

Ralf Schmidt, Tom Boenke, Thomas Abendroth, Holger Althues, Stefan Kaskel
Dresden University of Technology, Chair of Inorganic Chemistry I; Fraunhofer IWS

Optimized binder and conductive additive systems within SPAN cathodes enabling enhanced performance in Li-S Batteries

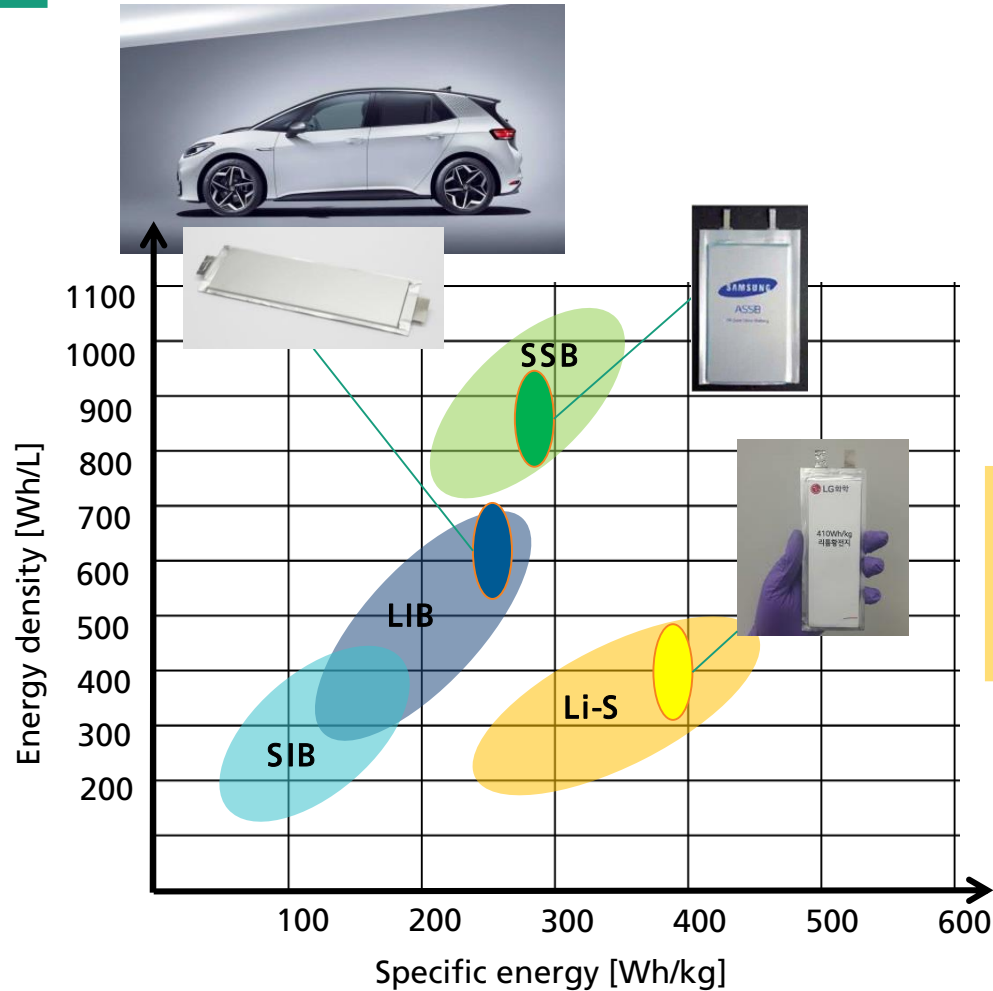
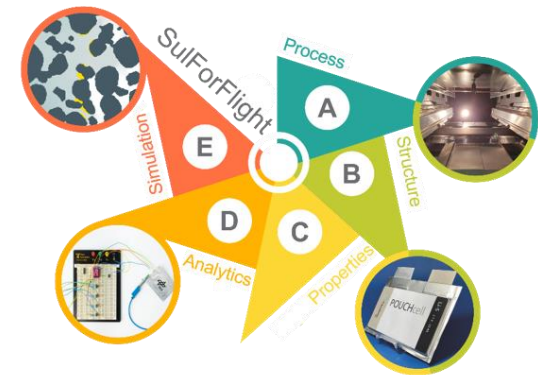
12th Workshop Lithium-Sulfur Batteries, Dresden// 18.11.2025

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75 YEARS OF
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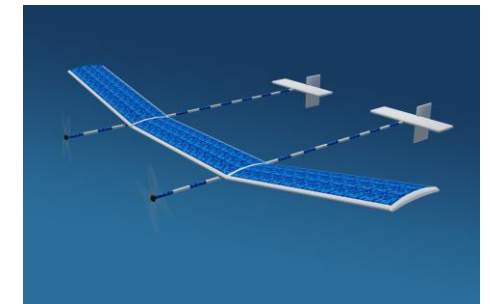
Introduction

Li-S-Batteries

Coordinated by DLR, together with TU Braunschweig



Aviation applications

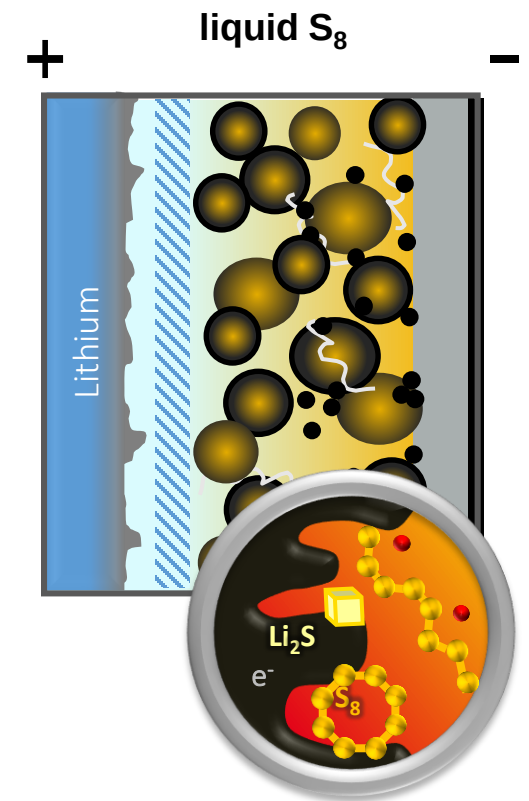
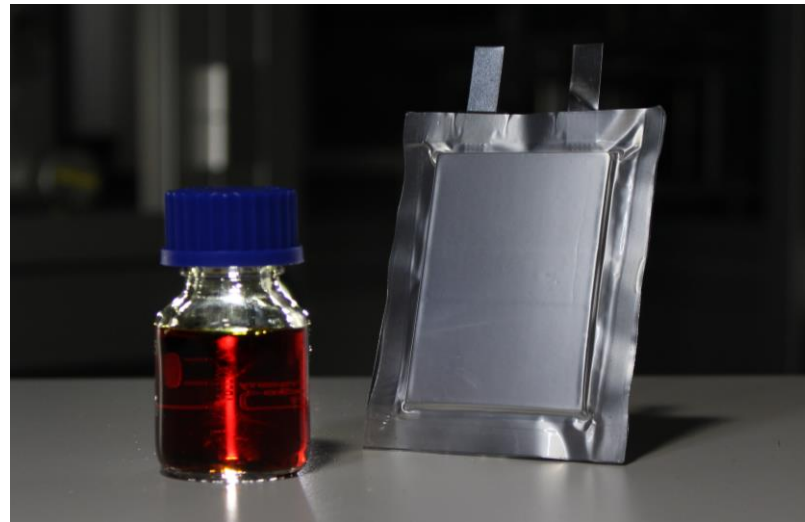


