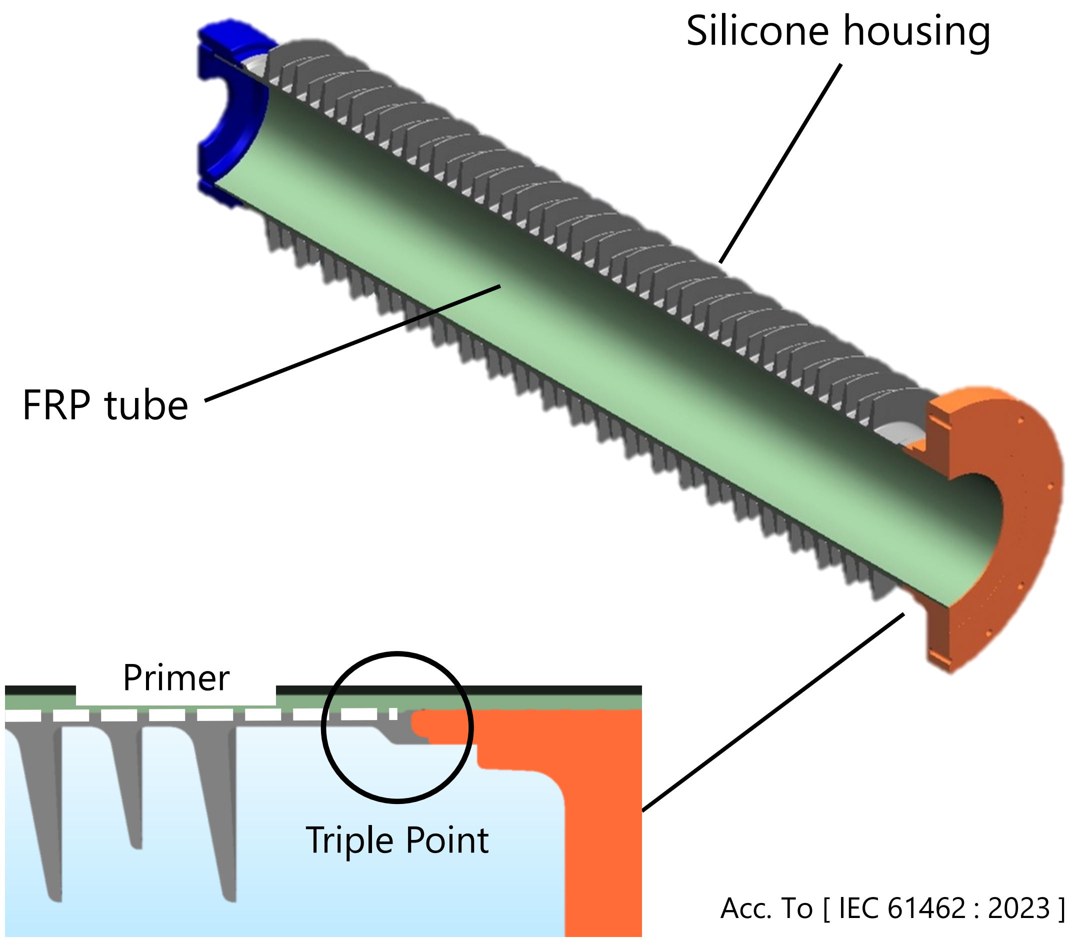
100 Years
THE POWER BEHIND POWER

Low-Pressure Mould Filling of Silicone Housing for HV Insulators

- Advantages and Potential

MR

Hollow composite Insulators (HCI)

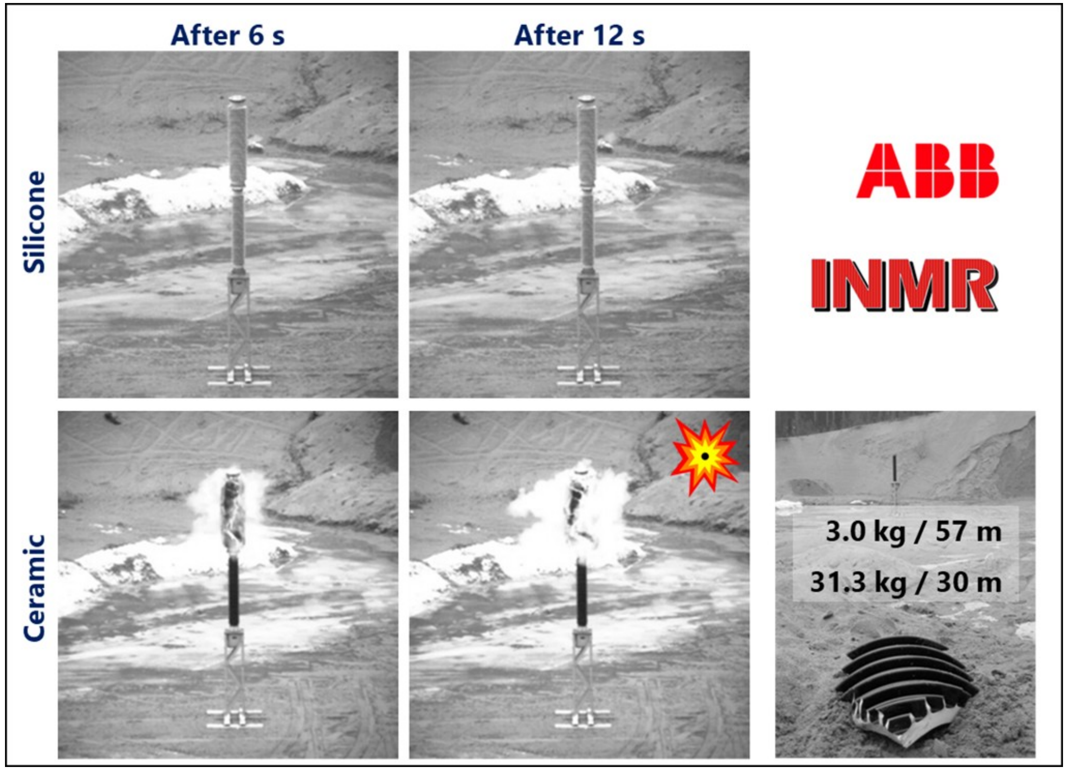


Acc. To [IEC 61462 : 2023]

1. Strength to weight ratio
2. Vandalism / Shock damage controllability
3. Hydrophobicity (self-regenerating)
   1. Self cleaning
   2. Low maintenance
4. UV and Weathering resistance
5. Arcing Resistance (pollution)

Sources: [1-4]

Composite Insulators for HV application



INMR.2025: Safety is Key Driver When Selecting Hollow Core Composite Insulators -

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2. Vandalism / Shock damage controllability
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Composite Insulators for HV application

