

Supporting Information to the article:

Mechanism of coking pressure generation in the light of the results of laboratory tests

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Section 2: Materials and Methods

Table S1. Characteristics of the examined coals.

Parameter	Coal		
	Budryk	Borynia	H. Robert
$W^{ad}, \%$	0.9	2.4	0.9
$A^{ad}, \%$	5.7	4.9	6.7
$V^{daf}, \%$	34.6	26.4	23.1
$R, \%$	0.90	1.08	1.30
$RI, \%$	75	73	72
$SI, \%$	8 ^{1/2}	8 ^{1/2}	9
p_{max}, kPa	67.9	91.8	132.0
Indices of coal fluidity by Gieseler:			
$t_1, ^\circ\text{C}$	386	394	406
$t_{max}, ^\circ\text{C}$	437	454	460
$t_3, ^\circ\text{C}$	478	489	492
F_{max}, ddpm	26,995	1312	102
Dilatometric indices by Arnu-Audibert:			
$t_I, ^\circ\text{C}$	362	385	399
$t_{II}, ^\circ\text{C}$	417	431	440
$t_{III}, ^\circ\text{C}$	465	479	479
$a, \%$	26	28	23
$b, \%$	106	100	39

Subsection 3.1: Impact of the plastic layer expansion on the generated coking pressure

Table S2. Maximal values of pressure generated by the examined coal samples (shares of grain size fractions: <0.5 mm - 45%; 0.5–1 mm - 20%; 1–3 mm - 15%; 3–5 mm - 20%). Characteristics of the examined coals.

Coal	Maximal generated pressure (kPa)		
	expansion of 0%	expansion of 10%	expansion of 20%
Budryk	1375	88	10
Borynia	336	14	1
H. Robert	30	0	0

Table S3. Measurement results of maximal pressure (kPa) generated within the temperature range of coal plasticity by selected grain size fractions – input data for the conducted statistical analysis.

Coal	Grain size fraction (mm)	Expansion of the carbonized sample, %				
		0	10	20	30	40
Budryk	2.5–3.15	1577	1230	1218	682	265
		1603	1260	1166	710	241
Borynia		877	695	210	58	29
		841	709	228	38	11
H. Robert		1199	39	34	0	0
		1179	17	18	0	0
Budryk	1.0–1.2	1015	552	397	108	0
		1049	534	421	126	0
Borynia		272	10	0	0	0
		302	22	0	0	0
H. Robert		453	22	0	0	0
		481	10	0	0	0
Budryk	0.5–0.63	826	573	59	0	0
		806	539	43	0	0
Borynia		278	0	0	0	0
		296	0	0	0	0
H. Robert		239	0	0	0	0
		217	0	0	0	0
Budryk	0.2–0.315	0	0	0	0	0
		0	0	0	0	0
Borynia		0	0	0	0	0
		0	0	0	0	0
H. Robert		0	0	0	0	0
		0	0	0	0	0
Budryk	0–0.5	1364	82	0	0	0
		1386	94	0	0	0
Borynia		323	22	0	0	0
		349	6	0	0	0
H. Robert		41	0	0	0	0
		19	0	0	0	0

Subsection 3.2: Relationship between the phenomenon of free swelling of coal grains and the coking pressure generated by their layer

Table S4. Characteristics of the examined coals.

