ENERGY STORAGE SYSTEMS
SAFETY & RELIABILITY FORUM

Are Aged Cells More Dangerous Than Fresh Cells?

Yikai Jia, Jun Xu*

Vehicle Energy & Safety Laboratory (VESL)
NC Motorsports and Automotive Research Center
Department of Mechanical Engineering & Engineering Science
The University of North Carolina at Charlotte
Email: Jun.Xu@uncc.edu

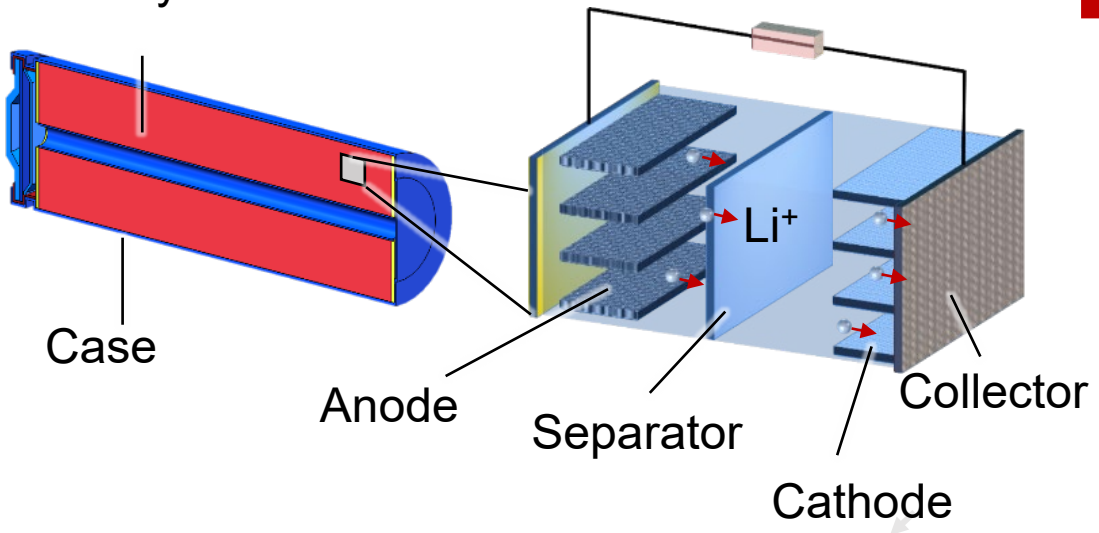
BACKGROUND

Safety issues of LIBs

Battery cell

Abusive loadings

Jellyroll



Battery related accident

EV

Battery energy storage system

Cell phone

https://qz.com/1371531/deep-learning-algorithms-are-being-used-to-detect-lithium-ion-batteries-in-airport-luggage/

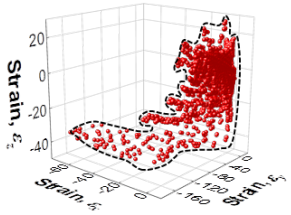
BACKGROUND

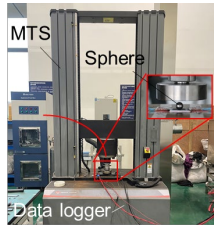
Evolution processes of safety issues

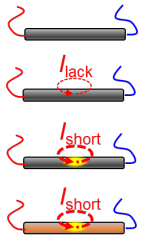
Typical milestone events

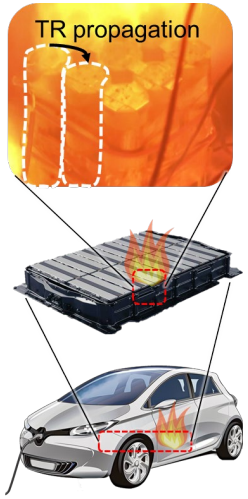
Deformation → Internal Short Circuit → Thermal runaway → Explosion/fire

	Deformation → Internal Short Circuit	Thermal runaway	Explosion/fire
Key Problems	ISC triggering mechanisms	ISC evolution processes and consequences	TR and TR propagation within packs
Possible Solutions	Criteria to predict ISC risk	Safety risk level evaluation	TR and TR propagation modeling







