# Decoupling Mechanical Deformation in Stack-Pressured Aqueous Zinc Batteries

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Topic: Zinc & Lead Batteries | Vertical: Materials and System Innovation | Strategic Pathways: Optimize | Project Start and Finish: FY25 – FY28 | Storage Innovations 2030

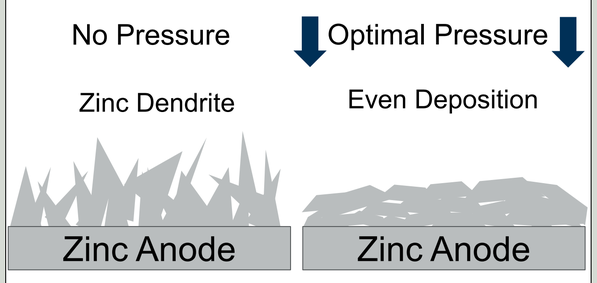
## Problem

• **Aqueous zinc (Zn) batteries** offer a low-cost, safe, and sustainable alternative to Li-ion for large-scale energy storage[1]

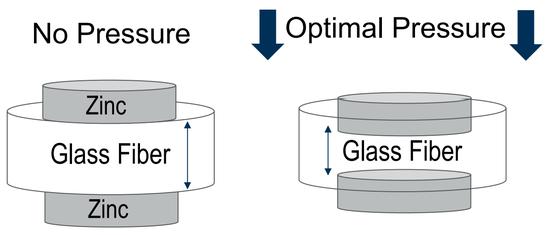
• Frequently fail due to Zn dendrite growth, gas evolution, and interfacial instability

• Researchers have pursued electrolyte and anode modifications to suppress dendrites, these approaches are complex, costly, and difficult to scale[2]

• **Stack pressure** offers a simple, low-cost physical strategy to promote uniform Zn growth and cycling stability[3]




• Prior studies have overlooked mechanical deformation of cell components under applied pressure, particularly the separator

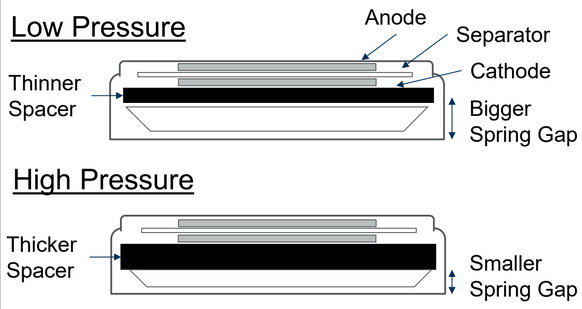



• In this study, we used an incompressible polycarbonate separator to decouple mechanical deformation from stack pressure, isolating pressure's intrinsic effects

• When utilizing stack pressure, **cell components become a large factor** in determining the electrochemical performance

