



Credit: Gianfranco Guidati (ETH)

# Tuning the microstructure of dry-coated NMC electrodes via continuous extrusion mixing

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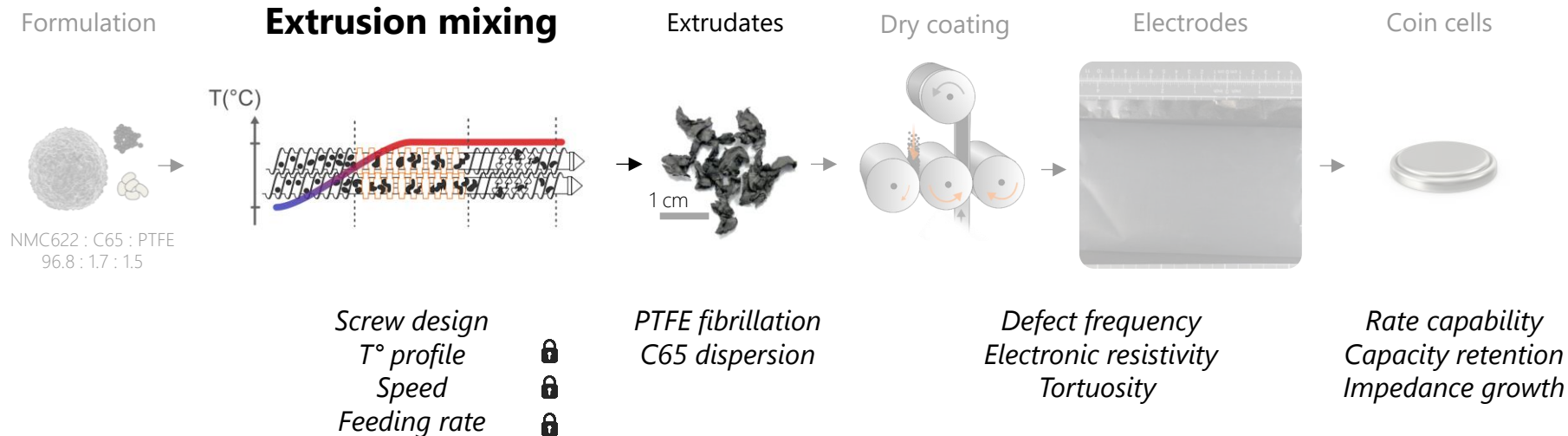
<sup>5</sup> Fraunhofer IWS

