



Preparation and Characterization of Starch-Based Hydrogel Electrolyte Membrane for Quasi-Solid-State Rechargeable Alkaline Zinc Battery[†]



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ABSTRACT

The development of hydrogel electrolytes is a crucial and urgent task to achieve reliable rechargeable alkaline zinc batteries. We have successfully prepared a starch-based hydrogel electrolyte membrane (SHEM) that holds a (4 mol dm⁻³ (= M) KOH + 0.3 M ZnO) aqueous solution. The prepared SHEM was so flexible that it could be stretched and bent freely, and showed high ionic conductivity comparable to that of the alkaline aqueous solution. A pouch-type Zn/Zn cell with SHEM did not short-circuit for more than 24 h, and uniform Zn deposition without dendritic growth was confirmed in scanning electron microscope images. In the charge-discharge cycle test of a pouch-type Zn/MnO₂ cell with SHEM, it was demonstrated that SHEM can fully function as an electrolyte for quasi-solid-state rechargeable alkaline zinc batteries.

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Keywords : Quasi-solid-state Rechargeable Zinc Battery, Hydrogel Electrolyte Membrane, Starch, Alkaline Solution

1. Introduction

The use of fossil fuels has a negative impact on the environment, which has led to the development of renewable energies such as geothermal, wind, and solar energy. However, because of the intermittent and unstable nature of these energies, their applications are limited. Rechargeable batteries are effective energy storage systems that can store and conveniently use excess energy generated from renewable energies.¹ Lithium-ion batteries are often used for large-scale energy storage applications, but their energy density is approaching its limit.² Thus, there is an urgent need to develop next-generation rechargeable batteries with high energy density. Currently, rechargeable batteries that use metallic lithium and metals with multi-electron redox reactions such as Mg, Zn and Al are being investigated.^{3,4}

Zinc is abundant in global reserves and has a low standard potential of -0.76 V vs. standard hydrogen electrode, a high theoretical gravimetric and volumetric capacities of 820 mAh g⁻¹ and 5854 mAh cm⁻³, respectively, and high hydrogen overpotential of 0.72 V.⁵ Rechargeable alkaline zinc batteries (RAZBs), which use zinc as the negative electrode and alkaline electrolyte solution, are attracting attention due to safety and low cost in addition to the inherent advantages of zinc.^{5,6} However, the practical use of RAZBs is greatly hindered by problems at the negative electrode such as hydrogen evolution reaction (HER), corrosion, surface passivation and dendritic growth, which reduces the reversibility of Zn deposition/dissolution and decreases the charge-discharge cycle stability of RAZB.⁵ Much research has been done to solve these

problems in RAZB, including optimization of electrolyte composition and additives,^{7–9} construction of film-like solid electrolyte interphases,^{10–12} structural engineering of negative electrode surfaces,^{13–15} and use of polymer hydrogel electrolytes.^{16,17} Among these strategies, the use of polymer hydrogel electrolytes has attracted much attention due to the following aspects: (1) the interwoven molecular structure of polymer matrix contributes to a uniform ionic flux in the electrolyte, resulting in uniform Zn deposition on the negative electrode,^{18,19} (2) the host polymers often have numerous polar groups that hydrate or interact with water molecules in the electrolyte, reducing water activity and mitigating side reactions such as HER and corrosion,^{20,21} (3) the cation transference number can be increased by introducing anionic groups into the host polymer.²² The advantages of the zinc metal negative electrode in contact with polymer hydrogel electrolyte were demonstrated by a significant improvement in performance, including the suppression of dendrite formation and side reactions, which resulted in an extended cycle life.

Physical gels are formed by a three-dimensional network of non-covalent intermolecular interactions, including hydrogen bonds, hydrophobic interactions, and electrostatic interactions, among others.^{23,24} They are distinguished from chemical gels, which are chemically cross-linked. Consequently, physical gels are flexible and elastic, and can be reversibly deformed in response to external forces, and utilized in medical devices and flexible electronics.²⁴ Physical gels derived from polysaccharides, such as cellulose and alginic acid, which are naturally occurring polymers, demonstrate environmental adaptability and are biodegradability, thereby reducing environmental impact. Furthermore, physical gels have a high water content and exhibit high permeability to molecular and ionic diffusion. This facilitates the transport and exchange of substances, which is an important property in applications such as electrolytes and biosensors.²⁵

Starch is one of polysaccharides, and forms physical gel containing a large amount of water by gelatinization. Starch-based hydrogel membranes have been prepared from starch, water and glycerol as a plasticizer,^{26,27} and the resultant membranes have been

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applied in a variety of fields such as food packaging and medical materials.²⁸ Recently, SHEMs have been prepared by immersing starch-based chemical and physical gel membranes in alkaline solutions and applied to zinc-air batteries,^{29,30} but, there have been no reports on starch-based hydrogel electrolytes for rechargeable alkaline zinc battery. In this study, a simple method was developed for the preparation of SHEMs via a direct process involving the use of starch and an alkaline solution without the necessity for cross-linking agents and plasticizers. The prepared SHEM was characterized and applied to RAZB.

