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Research Article

Keywords: Macrotermes nigeriensis, Termite Biomass, Waste Valorization, Activated Carbon, Supercapacitor Electrode, Electrochemical Energy Storage

Posted Date: July 20th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-676433/v1>

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Version of Record: A version of this preprint was published at Waste and Biomass Valorization on January 13th, 2022. See the published version at <https://doi.org/10.1007/s12649-022-01680-6>.

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1. INTRODUCTION

Despite the food, feed and medicinal potentials of termites [1-12], different studies have reported that termites have devastating effects on woody materials [13], contribute to the rising levels of atmospheric CO₂ and CH₄ [14] and constitute some health risks (such as allergies, microbial contamination, parasitic and chemical hazards) when consumed as food [15-19]. In order to promote the non-food potentials of termites and also stall the contribution of termite activities to the rising levels of CO₂ and CH₄ in the atmosphere, Brune [20] showed that the enzymatic systems of some species of termites hold great potentials for biotechnological applications for the production of new enzymes. Similarly, Koenig et al. [21], Rumpold et al. [22] and Kalu-Uka et al. [23] reported that termites represent a promising alternative for the industrial conversion of lignocellulose and lignin to biofuels, as much as they can be used to synthesize low viscous biodiesel. To further investigate the non-food potentials of termites, the present work studies the potential for the production of termite-based activated carbon electrode for energy storage application in supercapacitors.

Energy storage in supercapacitors, unlike in rechargeable batteries and fuel cells, is attracting increasing attention because of their relatively high cycling stability, high power density and fast charging–discharging capacity [24-26]. However, the application of supercapacitors in electric vehicles and other digital electronic devices has been limited by the low energy density associated with the mechanisms (electric double layer capacitance and the pseudocapacitance) of energy storage in supercapacitors [27-31]. As a result, some research efforts have been made to improve the energy density of supercapacitors by either identifying new electrode materials with improved electrochemical properties or re-engineering the structural properties of existing electrode materials such as carbon nanomaterials, conducting polymers, transition metal oxides and waste biomass [28,32-44].

Although the use of waste biomass (such as animal products, plants and algae) for the production of supercapacitor electrodes has been widely reported, results in the literature have

also shown that the performance of biomass-derived supercapacitor electrodes do not depend only on the unique microstructure of the biomass precursors [26,30,32,34,45,46]. The presence of heteroatoms on the electrode surface [45], type and concentration of the electrolyte [47,48], dispersity of ion electrosorption at the electrolyte-electrode interface, and the methods of electrochemical testing, biomass carbonization and char activation have also been reported to greatly influence the performance of supercapacitor electrodes [49,50]. The attraction for the use of biomass in the production of carbon electrodes is due to their availability, natural porosity and ease of activation. Biomass can be physically activated in the presence of an oxidizing/gasifying atmosphere at high temperature, or chemically activated using corrosive chemicals (such as KOH, ZnCl₂ and H₃PO₄) as activating agents [35]. KOH activation of biomass occurs when the KOH-biomass mixture is heated to temperatures above the melting point of KOH (360 °C). Above this temperature, the volatile materials in the biomass are vaporized while the molten KOH reacts with the carbon in the biomass to form metallic K, H₂, and K₂CO₃. However, further heating of the mixture might result in the breakdown of the K₂CO₃ into K₂O, CO₂ and CO. By the end of the activation process, nearly all the H₂, CO₂ and CO will be released, leaving behind a highly porous carbon material [51].

One of the contributions of this work is the novelty of the biomass precursor, which was obtained from the waste generated during the production of biodiesel from termite biomass [23]. The termite biomass used in this study belongs to the species of *Macrotermes nigeriensis*. This species of termites is seasonally available in Nigeria (from March to July), and its estimated annual availability in Nigeria is 3.2×10^{11} kg [23]. To the best of the authors' knowledge, there was no single report on the potential of termite biomass for electrochemical energy storage at the time when this work was carried out. Also, the comparison of electrochemical performance of a supercapacitor electrode in two equimolar electrolytes is not

the common practice in existing literature (much less when the concentration of the electrolytes is as low as one mole). This was done in order to avoid the misgivings associated with the current practice, to reduce the risk of corrosion on the current collector due to the use of electrolytes of higher molar concentrations [48], and to promote the use of lower concentrations of environmentally toxic materials in the design of supercapacitors.

