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PROGNOSIS OF REACTIVITY AND STRENGTH OF COKE BASED ON MODIFIED BASICITY INDEX MODEL

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ABSTRACT

Metallurgical coke, as a fuel and a reducing agent, also allows for the gas to go through a charge in the blast furnace. The coke must have a strength, porosity, reactivity and a uniform granulation, because reaction of CO_2 *at high temperatures in the furnace. There are various mathematical models for the optimization of coal blend, which allow the forecasting of mechanical properties of coke in cold conditions as well as at high temperatures and presence of blast furnace gas.*

The so-called Modified Basicity Index (MBI) model is used for forecasting the following coke quality parameters: CRI (coke reactivity index) and CSR (coke strength after reaction with CO_2*), based on the content of volatile matters and ash in coal, as well as the chemical composition of coal ash.*

In this paper will be given the calculation of coke quality parameters based on the mathematical model MBI.

1. INTRODUCTION

Metallurgical coke, as a fuel and a reducing agent, is the most important and most widely used fuel for the iron production in blast furnace. For high-volume blast furnaces, a good leakage of gas backfilling is provided with a uniform, above 40 mm, granulation of coke. The typical parameters of mechanical strength of coke quality are determined following mechanical treatment in rotating drum. The strength to crush, which is evaluated by the granulation of coke above 40 mm, is the parameter M40. Abrasion is evaluated by the amount of low-granulation coke produced, below 10 mm, parameter M10. The typical parameters of mechanical strength of coke quality are not reliable for the prognosis of coke granulation change in blast furnace at high temperatures. The coke which goes through blast furnace is exposed to destruction due to the abrasive effect of the complete backfilling, alkali, and largely due to the reaction with CO_2 at high temperatures. Above mentioned factors individually or in a complex way condition the destruction of the coke structure, and thus the changes of the granulation and mechanical properties, which lead to the change of gas-dynamic and metallurgical-technological conditions in the work space of blast furnace. It was found that the coke starts to change in the lower part of the furnace and that the highest degree of coke degradation ends before entering the duct area.

Since recently, when assessing the coke quality, the parameters being examined are: CRI (coke reactivity) and CSR (coke strength after reaction with CO_2). Petrographic and volatile composition, CBI index of equilibrium composition, SI strength index, quantity and chemical composition of coal ash, all those properties affect coke strength after reaction with CO_2. Iron, calcium and alkaline elements in coal ash increase reactivity (CRI) and reduce the mechanical strength (CSR) of coke. Highly reactive coke loses a higher carbon content to the carbon dioxide gasification reaction in the upper-furnace zone, causing the coke microstructure to weaken. This results in loss of coke resistance towards crushing forces and breeze coke appears. Coke with higher strength, uniform granulation and low reactivity at high temperature conditions, as presented in blast furnace, has a lower degree of crushing, thus ensuring a good permeability in the furnace, lower specific coke consumption and a stable blast furnace operation.

2. PETROGRAPHIC PROPERTIES OF COKING COAL

The basic petrographic components of coal are: lithotypes, microlitotypes and macerals. The lithotypes represent microscopically visible strips of humous coals, and are divided into: *vitren, klaren, duren, fuzen*. Microlitotypes represent a group of macerals (microcomponents) divided into: *vitrit, durit, klarit* and *fuzit*. Based on their properties, microcomponents can be classified into two technological groups: coking microcomponents (including vitrinite and leptinite) and an inert group of fuzinite. Although fuzinite is inert, its optimum value affects the increase of coke strength. Petrographic properties of coal are one of main factors that influence the quality of metallurgical coke; so that the coke strength depends on the microstructure and the composition of the coking coal [6, 8].

During coking process, coking microcomponents melt and together with inert components form solid particles. In order to obtain the appropriate mechanical coke properties, coking coal must represent the optimum ratio of inert and coking components. Lack of inert components results in reduced coke strength, as during coking process separation of volatile matter occurs leaving a blank space inside the coke structure. The same case occurs when the amount of inert components is above the optimum value, because there is a smaller amount of reactive components that bind the inert components [7, 9].

Physical and chemical properties of coal blend are used in order to control the coking process, and thus to control the shape and size of the coke structure. Inert components, that can be organic and inorganic origin, do not go through the plastic transformation as macerals do and thus retain their shape and texture. Small inert organic components with reactive components increase the mechanical strength of coke by reducing the reactivity (CRI) while simultaneously increasing the mechanical strength (CSR) of coke after reaction with CO_2. The quality of metallurgical coke is satisfactory if CRI $< 35\%$ and CSR $> 48\%$, (Japanese standard) [10]. Greater inert components reduce the strength after the reaction and increase the coke reactivity. Iron, calcium, magnesium and alkaline elements in coke ash increase coke reactivity (CRI) and reduce mechanical strength (CSR) after CO_2 reaction [2, 5].

