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THE INFLUENCE OF THE RHEOLOGICAL PARAMETERS OF THE COAL MIXTURE ON THE STRENGTH OF METALLURGIC COKE

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ABSTRACT
Metallurgical coke as a fuel, reducing agent and permeable material in high-pressure processes must have pronounced strength and granulation properties due to expected changes in high temperature conditions. The best quality of metallurgical coke is achieved when coal mixtures satisfy a certain range of rheological parameters. The characterization parameters of the coking properties of the coal mixture are correlated with the mechanical parameters of the coke quality.

1. INTRODUCTION
The most important and most used fuel for the production of iron in a blast furnace is metallurgical coke. Metallurgical coke as a fuel, reducing agent, and material that determines the permeability of the furnace in high-pressure processes must have demanding properties in terms of strength and size of the coke piece due to expected changes in high temperature conditions. Current knowledge of coke behavior in a blast furnace indicates that the decisive influence of coke on furnace operation begins at high temperatures when structural and mechanical properties of the coke change. The coke has a special effect on the aggressive action of CO_2, water vapor, alkali and the abrasive effect of total fill [1].
The basic parameters used for coke quality are [2]:

- CSR (Coke Strength after Reaction),
- CRI (Coke Reactivity Index),
- CAS (Coke Abrasion Strength) – it is expressed by using MICUM 10 test,
- CFS (Coke Fragmentation Strength), it is expressed by using MICUM 40 test,
- Content and chemical composition of fly ash.

Changes in the physical and mechanical properties of coke under high temperature conditions and their effect on the operation of the furnace are observed depending on:

- characteristics of coal (physicochemical, rheological, coking components, amount of vitrinite, reflectivity of vitrinite, content of volatile matter),
- coking conditions and
- the property of the produced coke produced.

2. COMPOSITION OF COAL MIXTURE

The primary goal of composing the coal mixture is to produce coke of satisfactory quality, without the risk of increased mixture pressure on the walls of the coke battery. Industrial coal mixtures always consist of a minimum of three different types of coking coal, depending on the content of volatile matter, such that the following coals are represented [6]:

- high volatile – HV,
- medium volatile – MV,
- low volatile – LV.

In order to determine the coking properties of coking coal, a series of tests are performed to determine the rheological properties of these coals. This is primarily related to the testing of coal dilatation, fluidity and FSI (Free Swelling Index). Coking coals contain macerals that are reactive, soften and become plastic when heated. These macerals agglomerate with other non-softening macerates and then in the repolymerization process give the final coking product - coke [6].

2.1. High volatile – HV coals

The main role of high-volatile coals in the mixture is to control the shrinkage of the coal mixture during coking, to reduce the pressure on the furnace walls and to adjust the fluidity of the mixture. Thus, these coals are primarily viewed through the characteristic of fluidity, both as low or high fluidity coals. Thus, HV coals provide the mixture with contraction and fluid properties. Since they have a high volatile matter content, they are subject to shrinkage when heated, in proportion to the volatile matter content. They are characterized by high porosity. If used alone in a coal mixture, poor quality coke would be produced.

2.2. Medium volatile – MV coals

These coals form the basis of any coal mixture. They are important for achieving good rheological properties, especially dilatation. Accordingly, they are treated as high, middle or lower grade coals. This rank, the so-called bituminous coal results in the formation of coke of optimal strength, reactivity and structure. MV coals bridge the gap between LV and HV coals in the coal mixture. They can also cause the mixture to press on the walls of the furnace.

2.3. Low volatile – LV coals

The main role of these coals in the coal mixture is to improve the mechanical strength and the so-called dump of coke. They represent the main source of coke strength. Their dominant feature is the pressure on the walls of the furnace during coking, and accordingly they are divided into very dangerous, dangerous or harmless coals. Not subject to significant contraction, they generally spread during coking. They are characterized by low porosity. If used alone in a coal mixture, poor quality coke would be produced. These coals have a high level of organic maturity or rank coal (Ro), due to their lower inertinite content and high vitrinite content [3].

3. RHEOLOGICAL PROPERTIES (COXING COAL PROPERTIES)

The rheological properties of coking coals include: free swelling index, coal fluidity and reflection and vitrinite distribution.

3.1. Free Swelling Index –FSI

The value of the Free Swelling Index during the coking process is one of the most important analyzes for determining the coking properties of coal. One reason for this is the lower sensitivity of FSI to oxidation of coal, compared to fluidity and dilation tests. Coal with FSI values > 4 is considered as coking coal, while coal with FSI values > 7 is considered to be quality coking coal [2,3].

