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Corn Starch Derived Capacitive Carbon Prepared by One-Step K_2CO_3 Carbonization for Supercapacitors

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Abstract

High-performance carbonaceous electrode materials for supercapacitors were synthesized by subjecting corn starch to a simple molten salt activation process with K_2CO_3 at a temperature of 850˚C. The resulting carbon material, obtained after activating for 1 hour, displayed excellent capacitive properties due to the synergistic effects of its porous structure. Utilizing these electrodes, the supercapacitor exhibited a high discharge capacitance (248 F g^{-1} at 1 A g^{-1}), which is 2.4 times higher than that of activated carbon without K_2CO_3 activation. The enhancement in electrical performance was analyzed through SEM and XRD analysis, revealing that the porous and disordered structure provides a greater number of charge storage sites, resulting in improved capacitive performance.

Keywords

Activated Carbon, Porous Structure, Corn Starch, Supercapacitors

1. Introduction

In recent years, with the rapid development of the global economy and population growth, the depletion of non-renewable fossil fuel resources such as coal and oil has become increasingly severe, posing a serious crisis to the sustainable development of modern society [1] [2] [3]. Therefore, the development and efficient utilization of clean and sustainable energy sources, such as solar energy and wind energy, are considered the most promising solutions to address these challenges. However, the efficient utilization of these energy sources often requires advanced energy storage systems. Supercapacitors, as a new type of energy storage device, have attracted great attention due to their long cycle life

(>100,000 cycles), high charge-discharge efficiency, high power density, and excellent low-temperature performance [4] [5]. Based on their different energy storage mechanisms, supercapacitors can be divided into two categories: electric double-layer capacitors (EDLCs) and pseudocapacitors [6] [7]. In the case of EDLCs, the charge is stored through the electrostatic interaction of ions adsorbed near the surface of the active material. On the other hand, pseudocapacitors store/release energy through redox reactions, ion insertion/squeezing, and potential deposition. Compared to pseudocapacitors, EDLCs have lower energy density but exhibit better stability, higher cycling efficiency, and faster charge-discharge rates. The performance of supercapacitors is highly dependent on the choice of electrode material. Carbon-based materials are commonly used due to their excellent electrical conductivity, favorable physical-chemical stability, large specific surface area (SSA), and adjustable porous structures [8] [9] [10]. Among the various carbon-based electrode materials, biomass-derived carbon materials are considered promising candidates. They offer several advantages, including abundant renewable sources, low cost, self-doping with heteroatoms, and high capacitive performance [11] [12]. To date, numerous biomass-derived carbon materials have been reported [13]-[17].

Starch is widely recognized as an affordable, easily purified, and readily available carbon source. Extensive research has been conducted on the reactions of starch, allowing for easy control and manipulation. On the other hand, commonly used strong acid and alkali activators have strong corrosiveness to equipment. Herein, porous carbon materials were prepared by one-step method using discarded corn starch (CS) as carbon sources and neutral salt K_2CO_3 as activator. The prepared porous activated carbon exhibits excellent supercapacitive performance, providing a new avenue for the efficient resource utilization of starch waste in the future.

2. Experimental Method

2.1. Preparation of CSs

The corn starch was bought from Shandong Hengren Industry and Trade Co., Ltd. First, corn starch was transferred to a tube furnace at 500˚C for 1 hour with an increasing rate of 10˚C/min. After that, the sample is divided into two parts, one without activator, and the other with K_2CO_3 added in a 1:2 mass ratio. Then both samples were transferred to a tube furnace at 850˚C for 1 hour with an increasing rate of 10˚C/min. Lastly, the sample with K_2CO_3 was obtained by using 0.5 molar diluted hydrochloric acid (HCl) for cleaning and deionization, and this sample was named CSK850. The sample that has not been activated by an activator is named CS850.

2.2. Characterization

The morphology and phase structure of CS850 and CSK850 samples were characterized by scanning electron microscopy (SEM, GeminiSEM 500), and X-ray

diffraction (XRD, Cu Ka, 1.5418 Å), respectively.

