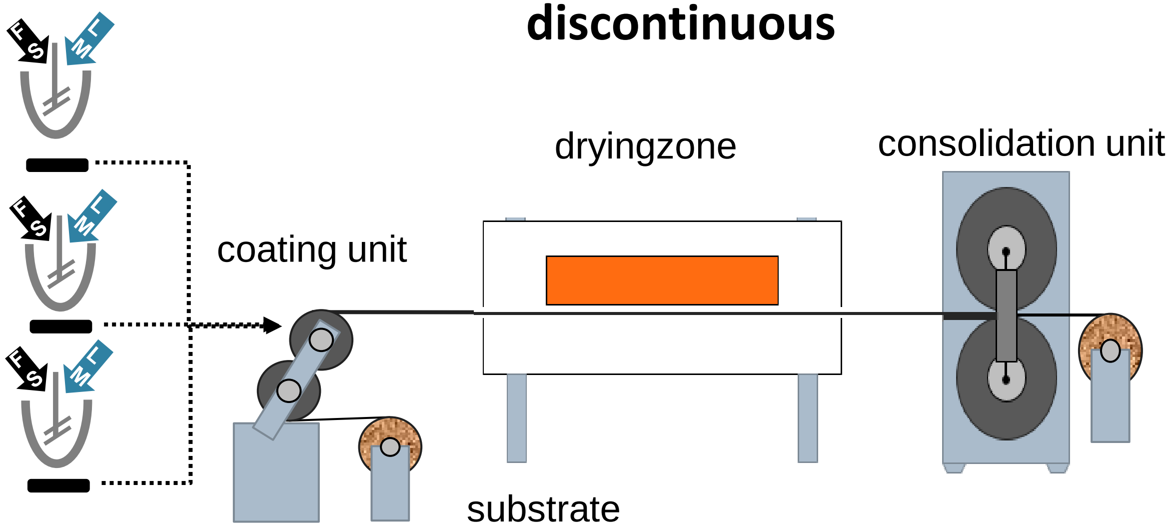
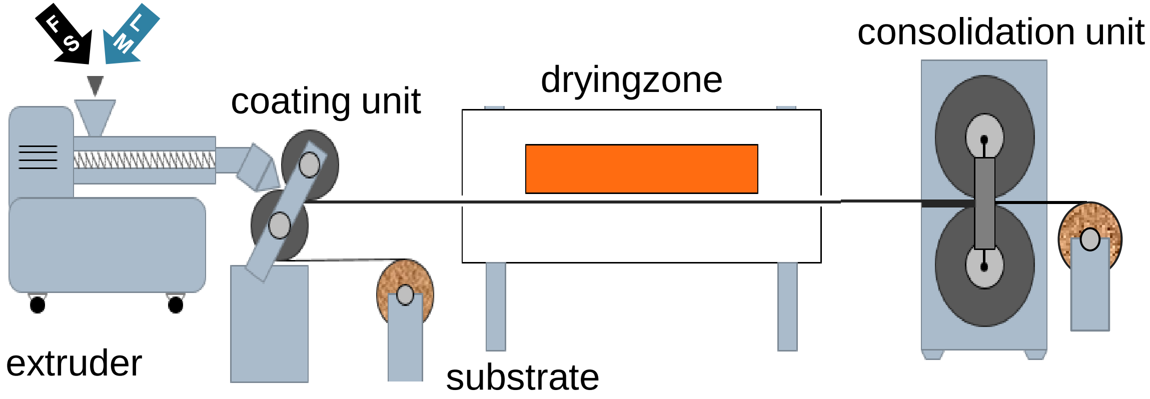
discontinuous



continuous



- Time and cleaning intensive, space blocking
- Low level o

- Integration of dispersion and coating

planetary mixer		extruder
3,81 €/$kg_{suspension}$	personnel costs	0,61 €/$kg_{suspension}$ [1]
0,005 €/$kg_{suspension}$	energetic costs	0,002 €/$kg_{suspension}$

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[1] Matthias Harmann; Projektvorstellung KonSuhl ,4. Forschungskolloquium in Münster 2018

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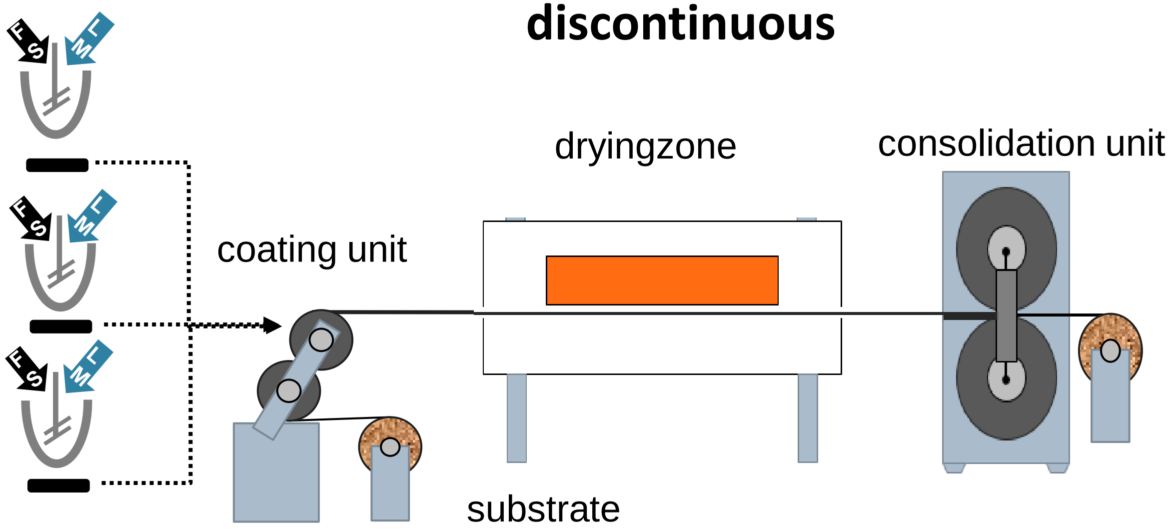

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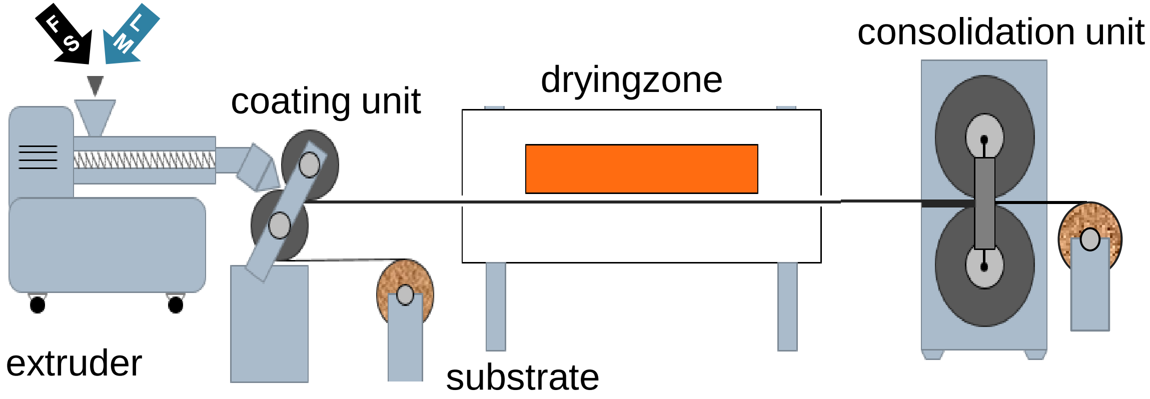

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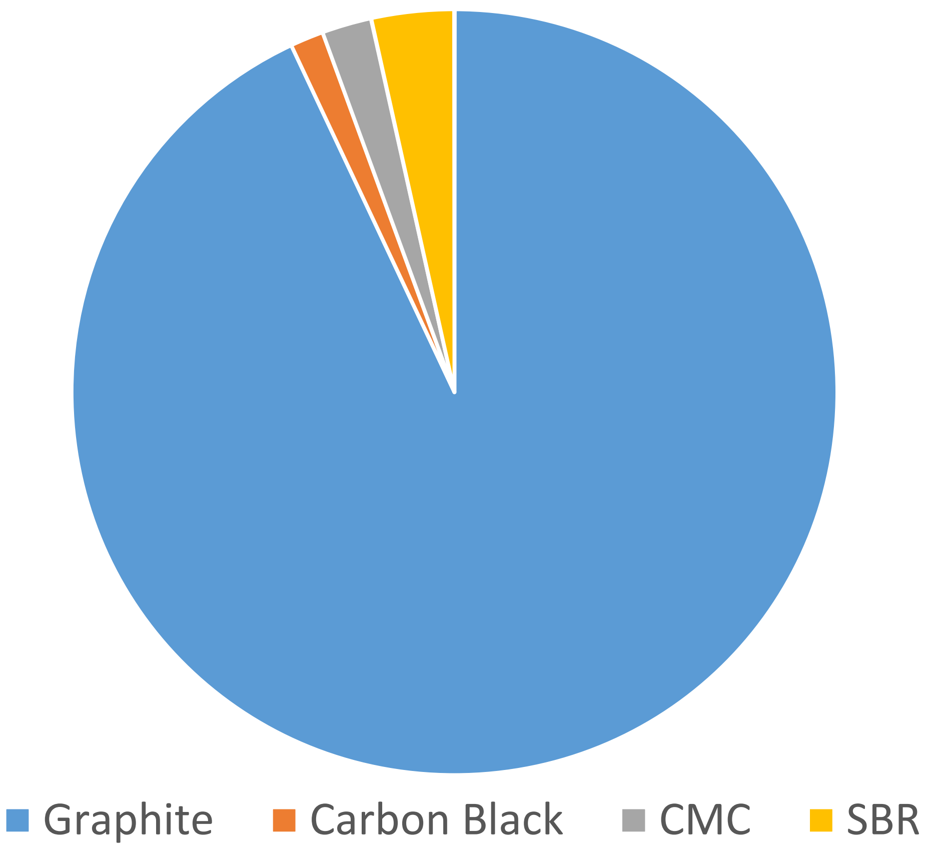
Process Parameter Effects on LIB (Anodes)

anode formulation



extrusion parameters

drive | solid content

influence on

slurry properties

particle size | viscosity

influence on

electrode properties

mechanics | conductivity

Influence of Drive - Slurry

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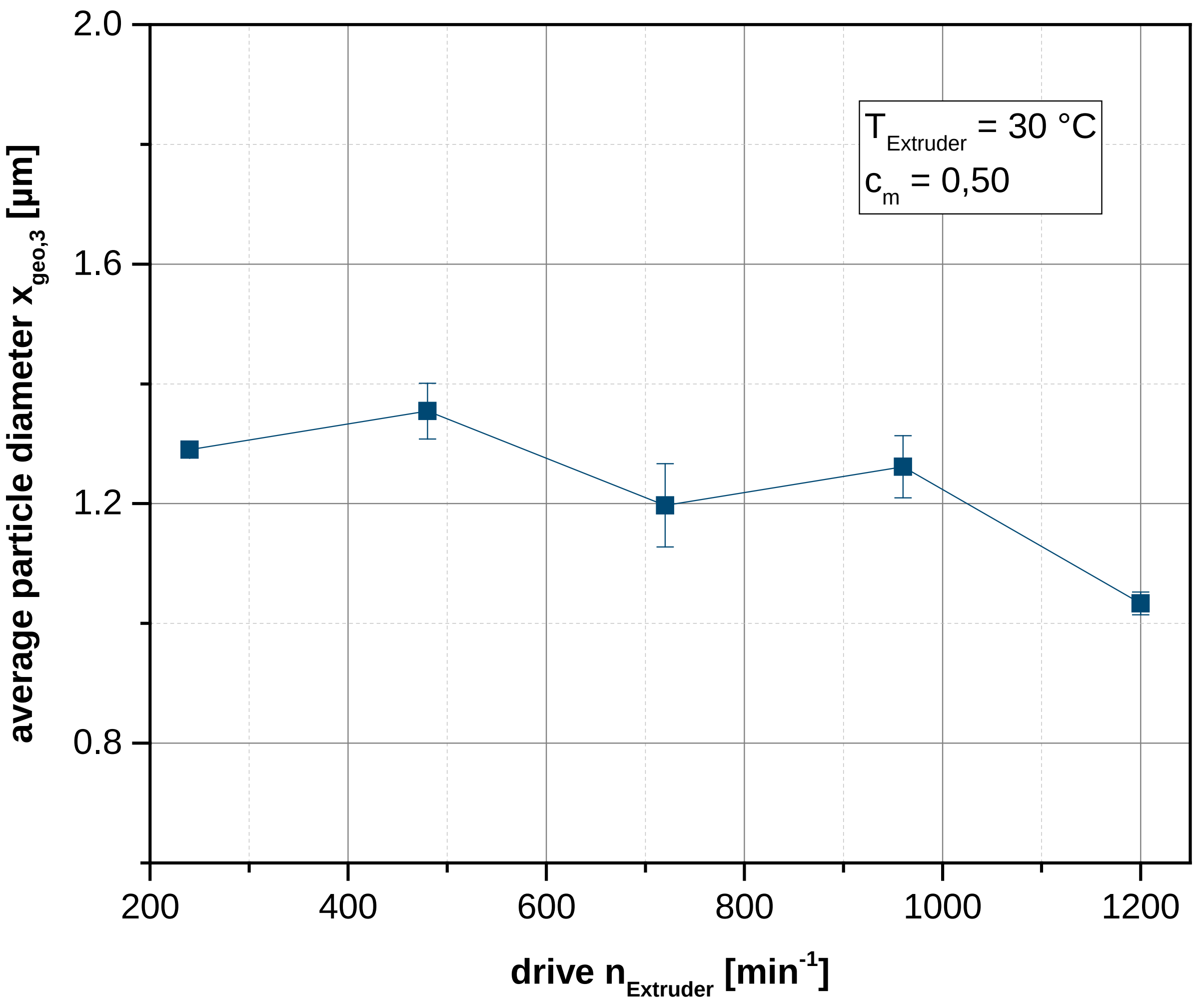
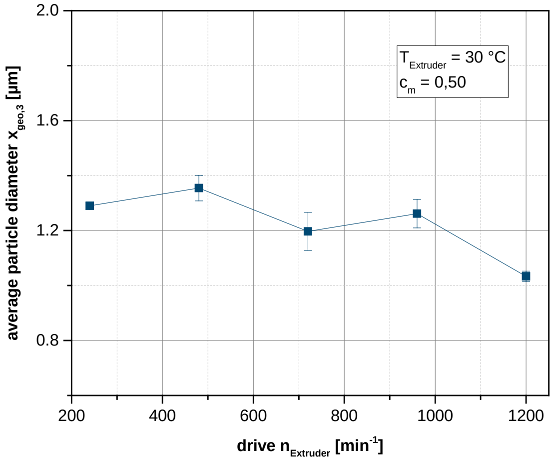