Parameter	Coal											
	Budryk			Zofiówka			Consolidation			Peak Downs		
	0.4–0.6, mm	1.4–1.5, mm	2.0–3.15, mm	0.4–0.6, mm	1.4–1.5, mm	2.0–3.15, mm	0.4–0.6, mm	1.4–1.5, mm	2.0–3.15, mm	0.4–.6, mm	1.4–1.5, mm	2.0–3.15, mm
W^{ad} , %	1.3	1.3	1.2	0.9	1.0	1.0	0.8	0.7	0.7	1.0	1.0	0.9
A^{ad} , %	9.7	8.0	8.5	6.1	8.2	10.8	4.0	5.4	8.4	9.3	12.3	13.4
V^{daf} , %	31.56	32.14	31.81	23.62	22.98	22.26	17.44	17.25	16.57	19.54	18.80	18.49
R, %	35.46	35.44	35.23	25.40	25.31	25.24	18.32	18.37	18.23	21.78	21.68	21.58
RI, %	73	73	69	77	70	65	70	68	56	66	60	53
SI, %	8	8	7	8.5	8	6,5	7.5	7	6	8	8	7
p_{max} , kPa	64.3	16.0	17.4	83.4	29.0	14.1	37.2	31.1	33.4	9.4	11.6	20.3
Indices of coal fluidity by Gieseler:												
t_I , °C	381	379	374	386	392	397	431	428	432	410	415	412
t_{max} , °C	438	439	438	453	457	456	475	474	474	468	466	464
t_3 , °C	474	475	474	491	492	491	502	500	495	493	490	486
F_{max} , ddpm	4 211	9 400	9 740	1 409	1 008	643	30	28	8	46	19	10
Dilatometric indices by Arnu-Audibert:												
t_I , °C	369	364	359	392	387	394	427	422	422	410	405	402
t_{II} , °C	417	419	419	432	432	442	466	466	496	454	457	469
t_{III} , °C	460	470	463	483	478	478	500	500	496	493	490	490
a, %	29	29	30	25	27	23	23	26	24	23	20	21
b, %	+86	+96	+89	+131	+80	+26	+20	+8	-20	+28	-4	-18

Table S5. Comparison of indices of the relative grain volume increase of examined coals (kv) with values of the maximal generated pressure (kPa) for different bulk densities of samples.

Coal	Size fraction (mm)	Index of the relative volume increase of coal grain; kv, -	p _{max} – max. value of generated pressure (kPa) for bulk density of sample	
			0.72 g/cm ³	0.80 g/cm ³
Zofiówka	0.4 – 0.6	1.42	346	902
	1.4 – 1.5	1.81	834	1253
	2.5 – 3.15	2.01	717	1010
Budryk	0.4 – 0.6	1.79	1160	1226
	1.4 – 1.5	2.71	2137	2620
	2.5 – 3.15	3.16	1929	2586
Consolidation	0.4 – 0.6	1.66	1600	2002
	1.4 – 1.5	1.70	1144	1642
	2.5 – 3.15	2.22	531	822
Peak Downs	0.4 – 0.6	1.57	1 019	1658
	1.4 – 1.5	2.03	181	713
	2.5 – 3.15	2.10	0	176

Table S6. Course and final results of significance analysis of linear correlation ($y = bx + a$).

	Bulk density of coal sample	
	0.72 g/cm ³	0.80 g/cm ³
Regression coefficient b	656.81	713.41
Regression coefficient a	-356.97	-53.35
Correlation coefficient r	0.269	0.407
Critical value of correlation coefficient $r_{0,05;10}$	0.576	0.576
Significance of correlation	no	no

Table S7. Course and final results of the Spearman-test – verification of the correlation between the index of relative increase of plasticized coal grain and maximal pressure generated by the bed of such grains (for bulk density of coal sample equal to 0.72 and 0.80 g/cm³)