M. nigeriensis activated carbon (MAC) was prepared by chemical activation method, using KOH powder as the activating agent. Different samples of the KOH-biomass mixture were activated under varying conditions of temperature, time and mixture ratio in order to optimize the specific surface area (SSA) and pore structure of MAC. The surface morphology, structure and functionalization of the optimal MAC were characterized with scanning electron microscope (SEM), transmission electron microscope (TEM), X-ray diffractometer (XRD), Raman spectroscopy and X-ray photoelectron spectrometer (XPS). The supercapacitor performance of MAC electrode (MAC-E) was later examined in 1 M H₂SO₄ and 1 M EMImBF₄ electrolytes. The results showed that specific capacitance of *M. nigeriensis* activated carbon electrode in 1 M H₂SO₄ ranges from 26 Fg⁻¹ (at 5 Ag⁻¹) to 76 Fg⁻¹ at (0.5 Ag⁻¹). In 1 M EMImBF₄, the specific capacitance was 17 Fg⁻¹ (at 5 Ag⁻¹) and 53 Fg⁻¹ at (0.5 Ag⁻¹). However, at 10 Ag⁻¹ and 10,000 charge-discharge cycles, the activated carbon electrode lost ~ 5% of its specific capacitance in 1 M H₂SO₄ and ~ 2% of its capacitance in 1 M EMImBF₄.

2. MATERIALS AND METHODS

2.1. Production, Optimization and Structural Properties of MAC

Analytical-grade quantities of KOH, H₂SO₄, EMImBF₄, PANI, PEDOT, PVD-HFP were purchased from Merck, India. Waste termite biomass was obtained during the production of biodiesel from *M. nigeriensis* [23]. Before commencing the production of activated carbon

from waste *M. nigeriensis* biomass, thermal decomposition behavior of the waste biomass was analyzed in a TG-MS system (Setsys, Setaram) to monitor the effect of temperature (25 – 1000 °C) on the decomposition process, and also identify the gases which evolved in the process. Afterwards, a sample of the termite biomass was dried in an oven at 110 °C for 12 h, milled into fine particles and mixed with KOH powder, using a KOH-biomass ratio of 2:1. The mixture was activated in a tubular furnace at 500 °C for 5 h, in the presence of N₂ gas. The activated carbon which resulted from the heating process was washed with dilute 10% HCl, and repeatedly rinsed in warm water until the filtrate reached a pH value of 7 [28]. The filtrate was later dried in an oven at 120 °C for 2 h, stored in a dry glass vial, and labelled MAC500-5h-2r. The highlights of the above production process are shown in Fig. 1.

Fig. 1 Schematic illustration of the production of activated carbon electrode from termites (*M. nigeriensis*), showing the biomass precursor as the waste generated during the production of termite biodiesel

The specific surface area (SSA) and pore structure of MAC was later optimized by repeating the above procedure using different activation temperatures, activation times, and biomass-KOH mixture ratios to produce MAC700-5h-2r, MAC900-5h-2r, MAC900-7h-2r, MAC900-9h-2r, and MAC900-9h-3r and MAC900-9h-4r. The optimal MAC sample was determined from results of the N₂ adsorption-desorption experiments which were performed on a BET analyzer (Micromeritics ASAP 2020 V4.02 - V4.02 H). Before performing the BET analysis, the MAC samples were degassed at 200 °C for 12 h in order to reduce the residual pressure to values less than 1.0×10^{-3} mbar [33] and to eliminate all the surface gaseous contaminants [52]. The SSA and pore size distribution (PSD) of the MAC samples were respectively determined using the Brunauer-Emmett-Teller (BET) and the Barrett-Joyner-Halenda (BJH) methods. The total combined volume of the mesopores and macropores, V_{mm}

was calculated by subtracting the amount of N₂ gas adsorbed at a relative pressure of 0.1 from the amount of N₂ gas adsorbed at a relative pressure of 0.95 [53]. The specific surface area of the micropores, S_{micro} was calculated from the t-plot by solving Eqn. 1 [33].

