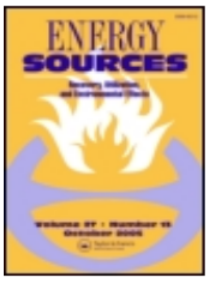
Biomass-based activated carbon monolith from Tectona grandis leaf as supercapacitor electrode materials

by Rika Taslim

Submission date: 01-May-2023 08:48PM (UTC+0700)
Submission ID: 2080915521
File name: taer2021.pdf (3.21M)
Word count: 6087
Character count: 32394



Taylor & Francis
Taylor & Francis Group

Energy Sources, Part A: Recovery, Utilization, and Environmental Effects

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ueso20

Biomass-based activated carbon monolith from *Tectona grandis* leaf as supercapacitor electrode materials

Erman Taer, Melisa Melisa, Agustino Agustino, Rika Taslim, Widya Sinta Mustika & Apriwandi Apriwandi

To cite this article: Erman Taer, Melisa Melisa, Agustino Agustino, Rika Taslim, Widya Sinta Mustika & Apriwandi Apriwandi (2021): Biomass-based activated carbon monolith from *Tectona grandis* leaf as supercapacitor electrode materials, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, DOI: 10.1080/15567036.2021.1950871

To link to this article: https://doi.org/10.1080/15567036.2021.1950871

ENERGY SOURCES, PART A: RECOVERY, UTILIZATION, AND ENVIRONMENTAL EFFECTS
https://doi.org/10.1080/15567036.2021.1950871

Biomass-based activated carbon monolith from *Tectona grandis* leaf as supercapacitor electrode materials

Erman Taer[a], Melisa Melisa[a], Agustino Agustino[a], Rika Taslim[b], Widya Sinta Mustika[a], and Apriwandi Apriwandi[a]

[a]Department of Physics, University of Riau, Simpang Baru, Indonesia; [b]Department of Industrial Engineering, State Islamic University of Sultan Syarif Kasim, Simpang Baru, Indonesia

ABSTRACT

The complete study on the synthesis of biomass waste-based activated carbon monolith from *Tectona grandis* leaf for supercapacitor electrode materials has been successfully studied. This study was performed through a combination of chemical and CO_2 activation methods. The KOH was used as an activating agent in the chemical activation process. The pyrolysis process includes carbonization and CO_2 activation used integrated systems were conducted at temperature of 600°C under N_2 gas atmosphere, and CO_2 activation at different temperatures, specifically 750, 800, 850, and 900°C. The *Tectona grandis* leaf-based activated carbon (TL-AC) samples show different structures such as carbon rod (750°C), carbon sheet (800°C), and carbon fiber (900°C). The optimum-specific capacitance of the TL-AC samples as high as 168 F g^{-1} in 1 M sulfuric acid solution using two-electrode configuration. This study provides an economic approach needed in the preparation of electrode materials with different structures for energy storage systems by abundant materials.

ARTICLE HISTORY
Received 25 February 2021
Revised 10 June 2021
Accepted 28 June 2021

KEYWORDS
Biomass; *Tectona grandis* leaf; activated carbon monolith; electrode materials; specific capacitance; supercapacitor

Introduction

The increased development of technology has caused a spike in energy consumption. Therefore, we need alternative energy sources to help satisfy the urgent demand. The energy storage devices were needed to be expected to efficiently save, have longer lifetime rather than batteries, store large quantities of power, and eco-friendly. One of the innovative energy storage technology products is the supercapacitor. Supercapacitors have been regarded as one of the most attracting research, due to their various applications in pulsing technique (Liu et al. 2016), digital devices (Dyatkin et al. 2013; Wu et al. 2019; Zhao et al. 2019), electrical vehicles (Choi et al. 2012; Wang et al. 2020), telecommunications (Cheng et al. 2021), aerospace and military (González et al. 2016), etc. This is due to superior pulse charge–discharge rate (Wang, Song, and Xia 2016), the high durability, excellent cyclic reliability and fast charging–discharging mechanism (Bose et al. 2012; Winter and Brodd 2004), high power density (Bose et al. 2012; Jayalakshmi and Balasubramanian 2008), and relatively simple cell configuration (Zhu et al. 2018). With their excellent performance, carbon materials have attracted attention in the field of energy conversion and storage studies (Ma et al. 2017). Various carbon materials such as carbon nanotubes (CNTs), single-walled carbon nanotubes (SWNTs), and graphene are often used in supercapacitor devices. The study on CNT and graphene-based supercapacitors in the past few years is stagnant; this is due to the high cost of the electrode material preparation process. Now, the concern has shifted toward carbon materials derived from biomass waste (Divyashree et al. 2016; Zhang et al. 2015).

CONTACT Erman Taer erman.taer@lecturer.unri.ac.id Department of Physics, University of Riau, Simpang Baru 28293, Indonesia

Biomass materials are one of the alternative energy sources with very abundant availability. Biomass materials can be classified into various types, namely, (i) wood and woody, (ii) herbaceous, (iii) aquatic, (iv) animal and humans waste, and (v) biomass mixtures (Tursi 2019). These materials have high compositions of cellulose, hemicellulose, and lignin. With the high composition of cellulose, hemicellulose, and lignin, biomass materials can be converted into activated carbon for various applications, one of the most is as supercapacitor electrode materials.

Waste management has been tagged as a huge challenge for some big cities, one of them is Pekanbaru city, Indonesia. The provision of waste separation plants in these cities helps segregate organic and inorganic waste. This was unsuccessfully performed due to increased number of carelessly disposed household, agricultural, factory, and industrial wastes. Most of these wastes are rich in carbon content, despite the presence of other elements with different portions, depending on the waste type and source. Natural wastes are usually burnt and produced of harmful gas pollution.

The raw materials for production of supercapacitor carbon electrodes can be made from several leaves waste that has been reported such as phoenix (Ma et al. 2017), tea (Peng et al. 2013), neem and ashoka (Biswal et al. 2013), willow (Liu et al. 2016), pineapple (Sodtipinta, Amornsakchai, and Pakawatpanurut 2017; Sodtipinta et al. 2017), ginkgo biloba (Hao et al. 2017; Zhu et al. 2018), *Terminalia catappa* (Taer et al. 2018a), etc. The preparation of electrode made from phoenix tree leaves waste was performed using two steps, namely, hydrothermal carbonization method and chemical activation with KOH produce specific capacitance 367 F g^{-1} and 240 F g^{-1}, respectively (Ma et al. 2017). These materials show promising potentials to serve as raw materials in production, based on availability and low cost of materials.

This study aims to report the potential use of *Tectona grandis* leaf (TL) waste for the production of activated carbon monoliths as electrode materials for supercapacitor. For the production of supercapacitor electrodes, generally use the addition of several materials such as conductive materials, adhesives materials, metal oxide, etc. In this study, the electrodes were prepared in monolith form due to their good mechanical stability and with the 3D pore structure that leads to high electrical conductivity and good accessibility of the electrolyte ion so that it can improve the supercapacitor performance (Moreno-Fernandez et al. 2017; Wang et al. 2019). The production of the electrode was performed through the chemical activation and followed by carbonization and CO_2 activation at different activation temperatures, that is, 750, 800, 850, and 900°C under an integrated system. The influence of varous activation temperature on the physical and capacitive properties will be discussed in this study.