2. Experimental

2.1 Materials

All chemical reagents and raw materials were commercially purchased and used without further purification. The starch, which is derived from corn, ZnO, MnO₂, KOH and N-methyl-2-pyrrolidone (NMP) were purchased from Fujifilm Wako Chemicals. Zn foil (thickness: 0.2 mm), Cu mesh (100 mesh) and Cu foil (thickness: 0.05 mm) were purchased from Nilaco Corporation. Membrane filter (4-904-27) was purchased from Advantec MFS, Inc. Nickel foam was purchased from Sumitomo Electric Industries, Ltd. Ketjen black (EC300J) was purchased from Lion Specialty Chemicals. Polyvinylidene fluoride (PVDF) was purchased from Sigma-Aldrich Co., LLC.

2.2 Preparation of SHEM

The SHEM preparation process is shown in Fig. 1a. 8 g of starch powder was mixed with 40 mL of (4 M KOH + 0.3 M ZnO) aqueous solution, followed by stirring for 40 h to prepare 0.2 g mL⁻¹ starch sol electrolyte. The resultant opaque homogeneous starch sol electrolyte was placed in a glass petri dish, and dried at 50 °C for 20 h to form an SHEM. The SHEM was immersed in the (4 M KOH + 0.3 M ZnO) aqueous solution for 5 min before each electrochemical measurement.

2.3 Characterization of SHEM

Scanning electron microscope (SEM) images and elemental maps obtained by energy dispersive X-ray spectroscopy (EDS) for the SHEM were measured by using a JCM-6000Plus (JEOL, Japan). Before measurements, SHEM was dried at 30 °C for 48 h. Fourier transform infrared (FTIR) spectra of the SHEM and starch powder were measured by using an FT/IR-6100FV (JASCO, Japan). The impedance measurement to evaluate ionic conductivity was performed by using an SI 1260 (Solartron, Japan) in the frequency range of 10⁵–10⁻² Hz. An AC perturbation signal was 5 mV. Rheological data were collected at 25 °C using an MCR102e rheometer (Anton Paar, Austria). A 25 mm parallel plate geometry was used. The gap between both plates was kept at 1 mm. The strain

amplitude sweep tests were conducted at a frequency of 1 Hz, and a strain ranging from 10⁻³ to 10³ %.

2.4 Assembly and electrochemical characterization of an asymmetric Cu/Zn cell and a symmetric Zn/Zn cell

Pouch-type asymmetric Cu/Zn and symmetric Zn/Zn cells were assembled as follows. The prepared starch SHEM (1.5 × 1.5 cm², thickness: ca. 1 mm) was sandwiched between two Zn foil electrodes (1 × 1 cm²) or Cu foil electrode (1 × 1 cm²) and Zn foil electrode (1 × 1 cm²), and this membrane-electrode assembly was wrapped by an aluminum laminate sheet. The pouch cell was sealed by clamping and hot pressed for 3 s at 60 °C. A similar procedure was also applied to the (4 M KOH-0.3 M ZnO) aqueous solution, except that a glass fiber filter was used instead of SHEM. The volume of the aqueous solution was 2 mL.

The CV measurement was performed by using an SI 1280B (Solartron, Japan) with an asymmetric Cu/Zn cell. The scan speed and range were 5 mV s⁻¹ and 0.5—0.5 V, respectively. The Charge-discharge cycle test was performed by using an HJ1001SD8 (Hokuto Denko, Japan) with a symmetric Zn/Zn cell. The current and time for charging and discharging were 1 mA and 30 min, respectively. X-ray diffraction spectrum of the Zn foil electrode after the charge-discharge cycle test was measured using a AERIS instrument (Malvern Panalytical, Japan) with a CuKα source (2θ = 0.1541 nm; 50 kV; 30 mA; 2° min⁻¹). The morphology of the Zn foil electrode before and after the discharge-charge test was analyzed using a JCM-6000Plus.

