Nissan Leaf

Electronic pathway length manipulation and impact on conductivity networks in lithium-ion battery electrodes

Jake Entwistle, Guo J Lian, Rachel Smith, **Denis Cumming**

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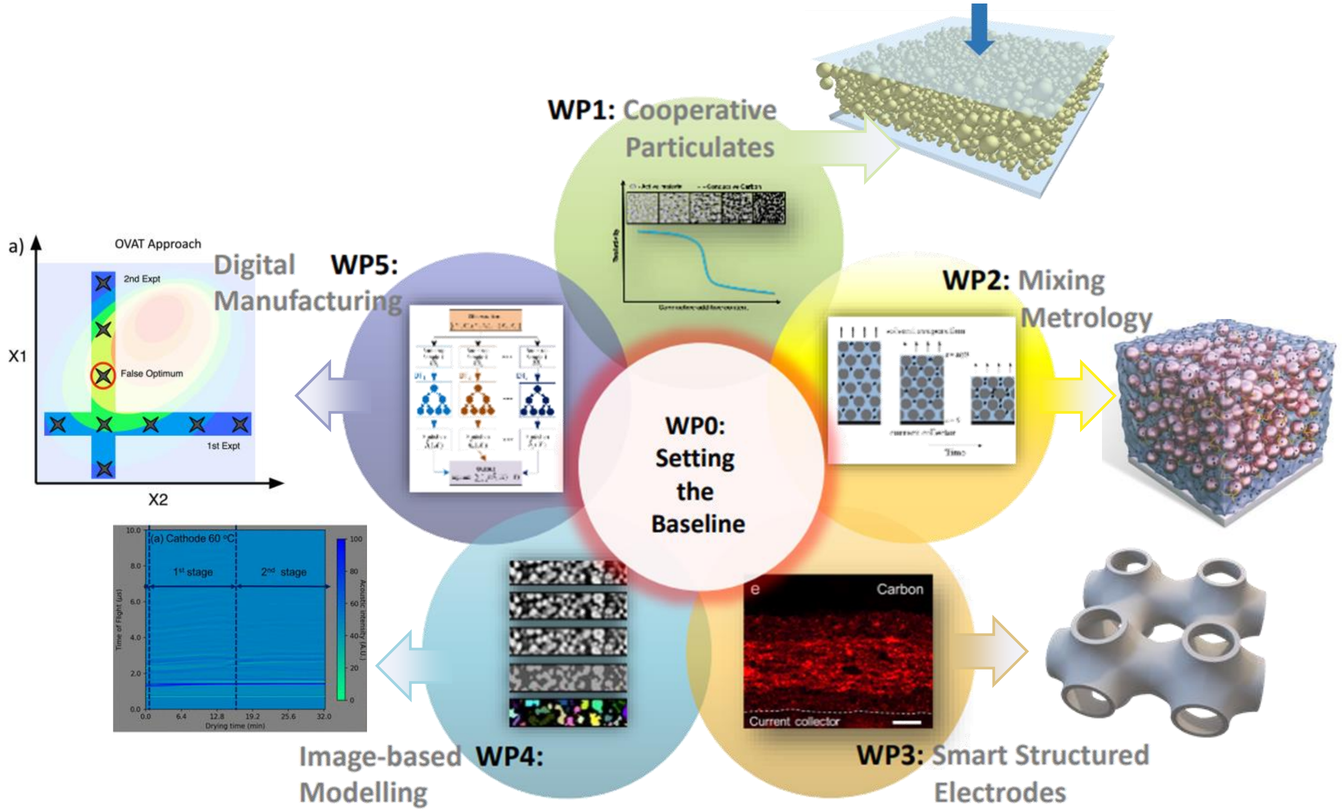
THE FARADAY INSTITUTION
ELECTRODE MANUFACTURING

NEXTRODE

Next Generation Electrodes (NEXTRODE)

- The Faraday Institution funded project- NEXTRODE



- **WP1: Denis Cumming**

  Ruihuan Ge (2nd Nov. 12:30)

- **WP2 and WP4: Yeshui Zhang (poster)**

  ACS Appl. Mater. Interfaces 2021, 13, 30, 36605–36620

- **WP3: Yige Sun (1st Nov. 14:50)**

- **WP5: Geanina Apachitei (2nd Nov. 15:35)**

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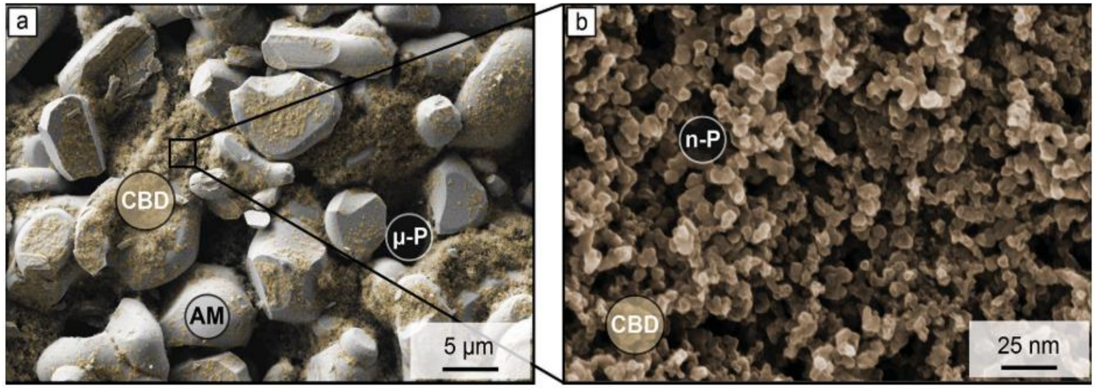
ELECTRODE ELECTRONIC CONDUCTIVITY