Concepts of liquid Li-S-Batteries

Conclusions from current research

Conventional liquid Li-S batteries

- Solid-liquid-solid conversion → **Polysulfide shuttle**
- + High S content in porous carbon (> 60 %)
- Lack of cycle stability (electrolyte consumption)
- Li metal degradation

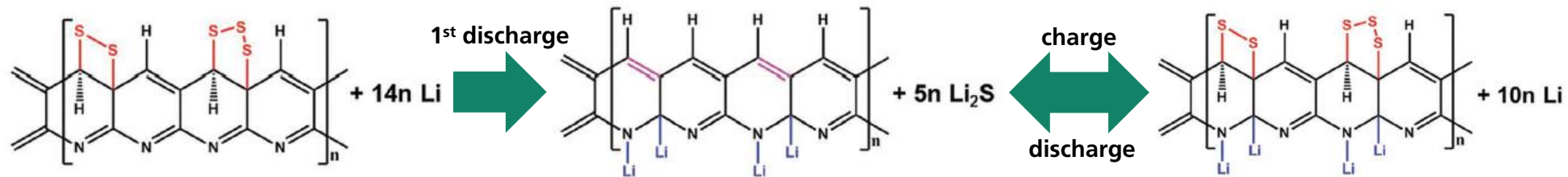


Concepts of liquid Li-S-Batteries

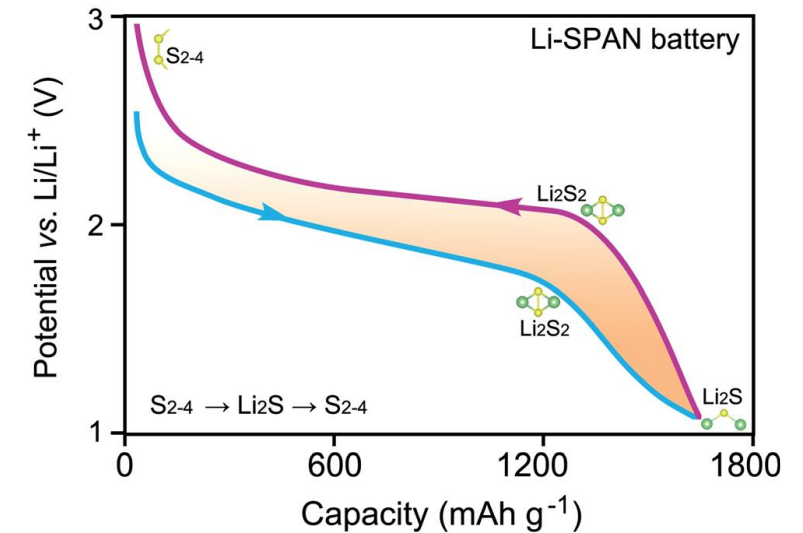
Conclusions from current research

Solid-solid conversion chemistry

- No polysulfides!
- Sulfurized polyacrylonitrile (SPAN) or microporous carbons*



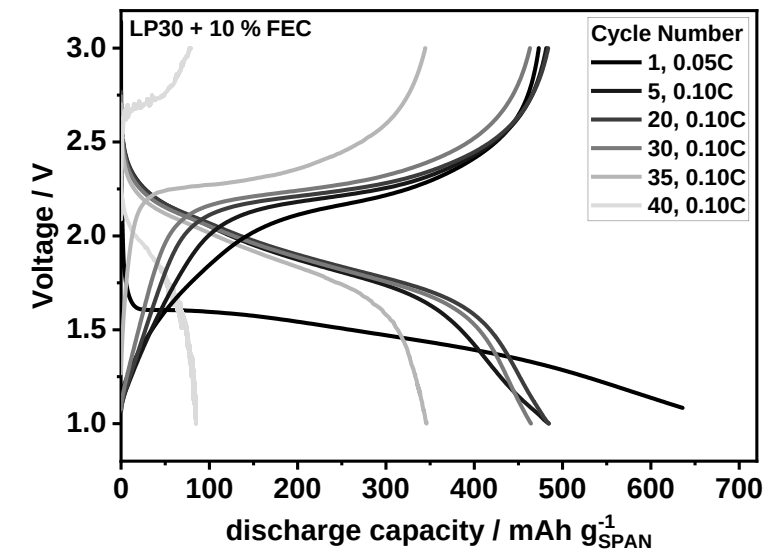
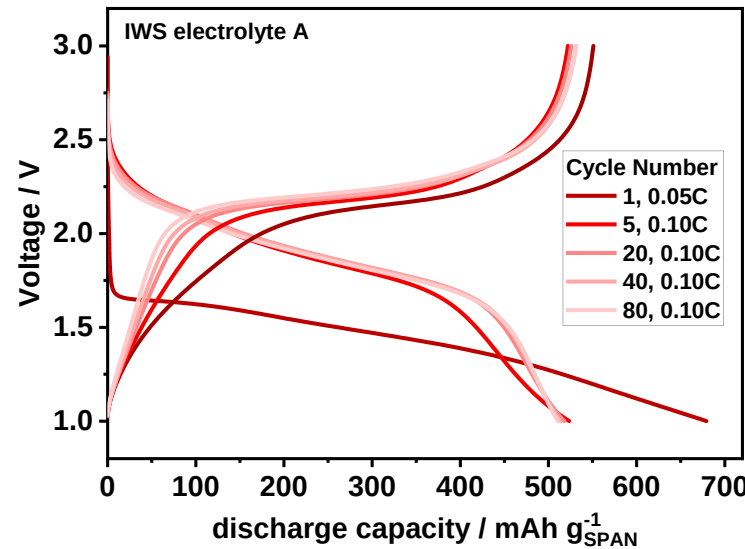
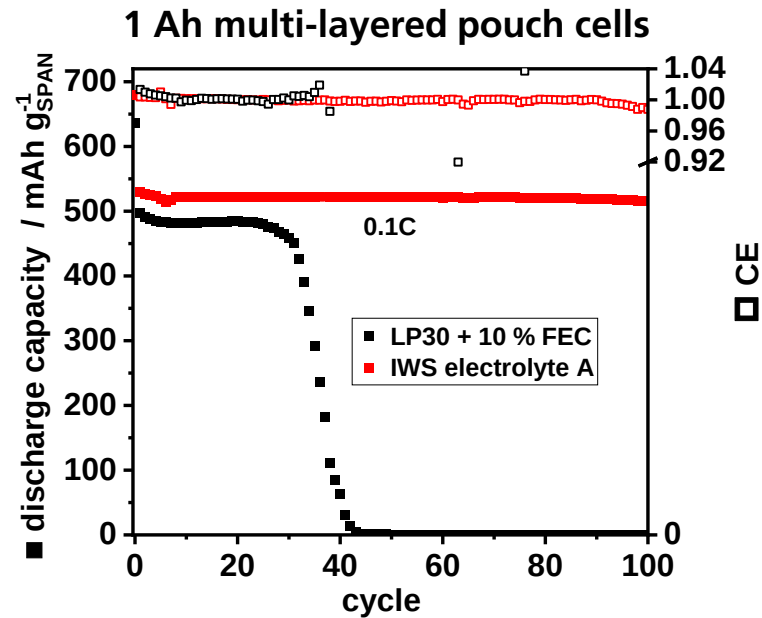
- + Increased S utilization ($> 80\%$)
- + Improved stability (cycle life and Li anode)
- Low S content in cathode ($< 50\%$)



