

Supporting Information

Table S1 Proximate and ultimate analyses of the raw samples

	PR	SR	CR	Coal
Proximate analysis(wt.%, ad)				
Moisture, M	2.31	2.34	2.05	2.33
Ash, A	8.29	12.91	6.21	13.41
Volatile, V	86.6	82.87	89.75	32
Fixed carbon, FC	2.81	1.88	1.99	52.3
Ultimate analysis(wt.%, daf)				
Carbon, C	45.76	48	44.83	72.85
Hydrogen, H	5.88	7.34	7.43	2.32
Nitrogen, N	5.21	5.76	8.47	8.64
Oxygen, O	35.14	34.35	28.9	16
Sulfur, St	0.63	0.51	0.57	0.87
Low-heating value (MJ kg ⁻¹ , ad)	17.43	20.11	16.33	27.40

ad: air-dried; daf: dry ash-free.

Table S2 Most commonly used kinetic mechanism functions.

N O	Function name	Integral forms $g(\alpha)$	Differential forms $f(\alpha)$
1	Parabolic rule	α^2	$1/2\alpha$
2	Valensi equation	$\alpha+(1-\alpha)\ln(1-\alpha)$	$[-\ln(1-\alpha)]^{-1}$
3	Jander equation	$[1-(1-\alpha)^{1/2}]^2$	$(1-\alpha)^{1/2}[1-(1-\alpha)^{1/2}]^{-1}$
4	Jander equation	$[1-(1-\alpha)^{1/3}]^2$	$1.5(1-\alpha)^{2/3}[1-(1-\alpha)^{1/3}]^{-1}$
5	G-B equation	$1-2\alpha/3-(1-\alpha)^{2/3}$	$1.5[(1-\alpha)^{-1/3}-1]^{-1}$
6	Inverse Jander Equation	$[(1+\alpha)^{1/3}-1]^2$	$(3/2)(1+\alpha)^{2/3}[(1+\alpha)^{1/3}-1]^{-1}$
7	Z-L-T Equation	$[(1-\alpha)^{-1/3}-1]^2$	$(3/2)(1-\alpha)^{3/4}[(1-\alpha)^{-1/3}-1]^{-1}$
8	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^{1/4}$	$4(1-\alpha)[- \ln(1-\alpha)]^{3/4}$
9	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^{1/3}$	$3(1-\alpha)[- \ln(1-\alpha)]^{2/3}$
10	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^{1/2}$	$2(1-\alpha)[- \ln(1-\alpha)]^{1/2}$
11	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^{2/3}$	$3/2(1-\alpha)[- \ln(1-\alpha)]^{1/3}$
12	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^{3/4}$	$(3/4)(1-\alpha)[- \ln(1-\alpha)]^{1/4}$
13	Mample Single Rule	$-\ln(1-\alpha)$	$1-\alpha$
14	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^{3/2}$	$(2/3)(1-\alpha)[- \ln(1-\alpha)]^{-1/2}$
15	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^2$	$(1/2)(1-\alpha)[- \ln(1-\alpha)]^{-1}$
16	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^3$	$(1/3)(1-\alpha)[- \ln(1-\alpha)]^{-2}$
17	Avrami-Erofeev Equation	$[-\ln(1-\alpha)]^4$	$(1/4)(1-\alpha)[- \ln(1-\alpha)]^{-3}$
18	Reaction Order	$1-(1-\alpha)^{1/4}$	$4(1-\alpha)^{3/4}$
19	Contraction Sphericity	$1-(1-\alpha)^{1/3}$	$3(1-\alpha)^{2/3}$
20	Contraction Cylinder	$1-(1-\alpha)^{1/2}$	$2(1-\alpha)^{1/2}$

21	Second-order	$(1-\alpha)^{-1}-1$	$(1-\alpha)^2$
22	2/3 Order	$(1-\alpha)^{-1/2}$	$2(1-\alpha)^{3/2}$
23	Third Order	$(1-\alpha)^{-2}$	$(1/2)(1-\alpha)^3$

Fig. S1 TG and DTG curves of AFRs and coal combustion at different heating rates.