Dry Coating Forum, November 3<sup>rd</sup> 2025



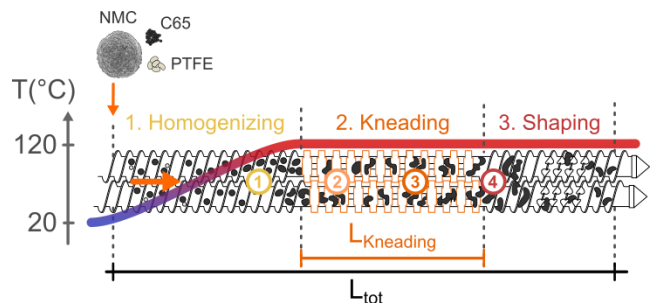
Preprint link

# Motivation and research goal

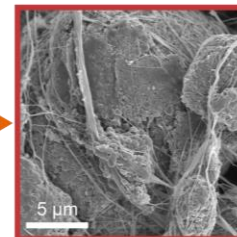
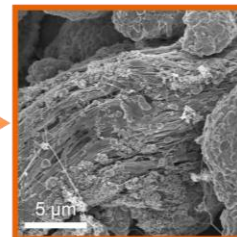
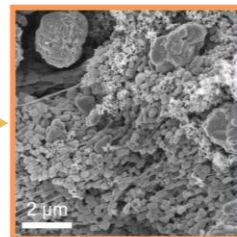
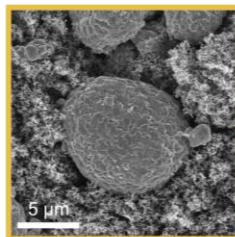
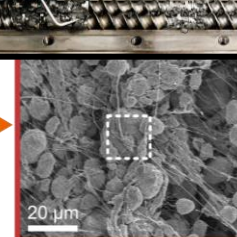
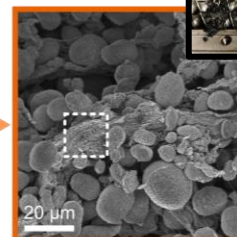
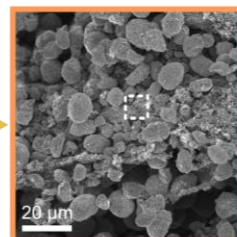
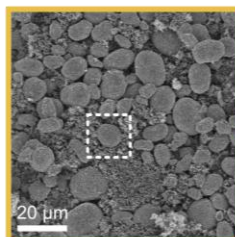


1. How does the extrudate microstructure impact **calenderability** and **electrochemical performance** of dry-coated electrodes?
2. Which **high-throughput metrological methods** inform about the extrudate microstructure?

# PTFE and C65 microstructure evolution during mixing



NMC622 : C65 : PTFE  
96.8 : 1.7 : 1.5

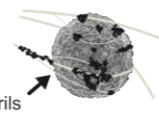
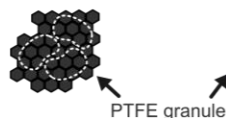


PTFE granules covered by C65

Chain of connected PTFE granules

Large strands of PTFE fibrils

Network of fine PTFE fibrils

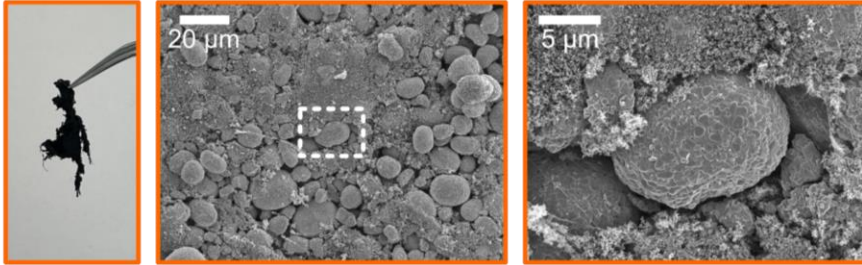


- PTFE microstructure changes from granules to fine fibrils along the kneading zone
- Effective C65 dispersion during mixing
- What is the impact of the **kneading length** on the microstructure and performance of electrodes?

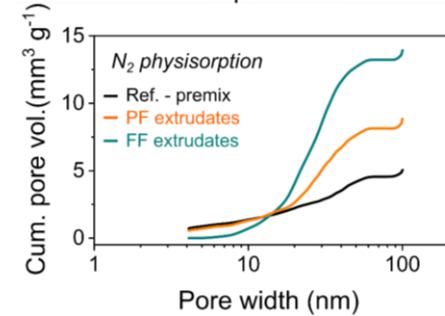
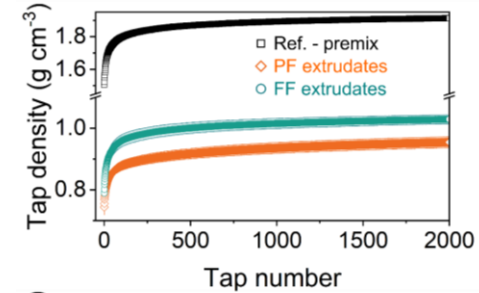
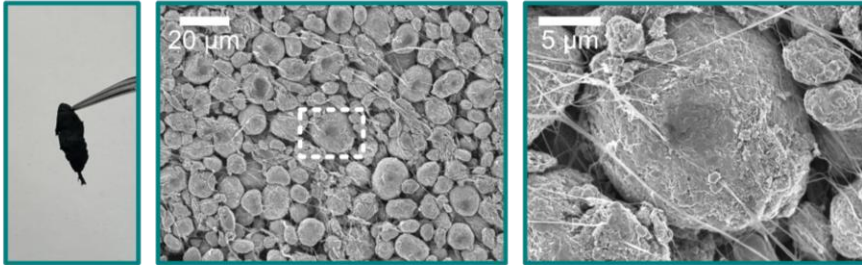
# Quantifying PTFE fibrillation and C65 dispersion in extrudates



