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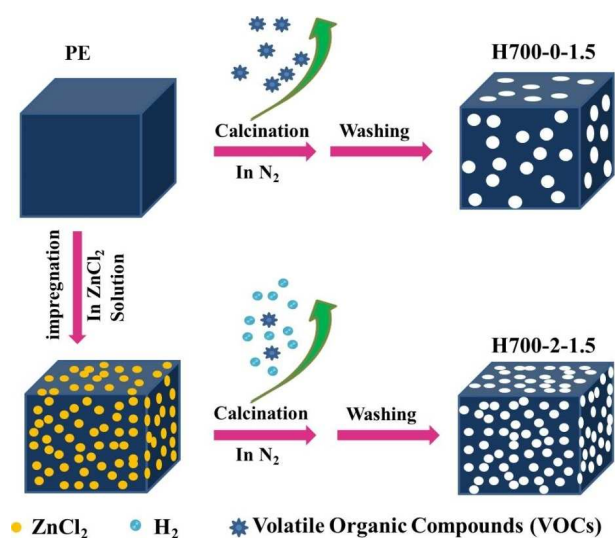
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Graphical Abstract

Porous carbons were prepared from enteromorpha overrunning in China Sea with ZnCl_2 as active reagent. The prepared porous carbon with a specific surface area of $1651 \text{ m}^2/\text{g}$ exhibited a specific capacitance of 206 F/g and capacity retention of 93% even after 5000 cycles, indicating good electrochemical properties and promising utilization future of enteromorpha as electrode materials for supercapacitors.



Enteromorpha based porous carbons activated by zinc chloride for supercapacitors with high capacity retention[†]

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Porous carbons were prepared from enteromorpha overrunning in China Sea with ZnCl₂ as active agent. The obtained porous carbons were used as electrode materials to make supercapacitors. In order to make enteromorpha based supercapacitors with high performance, the effects of preparation parameters including impregnation weight ratio of ZnCl₂ to enteromorpha, activation time and temperature on pore structure and electrochemical performances of enteromorpha based porous carbons (EBPCs) were investigated. The specific area and porous structure were characterized by nitrogen adsorption. Galvanostatic charge-discharge and cyclic voltammetry analysis were used to investigate the electrochemical properties of EBPCs. The results show that activation temperature of 700 °C, the impregnation weight ratio of 2/1 and activation time of 1.5 h are the optimal preparation parameters. The prepared EBPC with a specific surface area of 1651 m²/g exhibited a specific capacitance of 206 F/g and capacity retention of 93 % even after 5000 cycles, showing excellent electrochemical properties of EBPC and good utilization future of enteromorpha.

1. Introduction

Nowadays, the growing scarcity of fossil fuels and continually increasing greenhouse effect have impelled intensive research into environmentally effective energy storage all around the world. Among the energy storage devices, more and more attention has been paid to supercapacitors owing to their good electrochemical properties, *i.e.* high power density, high energy efficiency, excellent stability and long cycle life¹⁻³. Those advantages have promoted their applications in communication devices, portable devices, and electrical/hybrid vehicles. According to the energy storage mechanisms, there are mainly two kinds of supercapacitors, *i.e.* electric double layer capacitor (ions accumulate at the electrode/electrolyte interface) and pseudocapacitor (highly reversible redox reactions occur on the electrode)⁴. Various materials including porous carbon materials⁵, metal oxides^{6,7} and conducting polymers⁸ have been used as electrodes of supercapacitors. Among these materials, porous carbons (PCs) with low cost, high specific surface area, environmentally friendly nature and relatively high conductivity⁹, have become the most popular materials for supercapacitors.

PC can be produced from various biomass precursors (*e.g.* wood¹⁰, fruit shells¹¹) and some fossil-fuel based precursors including petroleum¹² and coal. O. Terasaki *et al.* reported PC by pyrolyzing the furfuryl alcohol derived from subsidiary agricultural products within the pores of SBA-15¹³. J. S. Qiu *et al.* synthesized a new hierarchical PC from coal tar pitch with nano-Fe₂O₃ as the template and activation agent coupled with KOH activation⁵. Beyond above mentioned raw materials, aquatic organism can also be used as PC precursors. F. Beguin *et al.* was reported to apply brown seaweed *lessonia nigrescens* based PC obtained by one-step carbonization at 600 and 750 °C to supercapacitors in KOH media with a high capacitance of 188 F/g at a current density of 200 mA/g¹⁴. They also prepared carbon materials through direct pyrolyzation of sodium alginate, a widely-used biopolymer extracted from seaweed, at 600 °C under argon protection. The specific capacitance stabilize at 180 F/g after 6000 cycles in a two-electrode system¹⁵.