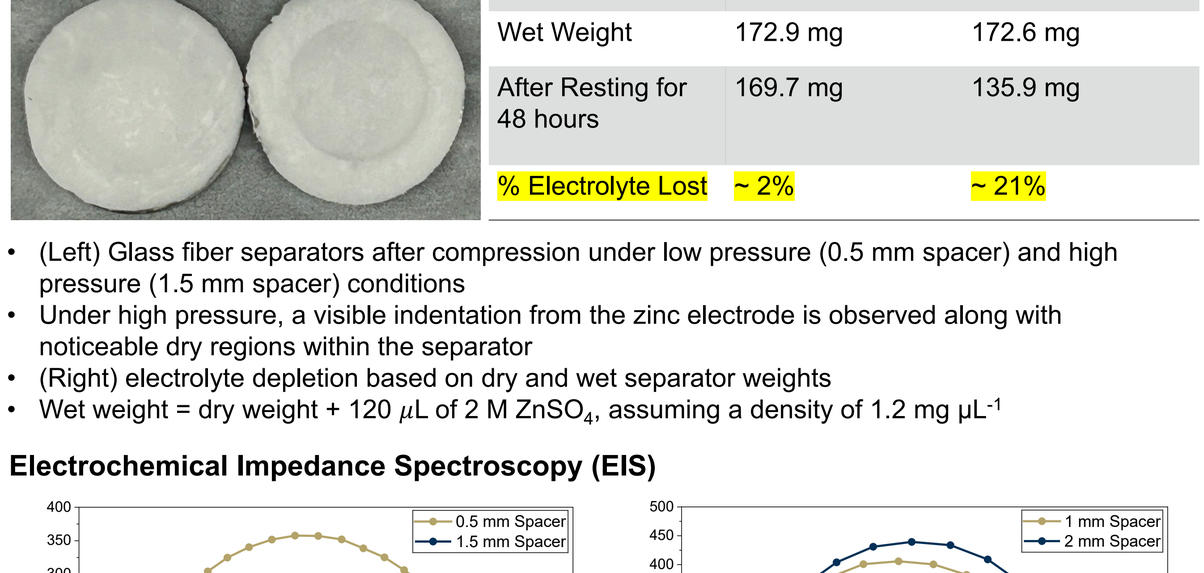
## Approach

- Zn Symmetric Cell
  - CR 2032 Coin Cell
  - Zinc Foil Electrode (10 mm Diameter, 0.25 mm Thickness)
  - Stainless Steel Spacer
  - Whatman Glass Fiber B
    - Electrolyte: 2 M $ZnSO_4$
  - Polycarbonate Separator (0.4 $\mu$m Pore Size)
    - Electrolyte: 1.5 m $ZnSO_4$ + 15 m LiTFSI
- Hookes Law: Force ∝ Displacement




## Results

### 1. Electrochemical Performance with Compressible Glass Fiber




- The cycling performance of zinc symmetric cells using a compressible glass fiber separator
- Increasing stack pressure significantly improves cycle life while reducing overpotential
- However, at higher pressures, separator compression reduces the distance required for dendrites to propagate and short the cell, which limits the beneficial effect of pressure

### 2. Quantifying Changes in Porosity, Tortuosity, and Electrolyte Wetting in Compressible Glass Fiber

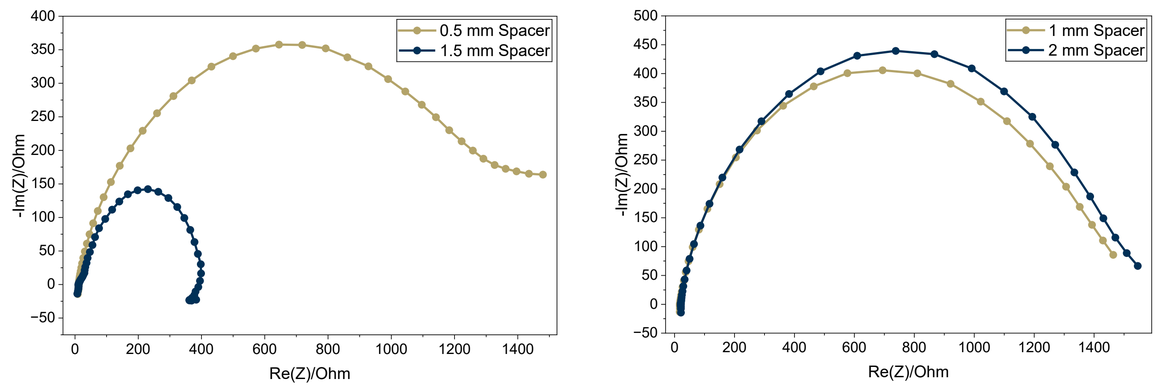
Low Pressure (0.5 mm Spacer) High Pressure (1.5 mm Spacer)



| | Low Pressure | High Pressure |
|---|---|---|
| Dry Weight | 28.9 mg | 28.6 mg |
| Wet Weight | 172.9 mg | 172.6 mg |
| After Resting for 48 hours | 169.7 mg | 135.9 mg |
| % Electrolyte Lost | ~ 2% | ~ 21% |