Challenges of Li-SPAN Batteries

Selection of the electrolyte

5 ds-cathodes (32.66 cm^2 , 0.72 g cm^{-3})
 $2 \times 50 \text{ } \mu\text{m Li}$
 $\text{E:S } 5 \text{ } \mu\text{l mg}_\text{S}^{-1}$
 $1.0\text{-}3.0\text{V } 1\text{x DCh with C/20; Ch/DCh with C/10}$
 $0.308 \text{ MPa } (3.14 \text{ kg cm}^{-2})$

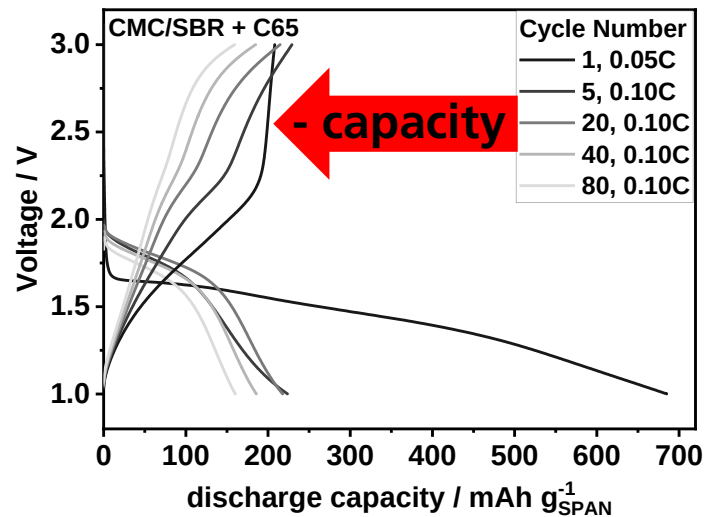


- (SPAN/C65/CMC-SBR: 90/5/5) reference cathodes
 - 38 % S in SPAN (ADEKA), theo. capacity of 530 mAh/g (1400 mAh/g-S)
- IWS electrolyte A stable over 100 cycles
- Electrolyte perfectly suited for Li-SPAN batteries

Challenges of Li-SPAN Batteries

Behavior under practical conditions

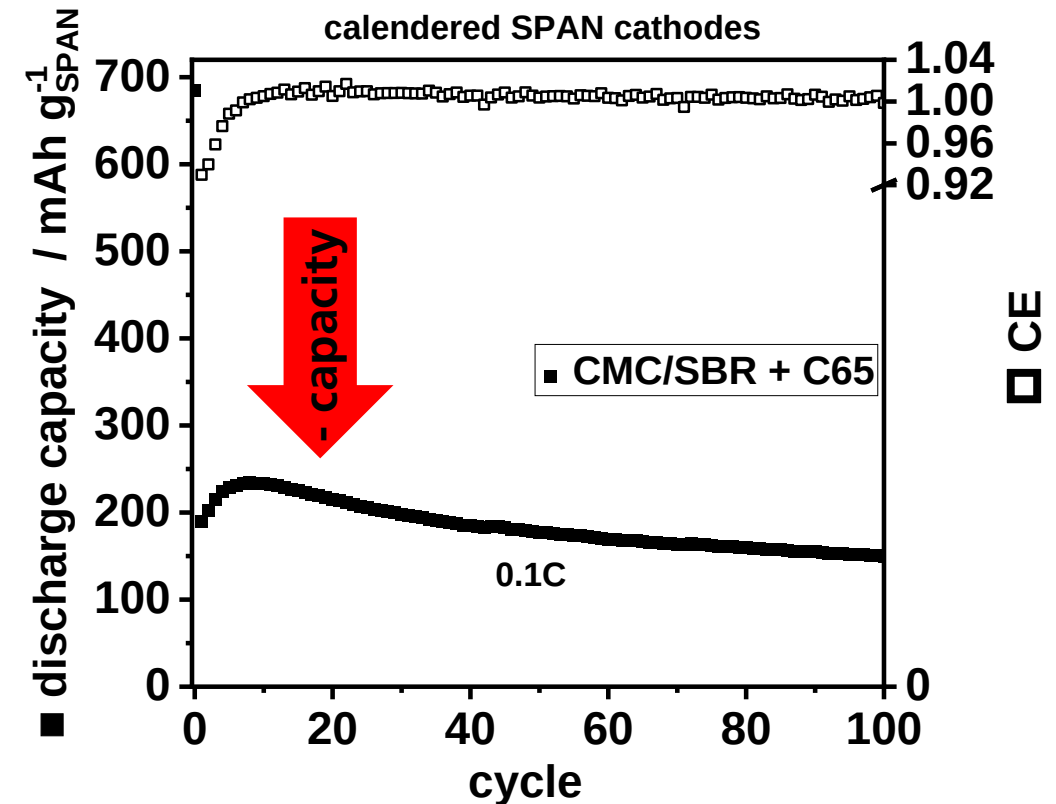
- (SPAN/**C65**/**CMC-SBR**: 90/5/5) reference cathodes calendered (**1 g cm⁻³**)
- Assembled pouch cells reveal strong capacity loss
→ Reference not suitable for practical relevant cells



5 ds-cathodes (32.66 cm²)
2*50 μm Li
E:S 5 μl mg_s⁻¹ IWS electrolyte A
1.0-3.0V 1xDCh with C/20; Ch/DCh with C/10
0.308 MPa (3.14 kg cm⁻²)



