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Zinc-Ion Battery Research and Development: A Brief Overview

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***Abstract* — With the advancement in the technology of lithium-ion batteries, the popularity and awareness of rechargeable, durable, long-lasting, and lightweight ion batteries have been in the public eye for a while now. Lithium-ion (Li-ion) is not the only type of ion battery out there. Zinc-ion (Zn-ion) batteries are a heavier, but safer, cheaper, and environmentally friendly form of this battery technology that has uses when portability is not the primary objective. One such use case is large format energy storage for intermittent renewable energy such as solar and wind fields for when the sun is no longer shining, or the wind blowing. One of the disadvantages of Zn-ion batteries is that the current battery life needs to be increased to stand a chance against Li-ion batteries in terms of consumer demands. This paper describes the effect of electrode structures and charging/discharging rates on battery cycle life in coin cells. The symmetric cell study shows that higher charging/discharging rates decrease the battery's cycle life, and the polymer-coated Zn anodes improve the battery's cycle life. It is also noted that maintaining good contact with all the major components in batteries is crucial for batteries to work properly. The battery-making process carried out in the lab and the important details of battery manufacturing are described in this manuscript.**

***Keywords* — Anode, Battery, Cycle Life, Energy.**

I. Introduction

The promise of having renewable energy is filled with fields of solar panels and wind turbines. However, these sources of energy cannot continuously produce power. Solar panels are only able to produce power when the sun is shining, and the amount of power depends on the intensity of the solar rays. Likewise, wind turbines can only produce power when the wind is blowing, and the amount of power depends on the strength of the wind. While combining these two sources of energy can help fill the gaps in generation and keep power available by overlapping, it cannot be certain that they always will. Eventually, they will both stop producing enough power at the same time, leading to a blackout. If humanity is to see a green future without the pollution of fossil fuels, this is a problem that needs a viable solution. The need for energy storage when no power is produced is essential for the future of green energy. It is easy to see why some might look to the technology of the lithium-ion battery. It is a high energy density, high power, lightweight, and market-dominant rechargeable battery. After all, there are many products on the market that claim to be portable power banks, and there are even electric vehicles powered by lithium-ion batteries. An article written by Thomas L. Gibson and Nelson Kelly has looked at the charging of lithium-ion batteries via solar panels [4]. The article states "It is envisioned that individual homeowners could charge electric and extended-range electric vehicles from residential, roof-mounted solar arrays, and thus power their daily commuting with clean, renewable solar energy" [1]. While lithium-ion batteries seem like the solution, these batteries are not only expensive but dangerous to both the environment and people when overheated or punctured. They are also specifically designed for lightweight applications involving transportation or portability. When a battery is needed as a stationary storage medium for widespread use, weight is not an issue, which means lithium does not need to be the metal for the anode of the battery. This is where the zinc-ion battery comes into play. Not only is zinc far cheaper than lithium, but it can also be used with an aqueous electrolyte solution, meaning it is not nearly as toxic as some of the electrolytes used in lithium-ion batteries where water cannot be used. Aqueous electrolytes would react with the lithium to produce hydrogen gas and explode. This paper describes the research related to these zinc anodes for use in zinc-ion batteries, and the results of different ways of charging as well as different coatings to put on these anodes to further the lifespan of the battery.

II. Literature Review

Despite the development of alkaline zinc batteries in the late 1800s, rechargeable non-alkaline zinc-ion batteries are a relatively new technology "Since they were first developed in 1899, Zn-ion batteries featuring an alkaline electrolyte became an important energy storage device, accounting for ~80% of the batteries manufactured in the U.S. in 2010. In recent years, however, the rechargeable Li-ion batteries (LIBs) have superseded older technologies." [2] According to Wikipedia, the first zinc-ion battery was made in 2011[3]. As one might suspect, this new research came about due to the importance of its creation. In fact, the United States Navy put out a proposal call in 2021 for zinc batteries in some of their naval vessels [4]. The proposal states "The U.S. Navy Submarine Fleet main storage battery currently employs Valve-Regulated Lead-Acid (VRLA) technology to meet platform energy and power requirements. However, with the increasing reliance of electronics on large platforms, future mission needs will require additional battery capacity beyond what current lead-acid battery technology is able to provide.