2.5 Assembly and charge-discharge characterization of a pouch-type Zn/MnO₂ cell

The negative electrode was prepared as follows. Zinc, zinc oxide, and PVDF as a binder were combined in a weight ratio of 90 : 5 : 5, and dispersed in 5 mL of NMP. 100 μL of the resultant homogeneous slurry was cast on a Cu mesh substrate (2 × 2 cm²) and subsequently vacuum-dried at 80 °C for 12 h. The positive electrode was prepared as follows. MnO₂, Ketjen black as a current collector, and PVDF were combined in a weight ratio of 80 : 10 : 10, and dispersed in 5 mL of NMP. 50 μL of the resultant dispersion was cast on a nickel foam (2.5 × 2 cm²) and subsequently vacuum-dried at 80 °C for 12 h. The loading of MnO₂ was 2.35 mg cm⁻². A pouch-type Zn/MnO₂ cell was assembled as follows. The prepared SHEM (2.5 × 2.5 cm², thickness: ca. 0.45 mm) was sandwiched between the MnO₂ positive electrode and Zn/ZnO negative electrode, and this membrane-electrode assembly was wrapped by an aluminum laminate sheet. The pouch cell was sealed by clamping and hot pressed for 3 s at 60 °C. A similar procedure was also applied to the (4 M KOH + 0.3 M ZnO) aqueous solution, except that a membrane filter was used instead of the SHEM. The volume of the aqueous solution was 2 mL.

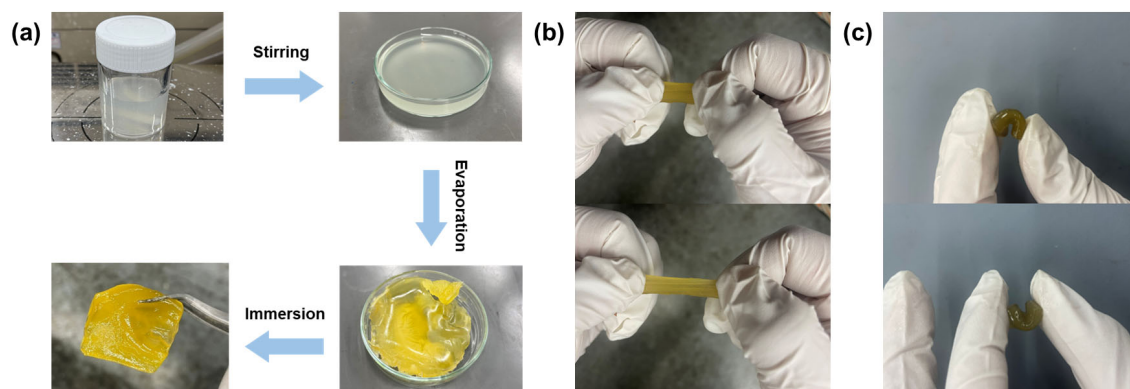


Figure 1. (a) Preparation process of SHEM and (b, c) photographs of stretching and bending tests.

The charge-discharge cycle test was performed by using an HJ1001SD8. In charging, The charge/discharge current was 2 C-rate, ($= 616 \text{ mA g}^{-1}$), and cut-off voltages for charging and discharging were 1.75 and 0.8 V, respectively. The rest times after charging and discharging were 1 min. In general, n C-rate is defined as the specific current at which the theoretical specific capacity of an active material is completely discharged or charged in $1/n$ hours. In this study, the redox reaction of MnO_2 is described by the following equation.



In Eq. 1, the theoretical specific capacity of MnO_2 is calculated to be 308 mAh g^{-1} , so 2 C-rate is 616 mA g^{-1} .

3. Results and Discussion

The prepared SHEM was so flexible that it could be stretched and bent freely, as shown in Figs. 1b and 1c. The SEM image of dried SHEM surface is shown in Fig. 2a, and the cross-sectional SEM images of dried SHEM are shown in Figs. 2b and 2c. Pores less than a few micrometers in diameter were observed on the SHEM surface. In contrast, the cross section of SHEM exhibited pores less than $1 \mu\text{m}$ in diameter, in addition to the pores with diameters ranging from 10 to $100 \mu\text{m}$. These results indicate that SHEM has a three-dimensional network of starch as host polymer, which makes it resistant to shape changes. The C, O, Zn and K elemental maps of cross-sectional SHEM analyzed by EDS are shown in Fig. 2d. Each element is assigned to starch, KOH, and ZnO, and uniformly distributed, as can be seen from Fig. 2d, indicating that dissolved KOH and ZnO are uniformly distributed in the SHEM with a three-dimensional network structure. Moreover, EDS analysis showed that the atomic percentages of C, O, K, and Zn elements were 41.30, 39.43, 17.71, and 1.56 at%, respectively. The K/Zn ratio was 11.4, which was close to the K/Zn ratio (13.3) of (4 M KOH + 0.3 M ZnO) aqueous solution. This suggests that the electrolyte composition changed little in SHEM.

