

Comparation of Activated Carbon Electrodes from Natural Materials for Supercapacitor Applications in Energy Storage Systems

Wichaid Ponhan^a, Tanachai Ponken^{a, b}, Apisit. Keacharoen^a

^a Program of Physics, Faculty of Science and Technology, Rajabhat Maha Sarakham University, Maha Sarakham, 44000, Thailand.

^b Renewable Energy and Nano-materials Research (RENr), Physics Major, Faculty of Science and Technology Rajabhat Maha Sarakham University, Maha Sarakham, 44000, Thailand.

*Corresponding authors: ponken.po@rmu.ac.th

<https://doi.org/10.55674/ias.v15i3.267854>

Received: 25 May 2026; Revised: 07 July 2026; Accepted: 10 July 2026; Available online: 01 September 2026

Abstract

This study presents the fabrication of activated carbon (AC) electrodes derived from natural materials for high-performance supercapacitor applications. Five types of biomass were used as carbon precursors: bamboo, rain tree wood, tiger grass, redwood, and litchi wood, respectively. The activated carbon was prepared via physical activation at 800 °C for 2 h. under an argon atmosphere. Structural, morphological, and elemental properties were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy (EDX). Electrochemical performance was evaluated through charge–discharge testing. The results reveal that the synthesized carbon exhibits an amorphous structure with characteristic peaks at (002) and (101) planes. SEM images show irregular porous structures with rough surfaces, contributing to high surface area. EDX analysis confirms high carbon purity (~99 wt%). The electrochemical measurements demonstrate a maximum specific capacitance of 50.50 F g⁻¹ at a constant current of 20 mA.

Keywords: Activated carbon; Biomass; Supercapacitor; Energy storage; Natural materials

© 2026 Center of Excellence on Alternative Energy reserved

1. Introduction

Currently, the demand for electricity is extremely high and continues to increase rapidly. However, electricity generation sectors are still insufficient to meet this demand, and traditional energy sources are rapidly depleting and non-renewable, such as petroleum, coal, and natural gas. Consequently, both research and industry have been actively developing and exploring alternative energy sources, including hydropower, wind energy, geothermal energy, biomass, and solar energy. Research efforts have advanced technologies and innovations to efficiently generate electricity from these sources, but production costs remain high, and continuous generation is not always feasible. Therefore, electrical energy storage systems or devices play a crucial role by storing the produced electricity. Currently, there are two main types of electrical energy storage devices: 1) batteries and 2) supercapacitors. Batteries tend to have drawbacks such as high cost, heavy weight, insufficient storage capacity, short lifespan, and environmental pollution from toxic waste that is difficult to manage. Hence, this research focuses on supercapacitors as an alternative to batteries due to their superior charge storage properties. The electrode materials used in supercapacitors have surface areas 100 – 10,000 times greater than conventional capacitors. They can charge rapidly within 1 – 10 s compared to lithium-ion batteries that require 10 – 60 min. Supercapacitors support 500,000 charge-discharge cycles, which is 100 times more than lithium-ion batteries and 1,000 – 10,000 times more than lead-acid batteries. Their cost per watt is also lower, around US\$25-50/kW, compared to lithium-ion batteries which cost US\$75-150/kW. Additionally, supercapacitors have a longer lifespan because their operation depends on electrolyte ion separation rather than electrochemical reaction kinetics. They also offer higher power density compared to batteries. Given these advantages, supercapacitors have wide-ranging applications, such as stabilizing voltage in power transmission, replacing batteries in uninterruptible power supplies (UPS), complementing batteries in electronic devices, aiding fuel cell vehicles, powering portable tools, and storing energy from renewable sources like solar and wind. Their deep charge-discharge cycle life can reach up to 20 years, comparable

to solar panel systems. Key components of supercapacitors include electrode materials like graphene, manganese nanomaterials, and conductive polymers like polyaniline, though some of these are costly. Previous studies, such as those by Yang et al. (2014) [1] and Huang et al. (2015) [2], demonstrated that carbon synthesized from bamboo pyrolysis, activated by potassium hydroxide, exhibits extremely high surface area and specific capacitance.

