New Capabilities in Zinc Battery Testing

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Zinc metal [1]


Zincite crystal [2]

Introduction

Project Goal: Understand the effect of pressure on zinc batteries.

Current Practice: Mechanical pressure is important in the performance of batteries but is often not detailed in the open literature. The optimal pressure for Zn batteries is unknown

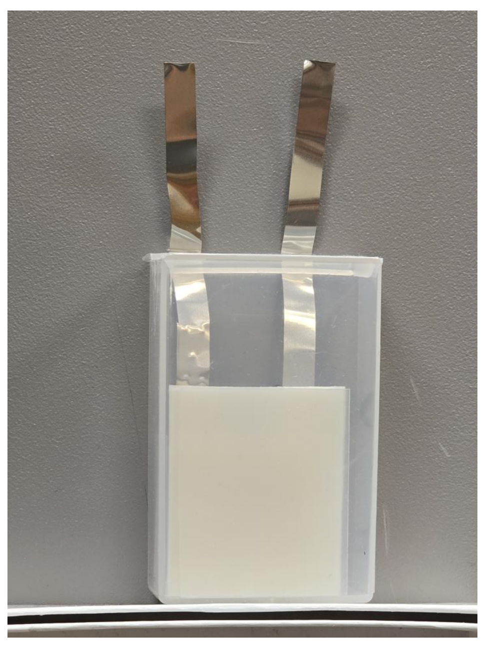
Sandia National Labs: Possesses extensive for *in situ* and *ex situ* characterization instrumentation. Strong combination of material science, engineering, and chemistry knowledge with significant experience in zinc-based batteries.

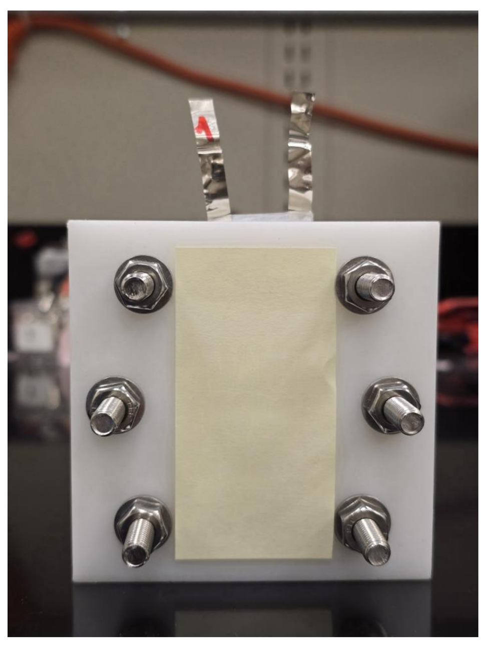
Innovation: Cathodes (e.g. MnO_2, NiOOH) are known to benefit from high pressures [3-5], but this relationship for Zn anodes is unexplored. A test setup was designed to apply a uniform pressure to cells during cycling and quantify their effects on battery performance and degradation. A capability was also developed to measure hydrogen gas evolution (unwanted reaction) *in situ*.

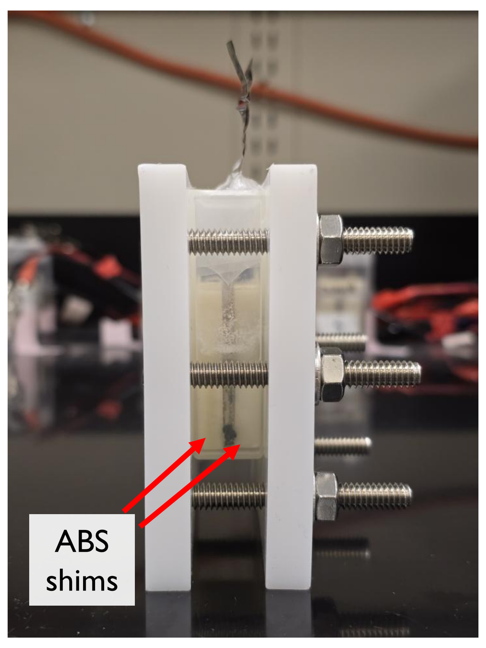
Impact: A Zn battery with high energy density, long cycle life, would be a lower cost and safer alternative to Li-ion batteries for energy grid storage.

Alignment: This technology directly relates to the Office of Electricity's mission of modernizing the nation's power grid to be reliable, affordable, and resilient by providing a safe (non-toxic, non-volatile), inexpensive energy storage solution - sourced and manufactured in the USA.