Coal	Size fraction (mm)	Value of parameter		Classification of parameter		d^2	r_s	r_{s-kr}	Signi- ficance
		kV, -	p _{max} , kPa	kV, -	p _{max} , kPa				
Bulk density of coal sample: 0.720 g/cm ³									
Zofiówka	0.4 – 0.6	1.42	346	1	3	4	0.119	0.506	no
	1.4 – 1.5	1.81	834	6	6	0			
	2.5 – 3.15	2.01	717	7	5	4			
Budryk	0.4 – 0.6	1.79	1160	5	9	16			
	1.4 – 1.5	2.71	2137	11	12	1			
	2.5 – 3.15	3.16	1929	12	11	1			
Consolidation	0.4 – 0.6	1.66	1600	3	10	49			
	1.4 – 1.5	1.70	1144	4	8	16			
	2.5 – 3.15	2.22	531	10	4	36			
Peak Downs	0.4 – 0.6	1.57	1019	2	7	25			
	1.4 – 1.5	2.03	181	8	2	36			
	2.5 – 3.15	2.10	0	9	1	64			
Bulk density of coal sample: 0.720 g/cm ³									
1.42	0.4 – 0.6	1.42	902	1	4	9	0.021	0.506	no
	1.4 – 1.5	1.81	1253	6	7	1			
	2.5 – 3.15	2.01	1010	7	5	4			
Budryk	0.4 – 0.6	1.79	1226	5	6	1			
	1.4 – 1.5	2.71	2620	11	12	1			
	2.5 – 3.15	3.16	2586	12	11	1			
Consolidation	0.4 – 0.6	1.66	2002	3	10	49			
	1.4 – 1.5	1.70	1642	4	8	16			
	2.5 – 3.15	2.22	822	10	3	49			
Peak Downs	0.4 – 0.6	1.57	1658	2	9	49			
	1.4 – 1.5	2.03	713	8	2	36			
	2.5 – 3.15	2.10	176	9	1	64			

Subsection 3.3: Impact of plastic layer thickness on the generated coking pressure

Table S8. Characteristics of the examined coal blend.

Parameter		Value
Proximate analysis	$W^{\text{ad}}, \%$	1.1
	$A^{\text{ad}}, \%$	7.0
	$V^{\text{daf}}, \%$	30.17
Size of grains < 3 mm	$\%$	91
Bulk density	$d, \text{g/cm}^3$	0.75
	$SI, -$	7.0
Coking properties	$t_I, ^\circ\text{C}$	385
	$t_{II}, ^\circ\text{C}$	430
	$t_{III}, ^\circ\text{C}$	460
	$a, \%$	30
	$b, \%$	+36

Subsection 3.4: Influence of the compression of the 'cool' part of coal charge and the migration of the plasticized coal matter outside the plastic layer on the generated coking pressure

Table S9. Characteristics of the coals used for examinations.

Parameter		Coal	
		Borynia	H.Robert
Proximate analysis	$W^{ad}, \%$	2.4	0.9
	$A^{ad}, \%$	4.9	6.7
	$V^{daf}, \%$	26.4	23.1
	$R_0, \%$	1.08	1.3
Coking properties	RI, -	73	72
	SI, -	8.5	9
	P_{max}, kPa	91.8	132.0
Indices of coal fluidity by Gieseler	$t_I, ^\circ\text{C}$	394	406
	$t_{II}, ^\circ\text{C}$	440	460
	$t_{III}, ^\circ\text{C}$	489	492
	F_{max}, ddpm	1312	102
Dilatometric indices by Arnu-Audiebert	$t_I, ^\circ\text{C}$	385	399
	$t_{II}, ^\circ\text{C}$	431	440
	$t_{III}, ^\circ\text{C}$	479	479
	a, %	28	23
	b, %	100	39

Table S10. Grain size distribution of the examined coals.

Size fraction, mm	Mass share of size fraction, %
below 0.5	45
0.5 – 1.0	20
1.0 – 3.15	15
3.15 – 5.0	20

Table S11. Characteristics of the examined coals.

