Effects of Pressure Distribution Within Battery Cells

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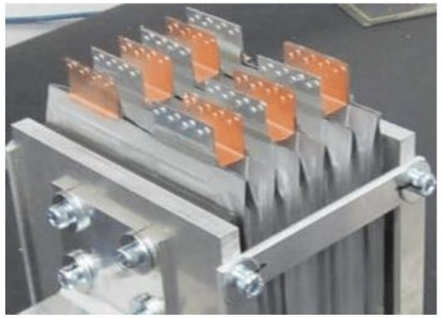
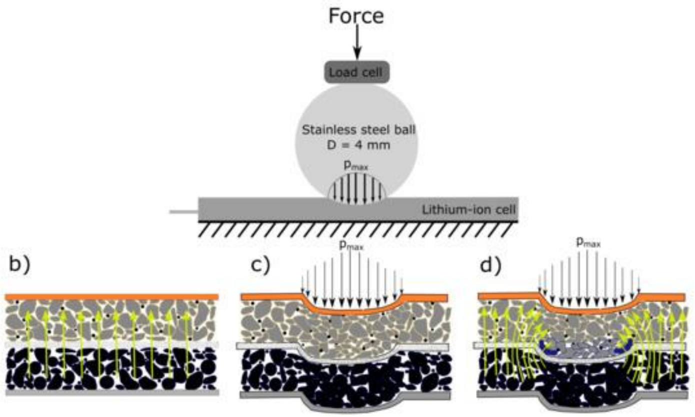
Background and context

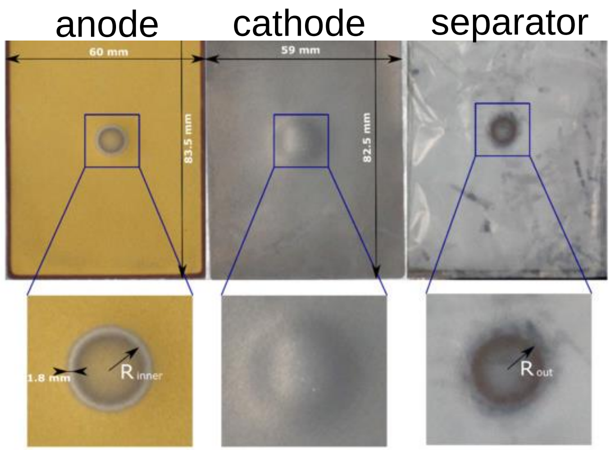
- Batteries require multiple cells configured electrically and *mechanically* prior to deployment for an intended application



A. Das, D. Li, D. Williams, D. Greenwood *World Electr. Veh. J.* **2018**, *9*(2), 22

- Studies recognize the influence of local pressures on cell performance and electrochemical degradation:



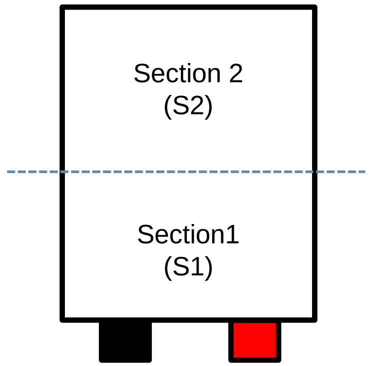


Fuchs, G.; Willenberg, L.; Ringbeck, F.; Sauer, D.U. *Sustainability* **2019**, *11*, 6738

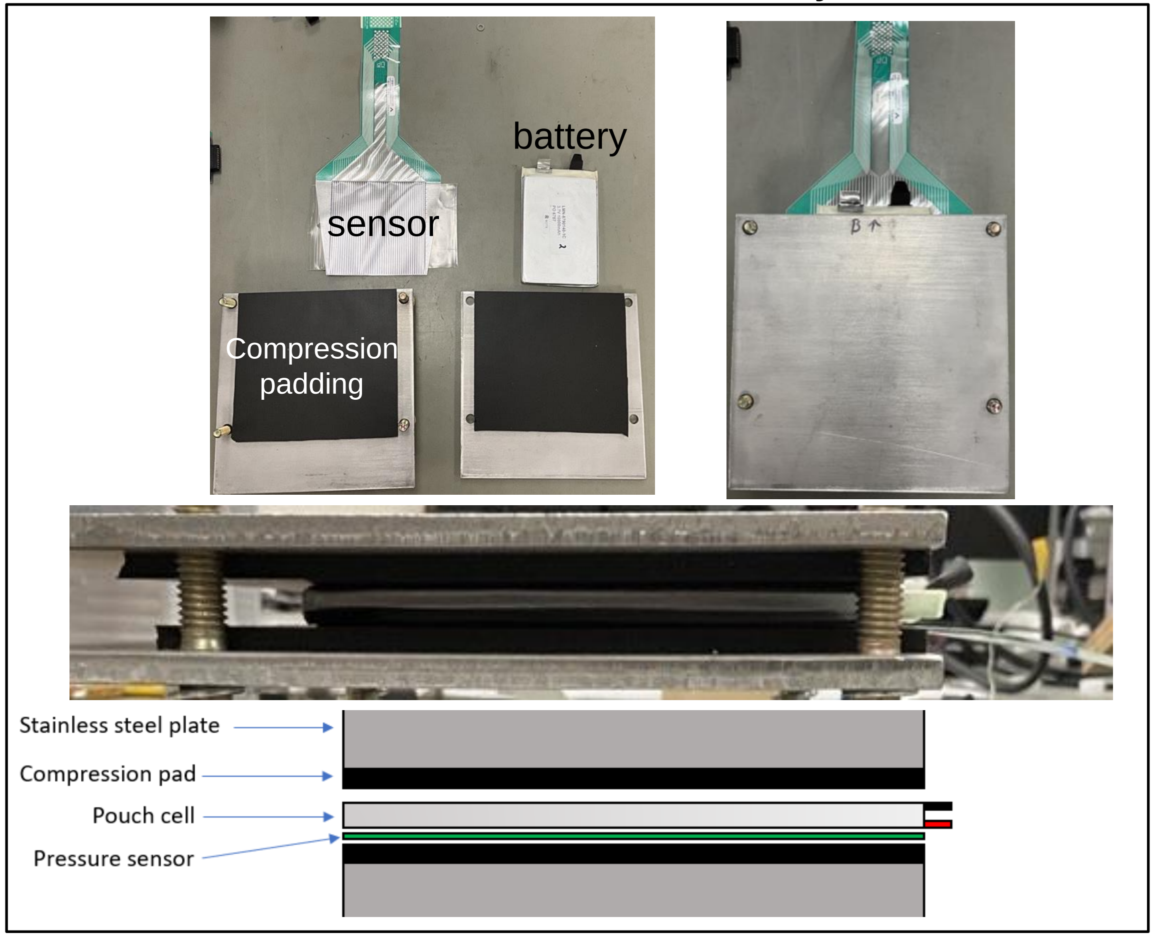
We seek to understand the impact of pressure distribution on the cycling behavior of cells

Materials and methods

1. Measurements collected at 20°C
2. Cell and cycling details:
    - NMC|graphite pouch cell, 10 Ah
        - Dimensions(LxWxH) 141.2mm x 91mm x 9.2mm
    - Two cells for each test condition:
        - C/2 cc + C/20 CV charge→4.2 V; C/2 cc discharge→2.75 V
3. Tekscan sensor, model 5101
    - Spatial resolution: 6.25 mm^2
4. Compression fixture: metallic plates and polyurethane foam to enclose cells under the following conditions:
    a) Homogeneous compression
    b) Heterogeneous compression:
        i. Close to current-collecting tabs (S1)
        ii. Distanced from current-collecting tabs (S2)

