Effect of Externally Applied Pressure on Rechargeable Alkaline Zinc Batteries

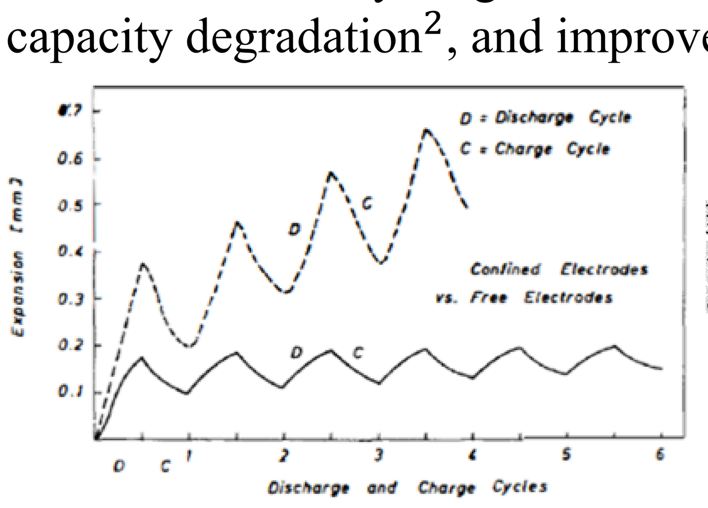
Deepak Kharel[1] , Timothy N. Lambert[2,3], Ciara Nicole Wright[2], and Yang-Tse Cheng[1,4]
[1]Physics and Astronomy, University of Kentucky, Lexington, KY 40506, USA
[2]Department of Photovoltaics and Materials Technology, Sandia National Laboratories, Albuquerque, NM 87185, USA
[3]Center for Integrated Nanotechnologies, Sandia National Laboratories, Albuquerque, NM 87123, USA
[1,4]Chemical and Material Engineering, University of Kentucky, Lexington, KY 40506, USA

Background and Project Overview

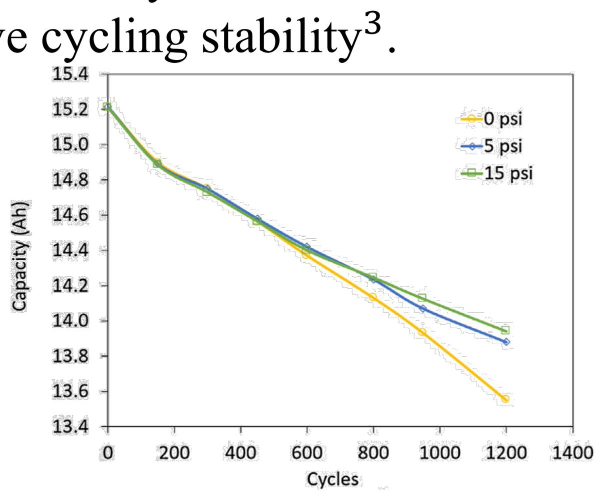
- **Project goal:** To understand the effect of applied pressure in alkaline Zn/MnO_2 batteries ensuring a mechanism for stable and long-lasting performance tailored for grid-scale energy storage.
- **Current practice:** Studies of Zn batteries often assume comparable mechanisms to Li-ion, but experimental validation is limited.
- **Why UK:** Offers advanced capabilities for *e.g.*, pouch cell fabrication, pressure cell studies, electrode characterization using nanoindentation, AFM, TEM, and cross-section ion polisher that helps understand the underlying mechanism for advancing aqueous Zn batteries.
- **Innovation:** New capabilities (lab-scale pressure cell) to investigate the effect of externally applied pressure on rechargeable alkaline Zn/MnO_2 batteries in pouch cell configuration which has not been extensively studied before.
- **Impact:** Our study will help improve grid stability and resilience by developing aqueous Zn batteries as an additional LDES devices using safe, inexpensive, and US-sourced materials providing a constant power supply needed for critical facilities, for *e.g.*, data centers, hospitals.
- **Alignment:** Facile manufacturing process with US-sourced materials for Zn batteries provides a new avenue for advanced grid-storage technologies to assist the modernization of the U.S. power grid with affordable and secure energy.