Influence of Drive - Slurry



Particle size

- High rotational speed → higher shear rates→ better dispersion
- High rotational speed → shorter retention time → worse dispersion

Influence of Drive - Slurry

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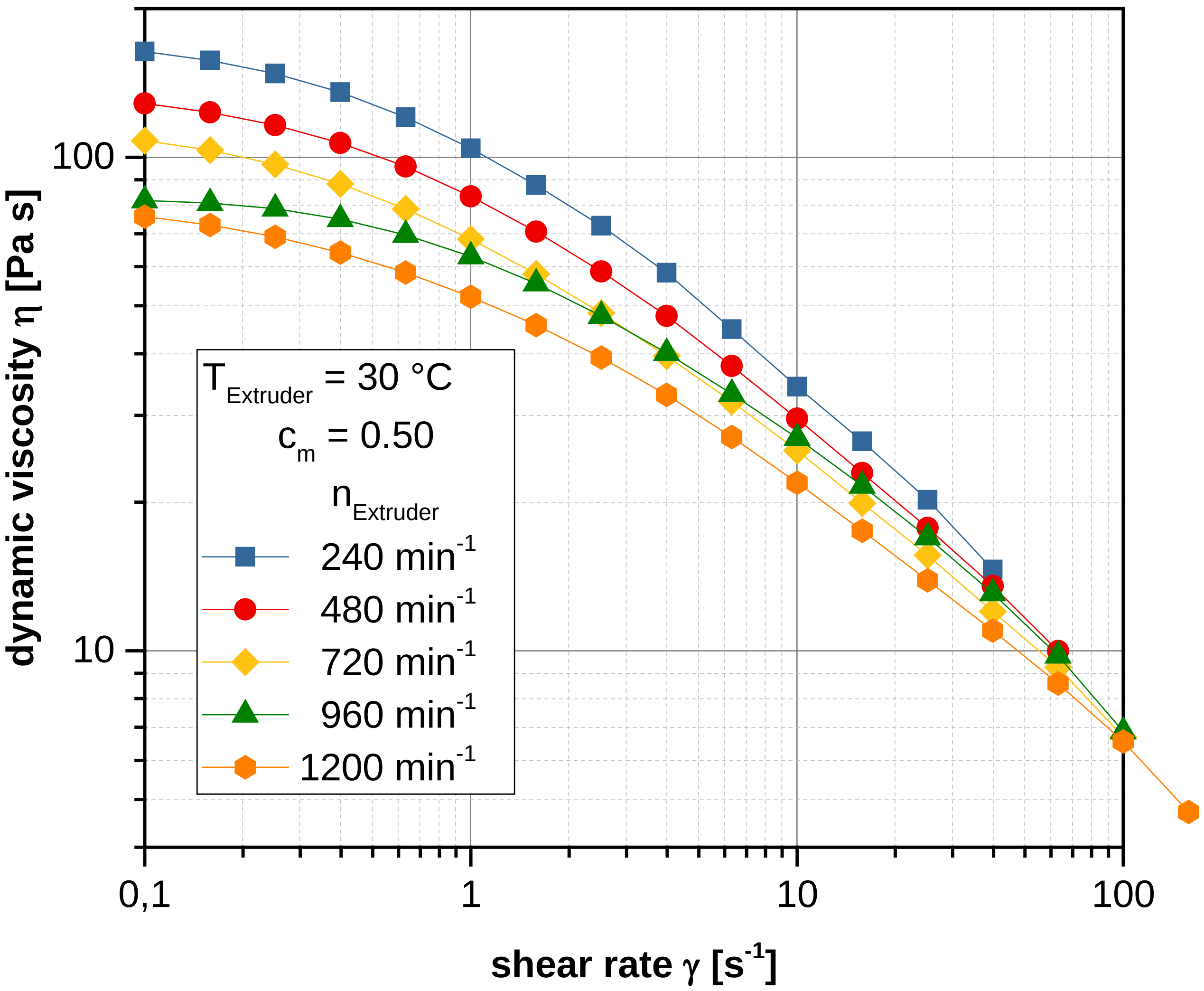

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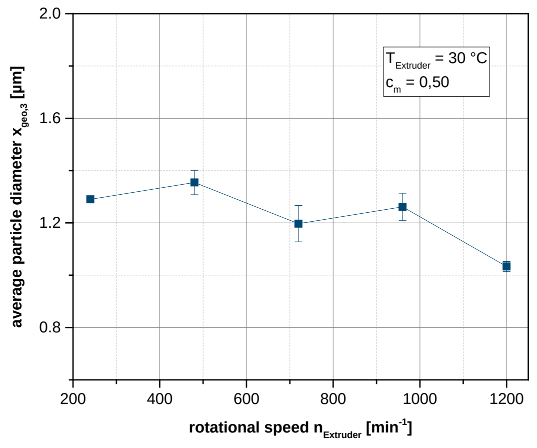

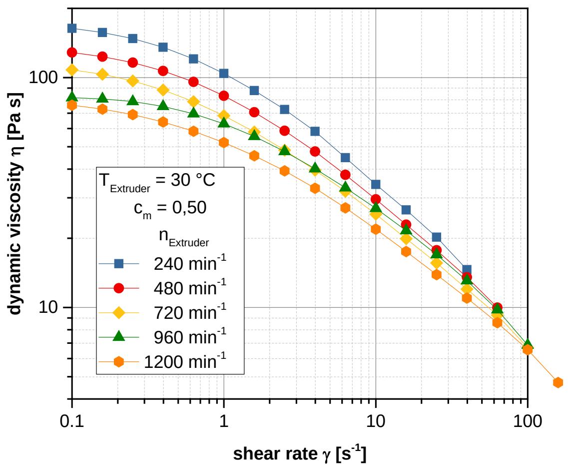

Particle size

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Rheology

- Shear dilutive | viscoelastic liquid
- Higher shear stress→ less cross-linking + network weakening

Influence of Drive - Electrodes

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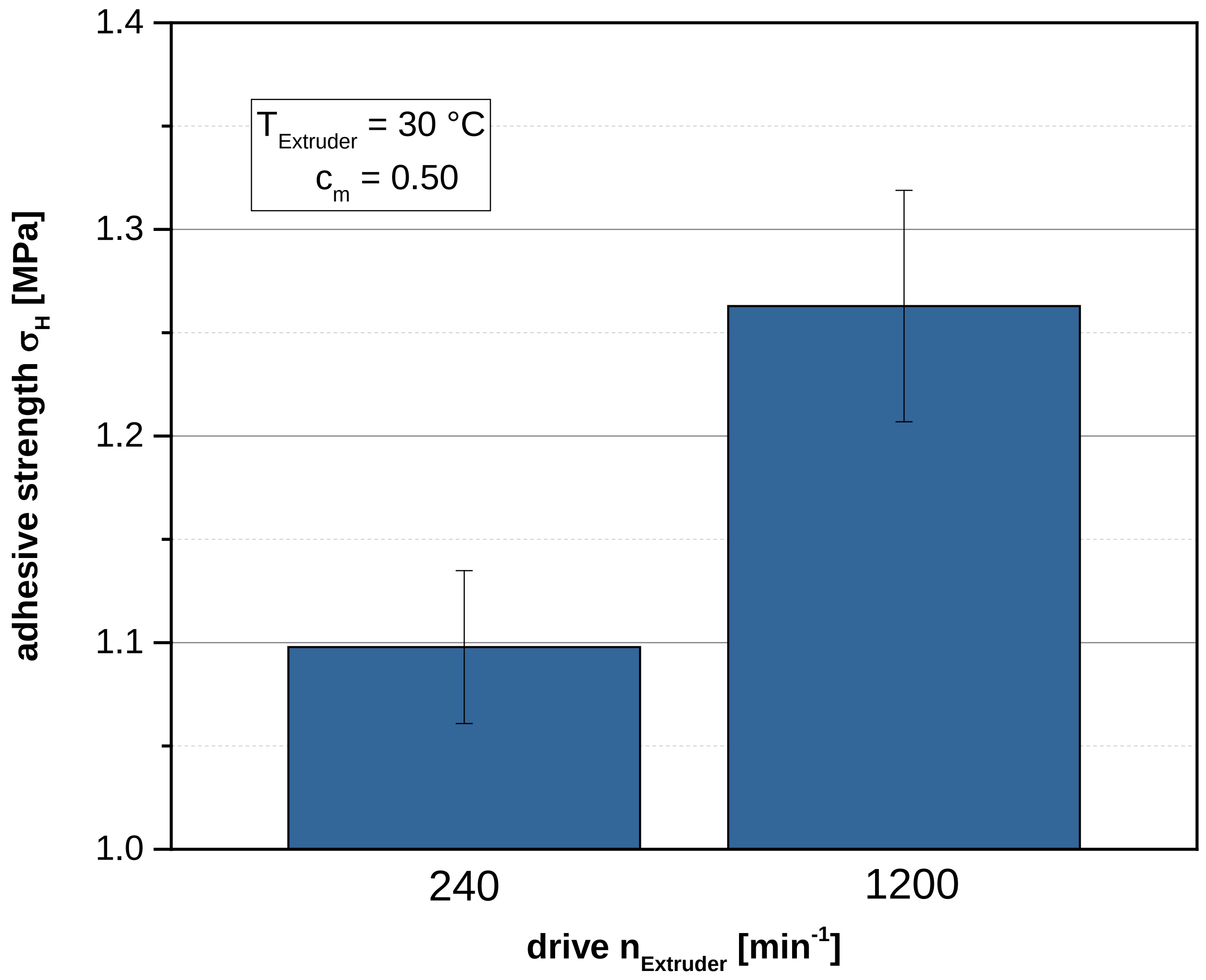
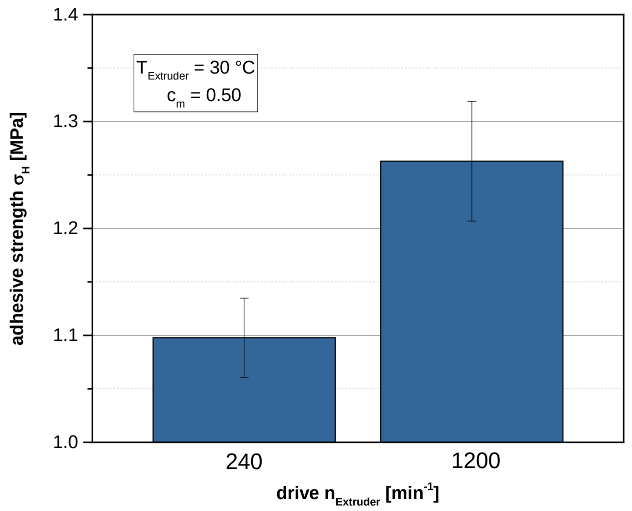


Influence of Drive - Electrodes



Adhesive strength

- Adhesive caused collapse → agglutination of SBR
- Smaller particels → higher specific surface + more contact points → improved adhesive strength

