Comparison study of the performance of aqueous zinc-ion batteries using carbon paper and Ti mesh and foil currents collectors

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1. Introduction

With the increasing growth of the use and development of different renewable energy sources [1] The need for well-developed energy storage devices is crucial for large-scale spread, applications, and accessibility [2] aqueous Zn-ion batteries (AZIB) stand as a promising candidate for energy storage systems because of their distinctive properties, including low-cost electrode materials, safe electrolytes, and high ionic conductivity [3] significant effort has been put to the development of all core components of aqueous zinc-ion batteries (ZIBs), including cathodes, stable zinc anodes, and advanced electrolytes, to overcome limitations in cycling stability and energy density [4] Nevertheless, compared to the other components, no significant efforts have been dedicated to improving the current collectors used in RZIBs, which are a prime part of the battery [5] Current collectors have numerous roles in AZIBs (as shown in Fig.1.)[6] .

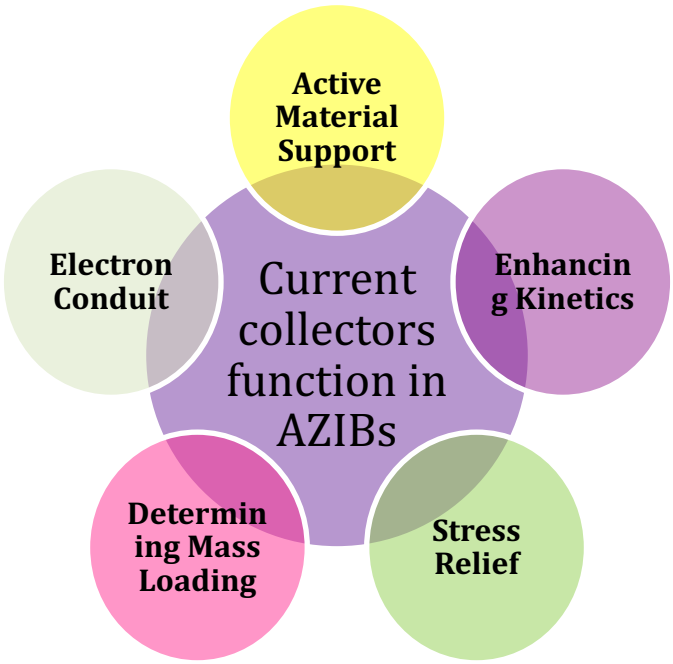


Fig.1. Current collectors' roles in AZIBs

In addition, picking the suitable substrate material for current collectors is crucial for improving battery performance [7]. Therefore, a comparison study was carried out to investigate the performance of ZIBs with Zn-HCF-based cathodes with different current collectors.

2. Objectives

- Developing the new generation of batteries by enhancing both their stability and performance by modifying the components of a rechargeable battery specifically the current collector.
- Comparing the performance of aqueous zinc-ion batteries with Zn-HCF based cathode with various current collectors as picking the suitable substrate material for current collectors is crucial for improving battery performance.
- To identify the most cost-effective and durable current collector material for next-generation practical aqueous zinc-ion batteries by evaluating its performance Zheng-HCF cathode materials.

3. Methodology

3.1. Preparation of Zn-HCF Cathode Material

Zn-HCF was synthesized via a simple co-precipitation method. 100 mL ZnSO4 solution was added dropwise into 100 mL K3Fe(CN)6 solution over 1 h under vigorous stirring. The suspension was stirred for 4 h, aged for 2 h, collected by centrifugation, washed three times with deionized water, and dried in air at 80 °C for 6 h.

3.2. Cathode Preparation

3.2.1. Ti mesh current collector

- Zn-HCF, Super C, and PTFE (7:2:1) were mixed homogeneously in water and blended under infrared heating until the desired texture was obtained.
- The mixture was rolled horizontally and vertically to 40 µm, then to 30 µm, and finally in one direction to 20 µm thickness.
- The resulting film was air-dried for 48 h, cut into small pieces, and loaded into 12 mm diameter Ti mesh discs.

3.2.2. Ti foil and carbon paper current collectors

- Zn-HCF active material, Super C, and PVDF were blended in NMP with a weight ratio of 7:2:1.

- The slurry was coated onto Ti foil and carbon paper current collectors and dried under vacuum at 60 °C overnight.
- Cathodes were cut into 12 mm diameter discs, with active material loading of ~1-2 mg cm^{-2}.

3.3. Electrolyte Preparation

1.1128 g of Zn(OTf)2 was dissolved in water to prepare 1 M zinc trifluoromethanesulfonate electrolyte.

3.4. Characterization

- XRD was used to analyze crystalline phases.
- SEM was employed to study microstructures.

3.5. Electrochemical Measurements

- Galvanostatic charge/discharge (GCD) and C-rate performance were evaluated.
- Cyclic voltammetry (CV) was conducted on a Bio-Logic VSP-300 electrochemical workstation.