Rechargeable alkaline zinc batteries (AZBs) are gaining interest for Long Duration Energy Storage (LDES) applications owing to their safety, abundance, and low cost, as well as facile manufacturing processes.

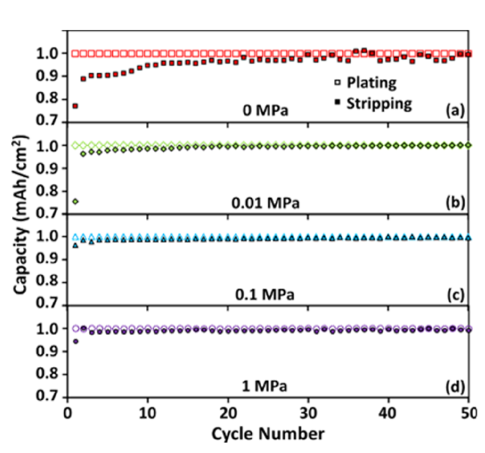
Studies have shown that applied pressure can reduce cell expansion during electrochemical cycling and increase cycle life with increasing pressure[1], minimize capacity degradation[2], and improve cycling stability[3].



MnO_2-graphite discs[1]



15 Ah-NMC/Graphite[2]



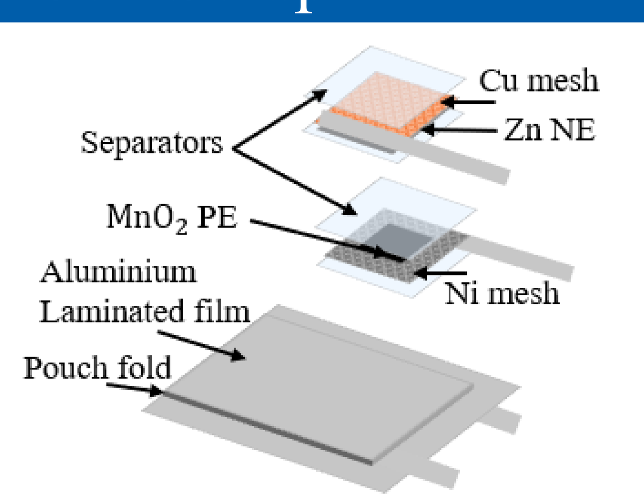
Li-metal in 4M LiFSI in DME[3]

Objectives

- Construct a lab-scale pressure cell setup to investigate the effect of externally applied pressure on rechargeable alkaline Zn/MnO_2 batteries in pouch cell configuration at various depth of discharge (DOD) for MnO_2.
- Understand the effect of externally applied pressure on electrochemical performance of cell using electrochemical methods, *e.g.*, electrochemical cycling and electrochemical impedance spectroscopy (EIS), as well as post-mortem characterization using SEM, EDS, XPS, and XRD.
- Establish the relationship between electrochemical performance, mechanical and electrical properties, and pressure of cells before and after cycling at several MnO_2 DOD values aiming to contribute to the development of low-cost and sustainable energy storage systems.

