

Supplementary Document

Development of Activated Carbon Textiles Produced From Jute and Cotton Wastes for Electromagnetic Shielding Applications

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S.1. Novelty Search

The novelty search was conducted in the Web of Science database on 04.11.2023 using the Boolean operators AND and OR in “all fields” (“microwave” AND “carbonization OR pyrolysis” AND Textile). A total of 36 documents were found. None of these documents were relevant to this study. The documents matching "textile" pertain to textile dyeing sludge, and those matching “microwave” pertain to microwave absorption (not heating). There are two similar studies about “self-purging” (Table S1).

Table S1. Studies with similarities and differences relative to this study and the originality of this study.

	Similar Study	This Study
[1]	PRECURSOR: Dried oil-palm shell (OPS)	PRECURSOR: Wet nonwoven-woven manufactured from jute-cotton wastes
	REACTOR: 1 cm-thick porcelain	REACTOR: 3 mm-thick porcelain
	SEALING: Casting plaster - brittle	SEALING: High-temperature Teflon (PTFE) – F=flexible
	PURGING: Self-purging (no inert gas)	PURGING: Self-urging (no inert gas)
	MICROWAVE HEATING: Under constant power (900 W) for 20 minutes	MICROWAVE HEATING: Slowly increasing power: 120 W (10 min.) + 350 W (15 min.) + 460 W (15 min.) + 600 W (40 min.) + 700 W (10 min.) = 1.5 hours
	FINAL PRODUCT: Powder biochar	FINAL PRODUCT: Activated carbon textile
[2]	PRECURSOR: Nonwoven manufactured from acrylic fibrous waste, 11.6 mm thickness	PRECURSOR: Wet nonwoven-woven manufactured from jute-cotton wastes The final average thickness is approximately 2.5 mm.
	UNDER CHARCOAL	UNDER HEMP DECORTICATION WASTE
	PURGING: Self-purging (no inert gas)	PURGING: Self-purging (no inert gas)
	HEATING: Traditional muffle furnace for approximately 10 hours	MICROWAVE HEATING: Slowly increasing power: 120 W (10 min.) + 350 W (15 min.) + 460 W (15 min.) + 600 W (40 min.) + 700 W (10 min.) = 1.5 hours
	FINAL PRODUCT: Activated carbon	
	TEXTILE STRUCTURE	

S.2. Raman Analysis

The ratio of the peak intensity of the D band to the G band, ID/IGm depends on the excitation energy. ID/IG can be related linearly to the inverse of the crystallite size along the basal plane L_a , per the equation developed by Tuinstra and Koenig (S1). In 1970, Tuinstra and Koenig found that the proportionality of $ID/IG \propto L_a^{-1}$ was valid for $L_a > 2$ nm (Equation S.1). The relationship developed by Ferrari and Robertson, $ID/IG \propto L_a^{-2}$, is used for $L_a < 2$ nm (Equation S.2) [3].

$$L_a(nm) = \frac{560}{E^4} \left(\frac{I_D}{I_G} \right)^{-1} = (2.4 \times 10^{-10}) \lambda^4 \left(\frac{I_D}{I_G} \right)^{-1} \quad (\text{For } L_a > 2) \quad \text{Eq. (S1)}$$

$$L_a(nm) = \sqrt[2]{\left(\frac{I_D}{I_G} \right) ((2.4 \times 10^{-10}) \lambda^4)^{-1}} \quad (\text{For } L_a < 2) \quad \text{Eq. (S2)}$$

Table S2. Raman analysis of activated carbon fabrics.