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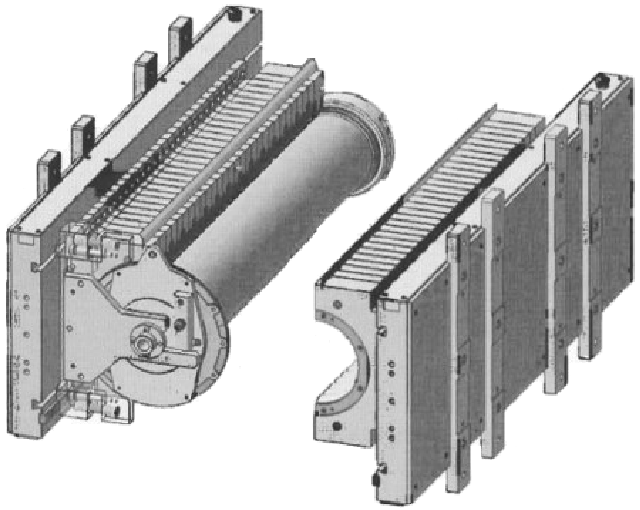
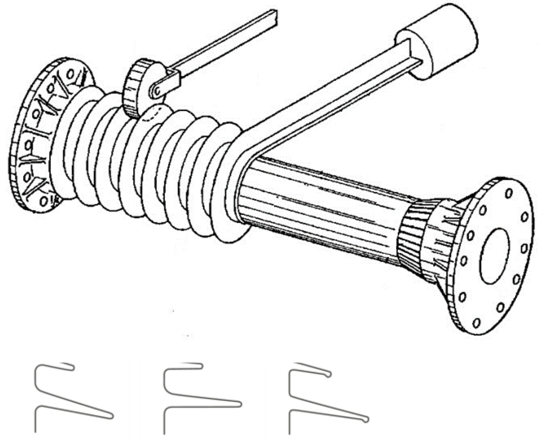
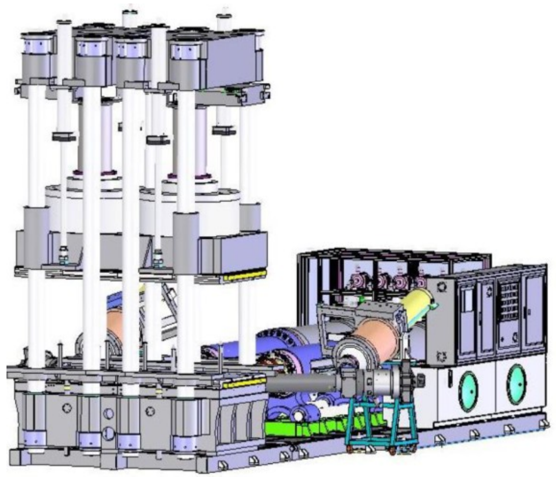
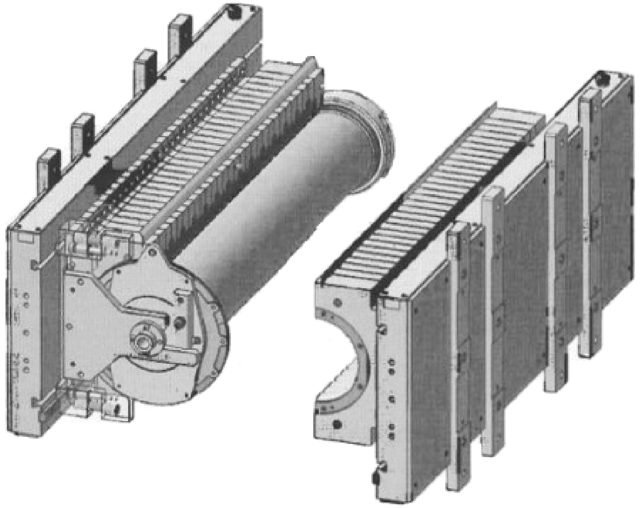
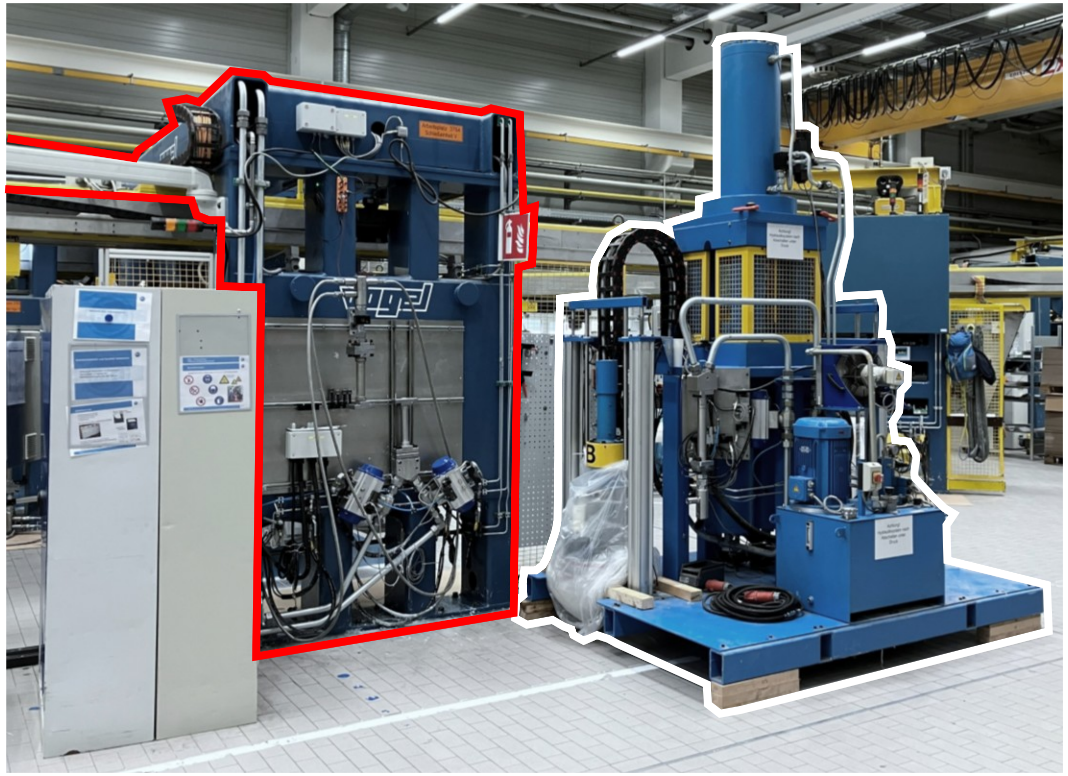
Silicone housing at RPC - Technologies

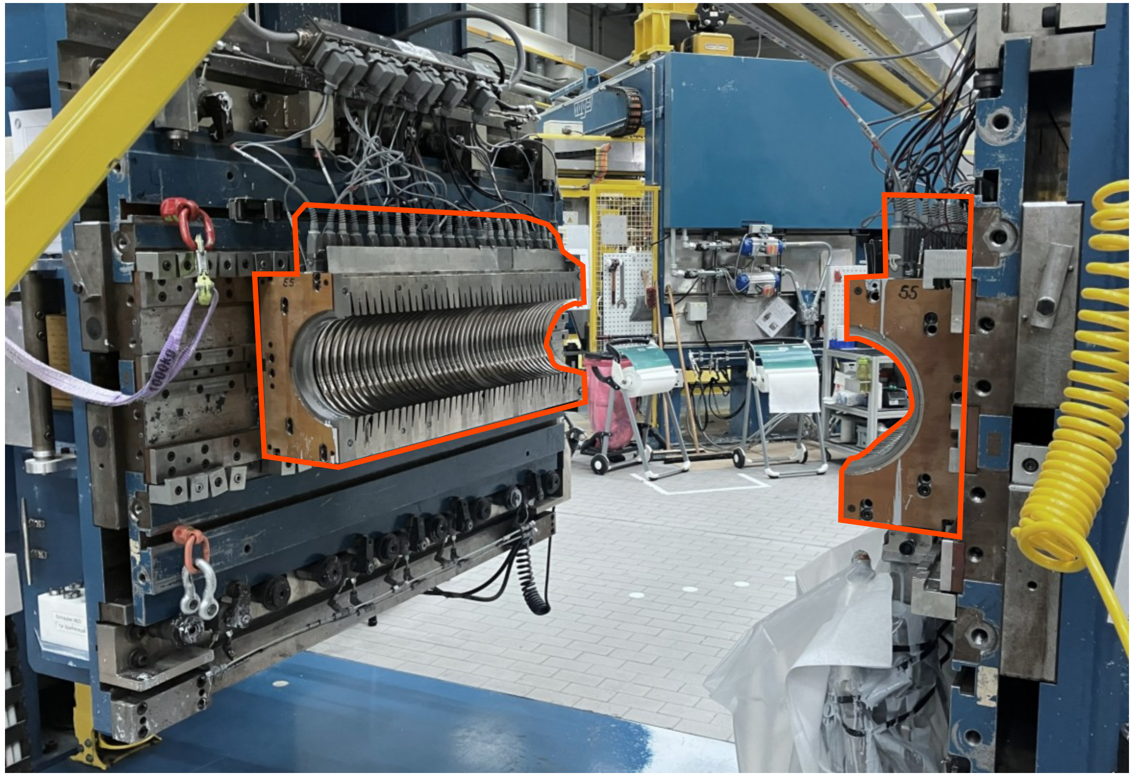
	Low Pressure Mould Filling	HTV Extrusion	HTV Injection
			
Material	**LSR** (2K-System)	**HTV** (ATH ~50 wt.%)	
Viscosity	≤ **15 Pa·s**	**Gum**	
Shed profiles	**CTO** *- Configured To Order*	**ETO** *- Engineered To Order*	**PTO** *- Picked To Order*
Cycle - Time	Fast	Slow	**Very Fast**

Silicone housing at RPC - Technologies

	Low Pressure Mould Filling
	
Material	**LSR** (2K-System)
Viscosity	**$\leq$ 15 Pa·s**
Shed profiles	**CTO** *- Configured To Order*
Cycle - Time	Fast

