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Research article

Banana-peel derived activated carbon for microwave absorption at X-band frequency

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ABSTRACT

The rapid advancement in information technology, communication, and electronic devices elevates the need to develop suitable materials for microwave absorption (MA) which should have the properties of an ideal microwave absorber. Porous activated carbon from agricultural wastes has piqued the interest of MA researchers due to their distinct properties such as good specific surface area, high dielectric loss, good electrical conductivity, and low density. Herein banana peel activated carbon was prepared by activating banana peel precursor with KOH and carbonizing at different temperatures. The difference in the porous structure with varying carbonization temperature was visible in the FESEM image, validated by BET analysis. The Banana Peel Activated carbon samples exhibited good microwave absorption performance, with BP-AC700 displaying a minimum Reflection Loss (RL) of -40.62 dB at 10.72 GHz & 3.0 mm thickness. In addition, the obtained effective absorption bandwidth of 3.5 GHz spanned through the X band frequency. This exceptional microwave absorption was attained due to the sample's good conductive loss and Porous favourable morphology. This study inspires the development of future facile functional agricultural waste-derived microwave absorbers.

KEYWORDS

Microwave absorbing materials (MAMs)
Banana peel-activated carbon (BP-AC)
Reflection loss (RL)
Porous material
Microwave absorption mechanism

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Nomenclature

Symbols		Symbols	
AC	Activated carbon	EMI	Electromagnetic Interference
BET	Brunauer–Emmett–Teller	GHz	Giga hertz
BP-AC	Banana peel activated carbon	M	Molarity
dB	Decibel	MA	Microwave absorber
FESEM	Field-emission scanning electron microscopy	MAM	Microwave absorbing materials
EAB	Effective absorption bandwidth	RL	Reflection loss
EM	Electromagnetics	SAP	Surface area and pore size

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1. Introduction

Electronic communication equipment has become part of our daily lives with the ongoing growth of current information technology. Nevertheless, the negative impact of electromagnetic (EM) radiation and interference, among others, must be addressed quickly [1–3]. To counteract these deleterious EMI problems, an ideal microwave MAM always favoured strong absorption ability, thin thickness, Lightweight, and broad effective absorption bandwidth (EAB). MAMs are characterized based on their loss mechanism (as a dielectric or magnetic material) and intrinsic EM properties, such as complex permittivity and permeability [4, 5]. MAMs are classified as dielectric or magnetic properties depending on their intrinsic electromagnetic characteristics, such as complex permittivity and permeability [6, 7]. Many conventional efforts have been geared toward fabricating a high-performance MAM. Conventional MAMs consume Electromagnetic energy by converting the EM energy to thermal energy or other forms of energy. Carbon material extracted from agricultural wastes has emerged as a typical absorbing material among alternatives owing to its benefits of repeatability, environmental friendliness, and abundance in nature [8, 9]. In addition, carbon formed from biomass is light in weight, possesses a conductive structure, and can be easily prepared, making it suitable to manufacture electromagnetic and electrical devices [10]. Kumar et al. synthesized a PC from mango leaves with a minimum RL of -23.65 dB @ 17.68 GHz and a thickness of 1.5 mm [11]. In another study, Wang et al. developed a nanoporous carbon from a walnut shell. At 70% filler loading, the absorber reached a minimum RL of -42.4 dB with an EAB of 7.2 GHz at 2.5 mm thickness [12]. Herein banana peel activated carbon was prepared via chemical activation and carbonization process. The EM properties of the fabricated sample were studied at X-band Frequency. This study revealed that BP-AC carbonized at 700 °C displayed good absorption performance with an RL peak of -40.62 dB at 10.72 GHz with an absorber thickness of 3.0 mm and EAB of 2.5 GHz. This study provides an alternate economical and sustainable way of fabricating microwave absorbers.

2. Experimental

2.1. Materials and reagent

The raw material (banana peels) was collected from a local market at Seri Iskandar Perak Malaysia. Potassium hydroxide (KOH) and 0.1 molarity hydrochloric acid (HCl) were purchased from R&M chemicals Malaysia. All the chemical reagents used were analytical grade. Equipment used includes an electrical grinding machine, a high-temperature tube furnace, a hotplate magnetic stirrer, pH probe, and drying oven.

