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Improving Li-ion Performance Through Mechanical Stimulation

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The Hypothesis: Mechanical stimulation of lithium-ion cells influences a cell's electrochemical performance.

The Objective: To understand the influence of mechanical stimulation on cells and to predict the requisite level and orientation of mechanical loading for maximum lithium-ion battery performance.

The Method: A combined experimental and computational approach to understand and produce a thermally, mechanically and electrochemically coupled predictive battery model, aiding engineers in the cell and pack design process.

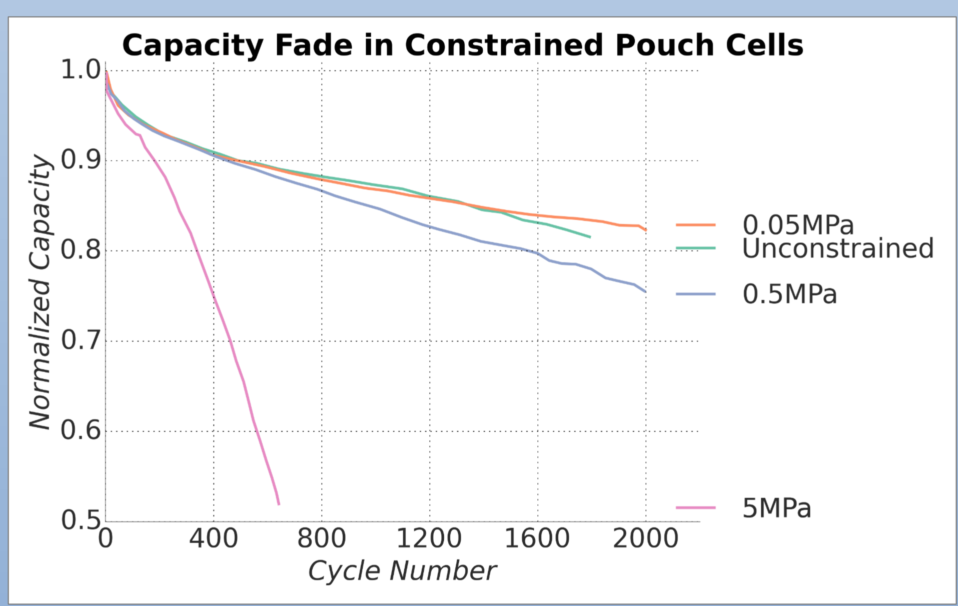


Figure 1: Fixed-displacement compression in the 0 – 0.05 MPa range (orange trace) reduced pouch cell capacity fade [1].

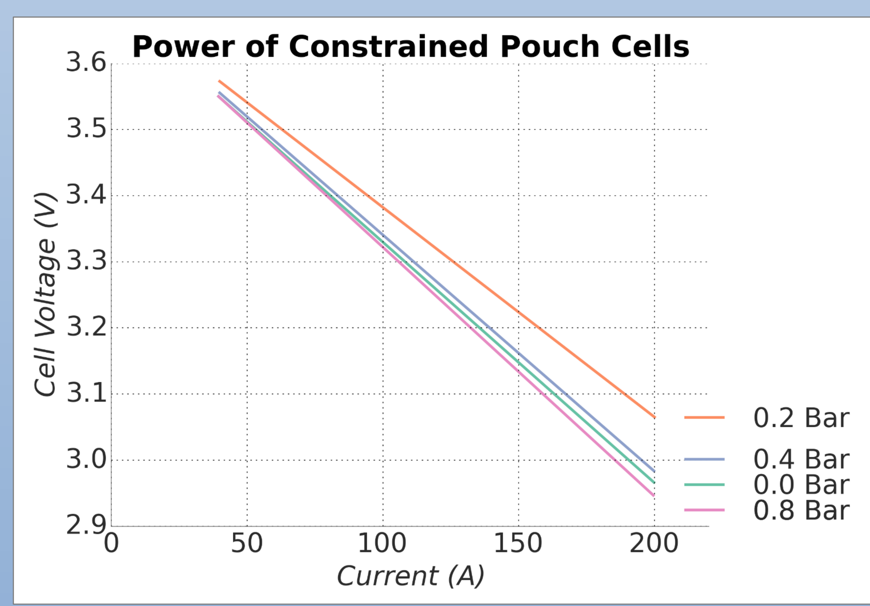


Figure 2: Fixed-load compression at 0.2 Bar (orange trace) improved pouch cell energy density [2].