Low Pressure Mould Filling – Production side

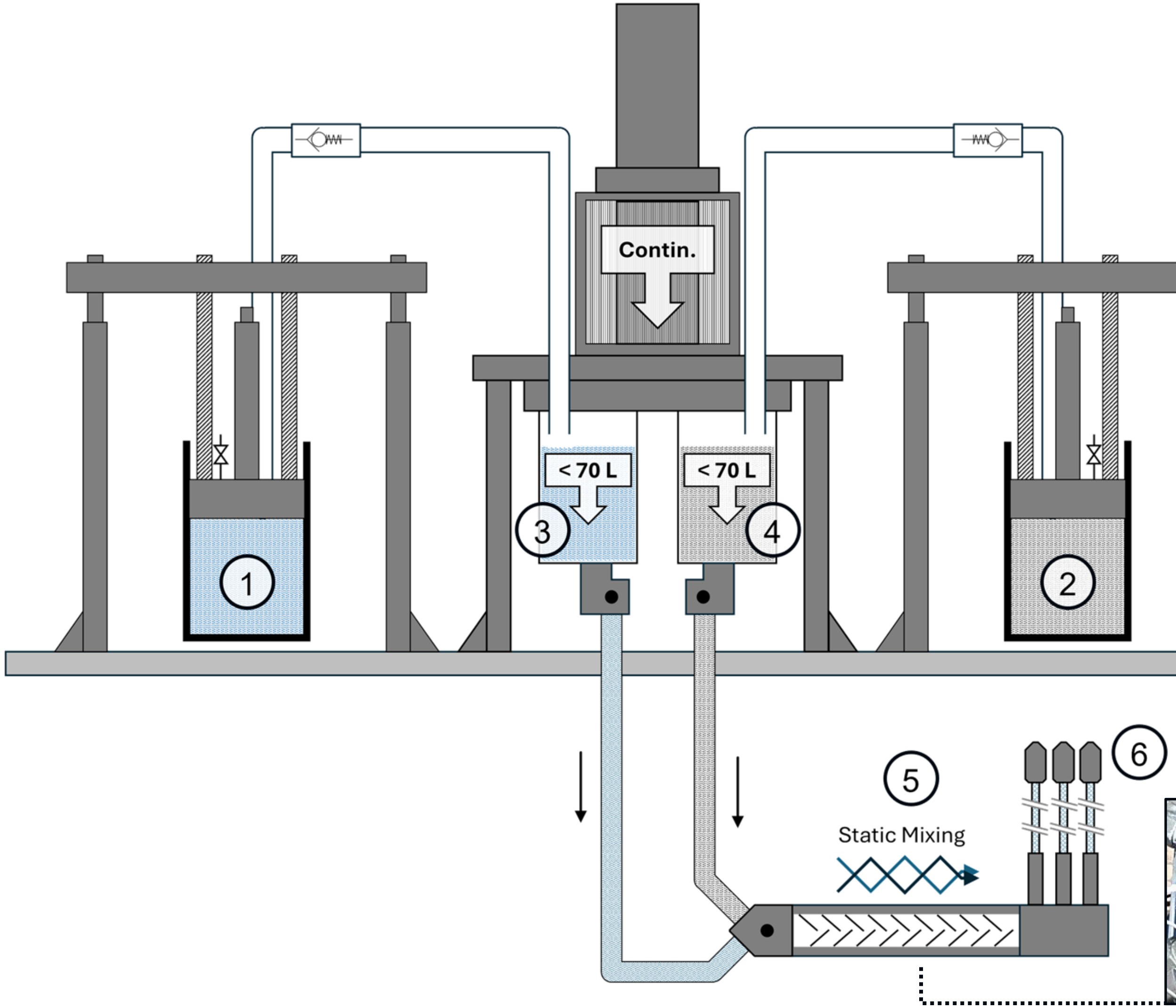


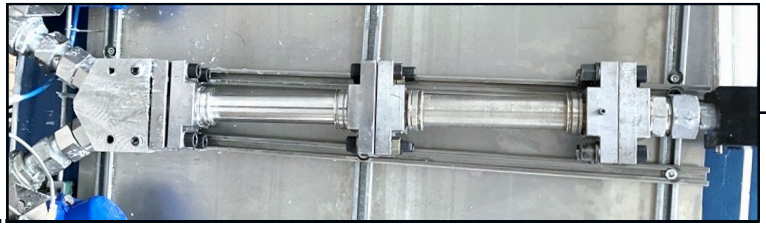


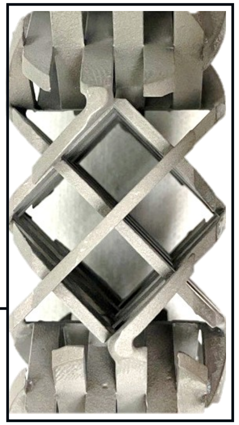
Machine setup for preliminary testing runs:

- Filling machine *DOSIL ONE* (white, Vogel moulds and machines AG) attached to clamping machine *HSM-X-6-100* (red, Vogel moulds and machines AG)
- Modular fill mould with alternating shed profile (orange, PS GmbH) for standard HCI design
- No contamination of the integrated HCI production with one *DOSKOSIL* and multiple clamping machines

Low Pressure Mould Filling – Filling Machine







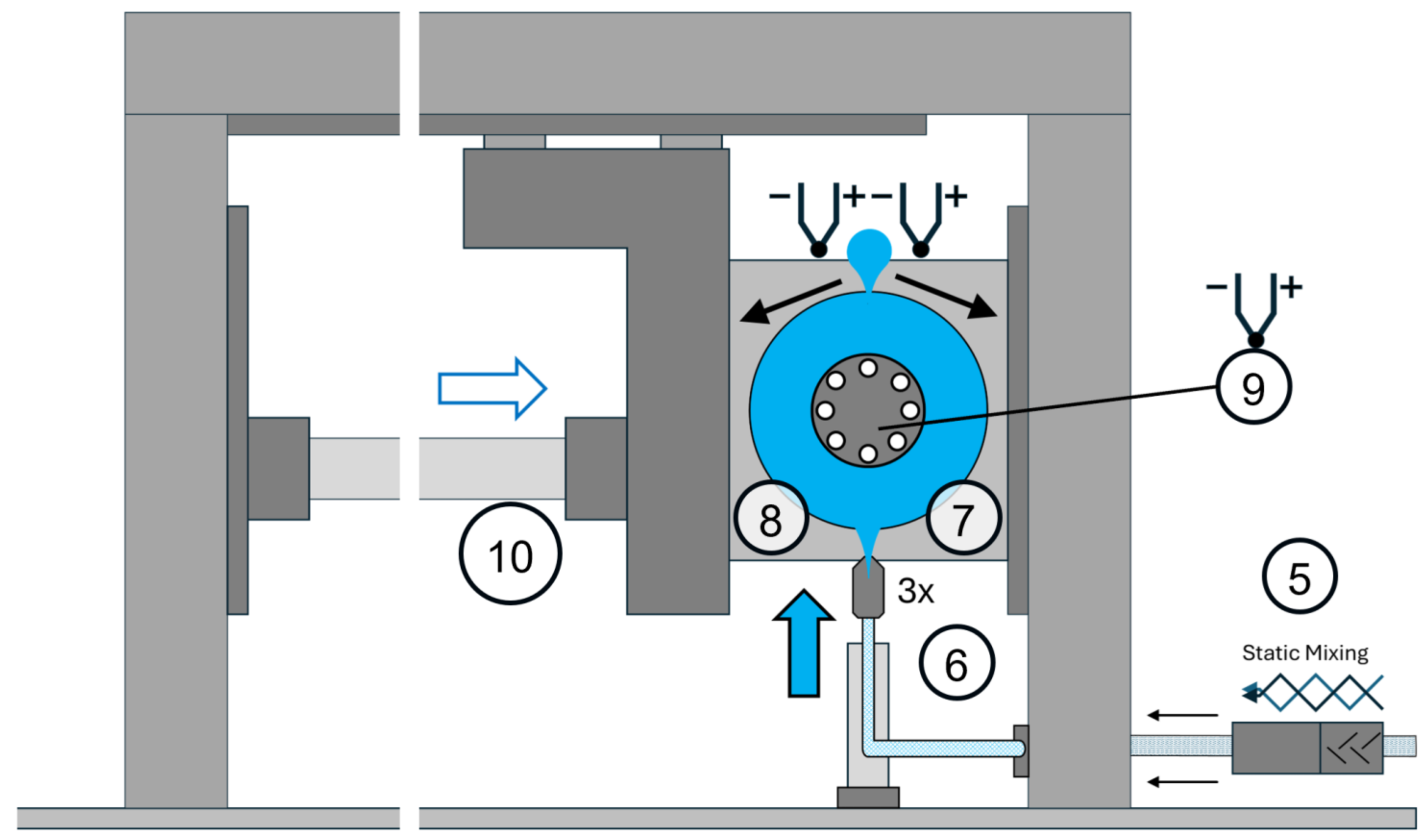
1. / 2. Barrel station A / B

3. / 4. Booster A / B

5. Static Mixer (2x)

6. Sprues (3x)

Low Pressure Mould Filling – Clamping Machine Setup



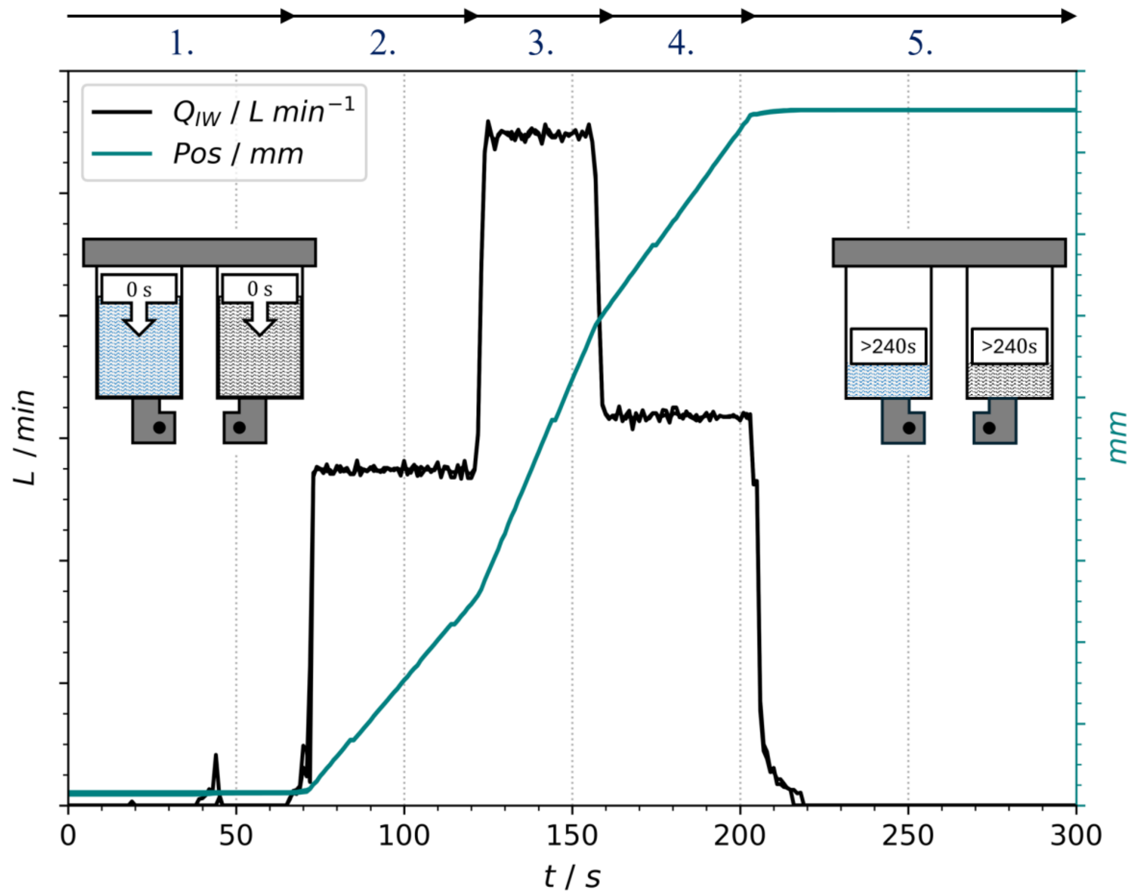
5. Static Mixer (2x)

