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Activated carbon synthesized from bamboo shoots for supercapacitor application

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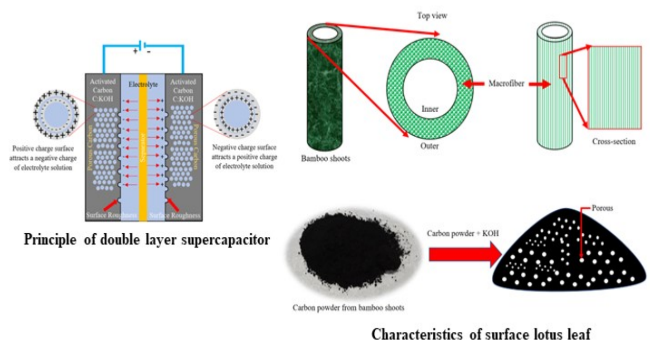
Abstract

Carbon powder was synthesized from bamboo shoots by chemical activation. The porous carbon powders were activated by potassium hydroxide (KOH) with a ratio of carbon powder (C) and KOH (C : KOH) of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 by weight, respectively. Structure, morphological properties, and the porosity of activated carbon powders were investigated by XRD, EDX, SEM, and BET. The electrochemical performances were measured by charge/discharge (CD) and cyclic voltammetry (CV) techniques. Specific surface areas increased to 1,017, 1,162, 1,257, and 1,012 m^2 g^{-1} for C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4, respectively. Specific capacitances were 11.30, 26.60, 50.50, and 40.50 F g^{-1} for the C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4, respectively. The activated carbon electrode with a C: KOH ratio of 1 : 3 sintered at 600 °C displayed the highest specific capacitance value of 50.5 F g^{-1}. It should be a good candidate material for high-performance supercapacitor electrodes.



Keywords: Activated carbon; Bamboo shoots; Supercapacitor; KOH activation; Carbon electrode

1. Introduction

Electric energy shortage is a crisis on the earth. Especially, electricity energy has been necessary for human life. Present, alternative energy is replacing petroleum, coal, and natural gas. Although it can be used to generate electricity in very high quantities, it can't be stored energy usable enough. Therefore, it is necessary to have energy storage devices such as batteries, capacitors, and supercapacitors [1]. A supercapacitor is an interesting energy storage device because of its high power density, high energy density, high-speed charging/discharging, and long-life cycle. A supercapacitor can be divided by the charge storage mechanism into three types: double-layer capacitors, pseudo-capacitors, and hybrid capacitors [2]. The double-layer capacitor focuses on this research due to its simple structure, easy fabrication, and low-cost materials [3]. The carbon double layer capacitor system consists of the carbon electrodes sandwich, electrolyte, and separated paper [4]. The carbon electrode is the factor affecting the development of the high performance of a carbon double layer capacitor. The suitable carbon electrode can be synthesized from activated carbon (AC), which must have high purity carbon, high surface area, high corrosion resistance, and high conductivity [5]. The low-cost AC is derived from natural materials such as wool felt, coconut waste, lotus leaf, mangosteen peel, biochar, orange peel, bamboo, bamboo shoots, et., respectively [6 – 17]. This work presents the method for synthesizing AC from bamboo shoots for supercapacitors.

2. Materials and Methods

Bamboo shoots of Dendrocalamus (Pai Tong in Thai), a tropical Asian genus of giant clumping bamboos, were used as a carbon source. We synthesized bamboo shoots as an activated carbon by a simple method as followings. The bamboo shoots were cut into thin pieces, then immersed in acetone, and ethanol to break the protein to shake with an ultrasonic machine (Branson, Thailand) for 1 hour. Afterward, the thin pieces of the bamboo shoots were heated at 80 °C for 12 hours, followed by heating at 400 °C for 1 hour with a heating rate of 5 °C per minute in an argon atmosphere.