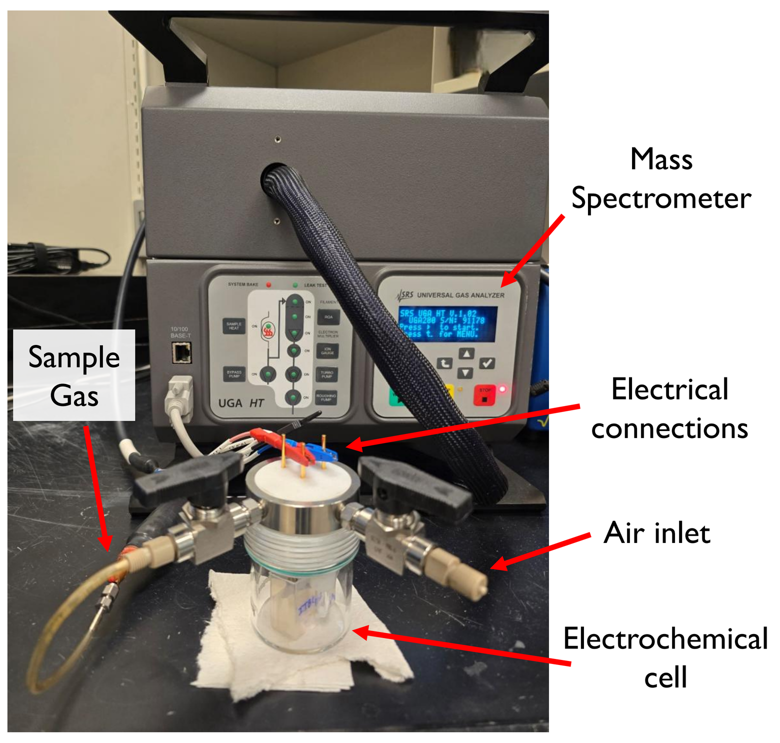
Experimental Setup


Assembled cell


Pressure clamp (front)



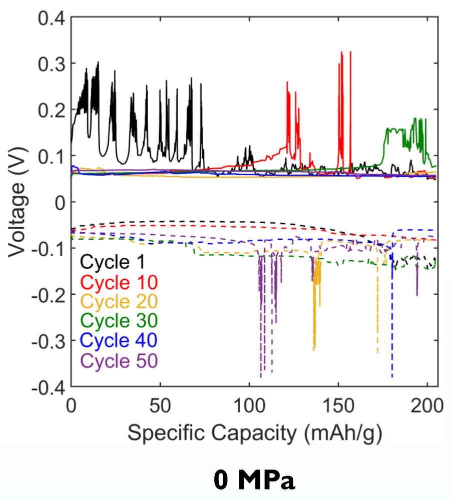
Pressure Clamp (side)



Gas Analysis Setup

- Pressure clamp calibrated using a force sensor to relate nut torque to resulting force.
- Zn and ZnO pasted electrodes were prepared with PTFE binder.
- Symmetric Zn metal cells were assembled in polypropylene boxes with mildly acidic electrolyte, then clamped.
- Full ZnO/NiOOH cells were assembled in polyethylene pouches with alkaline electrolyte, then clamped.
- Zn/Zn cells in acidic electrolyte were tested for fastest achievable C-rate.
- Alkaline cells were placed into a sealed gas analysis fixture; internal gas was sampled by an SRS mass spectrometer to measure hydrogen gas generation.

Results: Zn/Zn Cells in Mildly Acidic



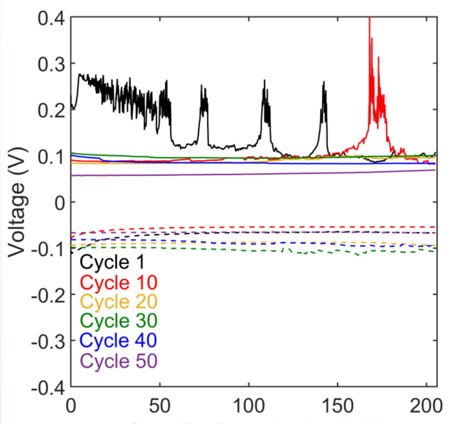
0 MPa
Max: C/20

Cell Details:

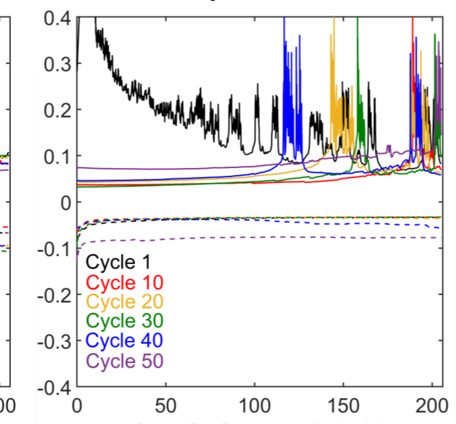
- Symmetric Zn cells cycled at maximum possible C-rates.
- Electrolyte: 10 mL of 5 m KOAc(aq):HOAc, 96:4 (pH=6.2).
- Cycling: 25% utilization (Zn) between 1.0V and -1.0V.
- Electrode oxidation/reduction [6]: $Zn \rightleftharpoons Zn[(H_2O)_6]^{2+} + 2e^-$

Results:

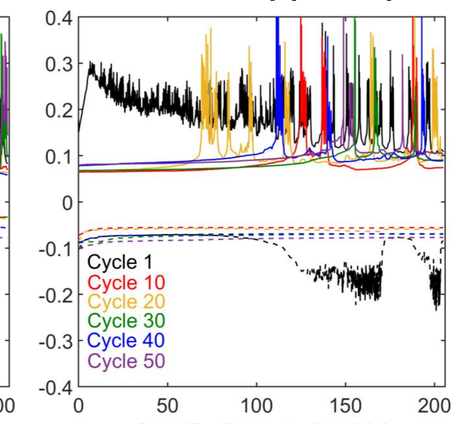
- Cells at moderate pressure (0.67 MPa) achieved the highest C-rate.
- Low- and high-pressure cells (0 and 3.16 MPa) could only cycle at C/20.
- Cell polarization increases with applied pressure.