Influence of Drive - Electrodes

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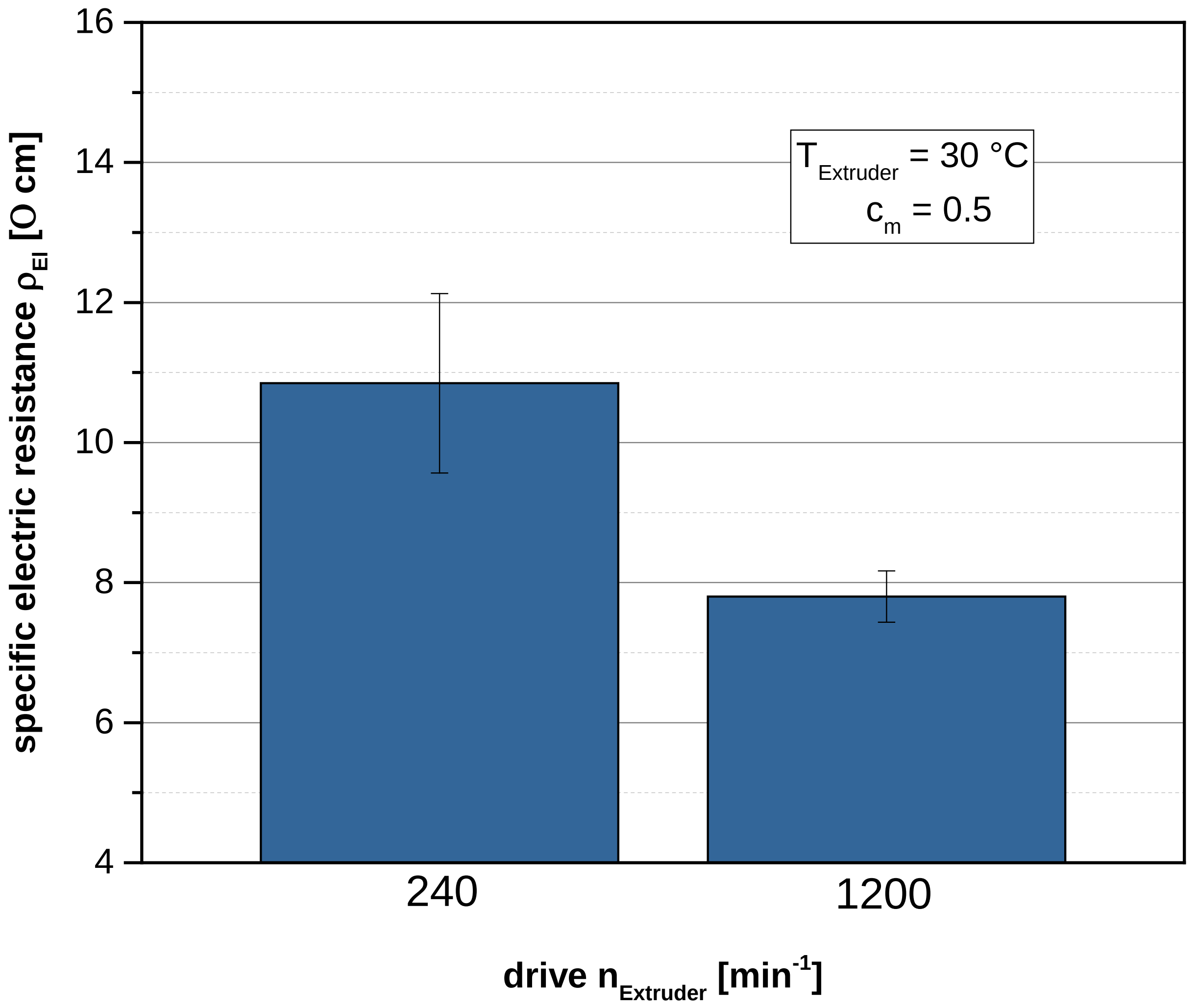

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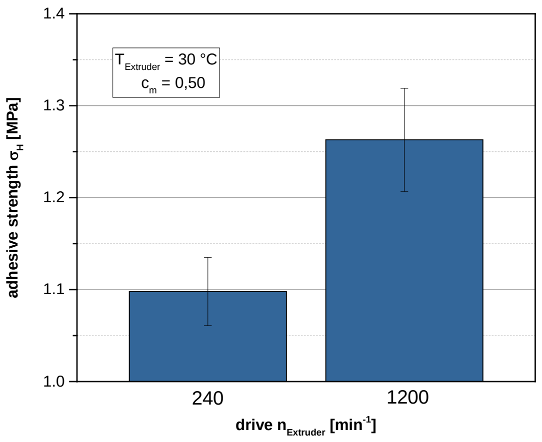

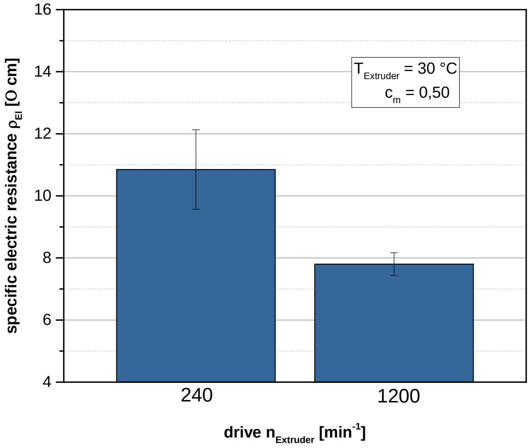

Adhesive strength

- Adhesive caused collapse → agglutination of SBR
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Electric conductivity

- Correlation with particle size
- Improved dispersion → homogenous allocation of carbon black

Influence of Drive - Electrodes

adhesive strength

- Adhesive caused collapse → agglutination of SBR
- Smaller particles → higher specific surface + more contact points → improved adhesive strength

conductivity

- correlation with particle size
- Increasing dispersion → homogenous allocation of carbon black

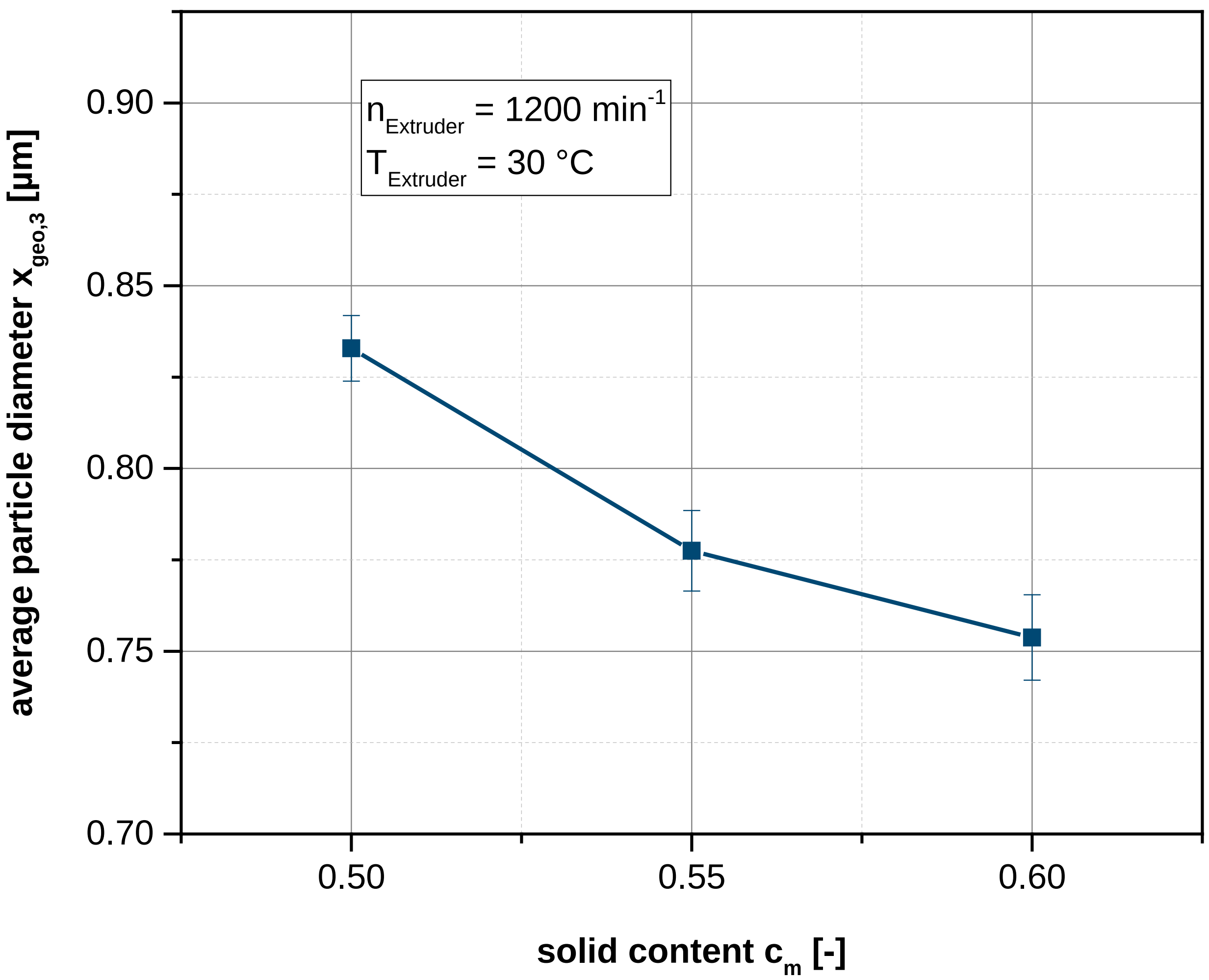
Influence of rotational high rotational speed

\+ Processability

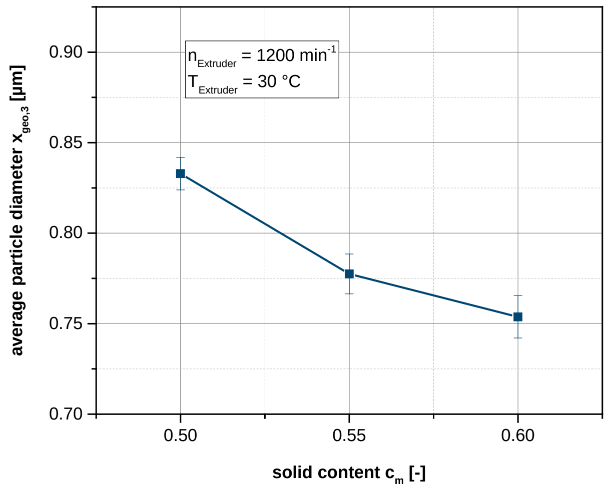
\+ Adhesive strength

\+ Conductivity

Influence of Solid Content - Slurry



Influence of Solid Content - Slurry



Particle size

- Higher particle conzentration → stress number and intensity increase → smaller particles
- Minimal particle size caused by stabilization

Influence of Solid Content - Slurry

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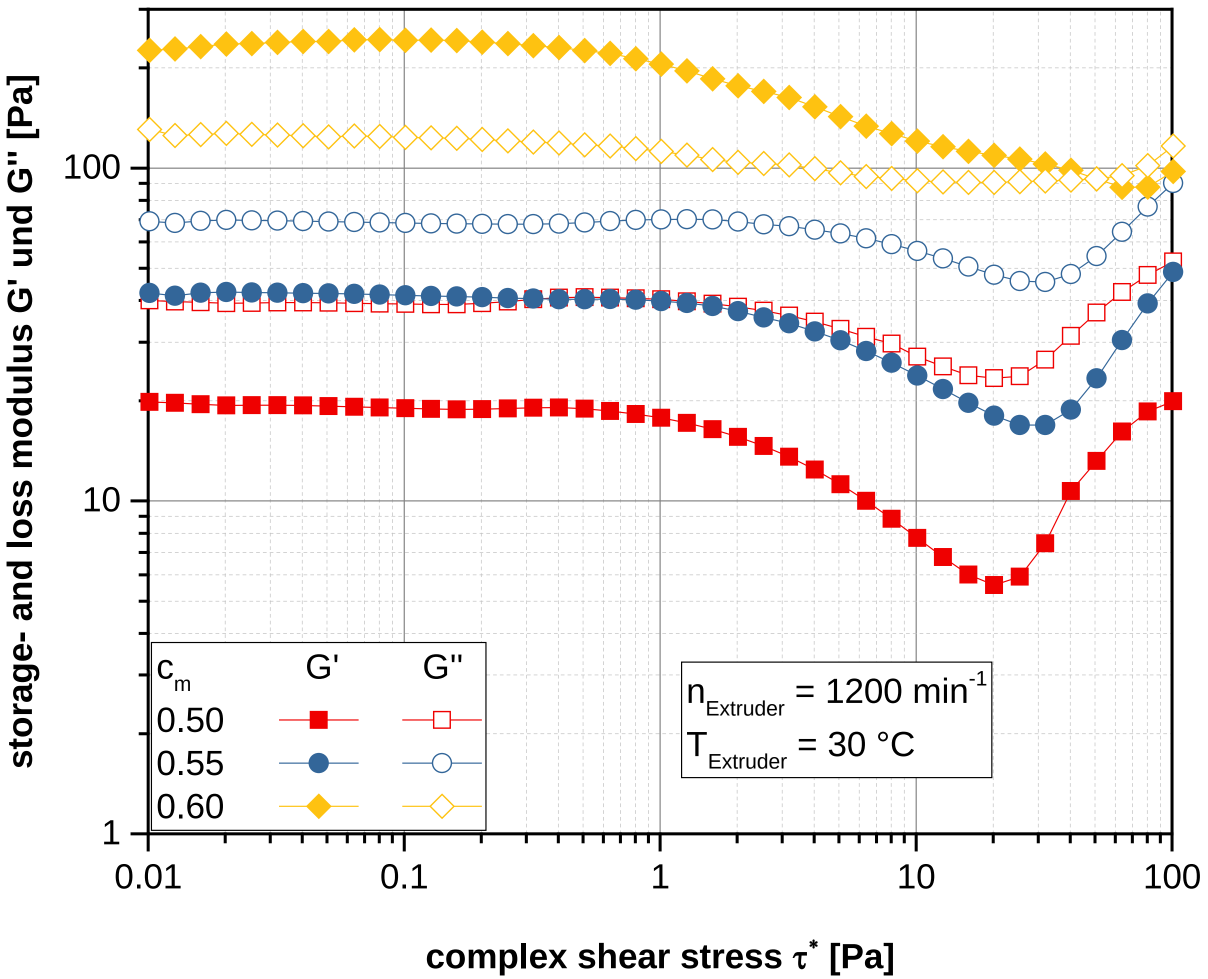