2.3. Electrochemical Measurements

Cyclic voltammetry (CV) curves were measured at different scan rates of 5, 10, 20, 40, and 60 mV/s. Galvanostatic charge-discharge (GCD) curves were studied at various current densities of 1, 2, 5, 10, and 20 A/g. All electrochemical measurements were conducted using the CHI660e electrochemical station.

3. Results and Discussion

Figure 1 shows the SEM images which demonstrated the morphology and microstructure of the CS850 and CSK850 samples. The carbon material directly pyrolysis of corn starch is blocky, and it is almost no porous structure on the surface of the material (Figure 1(a)). After activation with K_2CO_3, the sample CSK850 exhibits a porous structure as shown in Figure 1(b).

In order to further study the crystal structure of the sample, XRD tests were conducted on CS850 and CSK850 samples. As shown in the spectrum of Figure 2(a), two broad diffraction peaks were observed at $2\theta = 26^\circ$ and $2\theta = 44^\circ$, corresponding to the crystal planes of graphite (002) and (100), indicating the presence of certain graphite microcrystalline structures in activated carbon (amorphous carbon) [18]. With the use of activators, the peak intensity weakens at $2\theta = 44^\circ$ due to the large number of pores generated by activation, which

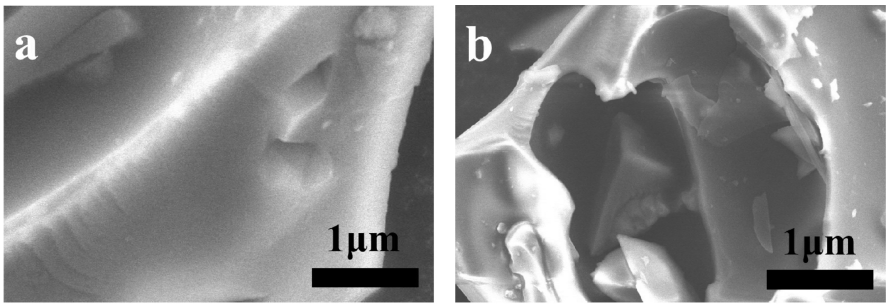

Figure 1. SEM images of (a) CS850 and (b) CSK850 samples.

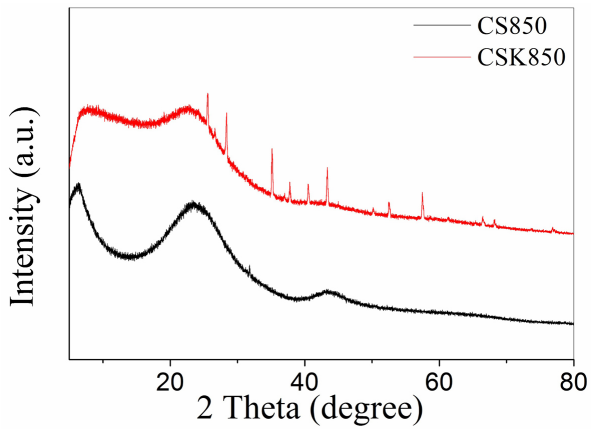

Figure 2. XRD patterns for CS850 and CSK850 samples.

destroys the graphite microcrystalline structure in the sample and reduces the degree of graphitization of the material (Figure 2(b)). This also proves the activation effect from another aspect, which is consistent with the SEM analysis results in Figure 1.

Cyclic voltammetry is a widely adopted and succinct testing technique for investigating the electrochemical performance of supercapacitors. By analyzing the characteristics of the cyclic voltammetry curve, researchers can gain insights into the redox reactions occurring on the electrode. The electrochemical characteristics of CS850 and CSK850 samples were examined in a three-electrode system using a 6 M KOH solution. The cyclic voltammogram at different scan rates was presented in Figure 3. In Figure 3(a), it can be observed that the corn-based activated carbon, which was not activated with K_2CO_3, demonstrates excellent symmetry. Its curve shape resembles that of a rectangle and shows no signs of oxidation peaks. This suggests that the electrode possesses minimal pseudo