Partially fibrillated  
 $L_{\text{Kneading}}/L_{\text{tot}} = 26\%$

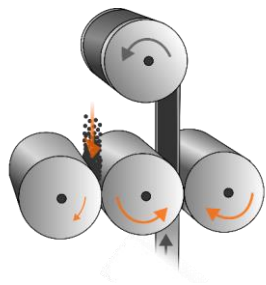


Fully fibrillated  
 $L_{\text{Kneading}}/L_{\text{tot}} = 31\%$



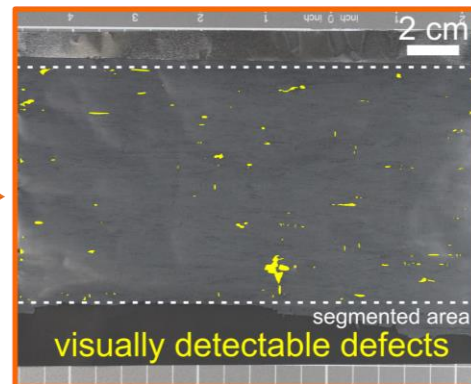
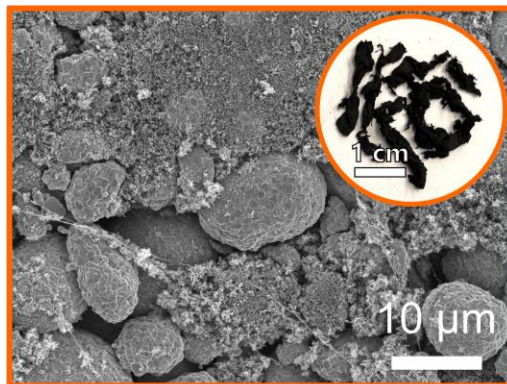
- Extrudates' microstructures vary depending on kneading length – **partially** or **fully fibrillated**
- **Tap density** – correlates to PTFE fibrillation degree
- **N<sub>2</sub> physisorption** – monitor C65 dispersion

# Extrudate microstructure impacts defects in sheets

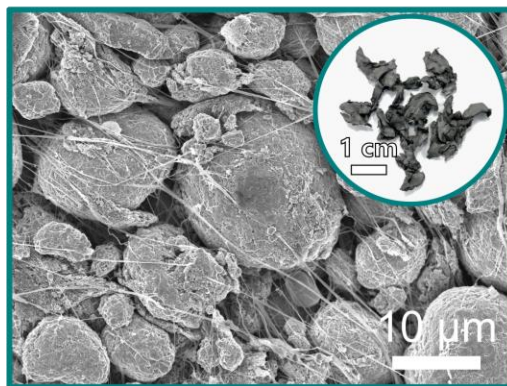


- Partially fibrillated extrudates – **more defects** in the sheets
- Fully fibrillated extrudates – **some defects**, due to extrudate size