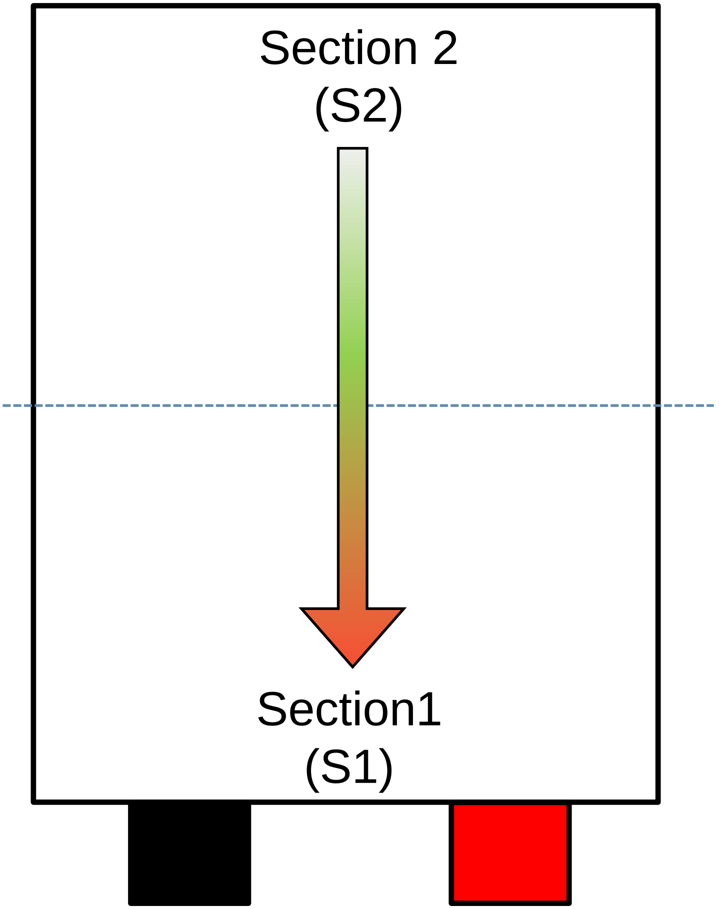


Measurement Assembly

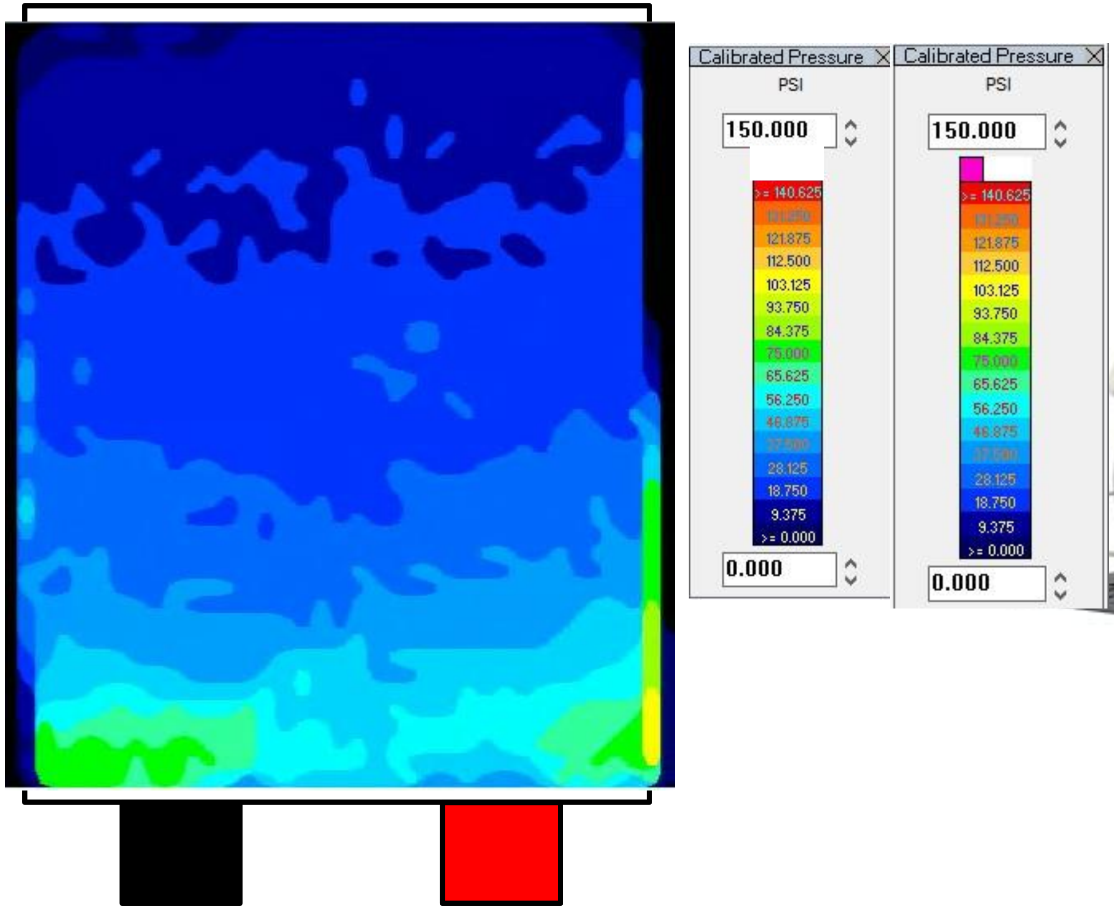


Mapping

Example: Pressure gradient S1>S2; cell 1



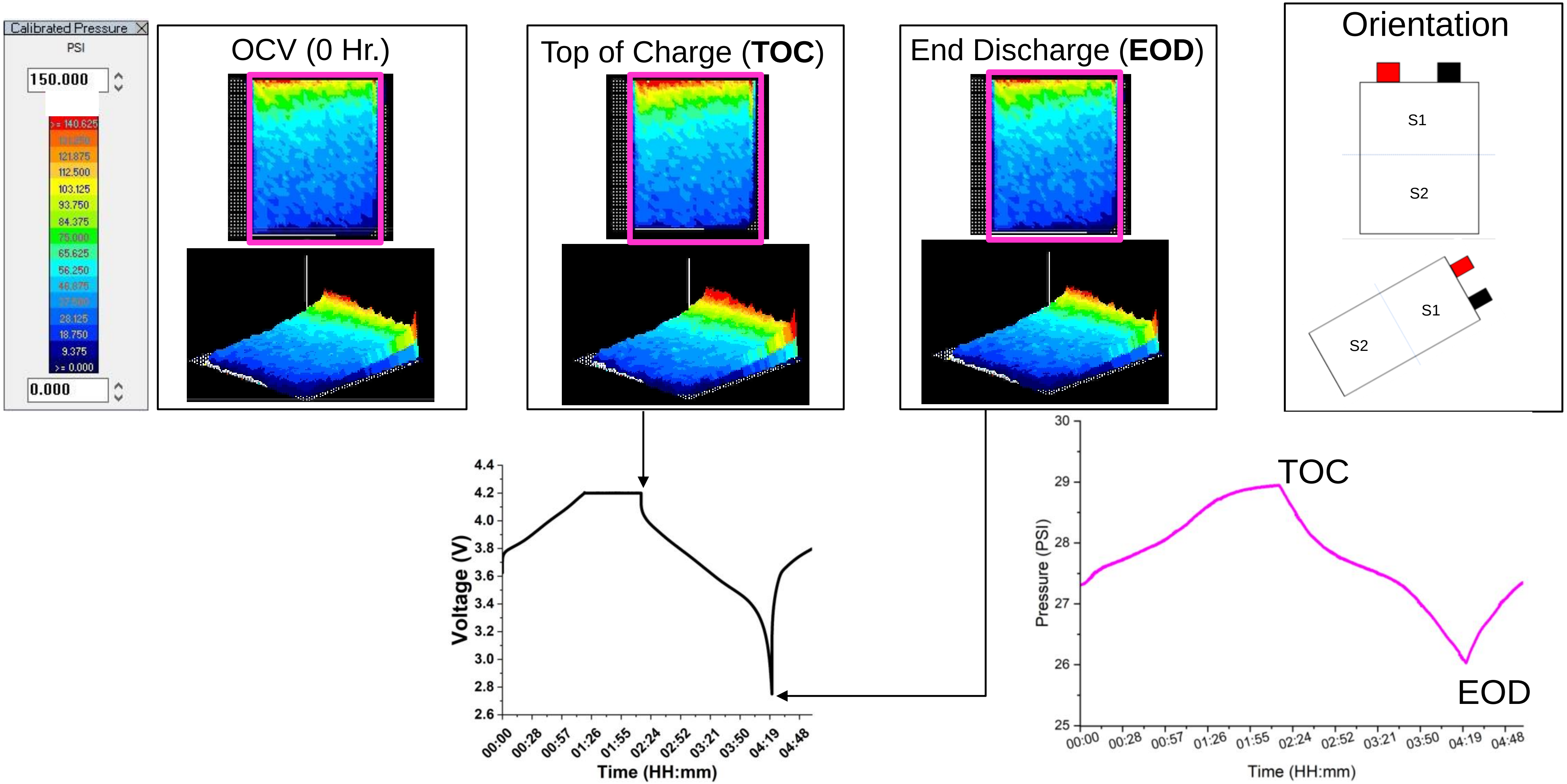
Tekscan© Mapping Interface



Pressure ranges across cell from 10 – 75 PSI

Real-time measurements

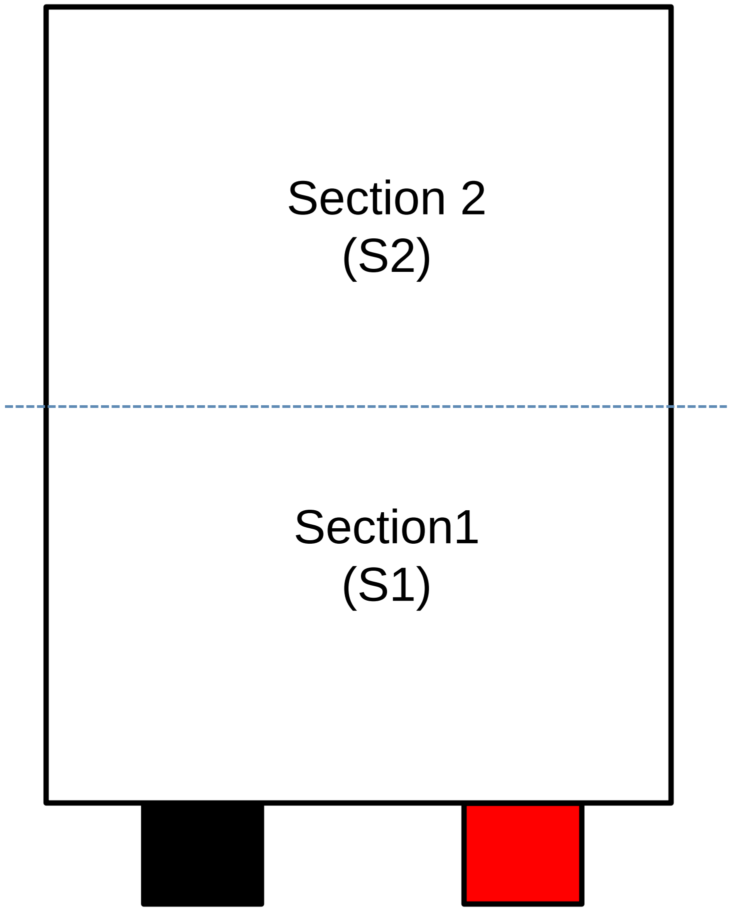
Example: Pressure gradient S1>S2



Top of charge and end of discharge correlate with the maximum and minimum pressures within the cell