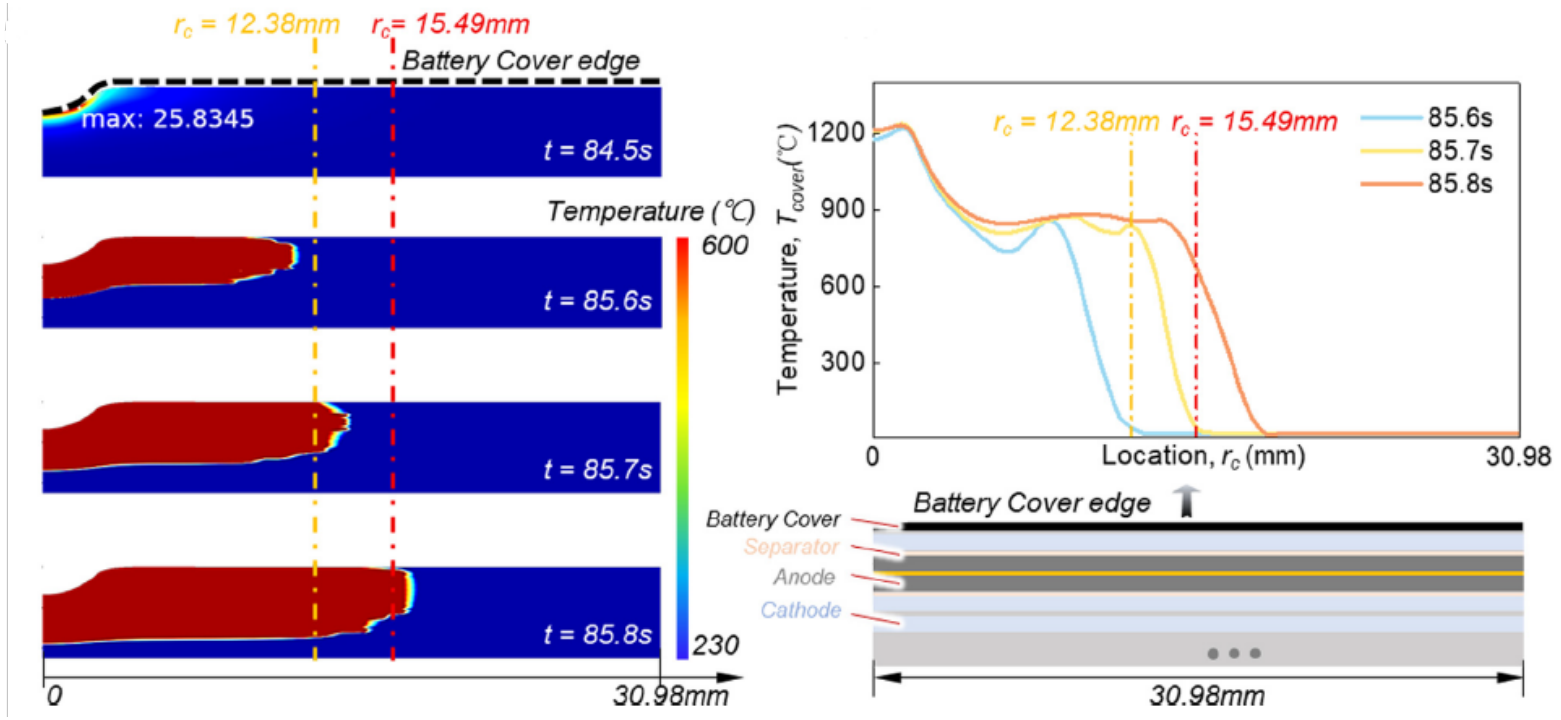


Liu et al., *Energy Storage Materials*, 2020

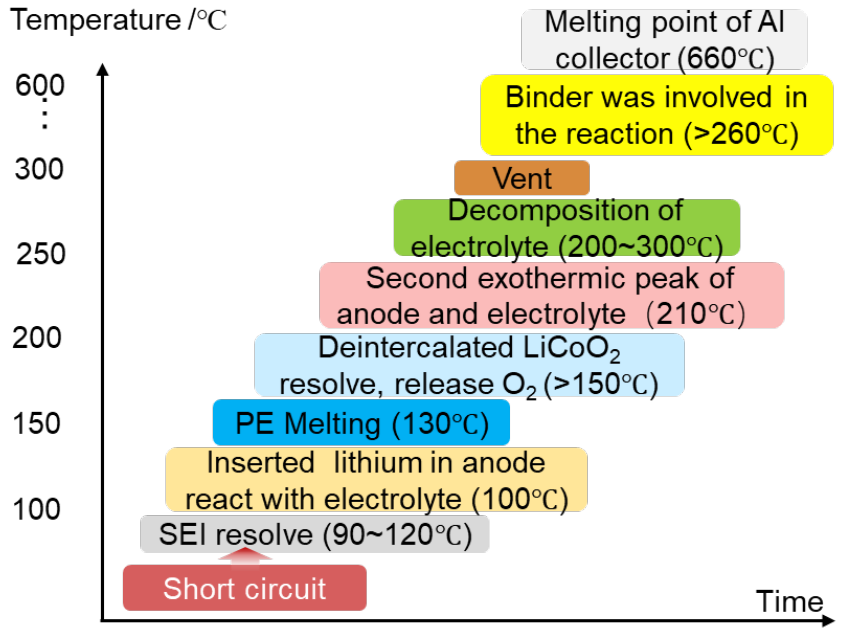
BACKGROUND

Evolution processes of safety issues

ISC evolution processes



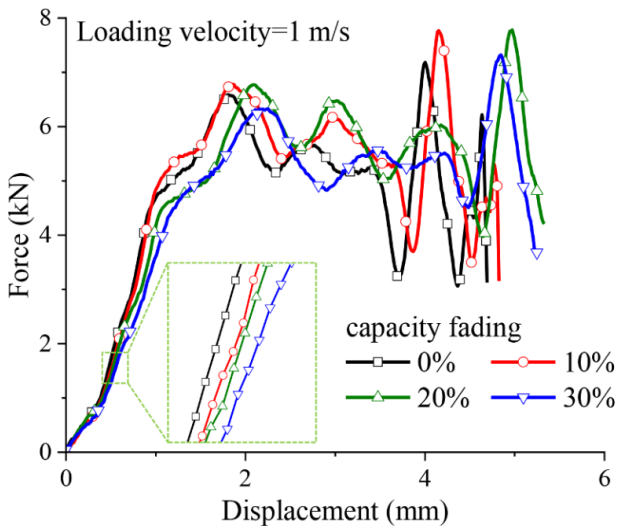
TR evolution processes

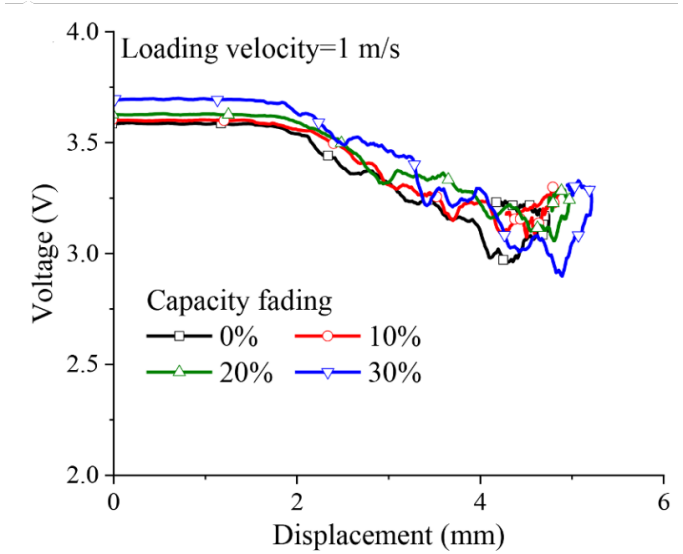


Duan et al., *Energy Storage Materials*, 2022
Feng et al., *J. Power Sources*, 2014

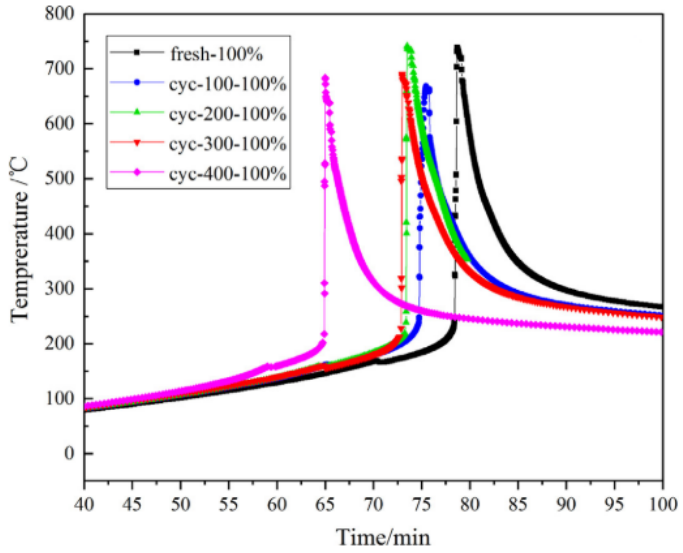
BACKGROUND

Cycle-aging effect on safety behaviors





Aged cell is more dangerous in thermal abuse condition



Aged cells may have some performance degradation caused by, e.g., loss of lithium inventory (LLI) and loss of active material (LAM)

Current research efforts focus on a **single aspect** of the safety risk, which leads to biased conclusions

- Electrochemical integrity
- ISC mode
- TR behavior (triggering and hazards)

Liu et al., *International Journal of Impact Engineering*, 2022
Zhao, et al., *Journal of Energy Storage*, 2020

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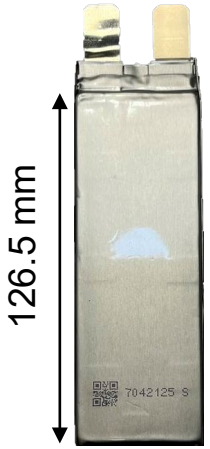
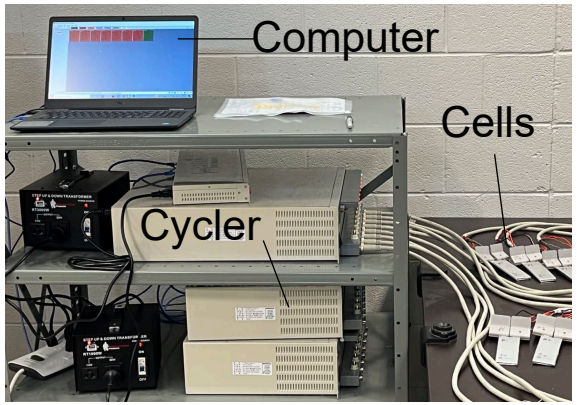
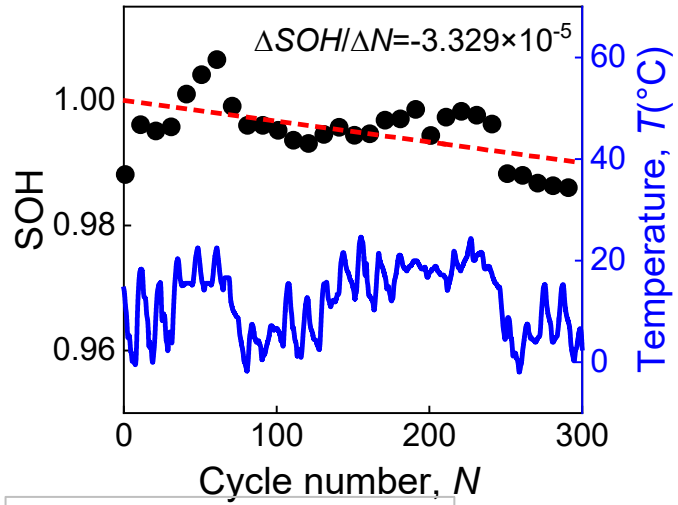
Cycling test



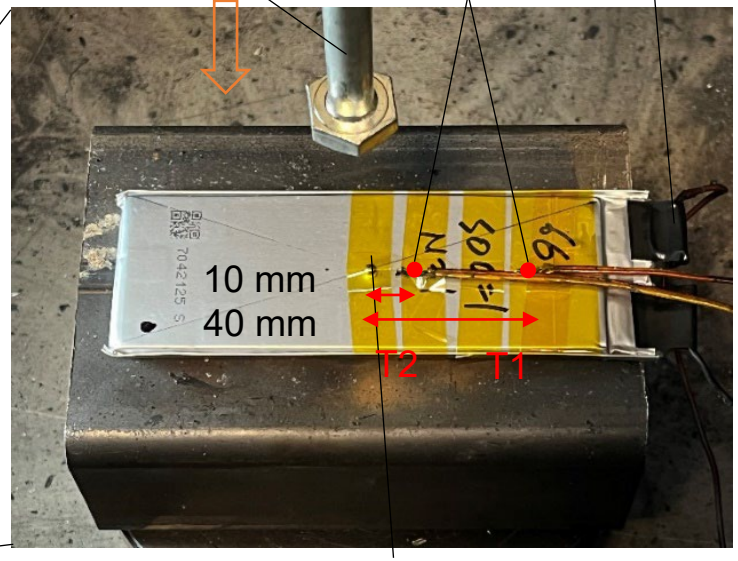


Thickness:
6.1 mm



Jia, et al., *Adv. Energy Mat.*, 2023

Short circuit triggering test



- Pouch cells with NCMA/graphite anode, 3.2 Ah
- Cycle numbers from 1~300 and SoCs from 20% to 100%