Enteromorpha is a kind of marine macroalgae, as a result of eutrophication¹⁶, and harmful to ocean transportation, environment quality and tourism. During the last decade, enteromorpha green tides broke out annually in the Yellow Sea of China and devastated the coastal marine ecological systems¹⁷. Enteromorpha continues to thrive nowadays and the vast majority is sent to landfills or just decomposed on the sea beach, causing serious resource waste and environmental pollution. How to efficiently use enteromorpha has become a burning problem. For dried enteromorpha, the main components are moisture (10 %), carbohydrate (48 %), protein

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(21 %), crude fibre (1.3 %), fat (0.3 %) and ash (18.6 %) ^{18,19}, most of which could serve as carbon precursors. Thus, we made an attempt to prepare PC from enteromorpha by ZnCl₂ activation. Compared with other active agents such as H₃PO₄, KOH and K₂CO₃ ^{20,21}, ZnCl₂ activation is milder and more controllable to obtain PC with higher surface area ²², which is beneficial to the electrochemical performances. Thus, ZnCl₂ was selected as active agent in present work.

To the best of our knowledge, despite the growing interest in enteromorpha for bio-oil ²³, PC prepared from enteromorpha for supercapacitors has not been reported. Herein, the relationship between different process parameters and the electrochemical performances of EBPC as supercapacitor electrodes was investigated.

2. Experimental

2.1. Preparation of EBPCs and their supercapacitors

Enteromorpha collected from Qingdao coastal district was washed with distilled water and dried thoroughly, then grinded into particles with size about 3 mm. After carbonized at 300 °C in a tubular furnace for 1.5 h, the as-made carbonized sample named pretreated enteromorpha (PE) was divided into three groups (I, II and III) equally. All EBPCs were prepared under a nitrogen flow of 60 mL/min with a fixed heating rate of 5 °C/min. Group I was pyrolyzed at 600, 700 and 800 °C for 1.5 h and the resulting carbons were denoted as H600-0-1.5, H700-0-1.5 and H800-0-1.5, respectively. Group II was impregnated in 25 wt% ZnCl₂ (AR, Sinopharm Chemical Reagent Co., Ltd.) aqueous solution with mass ratios of ZnCl₂/PE at 1/1, 2/1 and 3/1, and dried overnight before activation at 700 °C for 1 h. The obtained samples were named H700-1-1, H700-2-1 and H700-3-1. Compared with group II, group III was impregnated in 25 wt% ZnCl₂ solution with a fixed mass ratio (2/1) and activated at 700 °C for 1.5, 2 h. The carbons obtained were termed as H700-2-1.5, H700-2-2. The resulting samples of groups I, II and III were then washed 5 times with 5 M HCl and later washed with distilled water until a neutral pH was reached. The washed samples were dried at 100 °C overnight.

EBPCs were mixed with polytetrafluoroethylene (PTFE) binder and acetylene black as conductive additive in ethanol ²⁴ with a mass ratio of 85:10:5. The electrode was obtained through coating the slurry onto the nickel foam with a diameter of 12 mm. Finally, the electrode was dried at 110 °C for 60 min in a vacuum oven. Two electrodes were separated by a polymer separator (Celgard 2400) in 6 M KOH solution before sandwiched in a CR2032 coin cell.

2.2. Sample characterization

The structures and morphologies of EBPCs were characterized by X-ray diffraction (XRD) (X'Pert PRO MPD, Holland), field emission scanning electron microscopy (FE-SEM) (Hitachi S-4800, Japan). The functional groups in EBPCs were characterized by Fourier transform infrared spectrometry (FTIR) (Thermo Nicolet NEXUS 670, USA). X-ray photoelectron spectroscopy (XPS) was recorded on ESCALAB 250Xi spectrometer equipped with a pre-

reduction chamber. The pore structure characterization was performed on the basis of low temperature nitrogen adsorption-desorption isotherms on a sorptometer (Micromeritics, ASAP 2020, America).

2.3. Electrochemical measurements

Galvanostatic charge/discharge (current load 50 to 1000 mA/g) and electrochemical impedance spectroscopy (EIS) with frequency ranging from 10 mHz to 100 kHz were used to investigate the electrochemical properties of EBPCs on a Land CT-2001A cell tester. The cyclic voltammetry (CV) analyses (scan rate 2 mV/s) were performed using a Princeton electrochemical workstation (PARSTAT 4000, Princeton, USA).