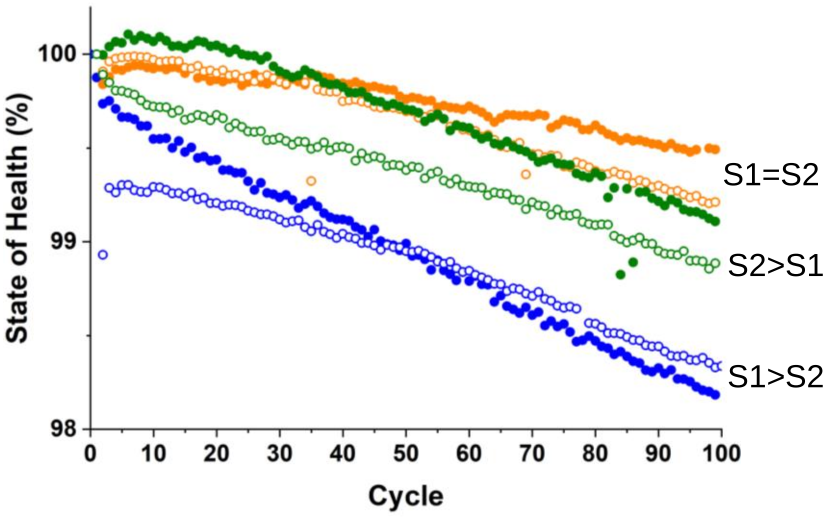
Trends in electrochemical performance

Influence of applied pressure on cycling behavior



Homogeneous compression
- S1= S2

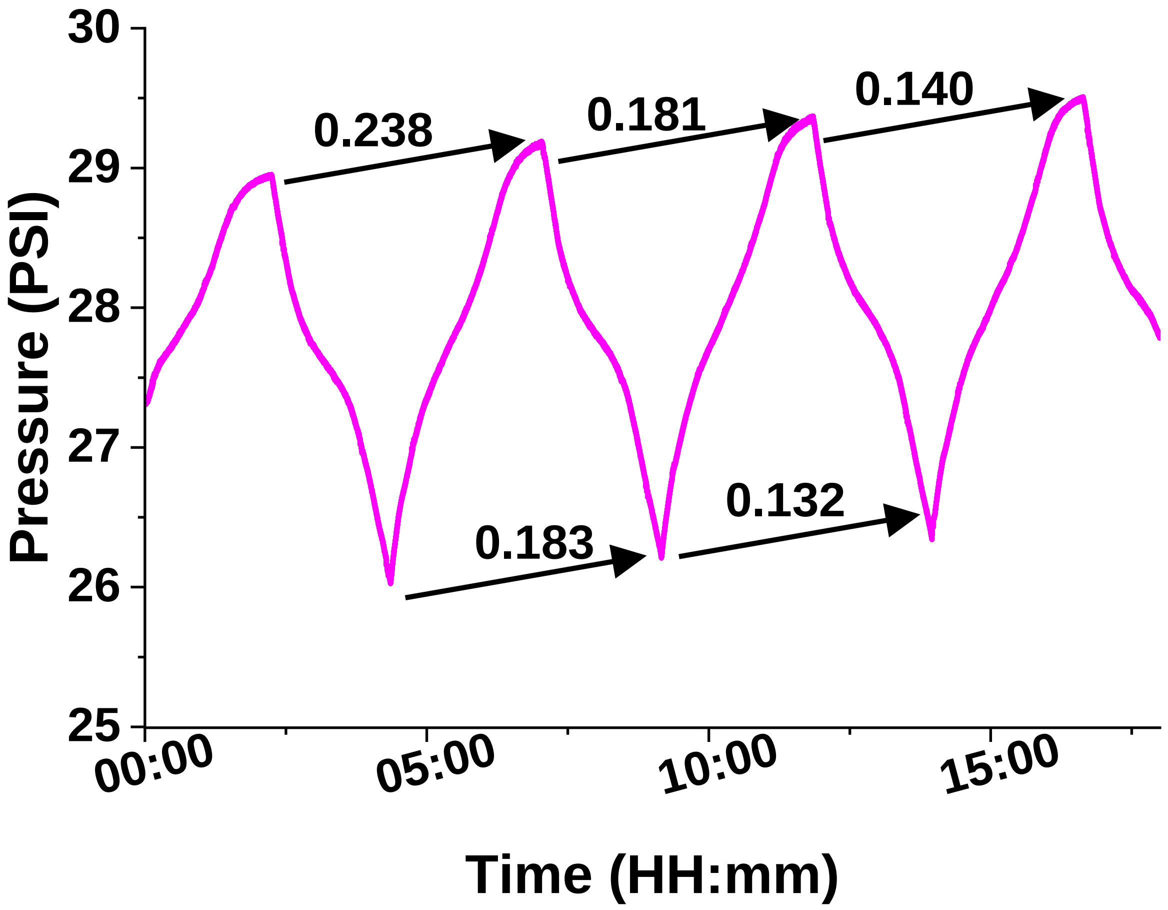
Heterogeneous compression
- S2>S1
- S1>S2

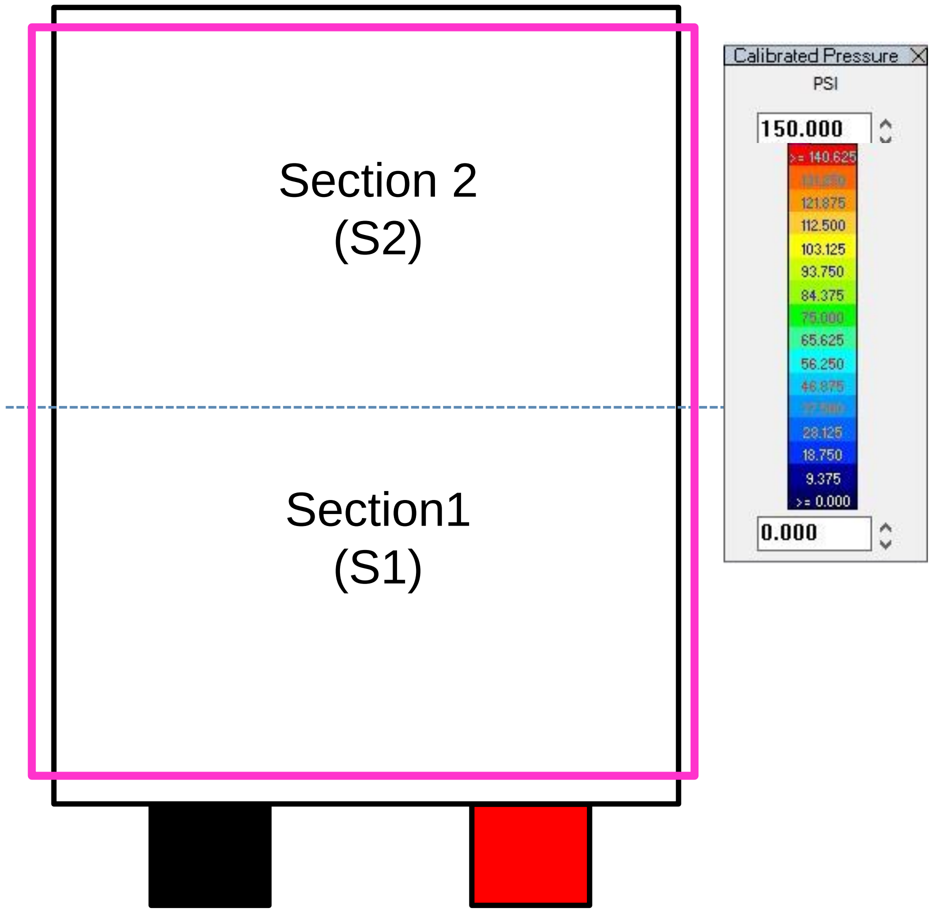


Cells *without* pressure gradient maintain higher SoH than cells with pressure gradients