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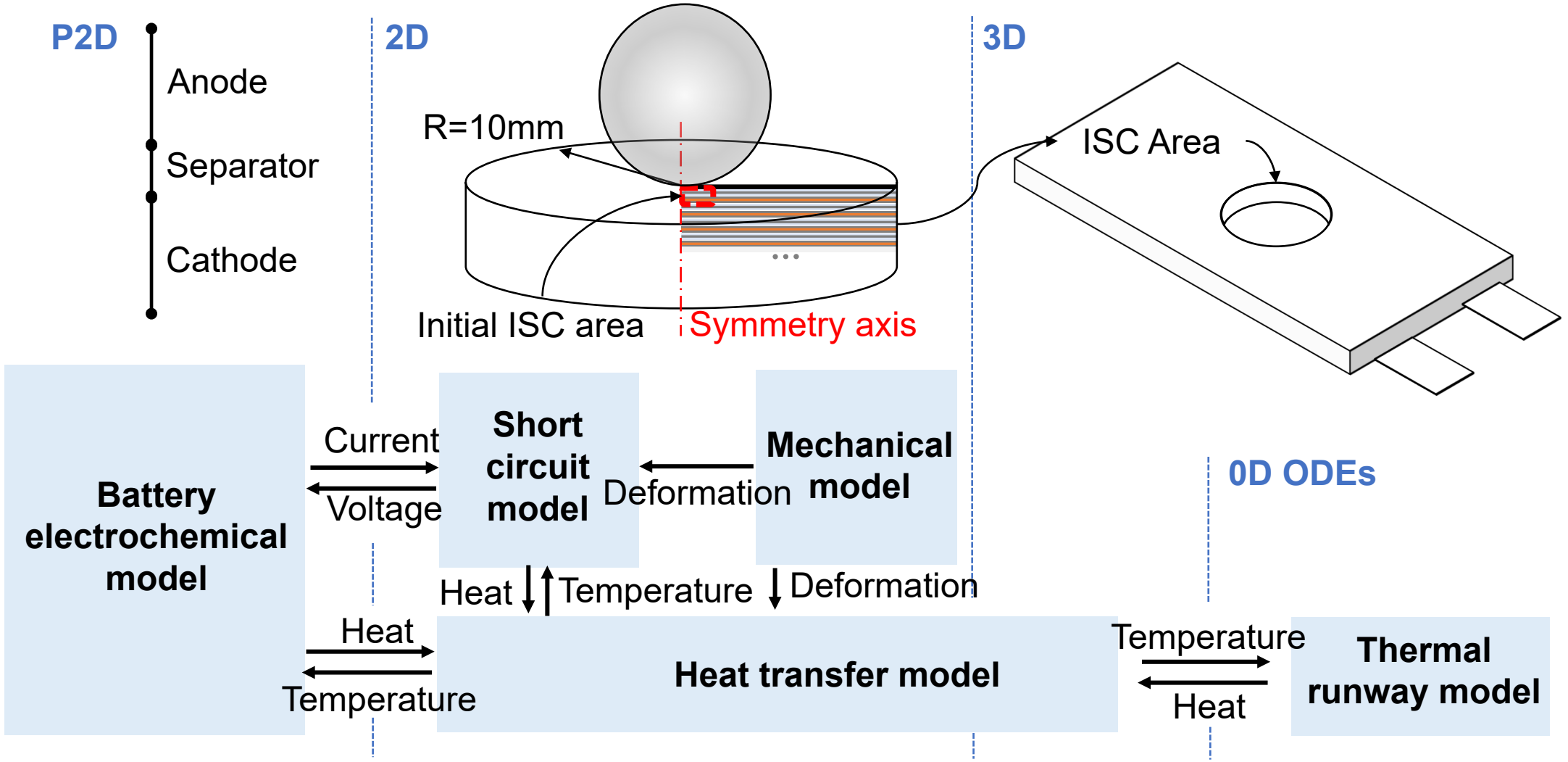
Multiphysics modeling



Jia, et al., *Adv. Energy Mat.*, 2023

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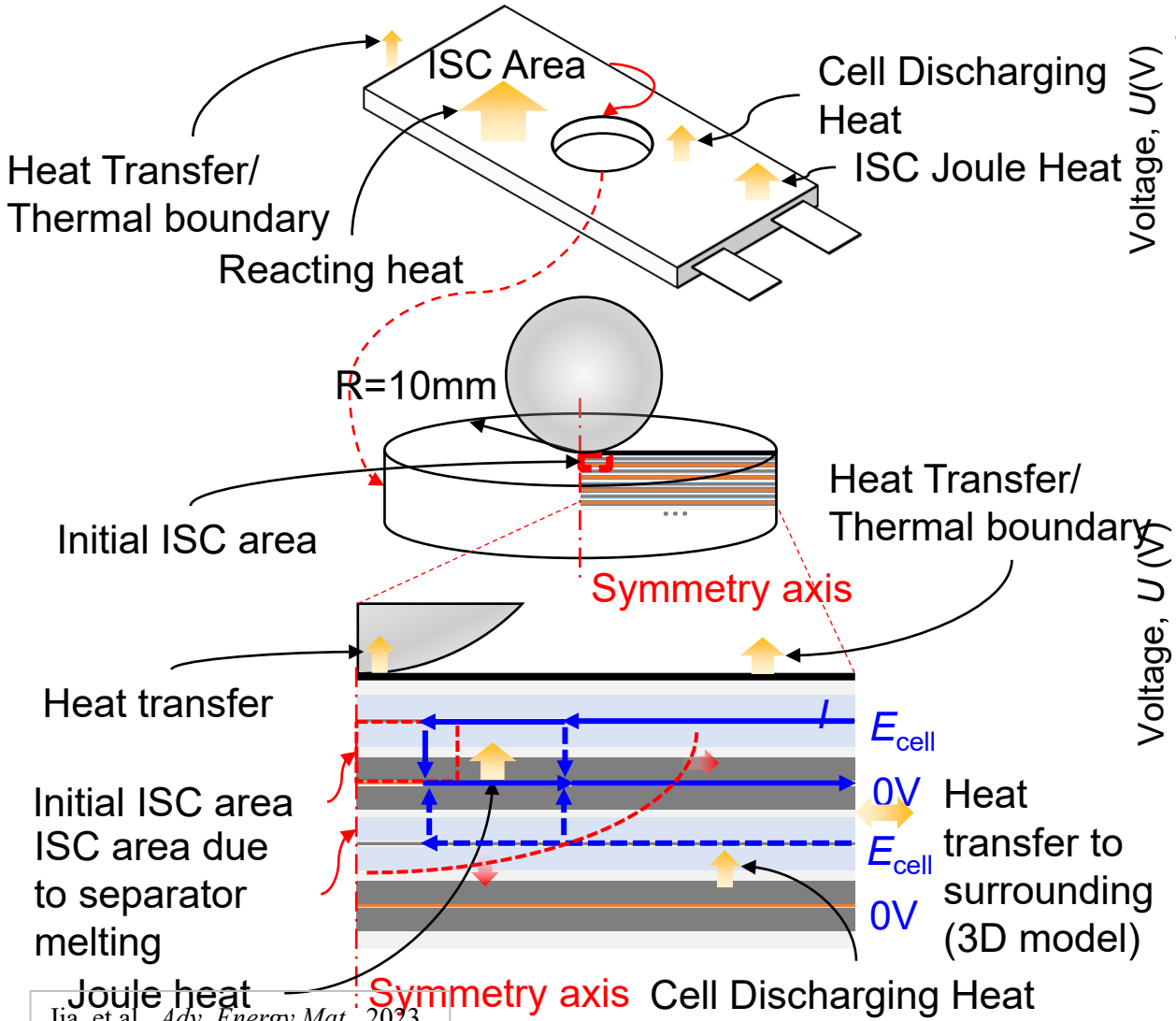
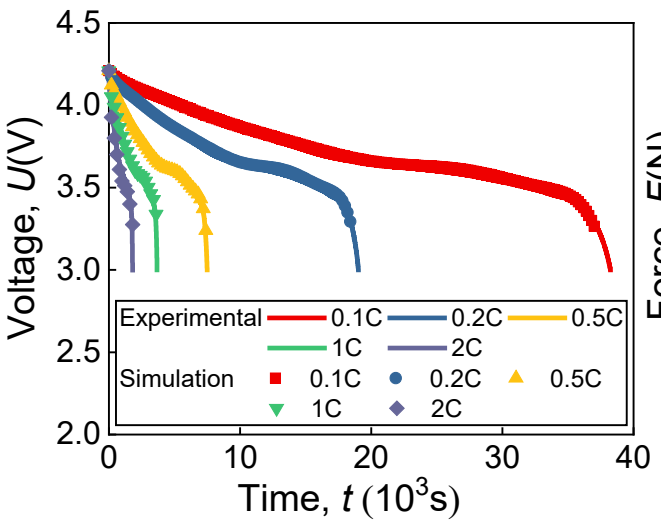
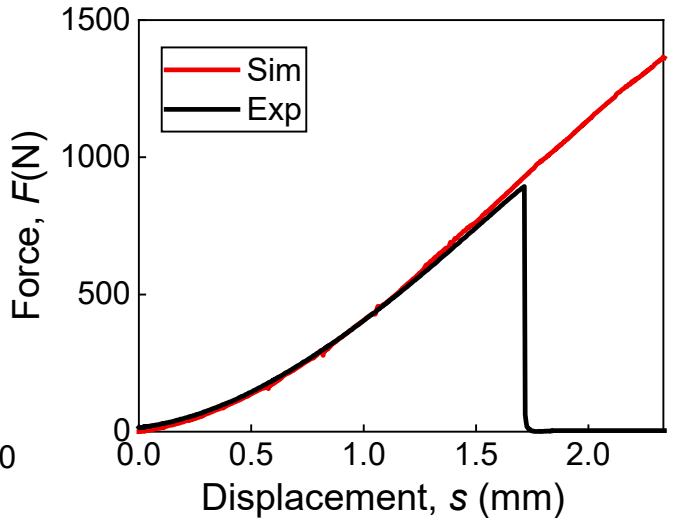
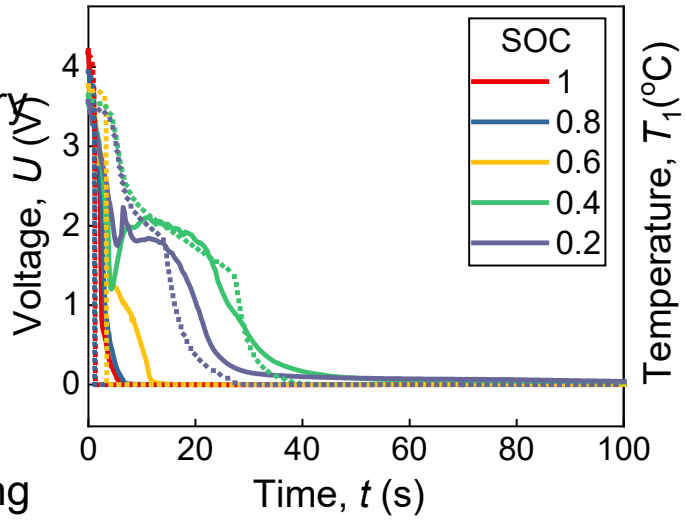
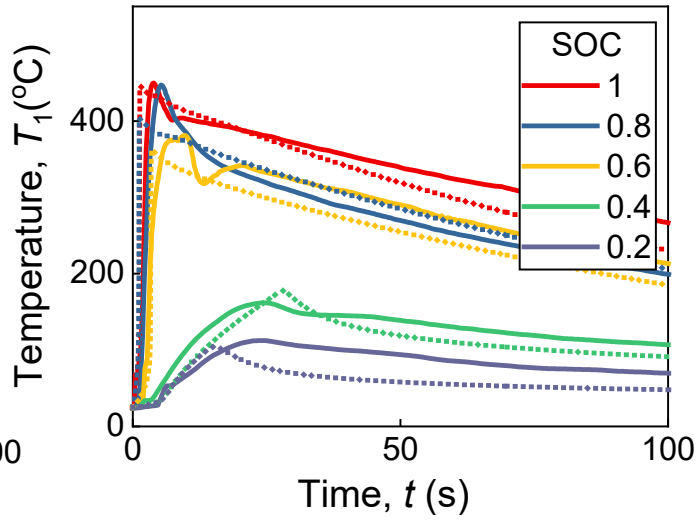
Multiphysics modeling











