Sengon wood (*Paraserianthes falcataria* (L.) Nielsen) carbon as supporting material for electrochemical double layer capacitor

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**Abstract.** A microstructure carbon electrodes was potentially developed into energy storage device, i.e electrochemical double layer capacitor (EDLC) or super capacitor. The structure has a large surface that able to increase the capacitance of electrodes. Sengon Wood Carbon (SWC) was one of microstructure carbon which mainly has honeycomb structure. SWC was prepared hydrothermally along with microwave heating. SWC has 202 m²g⁻¹ of surface area, 14.4 S.cm⁻¹ of conductivity and crystalline carbon peak at 29.55° with honeycomb structure. Mixtures of honeycomb sengon carbon and graphite were casted it into thin layer electrode (TLE). The electrodes are fabricated into EDLC along with aluminum foil, and their performance are tested by using Galvanostatic and capacitance meter. TLE had 2.984 to 3.547 μF/g of capacitance, initial voltage of EDLC ranged from 0.67 to 0.42 V. Capacitance of 3 cm x 4 cm EDLC ranged from 30.6 to 60 μF. Galvanostatic Charge-Discharge (GCD) indicated that SWC suitable for EDLC application.

1. **Introduction**

   Advance technology in electrical equipment has influenced the increasing of energy storages demand. Energy storage such as battery, fuel cell and super capacitor or Electrical Double Layer capacitor (EDLC) has became a mass production to fulfill needs. EDLC has some excellent things compare to other energy storage i.e: high energy density, high energy storage, simple principal and easy construction and also environmental friendly as well as free corrosive content. One of essential factor for EDLC is electrodes performance.

   Several research have previously made carbon electrodes from various nature derived carbons, i.e gelam wood bark that contain 40-45 % of carbon, 200-1200 m²g⁻¹ of surface area, 0.001-1.5 Scm⁻¹ of conductivity, 0.01-28 Fg⁻¹ of specific capacitance and contained micro-nano-structure [1]. Cui *et. al.*, (2013) [2] reported that microstructure of carbon i.e honeycomb structure exhibited lower sheet resistance and showed a record-high fill factor of 72% as a power conversion efficiency. Liu *et al.*, (2007) [3] reported extruding of a mixture of bituminous coal and organic additive for making activated carbon honeycomb (ACH) monoliths. It has significant effects on pore size distribution, lower values of the BET surface area and total pore volume. In general, it was concluded that microstructure showed a good properties for carbon electrode application.
A microstructure carbon was potentially obtained from sengon wood which abundantly planted in forestry. This research mainly discussed about development of sengon carbon as electrode to be applicable in EDLC. The high performance of EDLC was indicated by its capacitance and charge-discharge curve.

2. Materials and Methods

2.1 Materials

Sengon wood purchased from local forestry, distilled water, graphite, aluminum, stainless steel net sheet at 206 mm x 36 mm and thick 1 mm, gel polymer PVA (Merck), PVAc, K₂CO₃(Merck),Na₂CO₃(Merck), Na₂B₄O₇.10H₂O, CsH₁₀NNaS₈.3H₂O, aluminum foil, polyurethane.

2.2 Preparation of SWC

Sengon wood was sieved of sengon wood sized of 20 mm in length and 2 mm in diameter into chip, dried for 2-3 days under sunlight. The chip was powdered by using disk mill from JIMO FF-15. 40 g of sengon wood powder was blend with 100 mL distilled water, then stirred for 3 min. The sengon wood powder were heated hydrothermally as mentioned in Titiricci et al., (2007) [4]. The mixture was put on the hydrothermal reactor then sealed with 3M amalgamating tape and closed tightly. The reactor was placed inside electric oven, heated for 16 h in 180°C for generated 30 bar hydrothermal pressure inside reactor chamber. The process obtained brownish black constituent that called torrefaction material. The material was transferred from the hydrothermal reactor to microwave furnace and pyrolyzed in domestic microwave oven at 1000 watts of power. 2 g of torrefaction material was mixed with 0.4 g graphite or activated carbon, and contacted microwave for 25 min. In this condition, the temperature inside furnace can reached 800 °C. Graphite was added as microwave adsorbent. The furnace was tapped from the oven after being cold in room temperature. The result of this process was carbon with honeycomb structures.