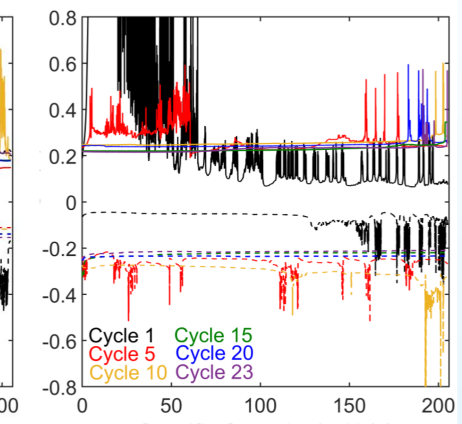
0.67 MPa
Max: C/5 – C/10



1.51 MPa
Max: C/10

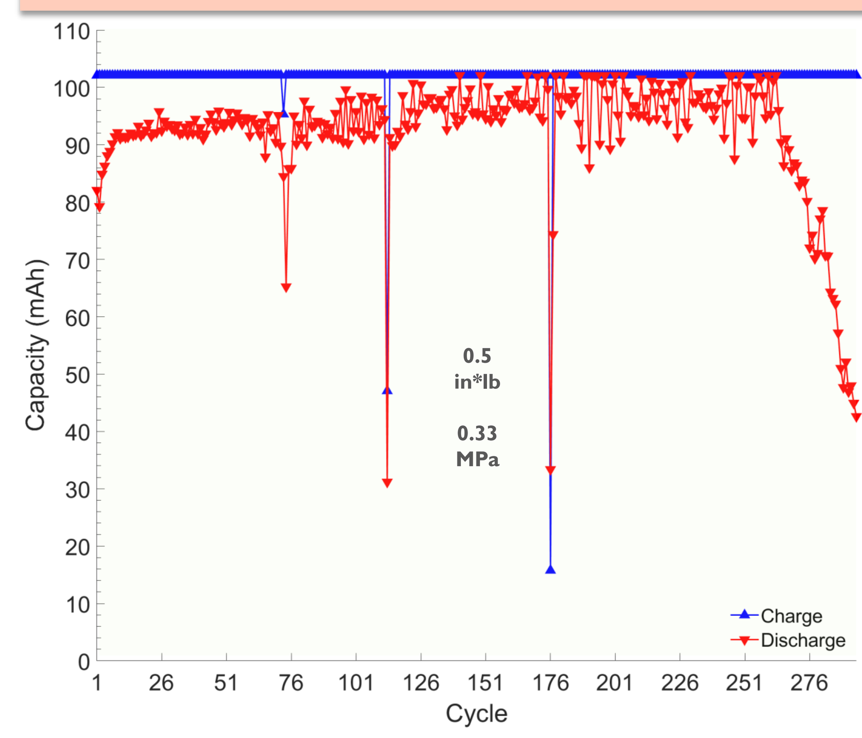


2.37 MPa
Max: C/10 – C/20

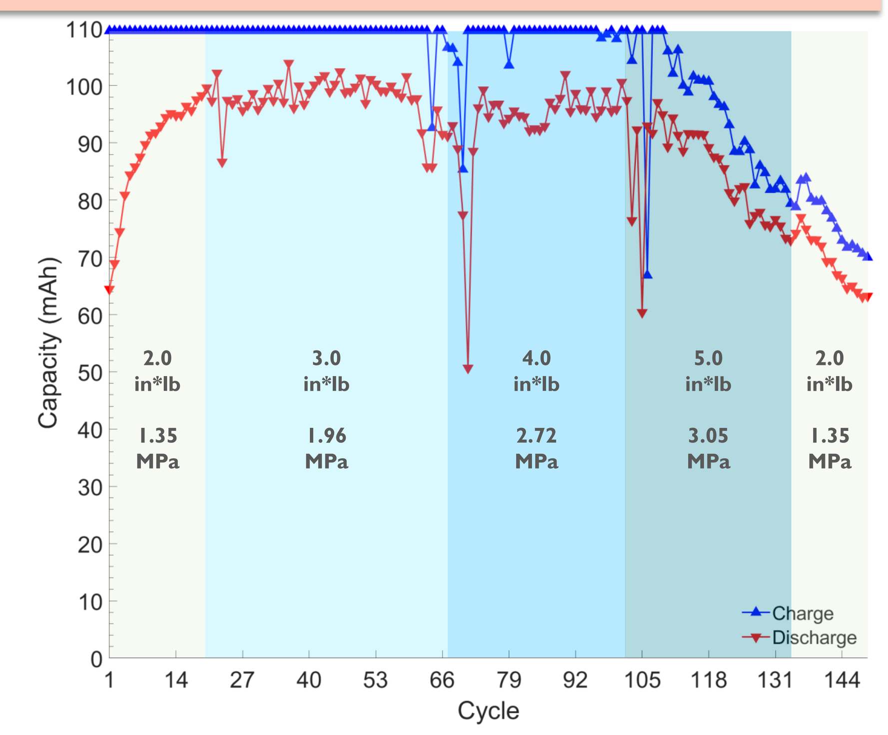


3.61 MPa
Max: C/20

Results: ZnO/NiOOH Cells in Alkaline



Low torque cell



Varying torque cell

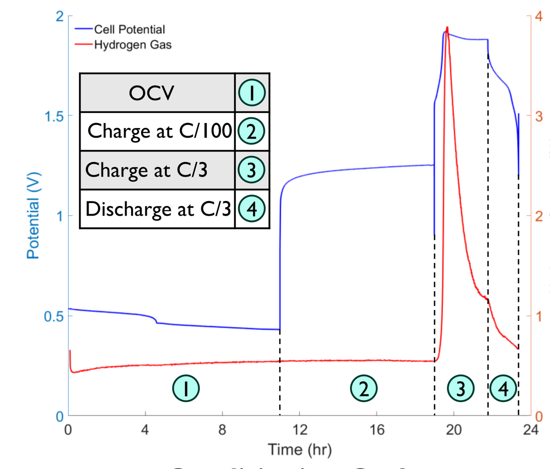
Cell Details:

- Anode: $ZnO/Ca(OH)_2/Bi_2O_3$/PTFE.
- Cathode: NiOOH.
- Electrolyte: 20 wt.% KOH.
- Cycling: 30% utilization (ZnO) at C/3 between 1.2V and 1.98V.
- Cell charge/discharge reactions:
  $ZnO + 2Ni(OH)_2 \rightleftharpoons Zn + 2NiOOH + H_2O$

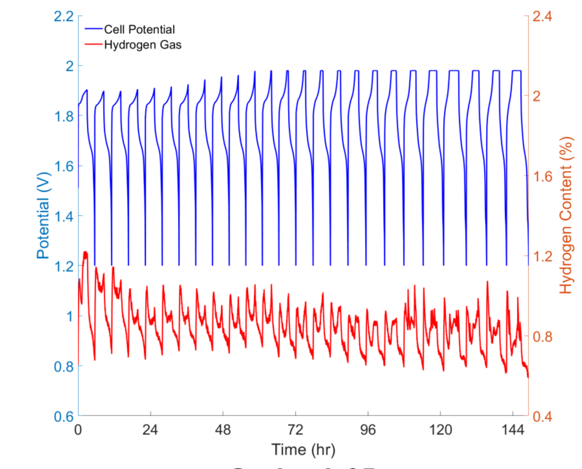
Results:

- Low torque cell (0.33 MPa) shows high Coulombic efficiency.
- Varying torque cell shows a decrease in charge and discharge capacities past 3.05 MPa.
- Cell capacity does not recover after alleviating pressure.