Particle design

Active material (AM) particle engineering
- Particle surface coating
- Core-shell structured particles
- Hybrid composite particles (coating, doping)

Carbon binder domain (CBD) engineering
- Carbon coating on AM particles
- Graphite/carbon nanotubes
- Intensive dry mixing for homogenous carbon coverage



Zielke et al., *Adv. Energy Mater.* ***2015 5***, 1401612

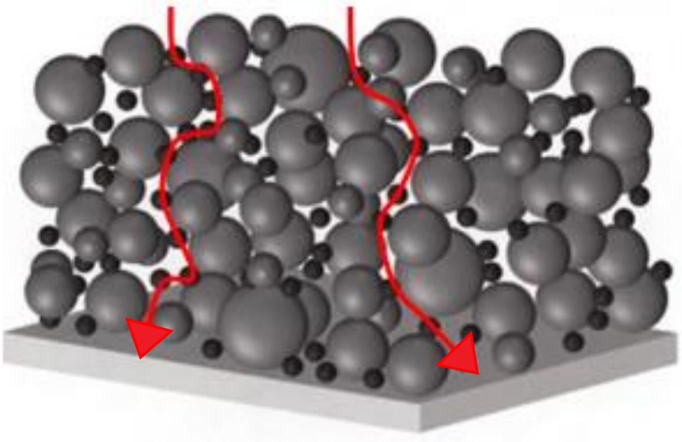
Electrode design

- High power and energy density requires thicker electrodes
- Efficient electron transport networks with decreasing proportions of conductive additives (CA)
- Incorporation of CA has secondary implications
  - Electrode porosity and tortuosity
  - Compressibility and mechanical properties
  - AM-binder interactions
  - Electrolyte reservoirs and wettability
  - SEI formation
  - Electrode thermal conductivity

LONG- AND SHORT-RANGE ELECTRONIC CONTACTS

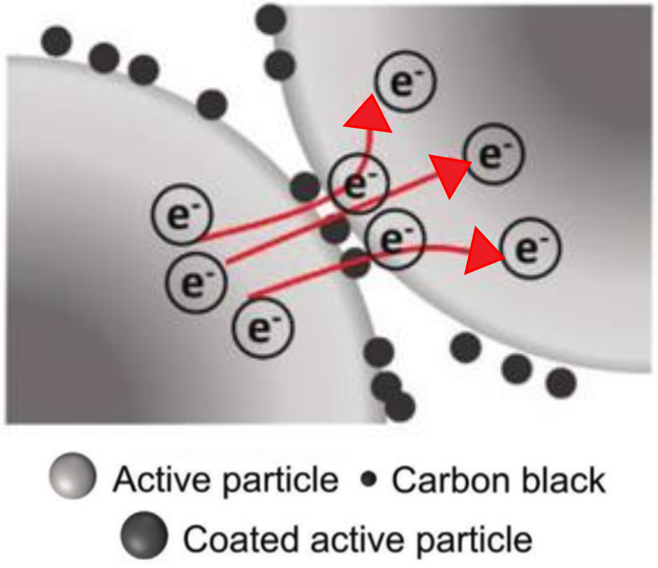
What we know

- Importance of long- and short-range electrical networks
- Destructive and constructive impacts of heterogeneity impacts rate capability[1]
- Processing techniques affects CBD formation and electronic and ionic networks[2][3]
- Targeted distribution of CA with binder in clusters localized next to contact areas with other AM particles[4]



No fundamental understanding

- Optimal quantity and location/ distribution of CA in an electrode
- Optimal combination of long- and short-range contacts
- Advance characterization of contact structure
- Simulation of traditional composite or structured electrodes