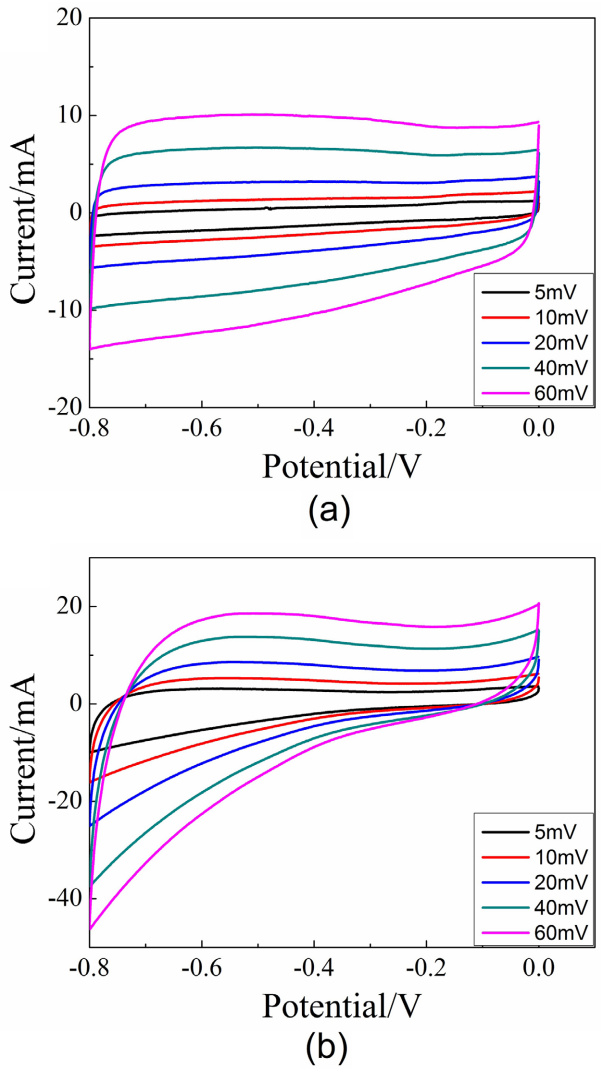

Figure 3. CV curves at various scan rates for samples (a) CS850 and (b) CSK850.

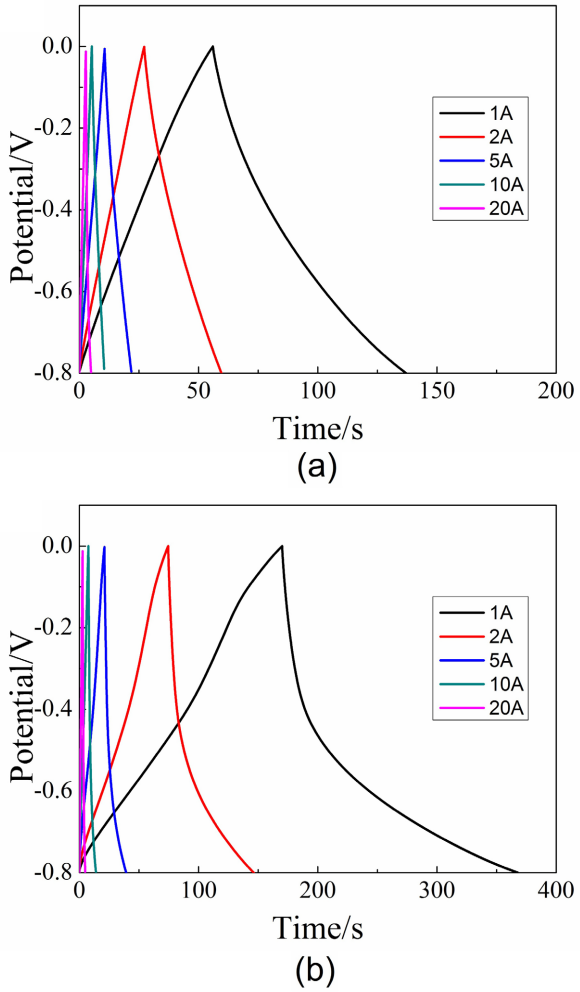

Figure 4. GCD curves at various current densities for samples (a) CS850 and (b) CSK850.

capacitance and falls under the category of a typical double layer capacitance. After activation with K_2CO_3, the voltammetry curve has an irregular rectangular shape. Moreover, it is apparent that the area bounded by the CV curve of CSK850 is much larger than that of CS850. This discrepancy can be attributed to the hierarchical porous structure and increased disorder resulting from K_2CO_3 reactivation. As a result, the CSK850 sample exhibits substantially higher capacitance when compared to the CS850 sample.