3. MODELS FOR COAL BLEND OPTIMIZATION

In order to optimize the coal blend for coke production, the following coal coking properties are used:

- degree of carbon metamorphism,
- the ratio in-between inert and active petrographic components,
- plastometric and dilatometric characteristics,
- compatibility of coals in the blend.

Models used for coal blend optimization in process of metallurgical coke production are:

- Models that use the degree of metamorphism, fluidity, or coal dilatation characteristics. The plastic properties of coal are shown by Giesler plastometry, where: initial softening temperature, maximum fluidity temperature, hardening temperature and the maximum fluidity are being determined.
- Models that use the ratio of active and inert coal components. Among the most common applications used one can find the optimization by R.G. Moses, which according to the parameters CBI and SI defines the applicability of the blend, and provides the coke strength prognosis in the form of isolates. CBI represents the ratio of active components to the required ones, in corelation with the content of inert ones. The optimal CBI value is 1. SI represents the sum of the inerts influence, with respect to the active components. The optimal SI value for metallurgical coke is 3.5 – 4.1 for the equilibrium index 0.6-1.5 [2].
- Mathematical models are also used for the coal blend optimization (for predicting the mechanical properties of coke) and they are divided into two basic groups:
  - a model for determining mechanical properties in cold state, such as strength and abrasion;
  - a model for determining reactivity CRI and coke strength after reaction with CO_2, CSR.

Companies engaged in coke production use mathematical models for predicting the mechanical properties of coke, whose parameters are dependent on: the type of coal used, the plastic properties of coal, the petrographic composition of the coal and the chemical composition of coking coal ash.

A mathematical model that uses the amount of volatile matters in coal blend, the amount of ash, and the chemical composition of the ash is developed by Canmeta, and is called the Modified Basicity Index (MBI) model. Equations used for this mathematical model are given as (1), (2) and (3) [4].

$$MBI = \left[\left(\frac{100xA}{100-VM}\right)\right]\left[\left(\frac{Na_2O+K_2O+CaO+MgO+Fe_2O_3}{SiO_2+Al_2O_3}\right)\right], \qquad (1)$$

MBI – Modified Basicity Index (MBI) model
A – ash in coal, %,
VM – volatile matters in coal, %,
Na_2O – sodium oxide in ash, %,
K_2O – potassium oxide in ash, %,
CaO – calcium oxide in ash, %,
MgO – magnesium oxide in ash, %,
Fe_2O_3 – iron (III)-oxide in ash, %,
SiO_2 – silicon dioxide in ash, %,

Al_2O_3 – aluminium oxide in ash, %.

$$CRI = -17.53xMBI^2x65.41xMBI - 34.76 \tag{2}$$

$$CSR = -0.58xCRI + 80.63 \tag{3}$$

CRI – coke reactivity;
CSR – mechanical strength after reaction with CO_2.

This model gives an estimation of coke mechanical properties, based on the input parameters: coke ash, as well as composition and the amount of ash in coke. Based on this model it is possible to predict the CRI values, and then predict CSR values based on CRI.

4. EXPERIMENTAL PART

This paper presents basic parameters of coke quality produced in ArcelorMittal Zenica at the Coke plant, for three different coal blends. The aim of this paper is, as follows:

- Based on the mathematical Modified Basicity Index (MBI) model to calculate coke quality parameters (CRI and CSR) and compare them with actual laboratory values (CRI and CSR) of coke produced.
- Whether, based on calculated values of coke quality parameters (CRI and CSR), the expected value of parameters (CRI and CSR) after reaction with CO_2 at high temperatures in blast furnace can be predicted.

Coke production and testing of chemical-mechanical properties of coal blend and coke were carried out in ArcelorMittal Zenica. The petrographic composition and properties of coal for the production of coke were obtained directly from the coal producers. Physical-chemical properties of used coals are given in Table 1 [1]