Carbon powders were activated with KOH in C : KOH ratio of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 by weight, which was sintered at different temperature of 400 °C, 500 °C, and 600 °C for 2 hours with heating rates of 5 °C per minute in an argon atmosphere. The carbon powder was washed with hydrochloric and deionized (DI) water until pH was about 5. After that, it was dried at 150 °C for 6 hours to achieve AC powder.

The structural, quantitative analysis, morphological properties, the porosity of carbonaceous powders were investigated by X-ray diffraction (XRD) (Philips, PW 1830/40, France), energy-dispersive X-ray spectroscopy (EDX), scanning electron microscope (SEM) (JEOL, JSM-7001F), and the nitrogen adsorption techniques using Brunauer Emmett Teller (BET) (Quantachrome, US). The electrochemical performance was tested by the charging and discharging (CD) and the cyclic voltammetry (CV).

3. Results and Discussion

Fig. 1 shows the typical synthesized resultant of carbon powder from bamboo shoots in C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 by burning under an argon atmosphere. The dried bamboo shoots powder was heated at 400 °C, 500 °C, and 600 °C for 2 hours and achieved a black carbon powder.

Fig. 1 AC powder from a bamboo shoot with an activation ratio of C : KOH at 1 : 1.

The XRD patterns of AC powders with C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 activation at 600 °C for 2 hours were shown in Fig. 2. The carbon fraction of activation with KOH in different ratios is structurally amorphous carbon. XRD pattern of all AC powder shows a broad (1 1 1) peak near 22°, corresponding to amorphous carbon structure JCPDS no: 00-041-1487 [15], and there is other contaminants peak at 15°, 28°, 32°, and 41° from C powder amorphous substrate.

The elemental mapping of the synthesized AC powder with C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 at 600 °C for 2 hours were analyzed by the EDX technique, consisting of C, O, Si, Au, and Cu elements, [16] as shown in Table 1. As a result of EDX, carbon powder has a large amount of carbon. The O and Si elements may come from the nutrient the plant requires for growth. Au elements come from the Au coating sample for EDX measurement.

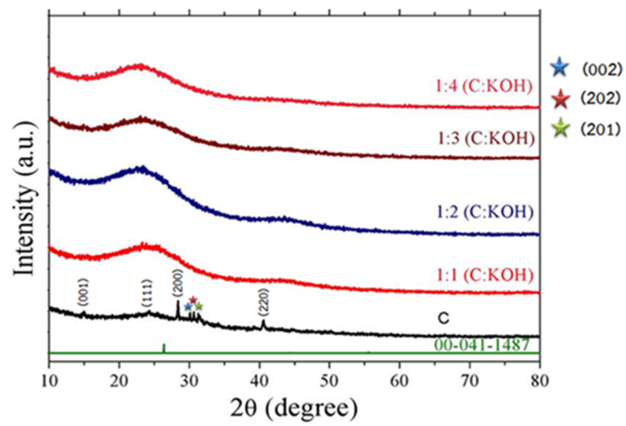


Fig. 2 XRD patterns of AC powders activated with different C : KOH ratios at 600 °C.

Table 1 Elemental in AC powders measured by EDX mapping.

C : KOH	%C	%O	%Si	%Au	%Cu
1 : 1	91.54	3.64	0.53	3.51	0.78
1 : 2	84.87	5.01	1.99	6.67	1.46
1 : 3	90.04	4.24	1.43	3.54	0.75
1 : 4	83.48	7.64	5.40	2.78	0.70

The SEM images revealed the surface morphology of AC powder differs from the non-activated carbon surface, as shown in Fig. 3. When increasing the ratio of C : KOH ratios to 1 : 2, 1 : 3, and 1 : 4, the surface of AC powders (Fig. 3(b) – (d)) is uniformly porous and has high porosity. The surface morphology of the non-activated carbon powder is rough and dense, with fewer holes. The hole size distribution is not uniform (Fig. 3(a)).