6. Sprues (3x)

9. Barrel station A / B

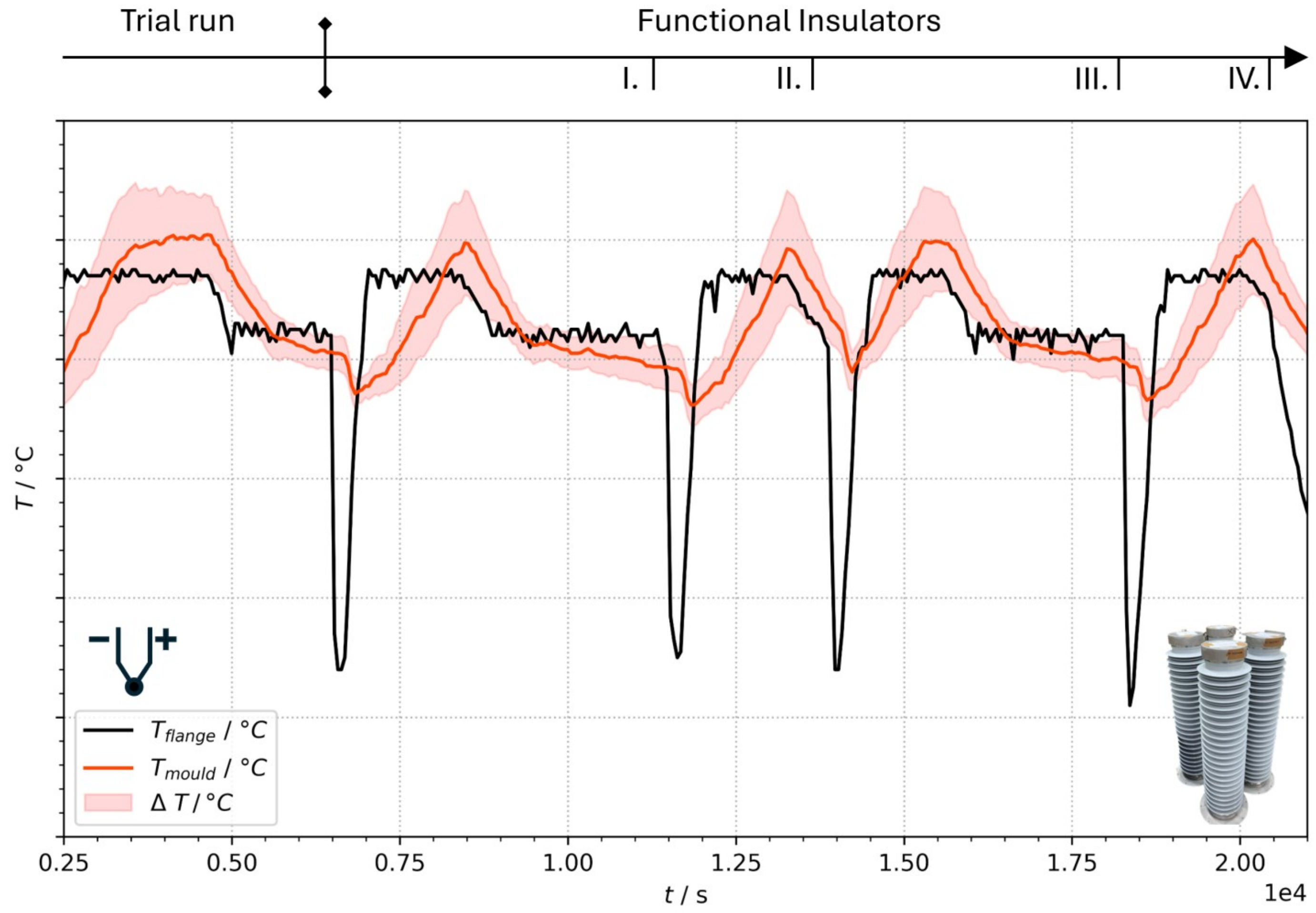
10. Clamping Cylinders

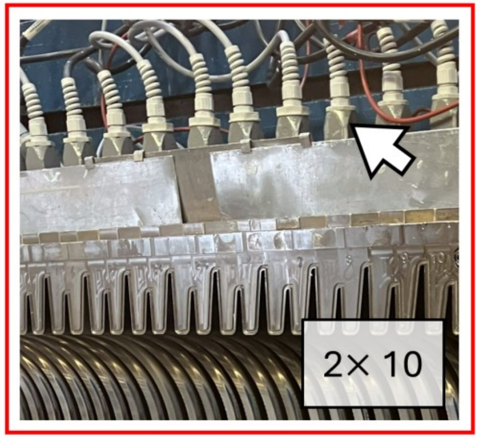
Low Pressure Mould Filling – Filling Process

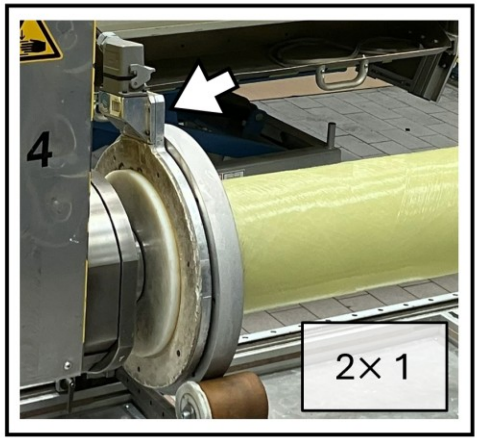


1. Venting of Boosters
2. Low flow level to prevent instability and droplet spraying
3. Main Stage / Continuous Filling
4. Moderate flow / Overfilling
5. Booster inactive / Curing stage

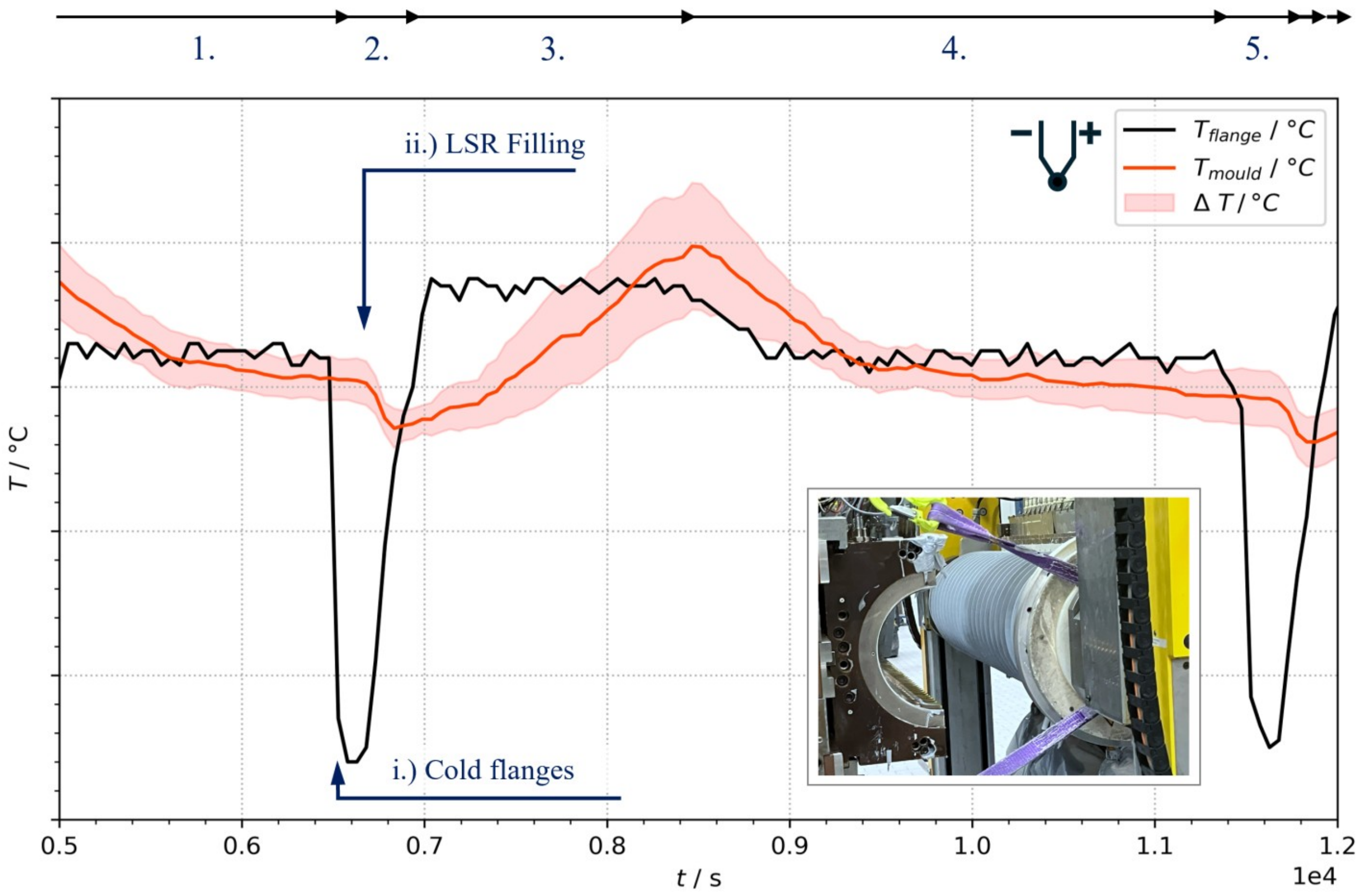
Low Pressure Mould Filling – Curing Cycle