3. Results and Discussion

XRD patterns of H700-2-1.5 and PE are shown in Fig. 1. For PE, XRD peaks at $2\theta = 16.2, 20.3, 22.1, 26.6, 29.5, 31.7, 34.7, 36.6$ and 45.8° reveal the presence of silica (SiO₂, JCPDS#79-1906) and calcium sulfate (CaSO₄, JCPDS#73-1942). Despite these identified compounds, the unidentified peaks are probably attributed to trace metal compounds. After ZnCl₂ activation and acid washing, H700-2-1.5 has a broad peak at $15-35^\circ$ corresponding to amorphous carbon, and the remaining peaks are attributed to silica as shown in Fig. 1(b). The peaks of SiO₂ and amorphous carbon in H700-2-1.5 are apparently similar to those of H700-0-1.5 (see Fig. S1), suggesting ZnCl₂ as active agent hasn't changed the basic crystallinity of the samples.

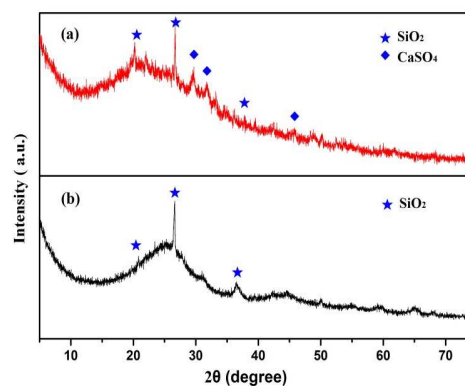


Fig. 1 XRD patterns of PE (a) and H700-2-1.5 (b)

FTIR curves of PE and H700-2-1.5 are shown in Fig. 2. The weak bands at 3237 and 2924 cm^{-1} represent O-H vibration and C-H stretching, respectively, and the band at 1684 cm^{-1} is assigned to C=O stretching vibration. Peaks around 2375 cm^{-1} is caused by CO₂ molecule existed in air ²⁵. The C=C stretching vibration in aromatic rings of PE and H700-2-1.5 could also be identified by peak around 1570 cm^{-1} , and the slender increase in peak intensity in H700-2-1.5 compared to PE attributes to the occurrence of condensation reaction during activation. FTIR curves also show C-H deformation vibration at 1443 cm^{-1} while the strong transmission from 900 cm^{-1} to 600 cm^{-1} could be signed as fingerprint region of C-H on aromatic ring ^{26,27}.

The weak peaks at 1104 cm^{-1} are assigned to C-O vibration²⁸. There are fewer bands in the spectra of H700-0-1.5 (Fig. S2) and H700-2-1.5 compared with that of PE owing to the high treatment temperature. Besides, the C=C bands of H700-0-1.5 are not as obvious as those of H700-2-1.5.

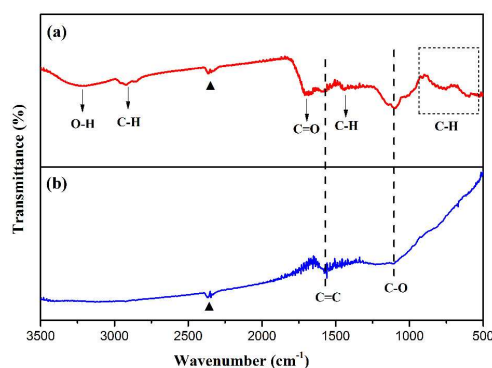


Fig. 2 FT-IR spectra of PE (a) and H700-2-1.5 (b)

FE-SEM images in Figs. 3(a), (b) and (c) show that PE, H700-0-1.5 and H700-2-1.5 have different morphologies. PE has smooth surface with little holes, H700-0-1.5 has some fractures and big holes as a result of high-temperature treatment while H700-2-1.5 has a rugged surface structure with many small pores after ZnCl_2 activation. PE, H700-0-1.5 and H700-2-1.5 can be imaged well without Au coating, suggesting that these samples possess good electrical conductivity. It can be deduced from the O1s spectra of PE and H700-0-1.5 (see XPS spectra in Fig. 3d) that high temperature can give rise to oxygen loss due to the fracture of chemical bond involved in oxygen containing functional groups, which also can be seen from their FTIR curves in Fig. 2 and Fig. S2. In comparison to H700-0-1.5, H700-2-1.5 has lower content of O and higher content of C (Figs. 3d and e). This change, as above mentioned, is most likely assigned to ZnCl_2 that leads to the charring and aromatization during the activation process²⁹.

