Petroleum and Coal

Article **Open Access**

THE USING OF COAL BLENDS WITH AN INCREASED CONTENT OF COALS OF THE MIDDLE STAGE OF METAMORPHISM FOR THE PRODUCTION OF THE BLAST-FURNACE COKE. MESSAGE 1. PREPARATION OF COAL BLENDS

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Received March 13, 2018; Accepted May 31, 2018

Abstract

Laboratory and industrial research confirm that decrease in the coking properties of bituminous coal with a high level of fluidity (HFC) when it is present to excess in the coking blend improves the strength of blast-furnace coke. If coal blend containing >70% HFC is crushed until its content of the ≤ 3 mm class is 90%, the crushability M_{25} may be increased by 1.8%, with a decrease in the abrasion strength M_{10} by 0.8%. This behavior may be explained in that increase in the specific surface of the coal particles reduces the fluidity of the plastic mass and hence increases its viscosity. Consequently, the residence time of the gaseous products in the plastic zone increases. That results in the formation of a large quantity high-molecular gas, creating higher expansion pressure. The overall outcome is greater utilization of the destruction products as plasticizers; the formation of an additional liquid from the gaseous products within the grains; and improvement in the contact conditions.

***Keywords**: coal blend; coal with a high level of fluidity grindability; coking properties; coke strength.*

1. Introduction

In previous work, we analyzed the reasons for the decline in quality of the coke produced at ArcelorMittal Kryvyi Rig [1–5]. They include the purchase of coal concentrates from a multitude of suppliers; the instability of the coke supplies for coking (sometimes as many as 60–80 changes in blend composition within a month); incorrect selection of the optimal degree of blend crushing (that is, the content of the ≤3 mm class), so that the packing density of the blend and the content of the poorly coking 0–0.5 mm class in the blend are not optimal with varying rank composition of the blend; elevated moisture and ash content of the blend sent for coking; and very variable coal and blend quality.

Attempts to improve blend preparation with the coal supplies currently available in Ukraine entail selection of the optimal degree of crushing of coal blend with a very high content of HFC [6]. Since the content of the ≤3 mm class varied from 76 to 89% in coke production at ArcelorMittal Kryvyi Rig, while the content of HFC (bituminous coal) varied from 56 to 89%, it is of interest to analyze the influence of these two factors on coke quality. If the content of HFC in the blend is 70–89%, the strength of the coke increases with increase in the degree of crushing. If the content of the ≤3 mm class in the blend is increased from 76 to 89%, with a corresponding increase in the <0.5 mm class from 37 to 47%, M_{25} increases from 85.6 to 87.3%, on average.

Obviously, if the content of HFC in the blend is too high to permit the production of coke with satisfactory strength, we must reduce the coking properties of the blend by further crushing. Note that the crushing of valuable HFC to reduce its coking properties should be regarded as a last resort to improve the coke quality when the content of the HFC in the blend is excessive. In other circumstances, it cannot be recommended for use in the preparation of coking blend.

It is expedient to investigate why the strength of the blast-furnace coke produced from a blend with >70% HFC improves if the content of the ≤3 mm class in the blend is increased from ~80 to ~90%. We will also study the change in the strength of the coke produced from a blend with <70% HFC.

2. Experimental

In the experiments, we use concentrates obtained from coal of different ranks available in Ukraine: Taltek (Russia); Kievskaya (Ukraine); Cherkasov Kamen' (Russia); and Kalinovskaya Vostochnaya (Ukraine).

Tables 1–3 present the technological properties, petrographic characteristics, and granulometric composition of the coal concentrates. Note that, since the experiment is conducted in two stages, we use two samples of Kievskaya concentrate and two samples of Kalinovskaya Vostochnaya coal. We know that oxidation of the coal samples has a considerable influence on their properties [7–9]. Therefore, we use only unoxidized coal (Δt < 6ºC).