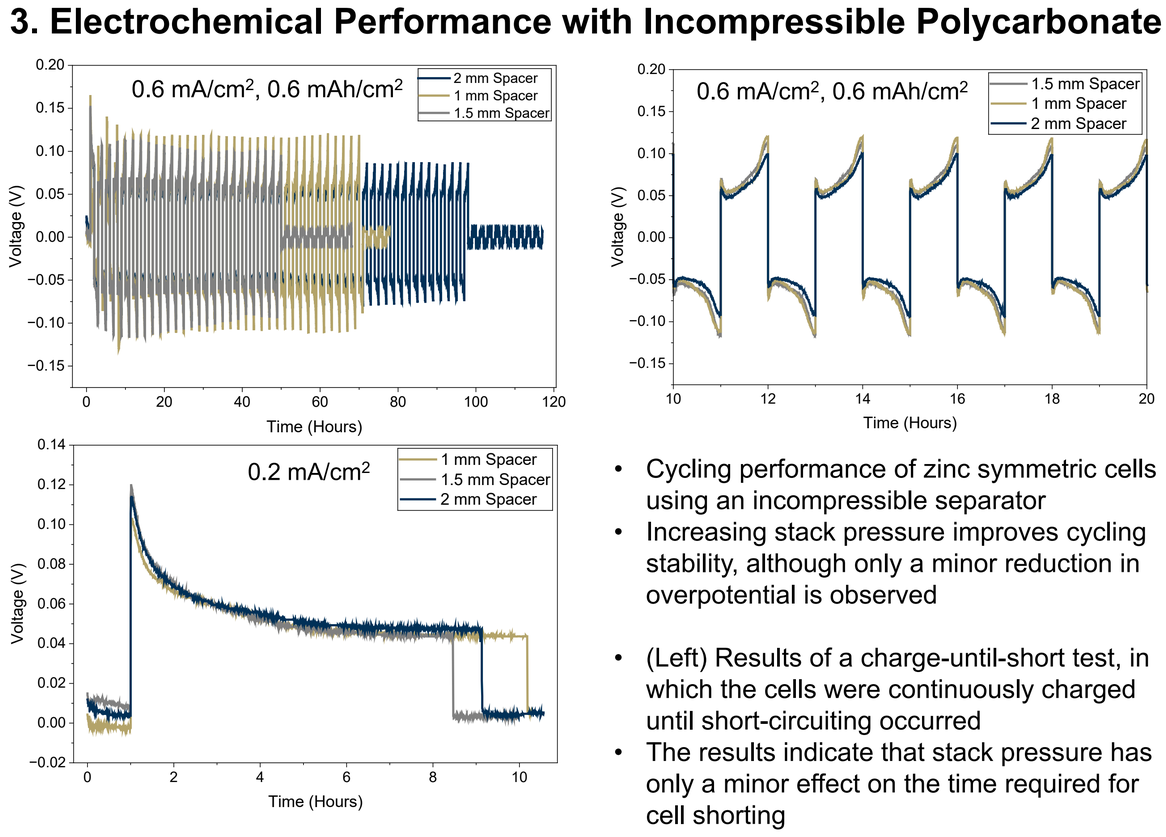
- (Left) Glass fiber separators after compression under low pressure (0.5 mm spacer) and high pressure (1.5 mm spacer) conditions
- Under high pressure, a visible indentation from the zinc electrode is observed along with noticeable dry regions within the separator
- (Right) electrolyte depletion based on dry and wet separator weights
- Wet weight = dry weight + 120 $\mu$L of 2 M $ZnSO_4$, assuming a density of 1.2 mg $\mu L^{-1}$

#### Electrochemical Impedance Spectroscopy (EIS)




- EIS spectra of glass fiber (left) and polycarbonate (right) separators under low- and high-pressure conditions after a 1 h rest period before cycling (1 MHz–100 mHz, 10 mV amplitude)
- The high-pressure glass fiber separator exhibited a reduced semicircle + inward low-frequency tail
- In contrast, the incompressible polycarbonate separator showed only a minor change in resistance with increasing stack pressure

### 3. Electrochemical Performance with Incompressible Polycarbonate




- Cycling performance of zinc symmetric cells using an incompressible separator
- Increasing stack pressure improves cycling stability, although only a minor reduction in overpotential is observed

- (Left) Results of a charge-until-short test, in which the cells were continuously charged until short-circuiting occurred
- The results indicate that stack pressure has only a minor effect on the time required for cell shorting

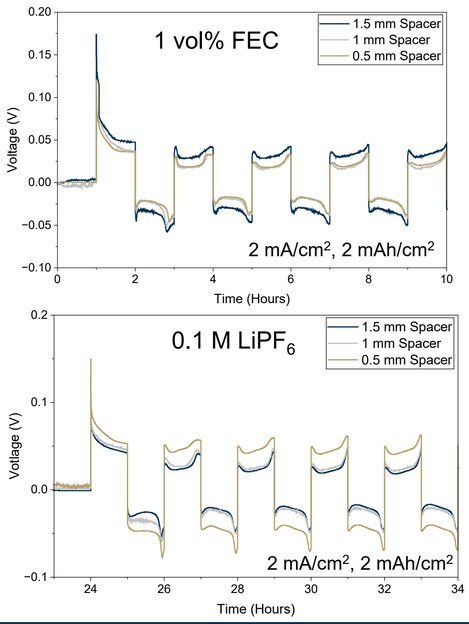
## Conclusions & Impact

- Applying stack pressure with a compressible glass fiber separator **increased cycle life by ~125 hours**
- Stack pressure reduced overpotential, improved electrode–separator contact, and suppressed dendrite growth
- Postmortem analysis revealed separator deformation and electrolyte depletion
- EIS spectra of glass fiber separators showed significant changes in porosity and tortuosity. In contrast, incompressible polycarbonate separators exhibited only minor resistance changes
- Using an incompressible separator revealed an optimum pressure regime
  - **Low stack pressure** creates interfacial voids that increase dendrite propagation distance
  - **Medium stack pressure** reduces void formation but provides limited dendrite suppression
  - **High stack pressure** eliminates interfacial voids and promotes dendrite suppression
- Minimal overpotential changes suggest that separator compressibility strongly influences interfacial behavior
- The dendrite suppression mechanism is primarily effective during continuous plating/stripping rather than plating alone

## Future Directions

• In situ **x-ray micro-computed tomography** (Micro CT)
  - Probe morphological evolution of battery electrode and components

• Stack pressure effects **on electrolyte additive-induced SEI**

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