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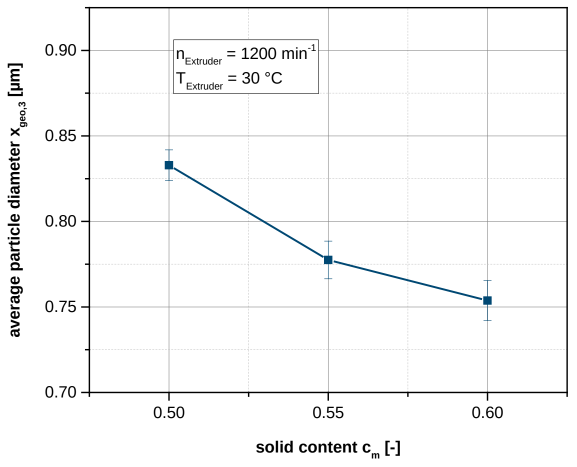

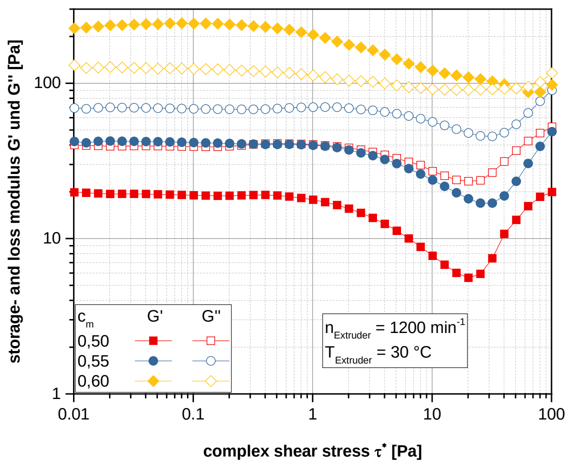

Particle size

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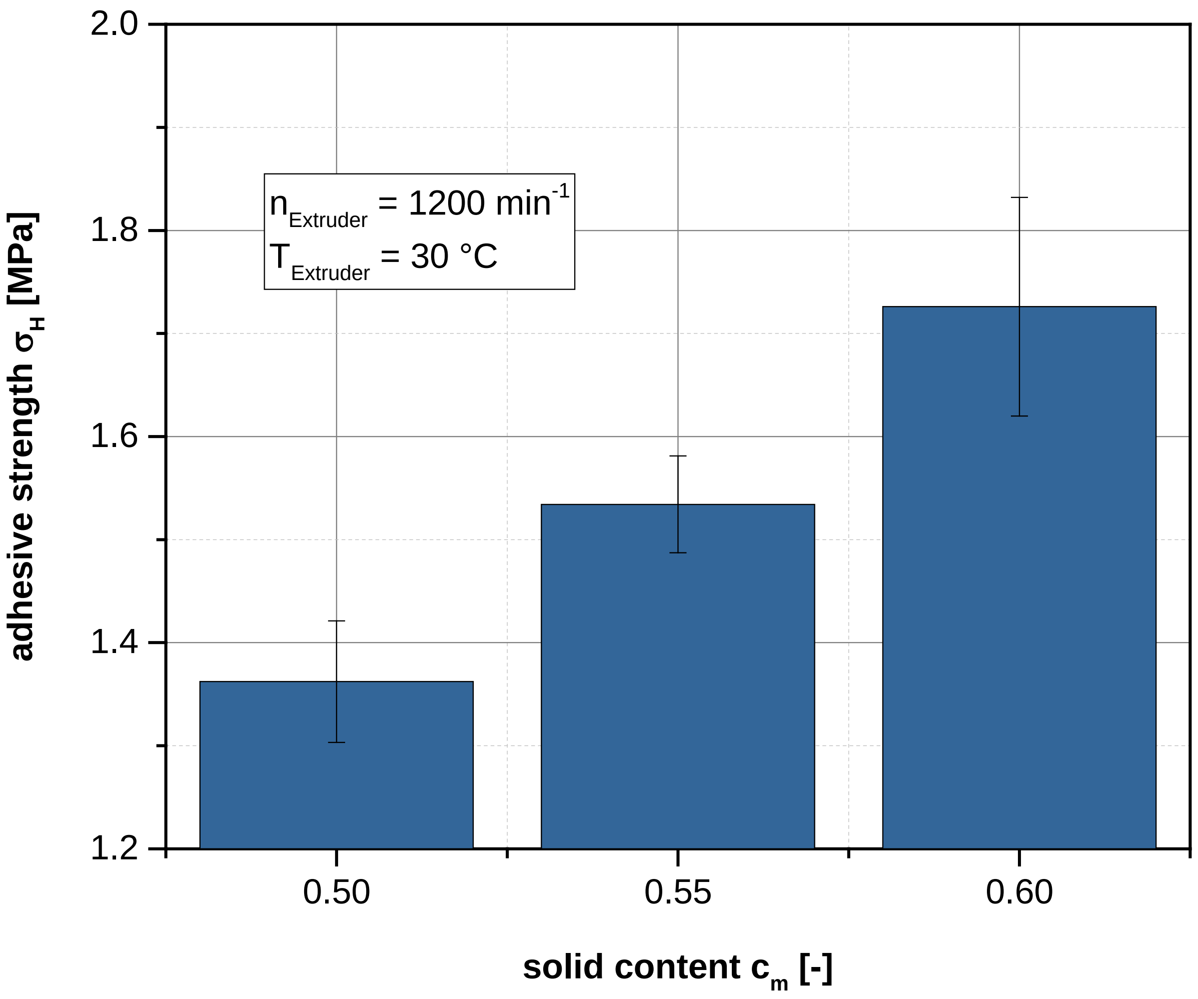
- Minimal particle size caused by stabilization

Rheology

- Viscoelastic solid body for $c_m > 0{,}60$
- Stability against seggregation
- High solid content → low mobility, stress number and intensity increase → higher viscosity

Influence of Solid Content - Electrodes



Influence of Solid Content - Electrodes

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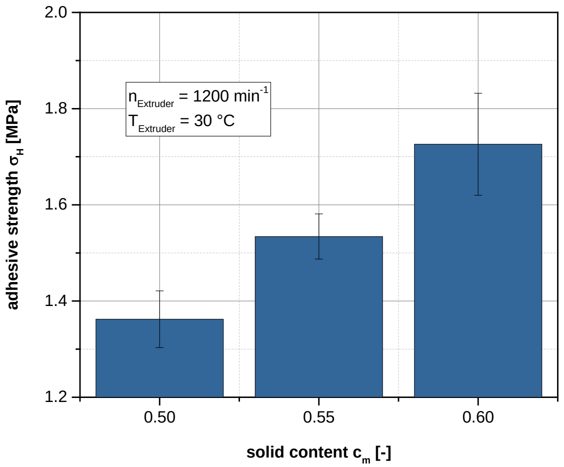
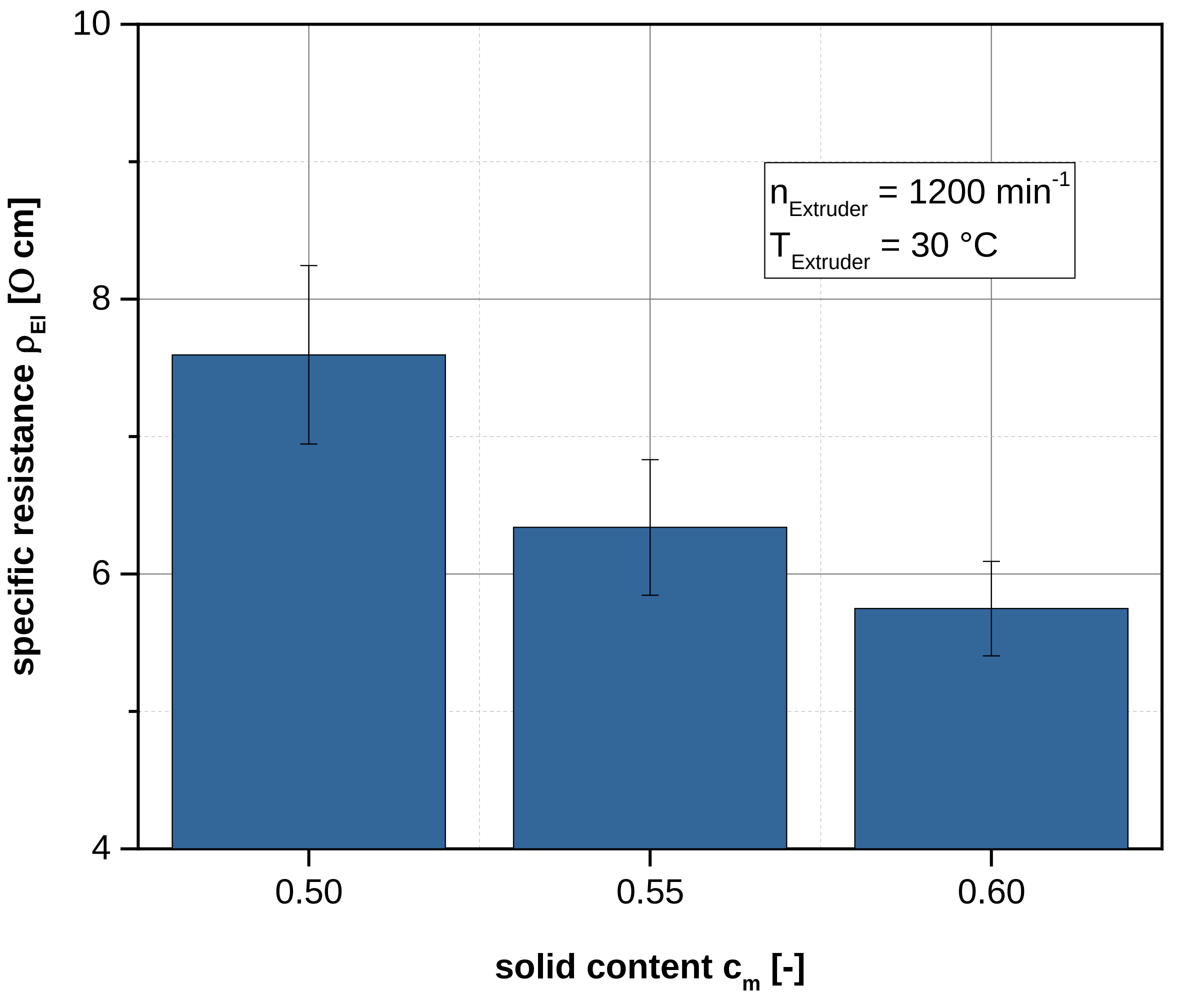


Adhesive strength

- Mainly adhesive caused collapse
- Smaller particles → bigger specific surface an more contact points → better adhesive strength
- Segregation of inactive material due to the low solid content→ lower adhesive strength

Influence of Solid Content - Electrodes



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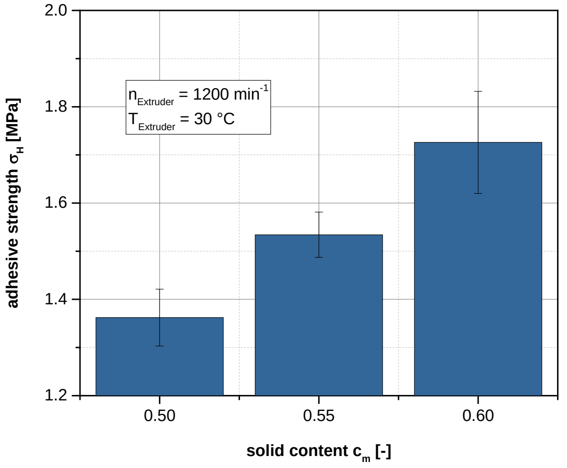