This research aims to develop supercapacitor electrodes using activated carbon derived from natural materials such as bamboo, rain tree wood, tiger grass, redwood, and litchi wood, respectively. These materials have high carbon content and porous structures similar to graphene, enhancing their surface area for electrolyte interaction and improving charge storage efficiency. Bamboo, in particular, has a naturally porous vascular structure favorable for this purpose. The activated carbon will be produced by pyrolyzing the natural materials in an argon atmosphere at 800°C for 2 h and characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX). The electrodes will then be fabricated and tested for charge-discharge performance using battery testers and cyclic voltammetry techniques.

This research expects to reduce the production cost of supercapacitors by using locally abundant natural materials, thereby increasing scientific competitiveness through advances in science, technology, research, and innovation for the country's foundational knowledge development.

2. Materials and Methods

2.1 Preparation of Natural Materials and Synthesis of Activated Carbon

Activated carbon was synthesized from five types of natural materials: Bamboo, rain tree wood, tiger grass, redwood, and litchi wood, respectively. The preparation process was carried out as follows: The natural materials were cut into small pieces and immersed in ethanol. The samples were then cleaned using an ultrasonic cleaner for 1 h. After that, the samples were placed on aluminum foil and dried in an oven (annealing process) at 80 °C for 12 h, as shown in Fig. 1. The dried samples were carbonized in a furnace under an argon atmosphere at 400 °C for 2 h with a heating rate of 5 °C min⁻¹. The obtained carbon materials were chemically activated using potassium hydroxide (KOH). The carbon and KOH were mixed at a weight ratio of 1:1 in a 25 mL beaker. Subsequently, 10 mL of deionized (DI) water was added together with a magnetic bar, and the mixture was stirred continuously for 2 h using a magnetic stirrer. The resulting carbon solution was dried in an oven at 100 °C for 12 h to remove moisture. The dried samples were then activated under an argon atmosphere at 800 °C for 2 h with a heating rate of 5 °C min⁻¹ to obtain activated carbon.



Fig. 1 Extraction of activated carbon from five natural materials: bamboo, rain tree wood, tiger grass, redwood, and litchi wood.

Fig. 1 Extraction and synthesis process of activated carbon derived from five natural materials: bamboo, rain tree wood, Siam weed stem, redwood, and Lin Fa wood.

2.3. Fabrication of Supercapacitors

Approximately 4.50 g of activated carbon powder from each material was mixed with 16 mL of Polyvinyl Acetate Resin (PVA 7%) binder solution. The prepared slurry was coated onto nickel foam to serve as the electrode material. The electrolyte solution was prepared by dissolving 52.80 g of tetraethylammonium tetrafluoroborate in 100 mL of acetonitrile. In addition, 24 g of polyethylene glycol was dissolved in 100 mL of acetonitrile. The electrolyte solution was coated onto a carbon film, and a separator paper was used between the electrodes. The supercapacitor cells were assembled by rolling the electrode

structure and connecting the cell terminals. The electrochemical performance of the fabricated supercapacitors was evaluated using charge–discharge testing with a battery tester. Cyclic voltammetry (CV) measurements were also performed to investigate the electrochemical behavior of the devices.

3. Results and Discussions

3.1 Morphological Characteristics of Activated Carbon Synthesized from Different Natural Materials

Activated carbon materials synthesized from different natural sources were successfully prepared using a chemical activation process under an argon atmosphere. The synthesis process was carried out in a closed system to prevent oxygen from reacting with the carbon precursor during thermal activation. The activation process was performed at 800 °C for 2 h under continuous argon gas flow, which promoted the formation of highly porous carbon structures.

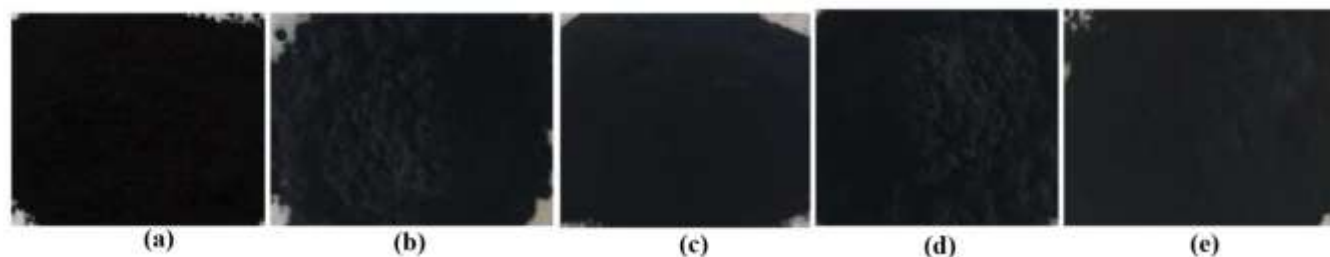


Fig. 2 The natural materials were cut into small pieces and immersed in ethanol. The samples were then cleaned using an ultrasonic cleaner for 1 h. After that, the samples were placed on aluminum foil and dried by an annealing process at 80 °C for 12 h.