4. Preliminary results and findings

4.1. Characterization

The SEM image is taken at 5500× magnification, scale bar 1 µm. The particles are mostly cubic-like crystals, consistent with the known cubic framework structure of Prussian blue analogues (PBAs) such as Zn-HCF. While particle sizes seem to be around ~1 µm. The XRD experimental peaks align strongly with the cubic Zn-HCF PDF#038-0687 Although some minor peaks could indicate traces of rhombohedral phase, but the dominant structure is clearly cubic. Therefore, we can conclude that the correct material was obtained, and it has the right structure according to the obtained XRD and SEM data.

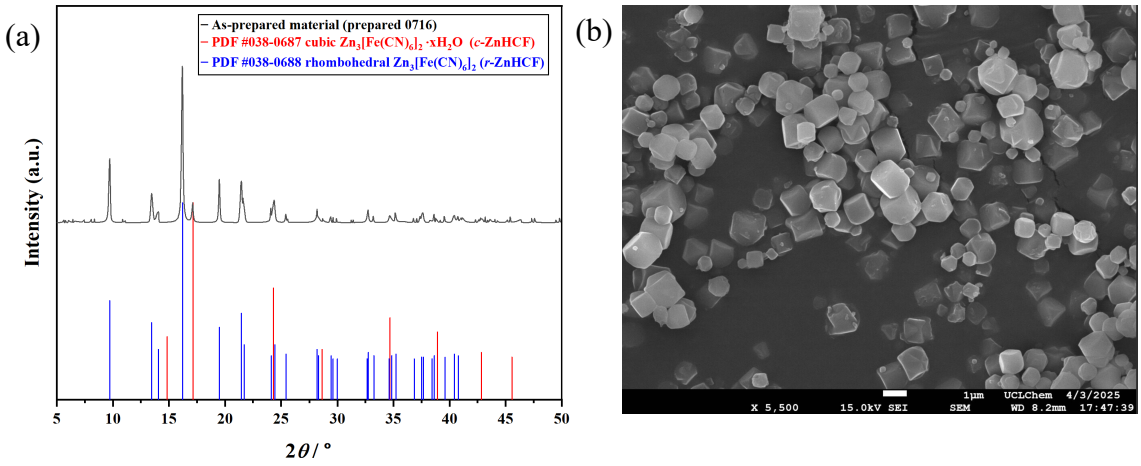


Fig.2. (a) X-ray diffraction patterns of Zn-HCF. (b) The SEM image showing the morphology of Zn-HCF.

4.2. Electrochemical Measurements

4.2.1. Cyclic Voltammetry (CV)

Ti mesh shows outstanding, highly reversible battery behavior with the highest current response which indicates fast kinetics. Carbon Paper shows clear battery behavior but with lower current response.

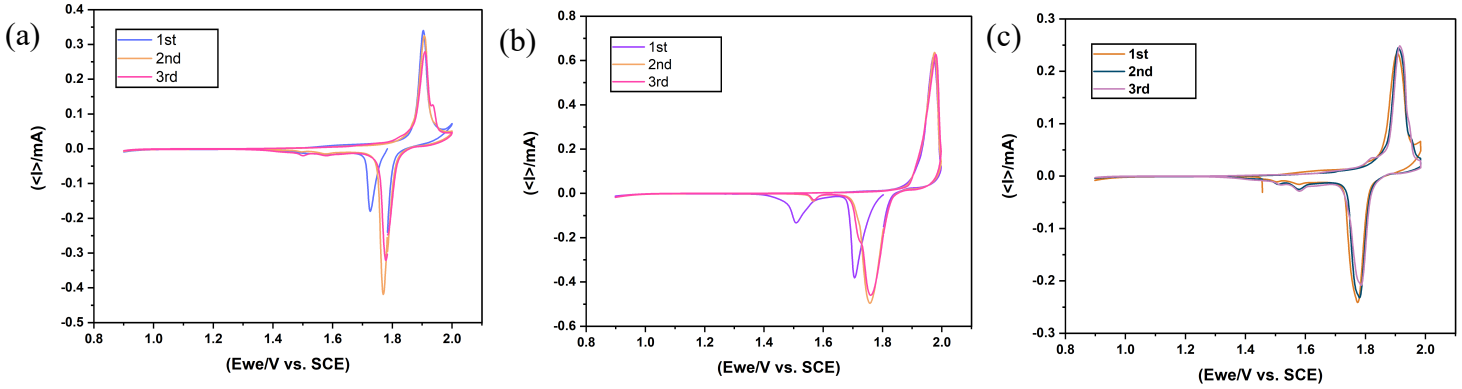


Fig.3. The cyclic voltammetry (CV) curves at a scan rate of 0.1 mV/s for (a) carbon paper (b) Ti mesh (c) Ti foil current collectors.

4.2.2. Galvanostatic Charge/Discharge (GCD)

Ti Mesh delivers the highest capacity with exceptional efficiency which could be attributed to its 3D porous structure providing high surface area, allowing for better conductivity. Whereas carbon paper delivers a good, stable capacity and Ti Foil (Poorest Performance) delivers a very low capacity.