Experimental investigations

Sample preparation

Tectona grandis leaf waste were obtained from Riau university campus area, Pekanbaru. Indonesia. The initial step of the sample preparation is drying and pre-carbonization at 250℃ for 2.5 h (Taer et al. 2018b, 2018c; Taslim, Agustino, and Taer 2018). The rarefaction of samples was carried out with a ball mill and then sieved to get a powder size ≤53 μm (Taer et al. 2018d). This sample powders were chemically activated using 0.4 M KOH followed by the process of molding into pellet forms using 8 tons of pressure. The pellets were carbonized at 600°C under N_2 gas atmosphere, followed by CO_2 activation at various temperatures, that is, 750, 800, 850, and 900°C. Then, the samples washed in distilled water to a pH neutral (pH = 7). Finally, the *Tectona grandis* leaf (TL-AC) pellets were polished to 0.20 mm thickness. The samples were coded TL-AC750, TL-AC800, TL-AC850, and TL-AC900, based on CO_2 activation temperature variations.

Characterization

The physical properties characterization of the TL-AC samples are (i) density, (ii) morphological structure and elemental compositions, (iii) crystallographic information, and (iv) specific surface area and pore size distributions. The morphological structure and elemental compositions of samples were observed from the SEM-EDX test (JEOL-JSM 6510LA). The BET-specific surface area and BJH pore size distribution of electrodes were observed using Quantachrome TouchWin v1.2. The crystallographic information was measured by the XRD (X-Pert powder panalytical). The interlayer spacing (d_{hkl}) was calculated by the Bragg equation.

$$n\lambda = 2d\sin\theta \tag{1}$$

The microcrystallite dimensions (L_c and L_a), were calculated by the Scherer in equation 2 (Cullity 1978; Lu et al. 2001; Serafin et al. 2019).

$$L_{c,a} = \frac{K\lambda}{\beta\cos\theta} \tag{2}$$

where L_c and L_a are stack height and witdh (nm), K is a constant depending on the reflection plane, λ represents wavelength (nm), β = bandwidth (°), θ is the diffraction angle.

Capacitive properties measurement

Supercapacitor cells consist of electrodes from *Tectona grandis* leaf activated carbon, separator from duck eggshell membrane, current collectors from stainless steel plates type 316 L, and sulfuric acid electrolytes. The production of supercapacitor cells began by immersing TL-AC samples into a 1 M H_2SO_4 electrolyte for 2 × 24 h. Furthermore, all supercapacitor cell components were then arranged in sandwich structure and capacitive properties tested using the cyclic voltammetry method. This test was performed at scan rate 1 mV s^{-1} and potential of 0–1 V in two-electrode configuration. The specific capacitance (C_{sp}), energy density (E), and power density (P) were calculated based on equations (Chang et al. 2013; Hao et al. 2017):

$$C_{sp} = \frac{2I}{sm} \tag{3}$$

$$E = \frac{1}{2}V^2 \cdot \frac{1}{3.6} \tag{4}$$

$$P = \frac{E}{\Delta t}3600 \tag{5}$$

where I, s, m, V, Δt are current (A), scan rate (mV s^{-1}), mass of the TL-AC samples (g), cell voltage (V), and the discharge time (s).

Results and discussion

The physical properties analysis

The decrease in density data of TL-AC samples (Figure 1), which is caused by removal of compounds other than carbon and formation of new pores. The highest decrease in density occurred at TL-AC800 sample with outcome equal to 42.22% followed by a 36.35 and 22.29% increase in temperature, to 850°C with 900°C, respectively. This elevation in density was attributed to the breaking of more carbon bonds, which resulted in atom rearrangement, to further facilitate a decline in porosity (Farma et al. 2013). However, higher density have been implicated in reduced electrode porosity, and consequently

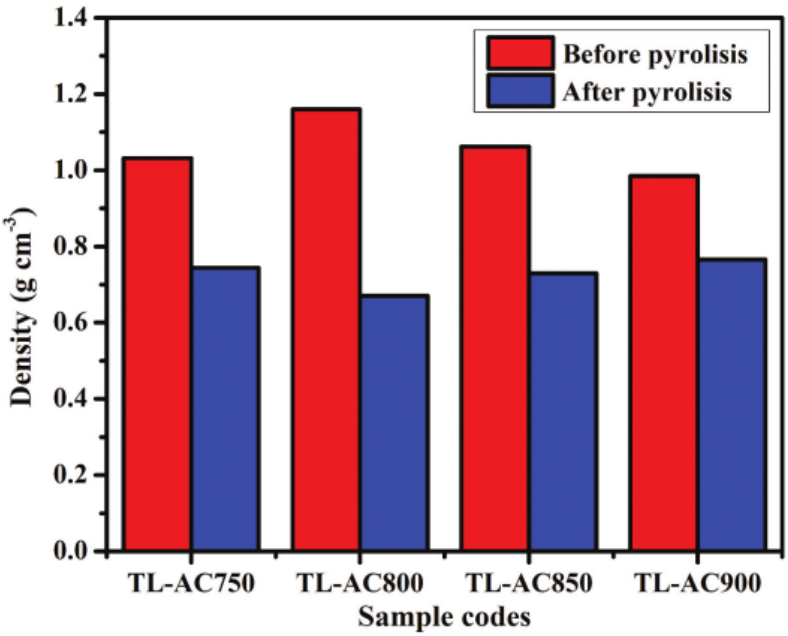


Figure 1. The density of TL-AC samples.

in decreased specific capacitance (Taer et al. 2019a). Based on obtained data, temperature of 800°C was determined to be the optimum level required for the formation process and development of pore structures. This was known to encourage the best outcome for specific capacitance. In addition, the changes in densities were similar to other biomass materials, especially oil palm empty fruit bunches (Deraman et al. 2010), oil palm empty fruit bunches fibers (Farma et al. 2011), and durian shell (Taer et al. 2019b).

Figure 2 displays the morphological structure of the TL-AC samples that were observed using SEM. The morphological structure of TL-AC750 sample (Figure 2 (a)) shows particles in the form of rods with particle sizes ranging 293–582 nm. The morphological structure of the TL-AC800 sample (Figure 2 (b)) shows the surface of the electrodes in the form of nanosheets with sizes in the range of 139 nm until 327 nm x 679 nm until 1679 nm. The TL-AC900 sample (Figure 2(c)) shows the presence of fiber with a clearer fiber shape with diameters ranging from 136 to 222 nm. The difference in the CO_2 activation temperature in TL-AC samples produces morphological structure with different structures, namely, rods, sheets, and fibers. The rod structure was obtained in the TL-AC750 because the lignin in the raw materials are not decomposed and still binds to cellulose. When the activation temperature was increased at the TL-AC800 sample, a sheet structure is obtained, where the lignin component begins to decompose due to heating and abandon little bond between lignin and cellulose. The highest activation temperature on the TL-AC900 sample results in the complete breakdown of the lignin and leaving only cellulose, which forms a single fiber structure.