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The submarine battery compartment cannot be expanded, so VRLA technologies have seemingly reached operational limits. Therefore, there is a mounting need to transition from the current VRLA battery to an alternative battery technology with a higher energy density and improved reliability. Accordingly, NiZn battery technology has the potential to bridge the energy density gap until Li-ion battery technology can be made reliably safe for submarine applications." [4]. As mentioned above, Li-ion batteries currently cannot meet the safety requirements needed on their ships. To meet these safety requirements, they looked to employ the help of Zn batteries. This is also one of the many key points of the Zn-ion battery. Other key themes one might read about Zn-ion batteries are their features, such as, low cost and environmental safety. While these positive themes are compelling at first glance, there are negative themes as well, such as, optimization of the anode/cathode materials and the electrolyte solution used [5]. This is a very important part of the battery, and if the relevant problems are not solved, the life span will be short. One specific problem being faced is the growth of dendrites on the anode's uneven surface. Dendrites are small, sharp crystals that grow on the anode's surface due to the electrochemical reactions in the battery. The problem with these dendrites is that when they grow normal to (perpendicular to) the anode, they will puncture the separator between the anode and cathode. When this happens, the battery will short circuit and kill the battery. The process of how this problem was studied can be found in the methodology.

III. Methodology

The stability of the anode was studied with symmetric cells which use same electrodes as cathode and anode in the battery. The overall test involved two sets of four different symmetric cells, making a total of eight cells. These cells had two main differences from each other. Four cells had bare zinc electrodes while the other four had polymer-coated zinc electrodes. Two of each battery were charged and discharged at 5mA while the others were charged/discharged at 1mA to show the relationship between the longevity of a battery and how fast a battery is charged over time.

A. *Preparation of Electrodes*

The electrodes were made by cutting two sheets of zinc from a larger roll.

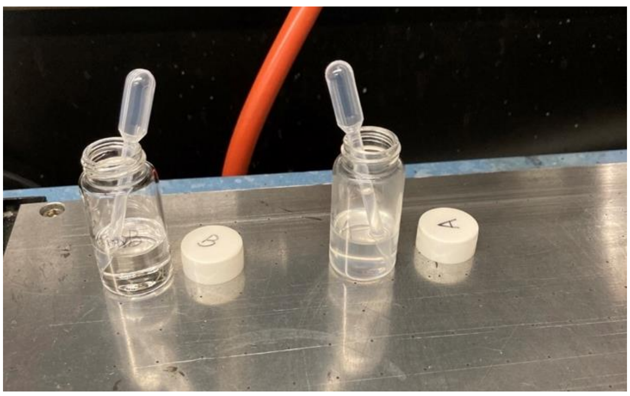

Fig. 1. Solutions A and B used to form the polymer coating.

One of these sheets was coated in an undisclosed polymer coating (see Fig. 3), and the other one was left as bare metal. The polymer coating is put onto the zinc sheet by using a doctor blade (See Fig. 2) by putting two solutions labeled Solution A and Solution B (See Fig. 1). These two solutions, when mixed together form the polymer coating, similar to how a two-part epoxy works. After preparing the zinc sheets, anodes were cut from the sheets by using a punch and die machine (see Fig. 4).

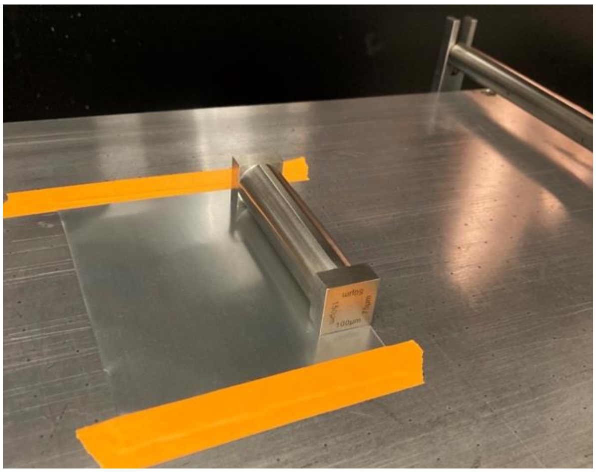

Fig. 2. Spreading blade and zinc sheet on top of spreading table.