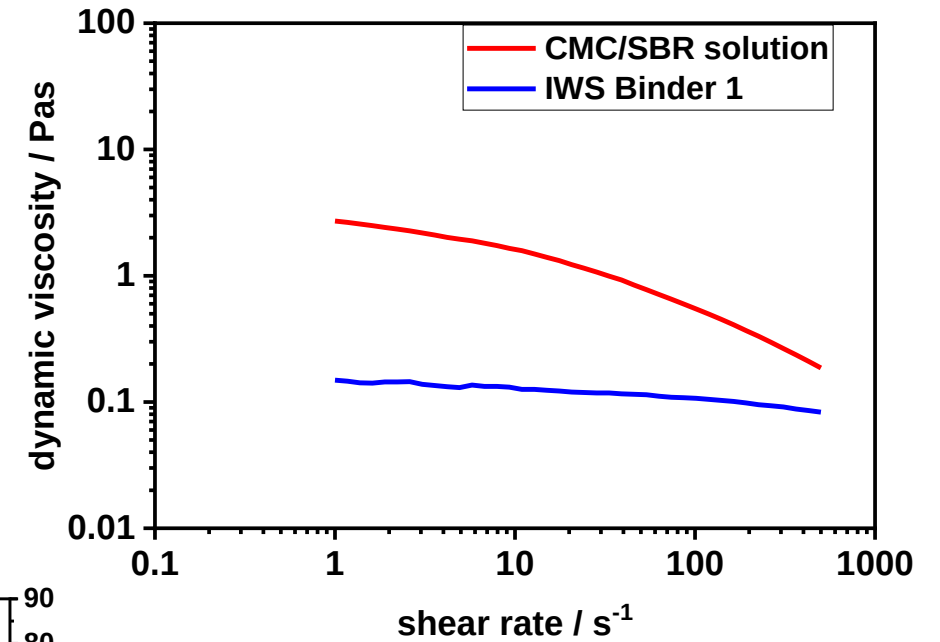
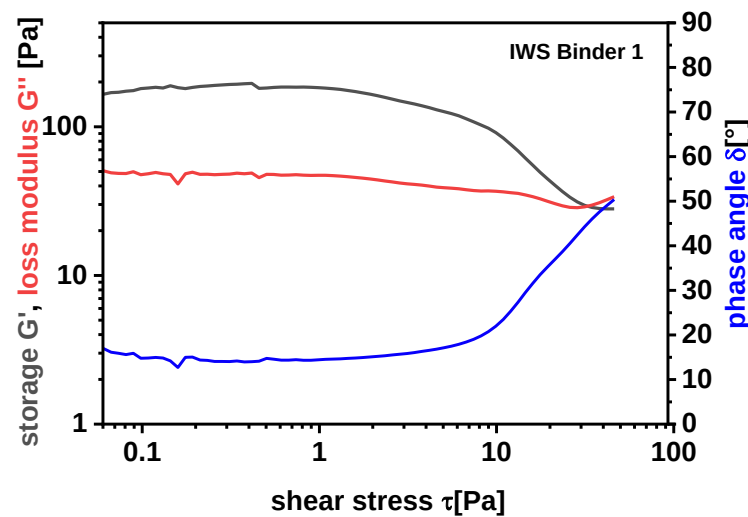
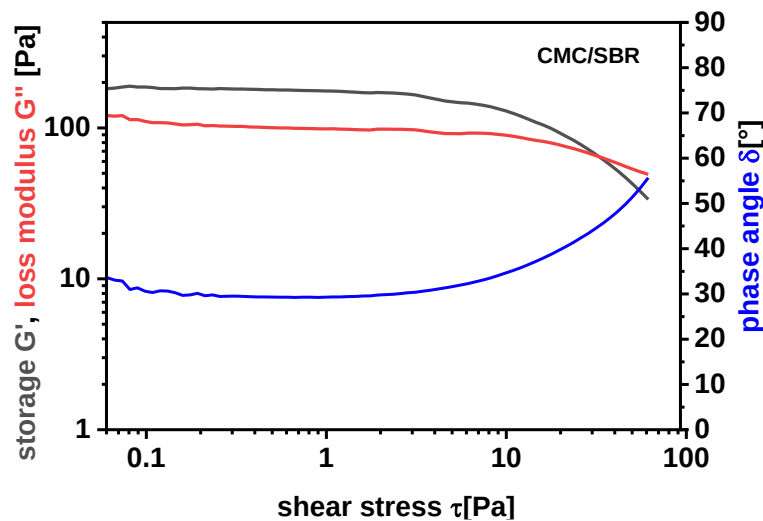
1 Ah multi-layered pouch cells



Solution: Binder adaption

Comparison of common binders

- CMC/SBR binder as reference
 - Additional binders were tested (one selected for comparison)
 - Pristine IWS Binder 1 less viscous

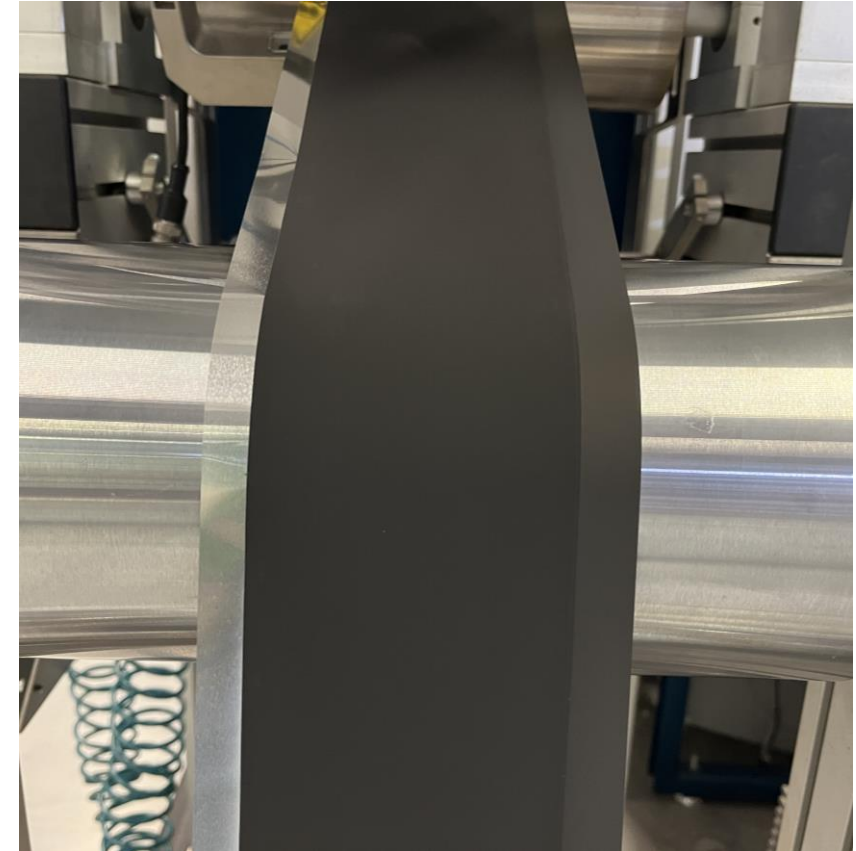


- Amplitude sweep measurement of SPAN suspension (with MWCNT):
 - CMC/SBR and IWS Binder 1 comparable

Preparation: coating via film applicator or roll-to-roll device

Electrode manufacturing

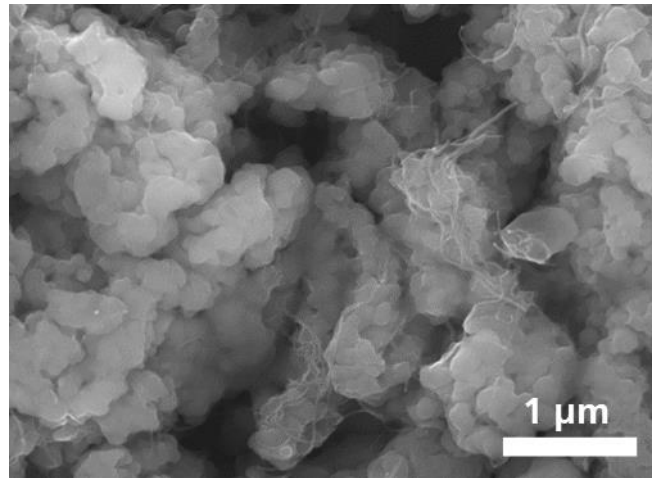
- Preparation of SPAN suspension in dissolver mixer
 - For parameter screening coating via doctor blade
 - Roll-to-roll device for preparing high amount of electrodes
 - Double-sided coatings around 10 m possible