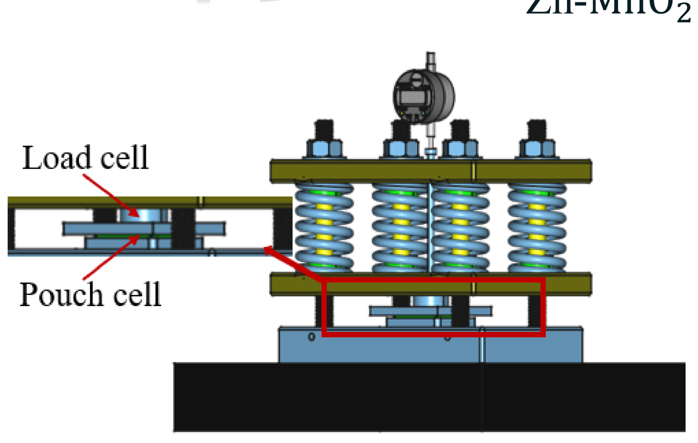
Cell Assembly and Pressure Cell Setup


Electrode preparation



$Zn-MnO_2$ pouch cell configuration

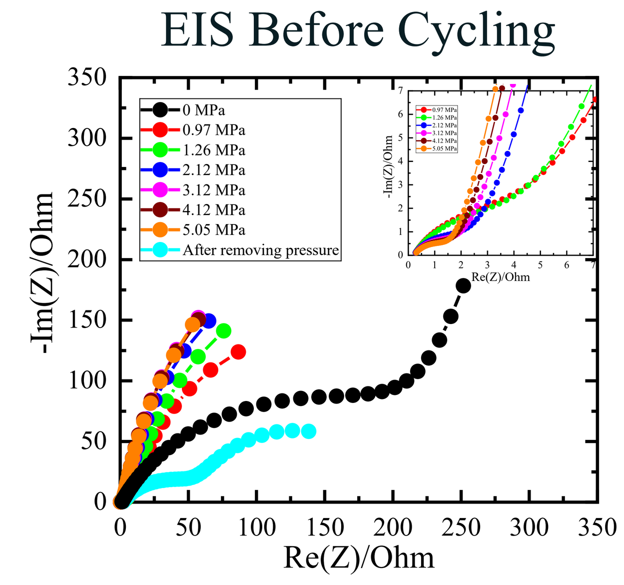

Freshly prepared $Zn-MnO_2$ pouch cell



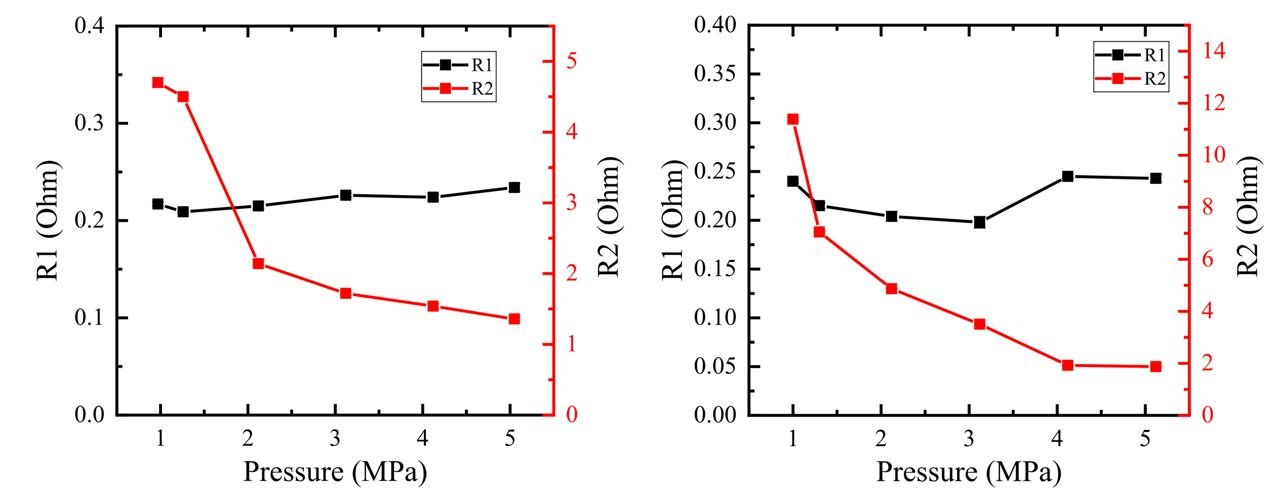
Pressure cell design

Electrochemical Performance

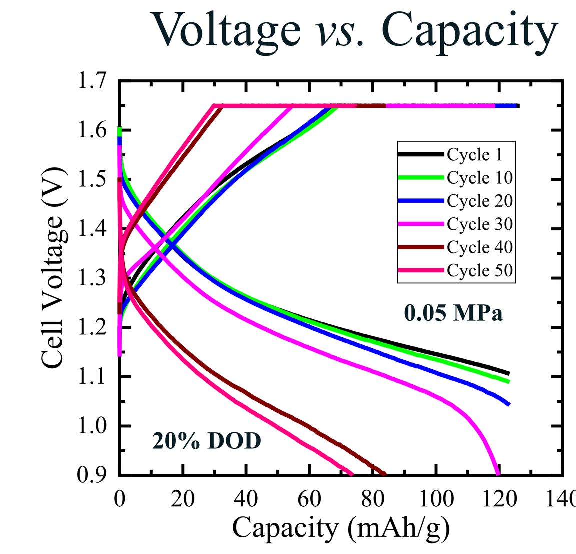
EIS Before Cycling



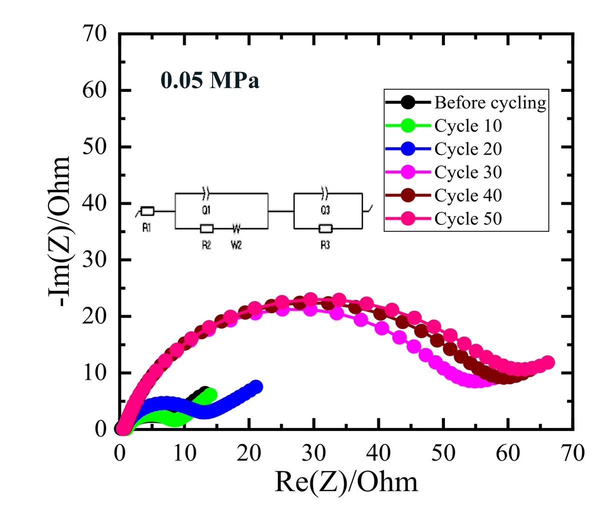
Comparison Between Two Pouch Cells

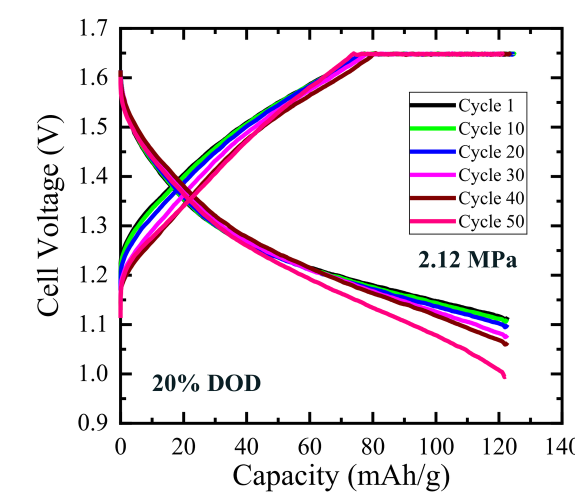


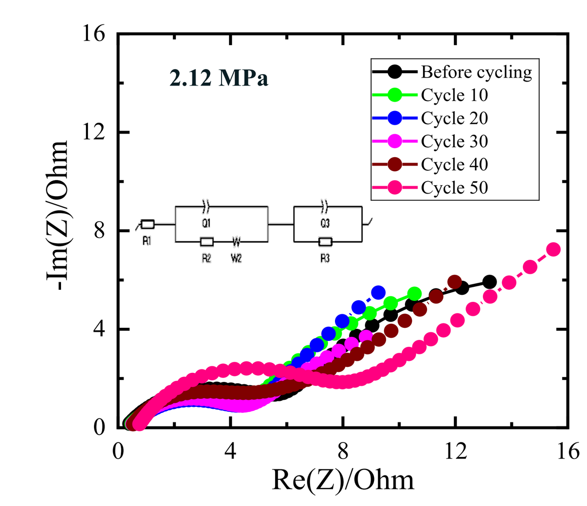
Voltage *vs.* Capacity



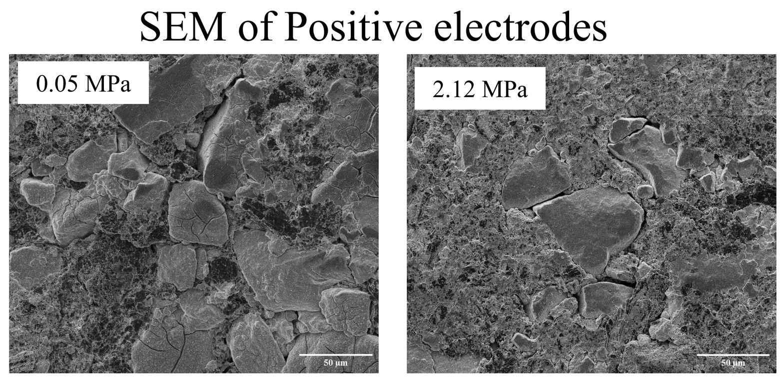
EIS



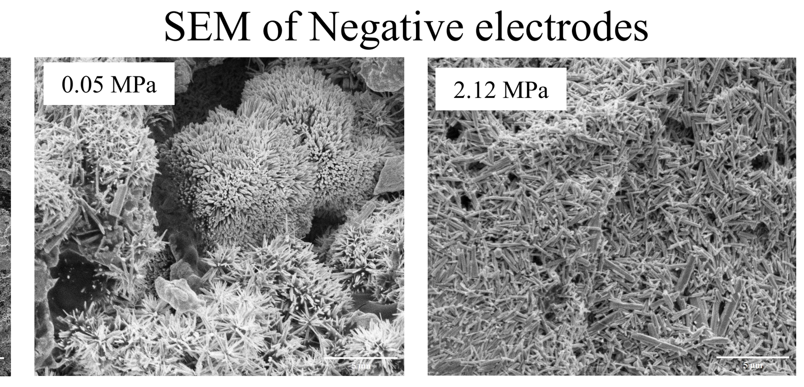




SEM of Positive electrodes



SEM of Negative electrodes



Conclusions and Future Work

Our experimental results show that pressure helps reduce internal resistance, minimize capacity degradation, and improve cycling stability. With further supporting evidence, it will be a promising approach to integrate into affordable large-scale energy storage systems.

