

Research Article

Processing of Superimpregnated Carbon Cloth Electrodes for Flexible Zinc Ion Capacitors

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Abstract

Flexible electronics aims to achieve high-electricity and high-power density strength storage innovation. Bendy power carport appliances exceed traditional portable electronics and renewable energy packages. Superimpregnated carbon electrodes for flexible zinc ion capacitors are processed in this study. The investigation tries towards enhancing atomic capacitors' strength storage capabilities, hiring to bendy electronics, using innovative methods and mindful design. This study explores superimpregnated carbon cloth electrodes for flexible zinc capacitors. The study optimizes electrode capacitance, cycle balance, and flexibility. Carbon cloth characterization, superimpregnated electrode production, electrochemical testing, and structural analysis are crucial. The proposed processing techniques increased carbon cloth electrode function, enabling bendy stiffness digital driveway system. This research emphasizes the efficiency and flexibility of zinc ion capacitors electrode materials, highlighting strength-related advancement in possibilities. By electrodeposition, the anode is zinc and the treated cathode is carbon cloth. The flexible zinc ion capacitor (FZIC) featuring carbon cloth cathode and Zn @ carbon cloth (Zn@CC) anode in aqueous ZnSO₄ electrolyte was studied for its shape and electrochemical performance. Good electrochemical performance was shown by the CC//Zn@CC system in ZnSO₄ aqueous liquid electrolyte, with an areal capacitance of 4.59 mF cm⁻², voltage window of 0.2-1.6 V. Cycling stability was 79.40% after 1000 cycles at 2 mA cm⁻². Finally, the increasing use of wearable and flexible electronics will drive demand for flexible zinc ion capacitors as key elements in the flexible capacitor and energy storage device market, exhibiting considerable potential opportunities.

Keywords

Electrodepositions, ZIC Capacitors, Flexible Electronics, Superimpregnated Carbon Electrodes, Carbon Cloth

1. Introduction

Energy storage is key for maximizing electronics and power, especially in flexible electronics for wearables electronics. Flexible, stretchable power devices offer us-

er-friendly interfaces, with self-repairing capabilities inspired by human skin for increased their durability [1]. Battery energy storage is also important for integrating renewable

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energy sources, grid stabilization, and resilience. Energy storage systems enhance grid reliability by providing backup power during outages and balancing electricity supply and demand. They can also lower electricity costs by storing energy during off-peak hours and using it during peak hours source of flexible energy [2]. Capacitors in wiring systems serve various roles: energy storage, filtering, timing, signal coupling, and voltage stabilization. They work by storing and releasing electrical energy [3]. Flexible conductors are vital for wearable electronics like smart watches, medical implants, and e-textiles. These devices rely on power sources like batteries and super capacitors [4]. Current energy storage devices can't fully meet consumer demand, and electrochemical energy storage (EES) must address safety flammable energy storage devices may explode [5]. Developing practical flexible zinc-capacitors [6] faces challenges: low energy density and limited lifespan of zinc anodes due to dendrite formation, hydrogen evolution, and corrosion, unlike the long cycle life of carbon cathodes. Flexible Zinc-ion capacitors, becoming a young technology, have potential for many energy storage applications, while practical executions are still being explored [7]. However in energy storage device era multiple problems must be addressed.

Efficient, adaptable electronics directly manufactured onto flexible surfaces are attracting significant research interest. This technology has the potential to revolutionize industries with lightweight, portable, and durable products across consumer electronics, healthcare, and automotive several years [8]. Moreover, Miniaturization is essential for businesses to predict duties, impacting electronics by enabling economical, reliable, and secure mobile devices. This evolution has integrated electronics into everyday life, increasing accessibility and effectiveness—effectiveness [9]. However, safety is a primary concern for wearable power storage due to potential toxicity from direct body contact.

In this study, Carbon cloth is used as an anode and Zinc ion as cathode material in flexible zinc-ion capacitors device, offering structural flexibility, a large surface area, and high electron conductivity, which collectively enhance performance. The objective is to enhance flexible zinc-ion capacitor (ZIC) performance and durability by optimizing zinc-ion utilization at carbon cloth electrodes. This involves developing superimpregnated carbon cloth electrodes and examining electrodeposition process parameters to improve energy density, cycling stability, areal capacitance, and overall efficiency. Flexible ZICs are appealing due to their enhanced energy efficiency, affordability, and potential for eco-friendly energy storage. Processing of Functional flexible zinc-ion capacitor (ZICs) with both high-performance energy storage and sensing properties was designed by introducing as the electrolyte. Capacitors are commonly utilized in electrical devices for a variety of reasons, and they are crucial for ensuring safety and reliability, especially in today's electronics which heavily rely on semiconductors and passive components [10].