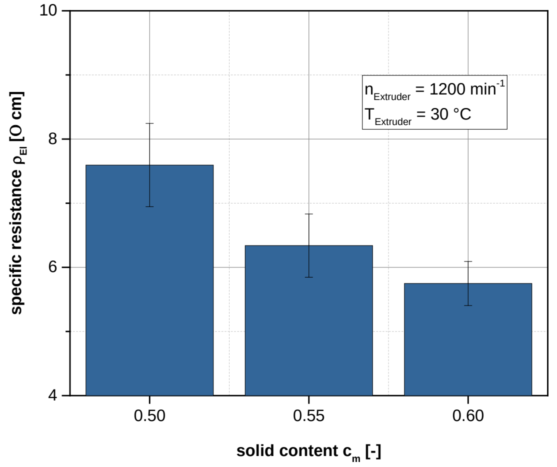

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Electric conductivity

- Correlation with particle size
- Segregation of inactive material due to the low solid content→ lower adhesive strength

Influence of Solid Content - Electrodes

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Influence of high solid content

- \+ Reducing drying costs
- \+ Adhesive strength
- \+ Conductivity
- \- Processability

Adhesive strength

- mainly adhesive caused collapse
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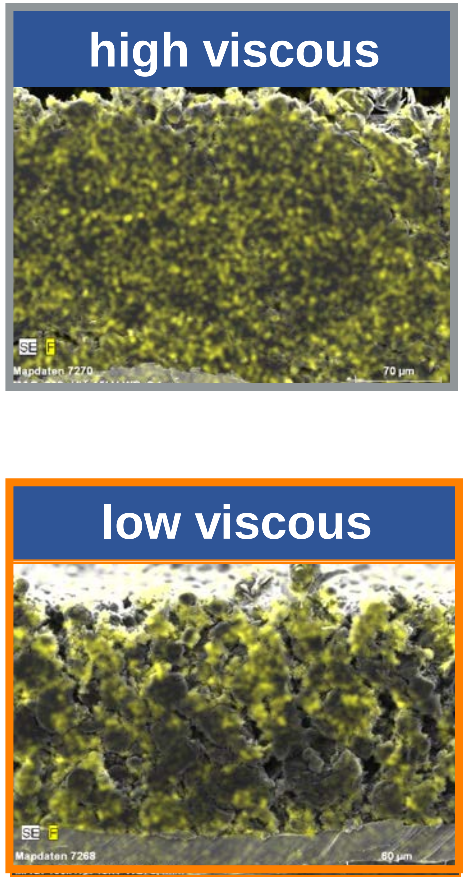
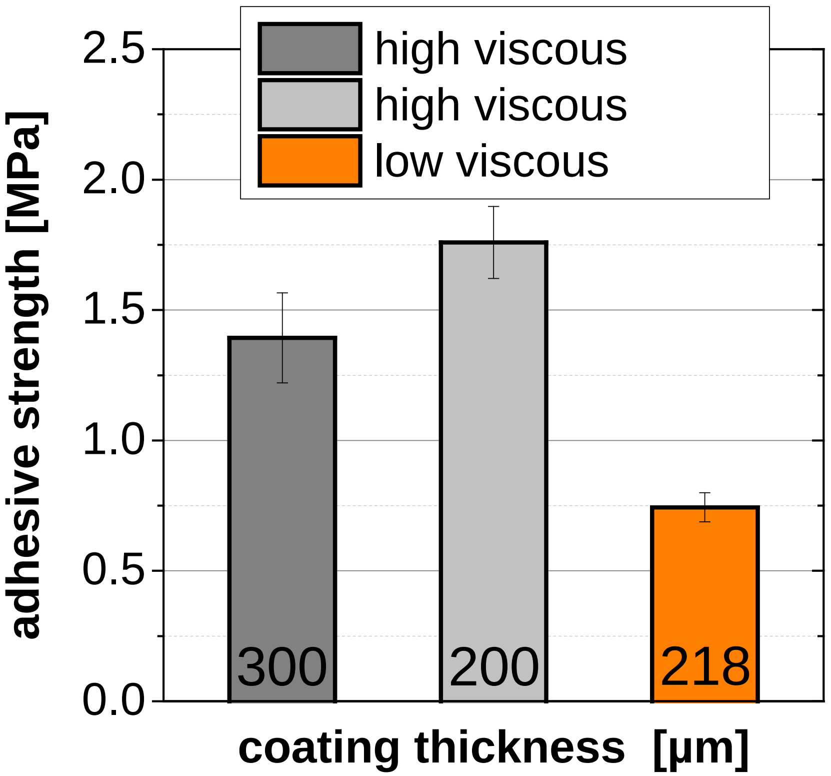
electric conductivity

- correlation with particle size
- Segregation of inactive material due to the low solid content→ lower adhesive strength

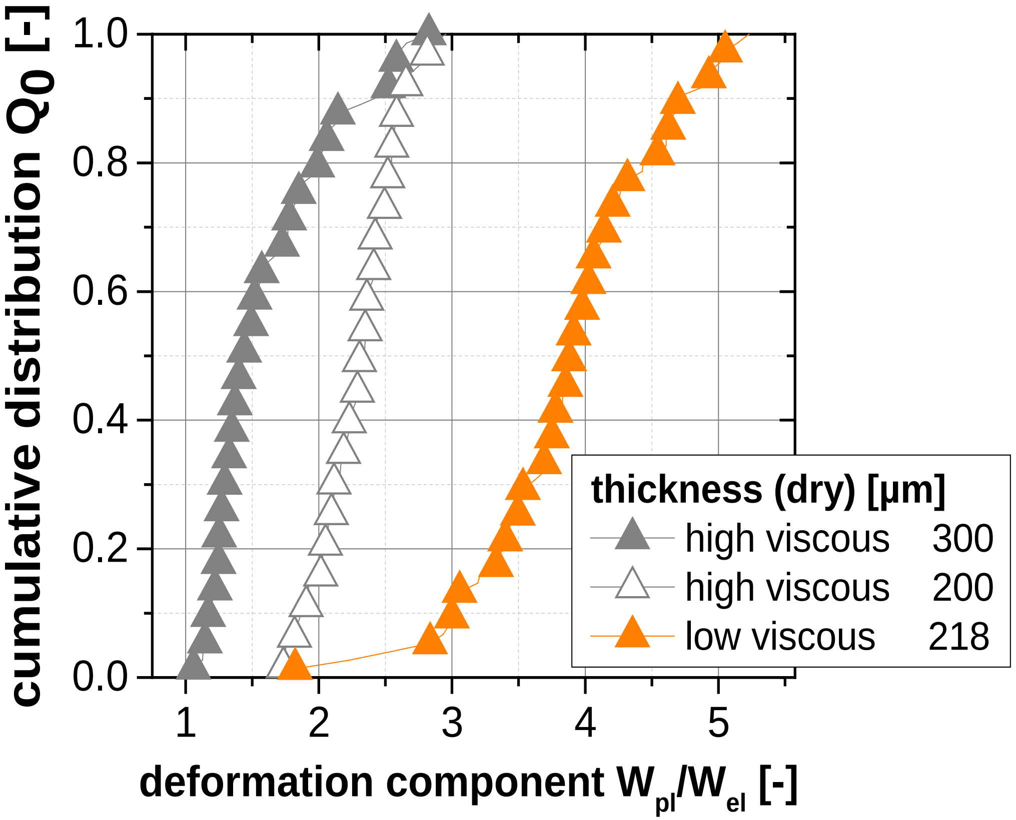
Outlook: High Solid Content c_m > 60%



Adhesion



Deformation



Outlook: High Solid Content $c_m > 60\%$

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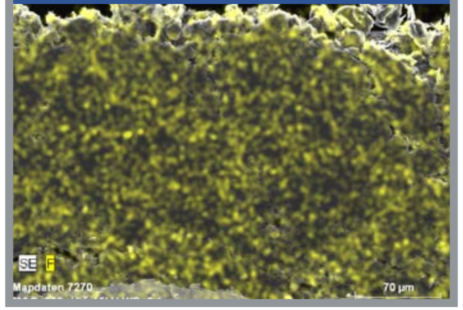
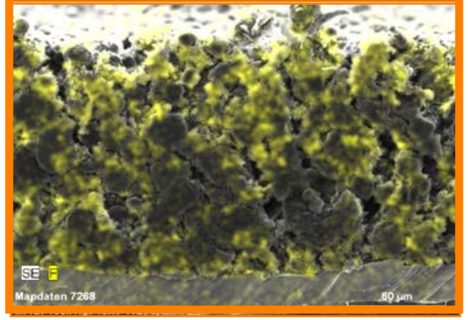
high viscous



low viscous



Benefit:

- No binder segregation
- Improved mechanical properties
- High cycle stability
  → range improvement
- Further reducing drying time/costs

Challenge:

- New coating system required
- Active material can be damaged
  → minimize shear stress

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Improved Extrusion Technology for the Production of Batteries – Enhancing Performance and Reducing Costs. A Current and Future Perspective

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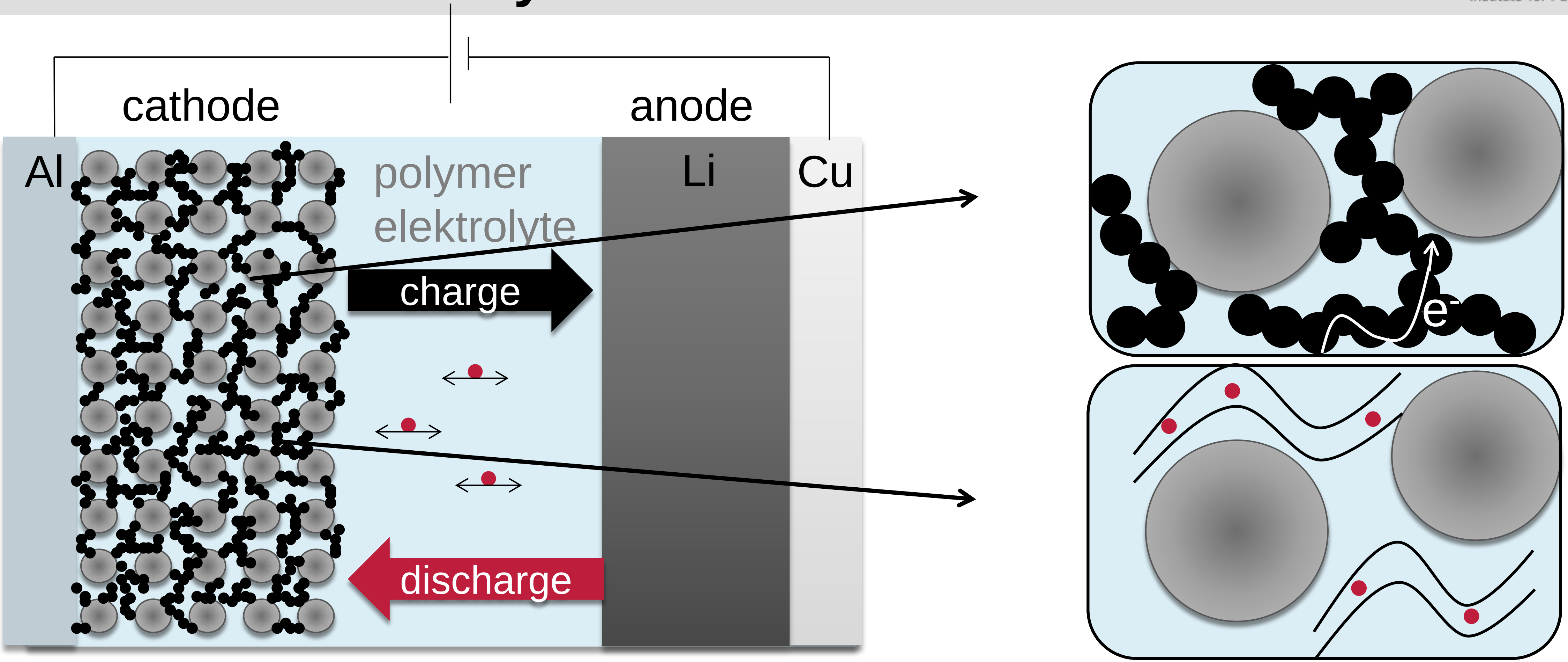
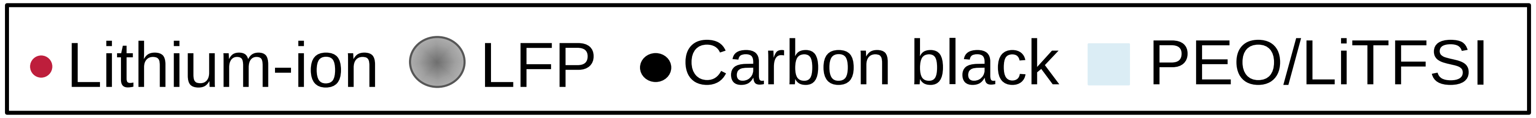
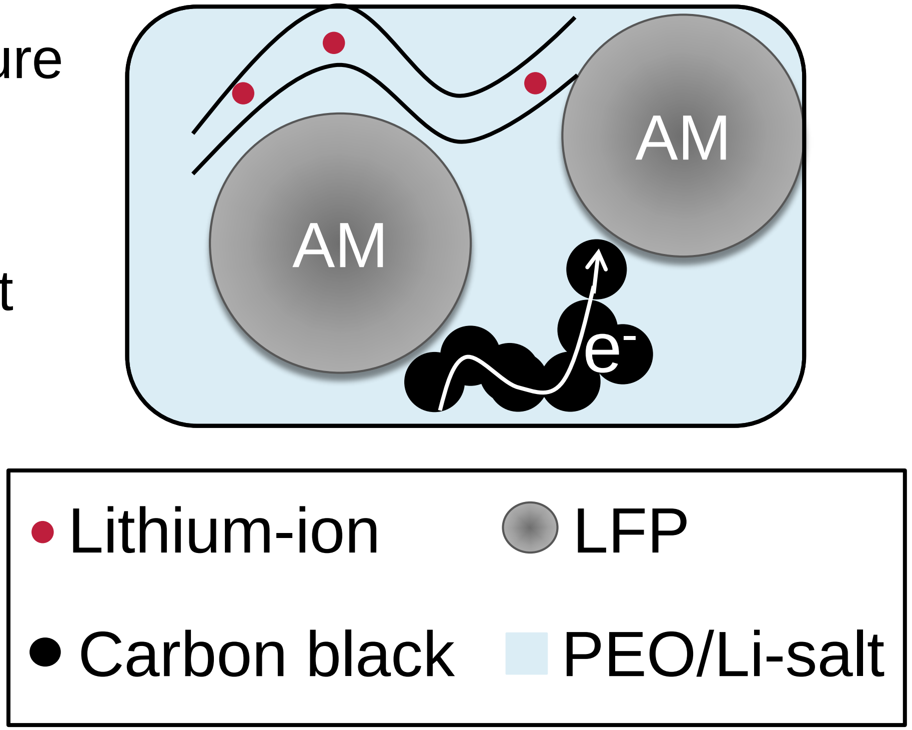
All-solid-state battery



