Supplementary Information

High-Efficiency and Environmentally Friendly Copper Recovery from Waste Copper-Clad Laminate and Its Pyrolysis Behavior through a Novel Low-Temperature Rotary Furnace Process

Submitted to

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Table S1. Kinetic parameters of the C-R method for the pyrolysis of PL-WCCL

raw material	n	fitting equation	r^2	E(KJ/mol)	A(min^{-1})
PL-NMWCCL	0.5	Y=-9.951-2495.239X	0.886	20.745	0.303
	1	Y=-8.624-3048.758X	0.957	25.347	1.018×10^{1}
	1.5	Y=-6.748-3842.899X	0.981	31.949	1.303×10^{3}
	2	Y=-4.438-4826.710X	0.953	40.129	4.508×10^{5}
	2.5	Y=-1.866-5922.628X	0.909	49.240	2.692×10^{8}
	3	Y=0.860-7083.236X	0.870	58.890	2.163×10^{11}
	3.5	Y=3.682-8283.827X	0.838	68.871	2.056×10^{14}
	4	Y=6.569-9511.024X	0.464	79.074	2.183×10^{17}
PL-WCCL	0.5	Y=-10.375-2232.583X	0.882	18.561	0.088
	1	Y=-9.038-2779.418X	0.959	23.108	3.177
	1.5	Y=-7.093-3588.637X	0.973	29.835	5.035×10^{2}
	2	Y=-4.683-4596.337X	0.927	38.213	2.286×10^{5}
	2.5	Y=-2.013-5714.559X	0.872	47.510	1.766×10^{8}
	3	Y=0.809-6894.776X	0.828	57.323	1.807×10^{11}
	3.5	Y=3.725-8112.889X	0.795	67.450	2.168×10^{14}
	4	Y=6.703-9356.099X	0.770	77.786	2.864×10^{17}

Table S2. Processing conditions and the metal separation rate in large-sized of PL-WCCL and WPCB

	dosage/ type/size	temperature/ atmosphere	reaction device	retention time	subsequent method of separation	Metal separation rate	Reference
1	**WPCB of household appliance 3×3 cm^2**	200℃	fixed furnace	120 min	crushing	0.3–2 mm 85.66%	1
2	**5 pieces FR4-WPCB 5cm^2**	300℃ air	electric furnace	30 min	crushing	710–1000 μm ≥90% 2000–2800 μm >99%	2
3	**PL-WCCL 25 × 45 mm^2**	300℃ air	fixed furnace	30min for 3 times in a row	peeling off manually	100%	3
4	**50g FR4-WPCB 4cm^2**	330℃ N_2	fixed-bed reactor	30min	crushing	92.38%	1
5	**60g FR4-WPCB 4*5cm^2**	500℃ N_2	fixed-bed reactor	60min	peeling off manually	100%	4
6	**3kg WPCB 5×5cm^2**	550℃ vacuum	fixed-bed reactor	120min	crushing、gravity force	99%	5
7	**4kg FR4 WPCB 2×1.5cm^2**	800℃ N_2	a fixed bed reactor with vertical stirring function	105min 18r/min	automatically	100%	6
8	**3 pieces of WPCB 170×30 mm**	Air	ultrasonic treatment	16h		99.99%	7

	dosage/ type/size	temperature/ atmosphere	reaction device	retention time	subsequent method of separation	Metal separation rate	Reference
9	**60 mm² NMP**	180℃ 30min	1000rar/min	30min	Overnight pre-swelling for 17 hours	99.9%	8

Table S3 Relative content (%) of main component screened by GC-MS in liquid products of pyrolysis with a retention time of 60 min

Chemical Name	Formula	PW-R-150-L	PW-R-200-L	PW-R-250-L	PW-R-300-L	PW-R-350-L
Phenol	C_6H_5OH	8.665	8.435	34.75	36.88	28.27
Phenol,2-methyl	C_7H_8O	10.045	9.93	12.52	14.83	11.32
p-Cresol	C_7H_8O	-	10.36	8.26	10.03	7.03
Phenol,2,6-dimethyl-	$C_8H_{10}O$	-	10.795	8.26	2.32	1.68
Phenol,2,4-dimethyl-	$C_8H_{10}O$	-	-	5.24	2.32	5.75
Phenol,4-ethyl-	$C_8H_{10}O$	-	11.985	-	1.25	1.14
Phenol,2,4,5-trimethyl-	$C_9H_{12}O$	-	12.505	-	-	1.4
Benzofuran, 4,7-dimethyl-	$C_{10}H_{10}O$	-	-	1.18	-	1.08
Phenol,4-(1-methylethyl)-	$C_{15}H_{16}O$	-	-	3.86	-	6.12
Phenol,2-(1-methylethyl)-	$C_9H_{12}O$	-	-	-	-	0.76
Phenol,4-bromo-2-chloro-	C_6H_4BrClO	-	-	-	-	0.24
Propiophenone	$C_9H_{10}O$	-	-	-	-	0.55
Phenol,2,4-dibromo-	$C_6H_4Br_2O$	-	-	-	-	0.31
Fluorene	$C_{13}H_{10}$	-	-	-	-	1.22