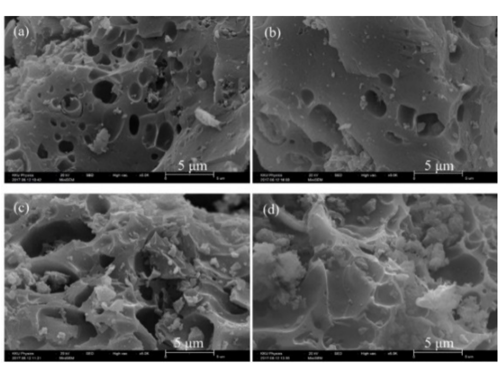


Fig. 3 SEM images of AC powder with C : KOH ratios of (a) 1 : 1, (b) 1 : 2, (c) 1 : 3, and (d) 1 : 4.

The specific surface areas, pore volumes, and average pore sizes were evaluated by BET measurement and summarized in Table 2. The data show that the non-activated carbon powder had a lower surface area and porous volume than carbon powder from activating with KOH. The specific surface area and porous volume trend towards increasing with an increasing ratio of C : KOH from 1 : 1 to 1 : 3. Then the value decreases at a ratio of 1 : 4 due to the excessive amount of KOH. The AC power with a C : KOH ratio of 1 : 3 had the highest surface area of 1,257 m^2 g^{-1} causing carbon surface cracking and too large holes. It has a pore volume up to 0.84 cm^3 g^{-1} and average pore size of 26.84 nm [16 – 17].

Figures 4(a) to 4(e) show CD curves at 1, 13, and 25 cycles of non-activated carbon and AC electrodes. It seems that the discharge time of the 1st cycle has the longest time than that of 13 and 25 cycles indicating that the specific capacitance decreased with an increasing number of charge/discharge cycles. Significantly, the C : KOH ratio of 1 : 3 AC electrode has the longest discharge time, indicating it delivers the highest specific capacitance than the other electrode.

Table 2 BET results of samples.

Samples	Surface area ($m^2 g^{-1}$)	Pore volume ($cm^3 g^{-1}$)	Average pore size (Å)
C	1.324	0.02	705.40
C : KOH 1 : 1	1,017	0.83	32.52
C : KOH 1 : 2	1,162	0.69	23.75
C : KOH 1 : 3	1,257	0.84	26.84
C : KOH 1 : 4	1,012	0.73	28.63