The elemental compositions of TL-AC samples were characterized using energy dispersive X-ray analysis (Table 1). The carbon (C) element has the highest percentage compared to other elements in TL-AC samples. Furthermore, oxygen (O) is one of the elements present in biomass, besides existence of polymeric cellulose analysis causing end results of carbonization processes (Yahya, Al-Qodah, and Ngah 2015). Meanwhile, silica (Si) elements were obtained as a side effect of the product commonly obtained after activation processes. The purity level of this element is influenced by activation duration and heating process applied to samples (Promdee et al. 2017). Based on presence of potassium (K) element, the chemical activation process uses KOH activator and imperfect washing. The calcium (Ca)

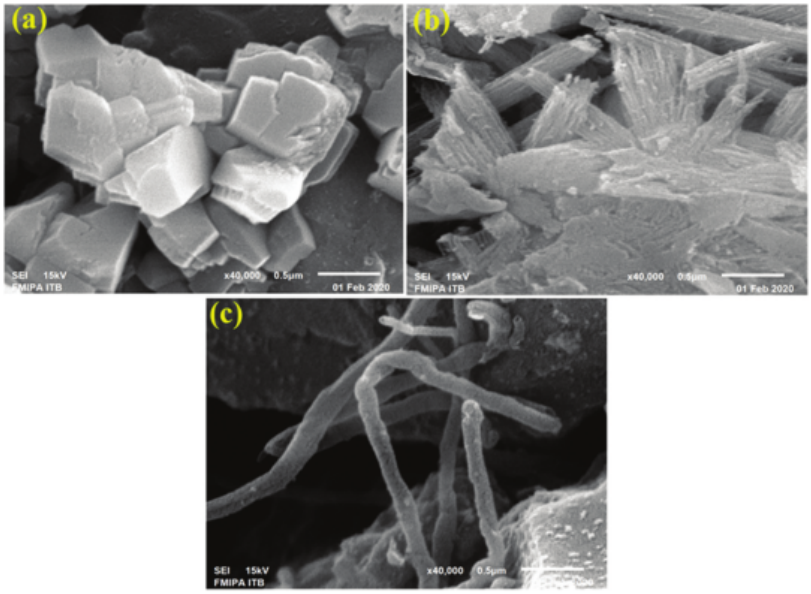


Figure 2. Morphological structure of TL-AC samples with magnifications 40,000 times.

Table 1. The elemental compositions of the TL-AC samples.

Elemental compositions	TL-AC750 Atomic (%)	TL-AC800 Atomic (%)	TL-AC900 Atomic (%)
C	81.34	83.30	83.52
O	14.50	14.40	13.79
Si	2.39	1.32	0.13
K	0.42	0.06	1.94
Ca	1.34	0.92	0.62
Total		100	

element is basically presentin *Tectona grandis* leaf, although the mineral concentration depends on soil type.

The EDX results show an increase in activation temperature. which increases the number of carbon elements in activated carbon TL-AC. Therefore as the CO_2 activation temperature increases, slight impurities and organic matter are formed such as oxygen, silica, calcium, and several other materials with different molecular masses.

Figure 3 showed the BET-specific surface area (S_{BET}) and BJH pore size distribution of the TL-AC samples at three different activation temperatures. Figure 3 (a) demonstrate the volume ads-des @STP ($cm^3\ g^{-1}$) versus relative pressure (atm). This was classified based on the IUPAC (International Union of Pure and Applied Chemistry) as a type IV isotherm, with H4 hysteresis loop type, which corresponds to the capillary condensation in mesopores for carbon materials (Biswal et al. 2013; Liu, Wang, and Teng 2005; Zhao et al. 2015). The TL-AC750 sample shows an imperfect hysteresis curve instigated by an incomplete desorption process, resulting from the presence of nitrogen trapped in pores (Qi et al. 2017). The shape of the ink-bottle neck triggers capillary condensation at the pore tissue to be blocked, due to narrowing, which slows down the desorption rate (Ayinla et al. 2019).

The BJH pore size distributions of the TL-AC samples are shown in Figure 3 (b). The average pore radius of the TL-AC samples increases from 2.718 nm to 1.258 nm with the application of high CO_2 activation temperatures from 750°C to 800°C, effectively. This change is attributed to the opening of more new pores, thus causing a shift in dominant size toward a relatively smaller direction, and

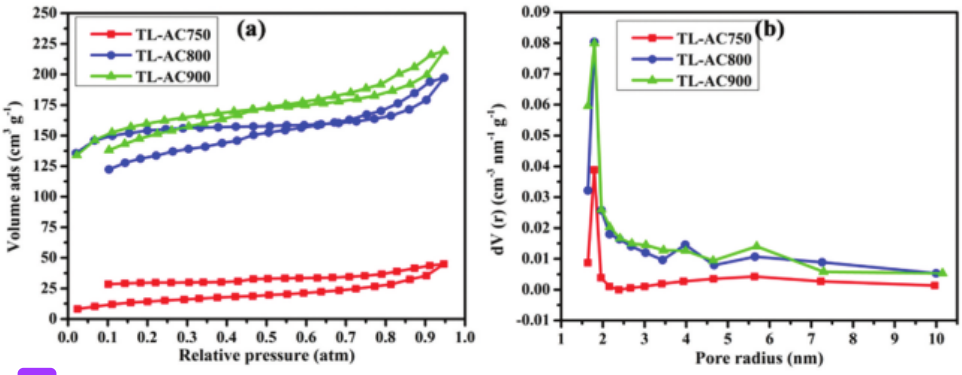


Figure 3. (a) Nitrogen adsorption–desorption isotherm and (b) BJH pore size distribution of the TL-AC samples.

a simultaneous increase in the pore volume from 0.069 $cm^3\ g^{-1}$ up to 0.306 $cm^3\ g^{-1}$. Moreover, the further elevation to 900°C causes a slight modification toward a greater size (1.320 nm). These data show an increase in pore volume from 0.069 up to 0.339 $cm^3\ g^{-1}$, which significantly elevates the specific surface area from 51 $m^2\ g^{-1}$ up to 512 $m^2\ g^{-1}$. The adjustments in terms of area provide more active sites in the electrolyte ions to diffuse on the electrode surface. The textural and structural parameters of the TL-AC samples are shown in Table 2.

Figure 4 displays the XRD pattern of the TL-AC samples. All the curves show the two wide peaks and can be indicated as an amorphous structure for carbon materials. These were recognized in biomass showing a random arrangement of atoms in sample. The scattering angle used was within the range of 10°–60°, where 2θ was identified in the range of 24°–45° for reflecting plane 002 and 100, respectively. Moreover, the sharp peaks observed indicate the presence of an element different from the carbon observed in the TL-AC samples, which was exhibited in the form of calcium carbonate ($CaCO_3$), at a 2θ angle of 29° (Taslim, Agustino, and Taer 2018). Table 3 shows the interlayer spacing (d_{hkl}) and microcrystallite dimensions (L_c and L_a) of the TL-AC samples.