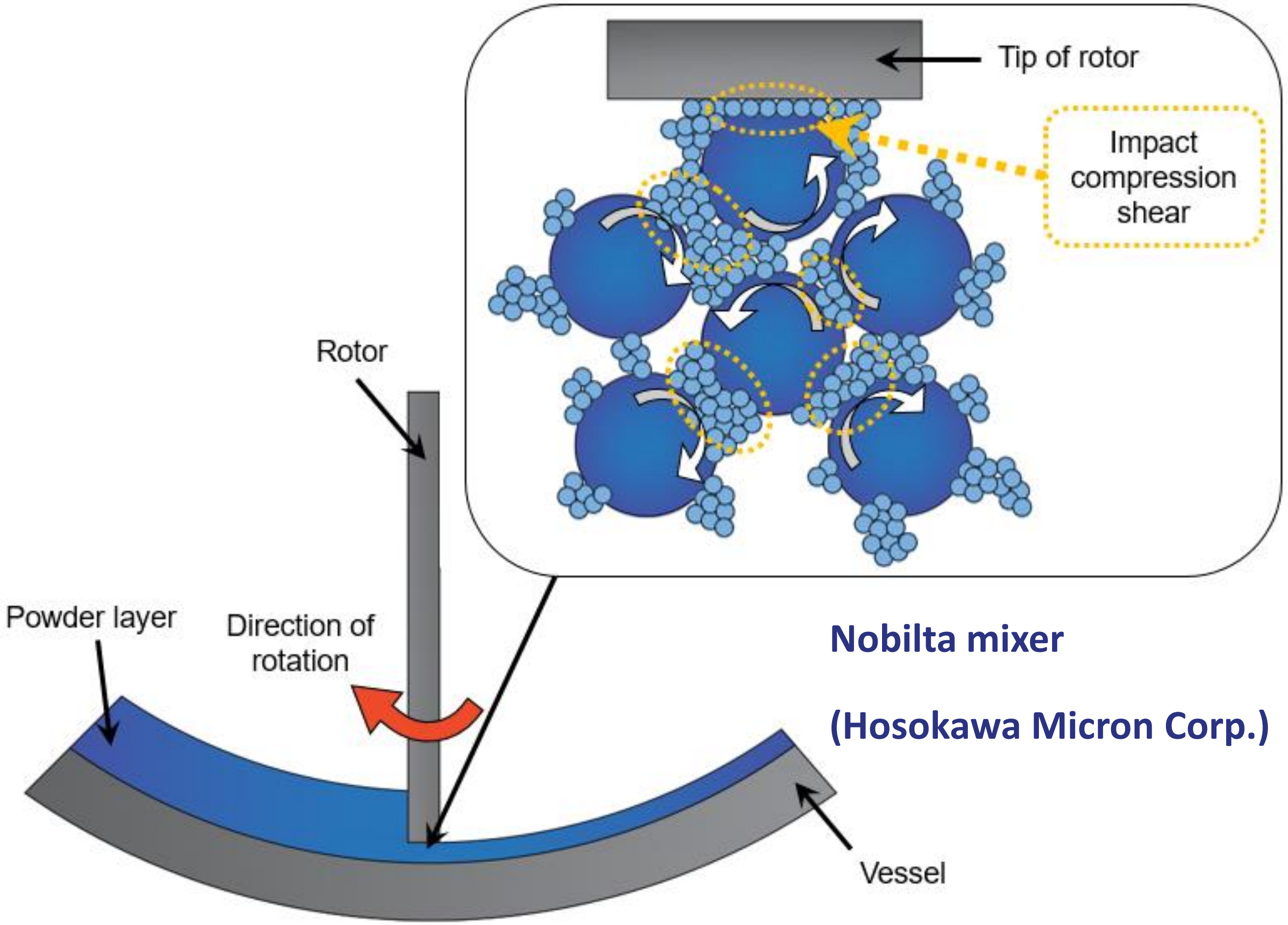


Park et al., *Adv. Energy Mater.* ***2020*** *10*

[1] Yari et al., *ACS Appl. Energy Mater.* **2020** *3*, 11820-11829
[2] Saraka et al., *ACS Appl. Energy Mater.* **2020** *3*, 11681-11689
[3] Dreger et al., *Journal of Elec Mater*. **2015** *44*, 4434–4443
[4] Bauer et al., *Journal of Power Sources.* ***2015*** *288,* 359-367