The obtained activated carbon samples derived from bamboo, rain tree wood, tiger grass, redwood, and litchi wood exhibited different physical appearances, particle sizes, and surface textures, as shown in Fig 2. After grinding into fine powders, all samples appeared as black carbon materials; however, differences in fineness and texture were clearly observed depending on the precursor material. Among all samples, the activated carbon derived from tiger grass exhibited the finest texture and the highest degree of porosity compared with the other materials.

3.2 Analysis of Natural Materials

3.2.1 Structural properties of Natural materials by X-ray diffraction (XRD)

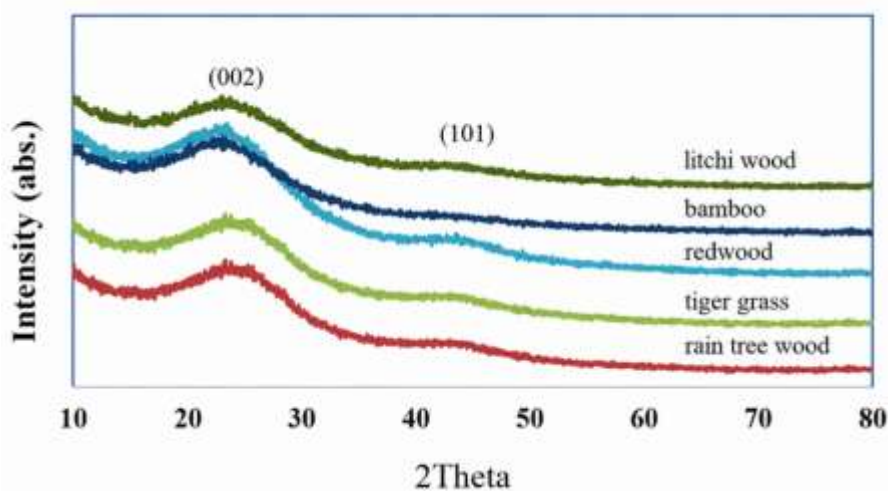


Fig. 3 X-ray diffraction (XRD) patterns of activated carbon synthesized from bamboo, rain tree wood, tiger grass, redwood, and litchi wood for structural characterization analysis using the X-ray diffraction (XRD) technique.

The crystal structures of activated carbon particles synthesized from different natural materials, including bamboo, rain tree wood, tiger grass, redwood, and litchi wood, were investigated using X-ray diffraction (XRD). The samples were physically activated in a closed system under an argon gas atmosphere for 2 h at an activation temperature of 800 °C. The obtained XRD patterns, showing the relationship between intensity and diffraction angle, are presented in Fig 3. By comparing the obtained diffraction data with the JCPDS database, the results revealed the formation of graphite-like carbon phases. However, the crystallization was not fully developed, as indicated by the broad diffraction peaks appearing at approximately $2\theta = 26^\circ$ and 44° , corresponding to the characteristic graphite planes of (002) and (101), respectively. These findings are consistent with the studies reported by Kim et al. (2021) [9] and Nilanka et al. (2021) [10]. In addition, the relatively low-intensity diffraction peaks indicate a low degree of crystallinity, suggesting that the carbon materials mainly possess an amorphous structure. The broad peak widths also imply that the synthesized carbon particles have small crystallite sizes. Such structural characteristics are highly suitable for use as electrode materials in supercapacitor applications due to their potential to provide high surface area and enhanced electrochemical performance.

3.2.2 The surface morphology of Natural materials by scanning electron microscopy (SEM)

The surface morphology of the synthesized activated carbon was further investigated using scanning electron microscopy (SEM), as presented in Fig. 3. The SEM results revealed that each carbon material possessed distinct surface characteristics, including differences in pore distribution, particle size, and structural roughness. These variations are strongly related to the intrinsic structure and composition of each natural precursor. Some samples showed highly porous and interconnected structures, while others exhibited denser and less porous morphologies.