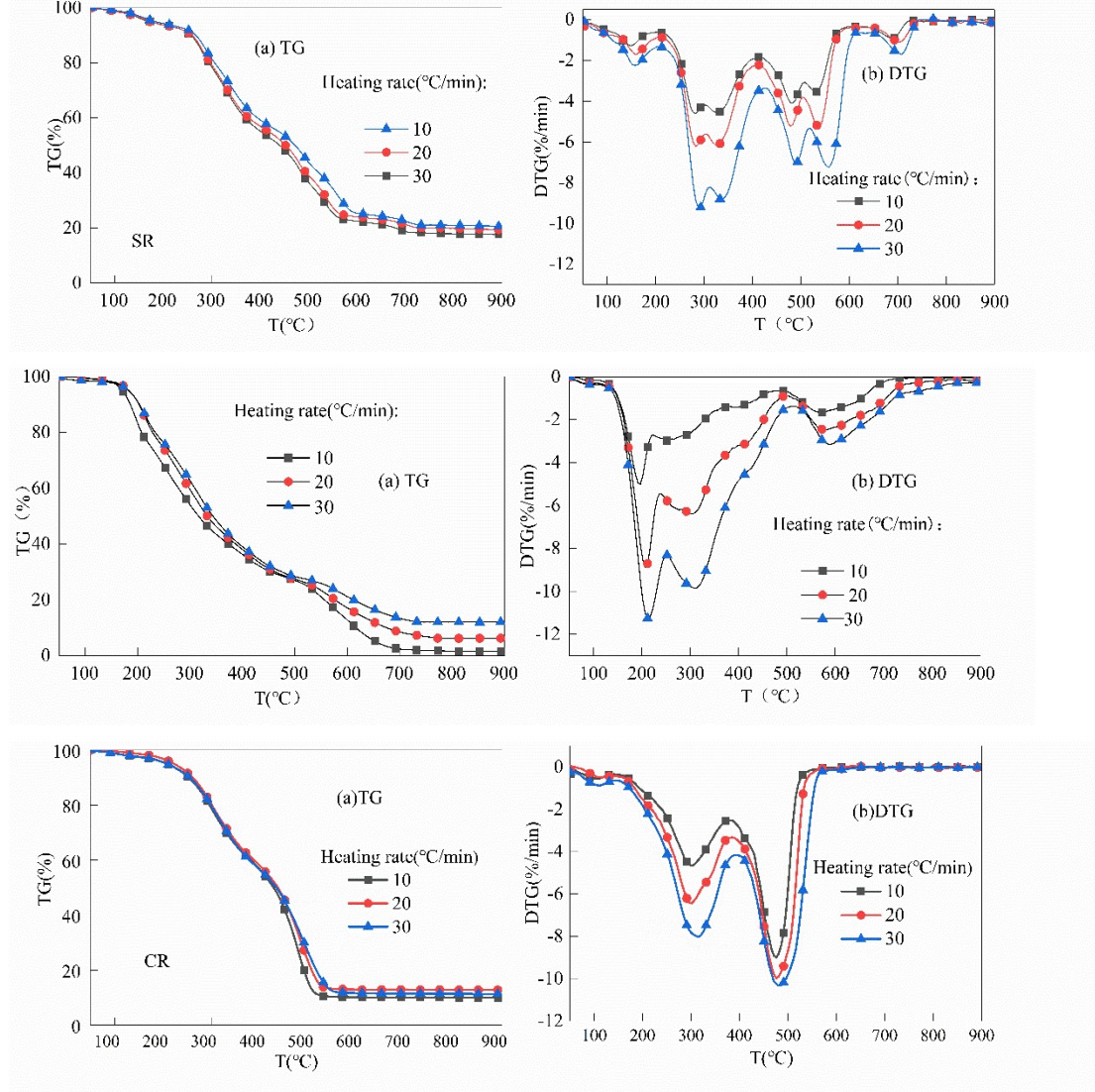


Fig. S2 Experimental TG curves and calculated TG curves of raw AFRs materials at 20 °C/min heating rate.