Pressure evolution as a function of cycling

Example: S1>S2

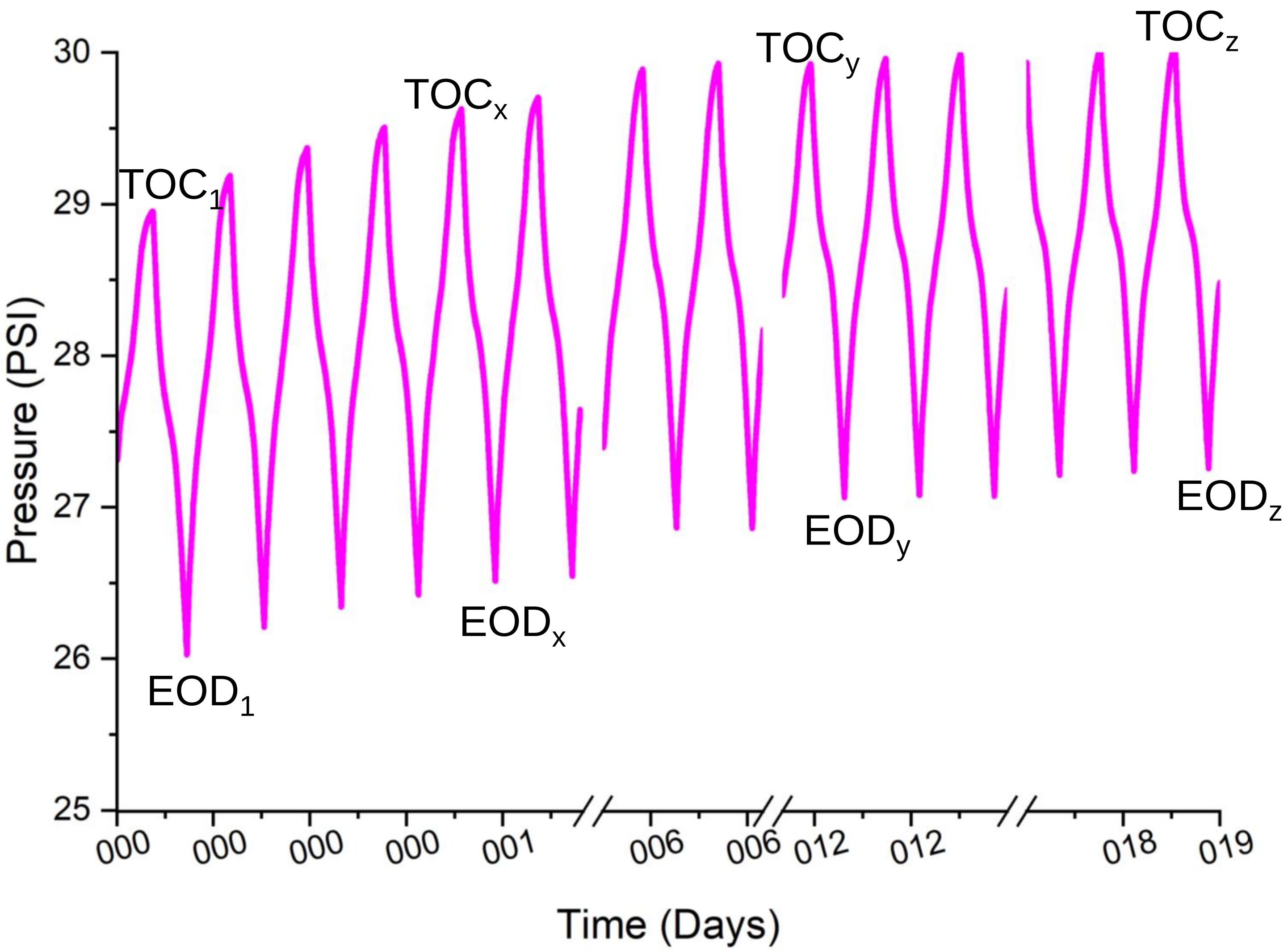


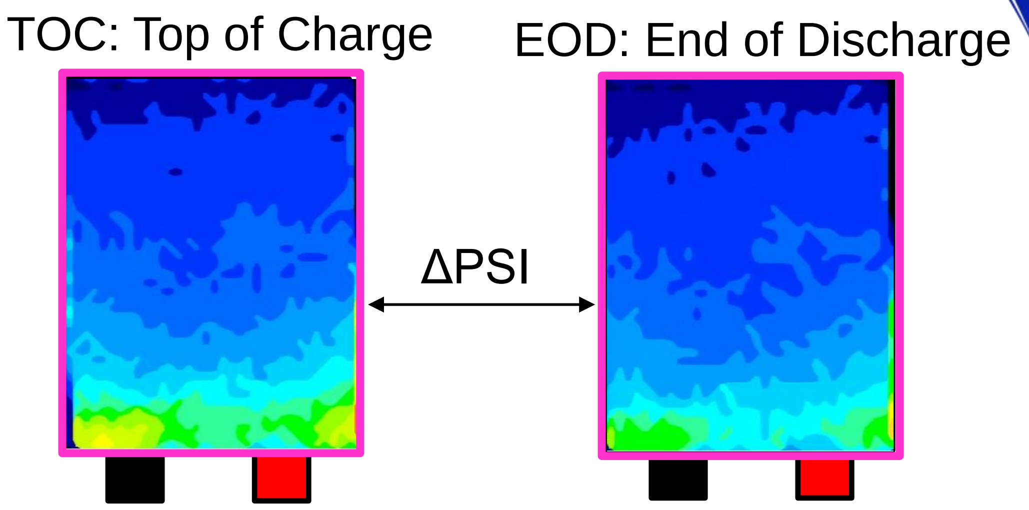


Pressure irreversibly builds within cell while cycling

Mapping changes in pressure across cells

Pressure gradient S1>S2





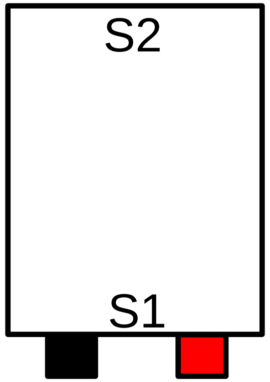
Two ways of mapping pressure:

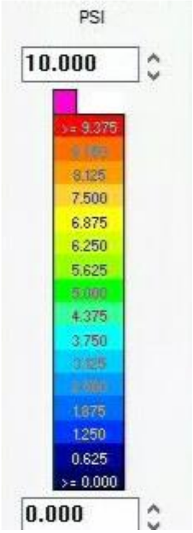
1) Within the same cycle:
   - ΔPSI $EOD_{cycle \#}$ → $TOC_{cycle \#}$
2) Between cycles:
   - ΔPSI TOC_1 → $TOC_{x/y/z}$
   - ΔPSI EOD_1 → $EOD_{x/y/z}$

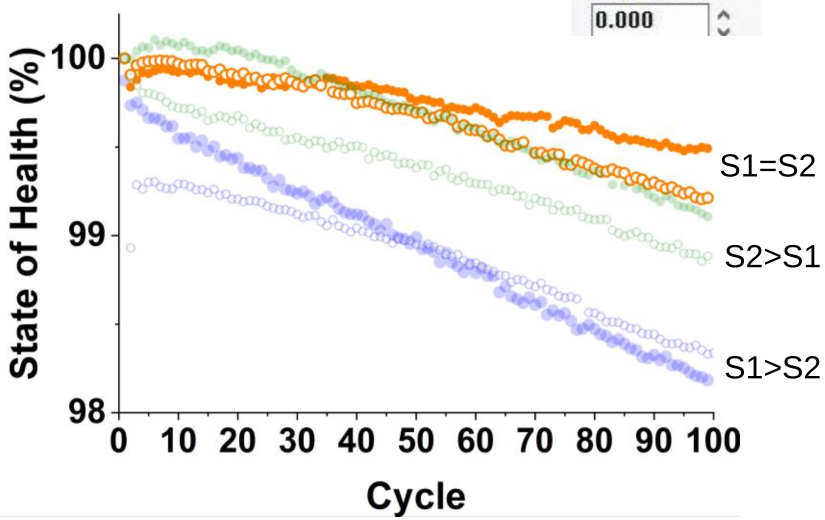
Distribution of pressures across cells can be visualized using maps at specific reference points

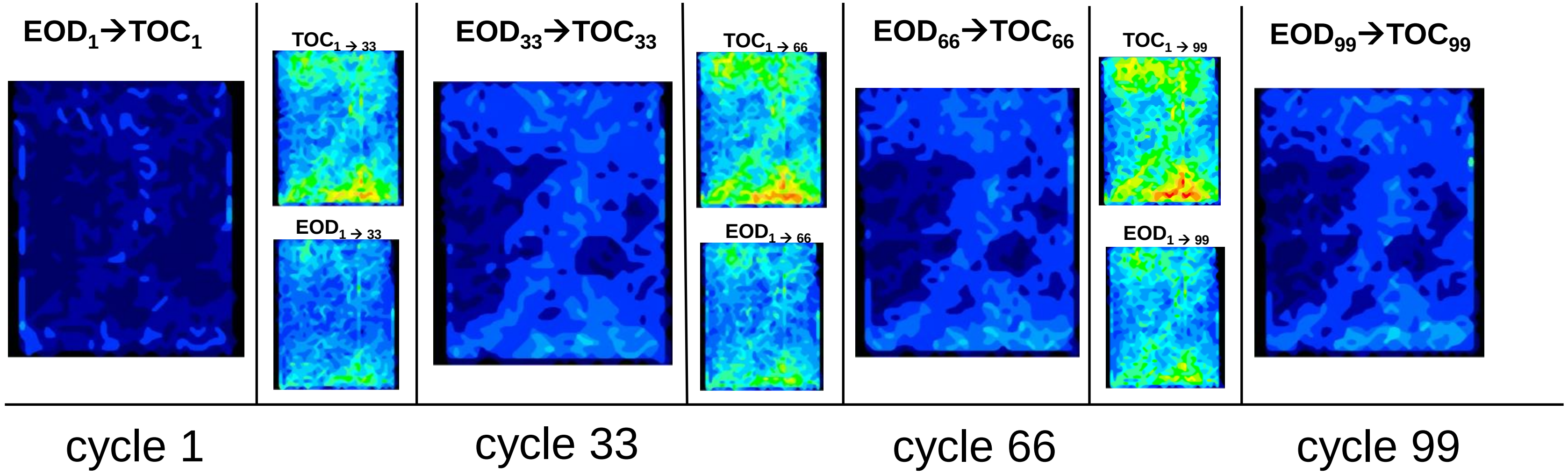
Visualizing Pressure Changes (ΔPSI) During Cycling

Homogeneous pressure (S1=S2)