Based on Table 3, the interlayer spacing (d_{hkl}), which calculated using equation (1), was found in the range of 3.49 nm up to 3.62 nm for d_{002} and 0.199 nm up to 0.204 nm for d_{100}, respectively. It showed the TL-AC samples structure that are higher than the graphite structure (d_{002} = 0.335 nm); this is indicates that the TL-AC samples have an amorphous structure (Ghosh et al. 2019). The microcrystalline dimension is calculated using equation (2) and obtained the L_c in the range of 0.899 nm up to 1.049 nm and 1.323 nm up to 4.779 nm for L_a, respectively.

The capacitive properties analysis

The CV curve of the TL-AC samples is shown in Figure 5. All the CV curves (Figure 5a) show the rectangular shape which is ideal for biomass-based activated carbon electrodes (González et al. 2016). The TL-AC800 sample presents a larger curve with a specific capacitance of 168 F g^{-1} and it was determined as optimum-specific capacitance, compared to other electrodes with specific capacitances of 135 F g^{-1}, 115 F g^{-1}, and 99 F g^{-1} for TL-AC750, TL-AC850, and TL-AC900 samples, respectively. This treatment was determined to possess the best CO_2 activation temperature required to produce

Table 2. The textural and structural parameter of the TL-AC samples.

Samples	S_{BET} ($m^2\ g^{-1}$)	S_{BJH} ($m^2\ g^{-1}$)	$r_{average}$ (nm)	V_{total} ($cm^3\ g^{-1}$)
TL-AC750	51	16	2.718	0.069
TL-AC800	486	61	1.258	0.306
TL-AC900	514	68	1.320	0.339

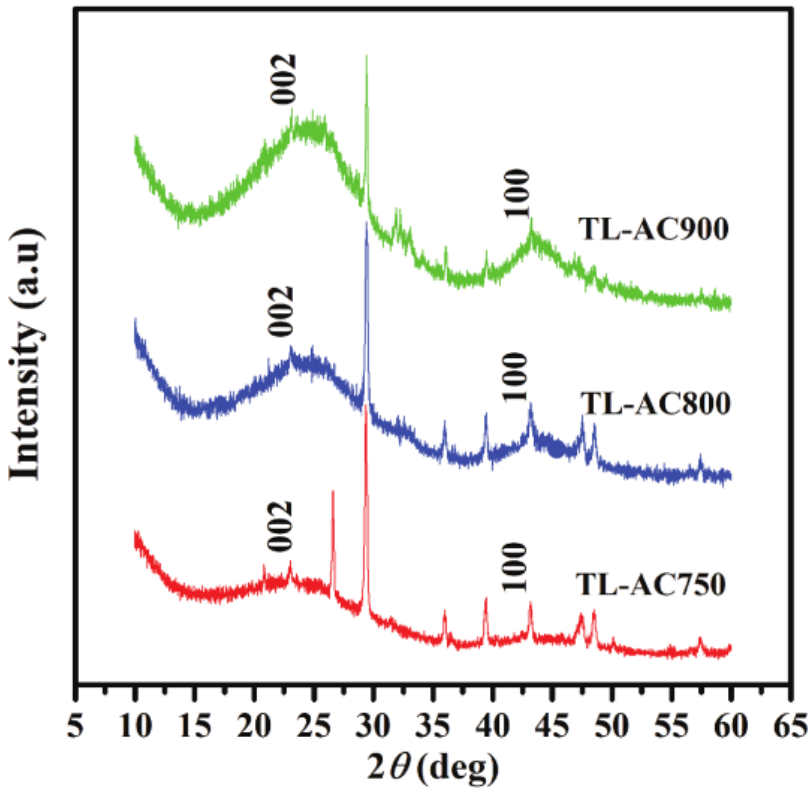


Figure 4. The X-ray diffractogram pattern of the TL-AC samples.

Table 3. The interlayer spacing and microcrystallite dimension of the TL-AC samples.

Samples	$2\theta_{002}$ (°)	$2\theta_{100}$ (°)	d_{002} (nm)	d_{100} (nm)	L_c (nm)	L_a (nm)
TL-AC750	25.462	45.306	0.349	0.200	1.007	1.323
TL-AC800	25.314	45.586	0.351	0.199	0.899	4.779
TL-AC900	24.555	44.389	0.362	0.204	1.049	3.135

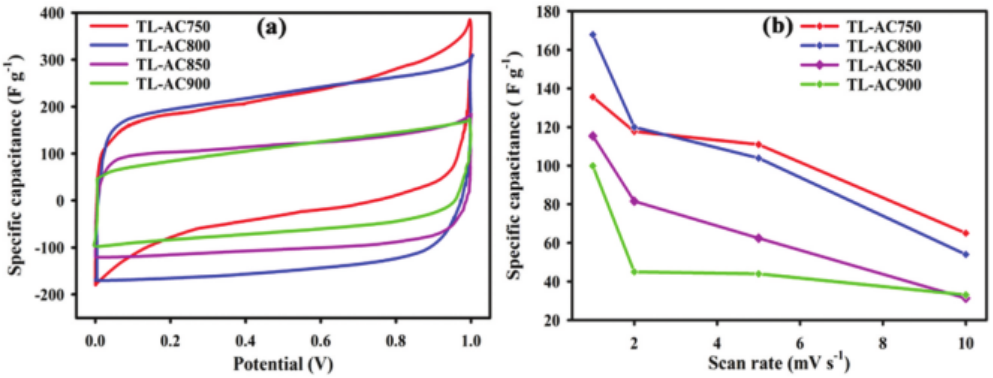


Figure 5. CV curve of the TL-AC samples (a) the specific capacitance vs. potential, and (b) the specific capacitance vs. scan rate.

Tectona grandis leaf activated carbon electrodes. The elevation in pyrolysis temperature from 750°C to 800°C shows a significant increase in specific capacitance from 135 F g^{-1} to 168 F g^{-1}. This characteristic is attributed to the ability for higher temperature to facilitate suitable pore distribution required to provide relatively more active sites needed for the formation of surface charge layers. This was confirmed by nitrogen adsorption–desorption analysis, which showed a significant increase in BET-specific surface area from 51 m^2 g^{-1} to 486 m^2 g^{-1}. Conversely, the addition of activation temperatures of 850°C up to 900°C showed decrease dramatically in specific capacitance from 115 F g^{-1} to 99 F g^{-1}. This is attributed to the shift in pore size distribution on the higher activation temperature, which interferes with a suitable pore combination to produce higher capacitance of TL-AC samples. The dominant pores size shifts in a direction to the higher activation temperature of 800°C to 900°C, it was confirmed on the nitrogen adsorption–desorption analysis although the specific surface area is slightly increased. This evaluation was also supported by density data, indicating an increase after the pyrolysis process.