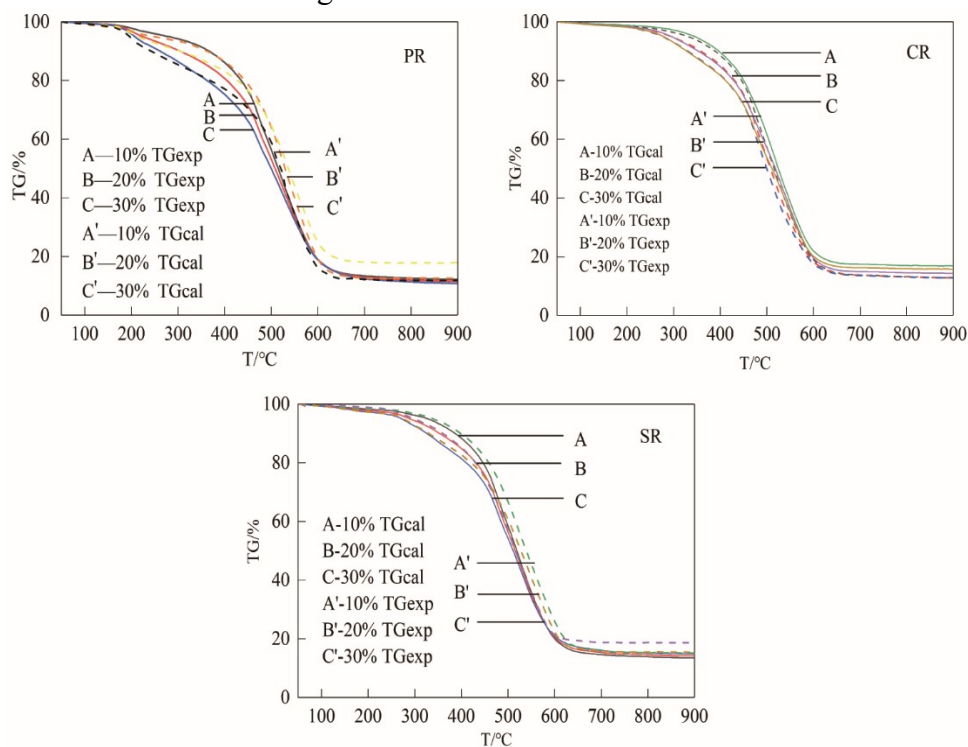


Fig. S3 XRD of raw AFRs materials

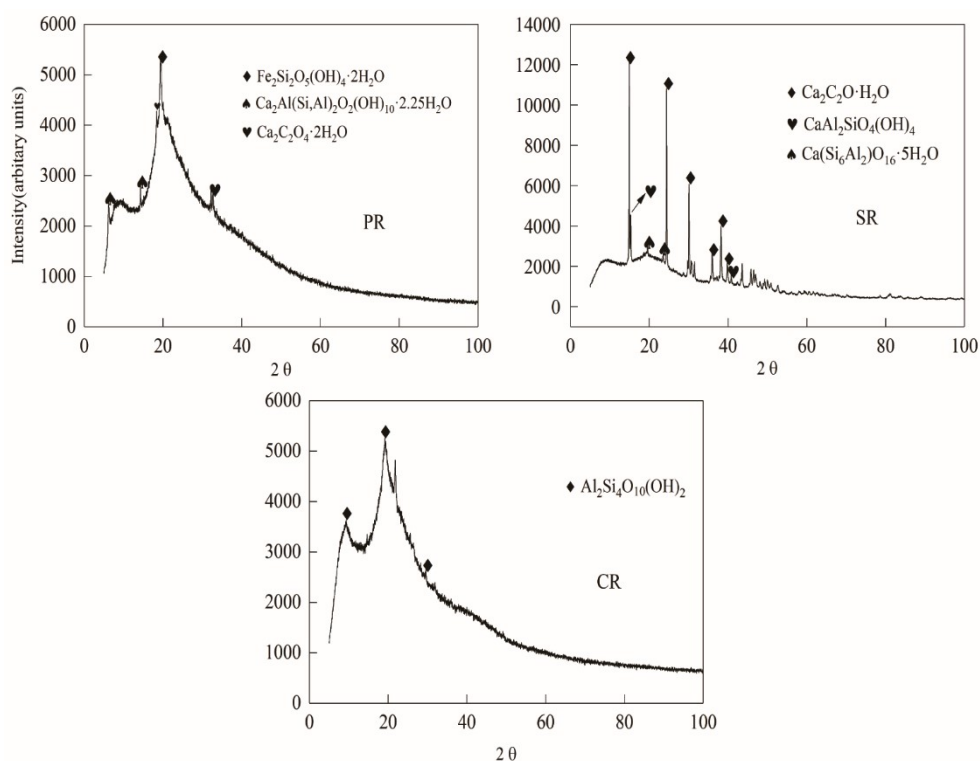


Table S3 Combustion properties of AFRs-Coal blends.

	10%	20%	30%	40%
PR-Coal				
Stage-I, (°C)	155-308	140-330	141-340	138-350
Peak temperature, (°C)	203	199	200.3	201
Mass loss (%)	6	10	16	18
Stage-II, (°C)	308-698	330 - 702	340-735	350-730
Peak temperature, (°C)	522	537	541.9	543.4
Mass loss (%)	80	72	70	74
Residue left, (%)	14	18	14	14
SR-Coal				
Stage-I, (°C)	180-360	180-370	180-380	180-393
Peak temperature, (°C)	-	-	-	-
Mass loss (%)	7	11	14	19
Stage-II, (°C)	360-694	370-660	380-710	393-720
Peak temperature, (°C)	526.4	533.1	531.7	527.4
Mass loss (%)	82.85	79	65	64
Residue left, (%)	14	7	20	15
CR-Coal				
Stage-I, (°C)	170-	172-375	170-375	163-373
Peak temperature, (°C)	513.3	-	-	306.6
Mass loss (%)	81	11	14	17
Stage-II, (°C)	375-688	375-492	375-500	373-513
Peak temperature, (°C)	-	472.1	471	474.1
Mass loss (%)	-	28	32	37
Stage-III, (°C)	-	492-685	500-690	513-680
Peak temperature, (°C)	-	527.7	543.8	546.2
Mass loss (%)	-	45	37	30
Residue left, (%)	17	14	16	13

Table S4

Calculation results of the apparent activation energy of SR-Coal by FWO and V methods
(stage 1)