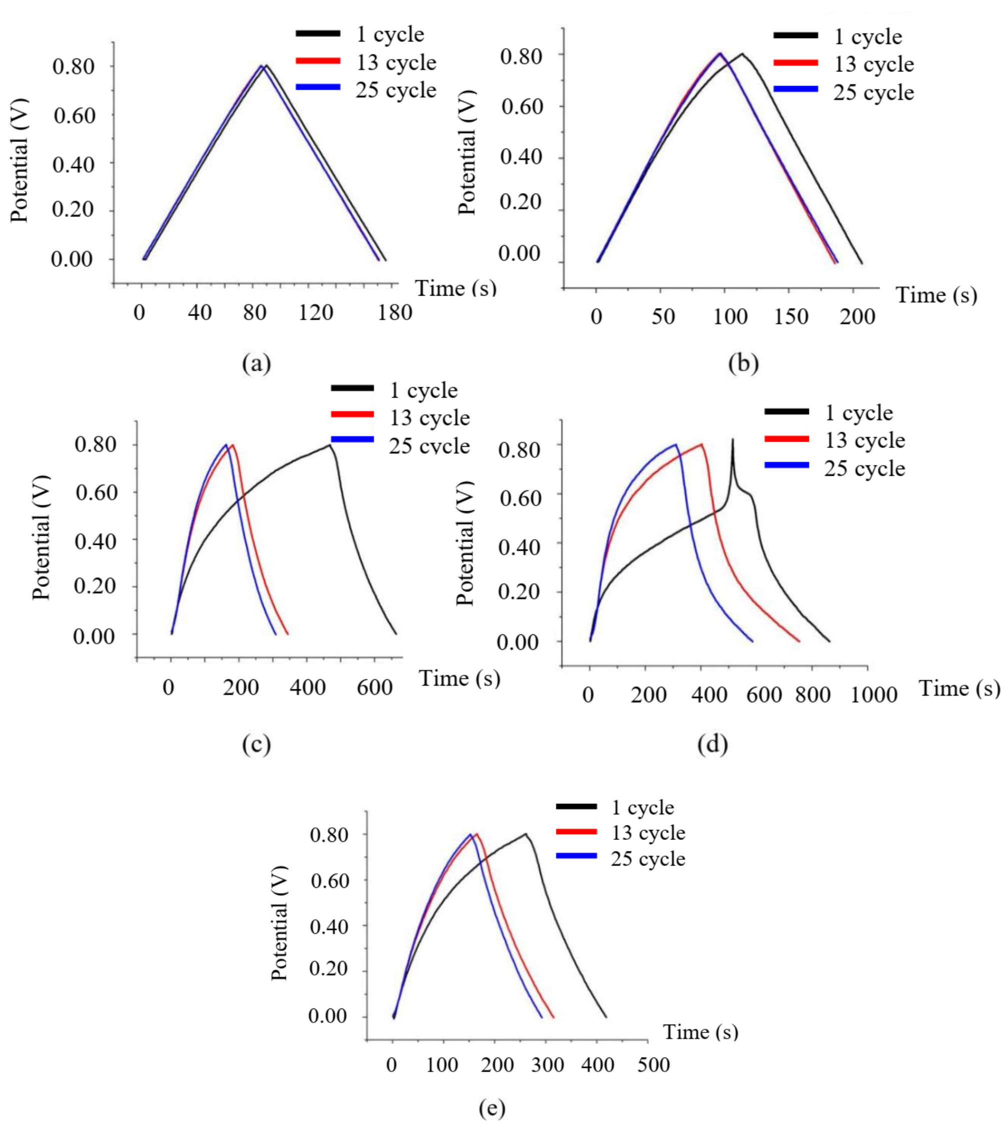


Fig. 4 CD curves at 1, 13, and 25 cycles of (a) non-activated carbon electrode and AC electrodes with C : KOH ratio of (b) 1 : 1, (c) 1 : 2, (d) 1 : 3, and (e) 1 : 4 at current 0.02 mA, respectively.

Fig. 5 shows the specific capacitance of all carbon electrodes. The specific capacitance in the 1st cycle is 6.52, 11.60, 31.60, 53.20, and 43.30 F g^{-1} for non-activated carbon, AC electrodes with C: KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4, respectively. With increasing charge/discharge cycle to the 25th cycle, the specific capacitance of non-activated carbon, AC electrodes with C : KOH ratio of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 electrodes, respect decreased to 1.07%, 2.60%, 27.90%, 22.40%, and 13.90% comparison to their value in the 1st cycle.