- The coupled model was validated

Jia, et al., *Adv. Energy Mat.*, 2023

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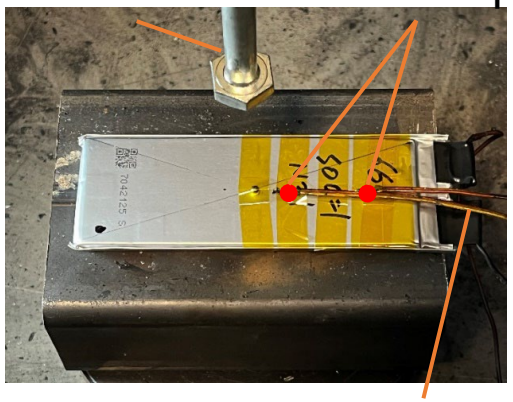
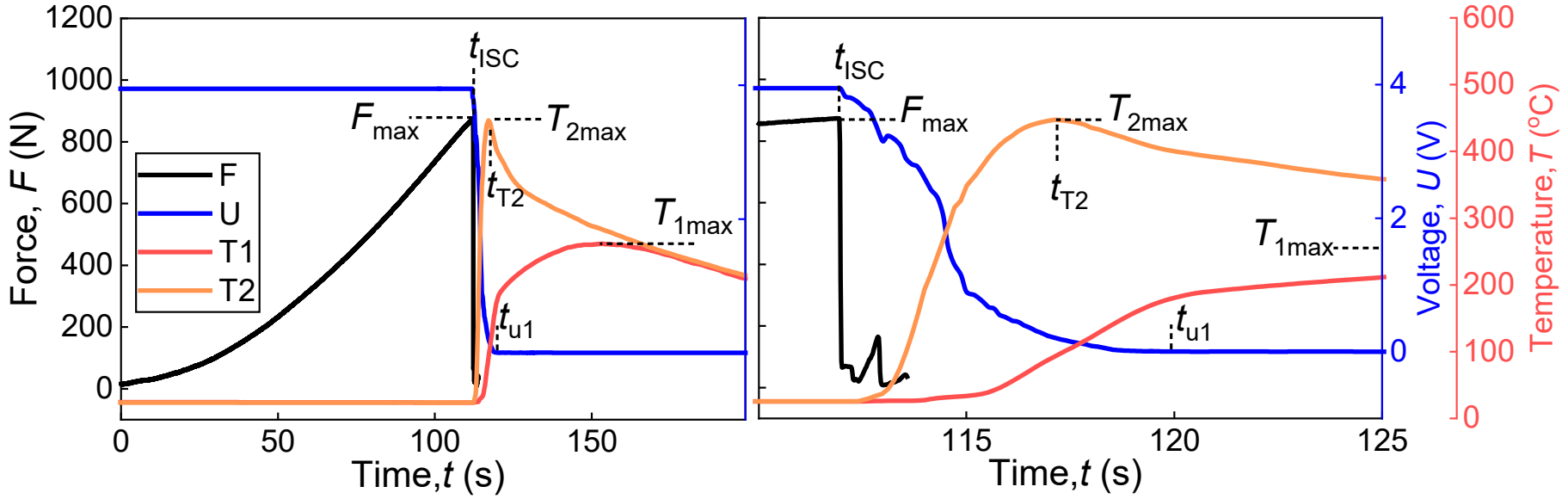
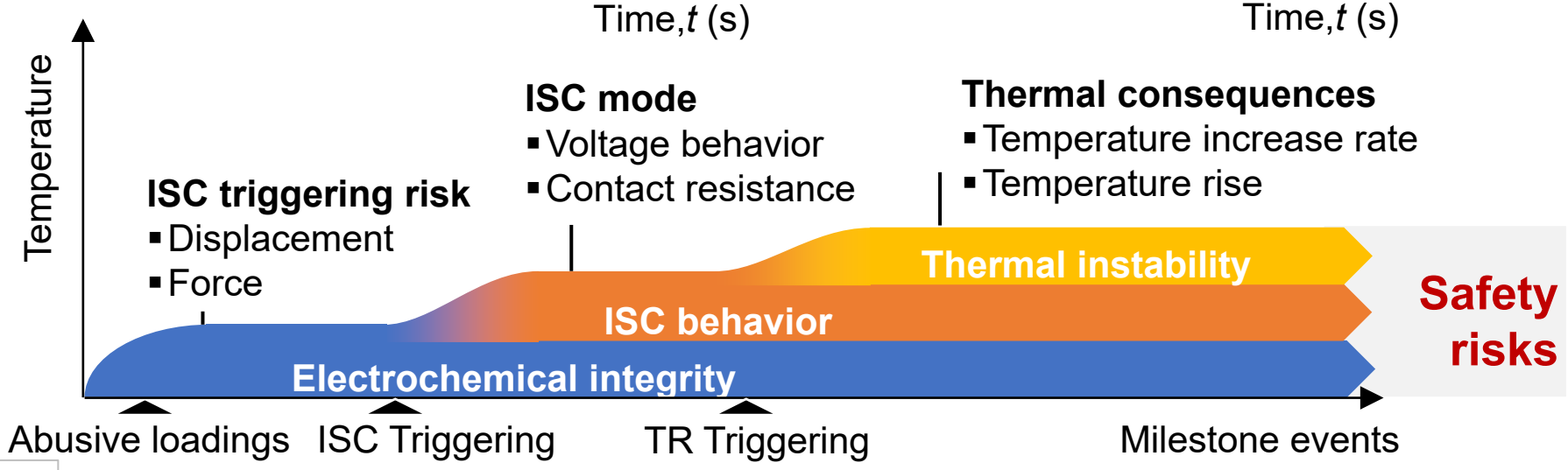
Evaluation methods