sample	α	FWO method		V method	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	101.54	0.98	103.32	0.96
	0.3	105.81	0.97	106.11	0.99
	0.4	114.72	0.98	117.1	0.96
	0.5	129.68	0.99	133.66	0.98
	0.6	134.53	0.98	135.19	0.96
	0.7	116.88	0.98	118.3	0.95
	0.8	108.5	0.97	107.52	0.97
	0.9	116.94	0.98	120.51	0.96
	Average	116.08	S ² =112.87	117.71	S ² =126.75
20%	0.2	100.36	0.99	104.16	0.97
	0.3	109.89	0.98	110.59	0.98
	0.4	124.93	0.94	126.84	0.95
	0.5	159.12	0.96	160.07	0.96
	0.6	112.96	0.99	116.6	0.94
	0.7	97.49	0.98	100.36	0.98
	0.8	105.94	0.97	106.22	0.96
	0.9	110.25	0.98	114.91	0.99
	Average	115.12	S ² =337.61	123.59	S ² =319.21
	e				
30%	0.2	121.88	0.98	139.77	0.95
	0.3	132.91	0.98	131.93	0.98
	0.4	153.97	0.98	181.56	0.98
	0.5	172.65	0.99	169.18	0.99
	0.6	111.79	0.97	110.57	0.97
	0.7	103.87	0.96	105.30	0.96
	0.8	102.11	0.95	107.39	0.98
	0.9	106.26	0.97	111.75	0.99
	Average	125.68	S ² =584.31	132.18	S ² =760.81
	e				
40%	0.2	131.56	0.97	138.35	0.97
	0.3	171.12	0.95	184.55	0.95
	0.4	151.10	0.99	158.90	0.99
	0.5	212.26	0.96	223.21	0.96
	0.6	202.26	0.98	213.21	0.98
	0.7	103.91	0.99	109.27	0.99
	0.8	108.65	0.95	113.74	0.97
	0.9	113.89	0.94	119.77	0.95
	Average	135.16	S ² =1566.16	142.71	S ² =1773.29