Table 1. Physical-chemical properties of coking coals

Parameters	Coal 1, HV^1	Coal 2, HV^1	Coal 3, MV^2	Coal 4, MV^2	Coal 5, LV^3	Coal 6, LV^3
Ash, %	8.20	7.05	7.40	8.13	7.25	5.80
Volatile matters (VM), %	29.60	33.95	22.00	26.67	17.34	18.40
Carbon, %	62.60	58.88	70.60	70.69	77.45	75.8
Total sulfur, %	0.89	0.97	0.94	0.91	1.05	0.77
Phosphorus, %	0.004	0.005	0.007	0.008	0.008	0.029
Vitrinite reflectance	1.075	0.99	1.2	1.19	1.68	1.456
CBI	1.108	0.87	0.891	1.45	3.14	2.03
Vitrinite, %	68.40	64.70	77.90	70.50	76.80	77.90
Inertite, %	8.90	8.50	4.20	4.80	6.30	7.50
Ash analysis, %						
SiO_2	53.52	55.5	51.22	53.54	49.27	51.50
CaO	1.23	1.5	2.08	1.5	3.34	2.16
MgO	1.05	1.1	1.26	0.96	0.98	1.15
Al_2O_3	27.31	28.5	27.94	29.02	28.16	29.80
Fe_2O_3	9.11	7.75	9.65	7.68	10.08	8.69
P2O5	0.11	0.09	0.21	0.24	0.28	1.15
K_2O	3.20	2.7	3.37	2.34	1.22	2.85
Na_2O	0.95	0.45	0.83	0.51	1.24	0.94

HV^1- high, MV^2- mid, LV^3- low volatile coal

The Table 2 shows the percentage composition of coals in coal blend and the time period of the production of metallurgical coke [1].

Table 2. Composition of coal blend for coking process

Coal blend	Coal blend composition, %						No of days
	Coal 1, HV[1]	Coal 2, HV[1]	Coal 3, MV[2]	Coal 4, MV[2]	Coal 5, LV[3]	Coal 6, LV[3]	
B1	30	10	45		15		56
B2		30	20	25		25	22
B3	30	25	30		15		12

HV[1]- high, MV[2]- mid, LV[3]- low volatile coal

The Table 3 presents chemical and mechanical properties of produced coke, for all three coal blends [1].

Table 3. Chemical and mechanical properties of produced coke

Coal blend	M10	M40	CRI	CSR	Moisture	Ash	VM	S	C
	%	%	%	%	%	%	%	%	%
Coal blend 1	76.98	7.12	30.32	57.20	3.22	9.75	0.54	0.78	89.70
Coal blend 2	78.83	7.11	28.10	61.40	2.80	10.71	0.62	0.66	88.67
Coal blend 3	77.73	7.44	32.89	50.01	2.67	10.22	0.62	0.82	89.16

Based on the Tables 1 and 2 and formula 1, the parameters for the coal blends required for the calculation of the values CRI and CSR are calculated, according to the mathematical Modified Basicity Index (MBI) model, Table 4.

Table 4. Coal blend parameters

Parameters	Coal blend 1	Coal blend 2	Coal blend 3
Ash, %	7.69	7.03	7.49
VM, %	23.15	25.61	26.04
Ash analysis, %			
SiO_2	52.04	53.03	53.25
CaO	1.96	1.55	1.44
MgO	1.13	1.11	1.10
Al_2O_3	27.83	28.78	28.40
Fe_2O_3	9.35	8.44	8.64
K_2O	2.97	2.83	2.58
Na_2O	0.87	0.67	0.69
MBI	0.20	0.17	0.18

The Table 5 shows coke quality CRI and CSR parameters, calculated by using Modified Basicity Index (MBI) model, and according to formulas (2) and (3) and laboratory values of the same parameters for produced coke.

Table 5. Values of CRI i CSR paramters

Coke	Calculated values %		Laboratory values, %	
	CRI	CSR	CRI	CSR
B1	24.57	66.38	30.32	57.20
B2	23.14	67.21	28.10	61.40
B3	28.58	64.06	32.89	50.01

From the Table 5 it is clear that coke quality CRI and CSR parameters (calculated and actual laboratory values) for the three coal blends meet the Japanese standard criteria (CRI < 35% and CSR > 48%).

5. CONCLUSION

- Coke quality parameters CRI and CSR, both calculated and actual laboratory values, for the three coal blends meet the Japanese standard criteria (CRI < 35% and CSR > 48%).
- Coal blend 2, has the lowest value of the Modified Basicity Index (MBI) model, ash content and also oxide content in ash – Fe_2O_3, CaO, MgO, K_2O and Na_2O.
- Coal blend 2 has the most favourable calculated and actual values of coke quality paramters, CRI and CSR.
- Increased content of iron, calcium, magnesium and alkaline elements in coke ash increase coke reactivity (CRI) and reduce mechanical strength (CSR) after reaction with CO_2.
- Comparative analysis of calculated and actual values of coke quality parameters CRI and CSR confirms that it is possible, based on the Modified Basicity Index (MBI) model, to predict the coke quality parameters CRI and CSR after reaction with CO_2 at high temperatures in blast furnace.

6. LITERATURE

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