Development of Microwave-Synthesized Peanut Shell–derived Porous Carbon as Sustainable Anode Materials for Sodium-ion Batteries

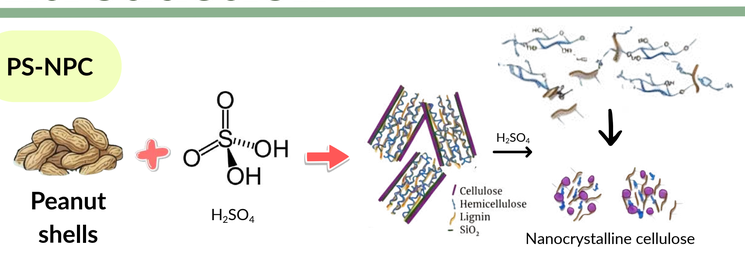
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Abstract

This research investigates the development of porous carbon derived from peanut shells via microwave-induced carbonization combined with potassium hydroxide (KOH) activation, utilizing agricultural waste as a sustainable anode material for sodium-ion batteries (SIBs). Biomass-to-KOH activation ratios ranging from 1:0 to 1:3 were systematically studied to evaluate their effects on structural evolution and physicochemical properties. X-ray diffraction (XRD) and Raman spectroscopy confirmed the transformation of crystalline biomass into a low-crystallinity disordered carbon structure, evidenced by the disappearance of sharp diffraction peaks and the presence of broad D and G bands, indicating abundant structural defects that provide active sites for sodium-ion storage. Scanning electron microscopy (SEM) revealed that higher KOH ratios promoted the formation of hierarchical porous structures. Brunauer–Emmett–Teller (BET) analysis showed that the 1:3 ratio produced the highest specific surface area of 798.17 $m^2 g^{-1}$. Electrochemical measurements demonstrated an initial discharge capacity of approximately 480 mAh g^{-1} and a reversible capacity of around 190–200 mAh g^{-1} after 50 cycles, with good rate capability and Coulombic efficiency approaching 100%. These results highlight that optimizing the KOH activation ratio combined with microwave carbonization is an effective strategy for producing porous carbon (PS-NPC) as a sustainable anode material for sodium-ion batteries.

Introduction

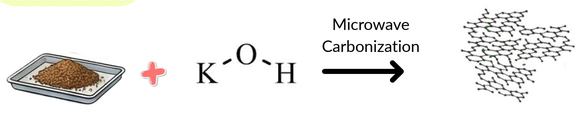
PS-NPC



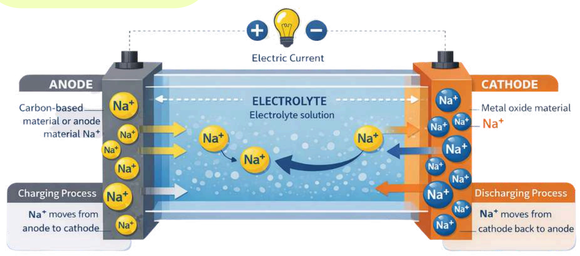
Advantages

- Abundant agricultural waste
- Low-cost and renewable resource
- Rich in lignocellulosic components suitable for carbon production

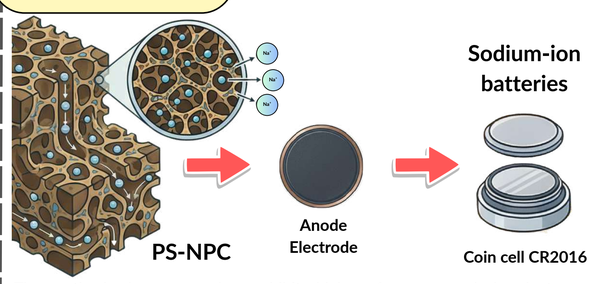
Microwave Carbonization Rapid and energy-efficient heating enables short synthesis time and uniform carbonization.