Figure 3 shows the Arrhenius plot of electrical conductivity for SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution. SHEM exhibited high ionic conductivity at 30°C of 0.349 S cm^{-1} , which was comparable to that of (4 M KOH + 0.3 M ZnO) aqueous solution (0.538 S cm^{-1}). In addition, the activation energy of SHEM was calculated from the slope of straight line in Fig. 3, and 19.0 kJ mol^{-1} , which was higher than that of (4 M KOH + 0.3 M ZnO) aqueous solution (12.7 kJ mol^{-1}). This is because of the decrease in mobility of ions by the intermolecular interaction with starch.

FTIR spectra of starch powder and SHEM are shown in Fig. 4. Starch powder showed several characteristic peaks:^{31–33} a broad O-H

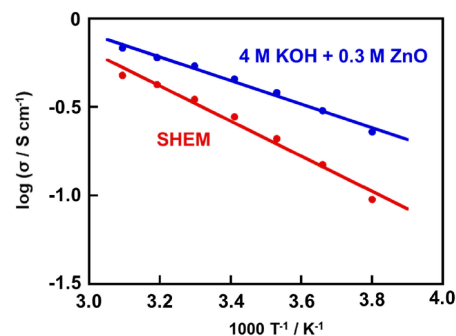


Figure 3. Arrhenius plots of electrical conductivity for SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution.

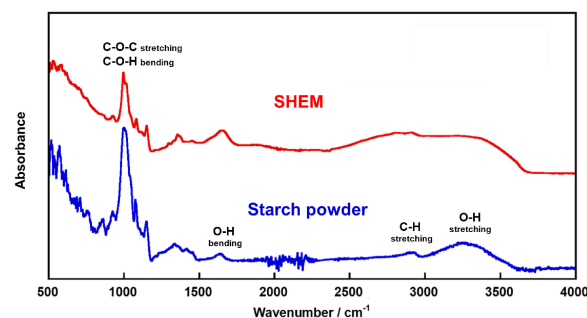


Figure 4. FTIR spectra of SHEM and starch powder.

stretching peak between 3100 and 3600 cm^{-1} , a C-H stretching peak around 2900 cm^{-1} , a O-H bending peak around 1640 cm^{-1} due to hydrogen bonding and water adsorbed in the amorphous region of starch, some C-O-C stretching and C-O-H bending peaks of the anhydroglucose units between 1000 and 1200 cm^{-1} , and a C-O-C stretching peak of α -1,4 glycosidic linkage around 930 cm^{-1} . For SHEM, the O-H stretching peak at 3100 – 3600 cm^{-1} and the O-H bending peak around 1640 cm^{-1} increased whereas the C-O-C stretching and C-O-H bending peaks at 1000 – 1200 cm^{-1} decreased, indicating that the SHEM absorbed and retained the (4 M KOH + 0.3 M ZnO) aqueous solution.

The storage modulus (G') and loss modulus (G'') evaluated by rheological measurements of SHEM after immersion in a (4 M KOH + 0.3 M ZnO) aqueous solution for different periods of time are shown in Fig. 5 as a function of the logarithm of the shear strain (γ). For the hydrogel membrane before immersing in the (4 M KOH + 0.3 M ZnO) solution (Fig. 5a), G' values were almost constant in the γ region less than 30 %. This region is called the

