Economical Preparation of high-performance activated carbon fiber papers as self-supporting supercapacitor electrodes

ABSTRACT:

This study introduces a practical and cost-effective method for producing highly efficient cellulose-based activated carbon fiber papers (ACFPs) as self-supporting supercapacitor electrodes. These ACFPs address the drawbacks of traditional cellulose-based electrodes, such as high costs, excessive cellulose content, and limited mechanical flexibility.

INTRODUCTION:

Wearable and portable electronic devices demand materials that are lightweight, slender and pliable, exhibiting outstanding electrochemical properties. Paper-based supercapacitors have emerged as promising solutions because of their elevated power density, rapid charge-discharge capabilities, extended cycle longevity, and compatibility with biological systems. However, developing cost-effective and high-performance electrode materials is essential for their scalability.

Cellulose fibers, derived from sustainable sources, are an attractive raw material. Yet, their insulating nature necessitates the integration of conductive and electroactive substances. Past approaches involved costly electroactive materials, limiting both cost-effectiveness and specific capacitance.

Innovative Approach:

This research introduces a novel method that combines wet papermaking, thermal carbonization, and double activation to transform the fibers of pulp into cellulose-derived activated carbon while integrating them with carbon fibers. The obtained ACFPs exhibit remarkable characteristics:

Greater Specific Surface Area: Ranging from 808 to 1106 m^2/g.

Excellent Conductivity: Measuring between 1640 and 1786 S/m.

Robust Mechanical Strength: With values between 4.6 and 6.4 MPa.

Flexible Processability: Facilitating various applications.

Additionally, the ACFPs showcase an impressive specific capacitance of 48.8 F/cm^3 (or 165 F/g) for the entire electrode, along with outstanding stability during repeated cycles. Furthermore, these ACFPs can be loaded with additional electroactive materials to further enhance their capacitance.

Enhancing Carbon Fibers:
The study also leverages carbon fibers to bolster the capacitive performance of ACFPs. Traditional carbon fibers lack sufficient surface area and porosity, requiring activation to enhance electroactivity. However, this study employs pulp fibers, primarily cellulose, for activation, ensuring sustainability and cost-effectiveness compared to petroleum-based carbon fibers.

EXPERIMENTAL METHODOLOGY:

The research details the preparation process, encompassing the fibrillation of cotton pulp, the creation of primary composite papers (CPs) by combining pulp fibers and carbon fibers, and subsequent impregnation with phosphoric acid. Thermal carbonization and double activation processes under controlled atmospheres transform the CPs into cellulose-based ACFPs. These ACFPs undergo comprehensive characterization for physical, chemical, and electrochemical properties. Their suitability for all-solid-state supercapacitors is demonstrated, highlighting their potential in energy storage for portable electronics.

RESULTS AND DISCUSSIONS:

Development and Production of ACFPs Using Cellulose:

The team's innovative approach involves mixing pulverized pulp fibers and carbon fibers (CFs) to create primary cellulose papers (CPs). These CPs are then subjected to pre-impregnation with a 20% H3PO4 solution, thermal carbonization, and double activation (H3PO4 + CO2) processes to produce ACFPs.

The CFs in the ACFPs form a conductive network, while the fibrillated pulp fibers create an ACF matrix. This matrix increases surface area and provides a flexible structure with exceptional mechanical properties. The researchers also found that ACFPs exhibited excellent electrical conductivity, making them suitable for use as self-supporting electrodes.

Characterization of ACFPs:

Scanning electron microscopy (SEM) images showed that ACFPs had a porous structure, with CFs tightly wrapped within the ACF matrix. The matrix contained both micro and mesopores, providing ample channels for ion transport and storage.

X-ray diffraction (XRD) and Raman spectroscopy confirmed the transformation of cellulose into amorphous carbon structures during the fabrication process.

X-ray photoelectron spectroscopy (XPS) analysis revealed the presence of phosphorus-containing functional groups resulting from crosslinking between phosphoric acid and fragments of carbon during the activation process.

Effect of CFs Addition:

The researchers investigated the impact of varying CF content in primary CPs. They found that adding 10-15% CFs produced ACFPs with high surface area, conductivity, and mechanical strength. However, higher CF content led to a decline in performance due to reduced adhesion between ACFs and CFs.

Electrochemical Properties:

ACFPs were directly used as electrodes without binders in a three-electrode system. They exhibited excellent capacitive behaviour, with nearly rectangular cyclic voltammetry (CV) curves even at high scan rates. Galvanostatic charge-discharge (GCD) curves displayed high coulombic efficiency.

The specific capacitance of ACFPs reached 35.8-48.8 F/cm^3 and 121-165 F/g at present densities of 0.1-5 mA/cm^2. Impedance spectroscopy (EIS) confirmed low resistance and nearly ideal capacitive behaviour in ACFPs.

Long-Term Stability:

ACFP-15 demonstrated outstanding stability with a sustained capacity of 100% after 10,000 cycles, showcasing its long-term durability.

Applications and Future Prospects:

The researchers assembled all-solid-state supercapacitors (SSCs) using ACFP-15 as electrodes with PVA-KOH gel electrolyte. The SSCs exhibited more energy density (6.01 Wh/kg) and power density (28.22 W/kg) while maintaining flexibility and stability.

CONCLUSION:

This study introduces an innovative method for producing cellulose-based ACFPs with exceptional electrochemical performance, conductivity, and mechanical properties. Researchers have developed cellulose-based activated carbon fiber papers (ACFPs) with remarkable conductive power and electrochemical properties. By mixing pulp fibers and carbon fibers, they created a flexible, high-surface-area material suitable for supercapacitor electrodes. ACFPs have demonstrated their potential as promising candidates for energy storage applications, offering a cost-effective and scalable solution for the future.