Details of the surface morphology, nanostructure and functionalization of the optimal MAC sample were later analyzed using scanning electron microscope (SEM-JOEL-JSM-7600F), transmission electron microscope (TEM-JEM-2100F), X-ray diffractometer (Rigaku D-Max-III C X-ray, Tokyo), Raman spectroscopy (RFT-6000 FT-RAMAN-JA) and X-ray photoelectron spectrometer (ESCA 220i – Thermo Fisher Scientific, Inc USA).

$$S_{micro} = S_{BET} - 15.47s \quad (1)$$

where S_{BET} is the BET surface area, and s is the slope of the t-plot

2.2. Preparation and Electrochemical Performance of MAC-E

M. nigeriensis activated carbon electrode (MAC-E) was prepared by mixing a sample of the optimal MAC with acetylene black and binder (PVdF-HFP) in a mass ratio of 85:10:5 [28]. The mixture was coated on a 16mm x 16mm diameter nickel foil, and dried in an oven at 105 °C for 12 h to remove the organic solvent. Afterwards, the electrochemical performance of MAC-E was tested in an electrochemical workstation (Autolab Potentiostat/Galvanostat Model-PGSTAT 302), using MAC-E, Ag/AgCl and platinum wire as the working, reference and counter electrodes respectively. The cyclic voltammetry (CV) patterns, galvanostatic charge-discharge (GCD) profiles and electrochemical impedance spectra (EIS) of MAC-E were analyzed in 1 M H₂SO₄ and 1 M EMImBF₄ electrolytes. The CV patterns of MAC-E at different scan rates between 50 mVs⁻¹ and 5000 mVs⁻¹ were obtained within voltage windows of 1.0 V (for 1 M H₂SO₄ aqueous electrolyte) and 4.0 V (for 1 M EMImBF₄ ionic electrolyte) [47]. The GCD profiles were generated at different current densities between 1 and 10 Ag⁻¹,

while the EIS readings were plotted for the frequency range from 0.01 Hz to 100 kHz. The specific capacitance, $C_{sp} (Fg^{-1})$, of MAC-E was calculated from the GCD experiments, based on Eqn. 2.

$$C_{sp, mass} = \frac{it_d}{mV} [Fg^{-1}] \quad (2)$$

where $i(A)$ is the applied discharge current, $m(g)$ is the active mass of the working electrode, $V(V)$ is the voltage difference during the discharging process, and $t_d(s)$ is the discharge time.

3. RESULTS AND DISCUSSION

3.1. Thermal Behaviour of Waste *M. nigeriensis* Biomass

Thermal decomposition behavior of waste *M. nigeriensis* biomass was examined using a TG-MS system. The TG curve in Fig. 2 showed that ~ 85% of the total mass of the biomass was lost via a three-stage decomposition process. It was observed that 3% of the total mass was lost in the first stage due to desorption of residual water molecules along with some oxygen functional groups (150 – 200 °C), while 62% of the mass was lost in the second stage due to the release of volatile gases such as CO, CO₂ and CH₄ (250 – 450 °C). The final stage of the decomposition process showed that 20% of the biomass was converted to ash (700 – 750 °C). The DSC curve in Fig. 1 also showed that the formation of ash at 700 – 750 °C was accompanied by a relatively high release of energy which was later utilized in refining the microstructures of the char and the fixed carbon. The hump which appeared over the temperature range of 200 – 500 °C showed that release of volatile materials such as CO, CO₂ and CH₄ was preceded by an exothermic reaction. Based on the report that all biomass-derived carbon with ~15% volatile matter was good enough for the production of activated carbon [29],

the optimal temperature range for the production of MAC was considered to be 700 – 900 °C. This range of temperature is also very typical of most biomass activated carbons [28,35,40,42].