Sodium-ion batteries



This research



The synthesized porous carbon exhibits high surface area and abundant pore structures, providing numerous active sites for Na^+ storage. This enhances ion diffusion, resulting in improved capacity and cycling stability in sodium-ion batteries.

Objective

- To add value to peanut shells as agricultural waste by synthesizing porous carbon via microwave-assisted carbonization for use as an anode material in sodium-ion batteries.
- To investigate the structural characteristics of peanut shell-derived porous carbon and evaluate the effect of KOH activation ratios on battery performance.

Experiment

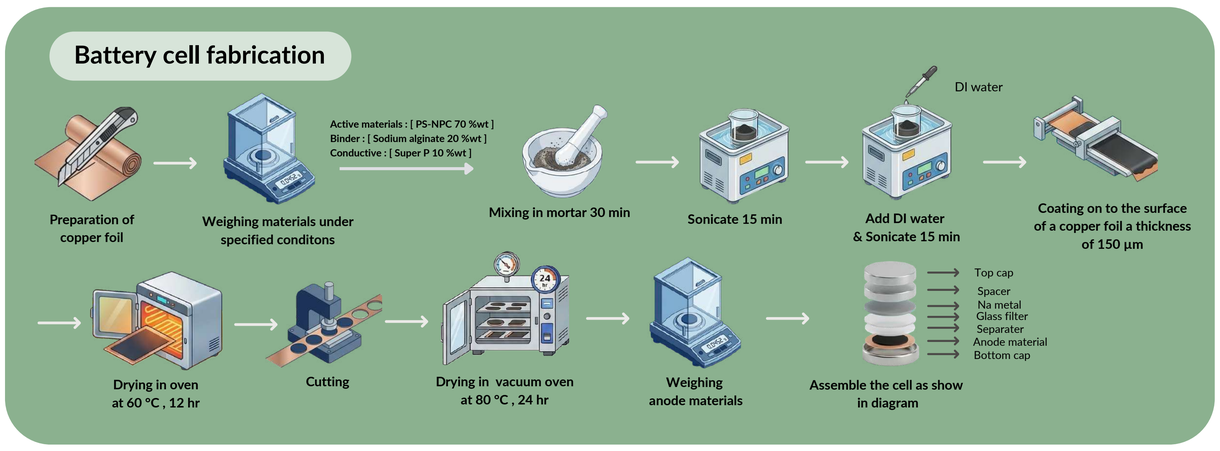
ATB Synthesis



PS-NPC Synthesis via microwave process



Battery cell fabrication



Conclusion

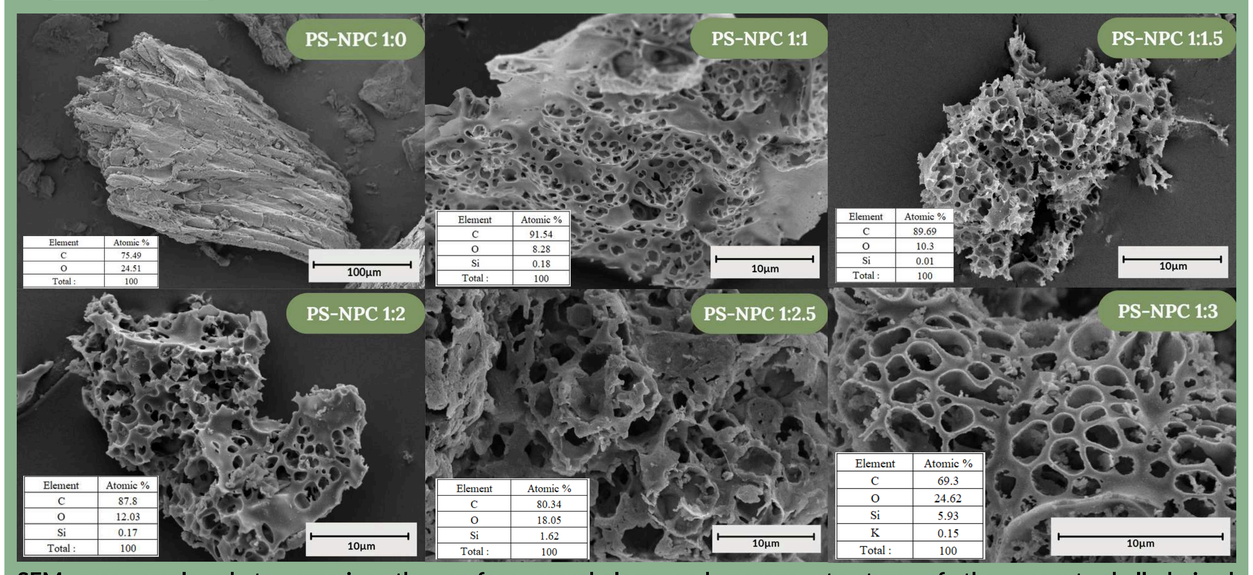
This research successfully developed porous carbon derived from peanut shells via microwave-induced carbonization combined with KOH activation as a sustainable anode for sodium-ion batteries. XRD and Raman confirmed the formation of low-crystallinity carbon with abundant defects. The 1:3 activation ratio achieved the highest surface area 798 $m^2 g^{-1}$. Electrochemical tests showed good reversible capacity, rate capability, and stable cycling with Coulombic efficiency approaching 100%, demonstrating promising potential as a sustainable anode material for sodium-ion batteries.