The porous structure of activated carbon plays an important role in electrochemical energy storage performance. Materials with higher porosity provide a larger specific surface area, allowing greater ion adsorption and charge accumulation on the electrode surface. Therefore, activated carbon samples with highly porous structures are expected to exhibit improved electrical conductivity and enhanced specific capacitance performance in supercapacitor applications.

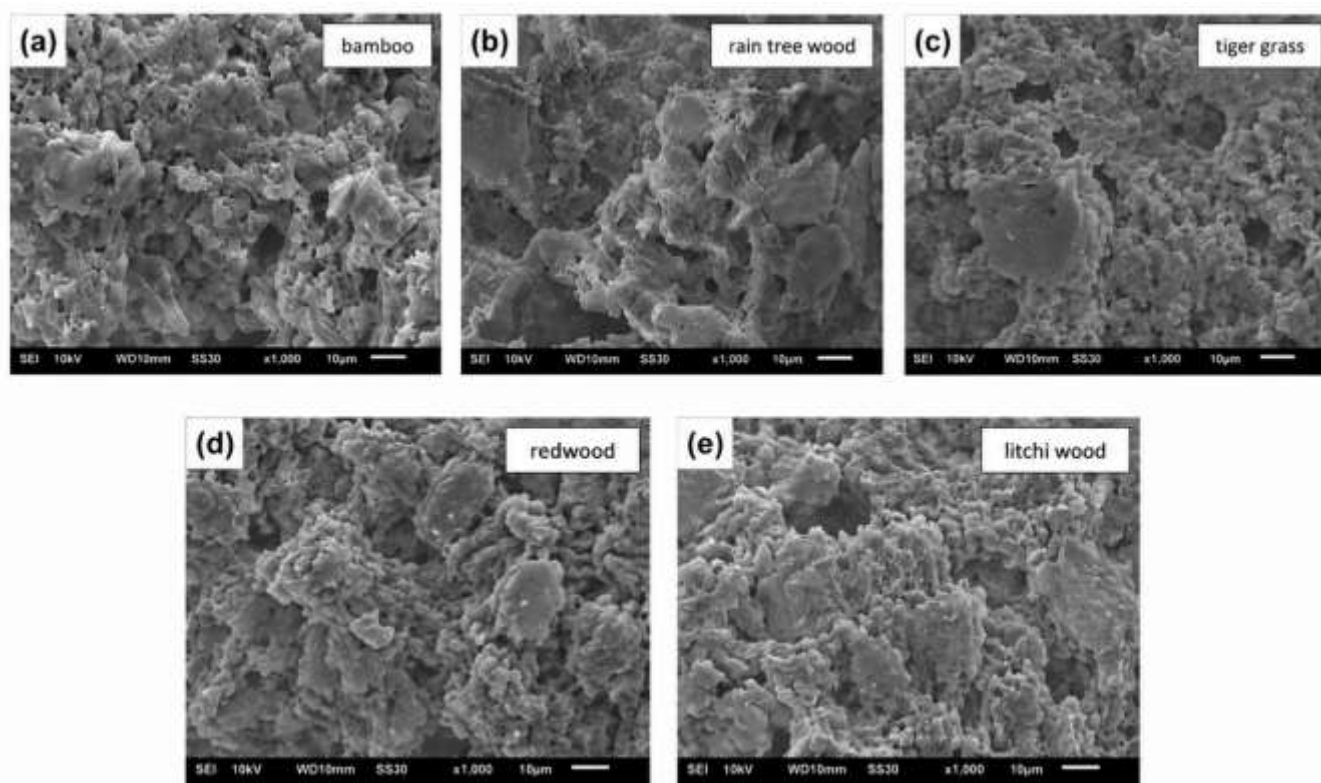
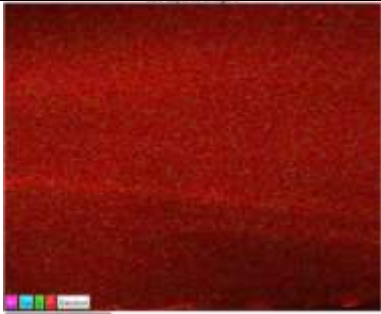
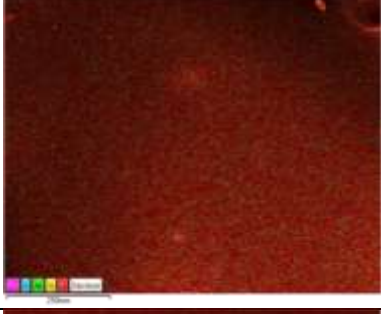


Fig. 4 SEM images showing the surface morphology of activated carbon were analyzed to investigate the morphological properties using Scanning Electron Microscopy (SEM).