2.3. Preparation of Electrochemical Double Layer Capacitor (EDLC)

A thin layer electrodes were made by casting carbon:graphite (w/w) on stainless steel sized 206 mm x 36 mm and thick 1 mm. The composite of honeycomb carbon, graphite and polyurethane (1:10:1w/w) was embedded on the stainless steel net sheet. The TLE acted as anode. Above TLE placed dacrone sheet as separator. Above the separator, gel polymer place the same electrode as cathode. Thin metal sheet stick was placed on the corner of TLE as current colector. Strip of metal strand was soldered on current collector as applicator. The electrodes, separator, current and applicator were packaged into cell with polypropylene sheet as cover.
2.4. Measurement and Characterization Method

The surface area of carbon was measured by calculating Metilen Blue and Iodine number. The formula were given below:

\[
S_{(m^2 g^{-1})} = 2.28 \times 10^2 - 1.01 \times 10^{-1} \text{ MBN} + 3.00 \times 10^{-1} \text{ IN} + 1.05 \times 10^{-4} \text{ MBN}^2 + 2.00 \times 10^{-4} \text{ IN}^2 + 9.38 \times 10^{-4} \text{ MBN IN} \tag{1}
\]

\[
V_{m_{(cm^3 g^{-1})}} = 5.60 \times 10^{-2} - 1.00 \times 10^{-3} \text{ MBN} + 1.55 \times 10^{-4} \text{ IN} + 7.00 \times 10^{-6} \text{ MBN}^2 + 1.00 \times 10^{-7} \text{ IN}^2 - 1.18 \times 10^{-7} \text{ MBN IN} \tag{2}
\]

\[
V_{t_{(cm^3 g^{-1})}} = 1.37 \times 10^{-1} + 1.90 \times 10^{-3} \text{ MBN} + 1.00 \times 10^{-4} \tag{3}
\]

The formula were used to calculate surface area, micro-pores volum and pores volum, respectively. Conductivity with two probe method. SEM micrographs were obtained on JEOL JED-2300. X-ray diffraction (XRD) patterns of the carbons were obtained on a Shimadzu X-ray diffractometer XRD 7000 operating at 40 kV and 30 mA, using Cu-Kα radiation. Working electrode is TLE and counter electrode is aluminum foil. EDLC performance was measured by Galvanostatic Charge and Discharge method and direct measurement of capacitance. Charging and discharging was done by function generator with potential difference given by two poles from function generator.

3. Results and Discussion

Electrochemical Double Layer Capacitor (EDLC) required a high adsorption capacity in order to store the electricity inside. Surface area was the most influenced properties related to adsorption capacity. The Metilen Blue and Iodine number calculation resulted a 202 m\(^2\) g\(^{-1}\) surface area, 0.181 cm\(^3\) g\(^{-1}\) of micro pores volum and 0.358 cm\(^3\) g\(^{-1}\) of pores volum. Surface area was the most influenced factor to determine the electrode capacitance. The SWC categorized as a large number of carbon surface area. Thus, the capacity of adsorption in carbon of sengon wood was high enough for EDLC application [5]. High temperature of microwave heating (up to 800°C) has eliminated the acid functional group and resulted on forming a hexagonal structure [6]. The structure with a free electron may increase the ability of carbon to conduct the electricity in surface [7]. In sengon carbon, the conductivity measured was 14.4 S cm\(^{-1}\) and suitable for EDLC application as the number was above the average activated carbon monolith as 13.87 S cm\(^{-1}\) [8].

Characterization method by using XRD and SEM proofing the honeycomb structure of Sengon carbon. XRD result (Figure 1a) indicates that the carbon has several crystalline structure. The peak of intensity was performed in ranged 29\(^{\circ}\) until 48.50\(^{\circ}\) [9]. The highest intensity was at 29.55\(^{\circ}\) and
indicated a carbon honeycomb structure. The SEM image (Figure 1b) indicates a hydrothermal treatment carbon of sengon with 2000 zooming has a plenty of holes inside the carbon. The structure is closed to honeycomb structure.

![SEM Image](image)

**Figure 1.** Characterization result by using (a) XRD  (b) SEM

Measurement due to SWC capacitance in two electrolyte percentage, K\(_2\)CO\(_3\) and Na\(_2\)CO\(_3\), and solid media as shown in Table 1 presented a various number of capacitance. The highest value for two electrolyte were 3.547 μF in Na\(_2\)CO\(_3\) 15%-PVA and 2.984 μF for K\(_2\)CO\(_3\) 15%-PVA. Those fulfilled the requirement for electrochemical double layer forming process [9]. However, those electrolyte has low stability in higher temperature so it easily to produces CO\(_2\) then caused a leak of device.