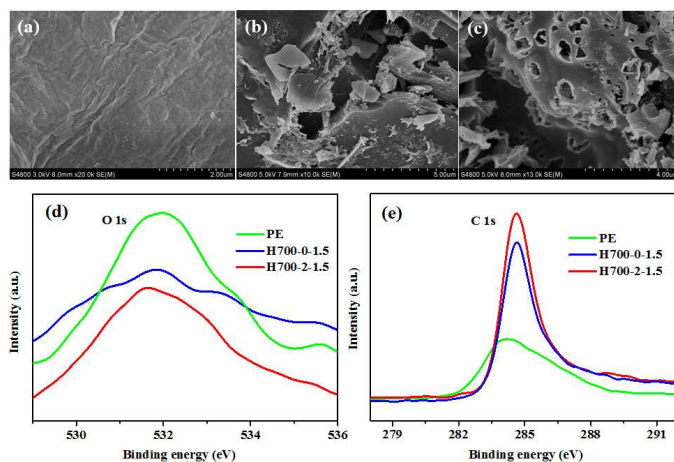


Fig. 3 SEM images of (a) PE, (b) H700-0-1.5 and (c) H700-2-1.5, XPS spectra of (d) O 1s and (e) C 1s of PE, H700-0-1.5 and H700-2-1.5

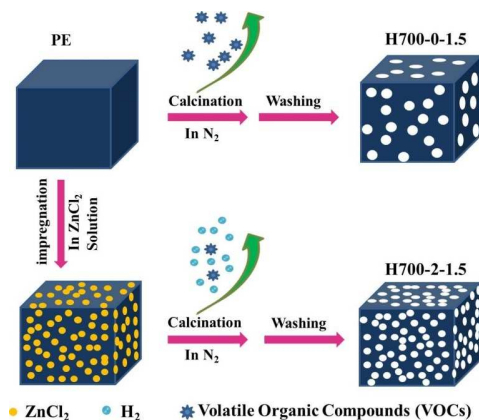


Fig. 4 Synthesis schematic of EBPC

To clearly show the process of ZnCl_2 activation, a preparation mechanism for EBPC is proposed in Fig. 4. H700-0-1.5 was prepared through carbonization with volatile materials evolved from PE, resulting in a mass of pores, 53 v/v% of which are mesopores (see Table 1), while H700-2-1.5 with a micropore volume ratio of 93% was obtained by the activation of ZnCl_2 uniformly dispersed in PE. Under the promotion of ZnCl_2 , the evolution of molecular hydrogen is more pronounced than other gaseous products²¹. H_2 gases are evolved from the hydroaromatic structure of the precursor and leave behind some sites for reaction. Finally, removing the chemicals left in the carbonized sample via washing yields porosity in the carbon structure.

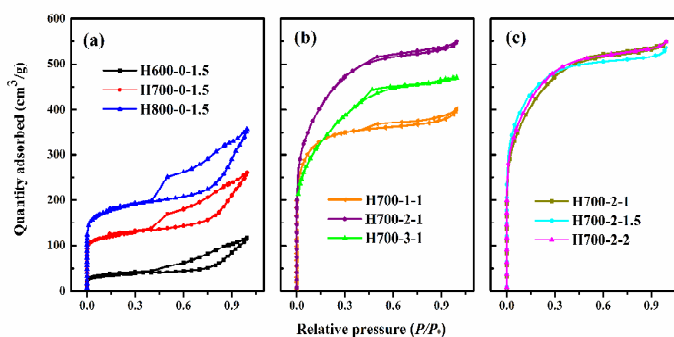


Fig. 5 Nitrogen adsorption-desorption isotherm curves of EBPCs

3.1 The effect of temperature

Table 1 shows the effects of temperature, impregnation ratio (ZnCl_2/PE) and activation time on the yield and porous structure of obtained EBPCs. With the increasing temperature, porosity forms while yield descends along with the depolymerization of biomacromolecule (e.g. cellulose) and the generation of volatiles. For H700-0-1.5, due to the sufficient carbonization, the BET surface area ($605\text{ m}^2/\text{g}$) and total pore volume ($0.48\text{ cm}^3/\text{g}$) are much higher than those of H600-0-1.5 ($131\text{ m}^2/\text{g}$ and $0.17\text{ cm}^3/\text{g}$).