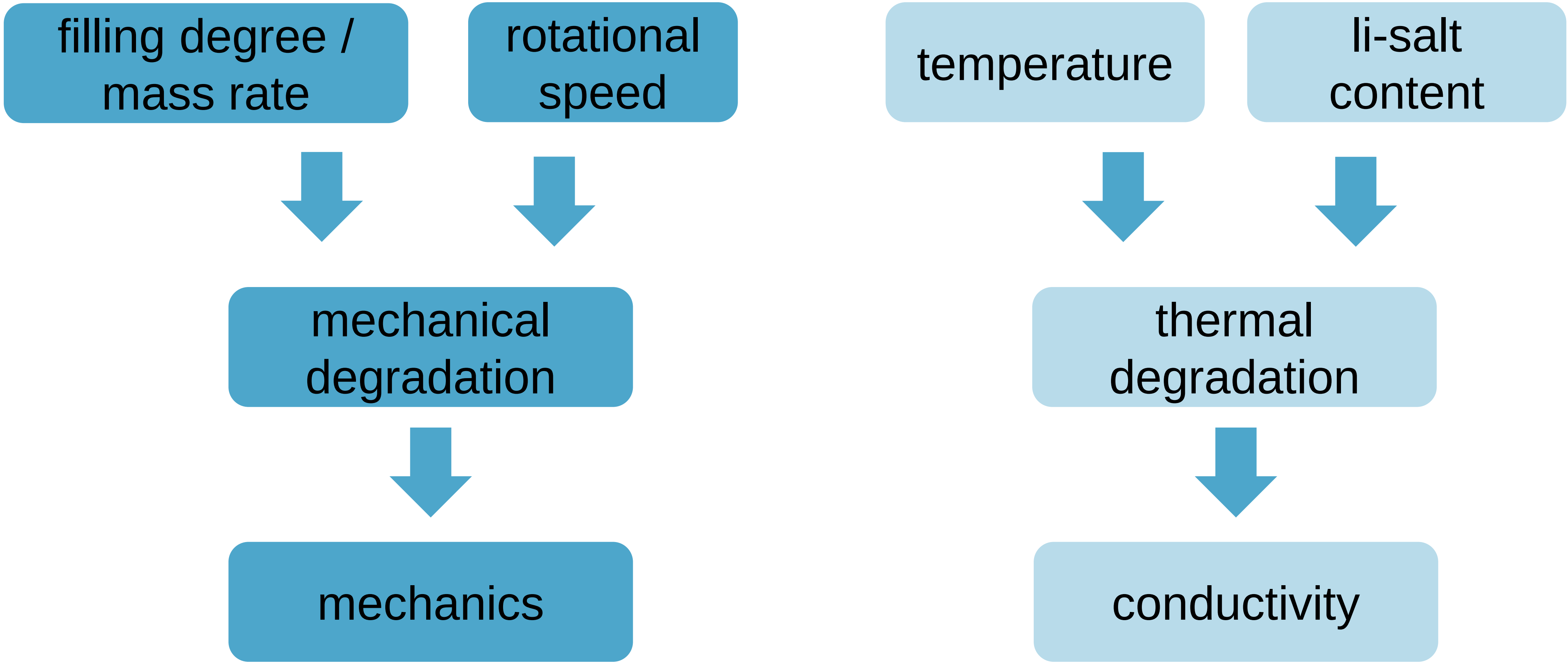


Requirements for All-Solid-State Processing

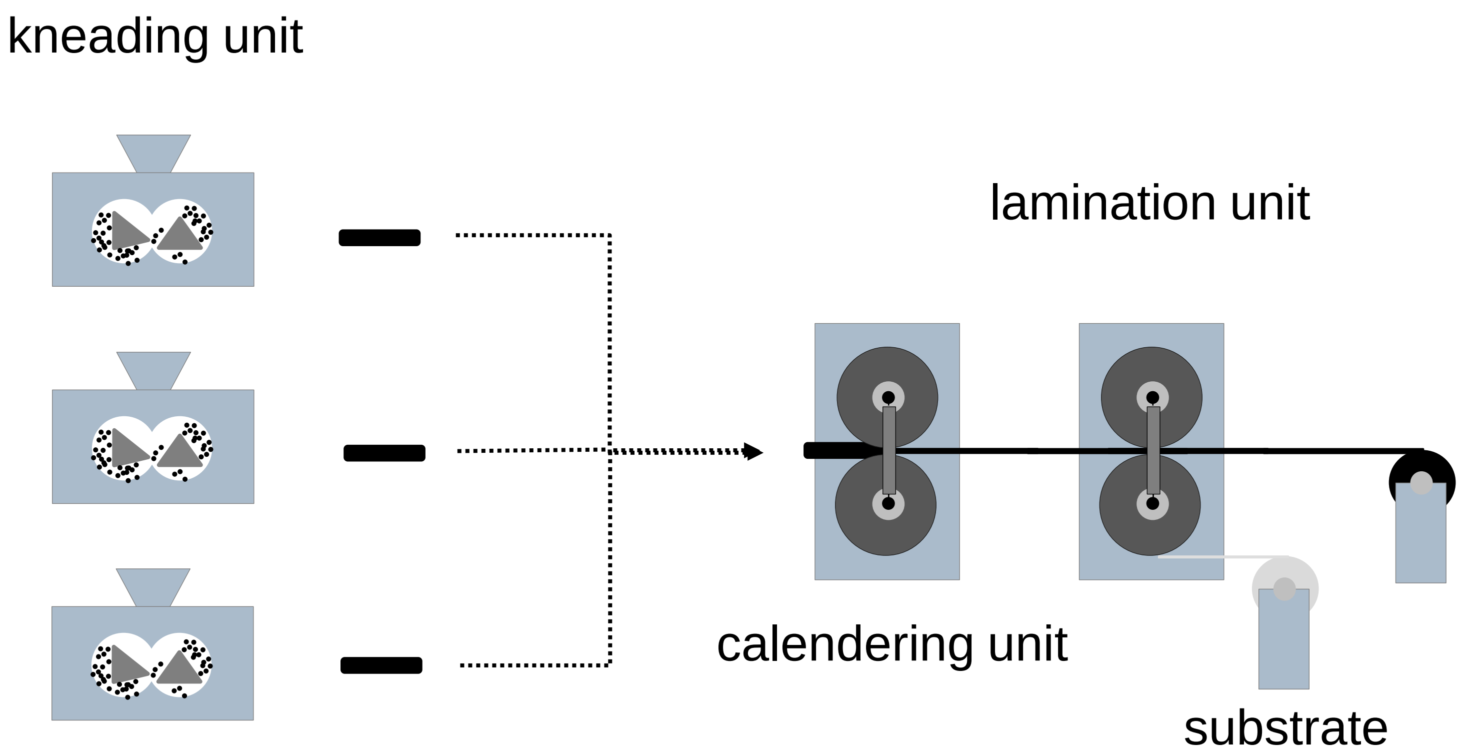
- Liquid electrolyte is replaced by a solid polymer-salt mixture
- No desired porosity like in classic Li-Ion batteries, goal is zero porosity
- Li-ion transport is dependent on polymer chain movement
- High homogenization degree is needed for high ionic conductivity
- Shear stress has to be minimized as it causes chain-degradation
- Solvent free process chain is used