Textile Sample	D	G	ID	IG	ID/IG	L_a (nm)	FWHM (cm ⁻¹)	
							D	G
WATER	1367	1586	5101.24	5949.68	0.86	0.21	226.47	103.75
WATER Microwave	1348	1582	1675.00	1586.00	1.06	0.23	191.89	96.91
2% H ₂ SO ₄	1369	1583	4236.58	5204.24	0.81	0.21	222.89	103.30
2% H ₂ SO ₄ Microwave	1352	1585	6202.61	7352.41	0.84	0.21	187.43	88.26
4% H ₂ SO ₄	1366	1584	3869.18	4982.3	0.78	0.20	129.01	88.82
4% H ₂ SO ₄ Microwave	1363	1585	4980.72	5893.47	0.85	0.21	100.79	82.76
8% H ₂ SO ₄	1366	1586	3217.54	4125.14	0.78	0.20	117.30	84.37
8% H ₂ SO ₄ Microwave	1348	1585	3669.00	3875.00	0.95	0.22	98.11	81.86

S.3. XRD Analysis

The size and lattice parameters of the crystal structure can be estimated through the following equations (S.3-4-5):

$$d = \frac{\lambda}{2\sin\theta_{(002)}} \quad \text{Bragg's Law} \quad \text{Eq. (S3)}$$

$$L_a = \frac{1,84\lambda}{\beta\cos\theta_{(100)}} \quad \text{Scherrer Equation} \quad \text{Eq. (S4)}$$

$$L_c = \frac{0,94\lambda}{\beta\cos\theta_{(002)}} \quad \text{Scherrer Equation} \quad \text{Eq. (S5)}$$

where d indicates the size of the crystal, λ represents XRD wavelength Cu K α ($\lambda = 0,15406$ nm), and L_a , L_c are crystal stacking width and crystal stacking height, respectively. B indicates full width at half maximum (FWHM) measured in radians, and θ is the diffraction angle. The “Gaussian peak fitting” method was used to separate the various peaks.

Table S3. XRD data analysis.

	(002)		Crystal Size	
	2Theta	FWHM	L_c (nm)	d (002)
2% H ₂ SO ₄	20,57	17,480	0,482	0,431
4% H ₂ SO ₄	20,24	14,793	0,570	0,438
8% H ₂ SO ₄	19,37	17,432	0,483	0,458

S.4. TGA Analysis

According to the TGA-DTG analysis (Figure S1) of the five-layer nonwoven made of cotton and jute fibers, there is an initial weight loss of 7.206%, which can be attributed to the removal of moisture from the cotton and jute fibers below 150°C. The fabric began to degrade at 335.74°C, with the greatest weight loss at 355.31°C. This weight loss can be attributed to the decomposition of cotton (α -cellulose) and jute (lignin) fibers. This finding is compatible with results in the literature [4,5]. The point at which thermal stability begins is 372.56°C. A residue of 5.862% was obtained at the end of the process.