3.1.1. Coal dilation and contraction

The value of coal dilatation is interpreted as an indicator of the coking properties of coal. For this parameter, the values of the followed characteristics are determined: contractions, dilations, softening temperatures, maximum contraction temperatures, and maximum coal dilatation temperatures. The dilatation is, in fact, the registration of a change in the length of a coal briquette under progressive heating under specified conditions. The contraction is the percentage reduction in the length of one coal briquette during heating. The temperature at which the contraction begins is called the softening temperature. The temperature at which the dilation ends is called the curing temperature. These two temperatures limit the plastic area of the coal. According to the obtained values of contraction and dilation, coals can be classified into three basic groups: coals prone exclusively to contraction, coals with negative dilation, and coals with low, medium or very high dilation. According to the ISO standard, there are two modifications to the dilatation test: Audibert-Arn and Ruhr test, which result in different dilatation and contraction values. These differences are attributed to the shortening of the length of the coal briquette from different ends [2,3].

3.2. Coal fluidity

Coal fluidity is determined by heating the coal. When coal enters a fluid (liquid) state, this parameter determines the fluidity of the coal. In the case of coal fluidity, the followed characteristics are determined: maximum fluidity, softening temperature, maximum fluidity temperature, (re) hardening temperature, and fluidity range.
The highest fluidity values are recorded for HV coals.

Fluidity is the most sensitive parameter when it comes to coal oxidation. It is not enough that the coal mixture has a satisfactory fluidity value to produce high quality coke, but also the fluidity ranges of the individual coals that are in the the mixture should overlap as much as possible, thus allowing the interaction of the coal particles during the carbonation process [2,3].

3.3. Reflection and distribution of vitrinite

Ro (Mean Maximum Reflectance) represents the degree or level of organic maturity or rank of coal. Vitrinite reflectance determines the rank of the coal or the degree to which the vegetable, organic matter will gradually be converted to coal by gradual heating and compression. The distribution of vitrinite is the only analysis that can confirm whether coal supply is made up of one or more different types of coal.

4. EXPERIMENTAL PART

In the experimental part of the paper, tests were carried out to determine the quality of coal according to the parameters required to determine the quality of coal, and then the composition and quality of the coal mixtures used for coke production were determined.

4.1. Testing basic quality parameters for each type of coal

Table 1 shows the average values of the basic quality parameters for each type of coal. The dilation was determined by the Audibert-Arnu test and the fluidity was determined in a Gieseler plastometer.

Table 1: The basic quality parameters of coals [7]

Parameters:	**Coal I Virginia (VV)**	**Coal II Shoal Creek (SV)**	**Coal III Integrity (SV**	**Coal IV Pinnacle (NV)**
Fixed carbon, %	57,60	61,70	67,10	74,50
Volatile matter, %	34,70	28,90	22,60	19,40
Sumpor, %	0,97	0,67	0,97	1,10
Phosphorus	0,004	0,0043	0.013	0,009
Ash, %	7,70	9,40	10,30	6,10
Maceral analysis:				
Vitrinite , %	75,00	75,00	73,20	73,50
Liptinite, %	8,80	6,10	2,60	0,60
Semi fusinite, %	10,20	8,10	8,50	13,50
Pseudovitrinite, %	3,00	4,80	11,70	7,00
Inertinite; %	3,00	6,00	4,00	5,40
Rheological properties:				

FSI, %	7,50	8,50	7,50	8,50
Dilatation %	133	169	2	22
Ro, %	0,85	0,95	1,17	1,51

4.2. Determination of basic quality parameters of coal mixtures

In table 2 gives the percentage composition of the coal mixtures used for coke production.

Table 2: Composition of the coal mixture[4]

Coal name:	Mixture I	Mixture II	Mixture III
Coal I: Virginia (HV), %	34,00	30,00	30,00
Coal II: Shoal Creek (MV), %	45,00	49,00	50,00
Coal III: Integrity (MV), %	11,00	11,00	12,00
Coal IV: Pinnacle (LV), %	10,00	10,00	8,00
Total %	100,00	100,00	100,00
The usage of the col mixture, days	28	77	18

Based on the coal quality parameter (Table 1) and the composition of the coal mixture (Table 2), a calculation of the basic quality parameters of the coal mixtures used for the production of metallurgical coke was made (Table 3).