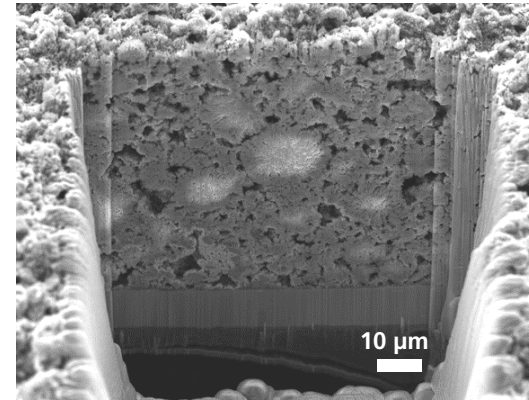
Solution: Conductive additive adaption

FIB-SEM imaging

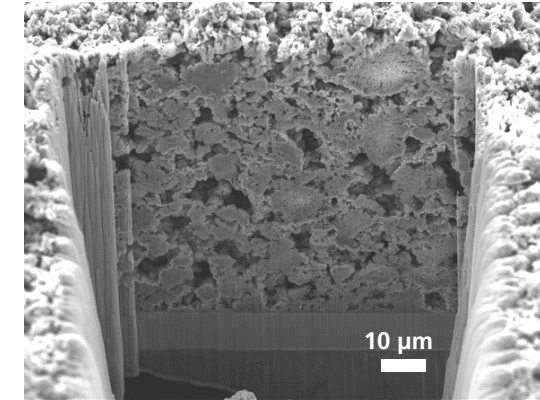
- Multi-walled carbon nanotubes (MWCNT) as alternative conductive additive
 - Horizontal cracks after calendaring
 - MWCNTs compensate by interconnecting AM
- Resistivity should increase stronger after calendaring when C65 is used



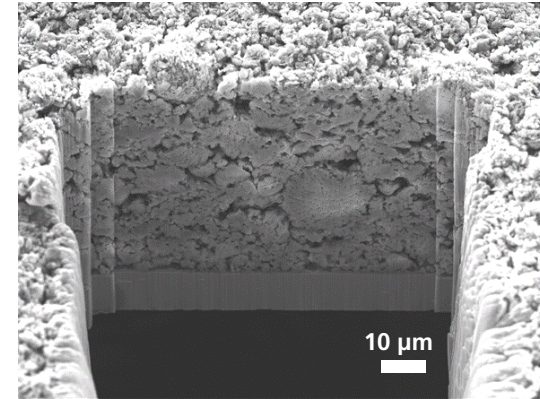
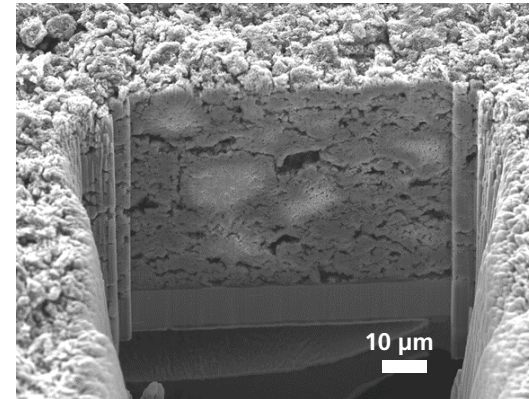
SPAN + C65



SPAN + MWCNT



Calendaring

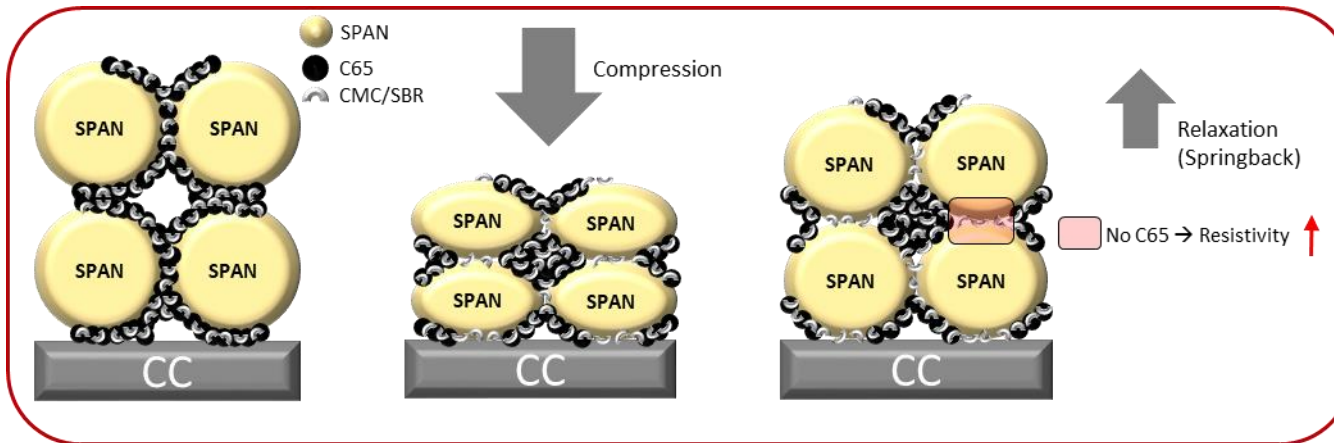


FIB-SEM images of SPAN-electrodes with different conductive additives before and after calendaring

