

Supplementary Data

Regenerated cellulose fibers from coaxial wet spinning of alginate with excellent flame retardancy

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Supporting Figures and Tables

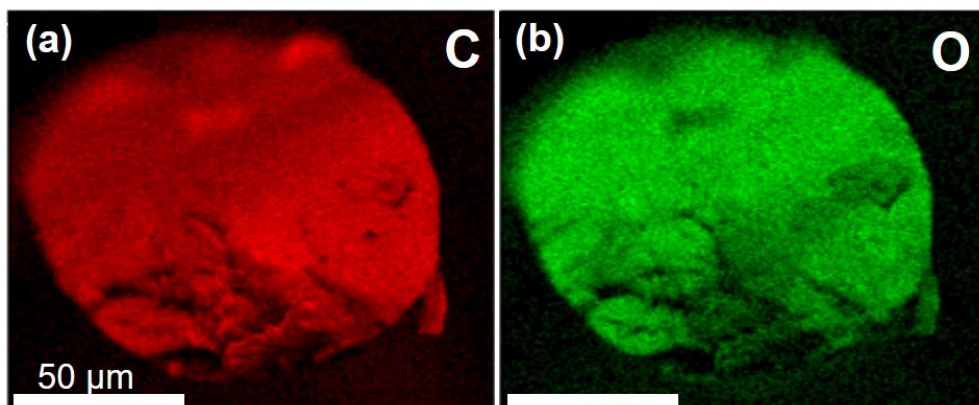


Fig. S1 Elemental mapping of C and O for RCF.

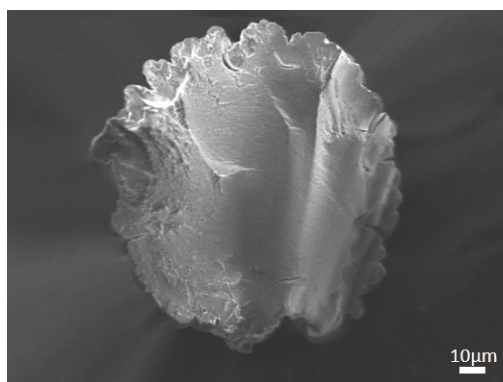


Fig.S2 Cross-sectional view of CAF after cyclic washing.

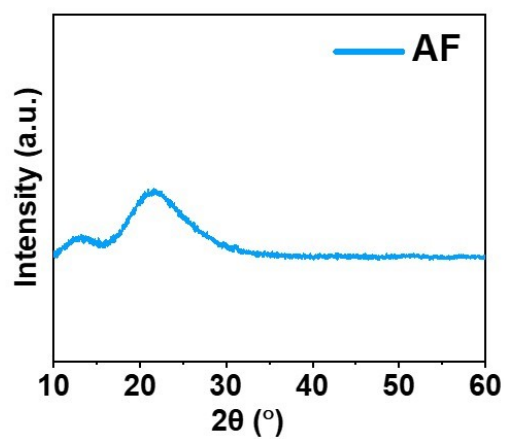


Fig. S3 XRD pattern of AF.

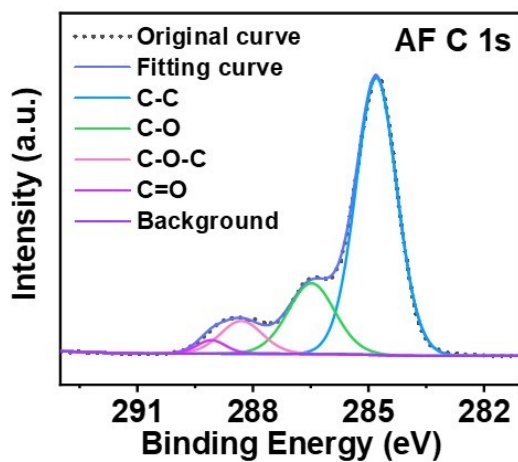


Fig. S4 C 1s XPS spectrum of AF.

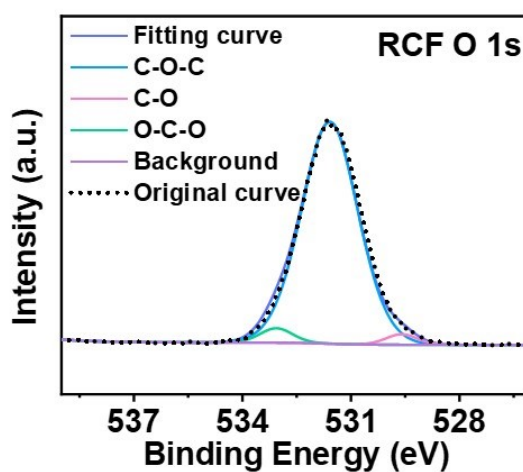


Fig. S5 O 1s XPS spectrum of RCF.