Table 1 Shows the quantitative elemental analysis using Energy Dispersive X-ray Spectroscopy (EDX) revealed that all wood-derived activated carbons.

The activated carbons synthesized from different types of wood	Elemental distribution mapping	%C	%S	%Cu	Si%
Bamboo		99.40	0.40	0.10	-
Rain tree wood		99.40	0.50	0.10	0.00
Tiger grass		99.40	0.40	0.10	-
Redwood		99.50	0.40	0.10	-
Litchi wood		99.50	0.40	0.10	-

3.2.3 Elemental of Natural materials by Energy Dispersive X-ray Spectroscopy (EDX)

Table 1, the quantitative elemental analysis using Energy Dispersive X-ray Spectroscopy (EDX) revealed that all wood-derived activated carbons, including carbon black, contained trace distributions of several elements, namely C, Cu, S, and Si. However, the dominant element in all samples was carbon, with a carbon content as high as 99 Wt%, while other elements were detected only in very small amounts. These results indicate that the activated carbons synthesized from different types of wood and carbon black possessed a very high carbon purity. The EDX results were consistent with the X-ray diffraction (XRD) analysis, which identified these minor elements in the form of oxide and compound phases such as CuCN, CaSO₄, CaO, Fe₃O₄, and SiO₂. Therefore, the synthesized activated carbons are considered suitable for application as electrode materials in supercapacitors due to their high carbon content and purity. Furthermore, the elemental mapping images of all wood samples and carbon black demonstrated a uniform elemental distribution across the surface, which corresponded well with the morphological characteristics observed from Scanning Electron Microscopy (SEM) analysis. The elemental mapping confirmed that the detected elements were distributed throughout the surface region of the activated carbon materials.

3.2.4 Capacitance and Specific Capacitance Measurements of Supercapacitors

3.2.4.1 Charge–Discharge Performance of Supercapacitors at a Constant Current of 20 mA

The charge–discharge behavior of the synthesized supercapacitors derived from different types of wood was investigated by applying a constant voltage and current. The charging voltage was set at 1 V, while the discharging voltage was fixed at 0.20 V, and a constant current of 20 mA was maintained throughout the experiment. The results revealed that the material derived from redwood exhibited much slower charge and discharge behavior compared to the other materials, which is consistent with the characteristics expected for an ideal supercapacitor according to capacitor theory as shows in the Fig 5.

