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ORIGINAL PAPER

Bioenzyme activation preparation of Fe_3O_4/carbon nanofibers as supercapacitor electrode materials

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Abstract

A new activation method for carbon-based pore expansion of composite materials was developed using the biocatalytic principle of amylase to hydrolyze cyclodextrin into small molecules of maltose and glucose. The composite carbon nanofiber mats were prepared by electrospinning with polyacrylonitrile (PAN), α-cyclodextrin, iron acetylacetonate as the iron oxide precursor, and hemp straw-based liquefied carbon as the electrospinning precursors. The α-cyclodextrin was hydrolyzed by medium-temperature α-amylase to generate pores, and a composite electrode material of carbon nanofibers with controlled iron oxide/porous structure was prepared through pre-oxidation and carbonization. Based on the morphology and structure of the prepared electrode materials and the electrochemical performance of three electrodes and two electrodes, it can be concluded that it is feasible to prepare electrochemical materials with the pore structure of carbon nanofibers by the enzyme pore enlarging method. Meanwhile, the $FePCNF_1$ reaches 314 F g^{-1}; at the current density 10 A g^{-1}, over 75.6% of initial capacitance is retained as the current density improves from 1 to 10 A g^{-1} and also exhibits an excellent cycling performance with 62% capacitance retention after 15,000 times charge/discharge cycles.

Keywords Iron oxide · Carbon nanofibers · Pore structure · Bioenzyme activation · Supercapacitors

Introduction

As an alternative energy storage device, supercapacitors have many advantages over conventional batteries, such as fast charge/discharge rate, high power density, and long cycle life [1–6]. The main component of a supercapacitor is the electrode material that dictates its capacitance and charge storage performance. The activation process is a key step in the preparation of biomass carbon materials both for double-layer capacitors and for pseudocapacitors. It is also an effective way to expand existing pores or modify them [7, 8]. During this process, the pore structure of the carbon material is formed, and the specific surface area increases, which is conducive to the infiltration of the electrode surface by the electrolyte. The open pores can provide more charge storage sites and transmission channels, shorten the diffusion distance of ions, and affect the electrochemical performance, which has a positive effect on the improvement of electrochemical performance [9, 10].

At present, two types of activation are commonly used: physical activation and chemical activation. Physical activation uses carbon dioxide, steam, or the mixture of these gases to create pores. These substances react with carbon atoms to form carbon monoxide, which leads to structural changes. The obtained micropore widths are relatively loosely correlated with experimental parameters such as temperature, pressure, and heating rate [11, 12]. During the chemical activation, activators such as KOH, $ZnCl_2$, or H_3PO_4 interact with the carbon to dehydrate or erode the feedstock at certain temperatures, resulting in pores. Compared with physical activation, chemical activation can better control the pore size distribution and obtain higher specific surface area and yield. However, KOH and other activators have certain corrosion characteristics and need to be cleaned strictly. More importantly, the production of carbon materials after

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