Table 1 Pore structure and yield of EBPCs

Sample	Yield (%)	BET surface area (m ² /g)	Total pore volume (cm ³ /g)	Pore size (nm)	Micropore volume (cm ³ /g)	V _{mi} /V _t (%)
H600-0-1.5	17	131	0.17	5.2	0.04	24
H700-0-1.5	15	605	0.48	3.2	0.24	47
H800-0-1.5	14	589	0.39	3.4	0.16	42
H700-1-1	19	1264	0.61	1.9	0.53	87
H700-2-1	23	1560	0.84	2.2	0.77	92
H700-3-1	24	1251	0.73	2.3	0.67	92
H700-2-1.5	21	1651	0.82	2.0	0.76	93
H700-2-2	20	1618	0.84	2.1	0.68	81

V_{mi}: micropore volume; V_t: total pore volume.

However, as the temperature further increases to 800 °C, the surface area and pore volume decrease as a result of the partial extinction of micropores³⁰.

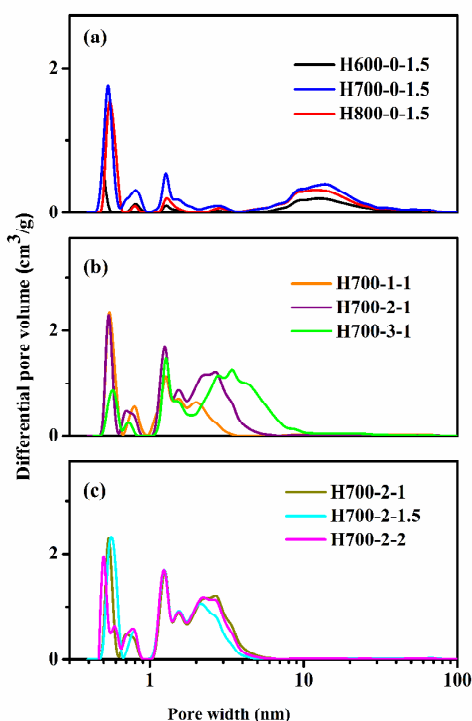


Fig. 6 Pore size distribution of EBPCs

Fig. 5 shows the N₂ adsorption-desorption isotherms of EBPCs. According to IUPAC classification method, adsorption-desorption isotherms of H600-0-1.5, H700-0-1.5 and H800-0-1.5 (Fig. 5(a)) belong to type IV isotherms and there are type H3 hysteresis loops, which is the most distinct characteristic of mesopores³¹. N₂ molecules are firstly adsorbed in micropores at low pressure stage as a result of strong interaction. Strong adsorption in mesopores and multilayer adsorption then begins to appear at medium pressure. Hysteresis loop is associated with capillary condensation.

Actually, the starting point of hysteresis loop corresponds to the appearance of capillary condensation. At high pressure, there is no limiting adsorption, indicating the existence of massive fracture pores due to the loose accumulation of flaky particles³². Fig. 6(a) shows the pore size distribution of H600-0-1.5, H700-0-1.5 and H800-0-1.5. Obviously, the pores of H600-0-1.5, H700-0-1.5 and H800-0-1.5 are mainly micropores and mesopores, which is consistent with Table 1.

Galvanostatic charge-discharge analysis carried out under different current densities is an effective method towards performance evaluation for supercapacitors. The electrode specific capacitance (C_p) is calculated by the following formula:

$$C_p = \frac{4I\Delta t}{m\Delta V} \quad (1)$$

where I (A), Δt (s), ΔV (V) and m (g) represent discharge current, discharge time, the potential drop in Δt and the mass of active material in two electrodes, respectively.

Fig. 7(a) shows the galvanostatic charge-discharge curves of EBPCs at the current density 100 mA/g in the voltage range 0 - 1 V. At different carbonization temperatures, the curves of H600-0-1.5, H700-0-1.5 and H800-0-1.5 exhibit high symmetry and linearity, indicating good supercapacitor behavior. Meanwhile, the charge-discharge time of H700-0-1.5 and H800-0-1.5 are much longer than that of H600-0-1.5, implying higher specific capacitance under the same current density. The varied specific capacitance at different current densities is shown in Fig. 7(b). When the current density is 50 mA/g, the specific capacitance of H700-0-1.5 is 144 F/g, much higher than 80 F/g of coconut shell, one of the most widely used biomass carbon materials³³. The specific capacitance of H600-0-1.5, H700-0-1.5 and H800-0-1.5 retains 69, 108 and 103 F/g at 400 mA/g, demonstrating 700 °C the most favourable heated temperature for energy storage. However, H800-0-1.5 has a specific capacitance of 81 F/g at 1000 mA/g, relatively higher than 78 F/g of H700-0-1.5. The changes in the specific capacitance should be attributed to the different pore structures of EBPCs (Table 1). Cyclic voltammetry test is also used to further evaluate the electrochemical performance of H600-0-1.5, H700-0-1.5 and H800-0-1.5 (Fig. 8(a)). In ideal electric double layer capacitor electrolyte, ion migration should not be restricted and the cyclic voltammetry curve should be ideal rectangle under constant current and scan rate. The cyclic voltammetry curves of H600-0-1.5, H700-0-1.5 and H800-0-1.5 show similar rectangles without apparent redox peaks, implying that