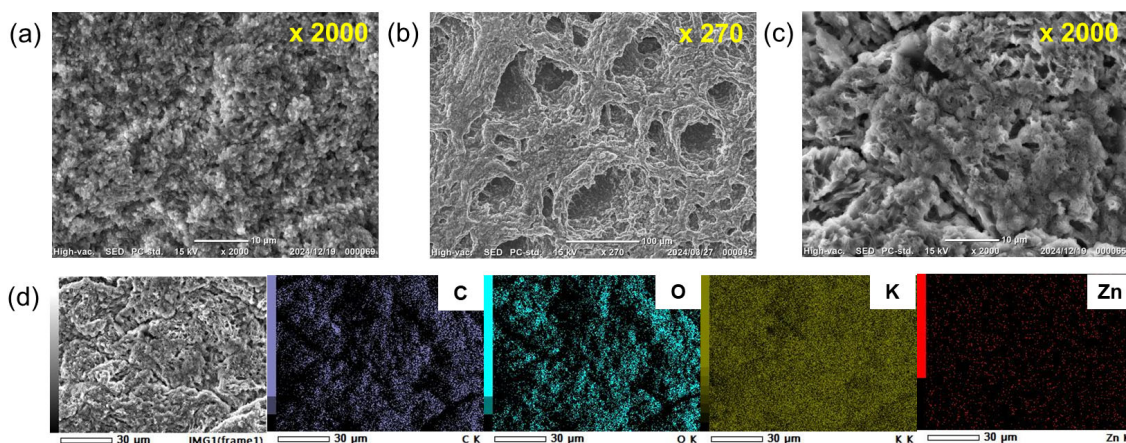


Figure 2. (a) SEM image of dried SHEM surface and (b, c) cross-sectional SEM images and (d) C, O, K and Zn element maps of dried SHEM.

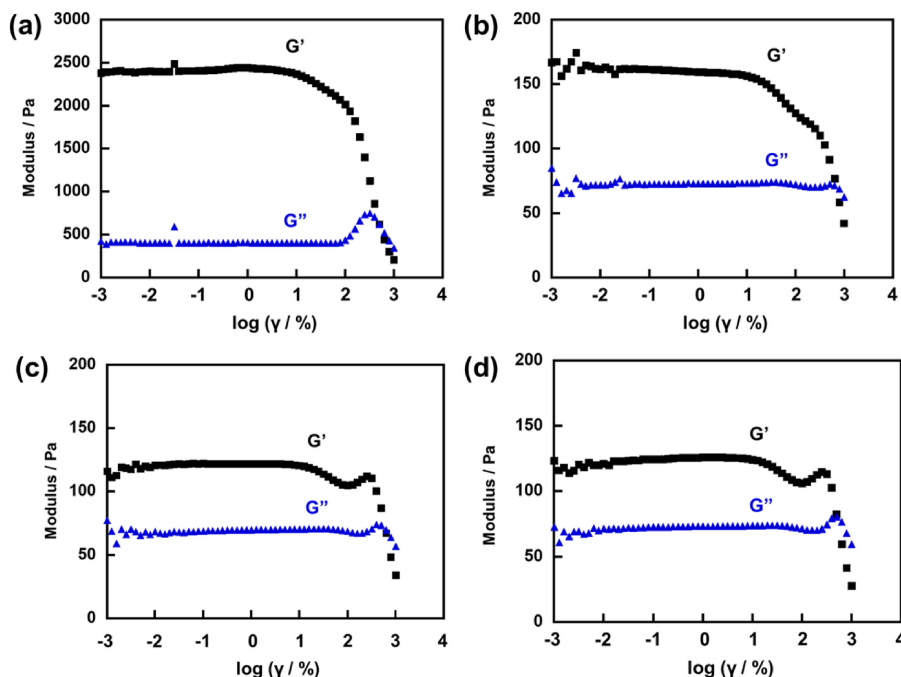


Figure 5. G' and G'' of SHEM (a) before immersion in a (4 M KOH + 0.3 M ZnO) aqueous solution and after immersion for (b) 3 min, (c) 5 min, and (d) 8 min.

linear viscoelastic region (LVER), indicating that the law of elasticity holds.³⁴ As can be seen from Figs. 5, the G' value was higher than the G'' value throughout the LVER, which clearly indicates that the SHEM has a gel structure. For the SHEM after immersing in the electrolyte solution for 5 min (Fig. 5c), the LVER was expanded, and the G'/G'' ratio in the LVER was decreased significantly, which is due to the retention of the electrolyte solution in the gel.³⁵ The change in G' and G'' values for the SHEM after immersing in the electrolyte solution for 8 min (Fig. 5d) almost agreed with that after 5 min, suggesting that the absorption of electrolyte solution into the gel was completed in 5 min. The yield point, shear stress at the upper limit of LVER, and flow point, shear stress at $G' = G''$, for SHEM remained constant irrespective of immersion time, indicating that the alkaline solution did not cause changes in gel structure due to bond breakage.