Jia, et al., *Adv. Energy Mat.*, 2023

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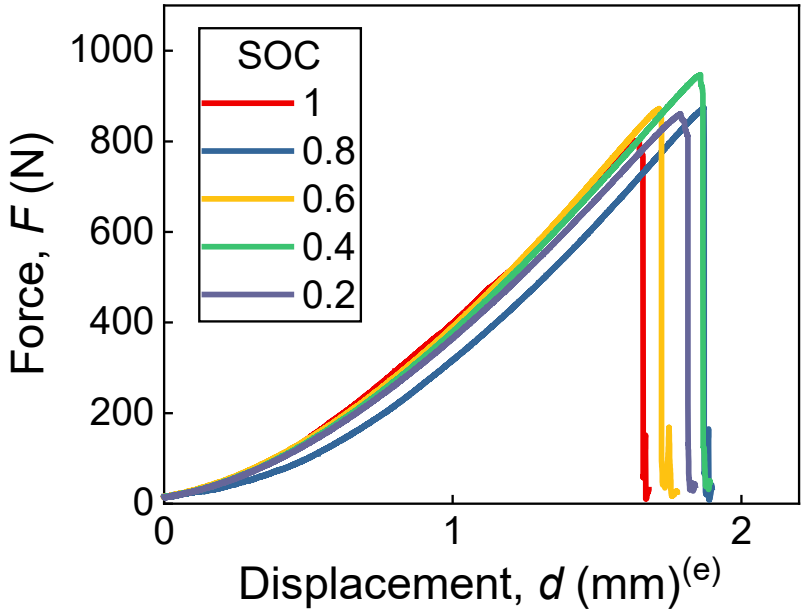
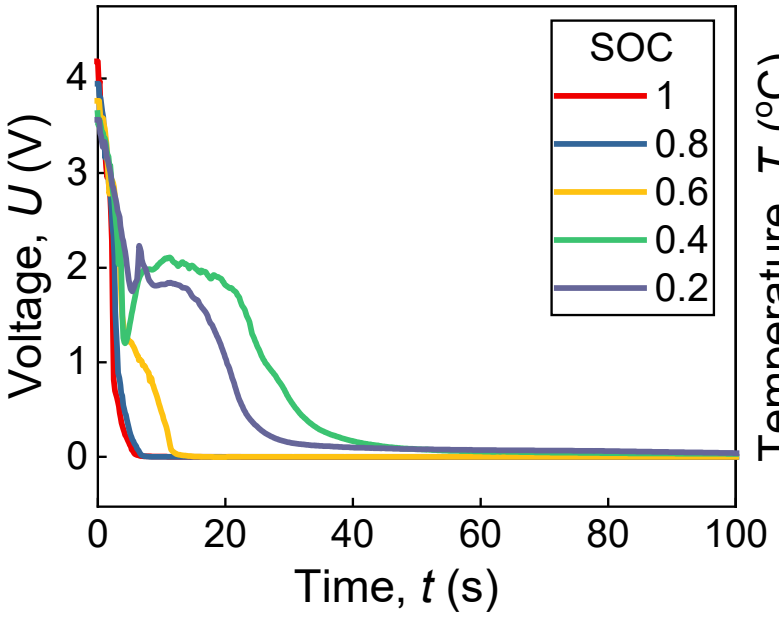
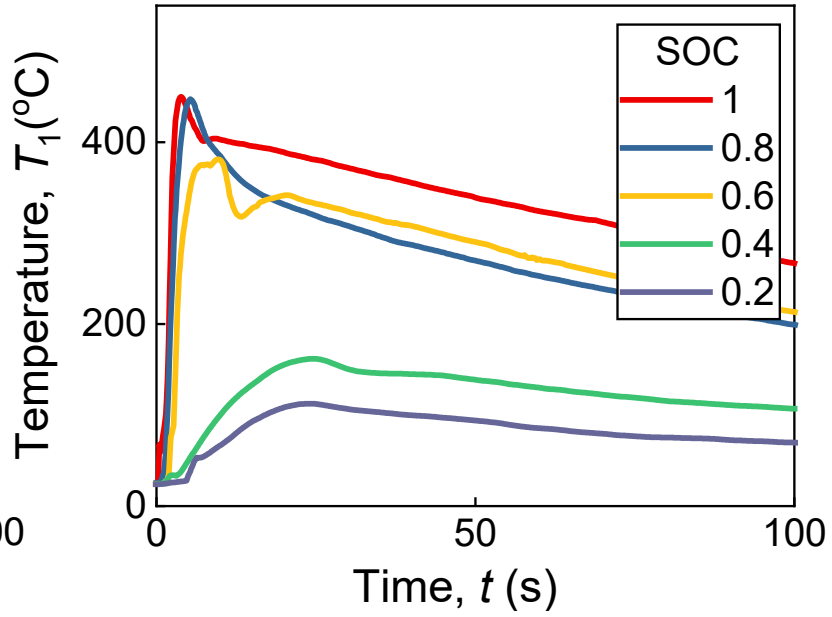
Typical results for different SOCs







- The mechanical performance of the cells has little SoC dependency
- The voltage and temperature responses are highly SOC (initial SOC) dependent

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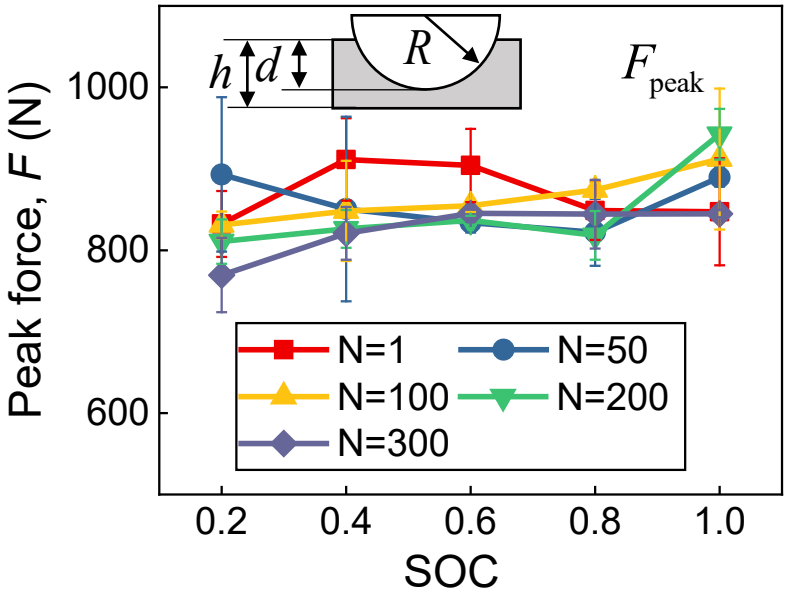
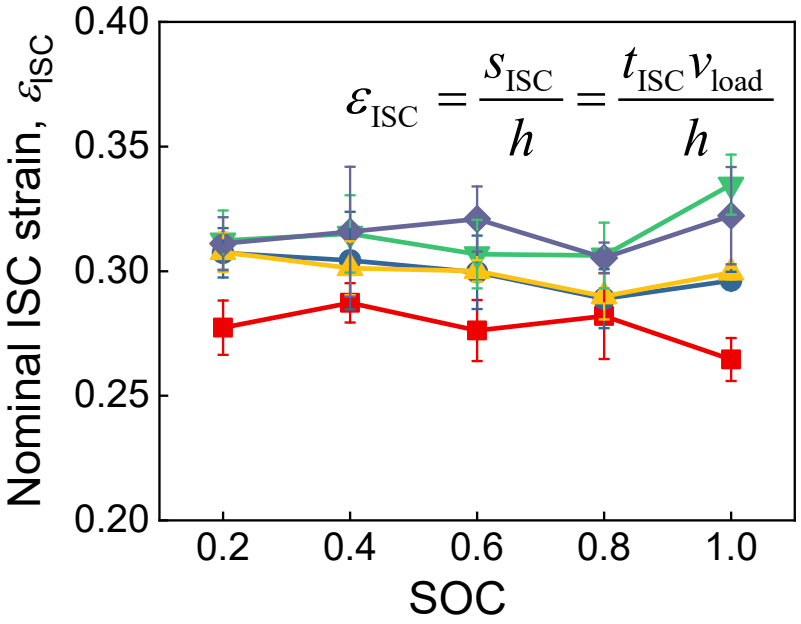
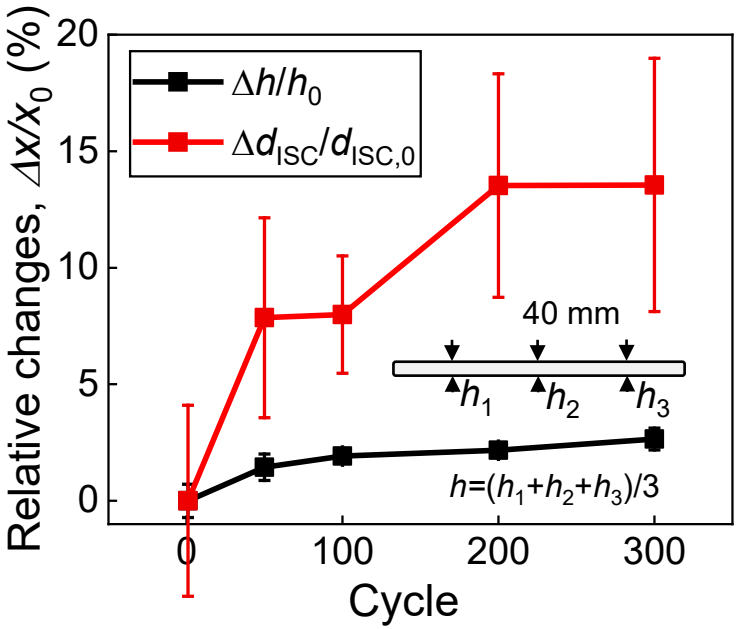
Cycle-aging effects on the mechanical behaviors