Fig. 2 Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC)

curves of *M. nigeriensis* Biomass

3.2. N₂ Adsorption-Desorption Isotherm

N₂ adsorption-desorption experiments were performed to identify the MAC sample which had the optimal SSA and PSD. The results shown in Figs. 3a and 3-S(a) suggested that all the MAC samples possessed reversible type-IV isotherm which confirmed the presence of mesopores [54-57]. The hysteresis loop observed in all the samples was attributed to the capillary condensation taking place in the mesopores [58]. Figs. 3b and 3-S(b) showed that MAC has a non-uniform PSD distribution, with the majority of the pores located within the range of micropores and mesopores. Details of the SSA and pore structure of all the MAC samples are shown in Table 1. Prior to KOH-activation, the SSA and average pore diameter of the waste *M. nigeriensis* biomass were recorded as 0.306 m²g⁻¹ and 9.736 nm, respectively. However, when the biomass was activated over 5 h and the KOH-biomass ratio was 2:1, the SSA of MAC increased from 670.68 m²g⁻¹ (at 500 °C) to 1064.28 m²g⁻¹ (at 900 °C). The low SSA observed at 500 °C suggested that some of the pores in MAC500-5h-2r were occupied by materials whose vaporization temperatures were above 500 °C. The maximum activation temperature was not allowed to exceed 900 °C in order to prevent the occurrence of excessive activation reactions that might affect the development of internal pores [59-60]. The table also showed that, at 900 °C and KOH-biomass ratio of 2:1, the variations in activation time had little effect on the SSA of MAC. However, when the activation temperature and time were kept at 900 °C and 9 h, the SSA of MAC increased from 1067.66 m²g⁻¹ (at 2:1 KOH-biomass ratio) to 1465.56 m²g⁻¹ (at 3:1 KOH-biomass ratio), and later decreased to 1440.65 m²g⁻¹ (at 4:1

KOH-biomass ratio). The lower SSA observed for MAC900-9h-2r was therefore attributed to the fact that the concentration of KOH in the mixture was not sufficient to promote the formation of the skeletal pore structure of carbon [61]. Also, the decrease in the SSA of MAC900-9h-4r suggested that some of the excess KOH in the mixture may have formed crosslinks which resulted in the production of more volatile matter [62]. Based on these observations, the optimal MAC was identified as MAC900-9h-3r. The relatively high SSA and non-uniform PSD of MAC900-9h-3r was indeed necessary to provide the critical adsorption sites and the short transmission path required in supercapacitor electrodes [40,63-65].

Table 1 BET surface area and pore size distribution of the prepared MAC samples

Fig. 3 (a) Nitrogen adsorption-desorption isotherms and **(b)** pore size distribution of samples of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

Fig. 3-S (a) Nitrogen adsorption-desorption isotherms and **(b)** pore size distribution of samples of KOH-activated carbon derived from *M. nigeriensis* biomass at different carbonization temperatures, activation times and KOH-biomass ratios

3.3. Morphology and Structural Order

3.3.1. SEM and TEM Images

Details of the surface morphology and nanostructure of MAC900-9h-3r were observed from SEM and TEM analyses, and the results are shown in Figs. 4(a and b). The SEM image in Fig. 4a showed that the surface of the activated carbon was composed of a relatively ordered network of honeycomb-like tunnels. The TEM image in Fig. 4b however showed that the honeycomb-like tunnel structure of MAC900-9h-3r had fully developed micropores [29].

Fig. 4 (a) SEM and **(b)** TEM images of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

3.3.2. XRD and Raman Spectroscopy

The XRD image of MAC900-9h-3r is shown in Fig. 5a. The XRD image showed two broad peaks at $2\theta = 28.5^\circ$ and 41.2° which corresponded to the (002) and (100) planes of a carbon structure [28,66]. The broadness and asymmetric nature of the (002) peak was attributed to the low scattering angle due to the presence of γ -band associated with the amorphous structure and/or irregularity in the packing of the aromatic structure [67]. The shift in the 2θ angle of the (002) plane from the $2\theta (= 26.6^\circ)$ angle for the (002) plane of graphite was due to the amorphous nature and low degree of graphitization of the activated carbon [68]. The (100) peak, however, was attributed to the two-dimensional reflection of X-ray from carbon layers, and the aromatic part of the carbon structure [69]. The increase in intensity of X-ray diffraction across the lower angles further suggested that the activated carbon is amorphous, and sufficiently porous [70,71].