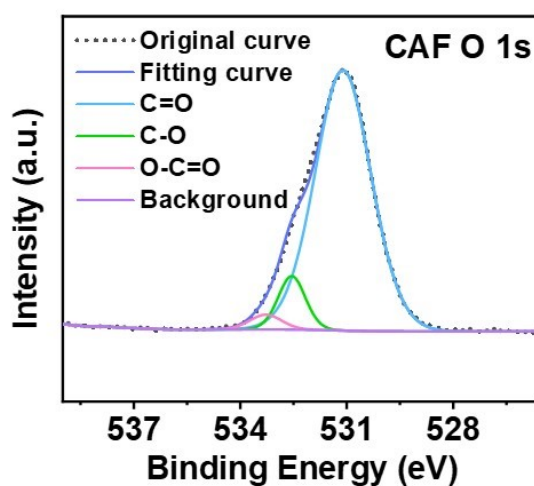


Fig. S6 O 1s XPS spectrum of CAF.

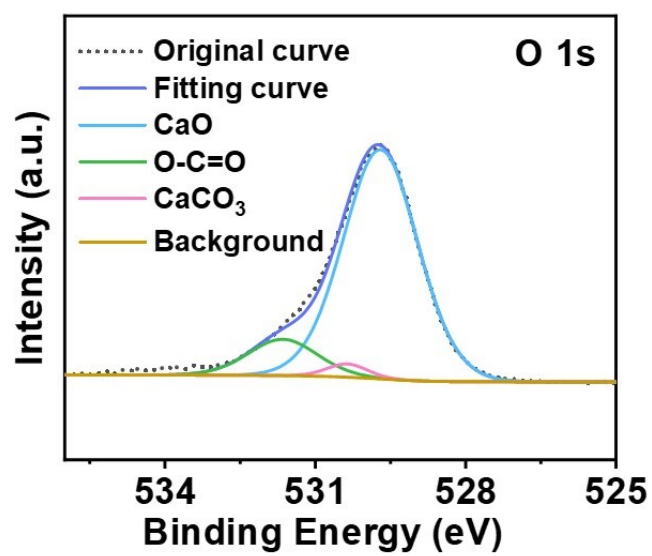


Fig. S7 O 1s XPS spectrum of CAF carbon residue.

Tables

Table S1 Comparison with the reported strengths of coaxial/uniaxial composite fibers.

Sample	Components	Strain (%)	Stress (MPa)	Ref.
CS/RO-CNC (coaxial)	Shell: chitosan (CS) Core: cellulose nanocrystals (CNCs) after modification	7.8	82	[26]
CNF1.5/PW (coaxial)	Shell: cellulose Core: cellulose nanofibrils (CNFs) paraffin wax (PW)	132	13.5	[27]
CNT@MXene (coaxial)	Shell: carbon nanotubes (CNTs) thermoplastic polyurethane (TPU) Core: MXene/TPU	513	10.1	[28]
CGF	Cellulose	20	71.8	[29]
CNF/SA	CNF/sodium alginate (SA)	13	2.8	[30]
HSiO ₂ /C@C (coaxial)	Shell: hollow silica (HSiO ₂) Core: cellulose	29	27	[31]
MXene/MnO ₂ -RC (coaxial)	Cellulose/MnO ₂ /MXene	9	145.8	[32]
TTF-60 (coaxial)	Shell: poly(<i>p</i> -phenylene benzobisoxazole) nanofibers (PNFs)/montmorillonite (MMT) protecting Core: poly(3,4-ethylenedioxythiophene)-poly(styrene sulfonate) (PEDOT:PSS) single-walled carbon nanotube (SWCNT-COOH)	13.8	12.3	[33]
SA/MWCNT	Shell: SA multi-walled carbon nanotubes (MWCNT) Core: SA/MWCNT The core and shell have different MWCNT concentrations.	10	111.8	[34]
MLM	Shell: waterborne polyurethane (WPU)/SA Core: magnetic liquid metal (MLM)/WPU	780	32	[35]
This work	Shell: cellulose Core: SA	20.5	137.4	

Table S2 Calcium ion concentrations in CAF with different shell layer concentrations.

Sample	CAF-1	CAF-2	CAF-3
Ca^{2+} (mg L ⁻¹)	4.55×10^{-4}	7.089×10^{-4}	8.035×10^{-4}

Table S3 Comparison of $\Delta PHRR$ and ΔTHR for cellulose fibers/fabrics.

Sample	Flame retardants	$\Delta PHRR$	ΔTHR	Ref.
S1	Trivinylphosphine oxide (TVPO)	40.2	69.2	[41]
CS/LS/cotton	Lignosulfonate/ CS	71.8	52.8	[42]
Lyocell@PPCA	Aspartic acid/ protocatechualdehyde	66.2	44.8	[43]
FRLF	Fabricate phosphorylated cellulose	50.9	42.6	[3]
VF/PPSPB20	A sulfur-free polymeric flame retardant (PPSPB)	60.0	60.0	[44]
CF-8	Graphene oxide (GO), phytic acid (PA)	60.1	47.5	[45]
3%CH/7%SA	CS/SA	48.2	44.6	[46]
G-Lyocell-Na	Sodium glycinate (glycine-Na)	36.5	36.3	[47]
A-Lyocell-Na	Sodium aspartate (aspartate-Na).	49.8	34.5	[47]
C/L10/PA	Hdimethyl phosphite lysine (LP)/PA	73.8	20.8	[48]
CAF	SA	76.1	75	

Table S4 TG data of RCF and CAF.