Figure 6a shows the CV of the asymmetric Cu/Zn cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution. In the Cu/Zn cell with SHEM, a couple of redox peaks due to Zn deposition/dissolution were observed and the electric quantities of Zn deposition and dissolution were almost the same, suggesting that the Zn deposition and dissolution reactions in SHEM occurred reversibly. In contrast, in the cell with (4 M KOH + 0.3 M ZnO) aqueous solution, the redox waves due to Zn deposition and dissolution were larger than those for the cell with SHEM, suggesting that the movement of zincate in the (4 M KOH + 0.3 M ZnO) aqueous solution is faster than that in the SHEM or three-dimensional network of starch.

Figure 6b shows the change in charge/discharge capacities for symmetric Zn/Zn cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution. The overpotential for the symmetric Zn/Zn cell with SHEM was ca. 20 mV, which was comparable to that (ca. 15 mV) using (4 M KOH + 0.3 M ZnO) aqueous solution. This suggests that the electrode/SHEM interface is as good as the electrode/aqueous solution interface, causing reversible Zn deposition and dissolution. Moreover, the Zn/Zn cell with aqueous solution showed the voltage drop due to short-circuits in 19 h, whereas the overpotential of the Zn/Zn cell with SHEM was almost maintained without short-circuits even after 25 h.

The SEM images of the Zn electrode surface after charge/discharge cycle tests for the Zn/Zn cells using (4 M KOH + 0.3 M ZnO) aqueous solution and SHEM are shown in Figs. 6c and 6d, respectively. For the Zn/Zn cell with aqueous solution, the electrode surface was covered with numerous porous protruding Zn deposits after the short-circuit, as shown in Fig. 6c. In contrast, for the Zn/Zn cell with SHEM, even after 25 hours of charge/discharge cycling, the electrode surface remained flat and no porous protruding Zn deposits were observed, as shown in Fig. 6d.

The XRD patterns of the Zn electrode before and after charge/discharge cycle tests for the Zn/Zn cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution are shown in Fig. 6e. In the Zn/Zn cell with SHEM, all diffraction peaks were attributed to metallic Zn, but in the Zn/Zn cell with (4 M KOH + 0.3 M ZnO) aqueous solution, small diffraction peaks at 31.8 and 34.5° were observed after charge/discharge tests in addition to the diffraction peaks assigned to metallic Zn. The additional diffraction peaks were assigned to the (100) and (002) peaks of ZnO, respectively, suggesting that the Zn electrode and Zn deposits partially corroded in the (4 M KOH + 0.3 M ZnO) aqueous solution. This also suggests that SHEM effectively suppressed ZnO formation due to corrosion.

It is known that the orientation of Zn deposits has a significant effect on dendritic growth. To evaluate the orientation of Zn deposits, the orientation index (N) of each facet was defined by the following Eq. 2.³⁶

$$N = (I\{hkl\}/\Sigma I\{hkl\})/(I'\{hkl\}/\Sigma I'\{hkl\}) \quad (2)$$

Here, $I'\{hkl\}$ and $I\{hkl\}$ are the intensities of the $\{hkl\}$ peak before and after Zn deposition on the Zn electrode, respectively. $\Sigma I'\{hkl\}$ and $\Sigma I\{hkl\}$ are the sum of the intensities of all diffraction peaks before and after Zn deposition on the Zn electrode, respectively. If the N value for a given $\{hkl\}$ facet is higher than one, Zn deposits can be considered to have grown along the $\{hkl\}$ facet. The orientation indices of the $\{002\}$, $\{100\}$, $\{101\}$, $\{102\}$, and $\{103\}$ facets were calculated to be 0.73, 1.05, 1.17, 1.37, and 1.26 for the cell with SHEM and 0.92, 0.81, 1.43, 0.63, and 0.46 for the cell with (4 M KOH + 0.3 M ZnO) aqueous solution, respectively. The evaluated N values for the two cells indicated that Zn deposits