Figure 5(b) shows the specific capacitance versus scan rate variation. The specific capacitance of the TL-AC samples decreases with increasing scan rate. This was due to less time required for the ions to diffuse into the carbon electrode pores. Conversely, the application of the low scan rate will produce more time for ions to diffusion completely in the carbon electrode pore (Awitdrus et al. 2016). Table 4 shows the capacitive properties of the TL-AC samples based on CV measurement.

Table 4. The capacitive properties of the TL-AC samples.

Samples	C_{sp} (F g^{-1})	E (Wh kg^{-1})	P (W kg^{-1})
TL-AC750	135	18.75	64.8
TL-AC800	168	23.19	83.56
TL-AC850	115	15.97	57.6
TL-AC900	99	13.75	50.4

Table 5 shows comparison of capacitive properties for *Tectona grandis* leaf and other leaf waste-based activated carbon electrodes and other leaf waste-based activated carbon electrodes previously reported. The TL-AC samples with different morphological structures show great potential for use as supercapacitor electrodes, due to the good capacitive properties.

Table 5. The comparison of capacitive properties for *Tectona grandis* leaf and other leaf waste-based activated carbon electrodes.

Materials	C_{sp} (F g^{-1})	E (Wh kg^{-1})	P (W kg^{-1})	References
Phoenix tree leaves	367	-	-	(Ma et al. 2017)
Tea leaves	330	-	-	(Peng et al. 2013)
Neem tree leaves	400	55	569	(Biswal et al. 2013)
Willow leaves	216	-	-	(Liu et al. 2016)
Pineapple leaf	131	-	-	(Sodtipinta, Amornsakchai, and Pakawatpanurut 2017)
Pineapple leaf	202	-	-	(Sodtipinta et al. 2017)
Ginkgo biloba leaves	364	16	50	(Hao et al. 2017)
Ginkgo biloba leaves	272	9.2	48	(Zhu et al. 2018)
Terminalia catappa leaf	54	-	-	(Taer et al. 2018a)
Scheffleraoctophylla leaves	336	47.5	71.9	(Yang et al. 2019)
Eucalyptus leaves	213	16.2	47.2	(Jain, Kanungo, and Tripathi 2020)
Tectona grandis leaf	168	23.19	83.56	This work

Conclusions

Based on all the analysis in the previously section, it can be concluded that:

- *Tectona grandis* leaf waste is a promising biomass with good potentials for use as a supercapacitor carbon electrode. This waste was successfully converted into activated carbon monolith for supercapacitor carbon electrodes achieved by applying various CO_2 activation temperatures.
- The density of TL-AC samples was a decline after the pyrolysis process. Based on SEM characterization, the TL-AC samples have different morphological structures such as rods, nanosheets, and fibers. The optimum-specific surface area and specific capacitance of the TL-AC samples is 514 $m^2\ g^{-1}$ and 168 $F\ g^{-1}$.

For the future research, it can be applied using a various chemical-activating agent such as KOH, NaOH, $ZnCl_2$, H_3PO_4, etc. for increasing the supercapacitor electrodes performance made from *Tectona grandis* leaf waste.

Acknowledgments

The authors acknowledge financial support rendered by the DRPM Ministry of Research, Technology, and Higher Education/BRIN, through the third-year Project of PD (contract no. 483/UN.19.5.1.3/PT.01.03/2021).

Funding

This work was supported by the Ministry of Research, Technology, and Higher Education, Republic of Indonesia (Kementerian Riset Teknologi Dan Pendidikan Tinggi Republik Indonesia).

Notes on contributors

Erman Taer is a lecturer and professor as well as the head of the study program in the Department of Physics, Faculty of Mathematics and Natural Sciences, University of Riau, Indonesia. In addition, he also serves as coordinator of the Material Physics and Nanotechnology Laboratory at the University of Riau. Apart from being a lecturer, he is also active in research. His research focuses on the technology of electrochemical energy storage, especially supercapacitor.

Melisa Melisa is a under graduate student from the University of Riau, Indonesia.

Agustino Agustino is a master's degree student from the University of Riau, Indonesia. In addition, he is active as a researcher assistant at the Material Physics and Nanotechnology Laboratory, Faculty of Mathematics and Natural Sciences, University of Riau.

Rika Taslim is a lecturer at the Department of Industrial Engineering, Faculty of Science and Technology, State Islamic University of Sultan Syarif Kasim, Pekanbaru. Indonesia. Apart from being a lecturer, she is also active in research. His research focuses on the technology of electrochemical energy storage, especially solar cell and supercapacitor.

Widya Sinta Mustika is a master's degree student from the Bandung Institute of Technology, Indonesia. In addition, she is active as a researcher assistant at the Material Physics and Nanotechnology Laboratory, Faculty of Mathematics and Natural Sciences, University of Riau.

Apriwandi Apriwandi is a master's degree student from the University of Riau, Indonesia. In addition, he is active as a researcher assistant at the Material Physics and Nanotechnology Laboratory, Faculty of Mathematics and Natural Sciences, University of Riau.

References

Awitdrus, A., M. Deraman, I. A. Talib, R. Farma, N. S. M. Nor, M. M. Ishak, and B. N. Dolah. 2016. Cyclic voltammometry of binderless activated carbon monoliths based supercapacitor from mixtures of pre-carbonized of fibers of empty fruit bunches and green petroleum coke. *KnE Engineering* 1 (2015):1–8. doi:10.18502/keg.v1i1.511.

Ayinla, R. T., J. O. Dennis, H. M. Zaid, Y. K. Sanusi, F. Usman, and L. L. Adebayo. 2019. A review of technical advances of recent palm bio-waste conversion to activated carbon for energy storage. *Journal of Cleaner Production* 229:1427–42. doi:10.1016/j.jclepro.2019.04.116.

Biswal, M., A. Banerjee, M. Deo, and S. Ogale. 2013. From dead leaves to high energy density supercapacitors. *Energy & Environmental Science* 6 (4):1249–59. doi:10.1039/c3ee22325f.

Bose, S., T. Kuila, A. K. Mishra, R. Rajasekar, N. H. Kim, and J. H. Lee. 2012. Carbon-based nanostructured materials and their composites as supercapacitor electrodes. *Journal of Materials Chemistry* 22 (3):767–84. doi:10.1039/C1JM14468E.

Chang, C. M., C. J. Weng, C. M. Chien, T. L. Chuang, T. Y. Lee, J. M. Yeh, and Y. Wei. 2013. Polyaniline/carbon nanotube nanocomposite electrodes with biomimetic hierarchical structure for supercapacitors. *Journal of Materials Chemistry A* 1 (46):14719–28. doi:10.1039/c3ta13758a.

Cheng, J., S. C. Hu, G. T. Sun, K. Kang, M. Q. Zhu, and Z. C. Geng. 2021. Comparison of activated carbons prepared by one-step and two-step chemical activation process based on cotton stalk for supercapacitors application. *Energy* 215:119144. doi:10.1016/j.energy.2020.119144.

Chmiola, J., G. N. S., Z. Chen, S. A. Freunberger, X. Ji, Y. K. Sun, K. Amine, G. Yushin, L. F. Nazar, J. Cho, and P. G. Bruce. 2012. Challenges facing lithium batteries and electrical double-layer capacitors. *Angewandte Chemie* 51 (40):9994–10024.