Table 1. Technological properties of coal concentrate

Component; country	Proximate analysis, %			Thickness of plastometric lager, mm	Hardgrove grindability, un.	Oxidation index, °C
	A^d	S^d_t	V^{daf}	x	HGI	Δt
Taltek' coal; Russia	8,7	0,51	36,5	10	53	3
Kievskaya coal; Ukraine, sample 1	8,8	1,56	31,2	22	76	2
Kievskaya coal; Ukraine, sample 2	8,7	1,57	30,9	22	78	1
Kalinovskaya Vostochnaya coal; Ukraine, sample 1	8,2	1,41	21,6	16	98	3
Kalinovskaya Vostochnaya coal; Ukraine, sample 2	7,7	1,64	21,5	16	91	2
Cherkasov Kamen' coal; Russia	9,6	0,53	27,9	14	67	1

Table 2. Petrographic characteristics of coal concentrate

Component; country	Petrographic composition (without mineral impurities), %					Mean vitrinite reflection coefficient, %	Distribution of vitrinite reflection coefficient, %					
	V_t	S_v	I	L	ΣFC	R_0	0.50–0.64	0.65–0.89	0.90–1.19	1.20–1.39	1.40–1.69	1.70–2.59
Taltek' coal; Russia	71	0	27	2	27	0,63	63	37	0	0	0	0
Kievskaya coal; Ukraine, sample 1	90	0	8	2	8	1,04	0	7	79	14	0	0
Kievskaya coal; Ukraine, sample2	91	0	8	1	8	1,04	0	3	95	2	0	0
Kalinovskaya Vostochnaya coal; Ukraine, sample 1	92	0	8	0	8	1,33	0	0	6	72	22	0
Kalinovskaya Vostochnaya coal; Ukraine, sample 2	90	0	10	0	10	1,40	0	0	3	49	48	0
Cherkasov Kamen' coal; Russia	57	0	43	0	43	0,99	0	15	85	0	0	0

Table 3. Granulometric composition of coal concentrates

Component; country	Granulometric composition (%) by class (mm)								Mean particle diameter, mm
	>25	13–25	6–13	3–6	1–3	0.5–1.0	<0.5	≤3	d_{me}
Taltek' coal; Russia	19.1	16.7	16.4	16.6	14.1	6.0	11.1	31.2	13.00
Kievskaya coal; Ukraine, sample 1	–	0.8	2.5	7.0	29.7	24.8	35.2	89.7	1.57
Kievskaya coal; Ukraine, sample 2	–	–	5.0	9.2	21.7	23.4	40.7	85.8	1.60
Kalinovskaya Vostochnaya coal; Ukraine, sample 1	–	1.3	3.9	11.1	22.7	14.9	46.1	83.7	1.80
Kalinovskaya Vostochnaya coal; Ukraine, sample 2	–	1.9	5.1	14.3	19.5	19.1	40.1	78.7	2.10
Cherkasov Kamen' coal; Russia	9.1	14.2	9.7	13.8	19.9	9.1	24.2	53.2	8.18

Analysis of Tables 1–3 indicates that the coal samples may be divided into two groups.

1. Taltek and Cherkasov Kamen', characterized by an elevated content of fusinized components (27–43%), poor coking properties (y =10–14 mm), and low Hargrove grindability (53–67 units). Coal in this group contains 33.0–52.2% of the >6 mm class and no more than 31.2–53.2% of the <3 mm class.

2. Kievskay and Kalinovskaya Vostochnaya, which are petrographically uniform ($\sum FC < 25\%$), with good coking properties (y = 16–22 mm) and Hardgrove grindability of 76–98. 2 units. Coal in this group contains 3.3–7.0% of the >6 mm class and 78.7–89.7% of the <3 mm class.

Table 4 presents the composition of the experimental blends. Blends 1–3 correspond to the actual blend composition used in coking at a Ukrainian plant, with 42% Kievskaya coal. In other words, the content of HFC is significant but less than 70%. In blends 4 and 5, the content of Kievskaya coal exceeds 70%; in fact, it is 80%. That may be due to temporary disruption of normal coal supplies to the plant.

Table 4 Composition of coal blends

Batch component; country	Blend, %	
	1–3	4, 5
Taltek' coal; Russia	35	15
Kievskaya coal; Ukraine, sample 1	42	0
Kievskaya coal; Ukraine, sample 2	0	80
Kalinovskaya Vostochnaya coal; Ukraine, sample 1	10	0
Kalinovskaya Vostochnaya coal; Ukraine, sample 2	0	5
Cherkasov Kamen' coal; Russia	13	0
Total	100	100

The whole blend is crushed at once. The content of the ≤3 mm class is 82.7–90.3% in blends 1–3 and 81.0–90.0% in blends 4 and 5. Increasing the degree of crushing decreases the mean diameter of the coal particles: from 1.68 to 1.45 in the first series (Table 4, blends

1–3); and from 2.39 to 1.56 mm in the second series (blends 4 and 5). Table 5 presents the granulometric composition of the experimental blends. Table 6 presents their technological properties, while Table 7 summarizes their petrographic characteristics.