Process Parameter Effects on Polymer Properties

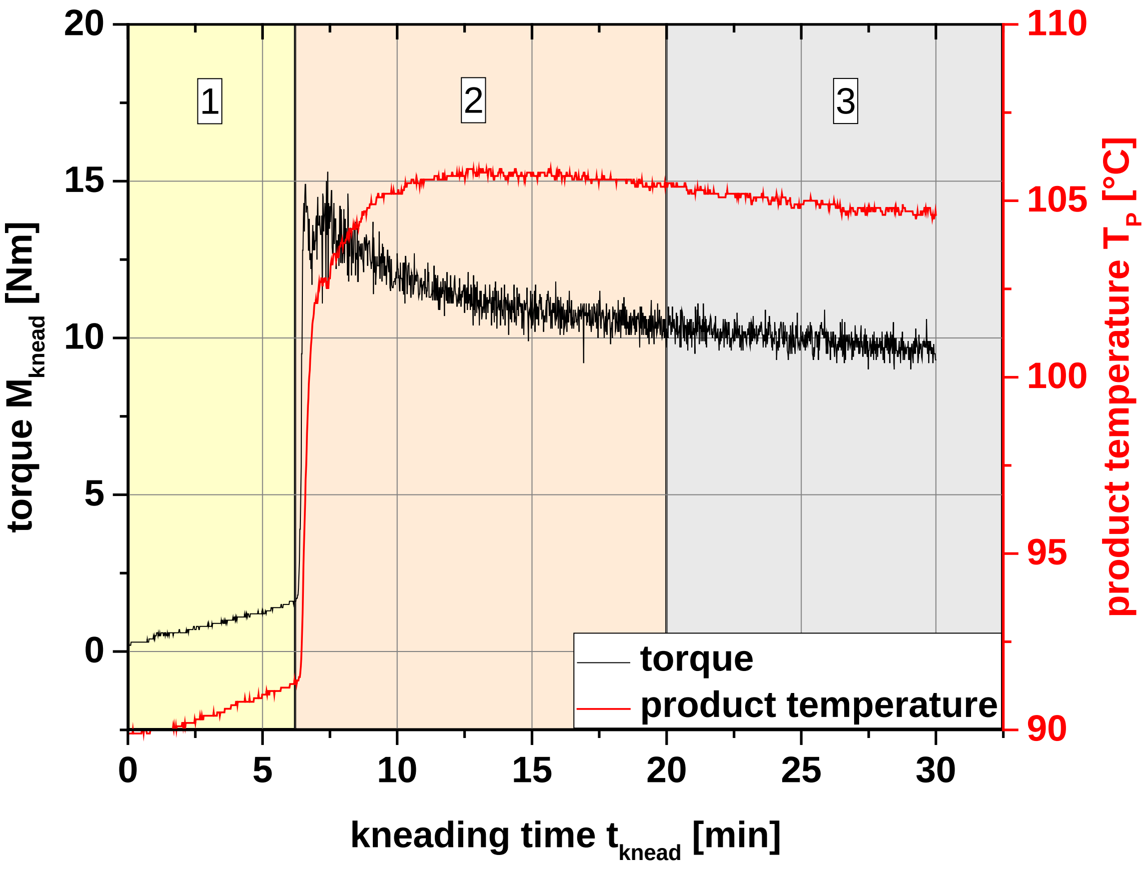


Batch Process for ASSB Production



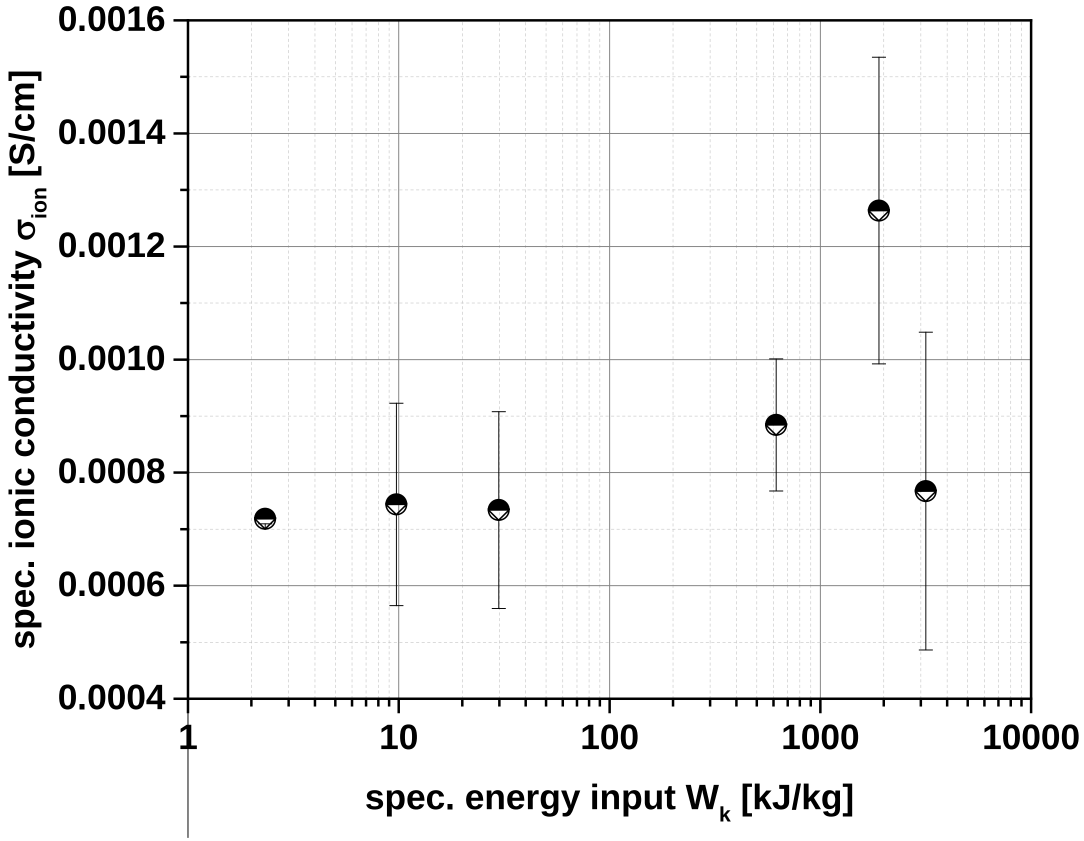
- Time and cleaning intensive
- Low level of automation
- Higher personnel and energetic costs

Batch Kneading Process for ASSB



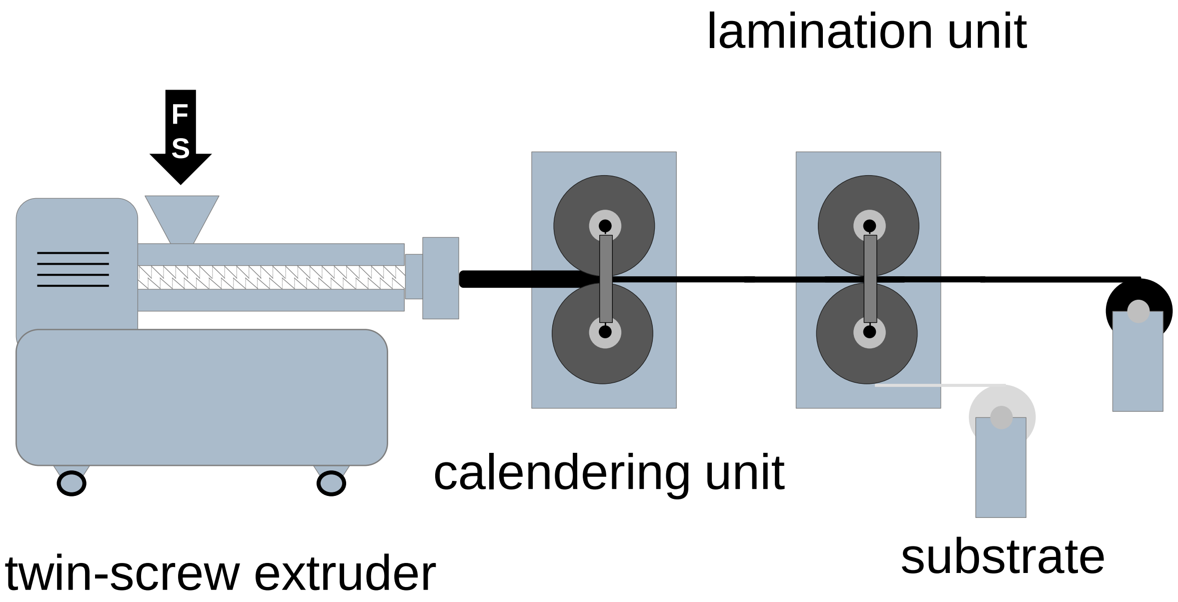
1. Homogenization of PEO particles
2. Plasticizing PEO melts and flow resistance decreases
3. Mechanical degradation of PEO

Batch Kneading Process for ASSB



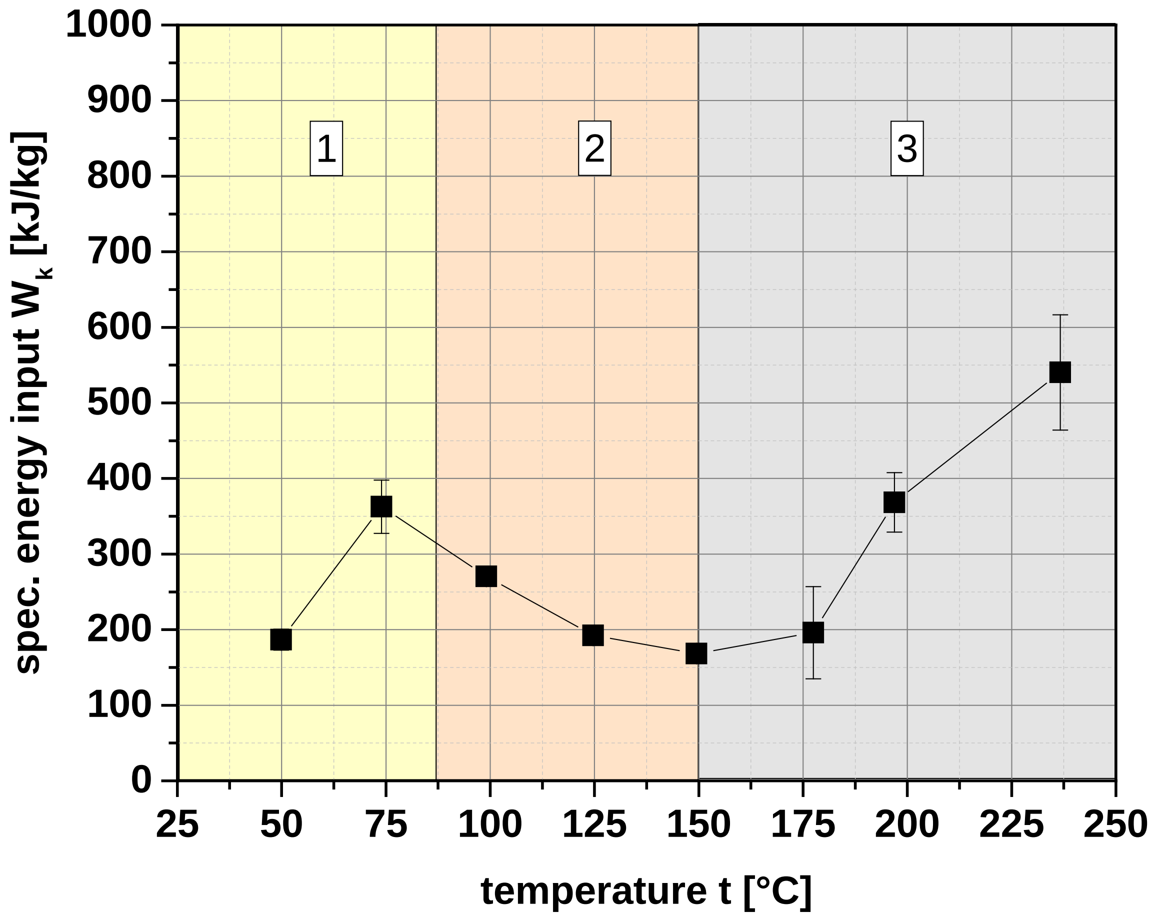
- Specific ionic conductivity increases with rising enery input through homogenization and chain-degradation
- For W_k > 2000 kJ/kg degraded polymer chains probably cross-link and the reduced chain mobility cause a decreased ionic conductivity

Continuous Process Chain for ASSB Production



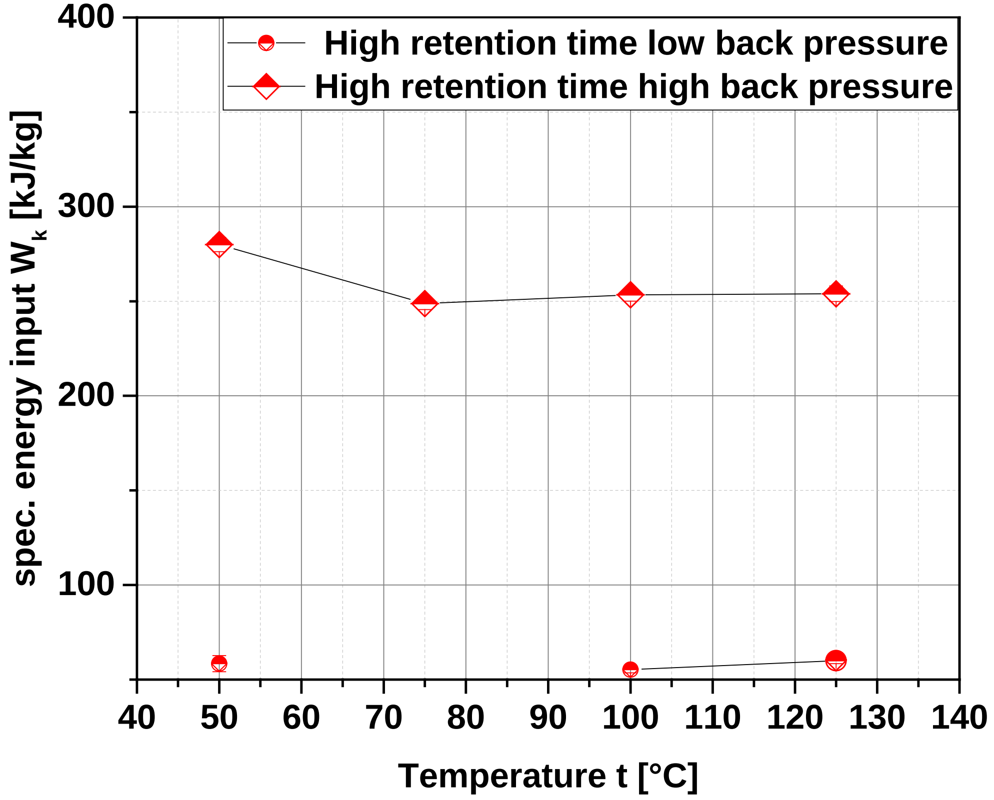
- Through solvent free process drying unit is saved
- For direct calendering thin and broad extrudates are desired
- Utilization of same process route for cathodes and separator

Influence of Temperature on Specific Energy Input



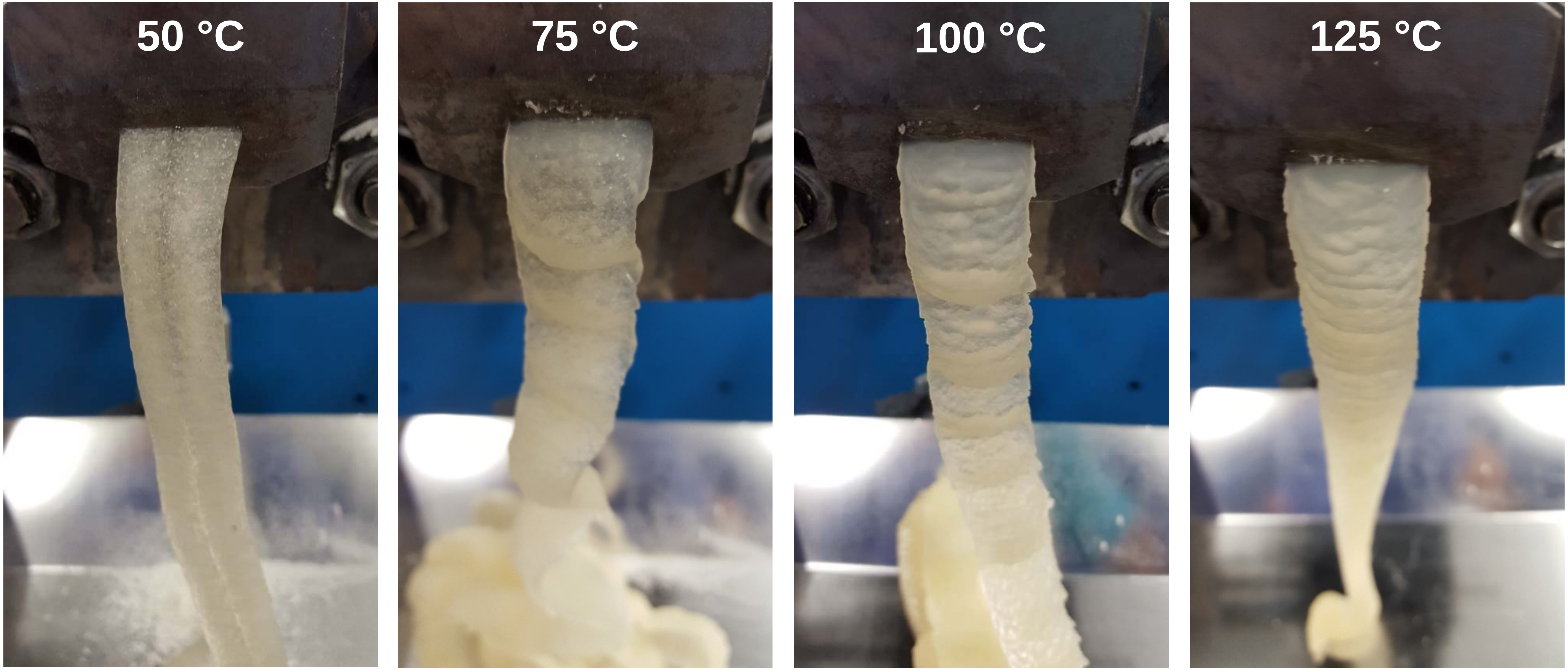
1. Homogenization of solid PEO particles
2. Plasticizing of molten PEO causes decrease in flow resistance
3. Thermal degradation and solidification of PEO