Not detected: -

Detection Threshold (Peak Area): $\geq$ 0.034

Table S4 The relative elemental contents of XPS overall spectrum of the copper foil surface obtained after pyrolysis in a rotary furnace at 150 ℃

Element name	Peak Position BE	Atomic%
C1s	283.91	53.32
O1s	530.96	14.37
Cu2p	932.66	4.06
Al2p	75.36	21.98
$Cl2p^3$	96.94	2.78
Si2p	101.57	3.50

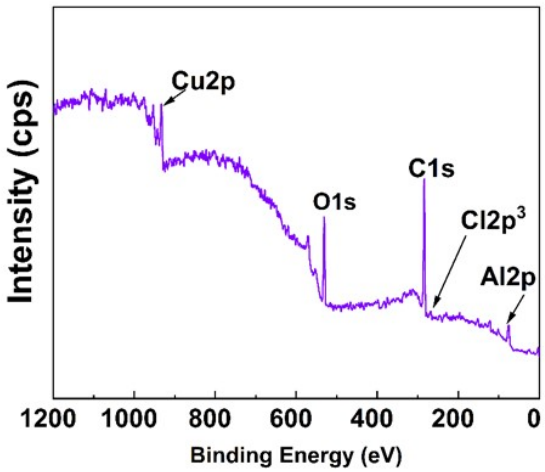

Fig. S1 The XPS overall spectrum of the copper foil surface obtained after pyrolysis in a rotary furnace at 150 ℃

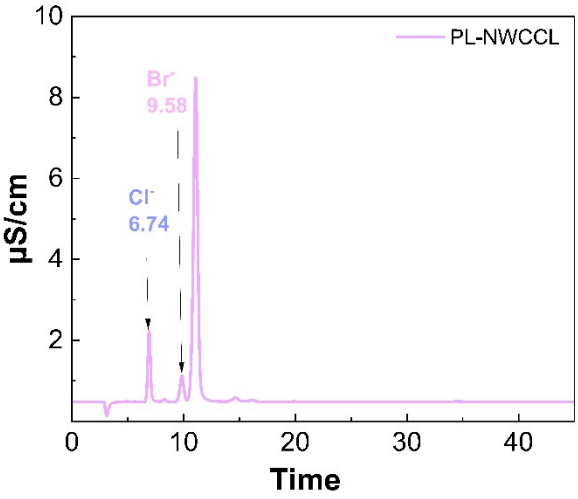

Fig. S2 The Ion chromatography analysis of PL-NWCCL.

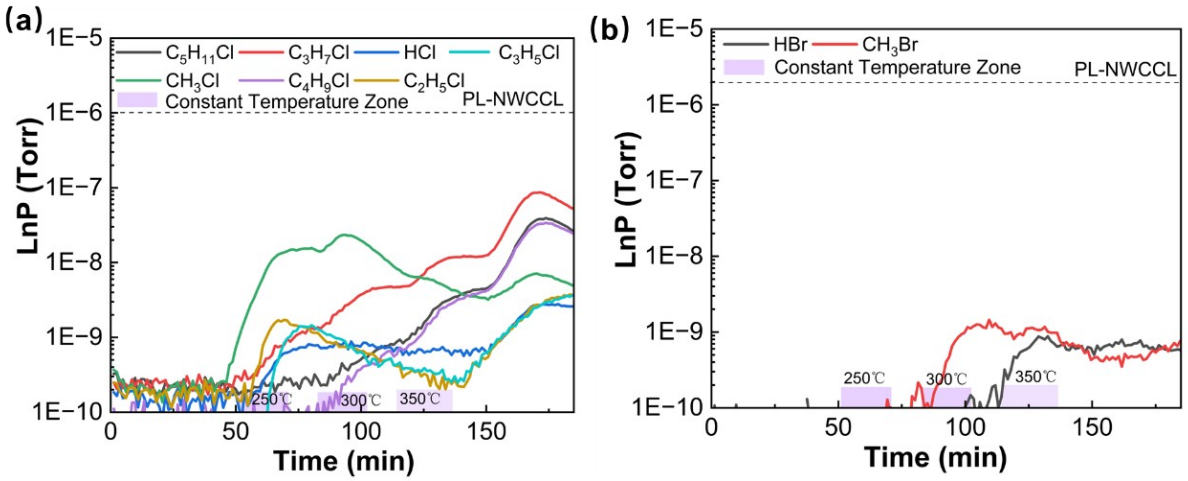

Fig. S3 Pyrolysis products of halogenated flame retardants of PL-NWCCL: (a) Chlorinated compounds，(b) Brominated compounds

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