Calculation results of the apparent activation energy of SR-Coal by FWO and V methods(stage 2)

Sample	α	FWO method		V method	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	173.89	0.98	177.12	0.96
	0.3	171.85	0.97	180.73	0.99
	0.4	152.24	0.98	168.63	0.96
	0.5	228.41	0.99	236.67	0.98
	0.6	186.69	0.98	181.94	0.96
	0.7	184.01	0.98	179.69	0.95
	0.8	160.36	0.97	162.29	0.97
	0.9	194.01	0.98	194.03	0.96
	Average	181	S ² =480.54	185.14	S ² =456.60
	0.2	144.35	0.99	146.37	0.97
20%	0.3	174.85	0.98	175.31	0.98
	0.4	183.94	0.94	182.83	0.95
	0.5	209.5	0.96	213.43	0.96
	0.6	168.14	0.99	165.27	0.94
	0.7	125.34	0.98	130.25	0.98
	0.8	139.91	0.97	141.26	0.96
	0.9	187.11	0.98	188.47	0.99
	Average	166.64	S ² =692.80	167.9	S ² =671.45
	0.2	107.29	0.98	106.06	0.95
	0.3	110.52	0.94	115.02	0.94
30%	0.4	204.91	0.94	211.15	0.98
	0.5	239.04	0.99	245.37	0.99
	0.6	223.72	0.94	234.33	0.94
	0.7	123.70	0.96	123.34	0.96
	0.8	178.56	0.95	176.14	0.92
	0.9	108.74	0.97	103.38	0.99
	Average	162.06	S ² =2725.86	164.35	S ² =3167.62
	0.2	133.61	0.97	130.00	0.97
	0.3	152.84	0.95	159.70	0.95
	0.4	188.98	0.99	187.18	0.99
40%	0.5	221.9	0.96	226.30	0.96
	0.6	186.7	0.98	183.54	0.98
	0.7	145.41	0.99	141.58	0.99
	0.8	125.41	0.95	131.88	0.97
	0.9	162.84	0.94	169.70	0.95
	Average	164.71	S ² =921.48	166.24	S ² =937.72

Calculation results of the apparent activation energy of CR-Coal by FWO and V methods(stage 1)