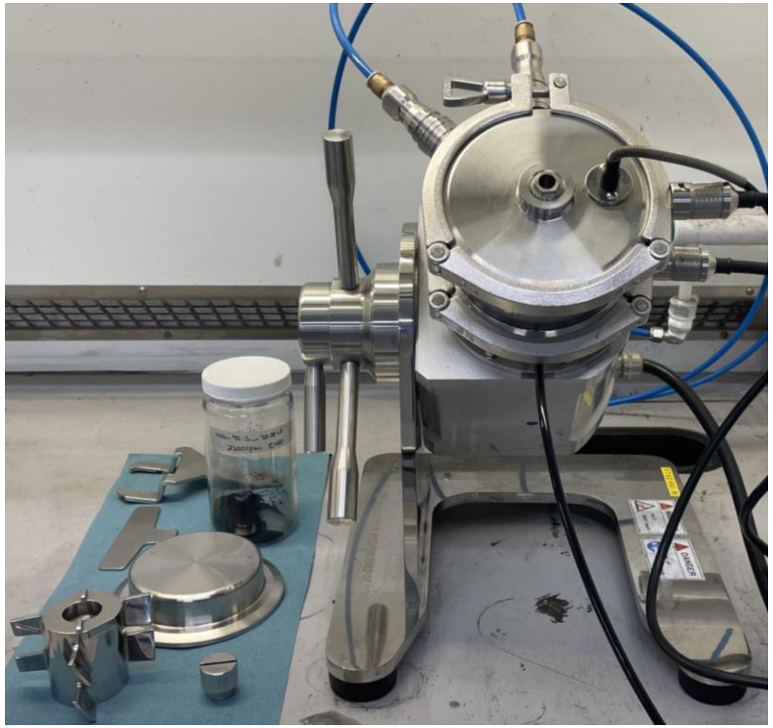
MECHANOFUSION PROCESS

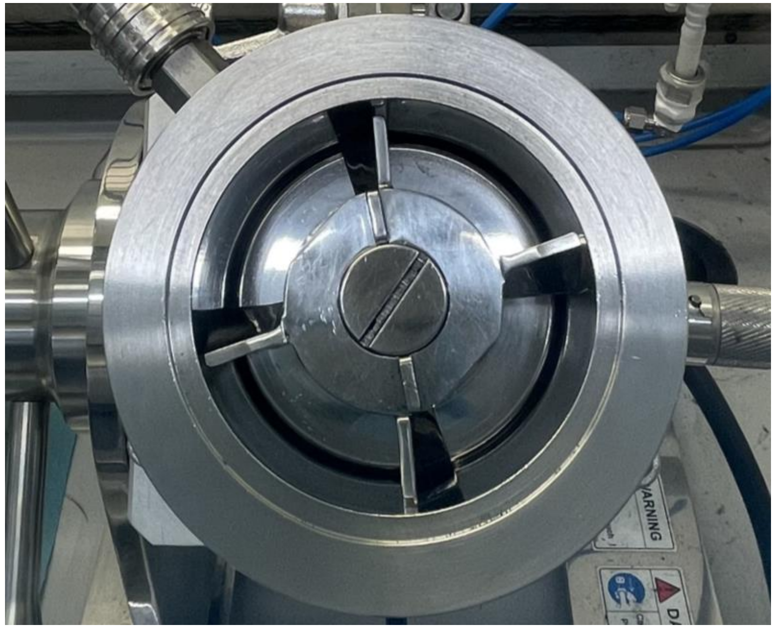
Use of mechanofustion to control degree of carbon black de-agglomeration as a measure of short-range contacts



Nobilta mixer

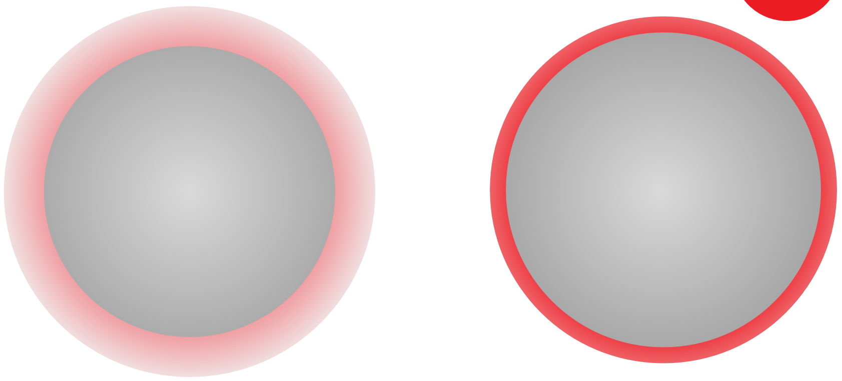
(Hosokawa Micron Corp.)

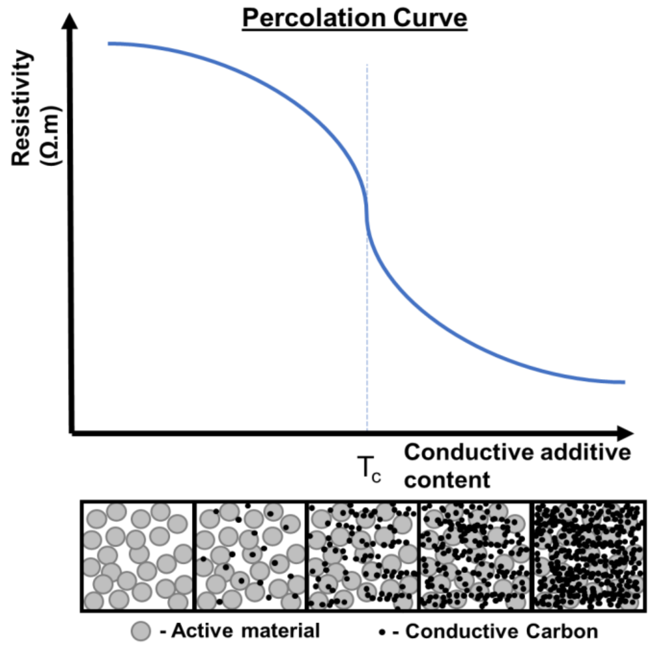




MECHANOFUSION CARBON COATING

- Constant solids to AM (NMC622 BASF) : binder (PVDF 5130 Solvay)
- Conductive additives – Imerys C65 and KS6 graphite
- AM:B ratio at 98:2wt%
- NMC coated over a range of wt% CB to develop variation in local percolation curve
- Percolation threshold – critical conductive additive concentration