the pseudocapacitance contribution is little, and specific capacitance derives mainly from electric double layer capacitance³⁴. In addition, the CV curve of H700-0-1.5 has a larger area than those of H800-0-1.5 and H600-0-1.5, indicating the highest specific capacitance, which can also be confirmed by galvanostatic charge-discharge curves in Fig. 7(a).

3.2 The effect of impregnation ratio

The impregnation ratio, namely the weight ratio of ZnCl_2/PE , is another crucial factor in ZnCl_2 activation process. The characteristics of EBPCs at 1 h of activation time and 700 °C of activation temperature with varied impregnation ratios of ZnCl_2/EP are listed in Table 1. As seen in Table 1, the yield, BET surface area and pore volume rise with increasing impregnation ratio from 1/1 to 2/1, which are attributed to the catalytic dehydroxylation and dehydration of ZnCl_2 ²¹. Volatiles including formed hydrogen and oxygen can promote the development of pores. As a kind of Lewis acid, ZnCl_2 can promote the condensation of aromatic hydrocarbons. Nevertheless, at the ratio of 3/1, decreases are found both in BET surface area and the micropore volume due to the continuous enlargement of micropores³⁵. H700-1-1 and H700-2-1 are microporous carbons evidenced by the type I isotherm in Fig. 5(b), while H700-3-1 have a certain amount of mesopores seen from its hysteresis loop, which can also be confirmed by the pore size distribution in Fig. 6(b).

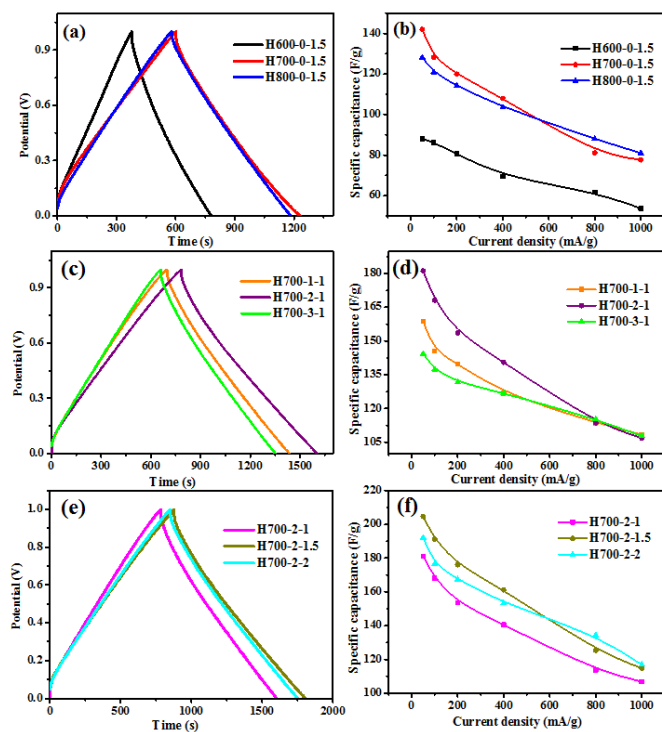


Fig. 7 Galvanostatic charge-discharge curves of EBPCs at 100 mA/g (a, c and e) and the specific capacitance of EBPCs at varied current densities (b, d and f)

Galvanostatic charge-discharge curves of H700-1-1, H700-2-1 and H700-3-1 are shown in Fig. 7(c). It can be easily seen that all the

curves are relatively symmetrical and nearly linear with longer charge-discharge time than those of the unactivated samples (*i.e.*, H600-0-1.5, H700-0-1.5 and H800-0-1.5), showing higher specific capacitance. As shown in Fig. 7(d), the specific capacitances of H700-1-1, H700-2-1 and H700-3-1 are apparently higher than that of H700-0-1.5, reaching a maximum of 184 F/g (H700-2-1, 50 mA/g) followed by 160 F/g (H700-1-1). With the increase of current density, the capacitances of H700-1-1 and H700-2-1 decay fast as the ions in the electrolyte have big difficulty in entering the pores in limited time. The attenuation of H700-3-1 is slow owing to its relatively higher mesopore ratios (Table 1). The electrochemical performances of H700-1-1, H700-2-1 and H700-3-1 are further evaluated by cyclic voltammetry curves in Fig. 8(b). Similar rectangles without apparent redox peaks reflect the typical characteristics of electric double layer supercapacitors. Besides, the CV curve area of H700-2-1 is larger than those of H700-1-1 and H700-3-1, implying the highest specific capacitance and the most suitable impregnation ratio (2/1).