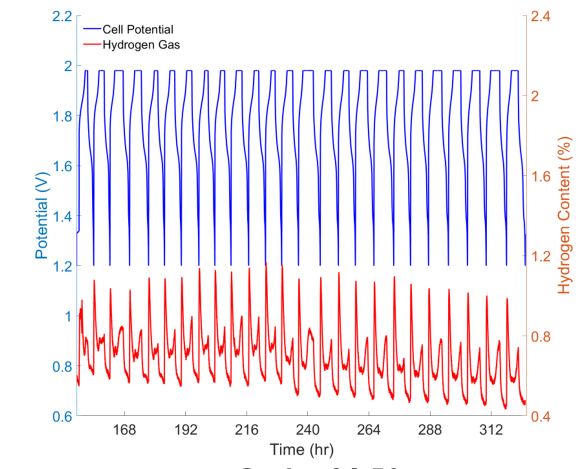
Results:



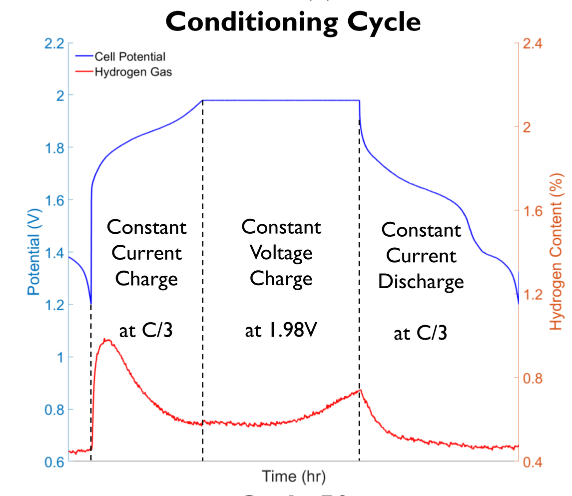
Conditioning Cycle



Cycles 1-25



Cycles 26-50



Cycle 50

Cell Details:

- Same design and cycling profile as alkaline ZnO cell.
- Mass spectrometer analyzes gas composition every ~15 sec.

Results:

- Significant H_2 generation during conditioning charge at C/3.
- Gas generation has a cyclic behavior.
- Most H_2 is generated during initial CC charge.
- Some H_2 is generated during the end of CV charge.
- Little H_2 is generated during discharge.

Conclusions

- Results show that pasted zinc-based electrodes cycle better with some applied pressure, but worse when the applied pressure is too low or too high.
- Experiments in a mildly acidic electrolyte suggest that zinc electrodes can achieve faster C-rates at moderate pressure.
- Alkaline full cell experiments show that too much pressure can permanently damage cells, reducing both charge and discharge capacities and therefore cycle life.
- Results indicate that applied pressure is an important design factor for zinc-based batteries.
- Hydrogen gas study shows that hydrogen forms at beginning of CC charge and end of CV charge.
- Currently studying the effect of pressure on cycle life, degradation, and C-rates for full cells.

References

[1] https://www.thoughtco.com/zinc-facts-606621
[2] https://beminimalist.co/blogs/skin-care/zinc-oxide-a-magical-shield-for-your-skin?srsltid=AfmBOoqEQK59mB1FR5aFfZc7T0RADg5ItmYbfX1mt0bNyJzcsVeuqJPH
[3] Kordesch, K., Gsellmann, J., Peri, M., Tomantschger, K., & Chemelli, R. (1981). The rechargeability of manganese dioxide in alkaline electrolyte. *Electrochimica Acta,* 26(10), 1495-1504.
[4] Maeda, K., Moritoki, M., Yae, S., Fukui, K., Fukumuro, N., & Sugahara, T. (2022). Pressure-induced evolution in the durability of nickel–metal hydride batteries under high-current charge. *Physical Chemistry Chemical Physics*, 24(22), 14085-14091.
[5] Müller, V., Scurtu, R. G., Memm, M., Danzer, M. A., & Wohlfahrt-Mehrens, M. (2019). Study of the influence of mechanical pressure on the performance and aging of Lithium-ion battery cells. *Journal of Power Sources*, 440, 227148.
[6] Wu, D., Housel, L. M., Kim, S. J., Sadique, N., Quilty, C. D., Wu, L., ... & Takeuchi, K. J. (2020). Quantitative temporally and spatially resolved X-ray fluorescence microprobe characterization of the manganese dissolution-deposition mechanism in aqueous Zn/α-MnO_2 batteries. *Energy & Environmental Science*, 13(11), 4322-4333.

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.
SAND# SAND2026-21106D

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