Within this piece of writing, we initially discussed the advantages and drawbacks of CC for high-performance zinc ion capacitor processing, along with introducing their operational principles. Subsequently, we presented a comprehensive summary and discussion on recent advancements in enhancing the capacitance of CC and their integration into capacitors. Notably, we emphasized plasma modifications such as chemical oxidation, electrochemical oxidation, thermal activation, plasma modification, as demonstrated in the results. Finally, an overview of the challenges and prospects of commercial CC as a leading-edge candidate for capacitor construction was provided. Plasma treatment, with its mix of neutral atoms, charged ions, electrons, and molecules, is a potent method to alter or remove materials on the surface of CC, especially with high-power plasma used in activation of CC.

2. Methodology and Materials

2.1. Methodology

In this study, the methodology search into the intricate process of creating electrodes from superimpregnated carbon cloth for utilization in flexible zinc ion capacitors. The fabrication procedure is carefully detailed, highlighting the optimization of these electrodes' performance specifically within flexible zinc ion capacitors. The primary emphasis is on clarifying the synthesis methods involving plasma modification techniques and the various characterization methods employed to augment the electrochemical characteristics of the electrodes. Through these detailed steps, the study showcases the considerable potential of these electrodes for applications in flexible energy storage systems.

The carbon cloth (CC) were supplied by WOS1002, Ce-Tech Co. Ltd. 60cm*50cm the length and width, 0.3mm thickness was cut in suitable size (nearly 1*1cm²) and removed the residue by washing it with deionized water surface impurity further time to dry for some minutes. The as obtained CC was placed in plasma cleaner YZD08-5C/Potentlube machine for total time durations for 20 minutes to obtain the oxygen plasma carbon cloths at out power /pressure 0.8, this method utilizes to optimize the surface morphology of the carbon cloths when zinc ion particle deposited on it in candidate flexible zinc anode. Electrolytes affect capacitance, steady voltage, and cycle duration. Combining the flexible zinc-based capacitor defends against environmental factors and retains its internal components after stacking and assembly. Encapsulation materials protect capacitors prevent moisture, impurities, and physical damage, extending their lifespan. In conclusion, the flexible zinc-based capacitor preparation schematic shows how to build a reliable energy storage device. The capacitor's components and layers interact to improve energy storage efficiency and device versatility for various applications.

Performs electrodeposition of zinc onto carbon cloth that has been sensitized with oxygen plasma. Initially, we made an

electrolyte solution. This was the first thing that we did. The material was named as follows hydrated zinc sulfate heptahydrate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), the powder form sodium sulfate (Na_2SO_4), and boric acid (H_3BO_3) in a ratio of 25:25:4 grams, respectively, and 200mL of The implementation of deionized water to be a solvent demonstrated. To get desired homogeneous mixture, it was stirred by a magnetic stirrer for more than 16 hours. The second step was cutting in suitable size zinc foil ($3 \times 3 \text{ cm}^2$) dried in an oven at a temperature of 60 Celsius after being cleaned with deionized water. We prepared more than eight samples of oxygen plasma-treated carbon cloth. In the electrodeposition working principle, duration is the parameter that can affect the zinc deposition on the carbon cloths. The setup was zinc foil, OPCC and 2M ZnSO_4 as positive, negative and electrolyte, respectively. In our experiment, we started from 5 minutes which means for 300 second to 20 minutes (1200 second) at 5 mA for different OPCC samples at a time. Time was recorded, and Zn@OPCC was washed by deionized water for long long times and lastly it was kept for drying in oven at 60 °C for more than 20 minutes. The Zn@OPCC system was created by coating oxygen plasma-treated carbon cloths with zinc using galvanostatic elec-

trodeposition techniques. Rotate between 5, 10, 15, and 20 minutes of practice in electrolyte ZnSO_4 solutions. We used DI water to wash each sample piece, then dried them in the oven and stored them in plastic bags.