Cullity, B. 1978. Elements of X-ray diffraction. 2rd ed. Notre Dame, Indiana: Addison-Wesley.

Deraman, M., S. K. Siti, M. M. Ishak, T. E. Awitdrus, I. Talib, R. Omar, and M. H. Mohammad. 2010. Carbon/carbon nanotubes (CNTs) composites from green pellets contain CNTs and self-adhesive carbon grains from fibres of oil palm empty fruit bunch. *AIP Conference Proceedings* 1284:179–86.

Divyashree, A., B. A. S. A. Manaf, S. Yallappa, K. Chaitra, N. Kathyayini, and G. Hegde. 2016. Low cost, high performance supercapacitor electrode using coconut wastes: Eco-friendly approach. *Journal of Energy Chemistry* 25 (5):880–87. doi:10.1016/j.jechem.2016.08.002.

Dyatkin, B., V. Presser, M. Heon, M. R. Lukatskaya, M. Beidaghi, and Y. Gogotsi. 2013. Development of a green supercapacitor composed entirely of environmentally friendly materials. *ChemSusChem* 6 (12):2269–80. doi:10.1002/cssc.201300852.

Farma, R., M. Deraman, A. Awitdrus, I. A. Talib, E. Taer, N. H. Basri, J. G. Manjunatha, M. M. Ishak, B. N. M. Dollah, and S. A. Hashmi. 2013. Preparation of highly porous binderless activated carbon electrodes from fibres of oil palm empty fruit bunches for application in supercapacitors. *Bioresource Technology* 132:254–61. doi:10.1016/j.biortech.2013.01.044.

Farma, R., M. Deraman, R. Omar, I. M. M. Awitdrus, E. Taer, and I. A. Talib. 2011. Binderless composite electrode monolith from carbon nanotube and biomass carbon activated by KOH and CO_2 gas for supercapacitor. *AIP Conference Proceedings* 1415:180–84.

Ghosh, S., R. Santhosh, S. Jeniffer, V. Raghavan, G. Jacob, K. Nanaji, P. Kollu, S. K. Jeong, and A. N. Grace. 2019. Natural biomass derived hard carbon and activated carbons as electrochemical supercapacitor electrodes. *Scientific Reports* 9 (1):1–15. doi:10.1038/s41598-019-52006-x.

González, A., E. Goikolea, J. A. Barrena, and R. Mysyk. 2016. Review on supercapacitors: Technologies and materials. *Renewable and Sustainable Energy Reviews* 58:1189–206. doi:10.1016/j.rser.2015.12.249.

Hao, E., W. Liu, S. Liu, Y. Zhang, H. Wang, S. Chen, F. Ch[illegible] S. Zhao, and H. Yang. 2017. Rich sulfur doped porous carbon materials derived from ginkgo leaves for multiple electrochemical energy storage devices. *Journal of Materials Chemistry A* 5 (5):2204–14. doi:10.1039/C6TA08169J.

Jain, D., J. Kanungo, and S. K. Tripathi. 2020. Enhancement in performance of supercapacitor using eucalyptus leaves derived activated carbon electrode with CH_3COONa and HQ electrolytes: A step towards environment benign supercapacitor. *Journal of Alloys and Compounds* 832:154956. doi:10.1016/j.jallcom.2020.154956.

Jayalakshmi, M., and K. Balasubramanian. 2008. Simple capacitors to supercapacitors - An overview. *Int J Electrochem Sci* 3 (11):1196–217.

Liu, H. Y., K. P. Wang, and H. Teng. 2005. A simplified preparation of mesoporous carbon and the examination of the carbon accessibility for electric double layer formation. *Carbon N Y* 43 (3):559–66. doi:10.1016/j.carbon.2004.10.020.

Liu, Y., Y. Wang, G. Zhang, W. Liu, D. Wang, and Y. Dong. 2016. Preparation of activated carbon from willow leaves and evaluation in electric double-layer capacitors. *Materials Letters* 176:60–63. doi:10.1016/j.matlet.2016.04.065.

Lu, L., V. Sahajwalla, C. Kong, and D. Harris. 2001. Quantitative X-ray diffraction analysis and its application to various coals. *Carbon N Y* 39 (12):1821–33. doi:10.1016/S0008-6223(00)00318-3.

Ma, H., Z. Liu, X. Wang, C. Zhang, and R. Jiang. 2017. Supercapacitive performance of porous carbon materials derived from tree leaves. *Journal of Renewable and Sustainable Energy* 9 (4):044105-1-044105–8. doi:10.1063/1.4997019.

Moreno-Fernandez, G., M. Kunowsky, L.-R. MÁ, J. Ibañez, and J. M. Rojo. 2017. New carbon monoliths for supercapacitor electrodes. Looking at the double layer. *ChemElectroChem* 4 (5):1016–25. doi:10.1002/celc.201600848.

Peng, C., X. B. Yan, R. T. Wang, J. W. Lang, Y. J. Ou, and Q. J. Xue. 2013. Promising activated carbons derived from waste tea-leaves and their application in high performance supercapacitors electrodes. *Electrochimica acta* 87:401–08. doi:10.1016/j.electacta.2012.09.082.

Promdee, K., J. Chanvidhwatanakit, S. Satitkune, C. Boonmee, T. Kawichai, S. Jarernprasert, and T. Vitidsant. 2017. Characterization of carbon materials and differences from activated carbon particle (ACP) and coal briquettes product (CBP) derived from coconut shell via rotary kiln. *Renewable and Sustainable Energy Reviews* 75 (November 2016):1175–86. doi:10.1016/j.rser.2016.11.099.

Qi, L., X. Tang, Z. Wang, and X. Peng. 2017. Pore characterization of different types of coal from coal and gas outburst disaster sites using low temperature nitrogen adsorption approach. *International Journal of Mining Science and Technol* 27 (2):371–77. doi:10.1016/j.ijmst.2017.01.005.

Serafin, J., M. Baca, M. Biegun, E. Mijowska, R. J. Kaleńczuk, J. Sreńscek-Nazzal, and B. Michalkiewicz. 2019. Direct conversion of biomass to nanoporous activated biocarbons for high CO_2 adsorption and supercapacitor applications. *Applied Surface Science* 497 (August):143722. doi:10.1016/j.apsusc.2019.143722.

Sodtipinta, J., T. Amornsakchai, and P. P watpanurut. 2017. Nanoporous carbon derived from agro-waste pineapple leaves for supercapacitor electrode. *Advances in Natural Sciences: Nanoscience and Nanotechnology* 8 (3):1–10. doi:10.1088/2043-6254/aa7233.

Sodtipinta, J., C. Ieosakulrat, N. Poonyayant, P. Kidkhunthod, N. Chanlek, T. Amornsakchai, and P. Pakawatpanurut. 2017. Interconnected open-channel carbon nanosheets derived from pineapple leaf fiber as a sustainable active material for supercapacitors. *Industrial Crops and Products* 104 (April):13–20. doi:10.1016/j.indcrop.2017.04.015.