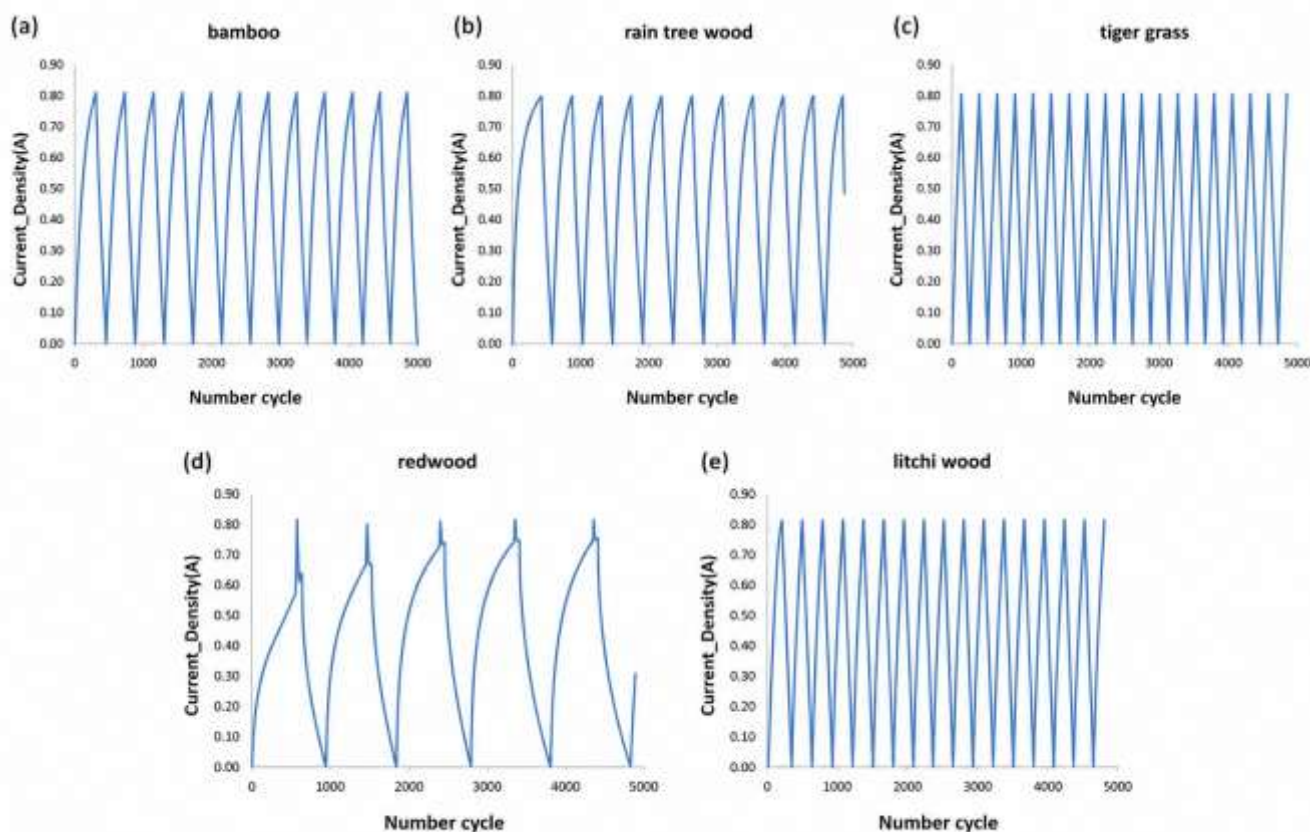


Fig. 5 Charge–discharge profiles of the synthesized supercapacitors activated at 800 °C under a constant current of 20 mA for 5,000 cycles.

3.2.4.2 Measurement of Capacitance and Specific Capacitance of Supercapacitors at a Constant Current of 20 mA

The capacitance and specific capacitance of supercapacitors fabricated using activated carbon materials synthesized from different types of wood were investigated under a constant current of 20 mA. The activated carbon materials were derived from bamboo, rain tree wood, tiger grass, redwood, and litchi wood. All samples were physically activated by carbonization in a closed system under an argon gas atmosphere for 2 h at an activation temperature of 800 °C.

Table 2 presents the capacitance and specific capacitance values of the supercapacitors fabricated from activated carbon materials synthesized from different wood species at an activation temperature of 800 °C under a constant current of 20 mA.

Constant current throughout the test (mA)	Type of wood	Specific capacitance (F g^{-1})
20	Bamboo	40.50
20	Rain tree wood	26.60
20	Tiger grass	11.30
20	Redwood	50.50
20	Litchi wood	6.46

The results showed that bamboo and redwood exhibited higher specific capacitance values than litchi wood, tiger grass, and rain tree wood. These findings are consistent with the charge–discharge performance results as well as the physical properties related to surface morphology and specific surface area.

4. Conclusion

The activated carbon materials synthesized from bamboo, rain tree wood, tiger grass, redwood, and litchi wood were successfully prepared by physical activation in a closed system under an argon atmosphere for 2 h at an activation temperature of 800 °C. The XRD analysis revealed the formation of graphite-like carbon structures with characteristic diffraction peaks observed at approximately $2\theta = 26^\circ$ and 44° , corresponding to the (002) and (101) planes of graphite. However, the diffraction peaks were relatively broad and of low intensity, indicating low crystallinity and predominantly amorphous carbon structures with small particle sizes. These structural characteristics are considered suitable for supercapacitor electrode applications due to their ability to provide effective ion transport and charge storage behavior. Morphological investigation using SEM at magnifications ranging from $\times 5,000$ to $\times 10,000$ showed irregular fractured particles with different surface textures and porosity depending on the wood precursor. Activated carbon derived from tiger grass exhibited highly porous structures with numerous small pores distributed throughout the surface, while redwood- and litchi wood-derived activated carbons also displayed porous morphologies, although with slightly lower porosity. The porous structures and surface characteristics of the activated carbon materials significantly influenced the electrochemical performance of the supercapacitors by enhancing the accessible surface area for electrolyte ion adsorption. Elemental analysis confirmed that all activated carbon samples, including carbon black, contained predominantly carbon with a purity of approximately 99 wt.%, while only trace amounts of impurity elements such as Cu, S, and Si were detected. The impurity elements were mainly present in oxide forms, including CuCN, CaSO_4 , CaO, Fe_3O_4 , and SiO_2 , which is consistent with the XRD analysis results. In addition, elemental mapping demonstrated a uniform distribution of the elements across the surface of the activated carbon materials, corresponding well with the FESEM observations. Electrochemical measurements revealed that the activated carbons derived from bamboo and redwood exhibited superior supercapacitor performance, providing specific capacitance values of 40.50 F g^{-1} and 50.50 F g^{-1} , respectively, which were higher than those obtained from litchi wood, tiger grass, and rain tree wood. The enhanced electrochemical properties were closely related to the favorable surface morphology, porosity, and specific surface area of the activated carbon materials, which contributed to improved charge–discharge behavior and energy storage capability.