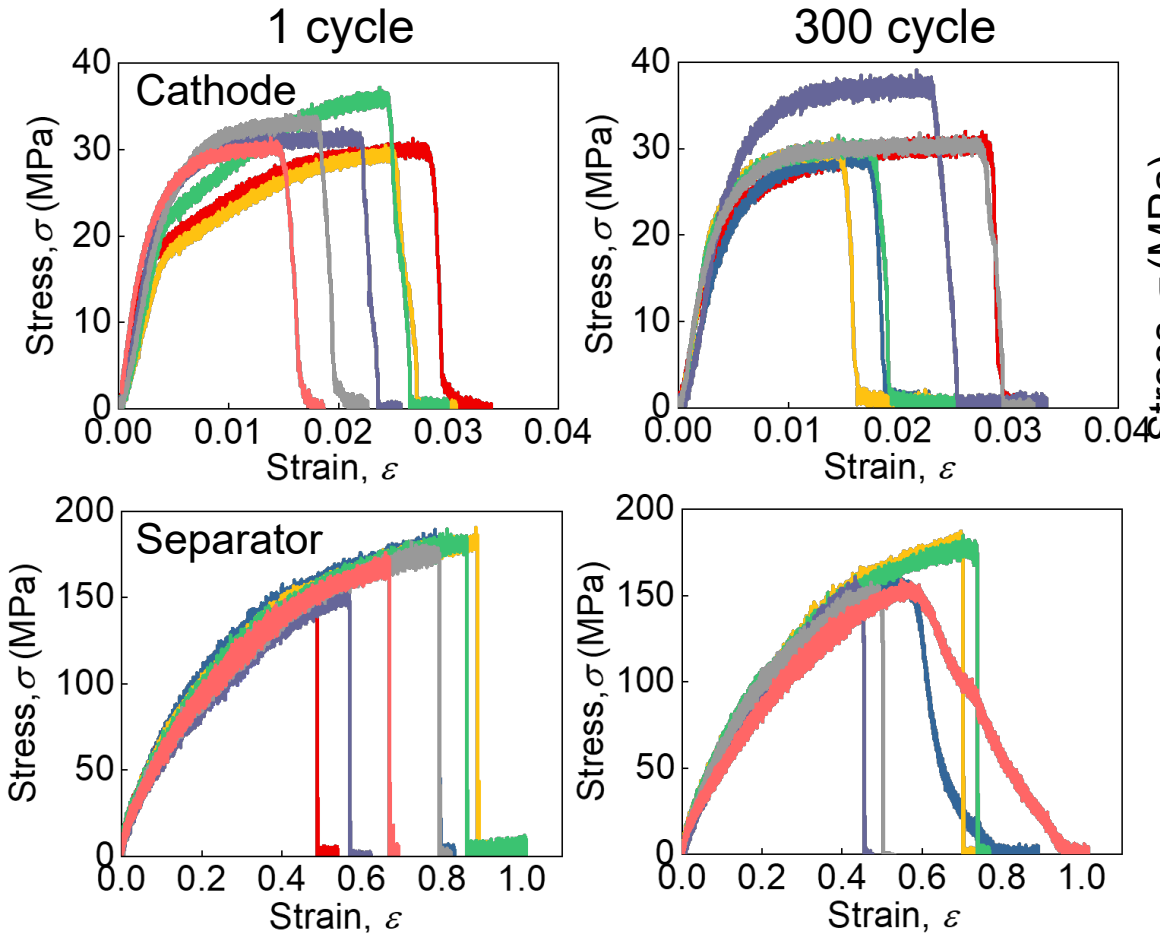


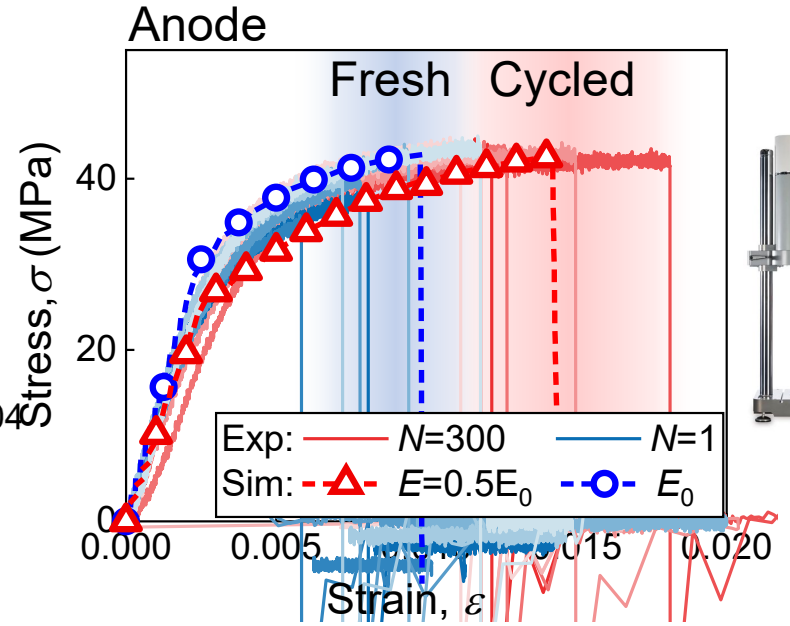
- F_{peak} has no obvious relationship to both the cycle number N and SOC
- Nominal ISC strain is not SOC dependent but positively correlated with N
- The thickness cannot be a responsible reason since the thickness increase will actually decrease ISC displacement

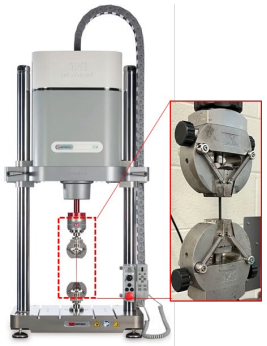
Jia, et al., *Adv. Energy Mat.*, 2023

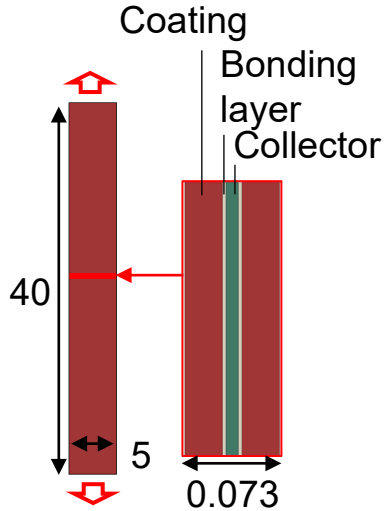
AGED CELLS

Cycle-aging effects on the mechanical behaviors









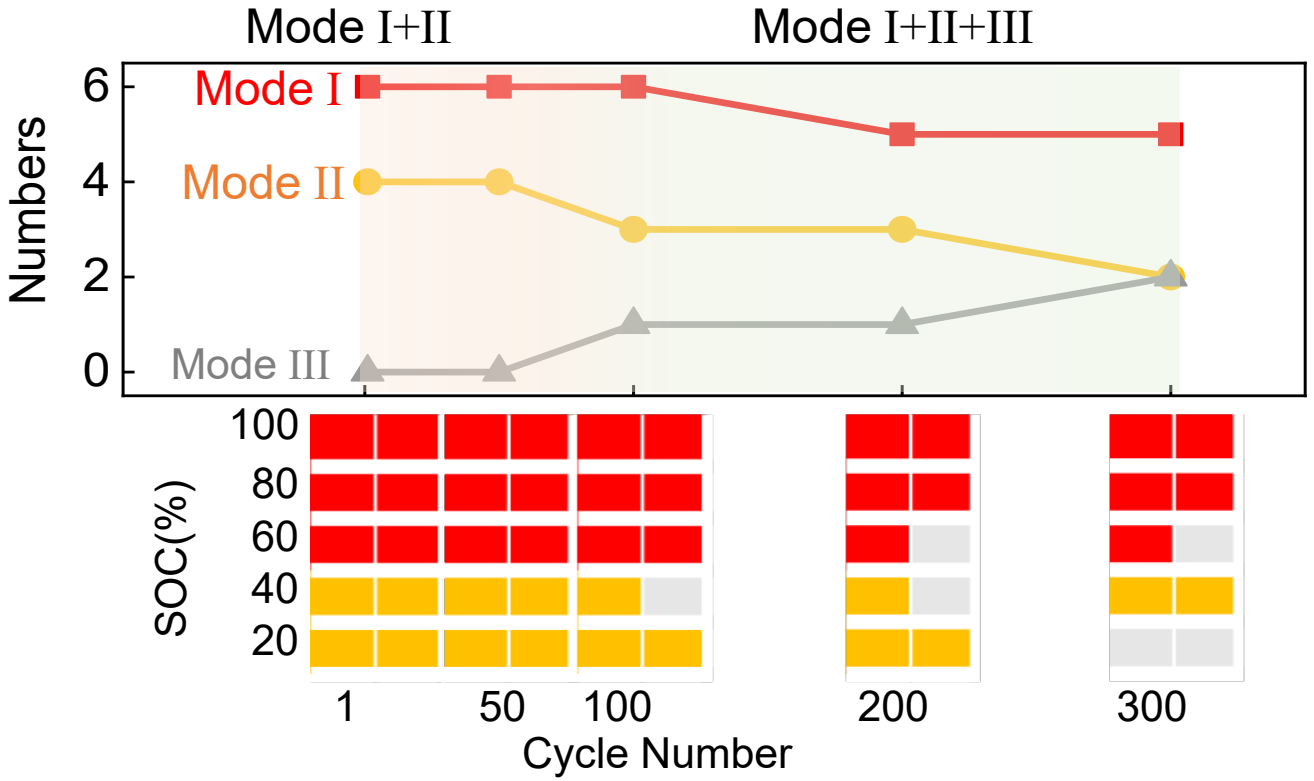
- The mechanical properties of anode and separator change little
- The failure strain of the cathode becomes larger
- Possible reason: Young's modulus of the cathode Al collector decreases due to side reactions [1]