Acknowledge

The author gratefully acknowledges Lecturer Dr. Thanapat Autthawong, Assoc. Prof. Dr. Thapanee Sarakonsri, Ms. Orapim Namsar, and Ms. Patrapee Sarapan for their guidance and experimental support at the PTEM Laboratory, Advanced Battery Research Unit, Renewable Energy Laboratory. This work was financially supported by the Fundamental Fund FY2025 (FF68), Chiang Mai University, and the Murata Science Foundation Research Grant 2025.

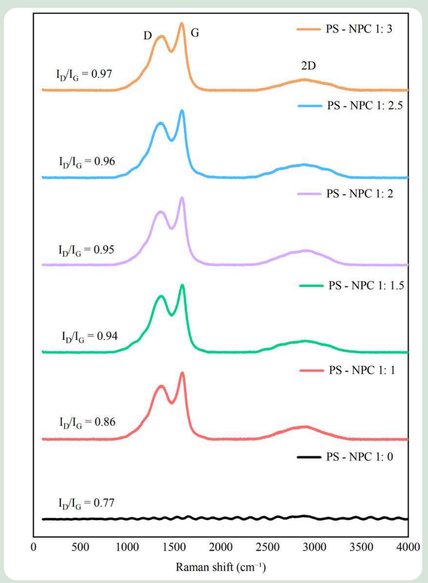
Results & Discussion

SEM & EDS

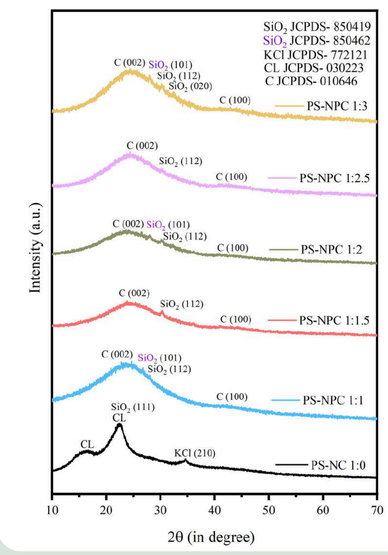


SEM was employed to examine the surface morphology and porous structure of the peanut shell–derived nitrogen/phosphorus-doped porous carbon (PS-NPC) materials. EDS analysis further confirmed the elemental composition and verified the successful carbonization and heteroatom incorporation within the carbon framework.