2.2. Preparation of banana peel-activated carbon (BP-AC)

Fig. 1 illustrates the sample preparation process before impregnation with a chemical activating agent. First, the collected banana peels were cleaned with deionized water to remove impurities and placed in an oven at 80 °C to dry completely. Next, the banana peels were crushed to a fine powder after drying using an electric grinding machine. Then, 20 g of powdered sample was impregnated in KOH at a 1:1 ratio and agitated at room temperature for 6 hours. Prior to the carbonization process, the slurry was oven-dried overnight. After drying, the samples were placed in a crucible boat and heated for 1 hour in a tube furnace at 500, 600, and 700 °C in an inert environment. Following that, the resulting AC was rinsed multiple times with 0.1 M HCL and deionized water until the pH was neutral. The samples were oven-dried and labelled as BP-AC500, BP-AC600, and BP-AC700 [13].

2.3. Characterization

X-ray diffraction (Malvern Panalytical, Malvern, UK) with a Cu Kα radiation source was used to study the phase crystallinity. Raman Spectroscopy (Horiba Jobin Yvon HR) was used to analyze the type of carbon present in the sample. The field-emission scanning electron microscopy (Carl Zeiss AG, Germany) at 5–10 kV was used to depict the sample's morphology. The samples were loaded in 20 wt% of paraffin wax and moulded into a rectangular form (10.16 mm × 22.86 mm) for EM properties measurement at X-band frequency. The complex permeability (μ_r) and permittivity (ε_r) which are the electromagnetic parameters, were measured using a vector network Analyzer (Key site E5071C). The frequency dependence of the reflection loss (RL) of the samples can be evaluated using the following equations according to the complex permittivity ($\varepsilon_r = \varepsilon' - j\varepsilon''$) and permeability ($\mu_r = \mu' - j\mu''$) of the sample.

$$Z_{in} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi fd}{c}\sqrt{\varepsilon_r\mu_r}\right) \quad (1)$$

$$RL = 20\log_{10}|\Gamma| \quad (2)$$

Z_{in} is the sample's intrinsic impedance, Z_0 is the intrinsic impedance of air, c is the velocity of light in air, d is the material's thickness, and f is the frequency of the incident EM wave [6].

3. Results and discussion

3.1. XRD and RAMAN analysis

The X-ray diffraction pattern of the synthesized BP-AC is shown in

Fig. 1. Banana peel sample preparation for chemical activation.

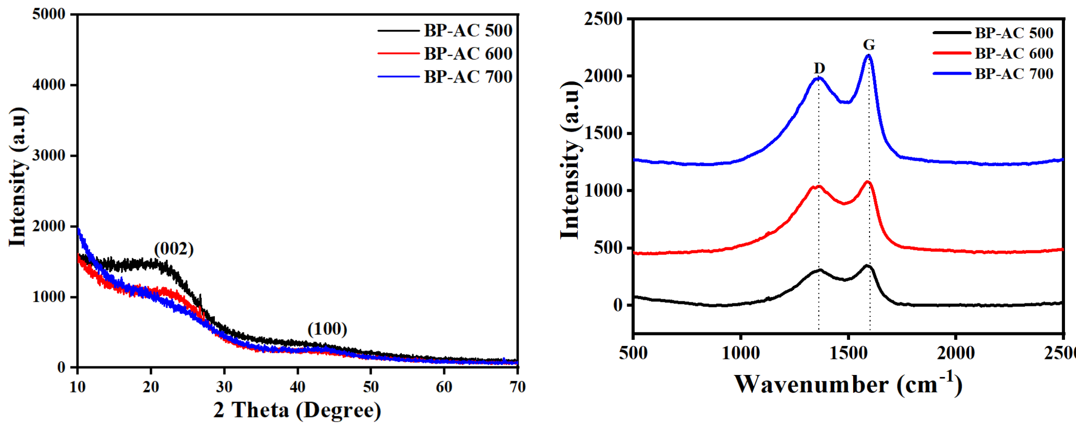

Fig. 2. XRD and RAMAN spectra of BP-AC samples.

Fig. 2a. The broad peak observed at 23 ° corresponds to the plane (002), whereas the weak peak at 43.2 ° relates to the plane (100). Thus, both planes demonstrate the existence of graphitic carbon [13, 14]. The Raman spectra of the BP-AC obtained from the banana peel are displayed in Fig. 2b. Two evident peaks were observed at about 1364.5 cm^{-1} and 1594.2 cm^{-1} which are ascribed to the D-band of distorted sp^3 hybridized carbon and the G-band of the sp^2 hybridized carbon [15, 16]. ID/IG estimates the degree of graphitization to determine the defect ratio of carbon. From the Raman spectra, it can be concluded that the degree of graphitization of the BP-AC samples increases with increasing carbonization temperature. Therefore, a higher graphitization degree indicates that the BP-AC samples contain more defects which is beneficial for a rapid attenuation of EM waves.

3.2. Surface area and pore size distribution

The surface area and pore size distribution of the BP-AC samples were analyzed to study the porous structure of the BP-AC samples. The summary of the measured specific surface area, pore size, and pore volume is given in Table 1.