Influence of Temperature on Specific Energy Input

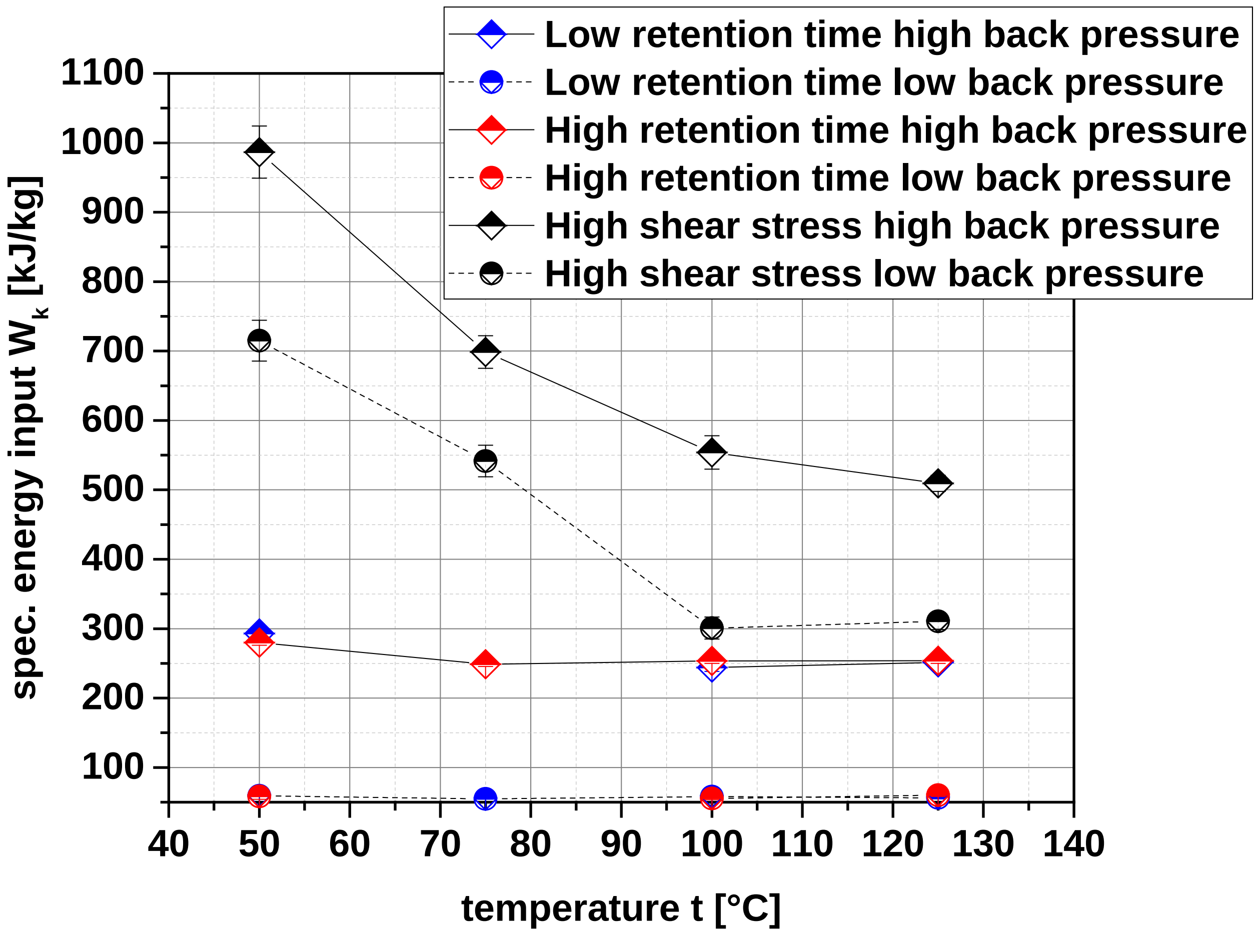


- Lithium salt works plastifiing
- For the high retention screw configuration the temperature impact on the specific energy input is neglectalbe
- High back pressure leads to increased specific energy input

Influence of Operating Temperature

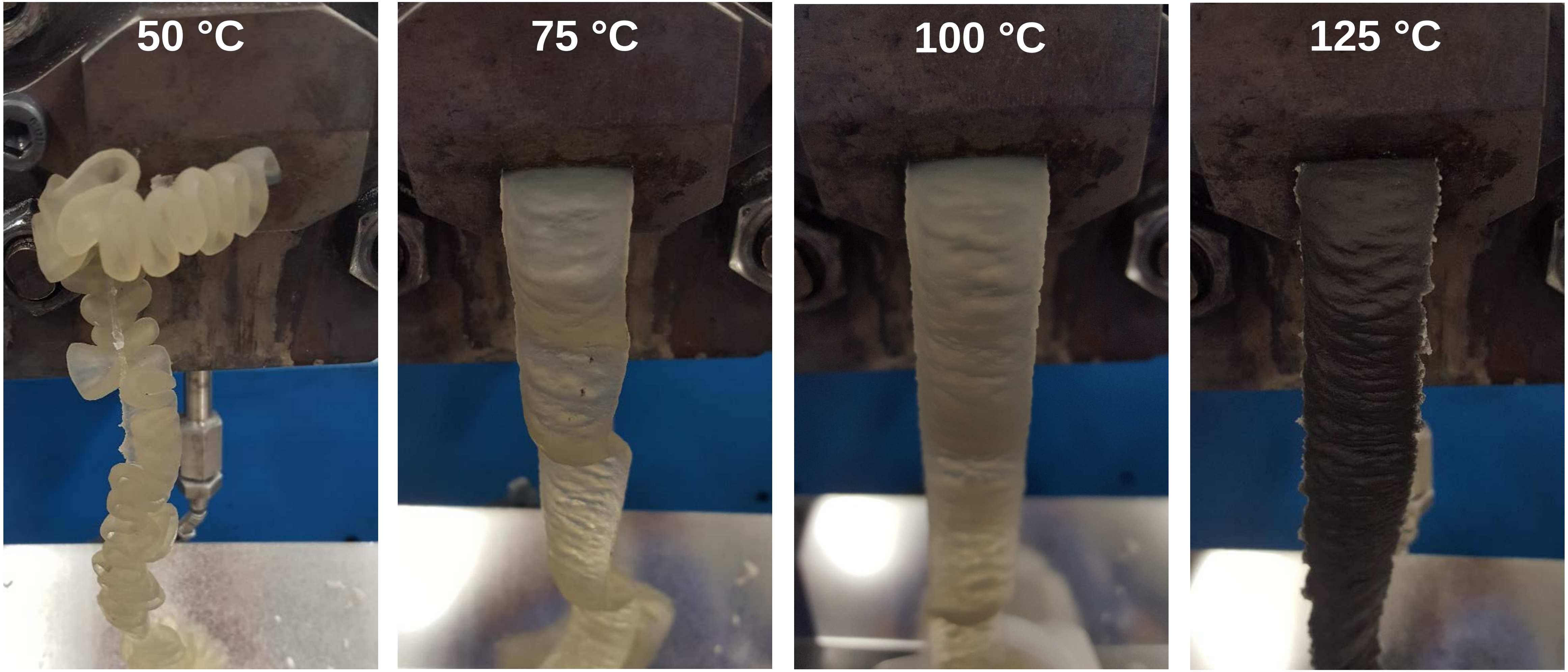


Influence of Screw Config. on Specific Energy Input

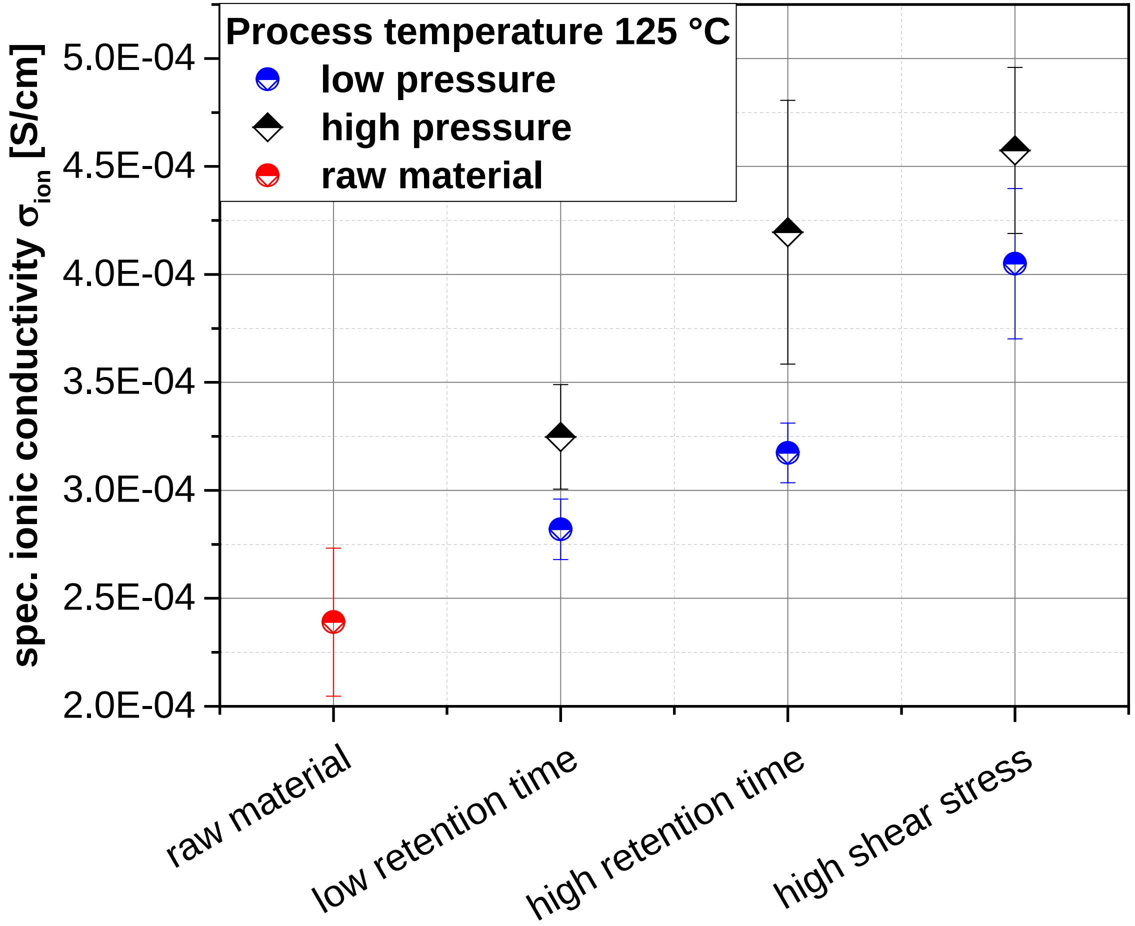


- Use of kneading elements leads to temperature dependency
- High shear stress causes thermal degradation for a temperature > 100 °C

Influence of Screw Config. on Specific Energy Input



Influence of Extrusion Parameters on Ionic Conductivity



- Higher retention time and higher shear stress lead to increased homogenization
- High shear stress and high retention time cause thermal degradation for 125 °C

Conclusions

- For kneading and extrusion process the polymer passes three phases depending on the specific energy input

- Batch kneading: higher energy input increases ionic conductivity
- Thermal degradation for W > 2000 kJ/kg

- Extrusion process: low retention time leads to low homogenization
- High retention time <u>and</u> high shear stress cause degradation

Conclusions

- Process window limited through thermal and mechanical degradation

- Continouos extrusion process: specific energy input controllable through screw configurations causing a specific retention time

- Solvent free processing of separator in the extruder is possible
- Reached ionic conductivities are slightly lower

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