Sample	α	FWO method		V method	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	106.7	0.97	111.32	0.98
	0.3	128.71	0.98	136.98	0.97
	0.4	154.5	0.97	158.71	0.98
	0.5	157.01	0.99	160.29	0.98
	0.6	131.53	0.99	143.16	0.98
	0.7	110.81	0.97	112.85	0.99
	0.8	126.43	0.98	132.43	0.99
	0.9	140.34	0.96	142.87	0.95
	Average	132.07	S ² =291.56	136.58	S ² =293.61
20%	0.2	127.76	0.99	127.31	0.98
	0.3	136.21	0.98	136.52	0.97
	0.4	138.85	0.94	136.73	0.96
	0.5	145.86	0.96	148.64	0.95
	0.6	127.88	0.99	131.58	0.96
	0.7	131.73	0.98	128.63	0.98
	0.8	131.98	0.97	133.48	0.98
	0.9	139.85	0.98	144.65	0.99
	Average	136.24	S ² =35.08	135.82	S ² =48.89
30%	0.2	127.65	0.98	135.63	0.98
	0.3	134.05	0.94	140.75	0.98
	0.4	143.125	0.94	145.61	0.97
	0.5	147.09	0.99	153.93	0.98
	0.6	138.74	0.94	134.06	0.96
	0.7	132.03	0.96	142.18	0.97
	0.8	132.8	0.95	133.83	0.95
	0.9	144.52	0.97	150.22	0.98
	Average	137.5	S ² =41.92	142.03	S ² =49.36
40%	0.2	128.68	0.98	130.53	0.97
	0.3	136.12	0.99	138.72	0.99
	0.4	137.78	0.99	145.03	0.98
	0.5	157.74	0.97	166.32	0.97
	0.6	143.35	0.98	150.46	0.98
	0.7	147.67	0.99	152.88	0.96
	0.8	140.03	0.98	142.11	0.97
	0.9	127.92	0.99	132.39	0.97
	Average	139.91	S ² =84.84	144.81	S ² =120.29

Calculation results of the apparent activation energy of CR-Coal by FWO and V methods(stage 2)

Sample	α	FWO method		V mehod	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	134.35	0.98	136.37	0.96
	0.3	151.85	0.97	151.3	0.99
	0.4	173.94	0.98	170.23	0.96
	0.5	196.5	0.99	193.43	0.98
	0.6	168.87	0.98	165.17	0.96
	0.7	128.34	0.98	130.25	0.95
	0.8	139.91	0.97	137.06	0.97
	0.9	162.11	0.98	158.21	0.96
	Average	156.98	S ² =458.40	155.25	S ² =389.65
	0.2	99.53	0.99	108.46	0.97
20%	0.3	115.04	0.98	122.85	0.98
	0.4	128.80	0.94	136.15	0.95
	0.5	147.33	0.96	154.96	0.96
	0.6	152.83	0.99	159.86	0.94
	0.7	148.47	0.98	156.35	0.98
	0.8	126.62	0.97	138.27	0.96
	0.9	136.59	0.98	144.48	0.99
	Average	131.90	S ² =282.78	140.17	S ² =276.51
	0.2	157.14	0.98	165.26	0.95
	0.3	177.99	0.94	187.16	0.94
30%	0.4	192.04	0.94	202.15	0.98
	0.5	196.20	0.99	206.12	0.99
	0.6	176.35	0.94	185.46	0.94
	0.7	156.52	0.96	164.61	0.96
	0.8	138.75	0.95	145.91	0.92
	0.9	127.38	0.97	133.96	0.99
	Average	165.30	S ² =529.93	173.83	S ² =585.65
	0.2	182.54	0.97	191.96	0.97
	0.3	196.64	0.95	203.90	0.95
	0.4	215.94	0.99	223.85	0.99
40%	0.5	219.04	0.96	227.86	0.96
	0.6	173.91	0.98	182.88	0.98
	0.7	152.21	0.99	160.07	0.99
	0.8	134.62	0.95	141.57	0.97
	0.9	126.59	0.94	133.13	0.95

Average	175.19	S ² =1079.39	183.15	S ² =1115.9 1
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Calculation results of the apparent activation energy of CR-Coal by FWO and V methods(stage 3)