Partially-fibrillated

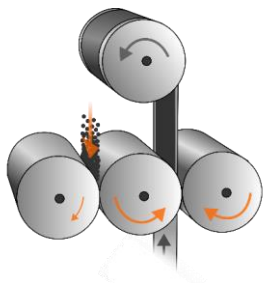


Fully-fibrillated



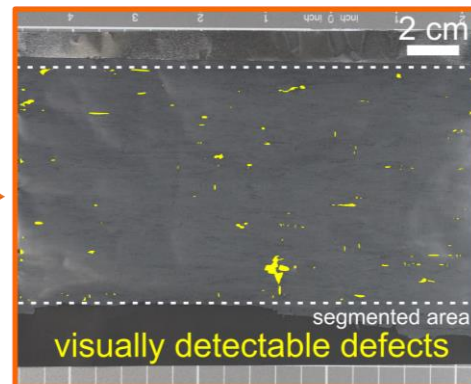
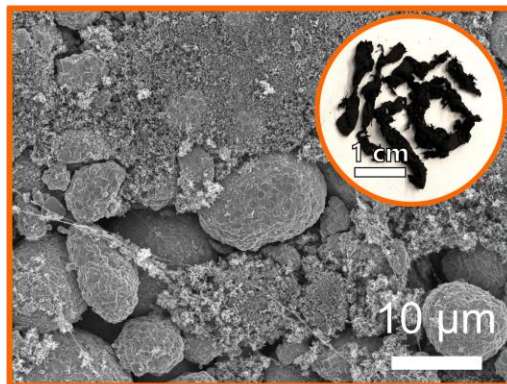
NMC622 : C65 : PTFE  
96.8 : 1.7 : 1.5

# Extrudate microstructure impacts defects in sheets

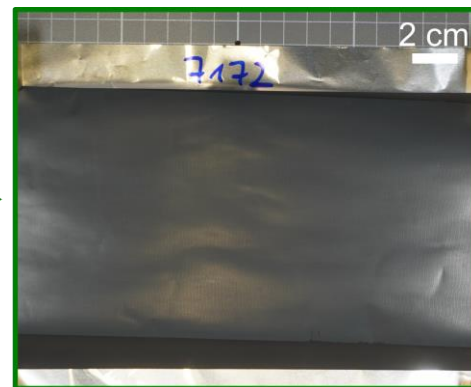
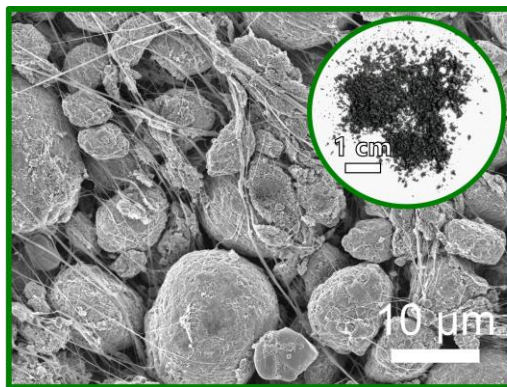


- Partially fibrillated extrudates – **more defects** in the sheets
- Fully fibrillated extrudates – **some defects**, due to extrudate size
- Defect-free sheets obtained with **fully fibrillated** and **fine** extrudates