The prepared BP-AC700 showed a relatively high surface area compared to BP-AC600 and BP-AC500. Also, the pore diameter of both BP-AC600 and BP-AC700 is relatively higher than that of BP-AC500. The SAP result shows that the BP-AC samples contain micropores and mesopores with a good surface area, making them a good candidate for composite formation for enhanced absorption of EM waves. The numerous pores can enhance the multireflection and dissipation of EM waves [17, 18].

3.3. Surface morphology

The FESEM image of the BP-AC samples presented in Fig. 3 gives information on the sample's microstructure. The porous cavities on the surface of the BP-AC samples are due to the interaction of the activating agent (KOH) with the precursor (banana peel) after the carbonization process. Besides, the activation of banana peel samples with KOH plays a key role in improving the architectural porosity of the BP-AC samples. The surface morphology of BP-AC500, as observed in Figs. 3a & 3b, reveals the presence of a poorly developed pore network with broken carbon walls. On the other hand, BP-AC600 and BP-AC700 reveal the presence of numerous uniform pores forming a net-like structure, as observed in Fig. 3c–f. The well-developed pores

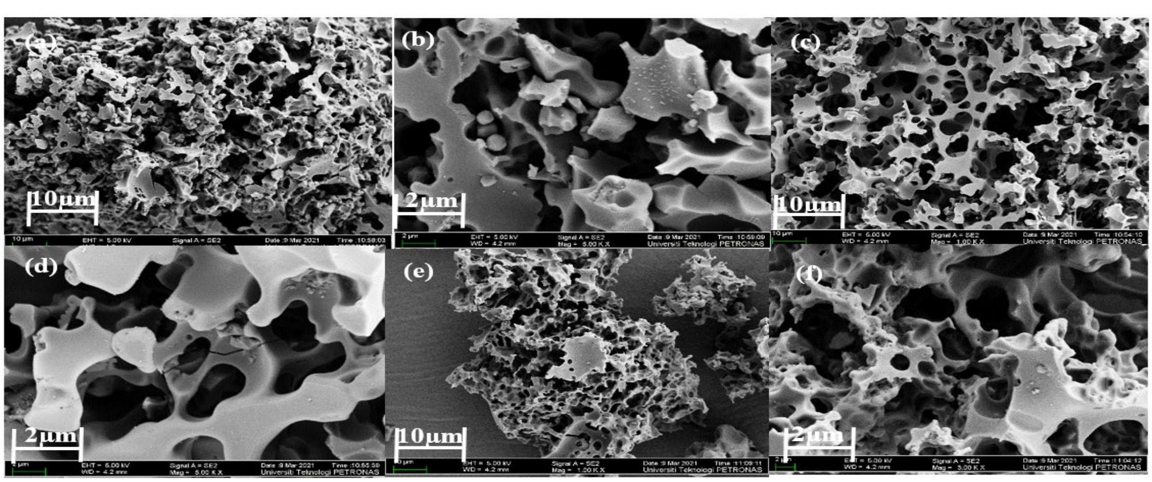

Fig. 3. Surface morphology of chemically activated carbon derived from the banana peel a, b) BP-AC500, c, d) BP-AC600, and e, f) BP-AC700.