Jia, et al., *Adv. Energy Mat.*, 2023

[1] L. Cong, *Journal of Power Sources* 2018

AGED CELLS

Cycle-aging effects on the ISC modes



Mode I: TR triggered;
Mode II: irrecoverable major ISC and no TR;
Mode III: Voltage recovered with minor ISC
The ISC modes of the aged cells also become milder

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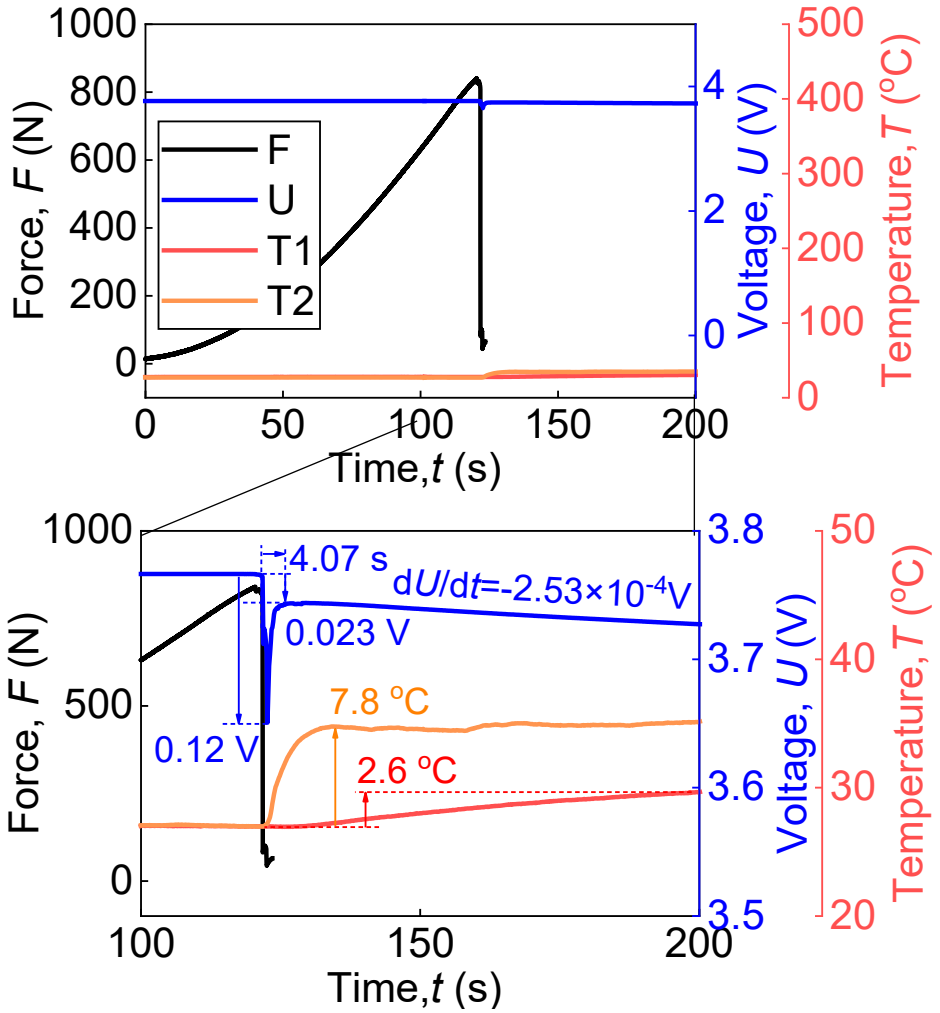
Voltage recovered case, Mode III



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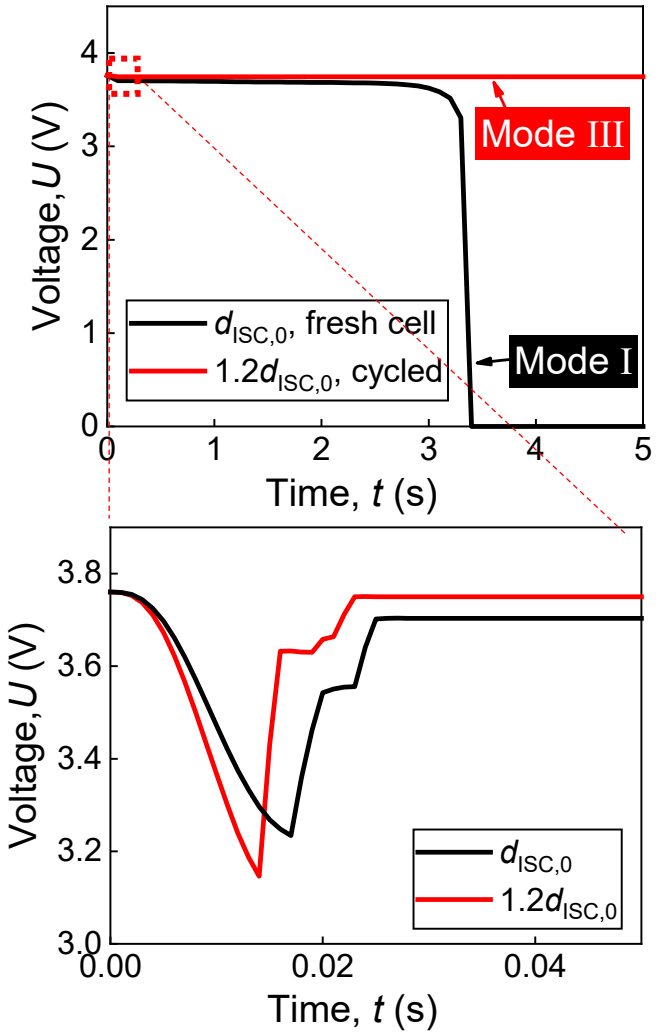
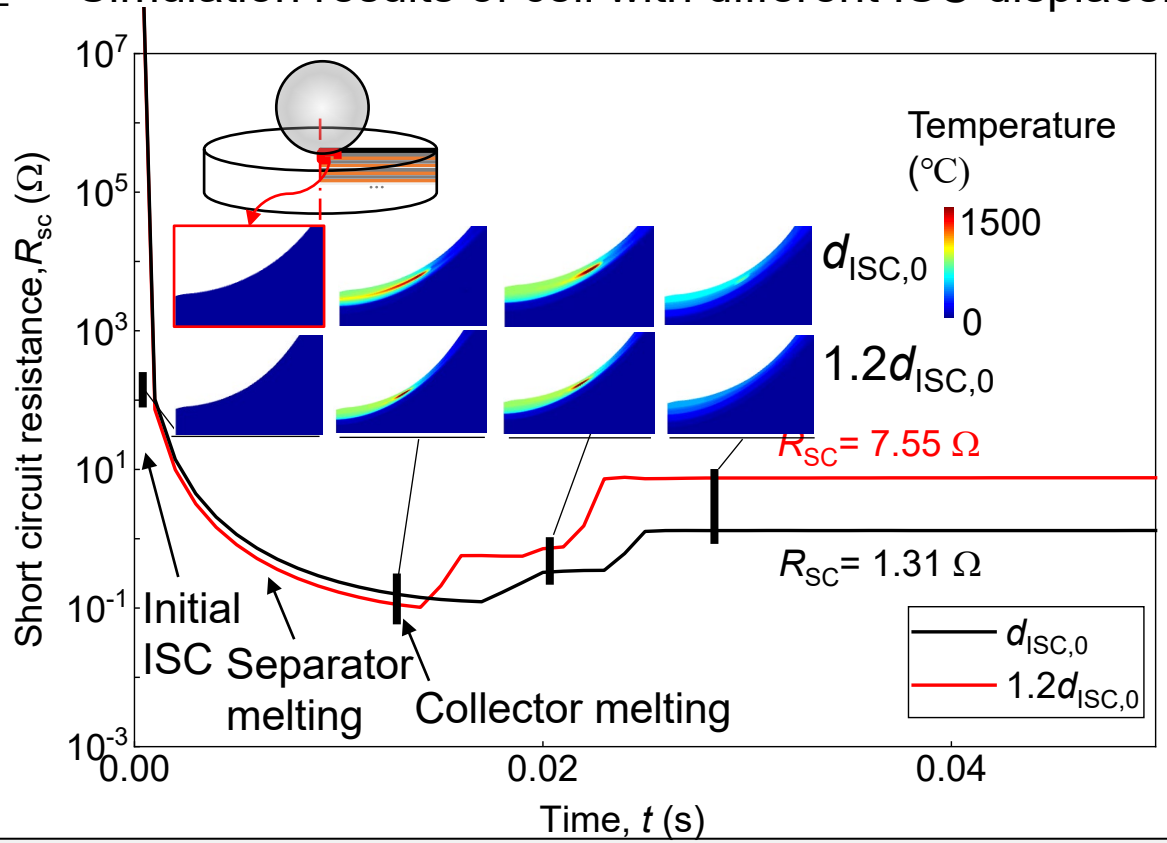
Cycle-aging effects on the ISC modes