Sample	α	FWO method		V method	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	-		-	
	0.3	-		-	
	0.4	-		-	
	0.5	-		-	
	0.6	-	-	-	-
	0.7	-		-	
	0.8	-		-	
	0.9	-		-	
	Average	-		-	
20%	0.2	166.62	0.94	173.94	0.92
	0.3	189.81	0.96	197.89	0.94
	0.4	195.61	0.96	201.48	0.98
	0.5	198.05	0.97	206.37	0.99
	0.6	175.64	0.96	171.09	0.96
	0.7	183.66	0.98	185.49	0.98
	0.8	176.21	0.97	184.27	0.93
	0.9	196.49	0.96	204.04	0.97
	Average	185.26	S ² =117.75	190.57	S ² =165.65
30%	0.2	146.39	0.97	158.76	0.99
	0.3	172.11	0.96	181.00	0.94
	0.4	185.69	0.94	184.75	0.94
	0.5	198.53	0.98	206.20	0.98
	0.6	150.97	0.95	152.44	0.98
	0.7	167.36	0.97	165.95	0.99
	0.8	145.34	0.99	151.81	0.98
	0.9	163.08	0.96	160.99	0.95
	Average	166.18	S ² =316.32	170.23	S ² =313.96
40%	0.2	153.10	0.99	156.62	0.98
	0.3	179.61	0.97	187.66	0.94
	0.4	196.85	0.96	204.62	0.95
	0.5	225.35	0.98	226.45	0.96
	0.6	121.61	0.98	118.16	0.96
	0.7	126.61	0.96	124.51	0.98
	0.8	136.17	0.97	143.26	0.98
	0.9	143.87	0.97	159.84	0.95

Average	160.46	$S^2=1184.5$ 2	165.14	$S^2=1282.76$
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Calculation results of the apparent activation energy of PR-Coal by FWO and V methods(stage 1)

Sample	α	FWO method		V mehod	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	100.09	0.97	102.73	0.98
	0.3	147.49	0.99	146.53	0.96
	0.4	90.867	0.97	93.31	0.98
	0.5	138.98	0.98	138.13	0.98
	0.6	134.03	0.96	133.42	0.97
	0.7	103.31	0.97	104.83	0.96
	0.8	139.86	0.96	140.39	0.99
	0.9	117.3	0.97	120.43	0.98
	Average	121.5	S ² =402.55	122.47	S ² =352.56
	0.2	110.83	0.96	113.54	0.98
20%	0.3	137.32	0.97	135.74	0.97
	0.4	120.33	0.97	122.43	0.96
	0.5	140.63	0.98	140.75	0.98
	0.6	148.11	0.97	143.43	0.97
	0.7	110.25	0.98	108.74	0.96
	0.8	128.38	0.98	126.84	0.98
	0.9	127.43	0.97	128.64	0.95
	Average	127.91	S ² =164.99	127.51	S ² =133.93
	0.2	108.44	0.98	113.54	0.98
	0.3	132.39	0.97	140.48	0.96
30%	0.4	138.83	0.97	118.64	0.97
	0.5	150.33	0.96	144.29	0.97
	0.6	152.13	0.99	150.46	0.98
	0.7	130.31	0.98	132.54	0.98
	0.8	110.32	0.98	114.57	0.96
	0.9	132.14	0.96	128.54	0.98
	Average	131.86	S ² =226.99	130.38	S ² =172.27
	0.2	99.54	0.97	101.43	0.98
	0.3	119.64	0.98	116.54	0.96
	0.4	128.94	0.98	134.65	0.99
40%	0.5	156.04	0.99	152.55	0.98
	0.6	143.91	0.97	141.48	0.97
	0.7	112.21	0.96	110.51	0.97
	0.8	132.59	0.98	130.74	0.98
	0.9	134.62	0.97	133.42	0.96
	Average	128.43	S ² =279.10	127.67	S ² =250.98

Calculation results of the apparent activation energy of PR-Coal by FWO and V methods(stage 2)