Fig. 5 (a) XRD and **(b)** Raman Spectra of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

Further details of the structural order of the activated carbon were obtained from Raman spectroscopy. The Raman spectra in Fig. 5b was analyzed within the wavenumber scope of 100 – 2000 cm^{-1} . The two peaks observed at 1340 cm^{-1} and 1588 cm^{-1} were respectively typical of the D band and the G-band that are found in the Raman spectra of every carbon material [28]. The broad G-band signified the stretching of the C=C sp^2 bonds in graphitic materials [28], while the D-band indicated the disorder in the graphite lattice due to the breathing mode of

hexagonal rings [33,72]. The amorphous nature of MAC900-9h-3r was confirmed by the fact that the I_V/I_G ratio is less than that of graphite [33,69] and $0.5 < I_D/I_G < 1$ [73].

3.4. Composition and Surface Functionalization

The composition and surface functionalization of MAC900-9h-3r were analyzed by XPS experiments, and the results showed that the surface composition was 82.95% C, 15.75% O, and 1.30% S. To further understand the functional nature of the carbon and oxygen atoms, the XPS survey was deconvoluted around the C 1s and O 1s spectra as shown in Figs. 6(a and b). Figure 6a showed that the major component of the C 1s spectra was observed at 284.24 eV. This represented the sp^2 C=C band for graphitic materials [69,74,75]. The peak at 286.01 eV represented the sp^3 C–C band for disordered carbon structures [76]. The band at 287.36 eV indicated the presence of C=O functional group [73]. However, the O 1s spectra in Fig. 6b showed that the C=O carboxylic and –OH hydroxyl bands appeared at 527.91 eV and 531.37 eV, respectively. Although the presence of the carboxylic and hydroxyl bands suggested that MAC900-9h-3r was not completely carbonized, their presence also predicted that the capacitance behaviour of MAC900-9h-3r would show some pseudocapacitance effect [30,68,73,77]. The slight shift from the peak positions of the carbon and oxygen species in the C 1s and O 1s spectra was due to the chemical nature of the neighbouring atoms on the surface of the activated carbon [33].

Fig. 6 XPS deconvolution for the (a) C 1s and (b) O 1s spectra of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

3.5. Electrochemical Performance

3.5.1. Effect of Scan Rate on Charge Storage

Cyclic voltammetry tests were conducted to study the effect of scan rate on charge storage properties of MAC-E. Figures 7(a and b) show the CV curves of MAC-E in 1 M H₂SO₄ (aqueous) and 1 M EMImBF₄ (ionic liquid) electrolytes. The CV curves were generated at varying scan rates from 50 mVs⁻¹ and 5000 mVs⁻¹. The maximum voltage window for each electrolyte was determined from existing literature [32,47]. The rectangular shape of the CV curves confirmed the capacitance behaviour of MAC-E in both electrolytes. However, the distortion in the rectangular shape of the CV curves suggested that the capacitance behaviour of MAC-E was a combination of EDLC and pseudocapacitance. The pseudocapacitance behaviour was attributed to the presence of oxygen functional groups on the surface of MAC-E [50]. However, the pseudocapacitance behaviour of MAC-E was more noticeable in 1 M H₂SO₄ than in 1 M EMImBF₄. The slight suppression of the pseudocapacitance behaviour of MAC-E in 1 M EMImBF₄ was attributed to the inability of the heteroatoms on the surface of MAC-E to form ionic solutions in 1 M EMImBF₄ electrolyte [78].