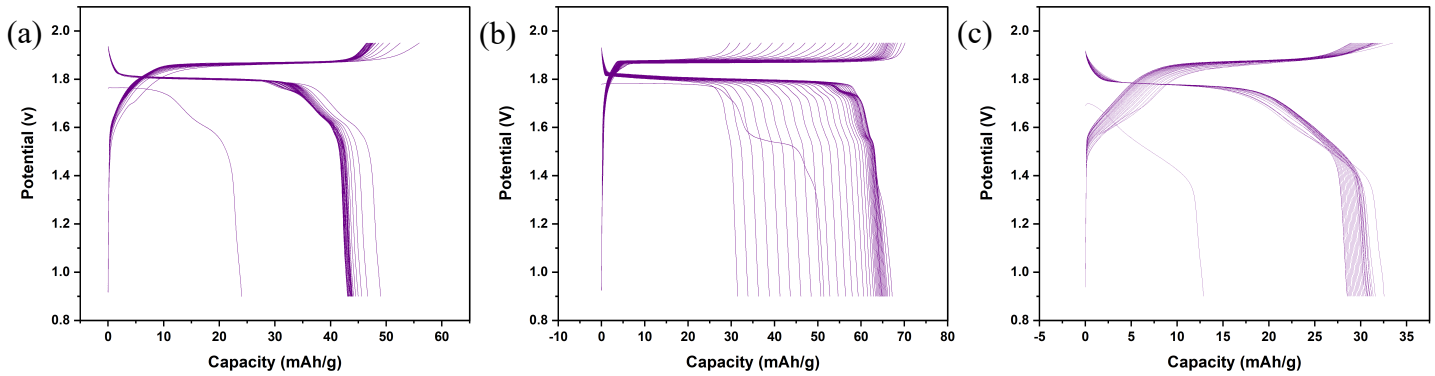


Fig.4. The cyclic voltammetry (CV) curves for (a) carbon paper (b) Ti mesh (c) Ti foil current collectors.

4.2.3. Cyclic Performance

Ti mesh has high initial capacity but catastrophic capacity fade which is very poor stability. Carbon paper starts with lower initial capacity but superior capacity retention maintaining the best stability. And when it comes to Ti foil it has very low initial capacity and also poor stability.

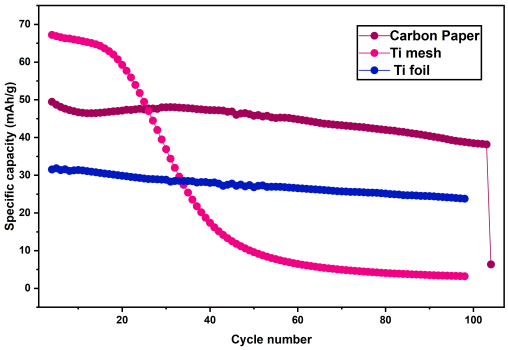


Fig.5. Cyclic performance of ZnHCF//Zn cells using a Zn foil anode and 1M Zn(OTF)2 aqueous electrolyte.

4.2.4. Rate-performance

Ti mesh has excellent C-rate as it shows the smallest relative drop in capacity when the C-rate is increased from 0.2C to 3C which could be attributed to its 3D structure. Carbon paper and Ti foil shows a large, steady drop in capacity.

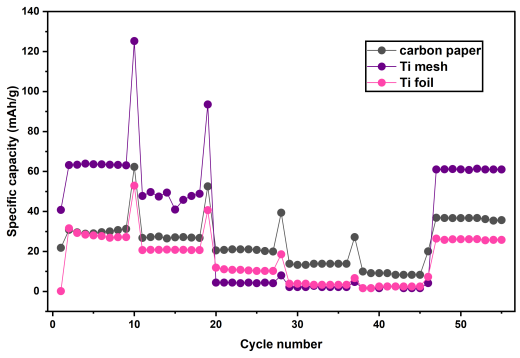


Fig.6. Rate-performance of ZnHCF//Zn cell at 0.2C, 0.5C, 1C, 2C, 3C, using a Zn foil anode and 1M Zn(OTF)2 aqueous electrolyte.

5. Conclusion and Future Work

In conclusion, the performance of aqueous zinc ion batteries was compared with three different current collectors. Where Ti mesh showed exceptional capacity and c-rate, surpassing Ti foil, emphasizing the effect of the material structure and carbon paper showed good properties, standing as the most stable current collector out of the three. This work provides a good guide to choosing the most suitable collector out of the three tested ones. Future work could focus on developing simulation approaches (e.g., high-throughput and virtual screening) to identify promising current collector materials and define structure–performance limits. Additionally, exploring simple, low-cost fabrication methods could improve mechanical properties and compatibility with commercial roll-to-roll manufacturing. Finally, performance evaluation of current collectors at larger scales will help assess their suitability for commercialization.

6. Challenges and obstacles encountered

The time was limited and working under a relatively short deadline while some experiments failed at multiple attempts and needed further optimization. In addition, to some technical issues where some test files couldn't be opened or had some weird data. Overall, we overcame these difficulties.

Acknowledgements

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