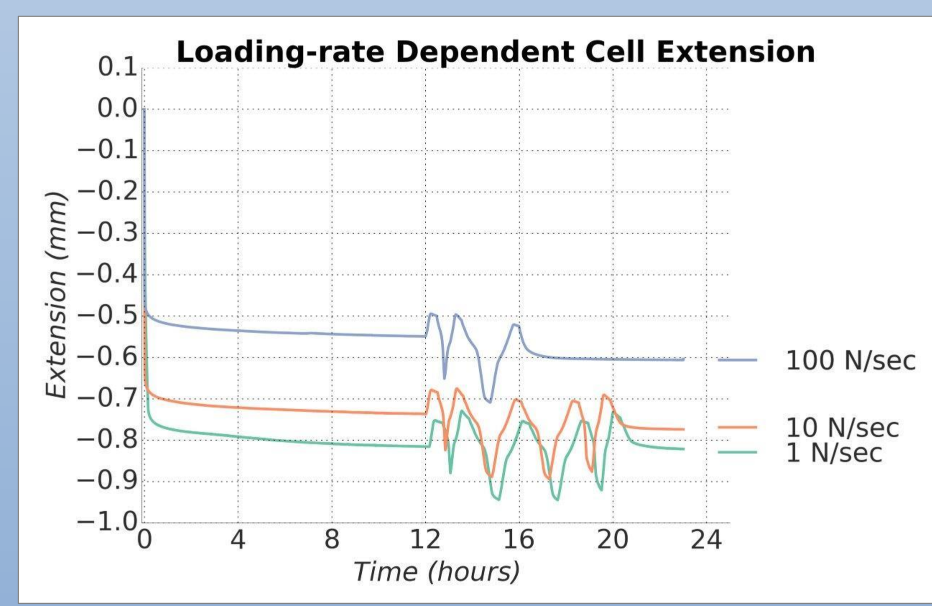


Figure 3: For any given load, the extent of cell compression varies with the rate of application of that load.

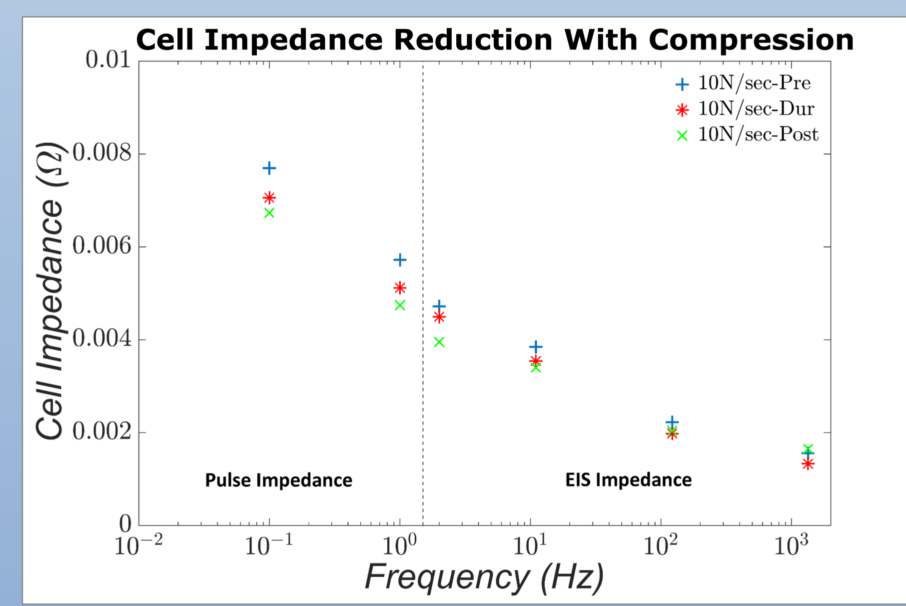


Figure 4: Fixed-load compression reduces pouch cell impedance versus the initial uncompressed state.

Loading Rate Dependent Cell Extension

- Loading Rate experiments arose from the research question:
  Does the rate at which a cell is mechanically compressed have an effect on the mechanical state of the cell and subsequently the electrochemical performance?
- Experiments performed on 5 Ah KOKAM, stacked electrode, pouch cells.
- The loading rates were applied uniformly up to 600 N, at 50% SOC at ambient temperature.
- Figure 3 shows an increased level of displacement for lower loading rates.
- Electrochemical cycling (extension fluctuations post 12 hours) induce increased displacement.
- This shows the mechanical state of the cell is path dependant and consideration must therefore be given to both loading rate and electrochemical cycling.