3.3 The effect of activation time

Activation time is also an important influencing factor to the porous structure and electrochemical properties. With varied activation time (1, 1.5 and 2h), the yield and pore structure parameters of EBPCs can be seen in Table 1. Notably, loss accretes in H700-2-1, H700-2-1.5 and H700-2-2 with the activation time increasing.

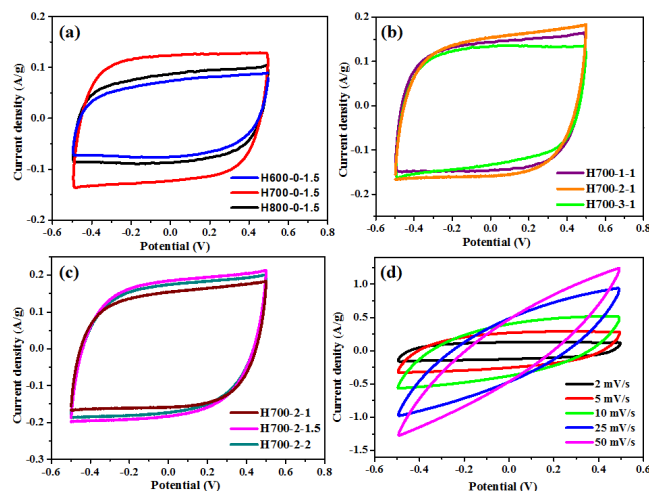


Fig. 8 CV curves of EBPCs at a scan rate of 2 mV/s (a, b and c) and CV curves of H700-2-1.5 at different scan rates (d)

The N_2 adsorption-desorption curves of H700-2-1, H700-2-1.5 and H700-2-2 (apparently type I) are shown in Fig. 5(c). No hysteresis loops exists, suggesting that micropores account for the majority of pores, which is consistent with Fig. 6(c) and Table 1. Furthermore, the pore sizes of ZnCl_2 activated EBPCs are relatively smaller than that of unactivated samples (H600-0-1.5, H700-0-1.5 and H800-0-1.5). Junichi Hayashi³⁶ thinks that pneumatolytic ZnCl_2 plays a role of skeleton through dipping into the internal carbon, where the carbonized polymer deposits.

The effects of activation time on the electrochemical performance can be seen in Figs. 7(e) and (f), Fig. 8(c) and Fig. 9. Superior electrochemical properties can easily be seen from its high linearity and longer charge-discharge time in Fig. 7(e). When the current density is 50 mA/g, H700-2-1.5 has the largest specific capacitance (206 F/g), owing to the largest surface area (1651 m²/g) in Table 1. However, as the current density rises from 50 mA/g to 1000 mA/g, the fastest decay occurs as a result of the minimal mesopore ratio. Furthermore, the nearly-rectangular CV curve of H700-2-1.5 has the largest area in Fig. 8(c), demonstrating the best electrical properties and the most suitable activation time, *i.e.* 1.5 h. Fig. 8(d) shows the cyclic voltammetry (CV) curves at various scan rates from 2 to 50 mV/s. As the scan rates increases, the CV curves become more and more oblique, an indicative of double layer capacitor behaviour³⁷.

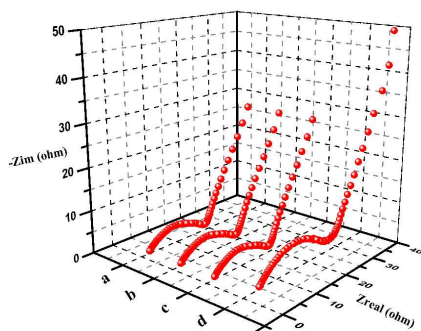


Fig. 9 EIS at (a) 0 V, (b) 0.5 V, (c) 1 V bias voltage of H700-2-1.5 and (d) EIS of H700-0-1.5