Cathode electrode preparation we looked over everything deeply one very efficient way to modify surfaces is to treat carbon cloth with oxygen plasma treatments before making flexible electrodes. By modifying the surface properties, adhesion, and wettability, this method has the ability to greatly improve the material's electrochemical performance, however carbon cloth is weak electric conductivity. To achieve desired results for particular electrochemical applications, oxygen location, performance, uniformity, cost, and complexity must be carefully tuned. I am grateful for the effort made in clarifying advantages oxygen plasma treatment. Before the electrodeposition, the methods used to prepare the flexible carbon cloth cathode were identical to those used to prepare the flexible zinc anode. Rough idea a flexible cathode is made in multiple processes to provide an efficient and high-performing cathode for devices that stores energy. Mechanically flexible cathodes are essential in capacitors and other technologies.

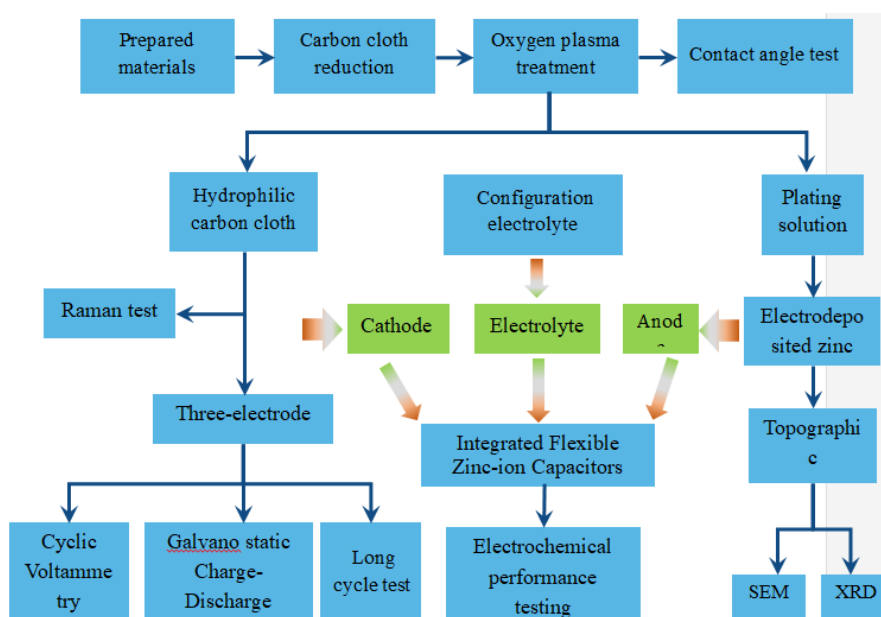


Figure 1. Schematic diagram of flexible zinc-based capacitor preparation the overall process, these techniques allow me to make or Processing of superimpregnated carbon cloth electrodes for flexible zinc ion capacitors in a laboratory using carbon cloths.

2.2. Materials

The materials listed for this study include carbon cloth, represented by the symbol CC, zinc sulfate heptahydrate with the chemical formula $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, zinc foil denoted by Zn, sodium sulfate indicated as Na_2SO_4 , boric acid specified as H_3BO_3 , and deionized water labeled as H_2O . This assortment of materials serves specific purposes within the experiment,

with carbon cloth likely being utilized as an electrode material, zinc sulfate heptahydrate and zinc foil potentially involved in electrolyte solutions or electrode fabrication, sodium sulfate and boric acid possibly used in buffer solutions or electrolytes, and deionized water employed for various preparations and cleaning processes due to its purity. Each material's distinctive properties and roles play a significant part in the experimental procedures and outcomes of the study.

3. Result and Discussion

3.1. Result

For the focus of the present study, a scanning electron microscope (SEM) was used to investigate the numerous molecular structural interactions that occur in surface chemistry. The research examined surface features in detail, identifying a region where chemicals and compounds interact in intricate chemical processes. Features that were previously invisible were revealed using scanning electron microscopy (SEM), the morphology structure to all the CC electrode preparation oxygen plasma treatment to increase their surface activation increased its wettability, reduce impurity in thinly size the complex interface between materials and their environment. The scanning electron microscope (SEM) was used in order to accomplish the surface chemistry of the electrode. By using this machine, we were able to check the ultra-three-dimensional structure of the anode materials.