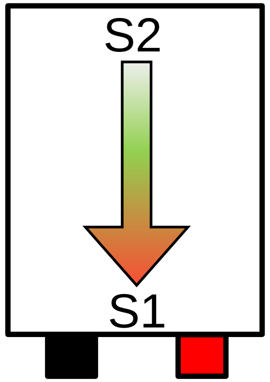


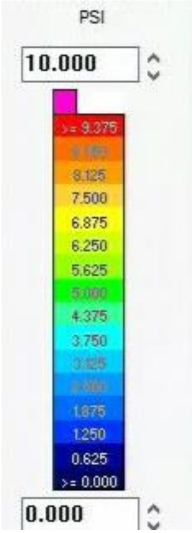


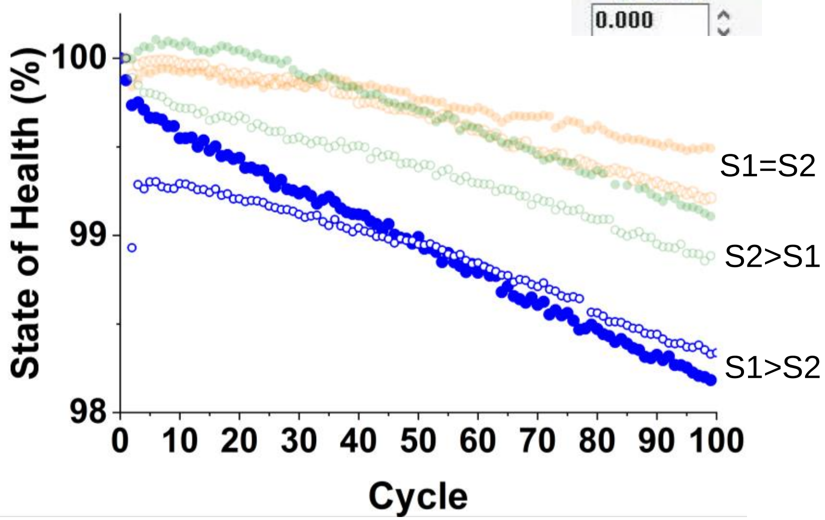
ΔPSI/cycle distributes homogeneously across cell; irreversible pressure builds up as cycling progresses

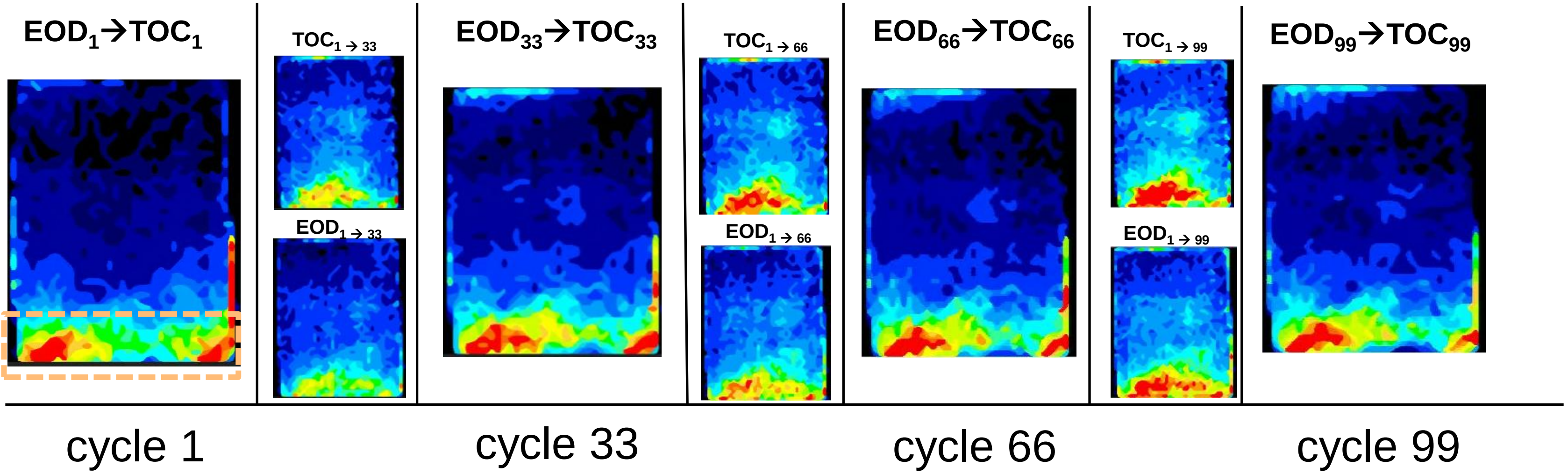
Visualizing Pressure Changes (ΔPSI) During Cycling

S1>S2





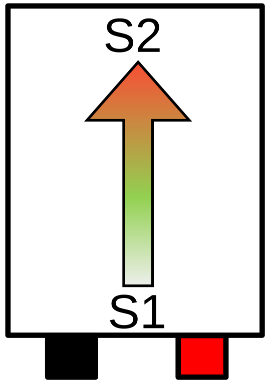


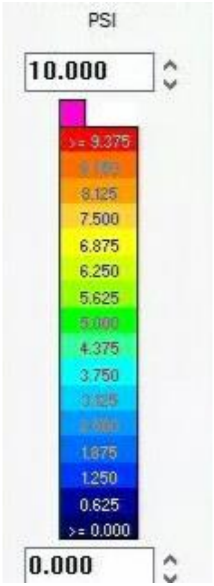


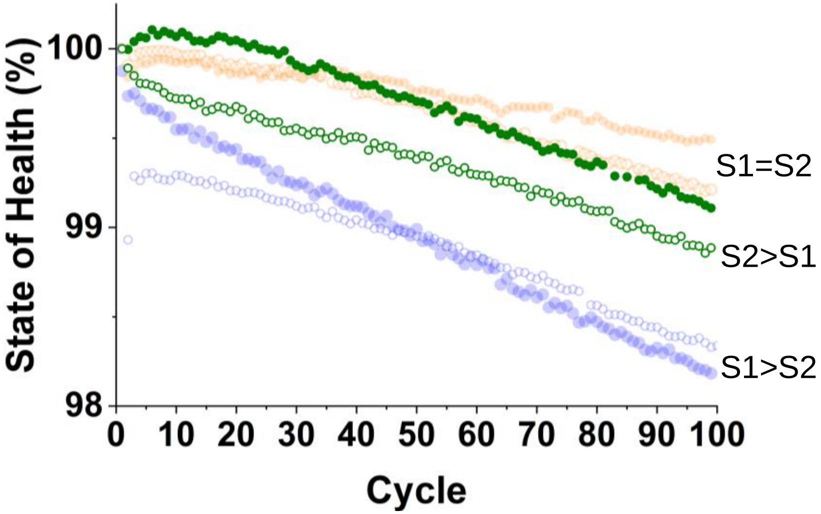
Greatest ΔPSI/cycle occurs near current-collecting tabs; TOC and EOD differentials reveal further activity in S2 region

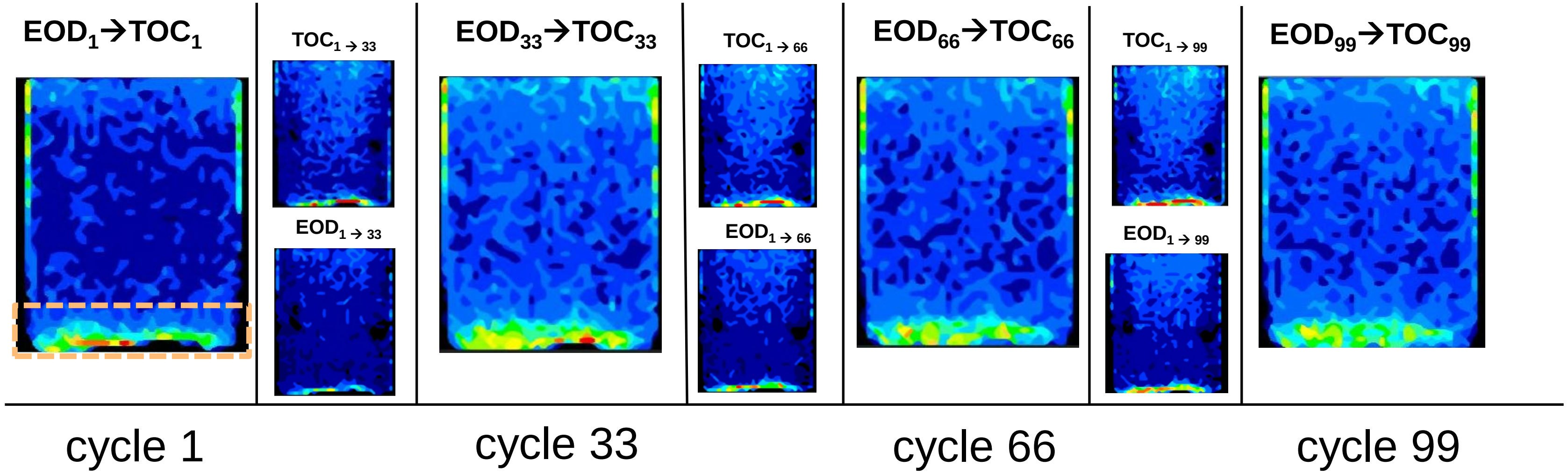
Visualizing Pressure Changes (ΔPSI) During Cycling