| Capacitance (μF/g) | K\(_2\)CO\(_3\) 10% | K\(_2\)CO\(_3\) 15% | Na\(_2\)CO\(_3\) 10% | Na\(_2\)CO\(_3\) 15% |
|--------------------|-------------------|-------------------|-------------------|-------------------|
| PVA                | 1.8               | 2.98              | 3.097             | 3.547             |
| PVAc               | 2.95              | 2.09              | 2.857             | 3.452             |

An EDLC performance were measured with variation of weight to weight composites carbon i.e; graphite, SWC, and SWC-graphite (1:10w/w). Each micro structure influenced its voltage and capacitance related to ionic adsorption in carbon molecules. Electrical conductivity also take a role in electron transfer inside the electrodes layer then increased the potential difference among the edges.
Graphite has a 21.2 S/cm of electrical conductivity therefore pure graphite variation has the highest voltage, 0.67 V. Meanwhile, the rest two variation, SWC-SWC and SWC-graphite exhibits a middle low voltage due to decreasing of SWC conductivity. Surface area of carbon affect the capacitance of electrodes. The highest capacitance was 60μF in variation of SWC-graphite composites in C₆H₁₀NNaS₈. 3H₂O electrolytes (Table 2). SWC was acted as filler between the layer of graphite that might also increased hollow area of composite SWC-graphite.

Surface area of composite was increased capacity of ionic adsorption inside the electrode. These number showed that SWC-graphite was applicable for supercapacitor material. SWC-graphite electrodes structure stored the energy longer and prevent self discharge, respectively. Organic electrolytes, Na₂B₄O₇.10H₂O and C₆H₁₀NNaS₈. 3H₂O. organic electrolyte was chosen related its stability in various temperature and pressure. Both electrolyte has complex functional groups and slowed to be decomposed. Therefore, organic electrolyte might prevent leak of EDLC. The capacitance of each variation was higher in sodium diethythiocarbamate (C₆H₁₀NNaS₈. 3H₂O) electrolyte because the electrolyte was able to have a binding force with electrode interface. The interaction increased a mass transfer inside EDLC then affect the capacitance itself.

Table 2. Variation of Electrode Composite in two organic electrolyte

| Electrode Composite | Voltage Na₂B₄O₇.10H₂O (V) | Voltage C₆H₁₀NNaS₈. 3H₂O (V) | Capacitance Na₂B₄O₇.10H₂O (μF) | Capacitance C₆H₁₀NNaS₈. 3H₂O (μF) |
|---------------------|----------------------------|-------------------------------|---------------------------------|----------------------------------|
| Graphite-graphite   | 0.67 V                     | 0.06 V                        | 1.1                             | 59.2                             |
| SWC-graphite        | 0.42 V                     | 0.03 V                        | 4.6                             | 60                               |
| SWC-SWC             | 0.43 V                     | 0.02 V                        | 0.02                            | 30.6                             |

Figure 2 showed the variation of electrode due to the slope of each variant that might indicate the charge-discharge performance. The charge and discharge measurement between variation of electrode composition was shown by the slope of sinusoidal waves.
Figure 2. Galvanostatic charge-discharge (GCD) curve

Galvanostatic spectra shown a period for supercapacitor to charge and discharge. The slope was one of parameter to determine the performance of EDLC. The greater slope implied a faster rate whether charging or discharging.

Table 3. Slope of Charge and Discharge in each variation

|                  | Charge  | Discharge |
|------------------|---------|-----------|
| Graphite-graphite| 0.18513 | -0.14622  |
| SWC-SWC          | 0.39156 | -0.30684  |
| SWC-graphite     | 12.04935| -10.94757 |

The highest slope, 12.04935 was showed by SWC-graphite composites due to its honeycomb lattice that has a large surface area. The large micro pores surface of SWC caused a double layer effect between electrode and electrolyte interface that increase rates of electron adsorption. Graphite has facilitate the electron transfer so affect to higher charging speed. The surface area of SWC-graphite also influenced discharging curve by having lowest slope that indicated a lower speed. A slow discharge time for SWC-graphite electrode (Table 3) due to honeycomb structure of SWC that able to adsorbed the electron inside the hollow cells. The longer EDLC discharge implied a higher performance of storage device.
4. Conclusion

The results show that honeycomb carbon was able to be an active material for fabricated the EDLC (Supercapacitor). The material was conductive and performed a good electrochemical result when combined with graphite. EDLC from honeycomb, carbon SWC, has granulated structure. EDLC of carbon graphite can store the energy longer as its high capacitance and also has a highest slope that indicate the lower self discharge on EDLC. Overall, SWC was suitable to be built into EDLC.

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