Table 5. Granulometric composition of coal blends

Blend	Granulometric composition (%) by class (mm)					Mean particle diameter, mm
	>3	1–3	0.5–1.0	<0.5	≤3	d_{me}
1	17.3	34.5	17.3	30.9	82.7	1.68
2	13.5	38.1	17.1	31.3	86.5	1.58
3	9.7	39.9	18.8	31.6	90.3	1.45
4	19.0	49.0	14.0	18.0	81.0	2.39
5	10.0	49.0	16.0	25.0	90.0	1.56

Table 6. Technological properties of coking batches

Blend	Proximate analysis, %			Thickness of plastometric lager, mm	Expansion pressure, kPa	Gieseler plastic properties				
	A^d	S^d_t	V^{daf}	y	P^n_{max}	t_1, °C	t_{max}, °C	t_{so}, °C	Δt, °C	F_{max}, ddpm
1	8.7	1.07	31.7	16	3.4	421	451	480	59	100
2	8.8	1.06	31.6	15	3.5	421	457	481	60	119
3	8.8	1.06	31.5	15	3.7	425	456	484	59	125
4	8.4	1.41	31.3	20	4.2	408	447	480	72	335
5	8.4	1.41	31.3	20	7.4	414	447	480	66	135

Table 7. Petrographic characteristics of coal blends

Blend	Petrographic composition (without mineral impurities), %					Mean vitrinite reflection coefficient, %	Distribution of vitrinite reflection coefficient, %					
	V_t	S_v	I	L	ΣFC	R_0	0.50–0.64	0.65–0.89	0.90–1.19	1.20–1.39	1.40–1.69	1.70–2.59
1	78	0	21	1	21	0.94	19	22	48	7	4	0
2	81	0	18	1	18	0.95	23	25	38	12	2	0
3	80	0	19	1	19	0.95	25	18	43	10	4	0
4	88	0	11	1	11	1.00	9	8	77	4	2	0
5	88	0	11	1	11	1.00	9	8	77	4	2	0

For better assessment of how the degree of crushing affects the strength of blast furnace coke, we determine the expansion pressure and the Gieseler plasticity of the coal blends. The expansion pressure is the pressure applied by the coal mass in a plastic state when the free expansion is impossible [10].

In the tests, we record the following temperatures (°C): the onset of softening t_1; maximum fluidity t_{max}; solidification t_{so}; and the plastic range $\Delta t = t_1 - t_{so}$. The most important of the measured characteristics is the maximum fluidity F_{max}, ddpm (dial divisions per minute), which characterizes the viscosity of the plastic mass.

3. Results and discussion

Analysis indicates that the results of the proximate and plastometric analysis are practically the same for the two series of blends. This indicates agreement of the actual and specified compositions.

If the content of the ≤3 mm class is increased from to 90.3% in the first series (Table 5, blends 1–3), the fluidity of the plastic mass increases somewhat (from 100 to 125 ddpm). That may be due to the more uniform distribution of petrographically distinct Taltek and Cherkasov Kamen' coal particles within the blend. With the increase in the degree of crushing in the second series (batches 4 and 5), the fluidity of the plastic mass declines considerably (from 335 to 135 ddpm), and its viscosity increases accordingly.

In that case, we may observe the effect noted in [11-12]: if coal blend with a high content of HFC is more finely crushed, the infusible grains are better dispersed in the surrounding plastic mass, with consequent increase in the concentration of the disperse phase and the viscosity of the dispersion medium. In those circumstances, the expansion pressure tends to increase (from 4.2 to 7.4 kPa). That may be explained by an increase in the proportion of vapor gas phase and hence in its pressure on the plastic layer. For example, a decrease in particle size is accompanied by an increase in the total surface of the disperse phase and decrease in the quantity of free dispersion medium, which results in increased viscosity of the plastic mass and improved coke quality.

If we regard blends 4 and 5 as practically the same, we may agree with the conclusion in [13]: "for all coal ranks, a more fluid plastic mass is formed with greater crushing." The increase in fluidity of the plastic mass in HFC is due to the greater delay in the formation of liquid products within the large grains, their tendency to plasticize the remainder of the grain, and its more complete transition to the plastic state, according to [13]. The crushing of the coal increases the specific surface of the particles, accelerates the evacuation of gases, and slows reduction processes, according to [14]. The overall result increases in the viscosity of coal in the plastic state.