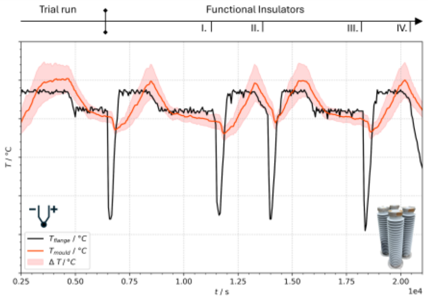






Low Pressure Mould Filling – Curing Cycle





1. Curing of Previous HCI housing
2. Insulator Loading / Mould Filling
3. Temperature Overshoot (deliberate)
4. Curing Temperature Plateau
5. Subsequent Cycle

Publicly funded project “Silikon +” (MW-2403-0005)

LSR without ATH (RPC)

- Low viscosity
- Low pressure mould filling
- Specialised machine park
- Material loss by overfilling

+ Cycle time
+ Machines
+ Low Pressure

Silikon+

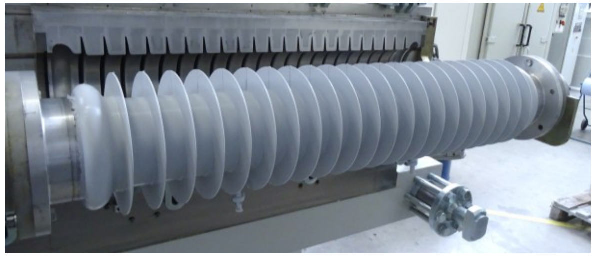
HTV with ≤ 60% ATH

- Material cost efficiency
- High viscosity
- High pressure and low flexibility
  - Extrusion: Low cycle time
  - Injektion: Damage to FRP-pips

+ Supply chain
+ ≤ 60% ATH

1. POC

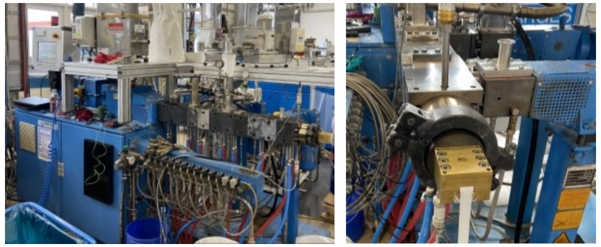
✓ Viscosity
✓ Electric Prop.
! Mechanics
! Additives



LSR + ≤60% ATH + Additive

2. Compound

✓ TSE - Degassing
✓ No machine modification

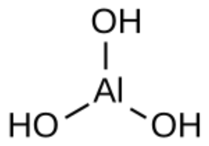


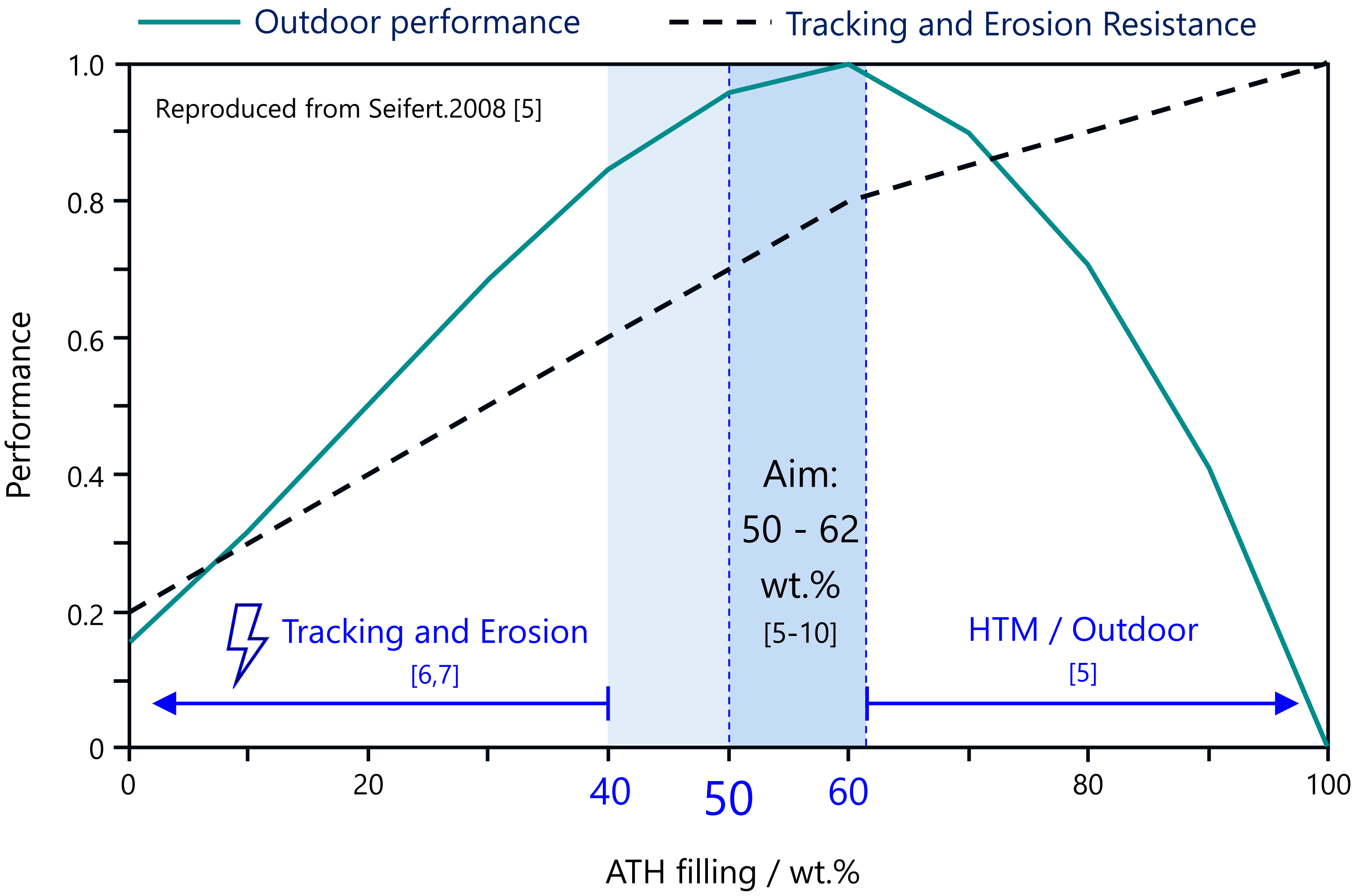
Twin snake extruder TSE (SKZ)

3. ATH: ≤ 60%

Silikon+ (2025)

ATH – Tracking Erosion and Outdoor Performance





Dehydration of ATH (endo.) [6]

First:

$$2\ Al(OH)_3 \xrightarrow[\geq 200\ °C]{} 2\ AlOOH + 2\ H_2O\ (vapor)$$

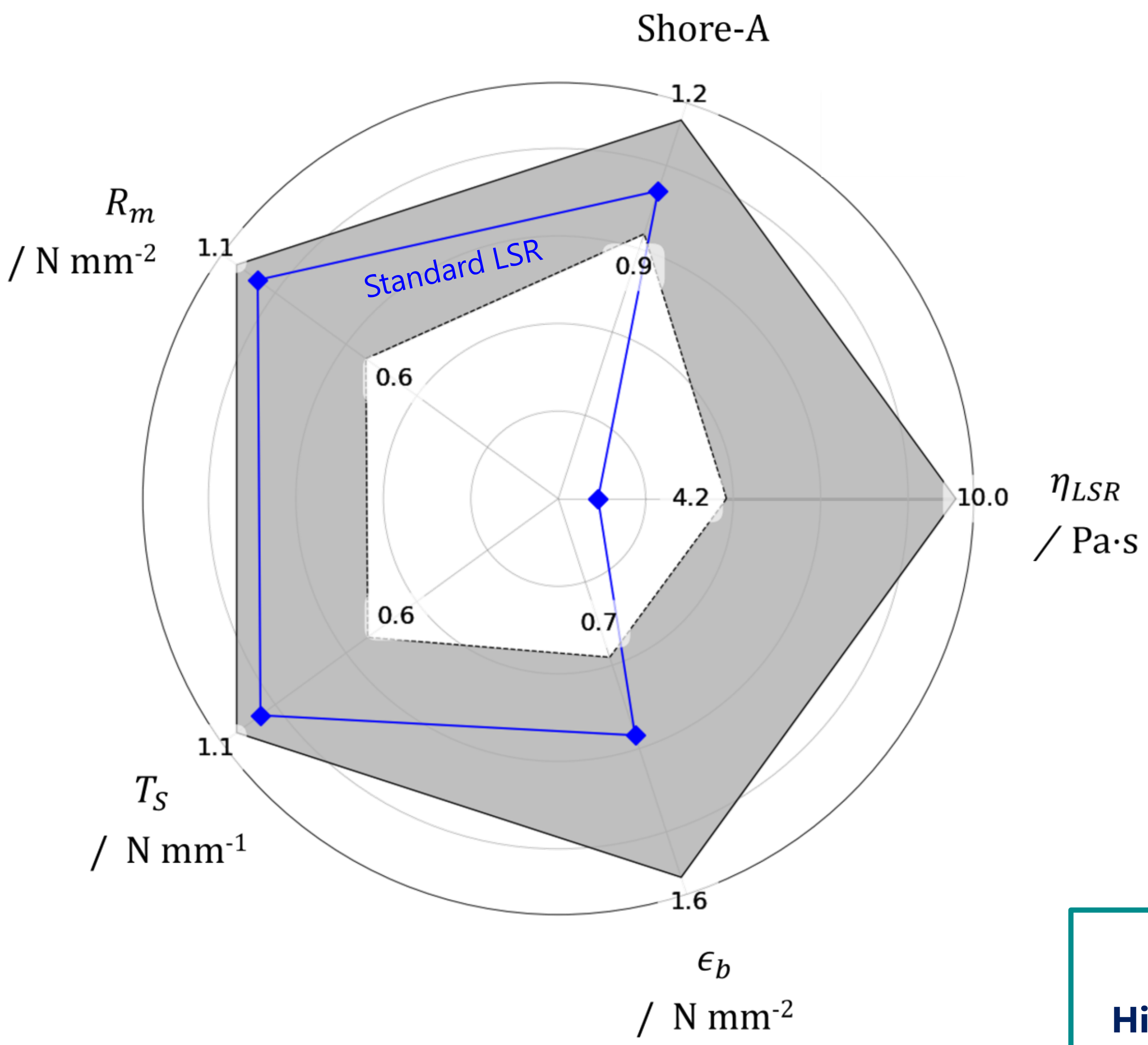
Second:

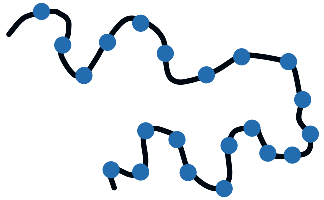
$$2\ AlOOH \xrightarrow[\geq 470\ °C]{} Al_2OH_3 + 2\ H_2O\ (vapor)$$

Suppression mechanism [8]:

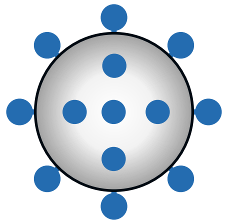
Surface temperature control [7], preventing degradation of Si-O chains [6], gas dilution following SiR decomposition [9,10]

LSR Matrix and Compounding

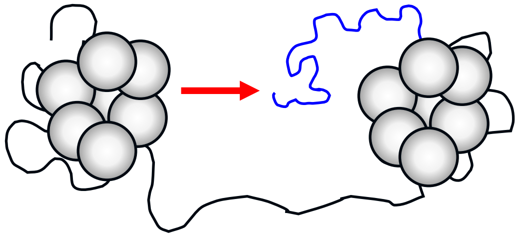




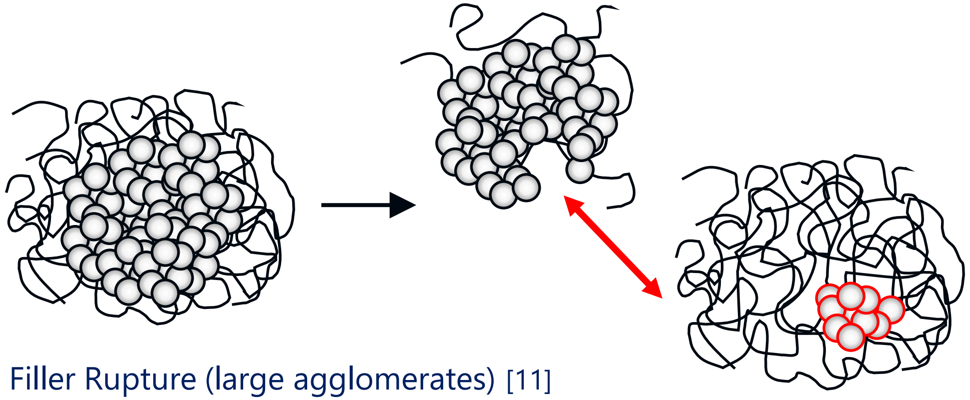
Si-O backbone with functionalized groups



Functionalized ATH particle



Bond Rupture / Molecule slipping (functionalization / functional groups) [11]

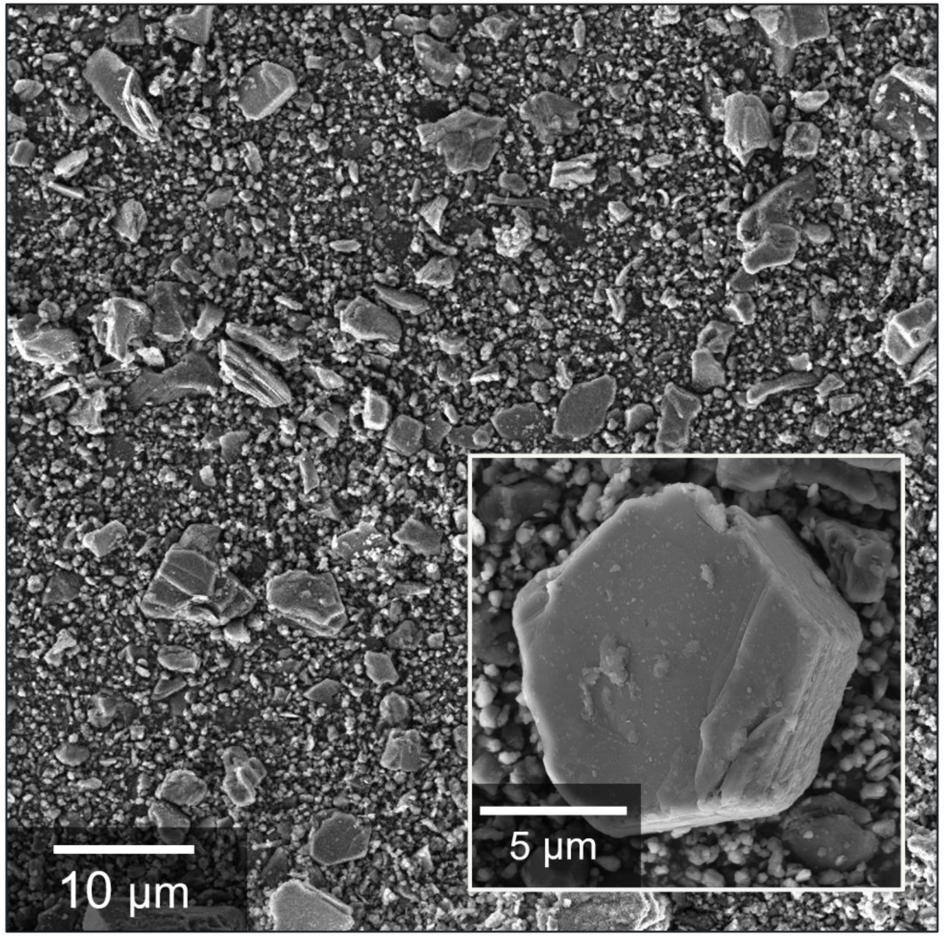


Filler Rupture (large agglomerates) [11]