S2>S1





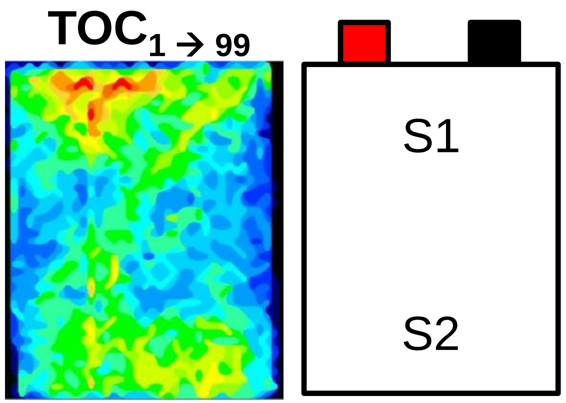


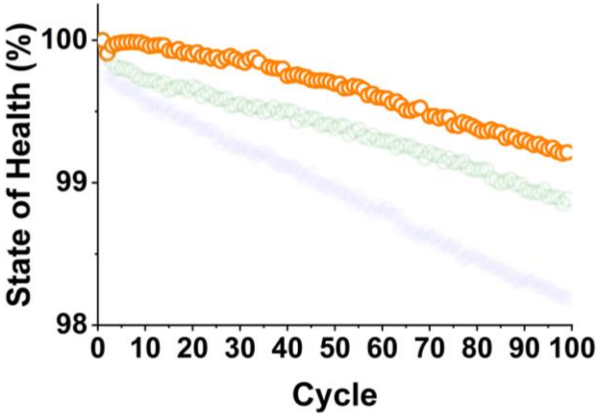


Greatest ΔPSI/cycle maintained near current collecting tabs as previously observed, despite gradient reversal

Corroborating pressure diagnostics with destructive physical analysis

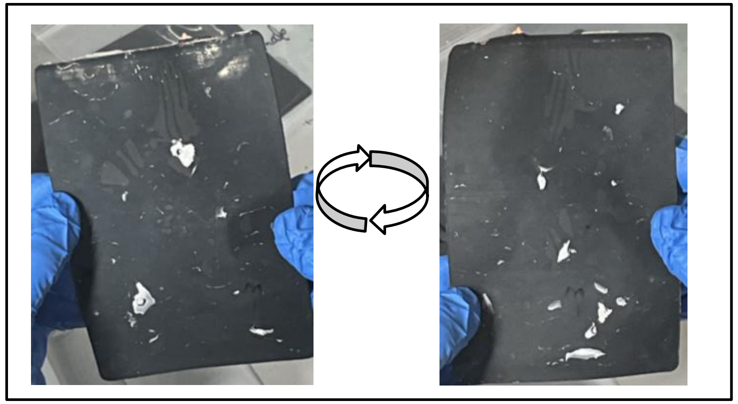
Homogeneous pressure



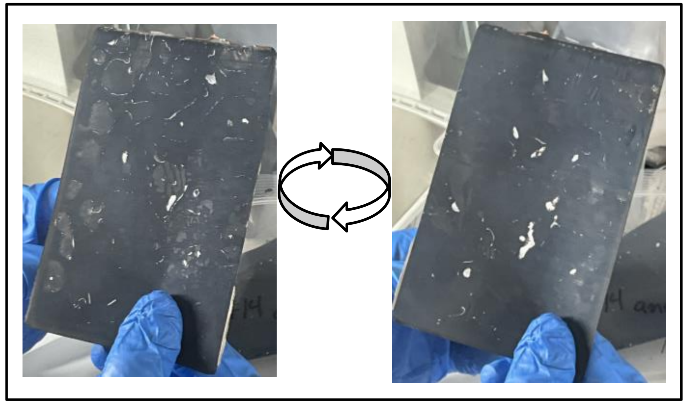


S1 = S2

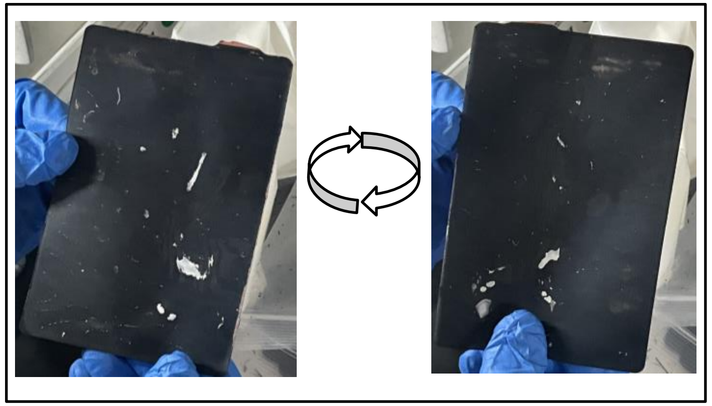
Beginning of stack



Middle of stack



End of stack

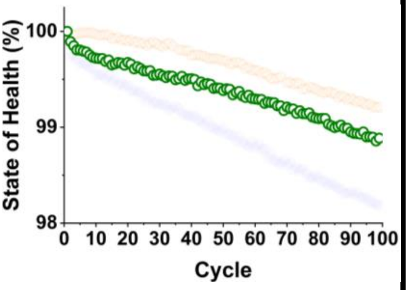


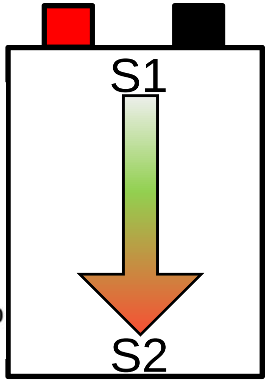
Build-up of material occurs across anode, deformation apparent near current-collecting tabs and middle of stack

Corroborating pressure diagnostics with destructive physical analysis

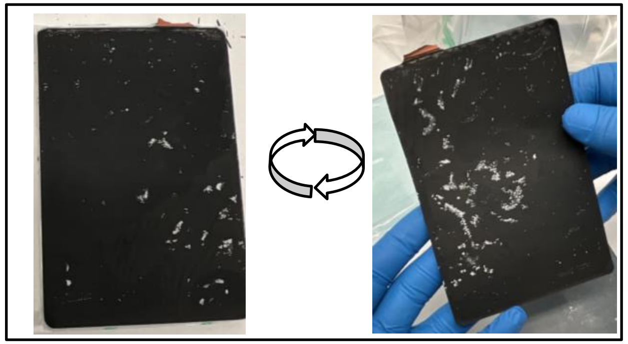
Comparison between heterogeneous pressures

Cell A (S2 > S1)

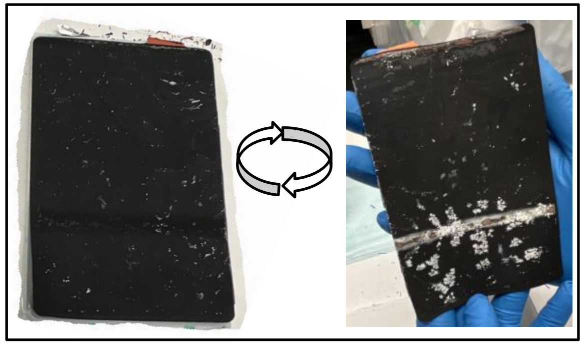




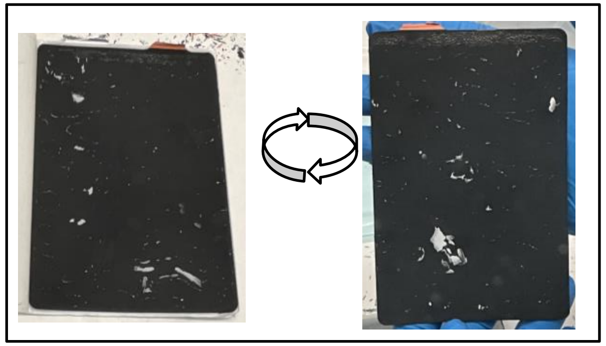
Beginning of stack



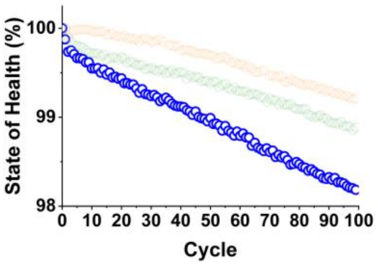
Middle of stack

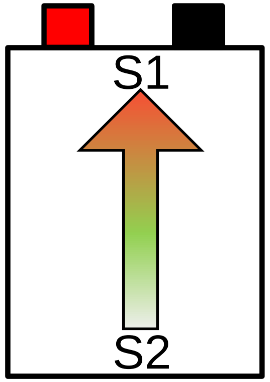


End of stack

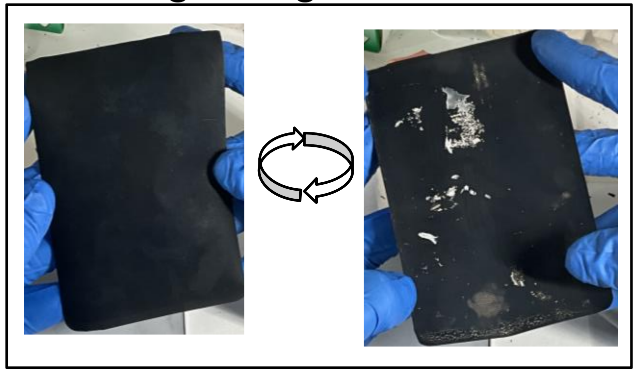


Cell B (S1>S2)