Parameter:		Coal:		
		Budryk No.1	Budryk No. 2	Pniówek
Moisture content	$W^{ad}, \%$	1.4	1.5	1.3
Ash content	$A^{ad}, \%$	5.0	6.1	4.9
Volatile matter content	$V^{ad}, \%$	31.53	31.85	27.11
Dilatometric indices:	$t_I, ^\circ\text{C}$	363	366	378
	$t_{II}, ^\circ\text{C}$	412	414	419
	$t_{III}, ^\circ\text{C}$	463	460	484
	$a, \%$	28	27	26
	$b, \%$	+129	+64	+153
	$t_I, ^\circ\text{C}$	379	388	387
	$t_{max}, ^\circ\text{C}$	437	437	446
Indices od coal fluidity:	$t_3, ^\circ\text{C}$	473	475	482
	F_{max}, ddpm	5208	2949	2185
Roga Index	RI, -	81	78	81
Free swelling index	SI, -	8.5	8.8	8.5
Indices of the Shapozhnikow-test:	X, mm	25	24	5
	Y, mm	28	16	28
Result of laboratory measurement of coking pressure by Polish Standard: PN -73/G-04522	P_{max}, Pa	46.6	25.7	>140

Table S12. Grain size distribution of the examined coals.

Size fraction, mm	Mass share of grain size fraction, %								
	Budryk No.1			Budryk No.2			Pniówek		
	>5mm	>3 mm	>2mm	>5mm	>3 mm	>2mm	>5mm	>3 mm	>2mm
0 – 0,5	19.5	38.4	61.8	17.0	51.1	56.4	37.0	47.1	68.6
0.5 – 1.0	17.7	23.4	19.3	12.6	18.9	20.9	18.4	20.9	17.2
1.0 – 2.0	21.1	25.9	18.9	20.7	20.4	22.7	22.6	21.9	14.2
2.0 – 3.0	19.2	12.3	-	20.7	9.6	-	14.7	10.1	-
3.0 – 5.0	22.5	-	-	29.0	-	-	11.3	-	-
Mean size of grain (mm)	1.88	1.01	0.58	2.13	0.82	0.64	1.39	0.86	0.51

Table S13. Results of coking pressure examinations (kPa) according to the design of the experiment.

Levels of the analyzed factors	Measurement No.1	Measurement No.2
1; I; A; α	15.0	0.0
1; II; B; γ	3.0	0.0
1; III; C; β	0.0	28.0
2; I; B; β	14.5	107.5
2; II; C; α	0.0	0.0
2; III; A; γ	224.0	0.0
3; I; C; γ	0.0	150.0
3; II; A; β	0.0	0.0
3; III; B; α	294.5	111.5

Table S14. Statistical significance of the analysed factors influencing the migration phenomenon in respect of the value of the generated coking pressure.

Analysed factor:	Calculated value of test F	Critical value of test $F_{0,05}$	Significance ($\alpha = 0.05$)
Fluidity of plasticized coal matter	26.560	4.26	Yes
Size of grains	16.174	4.26	Yes
Bulk density	47.038	4.26	Yes
Degree of expansion	5.207	4.26	Yes

Subsection 3.5: Preliminary assessment of the usefulness of laboratory measurements for the identification of dangerous coals (in respect of generation of an excessively high wall pressure)

Table S15. Characteristics of the examined coals (size fraction: 0–3.15 mm).

Coal	Proximate analysis			SI, -	Dilatometric indices by Arnu-Audiebert					Coal fluidity indices by Gieseler			
	W ^{ad} , %	A ^{ad} , %	V ^d , %		t _I , °C	t _{II} , °C	t _{III} , °C	a, %)	B, %	t ₁ , °C	t _{max} , °C	t ₃ , °C	F _{max} , ddp _m
Budryk	1.3	8.0	33.49	8.0	364	419	465	30	+96	379	439	474	9400
Szczygłowiec	1.5	4.4	30.20	7.5	369	430	463	27	+42	388	442	477	1314
Pniówek	1.3	10.6	25.95	7.5	370	425	464	35	+86	387	446	482	2185
Borynia	2.4	4.9	25.21	8.5	385	431	475	28	+100	393	452	486	1108
Zofiówka	0.8	7.5	23.61	8.0	375	430	465	34	+55	389	447	488	870
Burton	2.0	6.8	21.44	6.5	392	445	474	22	–7	410	457	482	72
H.Robert	0.9	6.7	21.59	9.0	399	440	479	23	+39	393	452	486	102