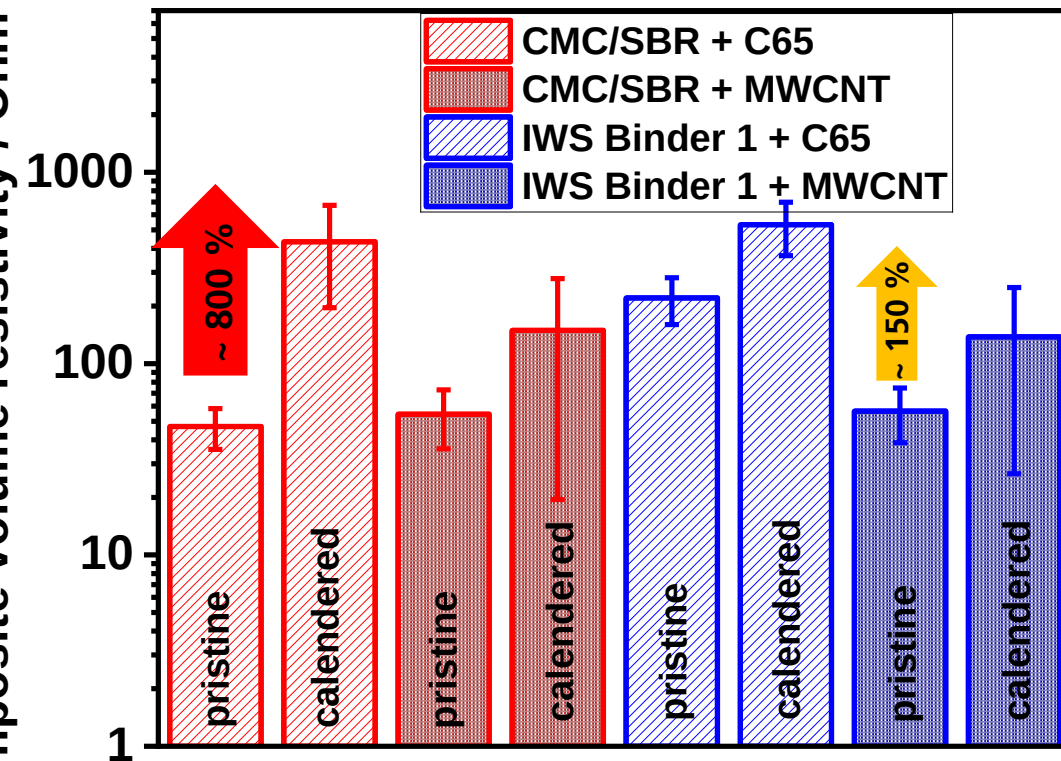
Solution: Conductive additive adaption

Resistivity investigation

- Composite volume resistivity (CVR) measurements prove observations of FIB-SEM
- After calendaring CVR are increased for all samples
 - Springback-effect of SPAN material*

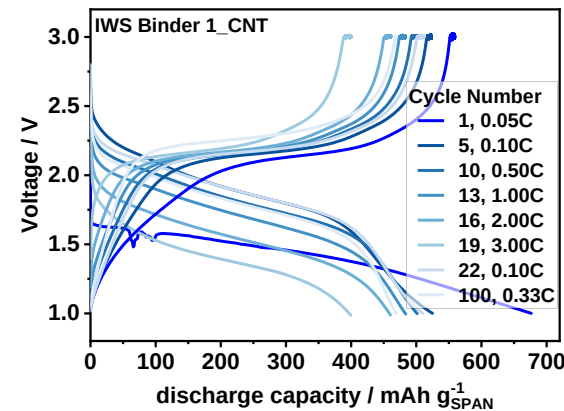
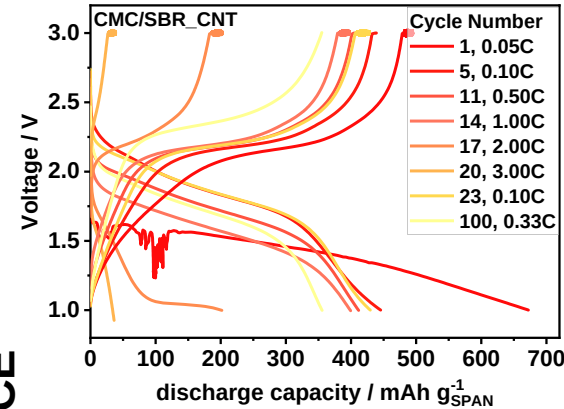
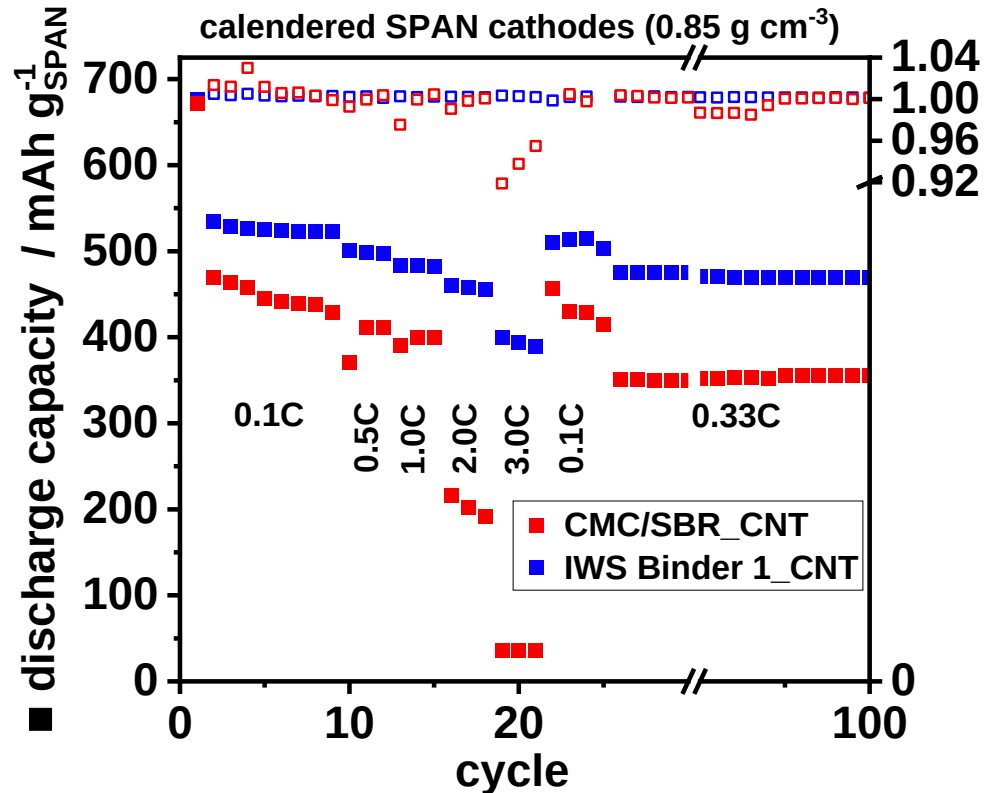


composite volume resistivity / Ohm cm



Investigation of coin cells

CA and binder influence



CR2016

Calendered 15 mm-cathodes ($5.3 \text{ mg}_{\text{SPAN}} \text{ cm}^{-2}$)