Working hypothesis ("A limited hypothesis is better than none"**):**

Higher LSR viscosity → Longer LSR backbones → Stronger bonds

ATH Filler – Bulk Material Analysis



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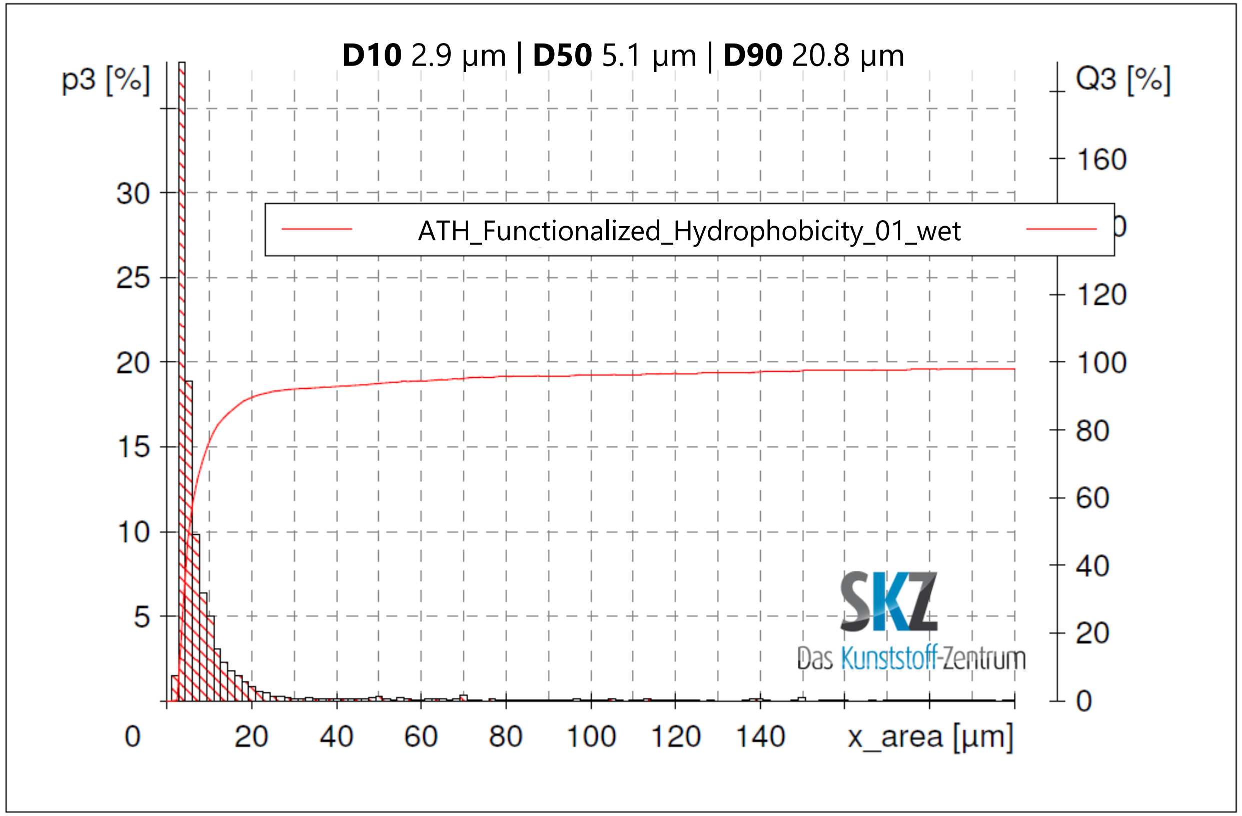
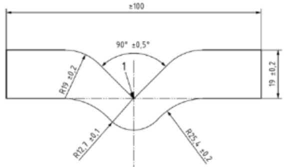
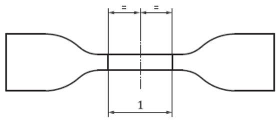


In-house compounding must be reproducible -> ISO 13322-2:2021 (*Dynamic Image Analysis; Laser Light Scattering*)

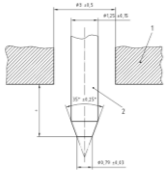
Best performing LSR-ATH compounds



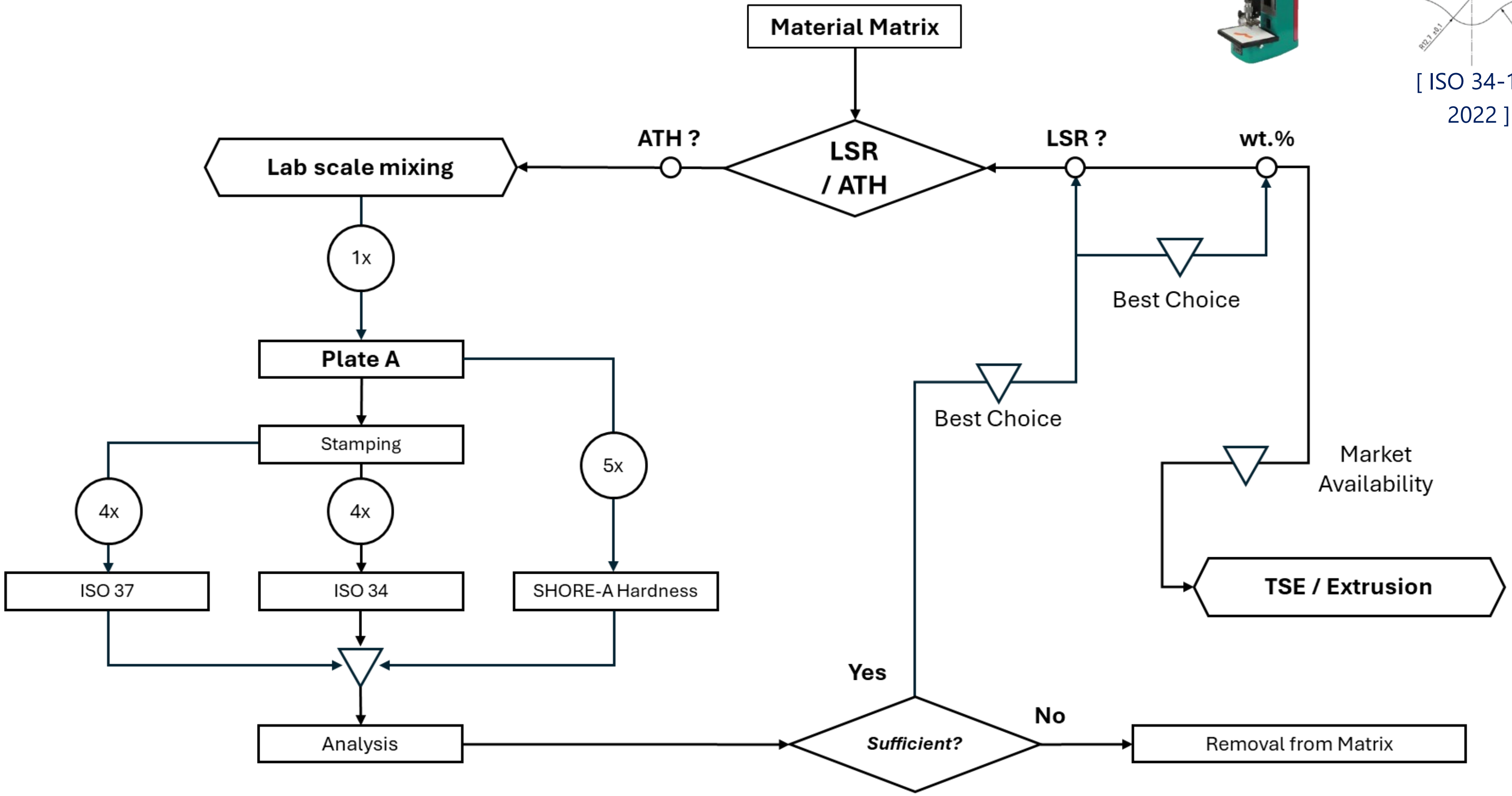
[ISO 34-1B : 2022]



[ISO 37 : 2017]

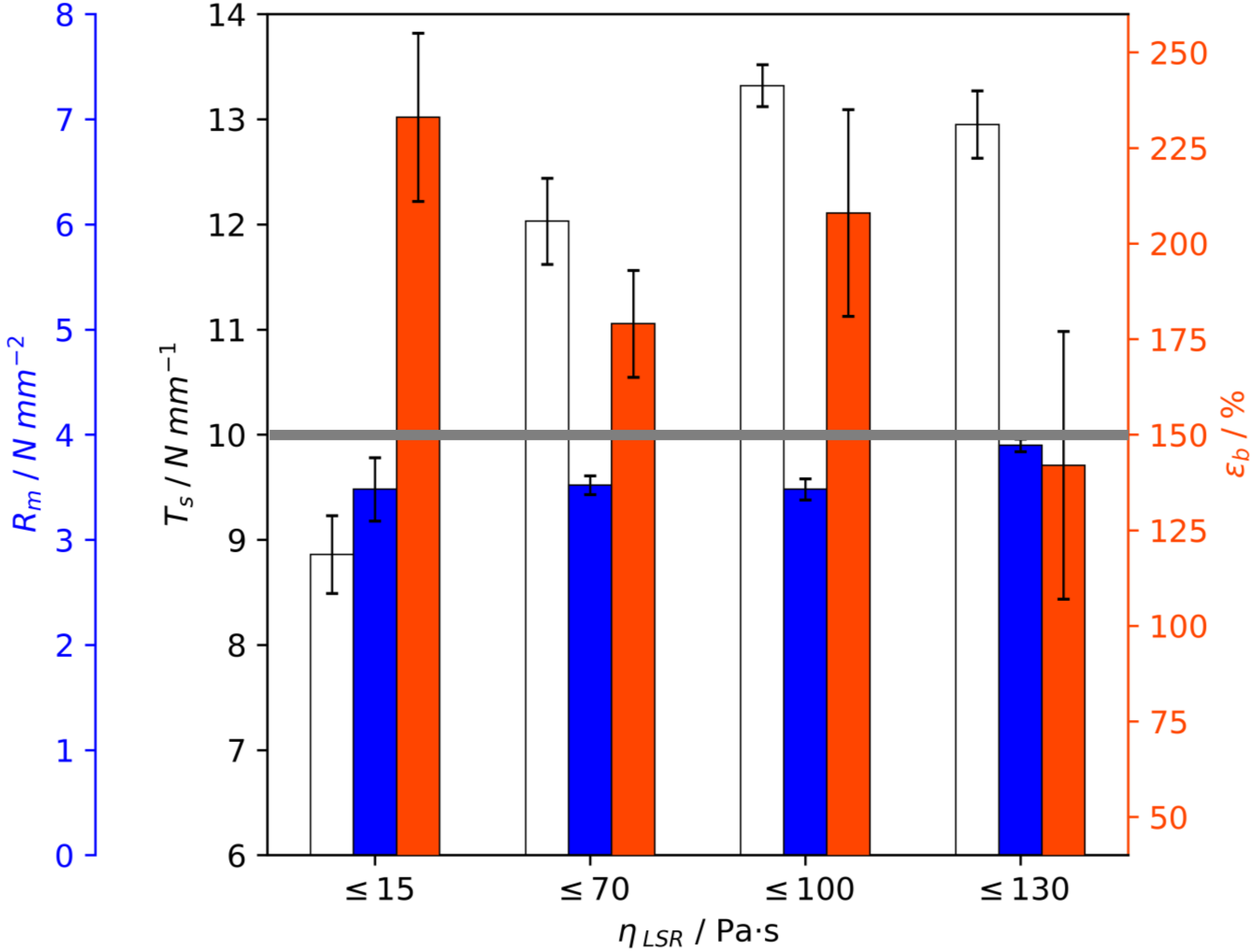


[ISO 868-1 : 2003]