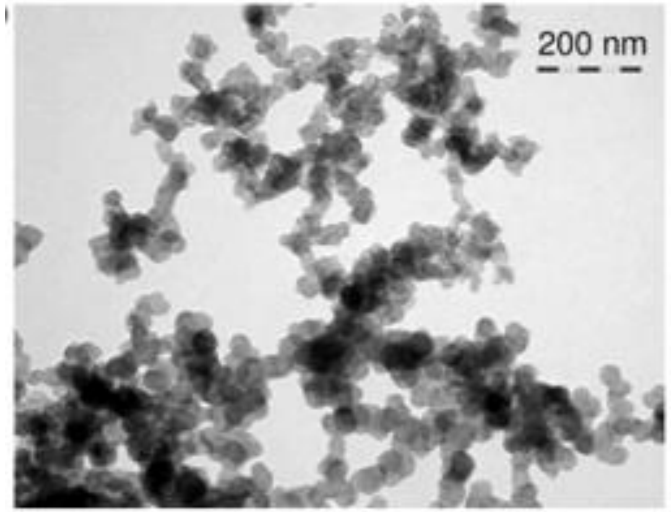


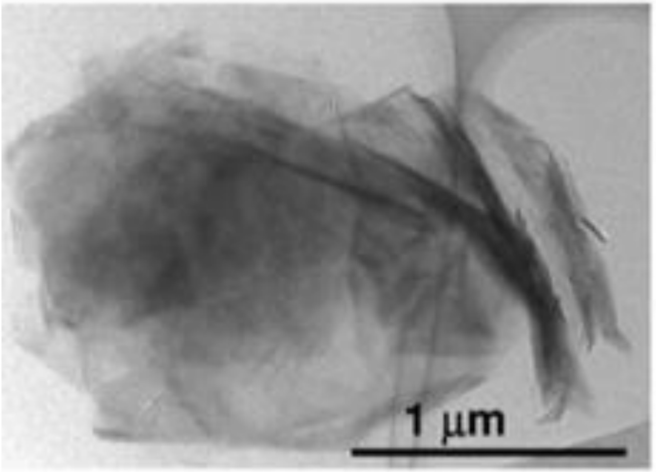
- Short to moderate mixing times
  - CB agglomerates broken down and NMC progressively coated
  - Improvements in electronic conduction
- Long mixing times
  - Compaction resulting in a thin and dense coating
  - Dense layer may impede ionic conduction

LONG- AND SHORT-RANGE CONTACTS

Formulation 96:2:2 NMC:C65:PVDF (wt%)		Nobilta Mixed (AM:CA wt %)	Slurry Mixed
Baseline (control)	Unknown	-	96:2:2wt% (all slurry mixed)
2% C65 Nobilta	100% short-range	96:2	2wt% – Binder
1% C65 Nobilta +1% C65 in slurry	50% long-range 50% short-range	96:1	1wt% – C65 2wt% – Binder
1% C65 Nobilta +1% Graphite in slurry		96:1	1wt% – Graphite (KS6) 2wt% – Binder

- Studying C65 and graphite and their ability to provide long range contacts
- Graphite used as an alternative LRC
- Comparing this to other formulations with lower carbon amounts (1wt%)
- Potential additional conductive additives e.g. carbon fibers, nanotubes have not been investigated



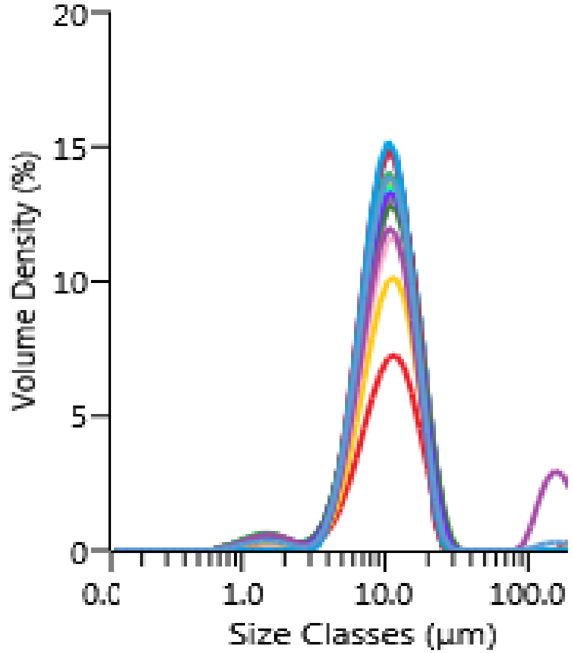


Spahr et al., *Journal of Power Sources.* **2011** *196,* 3404-3413

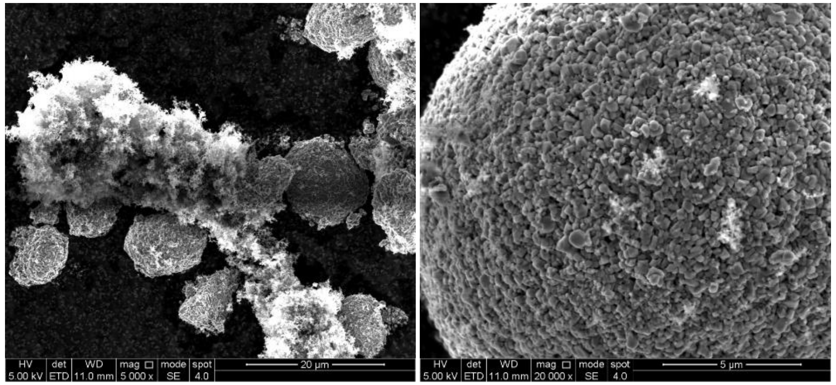
MECHANOFUSION EXPERIMENTS

Investigated 1 -10 wt% coating of C65 on NMC

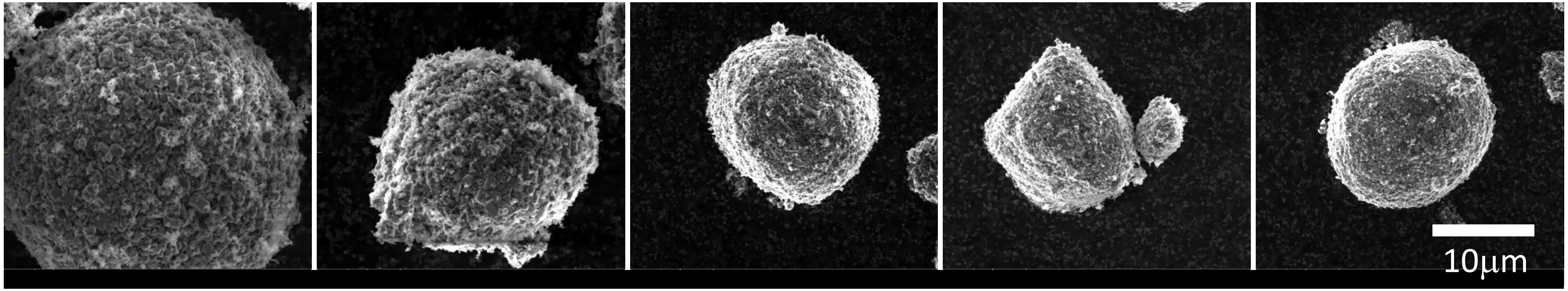
- Inspected with SEM at mixing times from 0 to 60 min
- Powder conductivity measured at time intervals