250 μm Li

7+2+2 μm separator

30 μl IWS electrolyte A

1.0-3.0V 1xDCh with C/20; DCh 8x C/10, 3x

0.5|1.0|2.0|3.0 C, Ch with C/10, sym. Ch/DCh with C/3

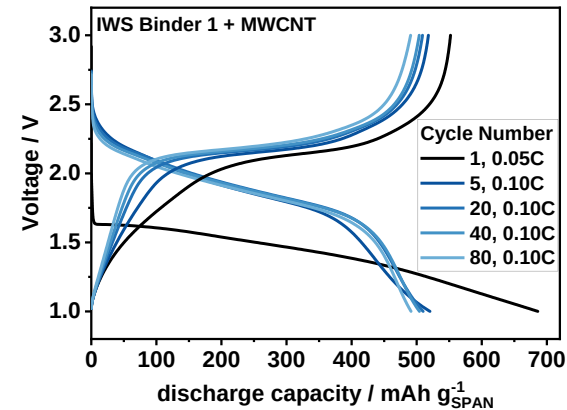
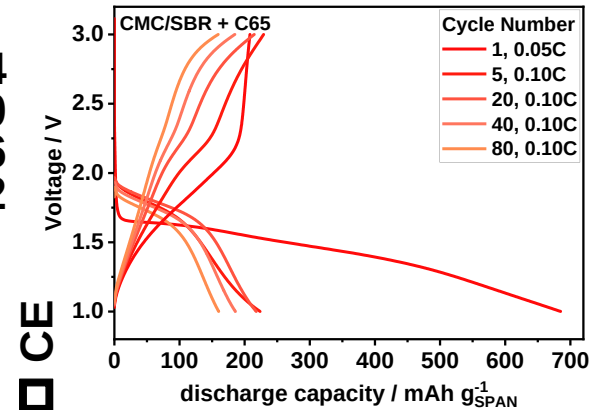
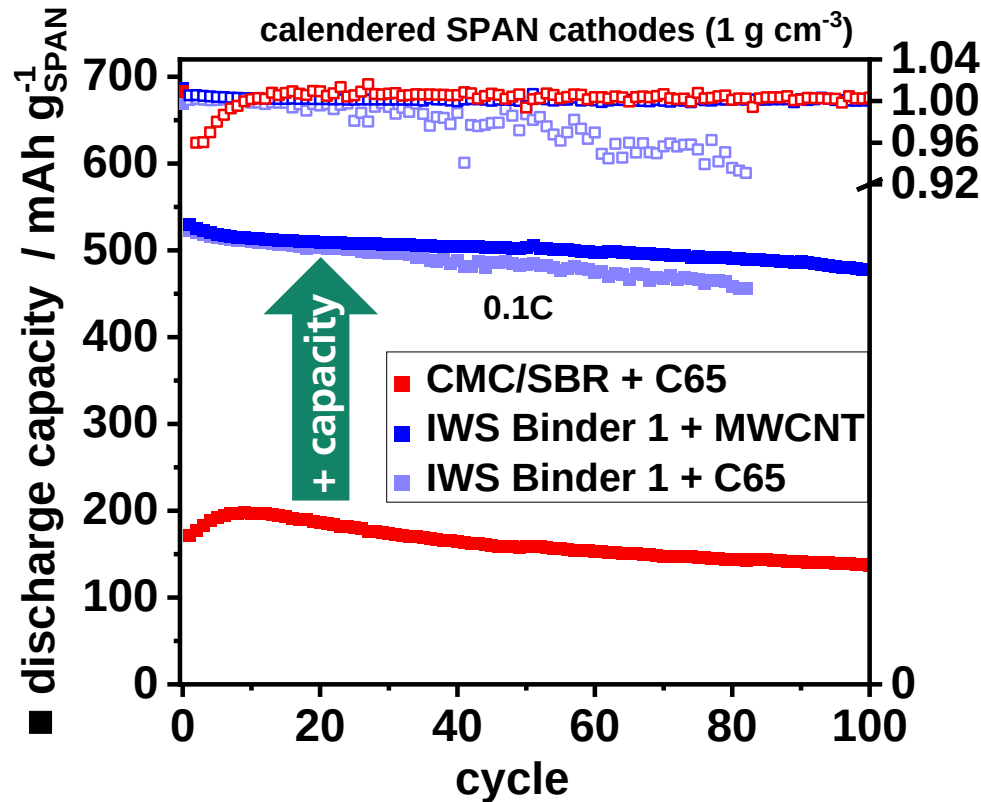


- **CMC/SBR** overall with decreased active material utilization
- **IWS Binder 1** with nearly similar active material utilization compared to pristine electrodes

Evaluation of pouch cells

CA and binder influence

1 Ah multi-layered pouch cells



Calendered 5 ds-cathodes (32.66 cm^2)
 $2 \times 50 \text{ } \mu\text{m Li}$
E:S $5 \text{ } \mu\text{l mg}_5^{-1}$ IWS electrolyte A
 $1.0\text{-}3.0\text{V}$ 1xDCh with C/20; Ch/DCh with C/10
 0.308 MPa (3.14 kg cm^{-2})

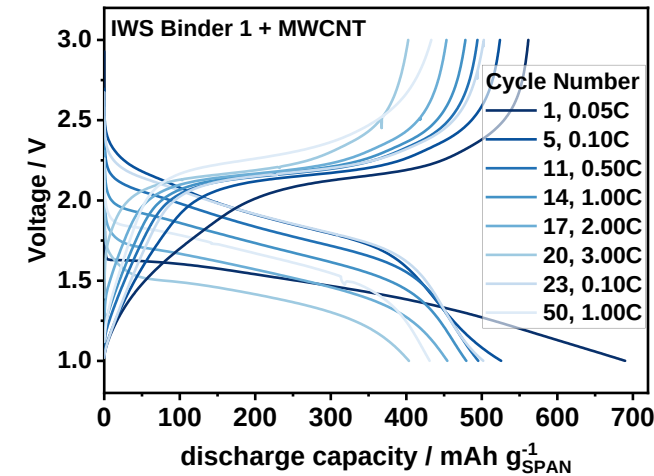
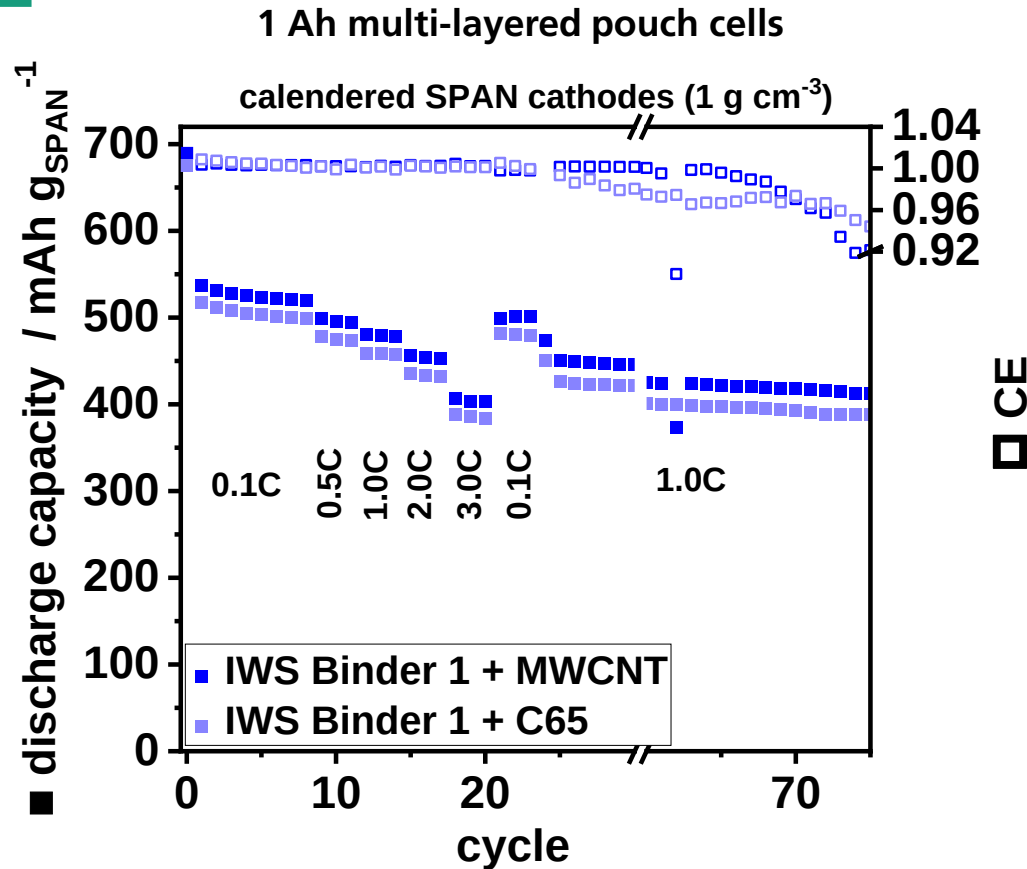