Partially-fibrillated

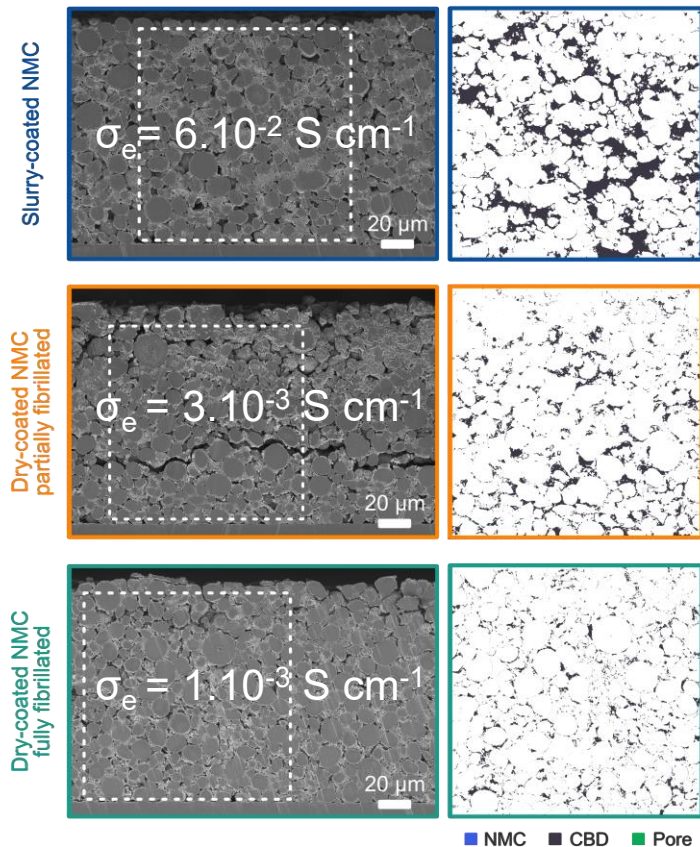


Fully-fibrillated



NMC622 : C65 : PTFE  
96.8 : 1.7 : 1.5

# Extrudate microstructure impacts sheet resistivity

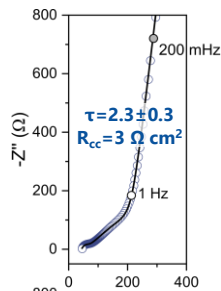
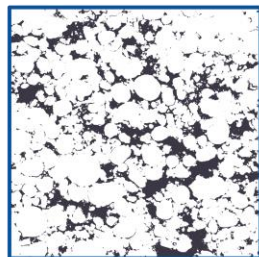
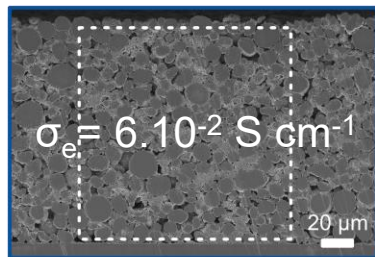


- Sheets from **PF** extrudates – visible **cracks**
- Sheets from **FF** extrudates – **no long-range percolation** of Carbon Binder Domain (CBD) – higher electronic sheet resistivity

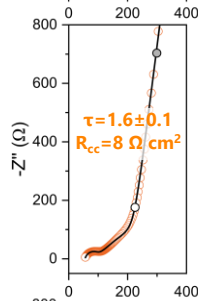
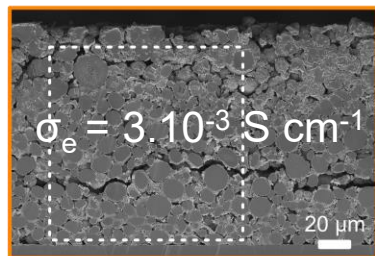
# Extrudate microstructure impacts tortuosity



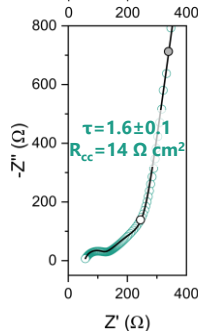
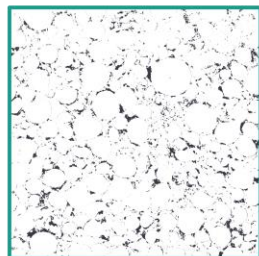
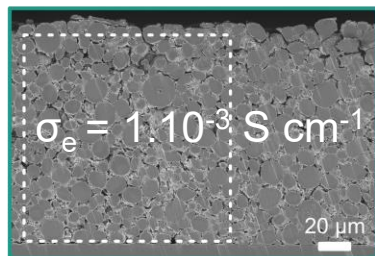
Slurry-coated NMC



Dry-coated NMC partially fibrillated



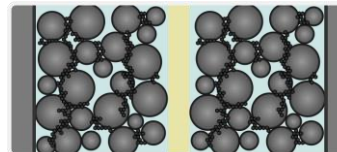
Dry-coated NMC fully fibrillated



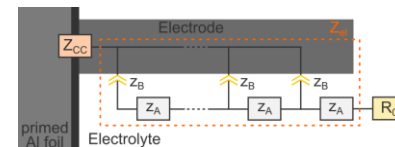
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■ NMC ■ CBD ■ Pore

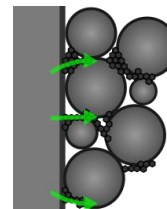
Tortuosity - symmetric cell  
10 mM TBAClO<sub>4</sub> in EC:EMC 3:7



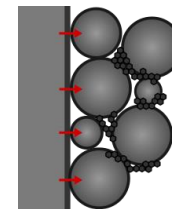
Equivalent circuit model



- Dry-coated electrodes have **lower tortuosity**
- But **higher** current-collector **contact resistance** (especially FF electrodes). *Why?*