- Before cycling, bulk resistance and charge transfer resistance decreased with pressure by approximately 40% and 97%, respectively.
- At 2.12 MPa pressure, stable capacity is observed for a cell cycled at 20% DOD for 50 cycles, while the bulk resistance and charge transfer resistance remain fairly constant.
- SEM observations reveal the formation of high surface area Zn deposits and particle cracking on negative and positive electrode, respectively, for a cell cycled at 0.05 MPa. Cracking is absent for cell cycled at 2.12 MPa pressure.

Future work:

- Pressure effect on capacity utilization/DOD
- Pressure effect on morphology, composition of the electrodes, and cycle life

Work presented here is part of an effort to understand the effect of applied pressure in alkaline Zn/MnO_2 batteries and realize improved performance.

References

1. K. Kordesch *et al.,* Electrochim. Acta 1981, **26** (10), 1495-1504.
2. A. Baral *et al.,* Journal of Energy Storage 2017, **13**, 211-219
3. K. L. Harrison *et al.,* ACS Appl. Matter. Interfaces 2021, **13**, 31668-31679

Acknowledgments

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division. This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multi-program laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government. This article has been authored by an employee of National Technology & Engineering Solutions of Sandia, LLC under Contract No. DE-NA0003525 with the U.S. Department of Energy (DOE). The National Technology & Engineering Solutions of Sandia, LLC employee owns all right, title and interest to their contribution to the article and is responsible for its contents. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this article or allow others to do so, for United States Government purposes. The DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan https://www.energy.gov/downloads/doe-public-access-plan."