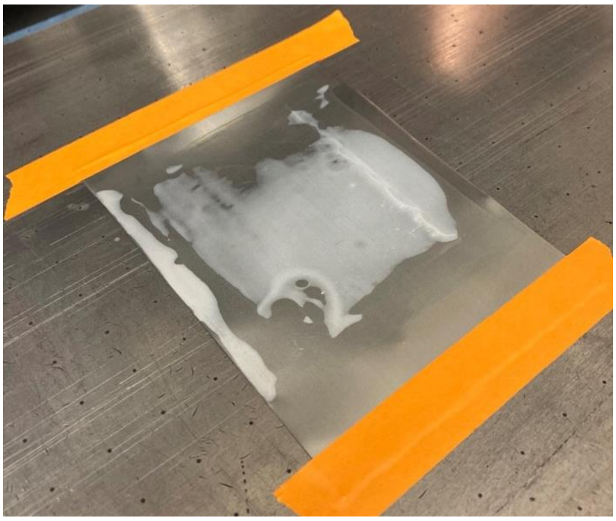

Fig. 3. Polymer coating spread across zinc sheet.

Fig. 4. Anodes cut out by punch and die.

B. Assembling the Coin Cells

After the electrodes were punched out, the electrodes were assembled into coin cells (like the batteries used in wristwatches). To do this, the cells were layered with two electrodes, a separator between them, and suspended in a solution of ZnSO4 (see Fig. 5). These were then crimped together in a hydraulic press (see Fig. 6) and put into the testing machine to undergo their charge/discharge cycles.

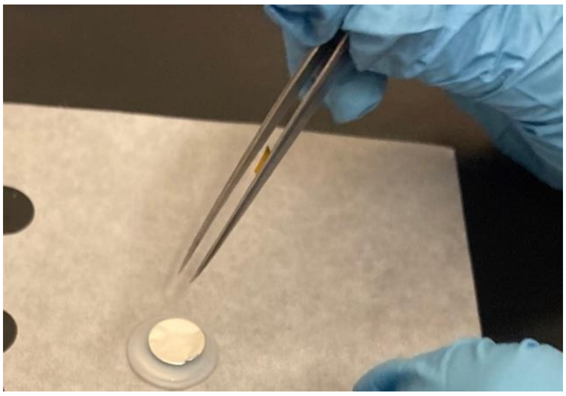

Fig. 5. Assembling the components of the coin cell.

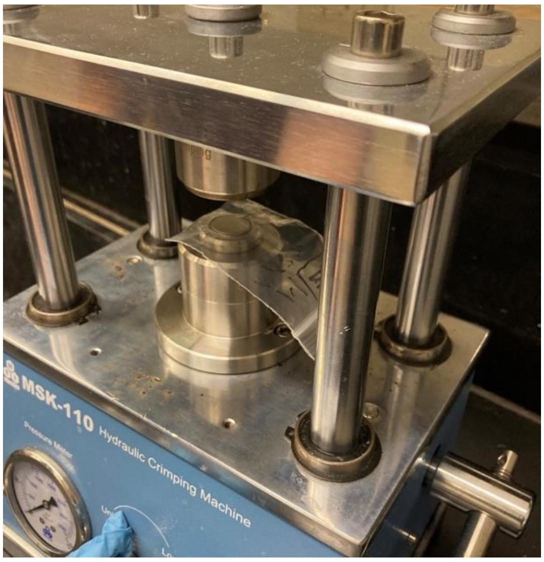

Fig. 6. Crimping machine used to finalize coin cell.

IV. Results

While hooking the cells up to the testing machine and putting them through the charge/discharge cycles, the program recorded graphs of the voltages over time. The results show that the polymer-coated zinc cells far outperformed the bare zinc cells. As shown in the figures below, the bare zinc cells only lasted around 40 cycles before dying, the polymer-coated zinc lasted over 100 cycles. The samples tested at 5mA fared worse and died off more quickly than the 1mA samples. This was to be expected and is usually the case with higher intensity charging due to the strain it puts on the cells.