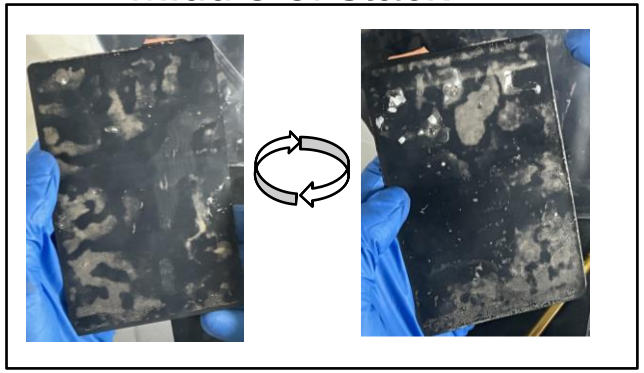




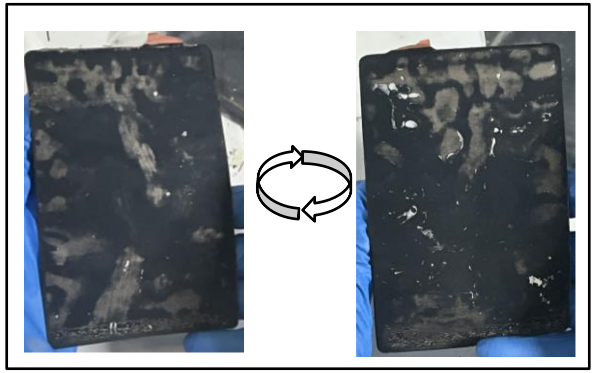
Beginning of stack



Middle of stack



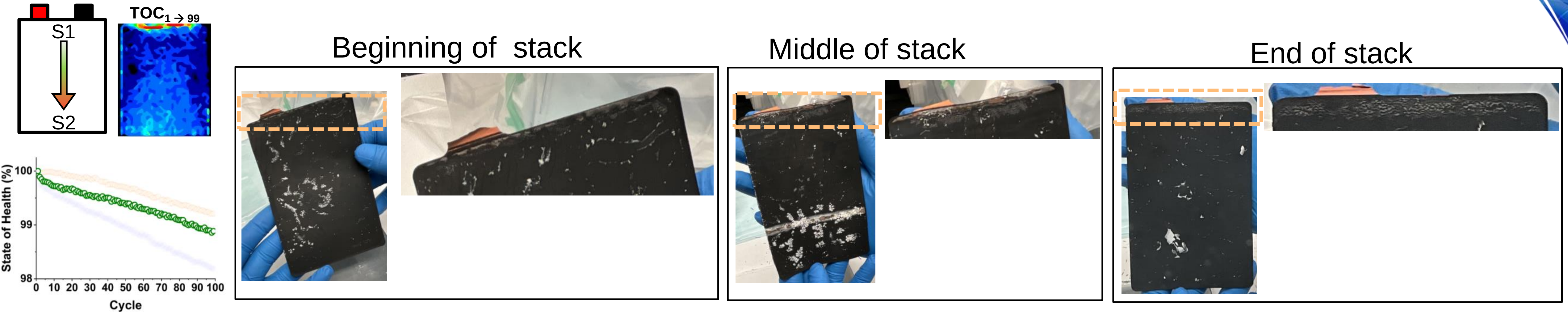
End of stack

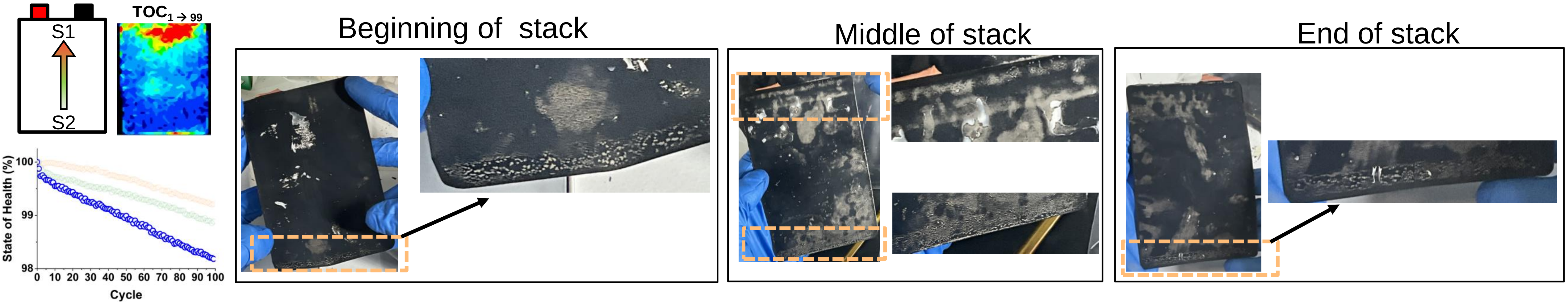


Anode degradation is exacerbated for cells experiencing heterogeneous pressure gradients and is worst in middle of stack

Corroborating pressure diagnostics with destructive physical analysis

Comparison between heterogeneous pressures



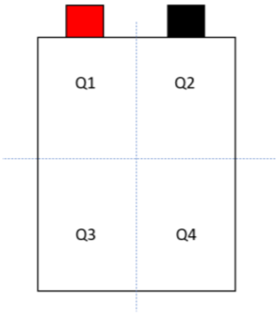


Anode degradation is exacerbated for cells experiencing heterogeneous pressure gradients and is worst in middle of stack

Conclusions and future directions

I. Conclusions
   1. Heterogeneous compression results in greater decline to cell state of health
      - Apparent anode deformation occurs in cells with heterogeneous compression
   2. Regardless of gradient direction, greatest ΔPSI/cycle evolves closest to current-collecting tabs
      - Compression nearest to current-collecting tabs ranks worst in performance

II. Project status and future directions
   1. Isolation of cell quadrants near cathode tab (in progress), anode tab (complete), acquire chemical data on regions of interest in DPA cells (to be completed).



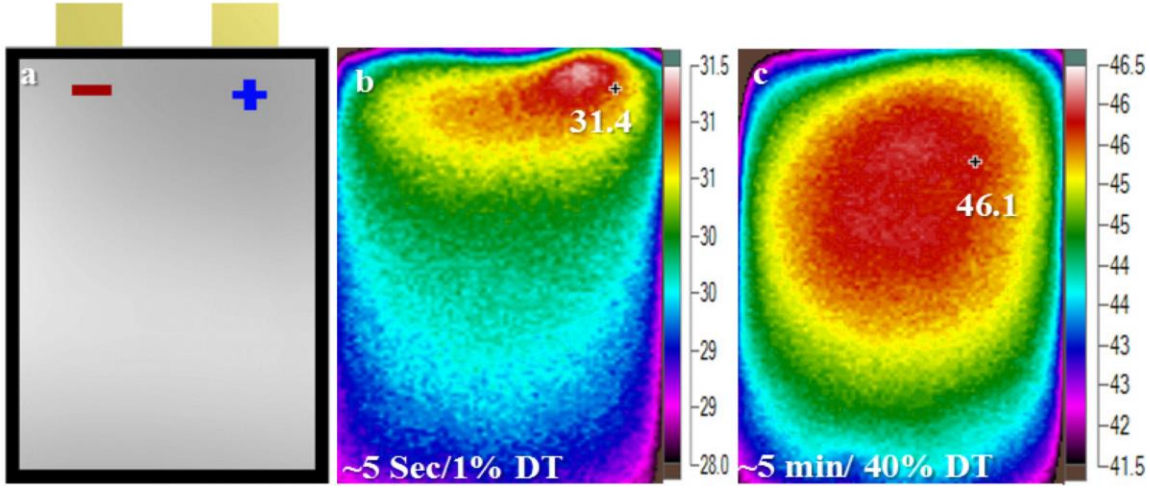
   2. Simplify system of interest to pouch cells with fewer internal layers; localize pressure gradients with greater precision
   3. Further non-destructive techniques to map internal properties of cells (acoustics, XCT)

Thank you!

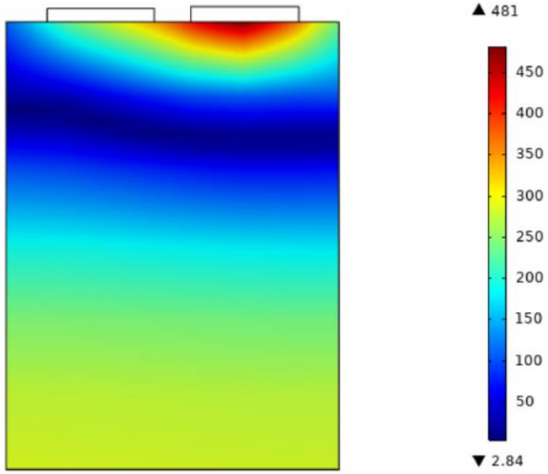
Supporting slides

Properties of devices under test

- Modeling and real-time measurements of operating batteries have identified a heterogenous distribution of thermal and electrical properties across cells