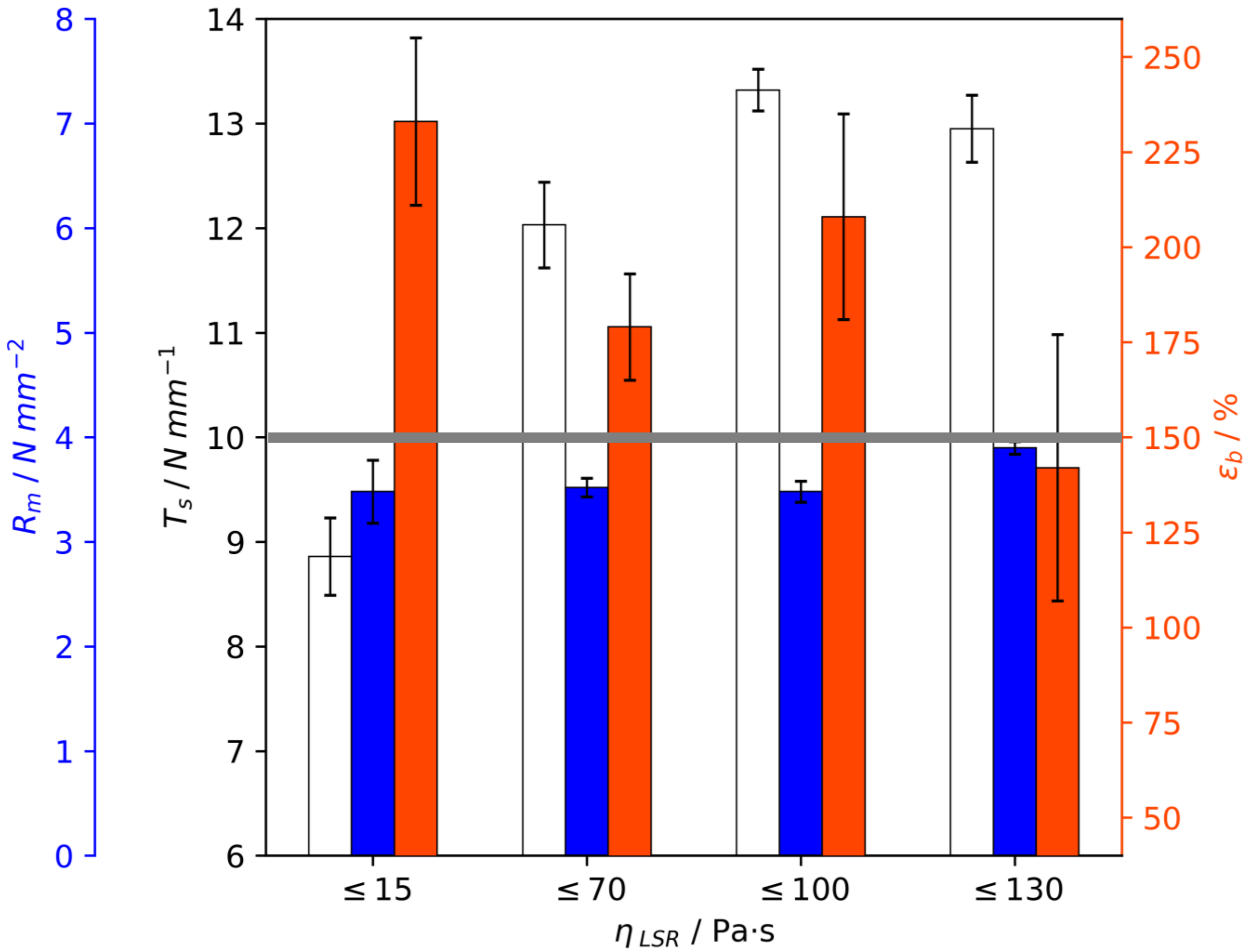
1. **ATH ?** – Functionalization with low viscosity LSR
2. **LSR ?** (chain length hypothesis) with optimal ATH functionalization
3. **wt.%** - Filling Degree

Best performing LSR-ATH compounds



+ Identical ATH type (hydrophobicity-functionalized)
+ Insufficient: Non-functionalized or vinyl-functionalized ATH
+ Requirements (Grey line):
  - Tear strength T_S ≥ 10 N/mm (IEC 62039:2021 and RPC standard)
  - RPC standard:
    - Tensile strength R_m ≥ 4 N/mm²
    - Elongation at break ϵ_b ≥150%

Best performing LSR-ATH compounds



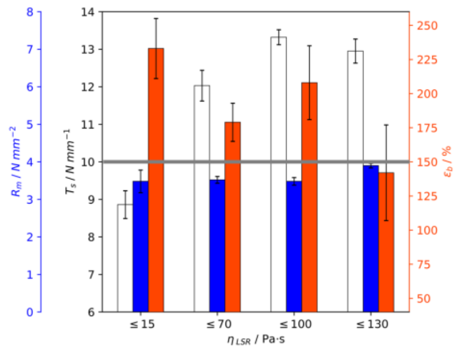
+ Higher η_{LSR}
  - T_S higher (white)
  - R_m higher (blue)
  - ϵ_b lower (orange)
  - Good agreement with HTV database by Kokalis [12]

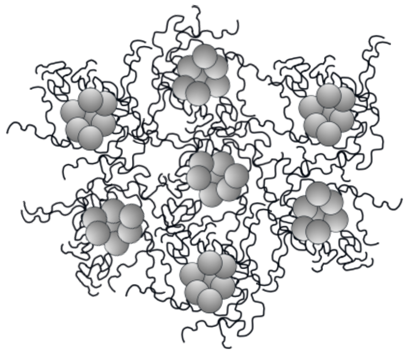
Best-performing compounds

+ exceed T_S acc. to IEC 62039:2021
+ at high η_{LSR}, nearly rec. R_m

Future Work Fields

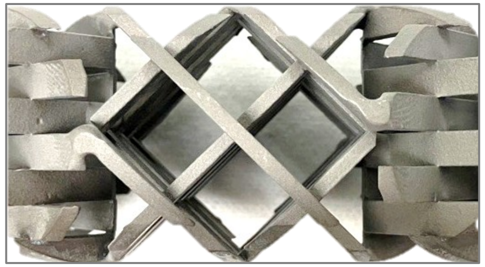
ATH Integration: LSR chain length / Number of functional groups





Twin-Screw Extruder (*SKZ - KFE gGmbH)*

- High Shear Force + Longer mixing times
- Improved ATH dispersion and thus mechanical performance
- Preliminary studies with mechanical and low vacuum degassing
- Components filled separately (premature curing, sufficient pot life)

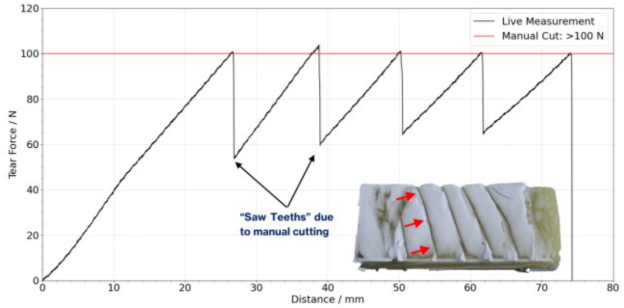


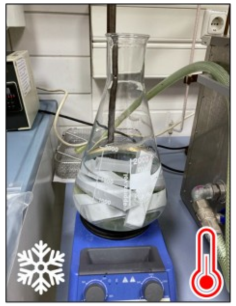
Premature curing during LPMF

- Continuous material flow (static mixer, into mould)
- In-depth rheological analysis + static mixing simulation campaign

FRP-SiR Interface connection and primer compatibility

- Lab scale: boiling (100°C / 100 hours) and peeling force testing
- Water diffusion test on core material with housing





Literature and Paper

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[11] J. Diani, B. Fayolle, P. Gilormini, „A review on the Mullins effect”, European Polymer Journal, Volume 45, Issue 3, pp. 601-612, 2009

[12] C.-C. A. Kokalis, V. T. Kontargyri und I. F. Gonos, „A Proposal for the Evaluation of HTV Silicone Rubber Composite Insulators,“ Polymers, Bd. 13, Nr. 21, pp. 3610, 2021.

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