Acknowledgement

This research project entitled “Fabrication of Electrodes Using Activated Carbon Extracted from Natural Materials for Application in High-Performance Supercapacitors for Electrical Energy Storage Systems” was financially supported by the Thailand Science Research and Innovation (TSRI). The research budget was allocated through the Science, Research and Innovation Promotion Fund for the fiscal year 2025, Rajabhat Maha Sarakham University. The authors would like to express their sincere gratitude to the Department of Physics, Faculty of Science and Technology, Rajabhat Maha Sarakham University, for providing research facilities and equipment that greatly contributed to the successful completion of this work. The authors also gratefully acknowledge the Department of Physics, Faculty of Science, Khon Kaen University, for their valuable consultation and support in providing charge–discharge testing instruments for this research.

References

- [1] C.-H. Yang, P.-L. Huang, X.-F. Luo, C.-H. Wang, C. Li, Y.-H. Wu, J.-K. Chang, Holey graphene nanosheets with surface functional groups as high-performance supercapacitors in ionic-liquid electrolyte, *ChemSusChem*. 8(10) (2015) 1779 – 1786.
- [2] J. Huang, P. Xu, D. Cao, X. Zhou, S. Yang, Y. Li, G. Wang, Asymmetric supercapacitors based on β -Ni(OH)₂ nanosheets and activated carbon with high energy density, *J. Power Sources*. 246 (2014) 371 – 376.
- [3] A. Balducci, C. Schütter, Carbon blacks as active materials for electrochemical double layer capacitors, *Bol. Grupo Español Carbón*. 37 (2015) 2 – 5.
- [4] A. Giessmann, *Coating Substrates and Textiles: A Practical Guide to Coating and Laminating Technologies*, first ed., Springer, Berlin, Heidelberg, 2012.
- [5] D. Wei, T.W. Ng, Application of novel room temperature ionic liquids in flexible supercapacitors, *Electrochem. Commun.* 11(10) (2009) 1996 – 1999.
- [6] Z. Hu, M.P. Srinivasan, Preparation of high-surface-area activated carbons from coconut shell, *Microporous Mesoporous Mater.* 27(1) (1999) 11 – 18.
- [7] K. Fic, G. Lota, E. Frackowiak, Electrochemical properties of supercapacitors operating in aqueous electrolyte with surfactants, *Electrochim. Acta*. 55(25) (2010) 7484 – 7488.
- [8] G.G. Stavropoulos, A.A. Zabaniotou, Production and characterization of activated carbons from olive-seed waste residue, *Microporous Mesoporous Mater.* 82(1–2) (2005) 79 – 85.
- [9] T. Yang, A.C. Lua, Characteristics of activated carbons prepared from pistachio-nut shells by potassium hydroxide activation, *Microporous Mesoporous Mater.* 63(1–3) (2003) 113 – 124.
- [10] J.-H. Kim, H.-M. Lee, S.-C. Jung, D.-C. Chung, B.-J. Kim, Bamboo-based mesoporous activated carbon for high-power-density electric double-layer capacitors, *Nanomaterials*. 11(10) (2021) 2750.
- [11] M.K. Sahoo, G.R. Rao, A high energy flexible symmetric supercapacitor fabricated using N-doped activated carbon derived from palm flowers, *Nanoscale Adv.* 3(18) (2021) 5417 – 5429.