Figure 4 showcases the galvanostatic charge-discharge (GCD) curves obtained from all samples at different current densities. Each sample exhibits a distinctive symmetrical triangular-shaped plot, indicating excellent electrochemical reversibility. By using the constant current charging and discharging method to calculate the specific capacity. The specific capacitances of the CS850 sample are 102, 81, 70, 65 and 56 F/g at a current density of 1, 2, 5, 10 and 20 A/g, respectively, and the CSK850 show the specific capacitance of 248, 180, 125, 80 and 60 F/g at the same current density. The CS850 sample by K_2CO_3 reactivation exhibits much higher charge/discharge time and specific capacitance, which is consistent

with the cyclic voltammetry test results. In comparison to CS850 without K_2CO_3 activation, CSK850 possesses a greater abundance of pore structures and a significantly higher specific surface area. As a result, CSK850 offers a larger number of charge storage sites compared to CS850 samples, leading to enhanced capacitive performance of CSK850 samples.

4. Conclusion

This study successfully synthesized porous carbon by utilizing waste corn starch as a carbon source and employing a one-step activation method with K_2CO_3. The activation conditions of this method are gentle, and the reaction process is easily manageable, resulting in reduced energy consumption and equipment corrosion when compared to the use of KOH activators. The resulting porous carbon exhibits a plentiful three-dimensional pore structure. When employed as an electrode material for supercapacitors, the porous carbon synthesized in this study demonstrates a remarkable capacity of up to 248 F/g at a current density of 1 A/g. This performance is 2.4 times higher than that of the non-activated material. The experiment validates the simplicity and feasibility of the method utilized in this study, which also involves the recycling of biomass waste. The utilization of biomass waste not only holds significant environmental value but also presents promising applications in the field of supercapacitors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Chu, S., Cui, Y. and Liu, N. (2017) The Path towards Sustainable Energy. *Nature Materials*, **16**, 16-22. https://doi.org/10.1038/nmat4834

[2] Yao, L. (2022) New Energy Utilization in Environmental Design and Realization. *Energy Reports*, **8**, 9211-9220. https://doi.org/10.1016/j.egyr.2022.07.029

[3] Poizot, P., Gaubicher, J., Renault, S., Dubois, L., Liang, Y.L. and Yao, Y. (2020) Opportunities and Challenges for Organic Electrodes in Electrochemical Energy Storage. *Chemical Reviews*, **120**, 6490-6557. https://doi.org/10.1021/acs.chemrev.9b00482

[4] Wang, G.P., Zhang, L. and Zhang, J.J. (2012) A Review of Electrode Materials for Electrochemical Supercapacitors. *Chemical Society Reviews*, **41**, 797-828. https://doi.org/10.1039/C1CS15060J

[5] Gonzalez, A., Goikolea, E., Barrena, J.A. and Mysyk, R. (2016) Review on Supercapacitors: Technologies and Materials. *Renewable & Sustainable Energy Reviews*, **58**, 1189-1206. https://doi.org/10.1016/j.rser.2015.12.249

[6] Patel, K.K., Singhal, T., Pandey, V., Sumangala, T.P. and Sreekanth, M.S. (2021) Evolution and Recent Developments of High Performance Electrode Material for Supercapacitors: A Review. *Journal of Energy Storage*, **44**, Article ID: 103366. https://doi.org/10.1016/j.est.2021.103366

[7] Nekouei, R.K., Mofarah, S.S., Maroufi, S., Tudela, I. and Sahajwalla, V. (2022) De-

termination of the Optimum Potential Window for Super- and Pseudocapacitance Electrodes via In-Depth Electrochemical Impedance Spectroscopy Analysis. *Journal of Energy Storage*, **56**, Article ID: 106137. https://doi.org/10.1016/j.est.2022.106137