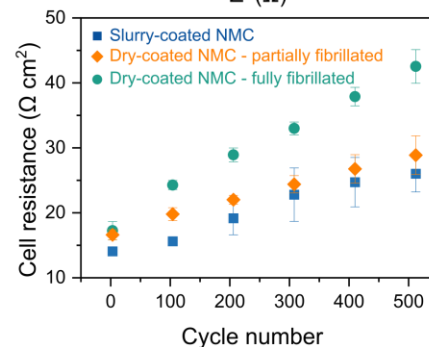
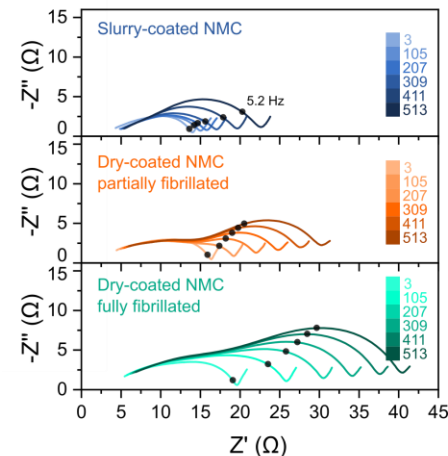
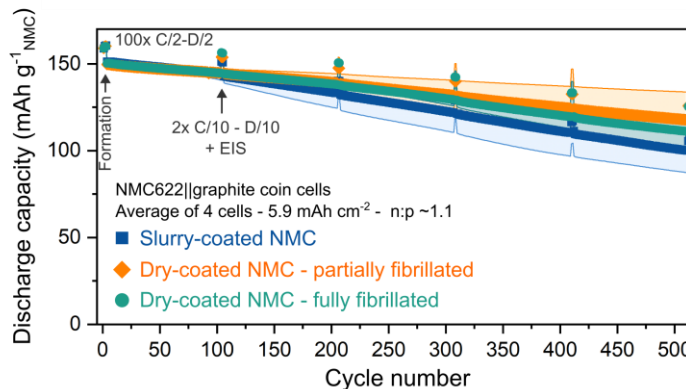
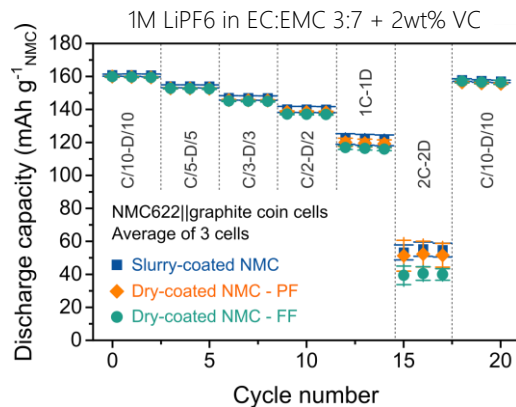


Electron transfer  
**through CBD**  
(slurry-coated)



Electron transfer  
**through NMC**  
(FF dry coated)

# Electrochemical performance of dry-coated NMC622



- Similar rate performance up to 1C for all cells
- Partially fibrillated NMC - better average performance but **larger cell-to-cell variations**
- Fully fibrillated NMC – reliable performance but **faster impedance growth**
- **Fe<sup>0</sup> residues** from equipment wear? **NMC fragmentation** during mixing?

# Conclusions and outlook

Quérel (preprint ChemRxiv), "Industrial dry coating of NMC battery electrodes enabled by continuous extrusion mixing"



- **Kneading length** is a key parameter controlling extrudate microstructure
- **Defect-free** electrode sheets obtained from extrudates with: **small size** and **fine PTFE fibrillation/C65 dispersion**
- Trade-off with long kneading length is **equipment wear**
- **Faster impedance growth** in dry-coated electrodes – new challenges to resolve
- Improved **electronic conductivity** with optimized formulations – ongoing work

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## Acknowledgements

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