Cell Impedance Reduction With Compression

- Impedance data gathered from the loading rate experiments shown in Figure 3.
- High frequency impedance data was gathered from EIS sweep, low frequency data from 10 second pulse discharge, all at 50% SOC.
- Figure 4 shows data from the same cell under different conditions, Pre (fresh cell), During (cell under 600N uniform compression) and Post (unloaded cell).
- Compression applied during electrochemical cycling reduces cell impedance cell at lower frequencies.
- Future work shall focus on these effects, including the further reduction in impedance when the cell is subsequently unloaded, in addition to linking these effects to the findings shown in figure 3.

Creating the Framework: A 3D Battery Model

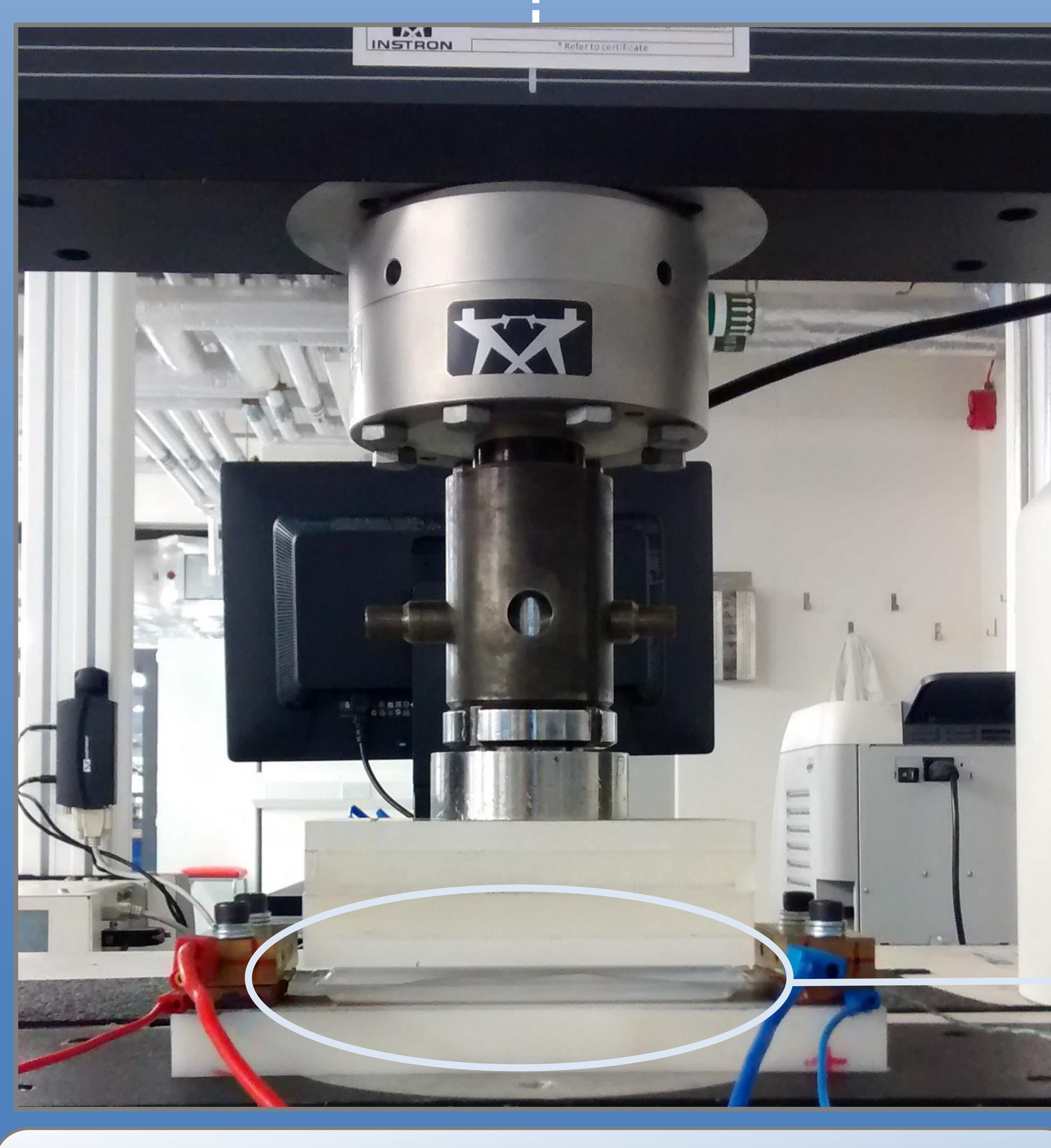
- Thermally-coupled, physics based numerical cell model.
- Distinct solid & electrolyte phases with charge & species conservation.
- 1D; through plane (depth), current collector to current collector.
- 1D; radial-direction electrode particle submodel.
- 1D; in-plane (length); cell end to cell end.