Fig. 7 Cyclic voltammetry of *M. nigeriensis* activated carbon electrode in (a) 1 M H₂SO₄ and (b) 1 M EMImBF₄ electrolytes

3.5.2. Capacitance Behaviour of MAC-E

Galvanostatic charge-discharge experiments were performed to determine the capacitance behaviour of MAC-E at different current densities, and the results for the two different electrolytes are shown in Figs. 8(a and b). The GCD curves showed a slight deviation from the normal saw-tooth shape of EDLCs which confirmed the effect of pseudocapacitance in the capacitance behaviour of MAC-E. The effect pseudocapacitance effect was attributed to the presence of oxygen functional groups on the surface MAC-E [79]. The voltage drop observed at the discharge section of the GCD curves also indicated the potential difference at the electrode-electrolyte interface [42]. Analysis of the GCD experiments however showed that

the specific capacitance of MAC-E in 1 M H₂SO₄ electrolyte was 26 Fg⁻¹ (at current density of 5 Ag⁻¹) and 76 Fg⁻¹ (at current density of 0.5 Ag⁻¹). However, in 1 M EMImBF₄ electrolyte, the specific capacitance was 17 Fg⁻¹ (at 5 Ag⁻¹) and 53 Fg⁻¹ (at 0.5 Ag⁻¹). The relatively low values of the specific capacitance of MAC-E in both electrolytes was attributed to the relatively low molar concentration of the electrolytes. However, the decrease in the specific capacitance of MAC-E as the current density increased was due to insufficient charge transport across the micropores [33,68].

Fig. 8 Galvanostatic charge-discharge curves of *M. nigeriensis* activated carbon electrode in (a) 1 M H₂SO₄ and (b) 1 M EMImBF₄ electrolytes

3.5.3. Electrochemical Impedance of MAC-E

Electrochemical impedance experiments were carried out to determine the electrode resistance, the electrolyte resistance and the diffusion resistance of MAC-E in 1 M H₂SO₄ and 1 M EMImBF₄ electrolytes. The values of these resistances are shown in Table 2. The disparity in the electrode resistance of MAC-E in the two different electrolytes suggested that the charge transfer resistance of MAC-E was dependent on the type of electrolyte. The Nyquist plots for the electrochemical impedance tests are also shown in Fig. 9a. At the low frequency range, the impedance spectra of MAC-E in the two electrolytes appeared as inclined lines which were shifted along the real z-axis by their respective series resistances [47]. The degree to which these lines were inclined also confirmed that the energy storage mechanism of MAC-E was a combination of EDLC and pseudocapacitance. The semicircular curves seen in the high-frequency range confirmed the porous nature of MAC-E [28,33,40]. The diameters of the two semicircular curves represented the respective resistances of the electrolytes in the electrochemical system [47,80,81]. The capacitance retention of MAC-E in 1 M H₂SO₄ and 1 M EMImBF₄ was examined after 10, 000 charge-discharge cycles at 10 Ag⁻¹. The result in Fig.

9b showed that MAC-E retained 95% of its specific capacitance in 1 M H₂SO₄, and 98% of it in 1 M EMImBF₄. The relatively lower capacitance retention of MAC-E in 1 M H₂SO₄ aqueous electrolyte was attributed to the poor redox reversibility of the oxygen functional groups which decreased the electronic conductivity of MAC-E [82,83].

Fig. 9 (a) Nyquist Plots and **(b)** Capacitance Retentions of *M. nigeriensis* activated carbon electrode in 1 M H₂SO₄ and 1 M EMImBF₄ electrolytes

Table 2 Electrochemical resistance of *M. nigeriensis* activated carbon electrode

4. CONCLUSION

This work considered the conversion of waste termite biomass into activated carbon for energy storage as a good way to combat the contribution of termite activities to the rising levels of atmospheric CO₂ and CH₄. Activated carbon was initially produced from waste termite (*Macrotermes nigeriensis*) biomass through a one-step carbonization KOH-activation process. The carbonization-activation process was performed under varied conditions of temperature, time and KOH-biomass ratio in order to optimize the specific surface area and pore structure of the activated carbon. The morphology, structure and surface chemistry of the optimal activated carbon sample were analyzed using standard analytical equipment, and the results showed that termite-based activated carbon can be used for energy storage in supercapacitor. For this reason, a sample of the activated carbon was formed into an electrode via a densification process. Electrochemical experiments were later performed on the activated carbon electrode in 1 M H₂SO₄ aqueous and 1 M EMImBF₄ ionic liquid electrolytes. Results of these experiments showed that the specific capacitance of the activated carbon electrode was higher in 1 M H₂SO₄ (78 Fg⁻¹ at 0.5 Ag⁻¹) than in 1 M EMImBF₄ (53 Fg⁻¹ at 0.5 Ag⁻¹). However, other results of the experiments showed that the capacitance behaviour of MAC-E in both electrolytes was a combination of EDLC and pseudocapacitance. The relatively low values of