Sample	T_{5%} (°C)	T_{second} (°C)	T_{max} (°C)	Residue at 800 °C (wt%)
RCF	76.01	–	317.78	12.13
CAF-1	70.77	233.46	303.76	24.68
CAF-2	57.15	232.44	300.70	22.70
CAF-3	53.71	226.45	299.69	21.85

Table S5 LOI values of CAF after cyclic washing³.

Washing cycles	LOI (%)		
	CAF-1	CAF-2	CAF-3
0	29.5±0.5	30.5±0.5	32.0±0.4
5	28.6±0.3	29.8±0.4	31.1±0.6
10	28.0±0.5	29.2±0.3	30.7±0.5
20	27.5±0.4	28.8±0.5	30.3±0.3
30	27.3±0.5	28.7±0.6	30.2±0.5

Element	Before combustion (at.%)	After combustion (at.%)
C	72.56	59.68
O	25.58	31.15
Ca	1.86	7.47
Na	–	1.7

Table S6 Atomic percent in the XPS full spectrum before and after CAF combustion.

References

3. Q. Zhang, J. Chen, D. Li, L. Sun, Y. Ren, C. Cheng and X. Liu, *Ind. Crops Prod.*, 2023, **199**, 116757.
26. Q. Gao, J. Wang, J. Liu, Y. Wang, J. Guo, Z. Zhong and X. Liu, *Cellulose*, 2021, **28**, 7995–8008.
27. K. Yang, C. Duan, R. Ma, X. Liu, Z. Meng, Z. Xie and Y. Ni, *Carbohydr. Polym.*, 2024, **346**, 122649.
28. W. Feng, L. Zou, C. Lan, S. E and X. Pu, *Adv. Fiber Mater.*, 2024, **6**, 1657–1668.
29. Q. Li, Z. Yuan, C. Zhang, S. Hu, Z. Chen, Y. Wu, P. Chen, H. Qi and D. Ye, *Nano Letters*, 2022, **22**, 3516–3524.
30. Y. Zhu, Y. Zhang, H. Yu, J. Li, W. Jiang, Y. Zhang and X. Wang, *Carbohydr. Polym.*, 2025, **368**, 124190.
31. S. Jiang, S. Jiang, J. Yan, C. Lin, W. Wang, S. Jiang and R. Guo, *Nano Energy*, 2025, **136**, 110688.
32. S. Wei, C. Wan, Q. Huang, H. Chai, Y. Chai, X. Li and Y. Wu, *Int. J. Biol. Macromol.*, 2024, **276**, 134152.
33. H. He, J. Xu, M. H. Mia, Z. Yu, Y. Wan, Q. Jiang, X. Qu, J. Liu, L. Hou, Y. Song and Z. Yu, *Chem. Eng. J.*, 2025, **521**, 167127.
34. R. Zhang, H. Wang, M. Qu, S. Li, Y. Ma, X. Li, P. Tang and Y. Bin, *Chem. Eng. J.*, 2025, **521**, 167127.
35. X. Gao, J. Su, C. Xu, S. Cao, S. Gu, W. Sun and Z. You, *ACS Nano*, 2024, **18**, 17913–

- 17923.
41. X. Bi, Y. Wang, D. Xue, C. Lv, Z. Li, Z. Chen and T. Zhao, *Prog. Org. Coat.*, 2025, **199**, 108949.
42. S.-Q. Li, R.-C. Tang and C.-B. Yu, *Polym. Degrad. Stab.*, 2022, **196**, 109826
43. Y. Liu, J. Zhao, X. Yu, Y. Ren and X. Liu, *Int. J. Biol. Macromol.*, 2024, **259**, 129252.
44. B. Wang, Z.-M. Hou, Y.-J. Xu and Y.-Z. Wang, *Ind. Crops Prod.*, 2025, **231**, 121163.
45. P. Zou, Z. Liu, D. Yang, Y. Li, L. Li, M. Liu, J. Xu and W. Meng, *Colloids Surf., A*, 2025, **717**, 136854.
46. P. Li, C. Liu, Y.-J. Xu, Z.-M. Jiang, Y. Liu and P. Zhu, *Polym. Degrad. Stab.*, 2020, **181**, 109302.
47. Y. Liu, W. Zhao, J. Zhang, Y. Ren, X. Liu and H. Qu, *Cellulose*, 2022, **29**, 5339–5358.
48. X.-H. Shi, C.-Y. Jing, H. Luo, H. Shi and D.-Y. Wang, *Polym. Degrad. Stab.*, 2024, **230**, 111069.