XRD

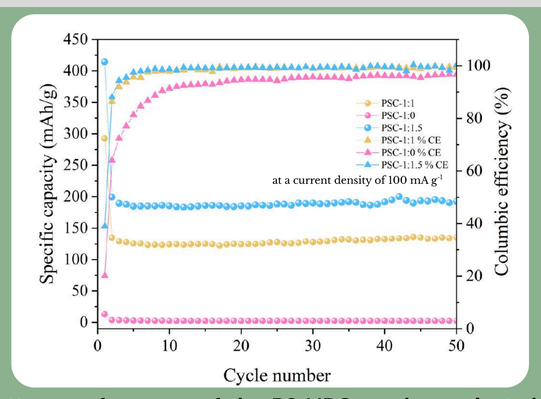


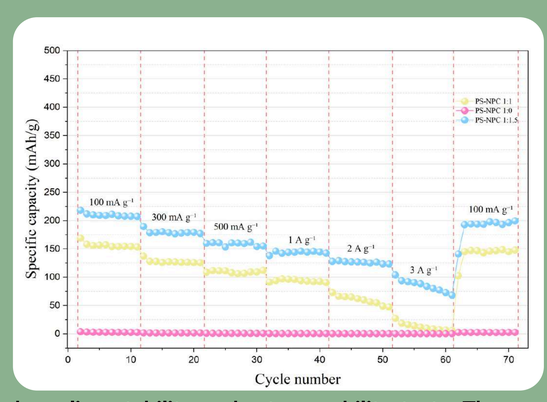
RAMAN



XRD patterns exhibit broad diffraction peaks, indicating the formation of low-crystallinity carbon after carbonization. Raman spectroscopy shows characteristic D and G bands, suggesting partially graphitized carbon with abundant structural defects, which are beneficial for enhancing Na^+ storage performance.

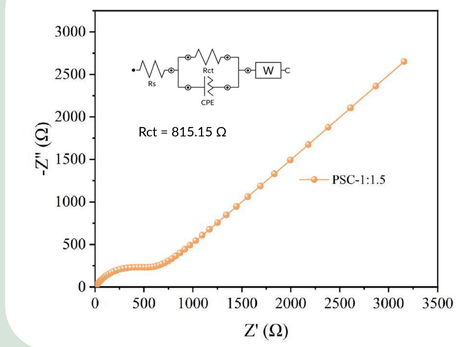
Battery testing: cycle stability & rate capability



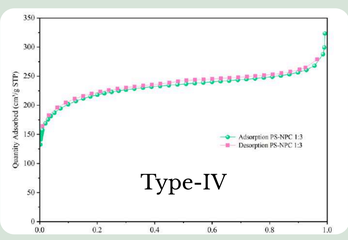


Battery performance of the PS-NPC anodes evaluated through cycling stability and rate capability tests. The results demonstrate stable cycling behavior and good capacity retention, with the PS-NPC sample at a precursor ratio of 1:1.5 exhibiting the best overall electrochemical performance.

EIS



BET



Sample	Specific Surface area (m^2/g), BET Theory	BET C-constant	Total Pore Volume, V_{tot} (cm^3/g)	Average Pore Diameter, (nm)
1 : 0	0.91	76.97	0.0058	25.4959
1 : 1	445.83	243.03	0.5341	4.79
1 : 1.5	444.73	1175.03	0.2416	2.17
1 : 2	619.46	647.41	0.3733	2.41
1 : 2.5	661.38	1858.31	0.3780	2.29
1 : 3	798.18	668.82	0.5014	2.51

EIS results indicate low charge-transfer resistance and efficient Na^+ transport. BET analysis shows that the 1:3 sample possesses the highest surface area (798.18 $m^2 g^{-1}$) with mesoporous characteristics, enhancing electrolyte accessibility.

Reference : Agarkar, S., Yadav, P., Fernandes, R., Kothari, D., Suryawanshi, A., & Ogale, S. Minute-made activated porous carbon from agro-waste for Li-ion battery anode using a low power microwave oven. Electrochimica Acta 2016, 07, 011