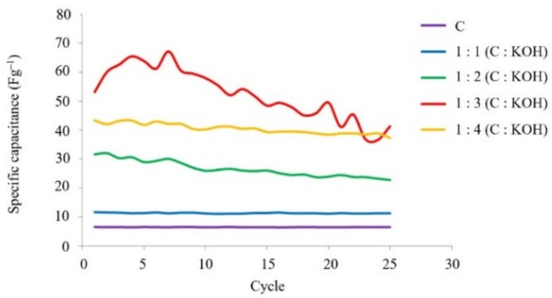
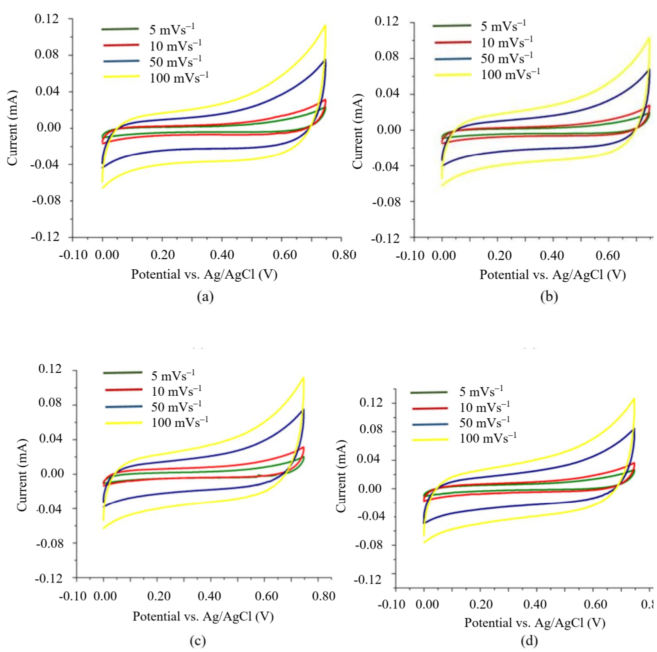


Fig. 5 Specific capacitance of all carbon electrodes.



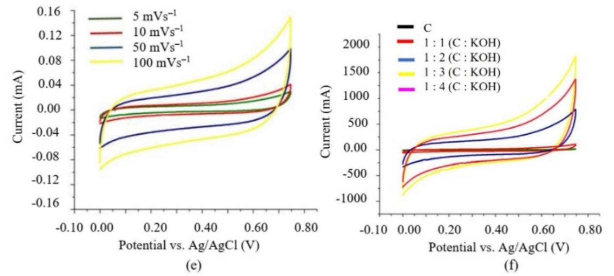


Fig. 6 CV curves of carbon electrodes with a different scan rate of 5, 10, 50, and 100 mV s^{-1}.

Fig. 6 shows the CV curves of the non-activated carbon electrode and AC electrodes with different C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 at the scan rate 5 to 100 mV s^{-1}. At a scan rate of 10 mV s^{-1} in Fig. 6(f), the CV curve of the C : KOH ratio of the 1 : 3 AC electrode gives a higher current density than another electrode, indicating it possesses the highest electrochemical performance. A rectangular shape, close to the ideal capacitor's behavior, can be clearly observed for all electrodes showing a double-layer capacitor [15 – 17]. The specific capacitance was calculated to be 0.40, 2.40, 19.70, 39.20, and 30.80 F g^{-1} for non-activated carbon electrodes, AC electrodes with C : KOH ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4, respectively.

4. Conclusion

The synthesized carbon powders from a natural material, bamboo shoots, were obtained by chemical activation using a KOH agent in various ratios of C : KOH of 1 : 1, 1 : 2, and 1 : 3, 1 : 4. The crystal structure of synthesized carbon powder obtained from XRD analysis found that all carbon powders were amorphous. The EDX technique found that the carbon powder consists mainly of carbon elements and other substances mixed with very little. SEM technique found that the surface of AC powder has a porous structure. AC power with a ratio of C : KOH of 1 : 3 has the highest porosity with specific surface area (1,257 m^2 g^{-1}) and pore volume at a maximum of 0.84 cm^3 g^{-1}. The electrochemical performance from CD and CV techniques found that the AC electrode with a ratio of C: KOH of 1 : 3 at 600 °C for 2 hours delivers the highest specific capacitance, equal to 50.50 F g^{-1}. This condition is suitable for application in the electrode of the supercapacitor.

5. Suggestions

This research focuses on synthesizing carbon powder from natural material from bamboo with the KOH activating agent in a C : KOH ratio of 1 : 1, 1 : 2, and 1 : 3 1 : 4, respectively. The attractive C : KOH ratio was between 1 : 2 and 1 : 3, which must be researched further.

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