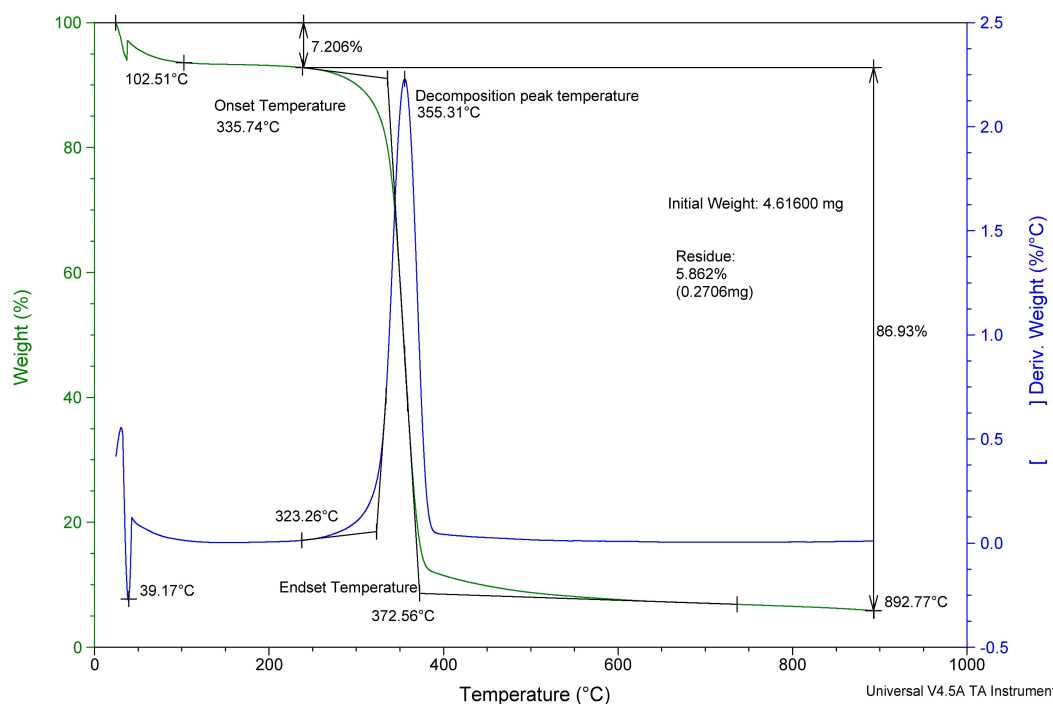


Figure S1. TGA-DTG analysis of a five-layer nonwoven fabric consisting of waste cotton and jute fibers.

The point at which thermal stability begins for the product carbonized with 8% acid is 673.45°C. A residue of 48.76% was obtained at the end of the process. A broad and wide TGA curve indicates the presence of impurities in the material (such as volatile, oily, tar-like materials adhering to the surface) that decompose at different temperatures. Small peaks around 420°C also support this conclusion (Figure S2).

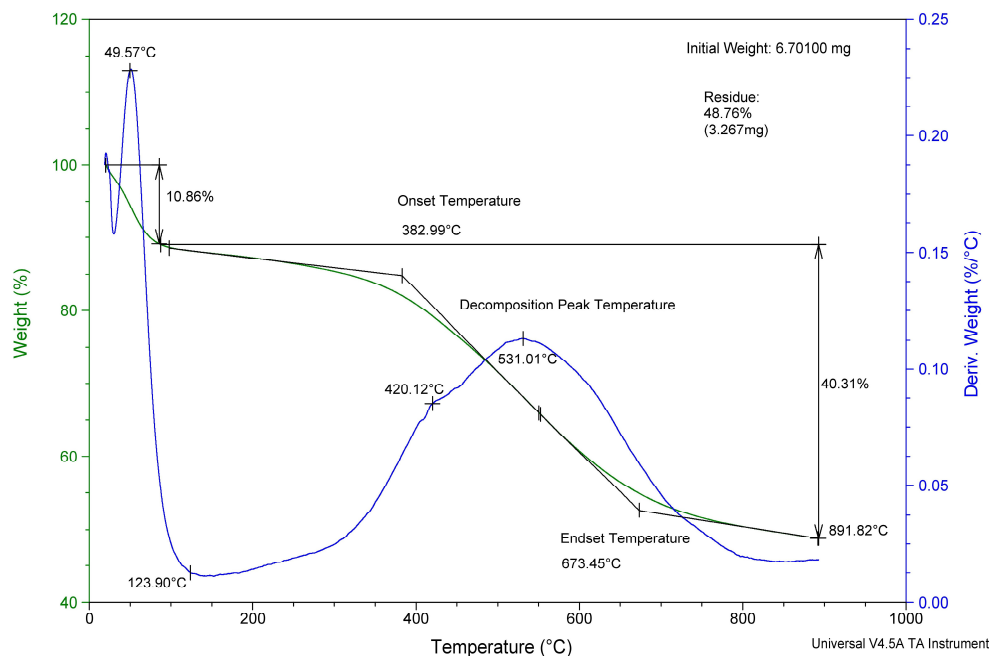


Figure S2. TGA-DTG analysis of activated carbon textile obtained with 8% acid.