Taer, E., A. Afrianda, R. Taslim, K. Krisman, M. Minarni, A. Agustino, A. Apriwandi, and U. Malik. 2018a. The physical and electrochemical properties of activated carbon electrode made from Terminalia Catappa leaf (TCL) for supercapacitor cell application. *Journal of Physics. Conference Series* 1120 (1):012007-1-012007–8. doi:10.1088/1742-6596/1120/1/012007.

Taer, E., A. Apriwandi, Y. S. Ningsih, R. Taslim, and Ag ino. 2019a. Preparation of activated carbon electrode from pineapple crown waste for supercapacitor application. *Int J Electrochem Sci* 14 (3):2462–75. doi:10.20964/2019.03.17.

Taer, E., A. Apriwandi, R. Taslim, U. Malik, and Z. Usm . 2019b. Single step carbonization-activation of durian shells for producing activated carbon monolith electrodes. *Int J Electrochem Sci* 14 (2):1318–30. doi:10.20964/2019.02.67.

Taer, E., P. Dewi, S. Sugianto, R. Syech, R. Taslim, S. Salomo, Y. Susanti, A. Purnama, A. Apriwandi, A. Agustino, et al.. 2018b. The synthesis of carbon electrode supercapacitor from durian shell based on variations in the activation time. *AIP Conference Proceedings* 1927:030026-1-030026–6.

Taer, E., Y. Susanti, A. Awitdrus, S. Sugianto, R. Taslim, R. N. Setiadi, S. Bahri, A. Agustino, P. Dewi, and B. Kurniasih. 2018c. The effect of CO_2 activation temperature on the physical and electrochemical properties of activated carbon monolith from banana stem waste. *AIP Conference Proceedings* 1927:030016-1-030016–5.

Taer, E., R. Taslim, W. S. Mustika, B. Kurniasih, A. A. Agustino, and Apriwandi. 2018d. Produ n of an activated carbon from a banana stem and its application as electrode materials for supercapacitors. *Int J Electrochem Sci* 13 (9):8428–39. doi:10.20964/2018.09.55.

Taslim, R., A. Agustino, and E. Taer. 2018. Naturalcarbon-metal composite for supercapacitor application. *Journal of Physics. Conference Series* 1120 (1):012008-1-012008–10. doi:10.1088/1742-6596/1120/1/012008.

Tursi, A. 2019. A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Research Journal* 6 (2):96 9. doi:10.18331/BRJ2019.6.2.3.

Wang, J., X. Zhang, Z. Li, Y. Ma, and L. Ma. 2020. Recent progress of biomass-derived carbon materials for supercapa tors. *Journal Power Sources* 451 (October 2019):227794. doi:10.1016/j.jpowsour.2020.227794.

Wang, Y., Q. Qu, S. Gao, G. Tang, K. Liu, S. He, and C. Huang. 2019. Biomass derived carbon as binder-free electrode materials for supercapacitors. *Carbon N Y* 155:706–26. doi:10.1016/j.carbon.2019.09.018.

Wang, Y., Y. Song, and Y. Xia. 2016. Electrochemical capa rs: Mechanism, materials, systems, characterization and applications. *Chemical Society Reviews* 45 (21):5925–50. doi:10.1039/C5CS00580A.

Winter, M., and R. J. Brodd. 2004. What are batteries, fuel cells, and supercapacitors? *Chemical Reviews* 104 (10):4245–69.

Wu, C., S. Zhang, W. Wu, Z. Xi, C. Zhou, X. Wang, Y. Deng, Y. Bai, G. Liu, X. Zhang, et al.. 2019. Carbon nanotubes grown on the inner wall of carbonized wood tracheids for high-performance supercapacitors. *Carbon N Y* 150:311–18. doi:10.1016/j.carbon.2019.05.032.

Yahya, M. A., Z. A odah, and C. W. Z. Ngah. 2015. Agricultural bio-waste materials as potential sustainable precursors used for activated carbon production: A review. *Renewable and Sustainable Energy Reviews* 46:218–35. doi:10.1016/j.rser.2015.02.051.

Yang, K., C. Yu, Z. Yu, M. Zhu, W. Zhao, H. Chen, and F. Pan. 2019. Hierarchically porous activated carbons derived from Schefflera octophylla leaves for high performance supercapacitors. *Materials Letters* 247:102–05. doi:10.1016/j.matlet.2 .03.101.

Zhang, L., Z. Liu, G. Cui, and L. Chen. 2015. Biomass-derived materials for electrochemical energy storages. *Progress in Polymer Science* 43:136–64. doi:10.1016/j.progpolymsci.2014.09.003.

Zhao, J., Q. Shi, Y. Guo, X. Wang, D. Wang, F. Tan, L. Jiang, and Y. Yu. 2019. Flash foam stamp-inspired fabrication of flexible in-plane graphene integrated micro-supercapacitors on paper. *Journal of Power Sources* 433 (February):226703. doi:10.1016/j.jpowsour.2019.226703.

Zhao, Q., X. Wang, H. Xia, J. Liu, H. Wang, J. Gao, Y. Zhang, J. Liu, H. Zhou, X. Li, et al.. 2015. Design, preparation and performance of novel three-dimensional hierarchically porous carbon for supercapacitors. *Electrochimica acta* 173:566–18 doi:10.1016/j.electacta.2015.05.096.

Zhu, X., S. Yu, K. Xu, Y. Zhang, L. Zhang, G. Lou, Y. Wu, E. Zhu, H. Chen, Z. Shen, et al.. 2018. Sustainable activated carbons from dead ginkgo leaves for supercapacitor electrode active materials. *Chemical Engineering Science* 181:36–45. doi:10.1016/j.ces.2018.02.004.

Biomass-based activated carbon monolith from Tectona grandis leaf as supercapacitor electrode materials

ORIGINALITY REPORT

13%	9%	6%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	fedetd.mis.nsysu.edu.tw Internet Source	<1%
2	repository.up.ac.za Internet Source	<1%
3	science-gate.com Internet Source	<1%
4	www.onlinelibrary.wiley.com Internet Source	<1%
5	www.srjis.com Internet Source	<1%
6	Sheila Hernandez, Juan V. Perales-Rondon, Aranzazu Heras, Alvaro Colina. "Determination of uric acid in synthetic urine by using electrochemical surface oxidation enhanced Raman scattering", Analytica Chimica Acta, 2019 Publication	<1%
7	Yu-zhu Ma, Bao-jun Yu, Yan Guo, Cheng-yang Wang. "Facile synthesis of biomass-derived hierarchical porous carbon	<1%

microbeads for supercapacitors", Journal of Solid State Electrochemistry, 2016
Publication