Simulation results of cell with different ISC displacement



- Due to the large deformation and small deformed thickness of the layers, R_{isc} of the aged cell is smaller
- If R_{isc} is large enough, the propagation of ISC cannot be maintained

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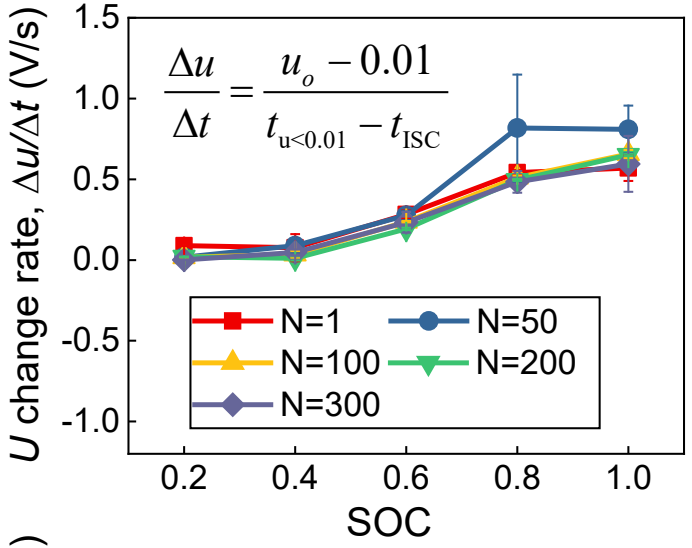
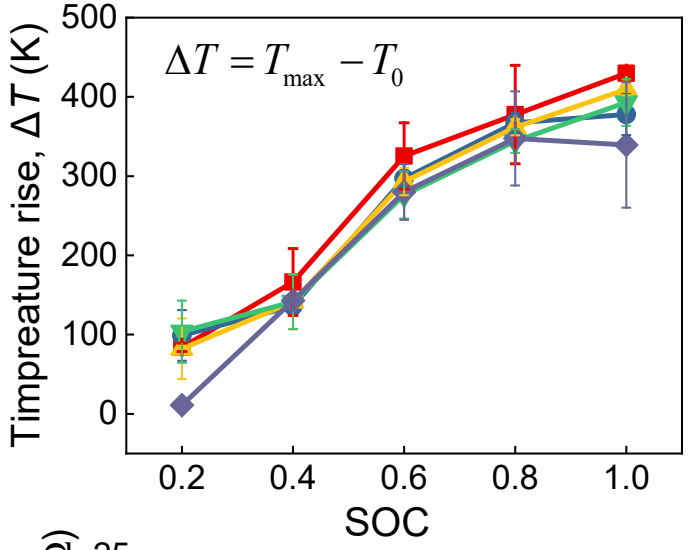
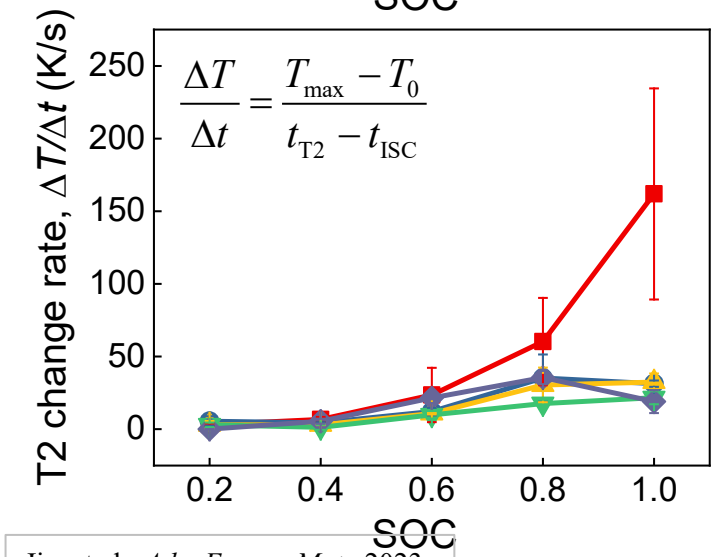
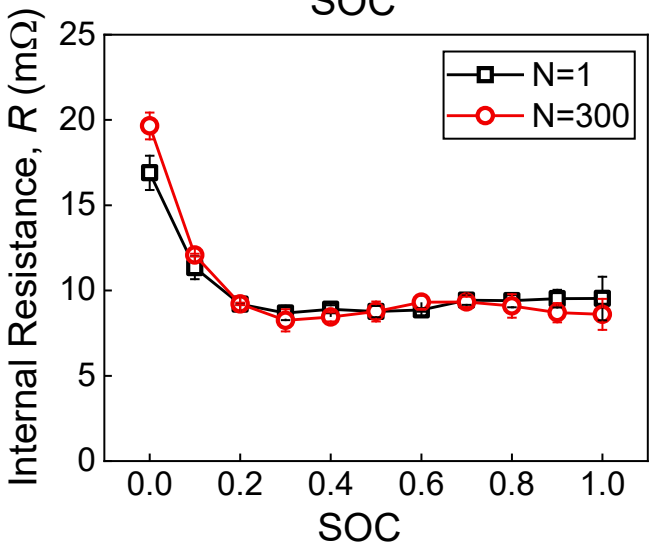
AGED CELLS

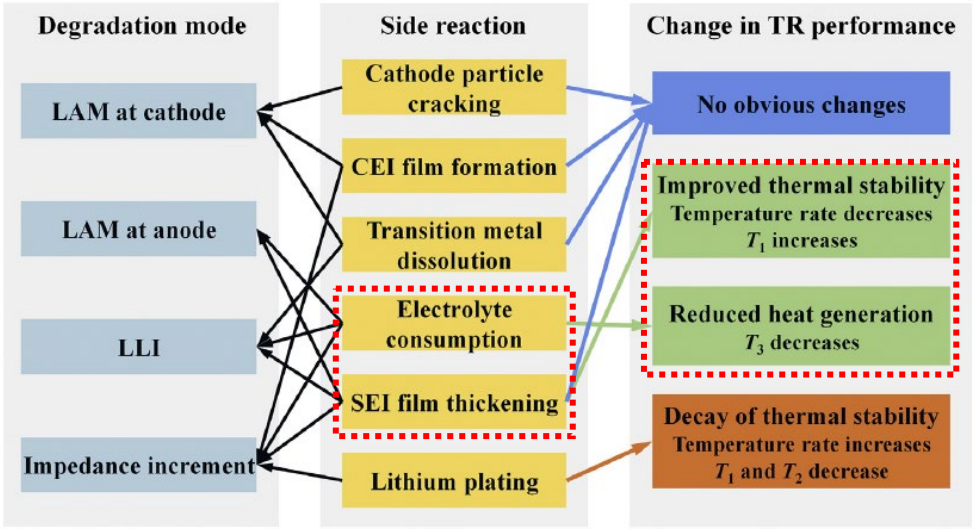
Cycle-aging effects on the subsequent thermal behaviors











- The temperature rise and temperature increasing rate decrease
- Reasons: electrolyte consumption and solid electrolyte interphase (SEI) film thickening [2, 3]

Jia, et al., *Adv. Energy Mat.*, 2023

[2] D. Ren, *eTransportation*, 2019
[3] X. Feng, *Appl. Energy*, 2019

CONCLUDING REMARKS

The safety risks were quantitively evaluated from three aspects: **ISC triggering risk, ISC modes**, and the **subsequent thermal behaviors:**

- **The triggering risks are lower** (pouch cells) **:** the increased nominal ISC triggering strain
- **The ISC modes become milder** (pouch cells) **:** the voltage recovery occurs more frequently in medium SoC cells.
- **Subsequent thermal behaviors are also safer** (pouch cells) **:** the decreased temperature change rate and the decreased maximum temperature rise.

Upon mechanical abusive loading, the overall safety for aged cells are slighter better vs. fresh cells

Jia, et al., *Adv. Energy Mat.*, 2023

THANK

Contact: **Prof. Jun Xu**
Email: jun.xu@uncc.edu