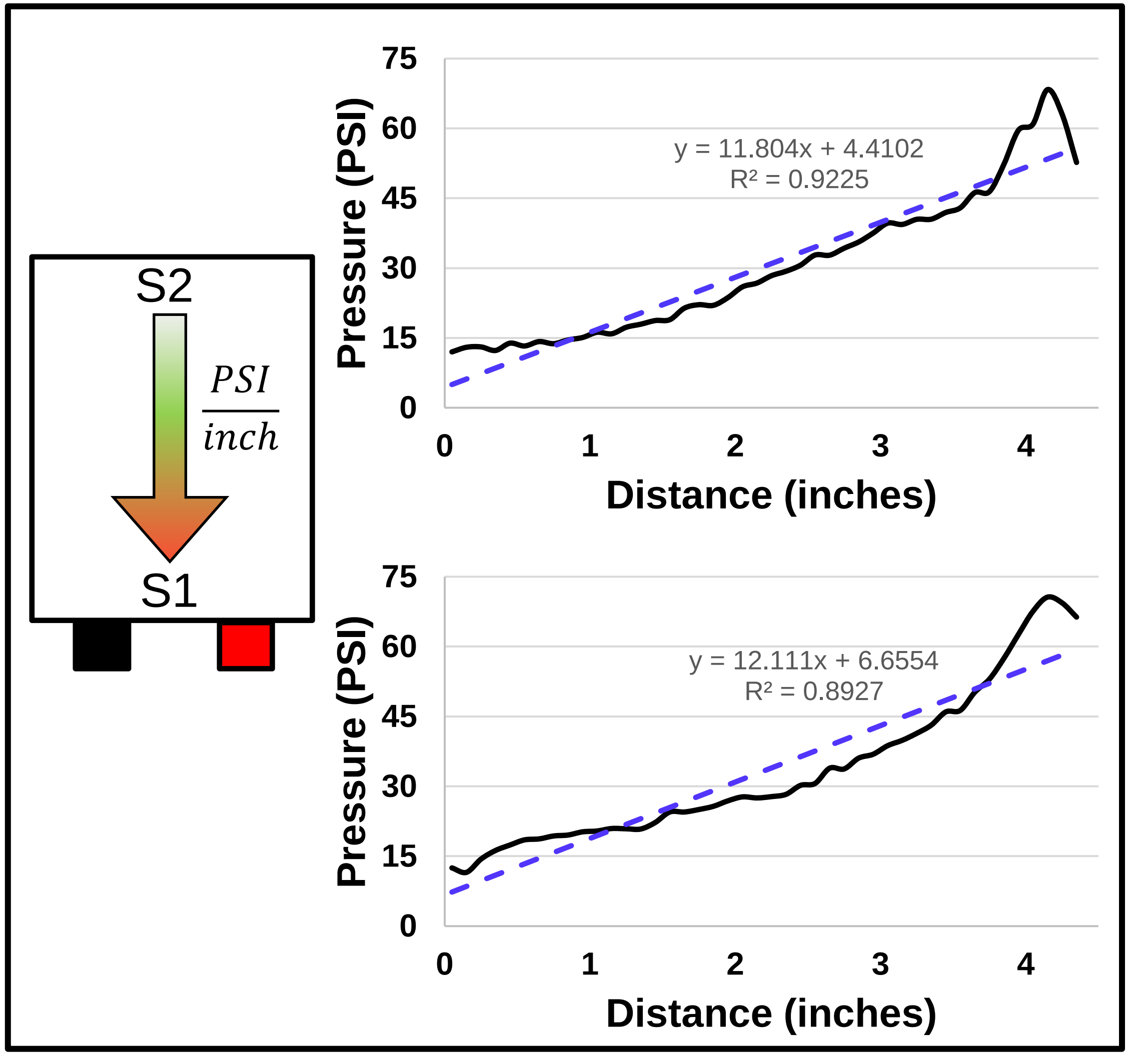


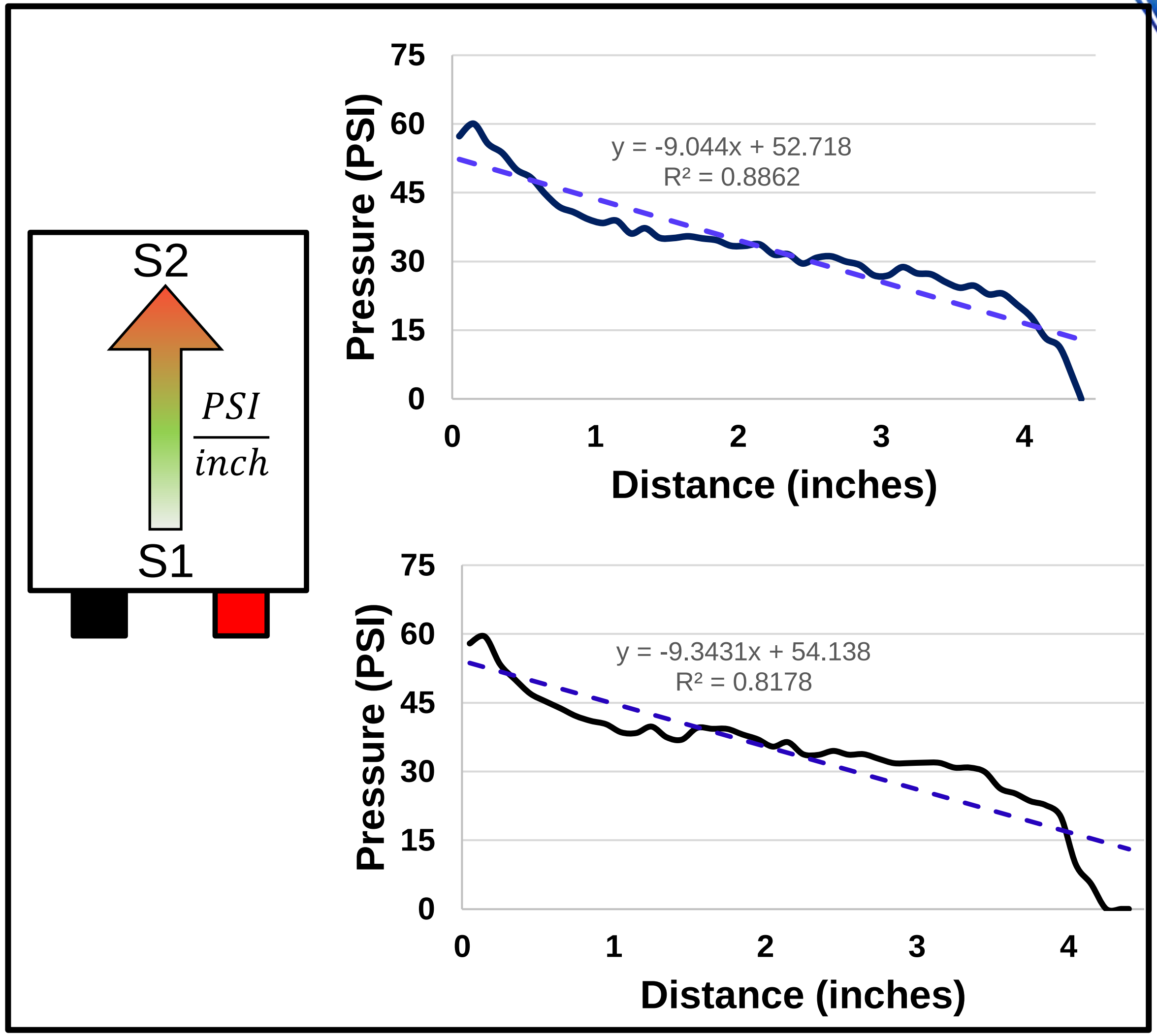
S. Goutam et al (2023) Energies



M. Javadipour, K. Mehran (2021) IET

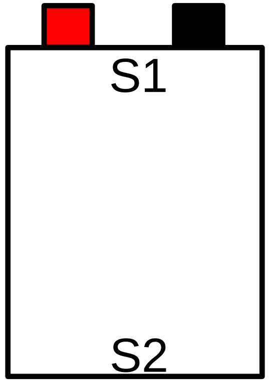
Quantification of gradients





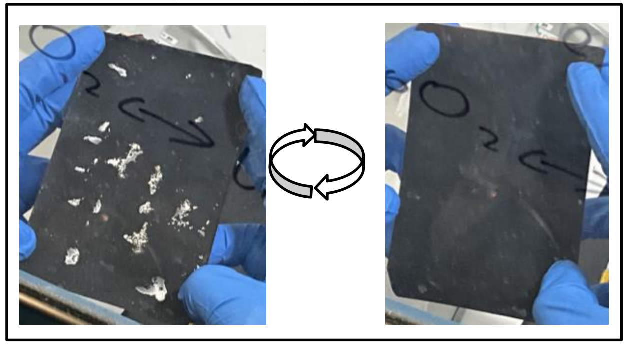
Linearity needs to improve, potentially with the use of more rigid plates and/or less compliant material

Extra slides



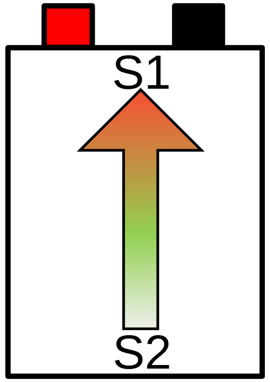
Cell B (S1 = S2)

Beginning of stack



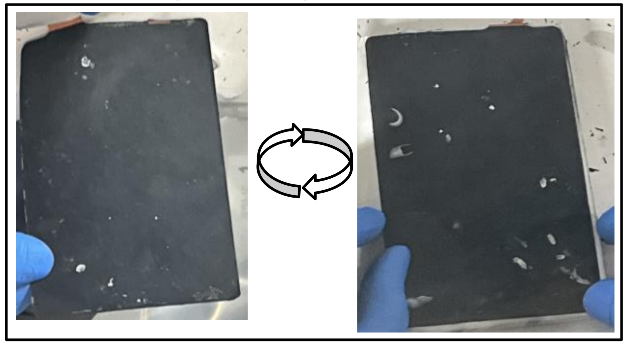
Middle of stack

End of stack



Cell A (S1 > S2)

Beginning of stack



Middle of stack

End of stack