According to the TGA-DTG analysis (Figure S3) of the microwave-post treated carbonized textile manufactured with 8% acid, there is an initial weight loss of 7.956% below 150°C, which can be attributed to the elimination of moisture and some small-molecule volatiles. The material decomposed at 434.77°C, and the largest weight loss occurred at 585.55°C. The point at which thermal stability begins is 697.96°C. At the end of the process, a residue of 62.70% was obtained. A broad and wide TGA curve indicates that there may be impurities (such as volatile, oily, tar-like materials adhering to the surface) that persist despite microwave treatment and that decompose at different temperatures (Figure S3).

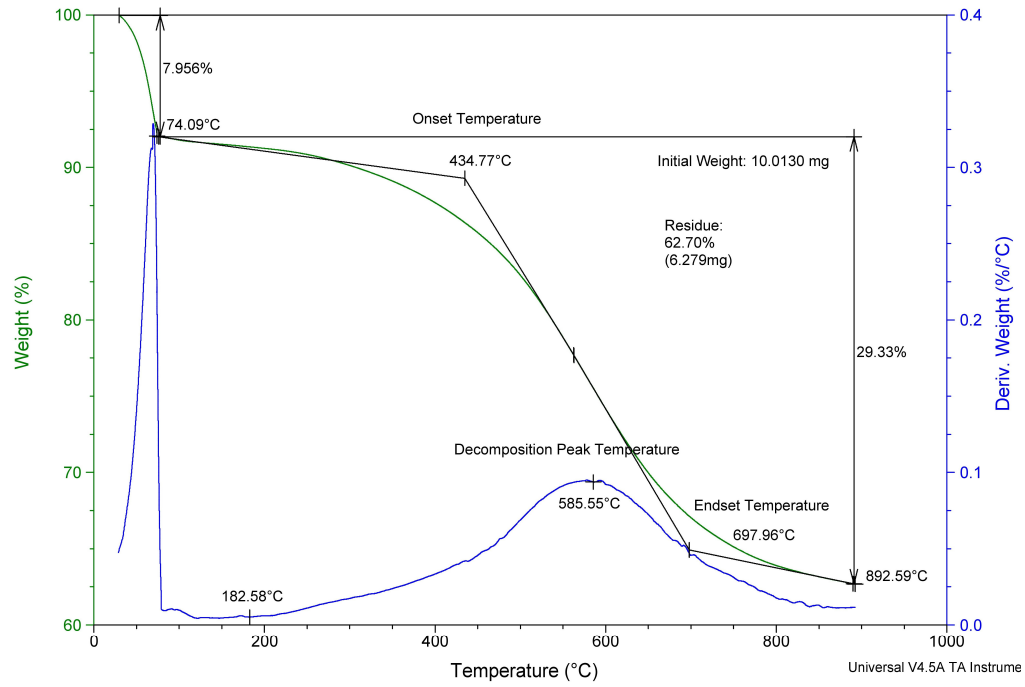


Figure S3. TGA-DTG analysis of microwave post-treated activated carbon textile manufactured with 8% acid.

S.5. Electromagnetic Shielding Efficiency

The electromagnetic shielding effectiveness (EMSE) is the ratio of electromagnetic energy before the shield to energy after the shield and can be expressed as Eq. S7:

$$SE = 10 \log \left(\frac{P_{input}}{P_{output}} \right) \quad \text{Eq. (S6)}$$

where P_i is the power of the incoming EM wave, and P_o is the power of the outgoing (returning) EM wave. The unit of SE is measured in decibels (dB).

$$SSE = EMI \text{ SE} / \text{density} \text{ (dB cm}^3 \text{ g}^{-1}) \quad \text{Eq. (S7)}$$

$$SSE/t = SSE / \text{thickness} \text{ (dB cm}^2 \text{ g}^{-1}) \quad \text{Eq. (S8)}$$

$$\% \text{ EMSE} = 100 - \left(\frac{1}{100^{\frac{SE}{10}}} \right) \times 100 \quad \text{Eq. (S9)}$$

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