Since the expansion pressure reflects the gas pressure developed within a volume surrounded by a plastic layer, we may expect that this pressure will increase with an increase in viscosity of the plastic layer, other conditions being equal [15].

By increasing pressure within the plastic zone and the contact between the particles, the increase in viscosity of the plastic mass hinders gas liberation. That extends the period during which the destruction products are plastic. In view of the foregoing, the increase in expansion pressure from 4.2 to 7.4 kPa when blend with a high content of HFC is more finely ground is entirely predictable.

The next step is box coking of the coal blends. The blends are placed in 200 × 200 × 300 mm iron boxes; three boxes are used for each coking blend. The packing density is 800 kg/m^3 in all cases; the coking time is 22 h; the actual temperature in the heating channels is 1167ºC on the machine side and 1174ºC on the coke side.

After coking, the boxes are cooled in water and opened. The coke is placed on trays and dried in a chamber to constant mass. Table 8 presents the characteristics of the coke produced.

The results indicate that the coke produced in each series is characterized by similar yield, ash content, and total sulfur content. The volatile matter is low (0.1–0.3%). That indirectly indicates that the coking process is over and the coke has been fully cooked.

It follows from Table 8 that, if blends containing <70% of HFC (blends 1–3) are more intensively crushed, the resultant increase in strength of the coke is slight. That is consistent, in particular, with the slight increase in expansion pressure (from 3.4 to 3.7 kPa). The crushability M_{25} increases by 0.4–0.6%, with a decrease in the abrasion strength M_{10} by 0.1–0.2%.

Table 8. Characteristics of the coke produced

Blend	Coke yield B_{co}, %	Proximate analysis, %			Mechanical strength, %	
		A^d	S^d_t	V^{daf}	M_{25}	M_{10}
1	74.5	11.7	0.90	0.1	90.9	7.7
2	74.6	11.8	0.89	0.2	91.3	7.6
3	74.5	11.7	0.87	0.1	91.5	7.5
4	74.8	11.2	1.19	0.3	89.3	8.4
5	74.9	11.3	1.21	0.2	91.1	7.6

In the present case, the increase in coke strength may be attributed to decrease in the local stress due to the coking of coal particles with different petrographic composition and hence volatile matter, thermal stability, and the physical properties [14].

If blends containing >70% of HFC (blends 4 and 5) are more intensively crushed, we note a considerable increase in the strength of blast furnace coke: the crushability M_{25} is increased by 1.8%, with a decrease in the abrasion strength M_{10} by 0.8%.That is due to the considerable increase in expansion pressure (from 4.2 to 7.4 kPa). On account of the increase in viscosity of the plastic mass, the residence time of the gaseous products in the plastic zone increases. That is associated with the formation of a larger quantity of high molecular gases, which create higher expansion pressure.

Therefore, in this case, the improvement in coke strength is predominantly due to increases in the expansion pressure of the coal blend, which results not only in the greater use of the liquid destruction products as plasticizers but also in the formation of an additional liquid from the gaseous products within the grains. That is associated with better softening of the coal grains and more complete contact between the grains (in some cases, their coalescence) [16].

Thus, we have studied how greater crushing of coal blend with a high content of HFC affects the properties of the plastic mass and the mechanical strength of the coke formed. Our research illuminates the factors responsible for the increase in the coke strength and confirms that, as previously determined by analysis, a decrease in the coking properties of HFC when it is present in the blend in excessive quantities improves the strength of blast-furnace coke.

Symbols

A^d	*ash content of coal in the dry state, %;*
St^d	*sulphur of coal in the dry state, %;*
V^{daf}	*volatile matter in the dry ash-free state, %;*
y	*thickness of the plastic layer, mm;*
HGI	*hardgrove grindability index, units;*
Δt	*oxidation index, °C;*
Vt	*vitrinite, %;*
Sv	*semivitrinite, %;*
I	*inetinit, %;*
L	*liptinite, %;*
∑FC	*sum of fusinized components, %;*
R_0	*mean vitrinite reflection coefficient, %;*
d_{me}	*mean diameter of coals particles, mm;*
P^h_{max}	*expansion pressure of coal (blend), kPa;*
t_1	*temperature of the onset of softening, °C;*
t_{max}	*temperature of maximum fluidity, °C;*
t_{so}	*temperature of soliditication, °C;*
F_{max}	*maximum fluidity, ddpm;*
M_{10}, M_{25}	*indices of resistance of coke abrasion and crushability, respectively, %.*

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