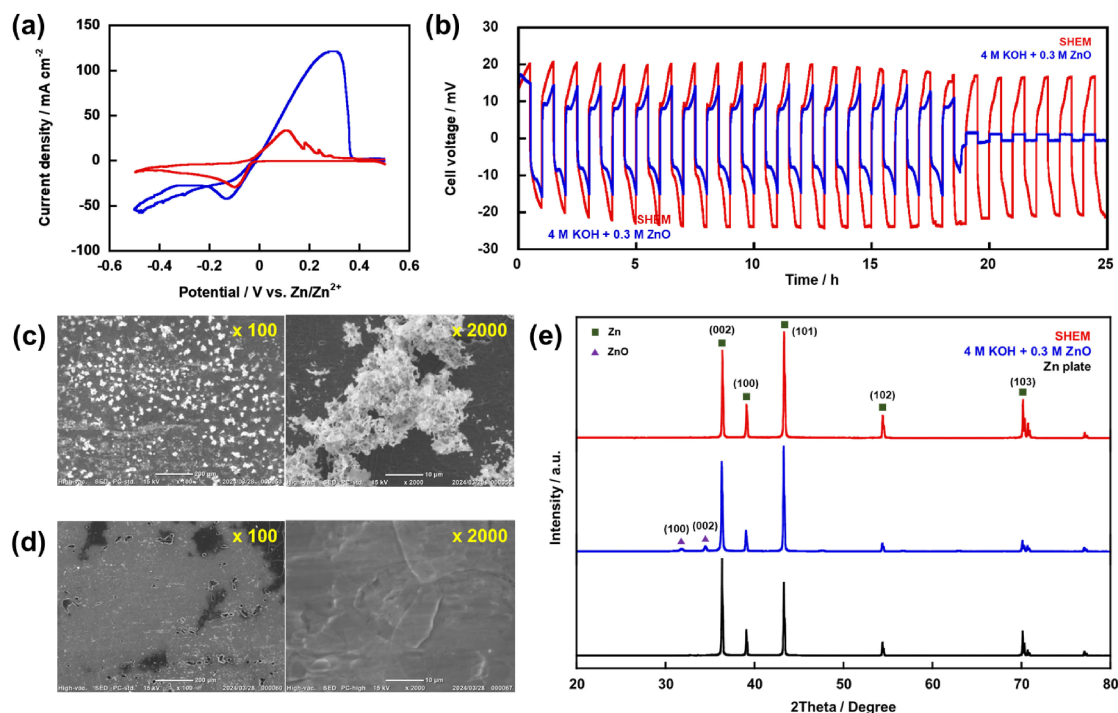


Figure 6. (a) CVs of the asymmetric Cu/Zn cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution, (b) charge/discharge curves of the symmetric Zn/Zn cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution, SEM images of the Zn electrode surface after the charge/discharge cycle tests for the Zn/Zn cells with (c) (4 M KOH + 0.3 M ZnO) aqueous solution and (d) SHEM, and (e) XRD patterns of the Zn electrode surface before and after the charge/discharge cycle tests for the Zn/Zn cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution.

grew predominantly along {102} and {103} facets in the cell with SHEM, whereas they grew preferentially along {101} facet in the cell with aqueous solution. This suggests that Zn deposits grew more perpendicular to the electrode surface in the aqueous solution, but more parallel to the electrode surface at the electrode/SHEM interface, which is consistent with the results of the SEM images (Figs. 6c and 6d). Consequently, SHEM was observed to inhibit the growth of Zn dendrites and to extend the charge-discharge cycle life of Zn/Zn cells.

Charge-discharge cycle tests were performed at a specific current of 2 C-rate for the Zn/MnO₂ cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution. The charge and discharge curves at 1st, 10th, 30th and 40th cycles and the change in charge and discharge capacities and coulombic efficiency with cycle number for the Zn/MnO₂ cell with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution are shown in Fig. 7. As shown in Figs. 7a and 7c, in both cases, the initial discharge curve clearly exhibited a plateau due to Eq. 1. The initial discharge capacity was 184 and 169 mAh g⁻¹ for the Zn/MnO₂ cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution, respectively, indicating that charging and discharging at high current density were possible even when SHEM was used as the electrolyte. As shown in Figs. 7b and 7d, regardless of the electrolyte used, the discharge capacity decreased with increasing cycle number, probably due to the accumulation of ZnMn₂O₄ formed during discharging. The discharge capacity at 40th cycle was 55 and 45 % of the initial discharge capacity for the Zn/MnO₂ cells with SHEM and (4 M KOH + 0.3 M ZnO) aqueous solution, respectively, suggesting that the former has better cycle performance than the latter. Moreover, coulombic efficiency, percentage of discharge capacity to charge capacity, remained above 95 % for all cycles for the Zn/MnO₂ cell with SHEM, but that for the Zn/MnO₂ cell with (4 M KOH + 0.3 M ZnO) aqueous solution varied widely during the initial 20 cycles. Thus, it has been demonstrated that the SHEM prepared in this study can fully

function as an electrolyte for quasi-solid-state rechargeable alkaline zinc batteries.