V. Conclusion

There are many advantages to having a rechargeable Zinc-ion battery, such as, survival during harsh conditions,

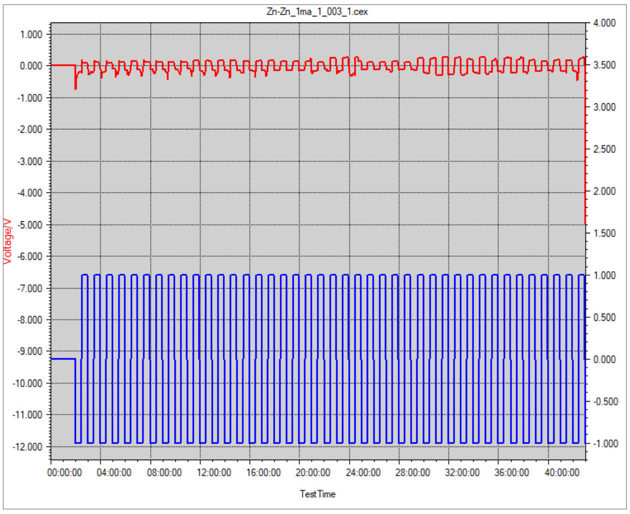

Fig. 7. Bare zinc cell performance at 1mA.

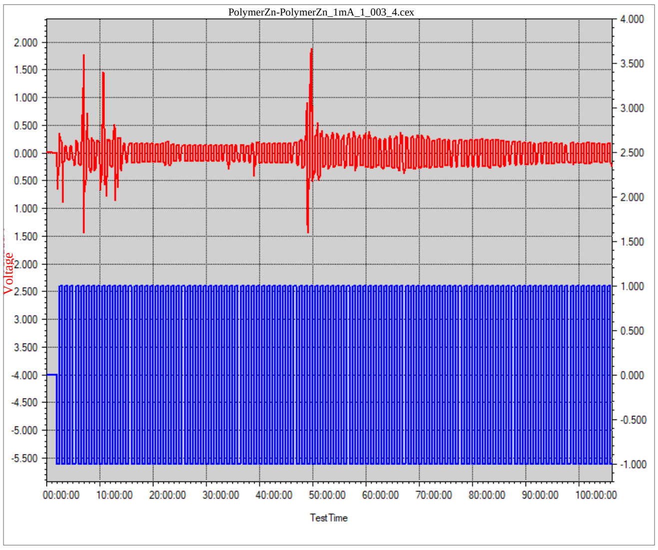

Fig. 8. Polymer-coated zinc performance at 1mA.

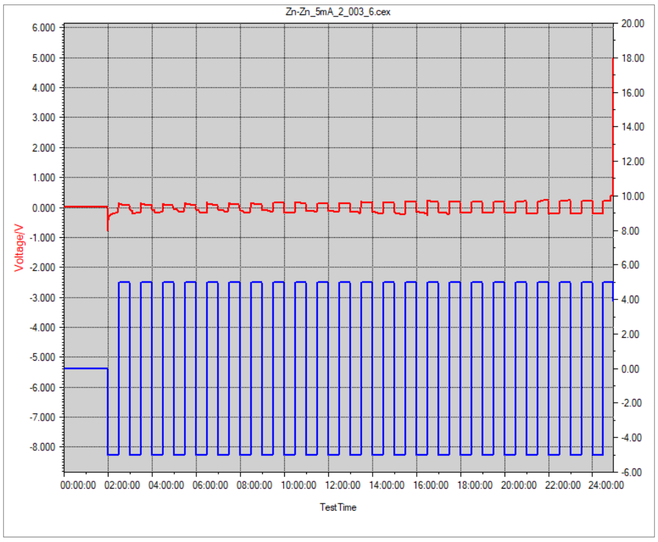

Fig. 9. Bare zinc cell performance at 5mA.

relatively cheap to produce, and more environmentally friendly than the lithium-ion battery. With the downsides yet to be ironed out, the research into how to produce this zinc-ion battery continues. Efforts are being made to solve many problems that come with these new batteries. The solutions to these problems will lead to better cathode materials, improved cell construction, and more. This will make possible the future of green energy and will result in new and improved energy storage for other technologies such as electric vehicles. and pave the way to a better tomorrow.

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