the specific capacitance was attributed to the low molar concentration of the electrolytes. However, the capacitance retention of the activated carbon electrode was examined after 10,000 charge-discharge cycles at 10 Ag^{-1} ; and the result showed that activated carbon electrode retained 95% of its specific capacitance in 1 M H_2SO_4 , and 98% of it in 1 M EMImBF₄. Whereas these results show that waste *M. nigeriensis* biomass could be valorized in the production of activated carbon for energy storage, the performance of the activated carbon could be improved by re-engineering the activation process and increasing the concentration of the electrolytes.

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Table 1 BET surface area and pore size distribution of the prepared MAC samples

Sample ID	Temp (°C)	Time (h)	KOH-Biomass Ratio	S_{BET} (m ² /g)	S_{mic} (m ² /g)	V_{Total} (cm ³ /g)	V_{mic} (cm ³ /g)	D_{avg} (nm)
MAC500-5h-2r	500	5	2:1	670.680	520.220	0.6512	0.11506	3.025
MAC700-5h-2r	700	5	2:1	1042.670	740.562	0.4512	0.15006	5.435
MAC900-5h-2r	900	5	2:1	1064.280	920.820	0.4512	0.15006	4.855
MAC900-7h-2r	900	7	2:1	1065.435	922.480	0.4512	0.15006	4.855
MAC900-9h-2r	900	9	2:1	1067.660	924.440	0.4512	0.15006	4.855
MAC900-9h-3r	900	9	3:1	1465.560	870.440	0.4533	0.15015	5.525
MAC900-9h-4r	900	9	4:1	1440.650	780.550	0.4512	0.15005	4.445

Table 2 Electrochemical resistance of *M. nigeriensis* activated carbon electrode

Electrolyte	$R_{Electrode}$ ($\Omega\ cm^{-2}$)	$R_{Electrolyte}$ ($\Omega\ cm^{-2}$)	$R_{Diffuse\ Layer}$ ($\Omega\ cm^{-2}$)	
1 M H ₂ SO ₄	1.0	0.5	2.0	650
1 M EmimBF ₄	1.2	0.8	1.4	651
				652

Fig. 1 Schematic illustration of the production of activated carbon electrode from termites (*M. nigeriensis*), showing the biomass precursor as the waste generated during the production of termite biodiesel

Fig. 2 TGA and DSC curves of *M. nigeriensis* Biomass

Fig. 3 (a) Nitrogen adsorption-desorption isotherms and (b) pore size distribution of samples of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

Fig. 3-S (a) Nitrogen adsorption-desorption isotherms and (b) pore size distribution of samples of KOH-activated carbon derived from *M. nigeriensis* biomass at different carbonization temperatures, activation times and KOH-biomass ratios

Fig. 4 (a) SEM and **(b)** TEM images of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

Fig. 5 (a) XRD and **(b)** Raman Spectra of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

Fig. 6 XPS deconvolution for the (a) C 1s and (b) O 1s spectra of KOH-activated carbon derived from *M. nigeriensis* biomass at 900 °C, 9 h and KOH-biomass ratio of 3:1

Fig. 7 Cyclic voltammetry of *M. nigeriensis* activated carbon electrode in (a) 1 M H₂SO₄ and (b) 1 M EMImBF₄ electrolytes

Fig. 8 Galvanostatic charge-discharge curves of *M. nigeriensis* activated carbon electrode in (a) 1 M H₂SO₄ and (b) 1 M EMImBF₄ electrolytes

Fig. 9 (a) Nyquist Plots and **(b)** Capacitance Retentions of *M. nigeriensi* activated carbon electrode in 1 M H₂SO₄ and 1 M EMImBF₄ electrolytes

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