The Nyquist plots for the supercapacitors with H700-0-1.5 and H700-2-1.5 electrodes are shown in Fig. 9, and their electrical equivalent circuits are illustrated in Fig. S4. Two electrodes have ideal electrochemical capacitance behaviour, *i.e.*, imaginary parts of impedance at low frequency region are nearly linear, which is typical of Warburg impedance, “W”³⁸. The plots also imply that the supercapacitor with H700-2-1.5 electrodes has lower internal resistance (R_s) (1.41 Ω), seen from the point of intersecting with the real impedance (Z_{real}) axis in the range of high frequency³⁷. Besides, smaller charge transfer resistance (R_{ct}) (14.38 Ω) of H700-2-1.5, which can be checked from the span of the single semicircle along the χ -axis from high to low frequency³⁹, can obviously be seen compared with 22.09 Ω of H700-0-1.5. There is no doubting that ZnCl₂ activation enhances the porosity, leading to the high specific capacitance and good electrochemical property for H700-2-1.5 electrode system. Furthermore, the EIS of H700-2-1.5 supercapacitor at different bias potentials from 0 to 1 V shows that there is no change with bias potential increasing, suggesting nonexistence of redox reaction or little effect of trace metal compounds on the electrochemical properties of EBPCs⁴⁰, which has also been testified by CV test in Fig. 8(c).

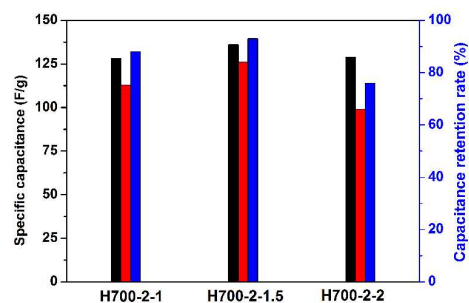


Fig. 10 The capacitance retention rate (blue) and the specific capacitance of H700-2-1, H700-2-1.5 and H700-2-2 after 50 (black), 5000 (red) cycles

Capacity retention rate is an important parameter for industrial application of the electrode material. The specific capacitances of H700-2-1, H700-2-1.5 and H700-2-2 electrodes before and after 5000 cycles at the same current density of 800 mA/g are shown in Fig. 10. All electrodes have good cycle stability, and H700-2-1.5 has the highest specific capacitance both after 50 and 5000 cycles. The specific capacitance of H700-2-1, H700-2-1.5 and H700-2-2 electrodes, reaches the highest value of 128, 136 and 129 F/g after 50 cycles at 800 mA/g, and 88% (113 F/g), 93% (126 F/g), 76% (99 F/g) can be retained even after 5000 cycles, indicating high capacity retention rate of EBPCs, especially for H700-2-1.5.

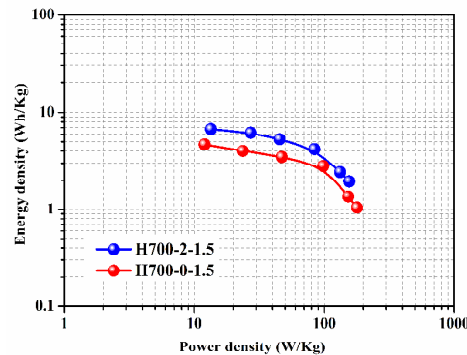


Fig. 11 Ragone plot of H700-2-1.5 and H700-0-1.5 supercapacitors

The Ragone plot (Fig. 11) shows the dependence between power density (P , W/kg) and energy density (E , Wh/kg) of the supercapacitor with H700-2-1.5 electrodes, which are calculated in terms of the following equations⁴¹:

$$E = \frac{C_p \times \Delta V^2}{8} \times \frac{1000}{3600} \quad (2)$$

$$P = \frac{E}{\Delta t} \times 3600 \quad (3)$$

As can be seen in Fig. 11, H700-2-1.5 with zinc chloride activated has better electrochemical performances, which should be ascribed to higher specific area and better pore development.

4. Conclusions

Marine pollutant (enteromorpha) was successfully used as the raw material to prepare porous carbon for the electrode material of supercapacitors. EBPCs obtained at the impregnation ratio (ZnCl₂/PE) of 2/1, activation time of 1.5 h and activation temperature of 700 °C has the best electrochemical properties with a

specific capacitance of 206 F/g in 6 M KOH electrolyte at 50 mA/g. Besides, the obtained H700-2-1.5 has a capacity retention rate of 93 % even after 5000 cycles, exhibiting high stability and promising electrochemical application of enteromorpha as electrode material for supercapacitors.

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