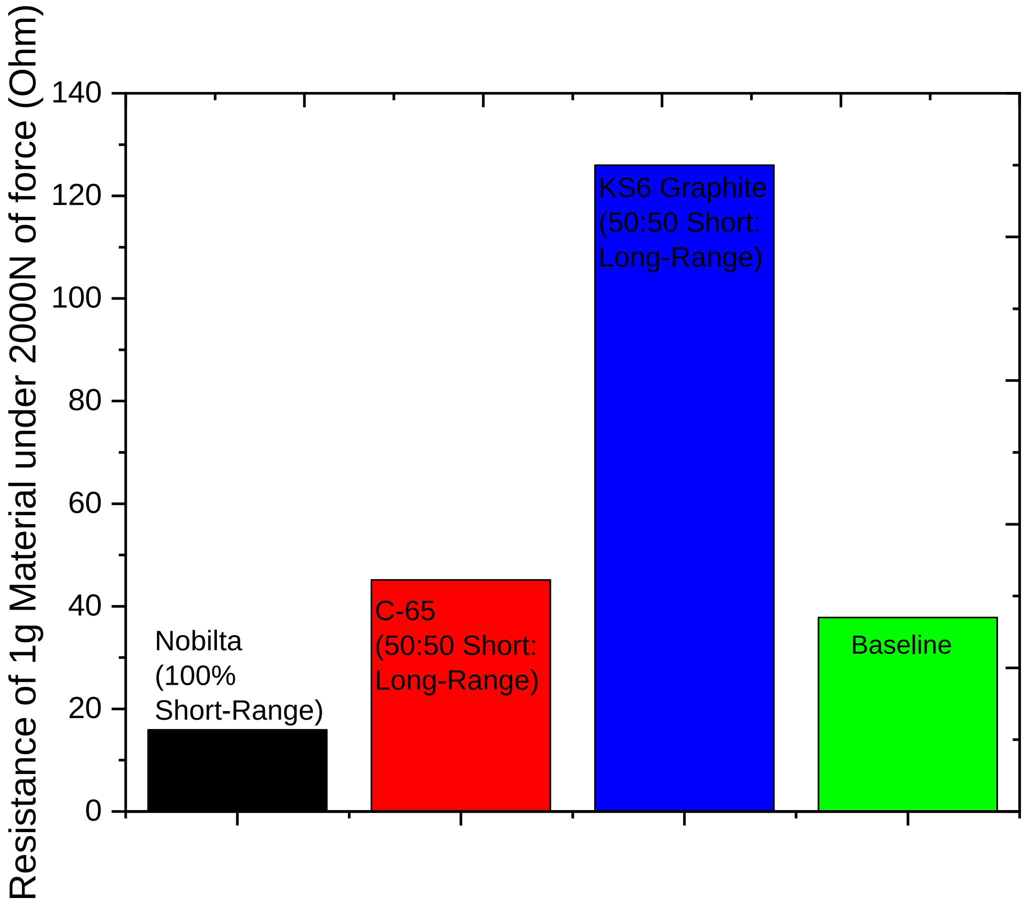
t=0 min

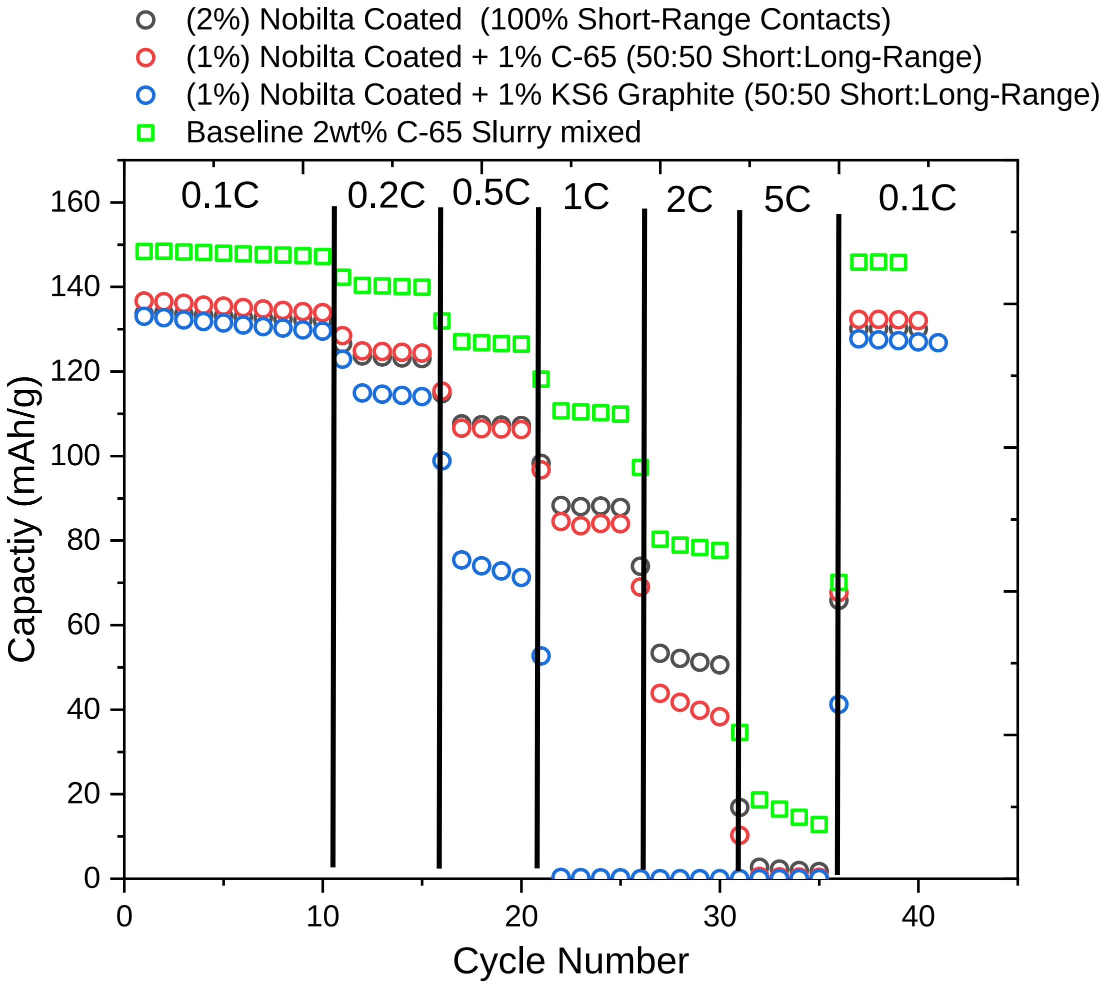


t=2 min **t=5 min** **t=10 min** **t=30 min** **t=60 min**



CONDUCTIVITY AND ELECTROCHEMISTRY





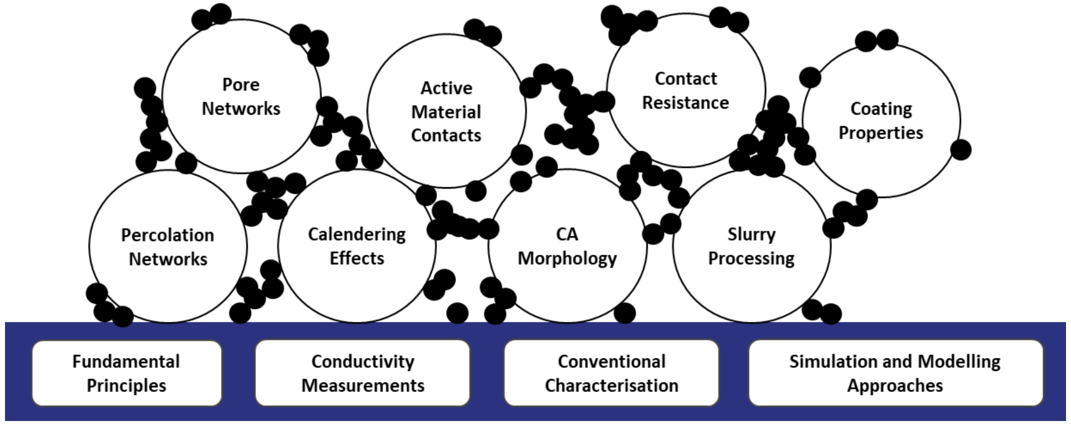
OUTLOOK

Conclusions

- Demonstrated mechanofusion as rapid and effective deagglomeration technique
- Manipulation of carbon black controls electronic conductivity
- Complex relationship between CBD processing and morphology on cell performance
- Binder location may differ in SR and mixed range structures
- Unknown impact of coating on calendering mechanics

Future Work

- Investigate mechanofusion mechanisms
- Further determination of control in long- and short-range electrical contacts
- Why does slurry casting perform so well?
- Best conductive additive for long-range contacts
- Better characterisation techniques to quantify pathways
- **Use our understanding and methods to produce designed conductive pathways and 3D architectures.**



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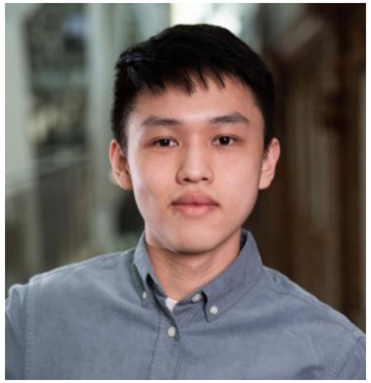

Guo J Lian
PhD Researcher

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The University Of Sheffield.
UNIVERSITY OF OXFORD
UNIVERSITY OF Southampton
UNIVERSITY OF BIRMINGHAM
UCL
WARWICK