4. Conclusion

A stable SHEM containing concentrated alkaline solution was successfully prepared by a simple method without any cross-linking agents in this study. The SEM images of dried SHEM suggested that the prepared SHEM exhibited a porous structure with a wide range of pore sizes, and starch as the host polymer had a three-dimensional network structure. The (4 M KOH + 0.3 M ZnO) aqueous solution was absorbed and held in SHEM, causing high ionic conductivity. The deposition and dissolution reactions of Zn were reversible in SHEM, and the redox current in SHEM was smaller than that in (4 M KOH + 0.3 M ZnO) aqueous solution, suggesting that the movement of zincate in the SHEM or three-dimensional network of starch was slower than that in (4 M KOH + 0.3 M ZnO) aqueous solution. This would lead to suppression of dendritic Zn growth and prevention of short-circuits, thereby extending the charge-discharge cycle life of symmetric Zn/Zn cell. For the Zn/MnO₂ cell with SHEM, the discharge capacity decreased with increasing cycle number, but remained more than half of the maximum discharge capacity even after 40 cycles, which was better than the Zn/MnO₂ cell with (4 M KOH + 0.3 M ZnO) aqueous solution. Thus, the SHEM prepared in this study was demonstrated to function well as an electrolyte for quasi-solid-state rechargeable alkaline zinc batteries. The above findings provide a new avenue for the development of future high-performance quasi-solid-state rechargeable alkaline zinc batteries.

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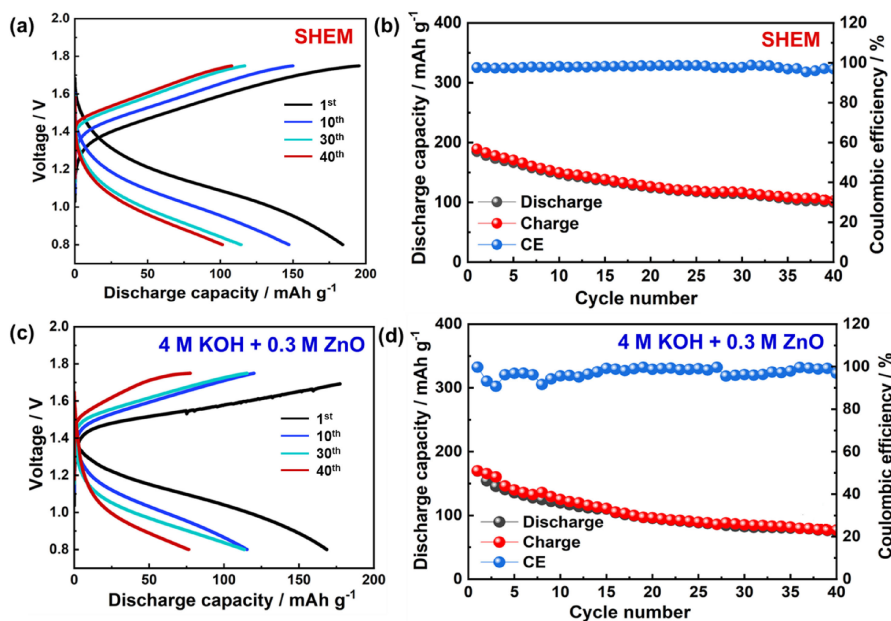


Figure 7. (a, c) Charge and discharge curves at 1st, 10th, 30th and 40th cycles and (b, d) change in charge and discharge capacities and coulombic efficiency with cycle number for the pouch-type Zn/MnO₂ cells with (a, b) SHEM and (c, d) 4 M KOH + 0.3 M ZnO aqueous solution. Charge/discharge current: 2 C-rate.

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CRedit Authorship Contribution Statement

Cheng Zhen: Data curation (Lead), Formal analysis (Lead), Investigation (Lead), Methodology (Equal), Writing – original draft (Lead), Writing – review & editing (Lead)

Patrick Kimilita Dedetemo: Data curation (Equal), Formal analysis (Equal), Investigation (Equal)

Masanobu Chiku: Investigation (Supporting), Methodology (Supporting)

Eiji Higuchi: Formal analysis (Supporting), Investigation (Supporting), Methodology (Supporting)

Hiroshi Inoue: Conceptualization (Lead), Data curation (Equal), Funding acquisition (Lead), Investigation (Equal), Methodology (Equal), Project administration (Lead), Supervision (Lead), Writing – original draft (Equal), Writing – review & editing (Lead)

Conflict of Interest

The authors declare no conflict of interest in the manuscript.

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