[8] Zhu, Y.W., Murali, S., Stoller, M.D., Ganesh, K.J., Cai, W.W., Ferreira, P.J., Pirkle, A., Wallace, R.M., Cychosz, K.A., Thommes, M., Su, D., Stach, E.A. and Ruoff, R.S. (2011) Carbon-Based Supercapacitors Produced by Activation of Graphene. *Science*, **332**, 1537-1541. https://doi.org/10.1126/science.1200770

[9] Popov, M.V., Brester, A.E., Yusin, S.I. and Bannov, A.G. (2021) Study of Porous Carbon Materials for Supercapacitors. *Chemistry for Sustainable Development*, **29**, 673-683. https://doi.org/10.15372/CSD2021348

[10] Jia, R., Qing, F. and Li, X. (2023) High-Throughput Growth of Hexagonal Boron Nitride Film Using Porous-Structure Isolation Layer. *Journal of Materials Science and Chemical Engineering*, **11**, 45-51. https://doi.org/10.4236/msce.2023.113004

[11] Lyu, L., Seong, K., Ko, D., Choi, J., Lee, C., Hwang, T., Cho, Y., Jin, X., Zhang, W., Pang, H. and Piao, Y. (2019) Recent Development of Biomass-Derived Carbons and Composites as Electrode Materials for Supercapacitors. *Materials Chemistry Frontiers*, **3**, 2543-2570. https://doi.org/10.1039/C9QM00348G

[12] Lu, H. and Zhao, X.S. (2017) Biomass-Derived Carbon Electrode Materials for Supercapacitors. *Sustainable Energy & Fuels*, **1**, 1265-1281. https://doi.org/10.1039/C7SE00099E

[13] Fu, G.S., Li, Q., Ye, J.L., Han, J.J., Wang, J.Q., Zhai, L. and Zhu, Y.W. (2018) Hierarchical Porous Carbon with High Nitrogen Content Derived from Plant Waste (Pomelo Peel) for Supercapacitor. *Journal of Materials Science-Materials in Electronics*, **29**, 7707-7717. https://doi.org/10.1007/s10854-018-8766-0

[14] Guo, D.D., Xin, R.R., Wang, Y.F., Jiang, W., Gao, Q.P., Hu, G.S. and Fan, M.H. (2019) N-Doped Carbons with Hierarchically Micro- and Mesoporous Structure Derived from Sawdust for High Performance Supercapacitors. *Microporous and Mesoporous Materials*, **279**, 323-333. https://doi.org/10.1016/j.micromeso.2019.01.003

[15] Bian, Z.T., Li, M., Liu, T.Q., Liu, C.C., Zhu, Y.Y., Cao, H.X., Zhu, G., Wang, H.Y., Chen, C. and Zhang, K.Y. (2023) From Weed to N/O/S Co-Doped Honeycomb-Like Porous Carbon for High-Performance Supercapacitors: A Facile and Friendly One-Step Carbonization. *Journal of Alloys and Compounds*, **965**, Article ID: 171347. https://doi.org/10.1016/j.jallcom.2023.171347

[16] Li, K., Liu, Z., Ma, X.M., Feng, Q.G., Wang, D.B. and Ma, D.C. (2023) A Combination of Heteroatom Doping Engineering Assisted by Molten Salt and KOH Activation to Obtain N and O Co-Doped Biomass Porous Carbon for High Performance Supercapacitors. *Journal of Alloys and Compounds*, **960**, Article ID: 170785. https://doi.org/10.1016/j.jallcom.2023.170785

[17] Li, X. and Wu, G. (2021) Porous Carbon from Corn Flour Prepared by H_3PO_4 Carbonization Combined with KOH Activation for Supercapacitors. *Journal of Power and Energy Engineering*, **9**, 18-25. https://doi.org/10.4236/jpee.2021.98002

[18] Xiao, K., Ding, L.X., Chen, H.B., Wang, S.Q., Lu, X.H. and Wang, H.H. (2016) Nitrogen-Doped Porous Carbon Derived from Residuary Shaddock Peel: A Promising and Sustainable Anode for High Energy Density Asymmetric Supercapacitors. *Journal of Materials Chemistry A*, **4**, 372-378. https://doi.org/10.1039/c5ta08591h