The surface structure of Zn nanoparticles that have been placed on the carbon cloth at different time for the electrodeposition, represented as Zn@CC. The morphology of the zinc that was deposited on the carbon fabric CC is characterized by the fact that the clusters on the CC are in ordered in a logical fashion. Analytical X-ray diffraction (XRD) angles that displays material crystalline structure. The crystalline characteristics of carbon fabric have been determined with the use of a procedure called X-ray diffraction (XRD). The anode materials Zn@CC had been identifying the atomic arrangement by exposing a sample to X-rays and observing the diffraction pattern we can see the defects that have impurities at the peak points.

This information allows for material composition and structure. After being treated with plasma, the surface roughness of the CC material increased and demonstrated many growths in the substrate zinc on carbon cloth in the [figure 4](#) SEM Zinc Nano flakes may limit mass-transfer overpotential of zinc metal by increasing zinc ion transfer onto substrate in plasma treatment. After the plasma treatment the morphology of Zn@CC is porous and dense structure.

Material characterization and analysis uses XRD pictures that show diffraction peaks at stipulated angles, which signal atom spacing in the structure of the material. illustrates X-ray diffraction pattern of the zinc that were electrodeposited on carbon The XRD study of the carbon fabric indicated unique peaks at various 2θ values, showing its structure. Its strong peaks at 37° ; 39° ; 44° ; 55° ; and 71° suggest crystalline composition.

These peaks indicate the material's unique atomic arrangement and composition by indicating well-defined crystal planes. The pattern displays the carbon cloth's crystallographic characteristics and interior structure, helping us understand its qualities and uses. This occurs when a thin coating of zinc Zn@CC is formed on the carbon fabric. Over a sequence of their cycles of charge and discharge, the morphology of the zinc anode is normally changed as an outcome of a variety of electrochemical responses. Zinc Nano flakes may limit mass-transfer overpotential of zinc metal by increasing zinc ion transfer onto substrate in plasma treatment. After the plasma treatment the morphology of Zn@CC is porous and dense structure. [Figure 4](#) frame represented that after following electrodeposition, the SEM pictures reveal challenging cross-linking patterns due to the different electrodeposition durations, which result in diverse morphologies represented in the images.

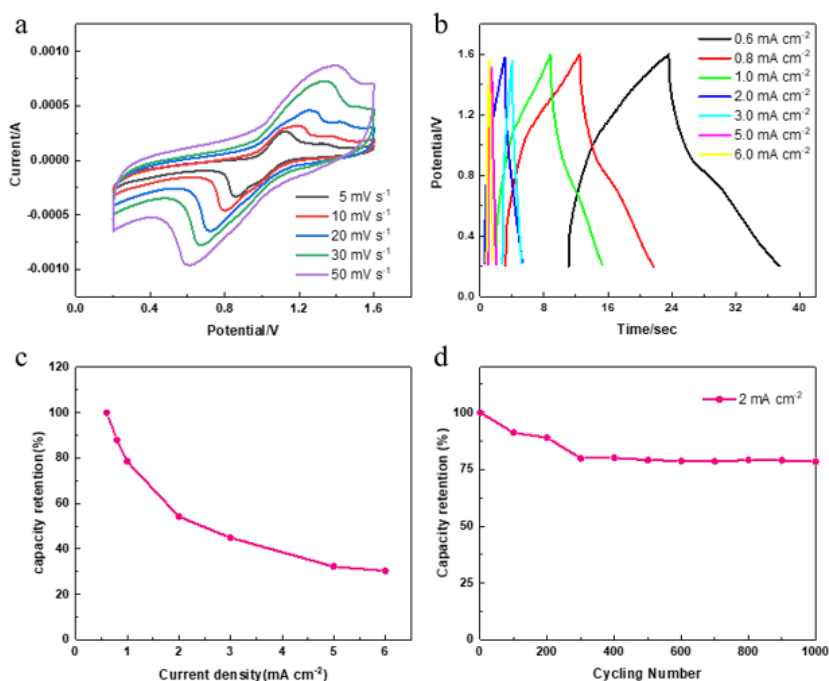


Figure 2. By the same fashion just change the time duration in a 2M ZnSO₄ aqueous liquid electrolyte, the CC//Zn@CC system operated well over a voltage window of 0.2-1.6 V.

Notably, a current density of 2 mA cm^{-2} , and 78.41% cycling stability after 1000 cycles. Its capacitance value was 3.24 mF cm^{-2} energy density electrodeposition lasted ten minutes.