Sample	α	FWO method		V mehod	
		E(kJ/mol)	R ²	E(kJ/mol)	R ²
10%	0.2	124.58	0.98	125.53	0.97
	0.3	113.11	0.96	118.42	0.98
	0.4	138.33	0.97	143.52	0.98
	0.5	164.21	0.97	159.68	0.96
	0.6	173.99	0.98	178.84	0.95
	0.7	150.42	0.99	155.43	0.98
	0.8	129.36	0.99	130.41	0.97
	0.9	133.56	0.98	134.75	0.97
	Average	140.95	S ² =370.15	143.32	S ² =356.58
	0.2	127.34	0.98	133.43	0.98
20%	0.3	120.42	0.95	118.65	0.97
	0.4	131.46	0.96	135.77	0.96
	0.5	183.73	0.99	186.26	0.98
	0.6	168.58	0.97	174.62	0.97
	0.7	152.61	0.96	157.46	0.96
	0.8	128.53	0.98	129.83	0.98
	0.9	133.47	0.98	130.69	0.95
	Average	143.27	S ² =449.19	145.84	S ² =509.71
	0.2	110.52	0.96	116.43	0.99
	0.3	118.43	0.98	125.27	0.98
30%	0.4	130.57	0.98	132.86	0.98
	0.5	170.66	0.99	1860.58	0.97
	0.6	188.84	0.96	180.54	0.96
	0.7	120.31	0.97	121.91	0.97
	0.8	143.15	0.98	144.65	0.98
	0.9	167.53	0.98	172.11	0.99
	Average	143.75	S ² =723.95	147.54	S ² =695.17
	0.2	118.6	0.98	115.42	0.96
	0.3	125.38	0.97	133.76	0.98
	0.4	143.84	0.98	136.83	0.98
40%	0.5	180.23	0.98	173.55	0.99
	0.6	167.76	0.99	160.2	0.99
	0.7	133.43	0.99	124.63	0.97
	0.8	146.32	0.96	140.14	0.98
	0.9	162.73	0.96	157.91	0.96
	Average	147.29	S ² =406.32	145.41	S ² =335.1
					1

Fig. S3 E as a function of conversion degree

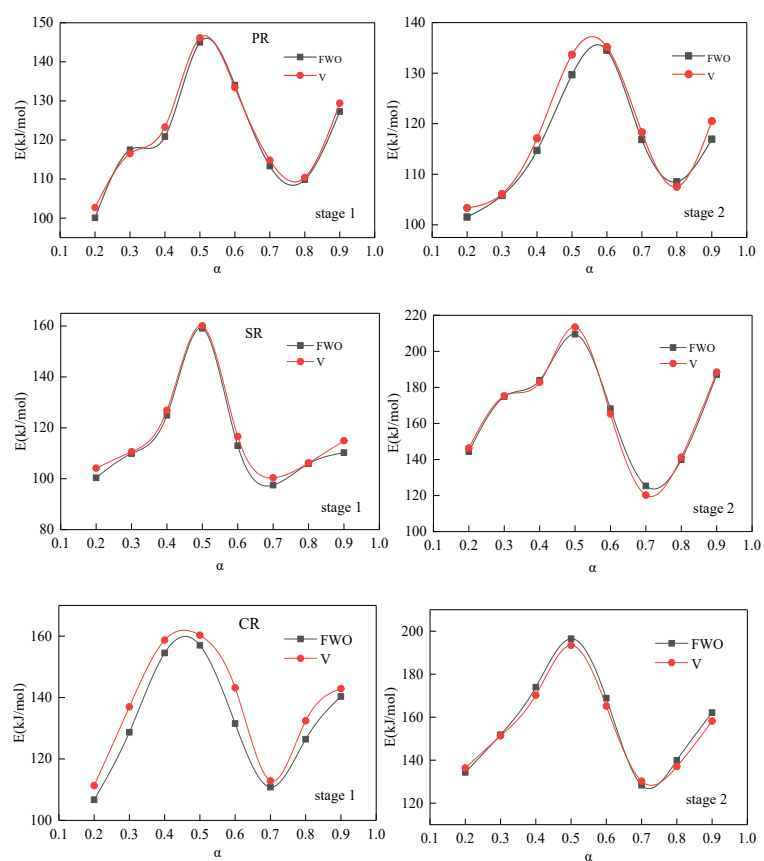


Fig. S4. The experimental master-plots of AFRs at different heating rates