The Sub-Models: Electrode, Separator & Electrolyte Compression

- Spherical particle electrode model. Diffusion induced stress, stress-induced by external loading, strain & volumetric change modelled. Initially graphite only, with subsequent expansion to include composite electrodes.
- Separator stress-strain-diffusivity model accounting for the combined viscoelastic and poroelastic behaviour of the flooded polymeric separator matrix.

Sub-Model Aggregation

- Aggregation of sub-models to produce the finished thermally, mechanically & electrochemically coupled 'complete' battery model.
- A novel tool for the prediction of optimum cell loading.



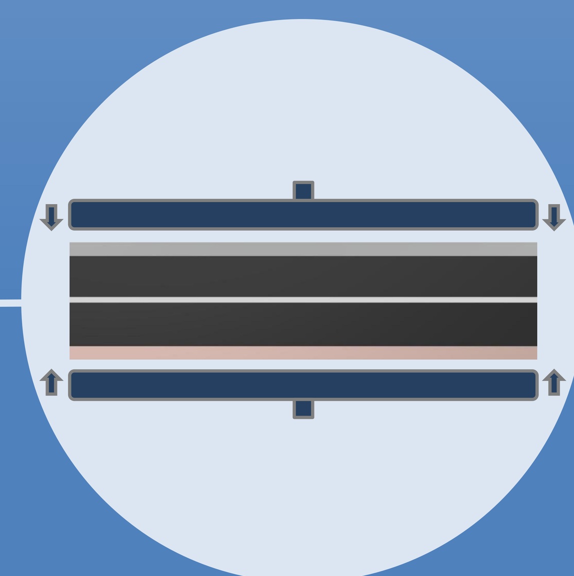


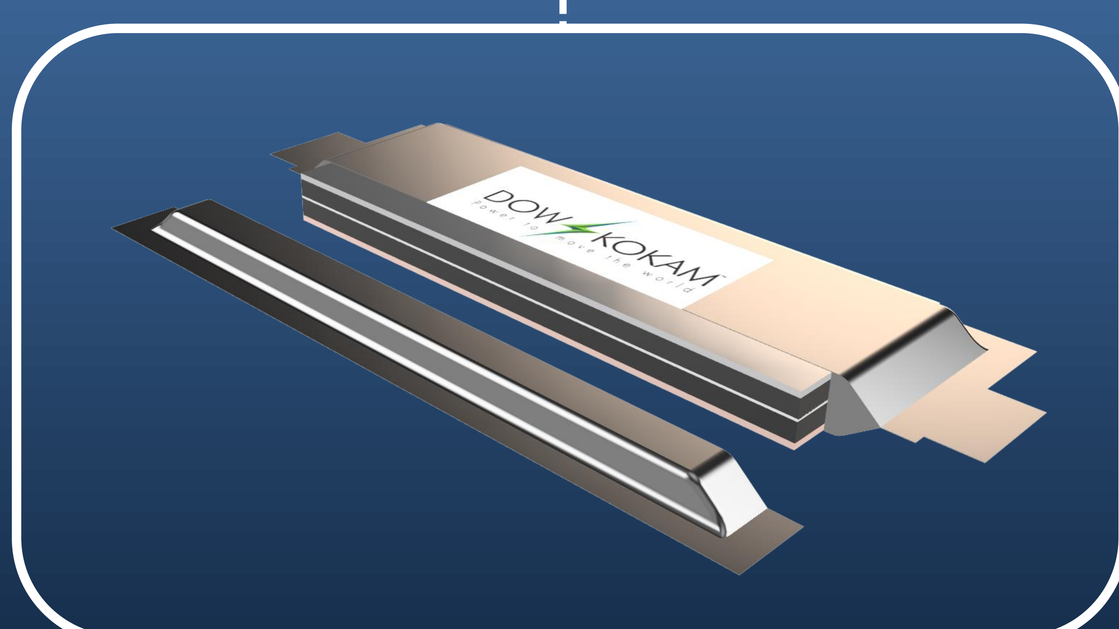
Figure 5: Uniaxial loading of a 5 Ah Kokam pouch cell with an Instron tabletop compression tester & electrochemical response measurement.

Mechanical

Thermal

Electrochemical

3D Model



References:
[1] J. Cannarella, C.B. Arnold, J. Power Sources 245 (2014) 745–751. [2] A. Barai, Y. Guo, A. Mcgordon, P. Jennings, in: 2013 Int. Conf. Connect. Veh. Expo, 2013, pp. 2–6. [3] J. Christensen, J. Electrochem. Soc. 157 (2010) A366. [4] G.Y. Gor, J. Cannarella, J.H. Prevost, C.B. Arnold, J. Electrochem. Soc. 161 (2014) F3065–F3071.