Thank you

- *d.cumming@sheffield.ac.uk*

- *www.nextrode.web.ox.ac.uk*

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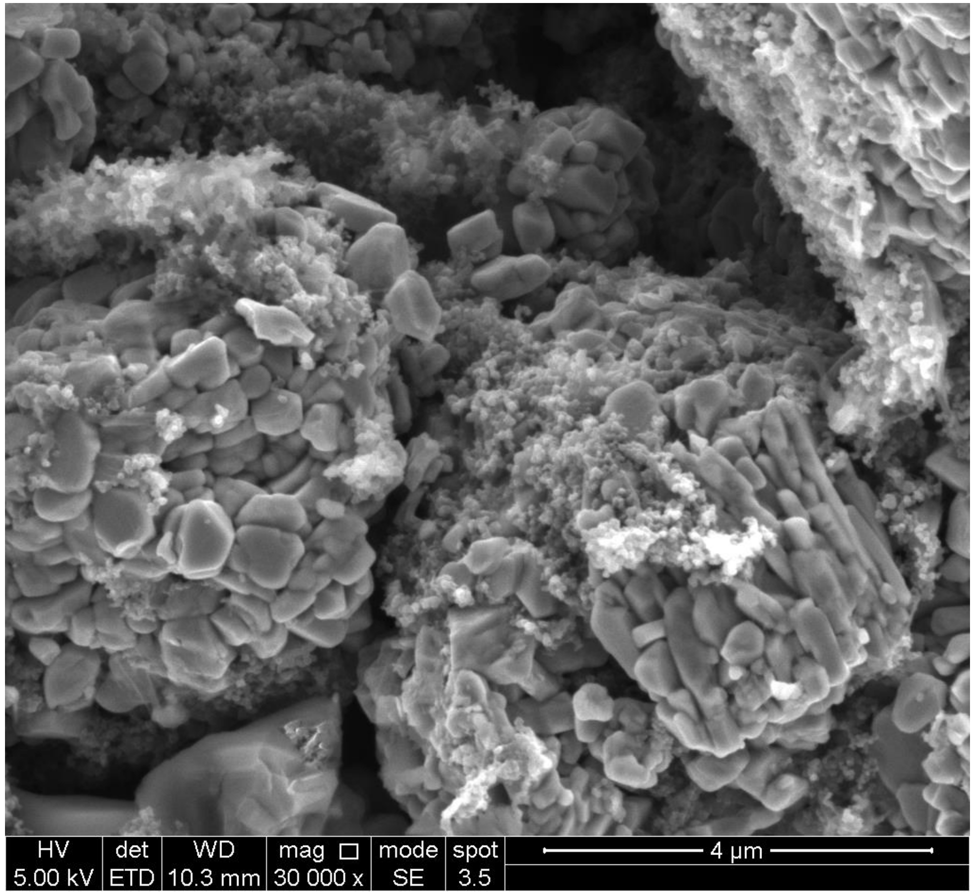
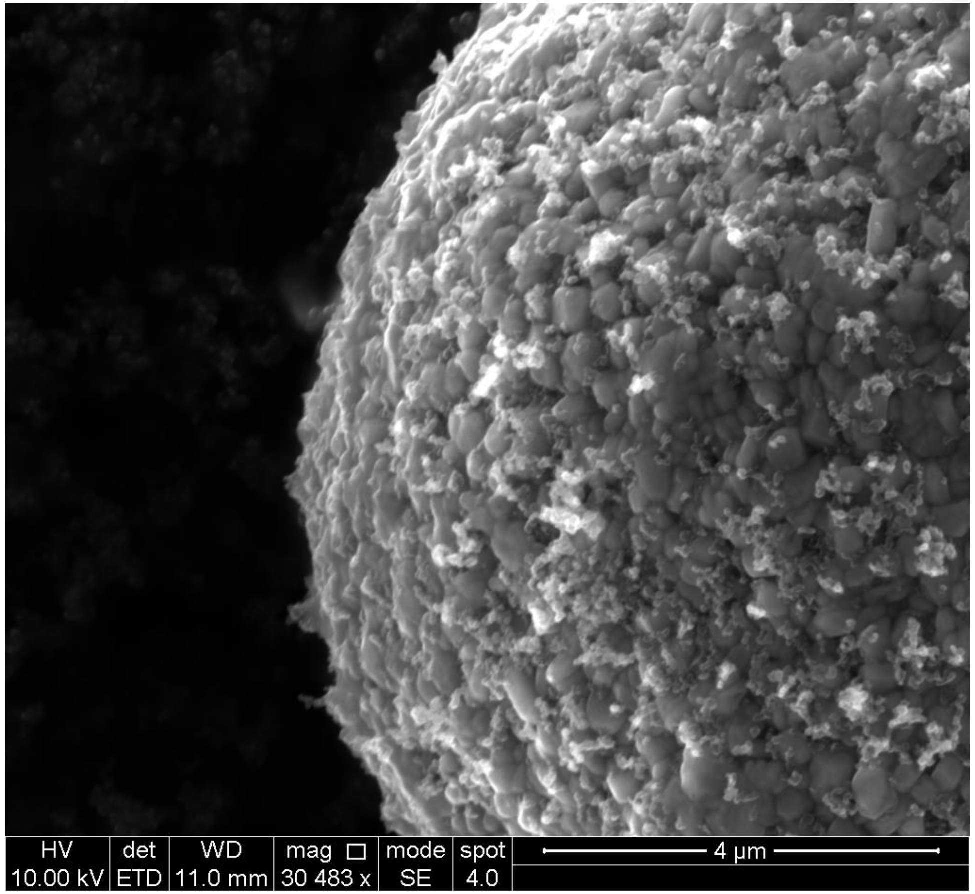
SHORT RANGE CONTACTS

Conventional slurry electrode NMC particle



Mechanofusion coated NMC particle



ELECTROCHEMICAL RESULTS

- Complex relationship between cell performance and CBD morphology
- Further work to investigate electrode pore properties, electrolyte reservoirs, EIS response etc.
- How does coating for short-range contacts change calendering mechanics