8	chemistry-europe.onlinelibrary.wiley.com Internet Source	<1 %
9	ejournal.unkhair.ac.id Internet Source	<1 %
10	openresearch-repository.anu.edu.au Internet Source	<1 %
11	rsdjournal.org Internet Source	<1 %
12	Ahmad, N.H., and M.I.N. Isa. "Characterization of un-plasticized and propylene carbonate plasticized carboxymethyl cellulose doped ammonium chloride solid biopolymer electrolytes", Carbohydrate Polymers, 2016. Publication	<1 %
13	Submitted to Madan Mohan Malaviya University of Technology Student Paper	<1 %
14	S. Yallappa, S.R. Kiran Kumar, K.L. Nagashree, Uma et al. "Fabrication of carbon nanospheres using natural resources and their voltametric studies of dopamine", Materials Today: Proceedings, 2018 Publication	<1 %

15	Submitted to Thammasat University Student Paper	<1 %
16	Submitted to University of Minnesota System Student Paper	<1 %
17	mostwiedzy.pl Internet Source	<1 %
18	Chinnasamy Sengottaiyan, Noordeen Abdul Kalam, Ramasamy Jayavel, Rekha Goswami Shrestha et al. "BiVO4/RGO Hybrid Nanostructure for High Performance Electrochemical Supercapacitor", Journal of Solid State Chemistry, 2018 Publication	<1 %
19	Submitted to Universitas Negeri Surabaya The State University of Surabaya Student Paper	<1 %
20	pure.rug.nl Internet Source	<1 %
21	Paul J. King, Thomas M. Higgins, Sukanta De, Norbert Nicoloso, Jonathan N. Coleman. "Percolation Effects in Supercapacitors with Thin, Transparent Carbon Nanotube Electrodes", ACS Nano, 2012 Publication	<1 %
22	Xiaozhong Wu, Wei Xing, Justyna Florek, Jin Zhou, Guiqiang Wang, Shuping Zhuo, Qingzhong Xue, Zifeng Yan, Freddy Kleitz.	<1 %

	"On the origin of the high capacitance of carbon derived from seaweed with an apparently low surface area", J. Mater. Chem. A, 2014 Publication	
23	id.sciencenet.cn Internet Source	<1 %
24	www.mlodzinaukowcy.com Internet Source	<1 %
25	www.sciencedaily.com Internet Source	<1 %
26	Bashir, Bushra, Wajeeha Shaheen, Muhammad Asghar, Muhammad Farooq Warsi, Muhammad Azhar Khan, Sajjad Haider, Imran Shakir, and Muhammad Shahid. "Copper doped manganese ferrites nanoparticles anchored on graphene nano-sheets for high performance energy storage applications", Journal of Alloys and Compounds, 2016. Publication	<1 %
27	Submitted to Multimedia University Student Paper	<1 %
28	Submitted to The Robert Gordon University Student Paper	<1 %
29	uinsuska.academia.edu Internet Source	<1 %
30	www.surrey.ac.uk	

	Internet Source	<1 %
31	Kim, Nam Hoon, Tapas Kuila, and Joong Hee Lee. "Enhanced mechanical properties of a multiwall carbon nanotube attached pre-stitched graphene oxide filled linear low density polyethylene composite", Journal of Materials Chemistry A, 2014. Publication	<1 %
32	www.sigma-not.pl Internet Source	<1 %
33	li.mit.edu Internet Source	<1 %
34	msptm.org Internet Source	<1 %
35	sustainenvironres.biomedcentral.com Internet Source	<1 %
36	www.e3s-conferences.org Internet Source	<1 %
37	Submitted to Ajou University Graduate School Student Paper	<1 %
38	Dehkhoda, Amir Mehdi, Naoko Ellis, and Előd Gyenge. "Effect of activated biochar porous structure on the capacitive deionization of NaCl and ZnCl2 solutions", Microporous and Mesoporous Materials, 2016.	<1 %

Publication

39	Submitted to Sogang University Student Paper	<1 %
40	Zhibin Lei, Zonghuai Liu, Huanjing Wang, Xiuxia Sun, Li Lu, X. S. Zhao. "A high-energy-density supercapacitor with graphene–CMK-5 as the electrode and ionic liquid as the electrolyte", Journal of Materials Chemistry A, 2013 Publication	<1 %
41	www.e-journals.in Internet Source	<1 %
42	www.scik.org Internet Source	<1 %
43	Álvarez-Gutiérrez, N., S. García, M.V. Gil, F. Rubiera, and C. Pevida. "Towards Bio-upgrading of Biogas: Biomass Waste-based Adsorbents", Energy Procedia, 2014. Publication	<1 %
44	K Nuilek, A Simon, P Baumli. "Synthesis and Characterization of Carbon Nanosheets from Stinging Nettle (Urtica Dioica)", IOP Conference Series: Materials Science and Engineering, 2019 Publication	<1 %
45	discovery.ucl.ac.uk Internet Source	<1 %
46	s-space.snu.ac.kr Internet Source	<1 %

47	Bekyarova, E.. "Adsorption of Supercritical N"2 and O"2 on Pore-Controlled Carbon Aerogels", Journal of Colloid And Interface Science, 20010615 Publication	<1 %
48	Jian-Jun Shi. "Enhanced electrochemiluminescent aptasensor for mercury based on CdTeSe@CdS QDs-DNA bioconjugates and enzymatic catalysis", International Journal of Electrochemical Science, 2018 Publication	<1 %
49	Yanwu Zhu, Shanthi Murali, Weiwei Cai, Xuesong Li, Ji Won Suk, Jeffrey R. Potts, Rodney S. Ruoff. "Graphene and Graphene Oxide: Synthesis, Properties, and Applications", Advanced Materials, 2010 Publication	<1 %
50	acp.copernicus.org Internet Source	<1 %
51	journals.rcni.com Internet Source	<1 %
52	jurnaliainpontianak.or.id Internet Source	<1 %
53	www.tfzr.uns.ac.rs Internet Source	<1 %
54	Foo, K.Y.. "Microwave-assisted preparation of oil palm fiber activated carbon for	<1 %

methylene blue adsorption", Chemical Engineering Journal, 20110115
Publication

55	Obreja, V.V.N.. "On the performance of supercapacitors with electrodes based on carbon nanotubes and carbon activated material-A review", Physica E: Low-dimensional Systems and Nanostructures, 200805 Publication	<1 %
56	Peng Dou, Zhi Liu, Zhenzhen Cao, Jiao Zheng, Chao Wang, Xinhua Xu. "Rapid synthesis of hierarchical nanostructured Polyaniline hydrogel for high power density energy storage application and three-dimensional multilayers printing", Journal of Materials Science, 2016 Publication	<1 %
57	fenix.tecnico.ulisboa.pt Internet Source	<1 %
58	www.scilit.net Internet Source	<1 %
59	Bong Gill Choi, MinHo Yang, Won Hi Hong, Jang Wook Choi, Yun Suk Huh. "3D Macroporous Graphene Frameworks for Supercapacitors with High Energy and Power Densities", ACS Nano, 2012 Publication	<1 %

60	Xiaolei Zhang, Weihong Yang, Wlodzimierz Blasiak. "Modeling Study of Woody Biomass: Interactions of Cellulose, Hemicellulose, and Lignin", Energy & Fuels, 2011 Publication	<1 %

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	Off		