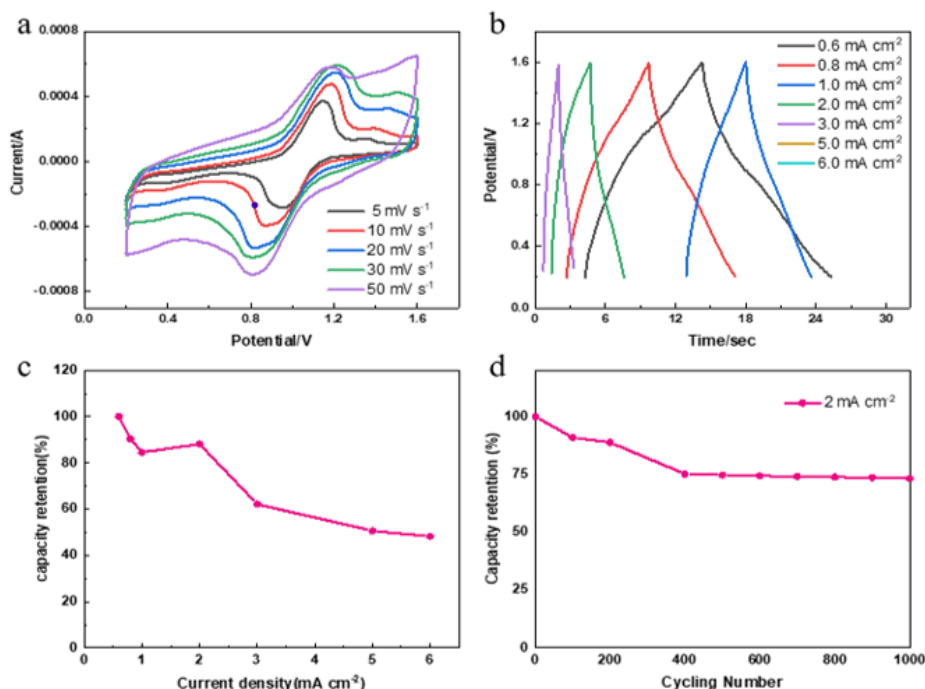


Figure 3. Electrochemical properties of aqueous two-electrode System-Electroplating 30 minute.

3.2. Discussion

The process of electrodeposition of zinc onto oxygen plasma-treated carbon cloth (OPCC) involves several key steps and materials. Initially, an electrolyte solution was prepared using hydrated zinc sulfate heptahydrate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), sodium sulfate (Na_2SO_4), and boric acid (H_3BO_3) in a weight ratio of 25:25:4 grams, dissolved in 200 mL of deionized water. This mixture was stirred for over 16 hours to achieve homogeneity.

Next, zinc foil was cut into 3 cm x 3 cm pieces and dried at 60 °C after cleaning with deionized water. More than eight samples of OPCC were treated with oxygen plasma to enhance their surface properties, which is crucial for effective zinc deposition. The electrodeposition setup consisted of the zinc foil as the positive electrode, OPCC as the negative electrode, and a 2M ZnSO_4 solution as the electrolyte.

The duration of the electrodeposition process was varied from 5 to 20 minutes at a current of 5 mA. Each sample's time was meticulously recorded, followed by thorough washing with deionized water and drying at 60 °C for over 20 minutes. This method aimed to create a uniform coating of zinc on the OPCC, leveraging the improved nucleation sites provided by the plasma treatment. The timing of the sample is mandatory if we stayed for long time the result was not good.

The surface modification of carbon cloth (CC) morphology is a critical step, especially when analyzed using Raman

spectroscopy, which probes the vibrational modes of molecules to determine chemical composition and functional groups. The technique relies on examining the scattered light from molecule vibrations. Contact angle measurements confirm that the outer region of the carbon cloth (CC) experiences significant oxidation after modification. This oxidation introduces hydrophilic functional groups during oxygen plasma treatments, enhancing the surface's wettability and chemical bonding.

Plasma treatment is effective for materials, including carbon materials. High-energy plasma impacts the CC surface, causing chemical bonds to break and reorganize. This improves the surface structure and adhesion between the CC and the matrix material of zinc. Plasma treatment is favored for its simplicity, efficiency, and environmentally friendly nature.

Evaluating flexible zinc ion capacitor performance relies heavily on electrochemical methods like Galvanostatic Charge-Discharge (GCD), Cyclic Voltammetry (CV), and Electrochemical Impedance Spectroscopy (EIS). These methods, conducted using electrochemical workstations, help measure crucial parameters such as voltage, current, time, and capacitance within a three-electrode setup. From this data, we can determine the power and energy capabilities of the tested device using mathematical formulas.