Table 3. The basic parameters of the quality of the coal mixtures quality I, II, III [4]

Parameters:	**Mixture I**	**Mixture II**	**Mixture III**
Fixed carbon, %	63,30	62,91	62,77
Volatile matter, %	28,67	28,54	28,68
Sumpor, %	0,86	0,85	0,87
Phosphorus, %	0,004	0,0043	0.013
Ash, %	8,03	8,55	8,55
Maceral analyses:			
Vitrinite , %	74,66	74,65	74,66
Liptinite, %	6,07	5,96	6,03
Semi fusinite, %	9,41	9,32	9,21
Pseudovitrinite, %	5,22	5,25	5,28
Inertinite; %	4,70	4,82	4,81
Rheological properties:			
FSI, %	7,78	8,08	8,08

Dilatation, %	123,69	125,13	124,40
Ro, %	1,00	0,99	0,98

In the table 4, for comparison, **the minimum required coke quality parameters for the blast furnace process,** are given.

Table 4: The minimum required coke quality parameters [5]

MICUM 40, %	MICUM 10, %	CRI, %	CSR, %	Ash, %
≥75	≤7	≤30	≥60	≤12

4.3. Determination of the quality of the produced coke

The quality of the produced coke from the coal mixtures is given in the table 5.

Table 5: The quality of the produced coke[4]

The quality of the metallurgical coke	MICUM 40,	MICUM 10,	CRI 10,	CSR,
	%	%	%	%
Mixture I	77,30	6,38	26,06	63,31
Mixture II	77,76	6,11	24,04	64,73
Mixture III	78,71	6,02	23,16	65,52

5. DISCUSION

To make the quality of coke consistent with the requirements of the blast furnace, coals of different properties are used for coking. Some coals have a high content of volatile matter. By their nature, they limit the adverse effects of high pressure during coking on the refractory wall of a coke oven furnace. Some coals contain a small amount of volatile matter, causing the coal mixture to build up on the battery wall. However, such coals are necessary to form a stable coal mixture that will produce coke of satisfactory quality. Therefore, in order to obtain the coke of the desired quality, it is necessary to make a balance in the ratio of coals of very different properties when preparing the coal mixture. All this research was done at the Department of Coke, ArcelorMittal Zenica.
The Coal Uplift Index (FSI) is fairly uniform so as to provide an optimal coal with favorable FSI. By examining the effect of coal expansion with a maximum dilation of 169% and a minimum of 2%, in combination with other coals, a good quality coal mixture can be assembled that satisfies the production of quality coke and the coking conditions on Coke Battery VI in Koksara, ArcelorMitalla Zenica.
Reflection and distribution of vitrinite (Ro) in coal varies from 0.85 - 1.51%, which allowed to provide Ro in the coal mixture a value of about 1.0%.

Examining the influence of the fluidity property of coal on the quality of the coal mixture, it is concluded that the maximum fluidity of the analyzed coals decreases with a decrease in the content of volatile matter in these coals.

By examining the influence of petrographic properties of coal on the quality of the coal mixture, the highest content of vitrinite macerals is possessed by the high and medium volatile coals in the mixture. In addition, based on the distribution of vitrinite in coal, it can be concluded that a good combination of coals of varying degrees of volatility has been made in the new coal mixture, thus providing a mixture that covers a wide area of vitrinite and medium maximum reflections of vitrinite, which has a positive effect on the quality of the resulting coke.
The content of intertinite increases with the decrease in the content of volatile matter in the coals. The decrease in the content of volatile matter in the tested coals is accompanied by a decrease in the maceral content of vitrinite.

6. CONCLUSION

Based on the results of the coke quality analysis, it can be concluded that the coke produced from the coal mixtures meets all the qualities required by the standards given in Table 4.
For the preparation of a coal mixture of good rheological properties, it is not sufficient for the coals to possess favorable fluidity values, it is necessary to match the fluidity ranges of the coals in the mixture as closely as possible.
Examining the influence of petrographic properties of coal on the quality of the coal mixture, it is concluded that the highest content of vitrinite macerals is possessed by the high and medium volatile coals in the mixture.
Vitrinite is the maceral that contributes most to the quality of coke.
The content of unsuitable - worse coal, Pinnacle LV in mixture II is therefore limited to 8%, which results in a more favorable and economical mixture of coal, while also providing less pressure on the walls of the furnace (below 7,000 Pa) which produces poor quality coke.

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