- Life test of calendered SPAN cathodes (1 g cm^{-3})
 - MWCNT as additive with high stability
- ➔ Strong improvement realized by IWS Binder 1

Evaluation of pouch cells

CA and binder influence

Calendered 5 ds-cathodes (32.66 cm²)
 2*50 µm Li
 E:S 3.5 µl mg_S⁻¹ IWS electrolyte A
 1.0-3.0V 1xDCh with C/20; DCh 8x
 C/10, 3x 0.5|1.0|2.0|3.0 C, Ch with
 C/10, sym. Ch with C/3/DCh with 1.0 C
 0.308 MPa (3.14 kg cm⁻²)



- Rate test for evaluation of previous results
 - ~ 75 % of initial capacity at **3.0C**
- Highly relevant cathodes for practical use

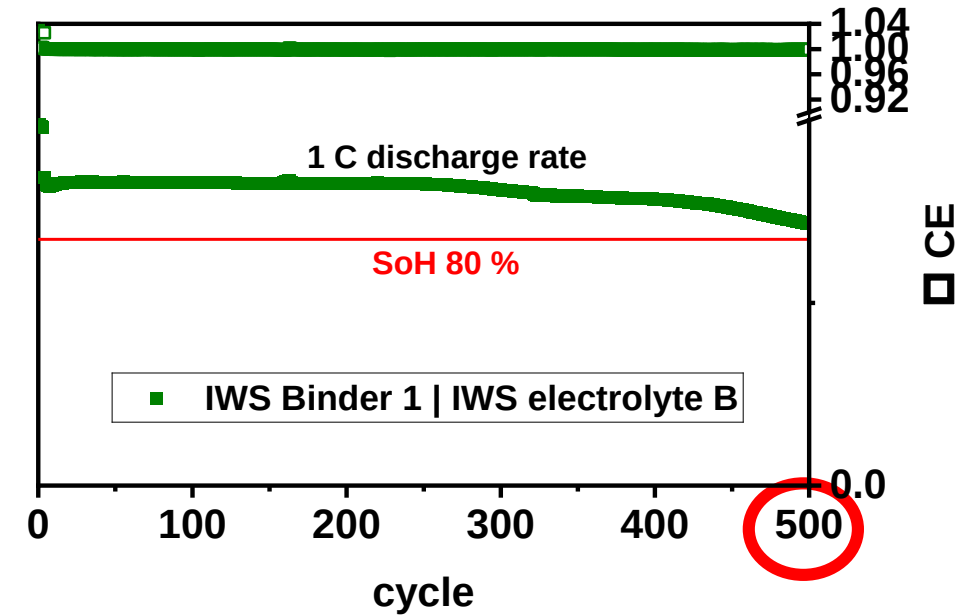
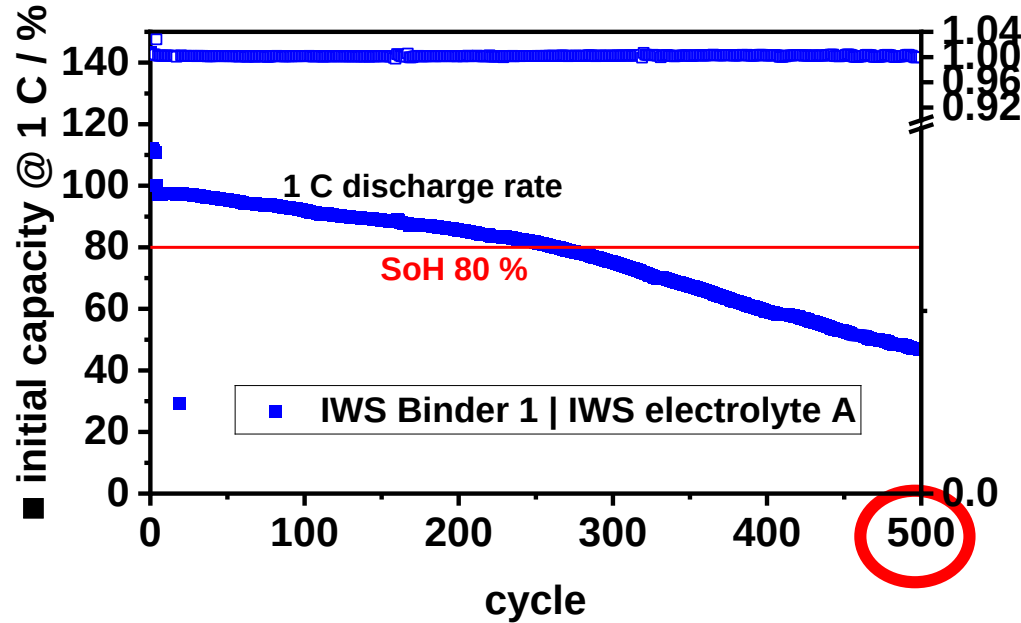
Evaluation of pouch cells

Cycle life

5 ds-cathodes (32.66 cm²)
2*50 µm Li
E:S 5 µl mg_S⁻¹
1.0-3.0V 1xDCh with C/20; 3xCh/DCh
with C/10; DCh with 1C, Ch with C/3
0.308 MPa (3.14 kg cm⁻²)



1 Ah multi-layered pouch cells



- Life test with high C-rate (**1.0C**)
 - IWS elec. A enabling more than **500** cycles
- Strong improvement in cycle life and rate performance for Li-S batteries

- Alternative electrolytes tested (IWS elec. B)
 - Outstanding stability
- Further adaptations successfully demonstrated

Evaluation of pouch cells

Conclusion

Summary

Binder adaption

- **IWS Binder 1** enabled improved performance

Conductive additive comparison

- C65 with facilitated coating
- MWCNT with improved rate capability (**3.0C**)

Electrolyte evaluation

- **IWS elec. B** with high stability (> **500 cycles**)
- Enabling improved AM utilization

Outlook

Binder and conductive additive

- Higher compaction rates possible?

Electrolyte evaluation

- Adapted IWS electrolyte with promising results
- low/high temperature behavior?

SPAN material

- Higher S content (~50 %) of interest

Thank you!

Contact

Ralf Schmidt
Advanced Battery Technology Center
Telefon +49 351 83391-3752
Fax +49 351 83391-3300
ralf.schmidt@iws.fraunhofer.de

Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS
Winterbergstraße 28
DE-01277 Dresden
www.iws.fraunhofer.de



This work has received funding from the Federal Ministry of Research, Technology and Space (BMRTS), support code 03XP0491C (SulForFlight) and 03ETE043E (BiPoLiS)



With funding from the:



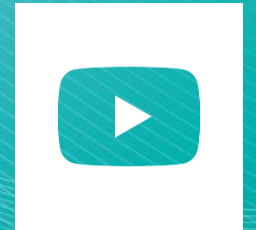
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