In our lab, we used a CHI 660E electrochemical workstation, with a three-electrode setup to analyze the cathode. The setup included Oxygen Plasma-Treated Carbon Cloth (OPCC) and a 2M ZnSO_4 electrolyte solution.

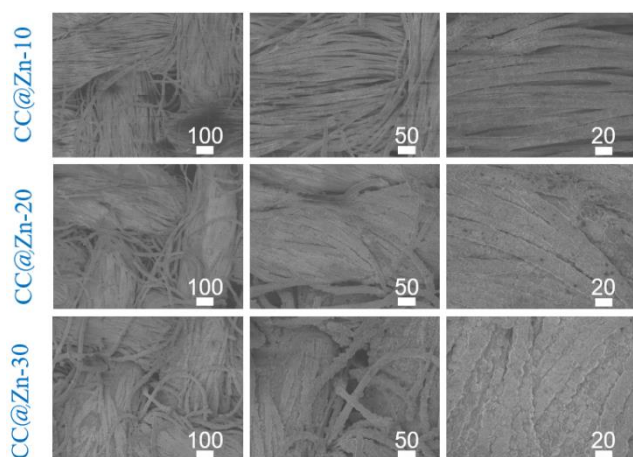


Figure 4. After many cycles, the morphology, structure, and substance of the Zn@CC anode were examined.

4. Conclusions

The research evaluated how superimpregnated carbon cloth electrodes increase flexible zinc ion capacitor performance. The electrodes' effects on capacitor energy density, power density, and efficiency were studied. Our investigation or finding good. Superimpregnated carbon cloth material electrode improving flexible zinc ion capacitor performance. The chemistry work gives them higher energy densities and power densities than ordinary electrode.

By the same fashion just change the time duration in a 2M ZnSO₄ aqueous liquid electrolyte solution the focus of our research was on creating three separate carbon fabric (CC) electrodes specifically designed for zinc deposition in order to explore the properties of bendable zinc anodes. Upon completing the deposition process, we meticulously cleansed and dried the electrodes, establishing the groundwork for the enhancement of flexible CC cathodes. Through the use of the oxygen plasma modification technique, we converted the electrodes into adaptable CC cathodes for the purpose of assessing the capacitance of the resulting capacitors. It is important to observe that the duration of the electrodeposition process varies among the electrodes, with deposition times of 10 minutes, 20 minutes, and 30 minutes, each displaying distinct performance characteristics. The variation in the length of the electrodeposition method had a significant influence on the strength and power density shown by the capacitors, resulting in different levels of efficiency and performance. Figure 2, figure 3 the above all results that show as good performance by the different steps that was planned to processed flexible zinc ion capacitors. The capacitors were suited for flexible and portable energy storage applications because the carbon fabric electrodes' structural flexibility assured their longevity and long-term stability. Integrating these electrodes improved the performance and operating features of flexible zinc ion capacitors, promising energy storage technological breakthroughs.

However, flexible zinc ion capacitors are still developing and have some challenges. FZICs' energy, power performance, and cycle life are greatly influenced by electrode and electrolyte construction. The CC//Zn@CC system performed well in a 2M ZnSO₄ aqueous liquid electrolyte. It had 0.2–1.6 V voltage range. It had 79.40% cycling stability after 1000 cycles. The device's area ratio capacitor or capacitances was 4.51 mF cm⁻². ZICs boost energy density and power output in energy storage devices. Processing of flexible zinc ion capacitor with superimpregnated carbon cloth electrode is major energy advancement with huge potential. The intricate link between candidate material properties, design parameters and electrochemical performance in this work situation was examined.

The research overview and experimental results demonstrate how superimpregnated carbon cloth electrodes improve zinc ion capacitor efficiency, flexibility, and performance. Ion diffusion kinetics, specific capacity, and cycle stability are enhanced by these electrodes unique structural characteristics and increased surface area.

These electrodes' versatility allows the development of wearable and portable energy-storing devices to meet current electronics and mobile application needs. Due to their mechanical flexibility and electrochemical efficiency, superimpregnated carbon cloth energy storage devices.

Abbreviations

CC	Carbon Cloth
OPCC	Zinc onto Oxygen Plasma-Treated Carbon Cloth

Conflicts of Interest

The authors declare no conflicts of interest.

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