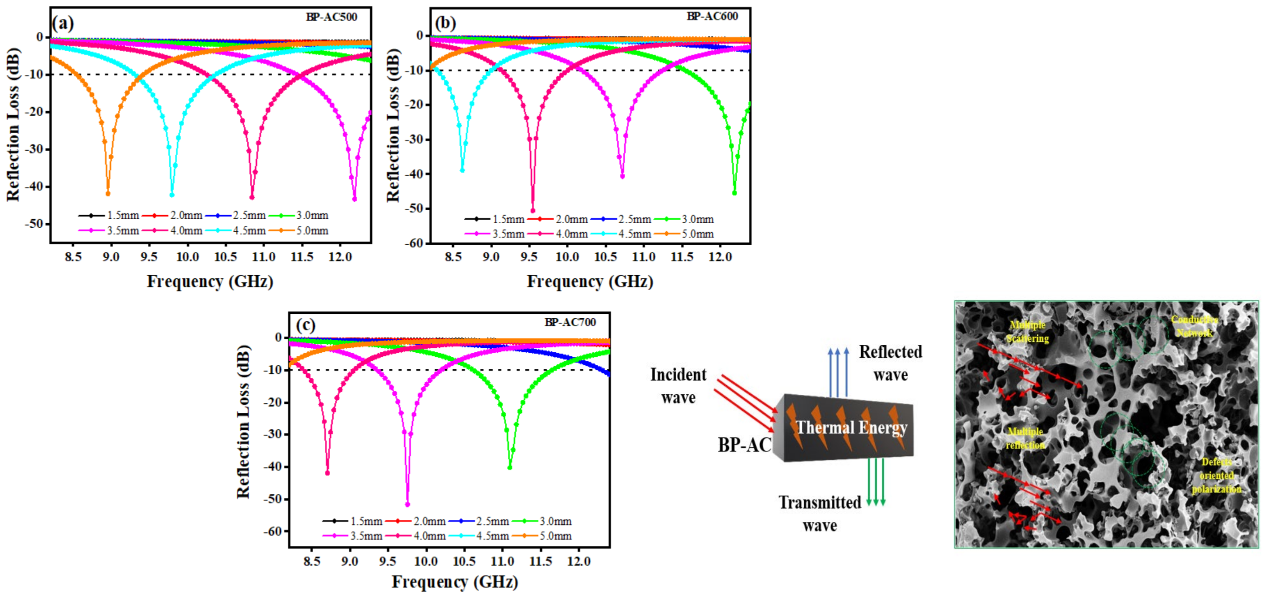

Fig. 4. Reflection loss curves of a) BP-AC500, b) BP-AC600, and c) BP-AC700 samples.

can be ascribed to the etching of the BP-AC samples with KOH and carbonization at relatively high temperatures. This suggests that when the temperature is raised, the porosity of the sample also increases. Furthermore, the Copious pores in the BP-AC600 and BP-AC700 samples are beneficial for the multi-reflection and scattering of EM waves inside the BP-AC samples, resulting in Enhanced EM absorption [19].

3.4. Electromagnetic wave absorption performance

Complex permittivity ($\varepsilon_r = \varepsilon' - j\varepsilon''$) and complex permeability ($\mu_r = \mu' - j\mu''$) are the two essential parameters that characterize the electromagnetic absorption properties of absorbing material. The energy storage of the sample is determined by the real part (ε' and μ'), and the EM wave energy dissipation ability is estimated by the imaginary parts (ε'' and μ''). As presented in Fig. 4, all samples displayed good EM absorption performance. In Fig. 4a, it was observed that BP-AC500 showed good absorption performance with a minimum RL value of -42.88 dB at 10.84 GHz at an absorber thickness of 3.5 mm. Fig. 4b showed that the absorption performance of BP-AC600 was more improved compared to BP-AC500 with a minimum RL of -45.49 dB at an absorption frequency of 12.19 GHz and an absorber thickness of 3.0 mm. For BP-AC700 (Fig. 4c), an effective absorption performance was achieved at a minimum RL of -40.62 dB at 10.72 GHz at an absorber thickness of 3.0 mm. This study suggests that BP-AC can be used for the absorption of the EM wave at 8.2–12.4 GHz due to its structural component, which is beneficial for multiple scattering, multiple reflection, and conductive networks [20].

Table 1. Surface area and pore size distribution of BP-AC sample.

Samples	Surface area $_{BET}$ (m^2/g)	Total pore volume (cm^3/g)	Pore diameter (nm)	
			Mesopore	Micropore
BP-AC500	263.006	0.0783	3.9	-
BP-AC600	479.337	0.2395	6.3	1.99
BP-AC700	648.1879	0.3329	6.5	1.96

4. Conclusions

Banana peel-activated carbon was prepared via chemical activation and carbonization at different temperatures in this study. The BP-AC at 700 showed good morphology and a large surface area with numerous pores. The good morphology and conductive effect of the BP-AC700 composites favour its excellent EM wave absorption performance with a minimum RL value of -40.62 dB at 10.72 GHz at an absorber thickness of 3.0 mm. This study suggests that agricultural wastes are promising materials for developing novel lightweight MAMs. The fabricated absorber would possess the ability to attenuate undesired electromagnetic radiation to our surroundings. The fabricated absorber could be used in EMI suppressor, chokes, and other engineering applications to solve the problem of device malfunction due to misinterpretation of transferred data or information loss. Banana peel-activated carbon can also be combined with ferromagnetic nanoparticles or other low density materials to enhance their EM absorption performance.

CRediT authorship contribution statement

Hojjatollah Soleimani: Investigation, Writing – original draft.
Jemilat Yetunde Yusuf: Resources, Writing – original draft.
Hassan Soleimani: Funding acquisition, Supervision, Writing – review & editing.
Lee Kean Chuan: Investigation, Methodology.
Maziyar Sabet: Visualization, Writing – review & editing.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

Declaration of competing interest

The authors declare that they have no know competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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