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BLAST FURNACE COKE REQUIREMENTS AND METHODS OF IMPROVING ITS QUALITY: A REVIEW

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Abstract The article analyzes the current understanding of the influence of coke quality on the ironmaking process. The requirements for its metallurgical characteristics are formulated. One of the main factors affecting the possibility of efficient operation of blast furnaces is the quality of coke. This quality significantly depends on the quality of coal raw materials, methods of coal batch preparation, and methods of its pretreatment. To ensure the efficiency and cost-effectiveness of coke production and expand the raw material base of coking coal, it is necessary to use scientifically sound, economically feasible approaches to the introduction of advanced technologies, such as frontal coal cleaning, prediction, and optimization of the batch composition taking into account the petrographic characteristics of its components and the expansion pressure of coal concentrates, modification of the batch using additives, rational preparation of coal by crushing, and coking of stamped batches. A comparison of coke quality prediction methods used in the testing of coal batches is presented. The main methods of improving coal and coal batch preparation (including those implemented at coke plants in Ukraine) are described. Research that was not available to the English-speaking reader is analyzed.

Keywords: coke, petrographic composition, coking coal quality, blast furnace, coal batch, coking processes.

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1. Introduction

Coke functions as a complex energy-technological material in the blast furnace. Primarily, coke is a reductant and heat source in the blast furnace process. A smaller part of the coke is spent on reduction processes, and the main part goes into the furnace and burns together with the fuel to CO_2, releasing the required amount of heat in the blast furnace. The formed carbon dioxide is reduced to carbon monoxide upon contact with red-hot coke. In addition to energy and reagent functions, coke as a solid material ensures uniform gas distribution over the cross-sectional area of the blast furnace unit.

Coke is the most expensive component of the iron smelting batch, so reducing its cost is an urgent task. This problem is solved in three directions:

production of better quality coke;

its cost reduction due to improvement of coking technologies and/or expansion of the range of raw materials for coke production;

replacing coke with less expensive energy carriers.

Therefore, the modern requirements for blast furnace coke quality are quite high: $M_{25} \geq$ 88.0-90.0%; M_{10} ≤6.0-6.5%; CSR – 60.0-75.0%; CRI – 25-30.0%, content of +80 mm fraction – no more than 5%; content of - 25 mm fraction is no more than 5%; moisture differences in both directions - no more than 0.5%.[1-3] Its ash content A^d_c should not exceed 11%, and the sulfur content S^d_c – 1.00%.[4]

Achieving the above necessary qualities of coke is carried out by three main methods/directions:

- selection of the coal batch optimal composition;
- change in coal batch properties;
- implementation of special methods of coal preparation.

New achievements in these three areas of improving the processes of batch preparation and coke production are discussed below.

2. Prediction and Selection of Optimal Properties of Coal Batch

The selection of optimal properties and composition of the coal batch plays a decisive role in achieving the required values of coke quality indicators. There are no universal models for determining the conditions for obtaining high-quality coke. However, some studies show that the coke quality can be predicted based on certain parameters of the coal batch (maceral composition, sobriety, composition of the mineral part, metamorphism degree, content of volatile substances, sulfur, *etc*.).[5]

The additivity of technical, petrographic, and plastometric analysis indicators for coal batch and its components is a well-known fact proven by numerous studies.

According to modern ideas about the coal properties and its transformation processes during coking, the composition of coal batches should be selected by individual components' sintering and coking indicators, their technological properties and features due to the coking technology adopted at the enterprise (layer coking, application of stamping, briquetting, thermal preparation), as well as taking into account blast furnace production requirements for coke quality characteristics (ash content, sulfur content, mechanical strength, reactivity, strength after reaction).[4]

In the case of traditional coking technology, the composition of coal batches was selected based on clinkering properties, and behavior characteristics during coal coking of various technological grades. The average requirements for the batch composition are as follows: low-metamorphosed coal, which ensures necessary shrinkage and ease of coke cake delivery, no more than 15 wt.%; good sintering coal from the middle stage of metamorphism, which is the sintering base of the coal batch, makes up 50-60 wt.%; highly metamorphosed coal, low clinkering properties, reduces cracking and contributes to the production of large strong coke, 15-20 wt.%.[5,6]

However, considering the improvement of medium metamorphism coal deposits (in individual countries and the world in general) and the deterioration of the mined coal quality.[7] the batch preparation of an optimal composition is economically unprofitable and often technologically impossible. Therefore, it is important to predict the coke quality based on the characteristics of the coal batch initial components when the composition of this batch changes.

One of the first and most important indicators of coal quality, used to characterize coal batch coking, is its petrographic composition. Petrographic composition refers to the microcomponents (macerals) content of the coal organic part (vitrinite, liptinite (exinite), and inertinite), which differ in properties and origin. Vitrinite is the main group of coal. To identify macerals, their gloss (ability to reflect/display light) is used. The light reflection indicators of macerals increase in the order of liptinite (exinite) < vitrinite < inertinite.[6,7]

Modern ideas about the influence of petrographic characteristics of coal on the obtained coke quality confirm the need to predict this quality based on a set of indicators. It is mandatory to form a coal mixture considering the maceral composition, vitrinite reflectance, and vitrinite component distribution by metamorphism stages, the optimal ratio between clinkering (ΣCK) and fusinized components (ΣFK). Predicting the yield and properties of coke, it is taken into account that the vitrinite, liptinite, and 1/3 semivitrinite macerals are the sum of reactive, cohesive components, and all inertinite and 2/3 semivitrinite have a fusinized effect on the whole system.[8-10]

Based on the data in Table 1, it can be stated that to predict the quality of coke, in addition to the most important (petrographic) indicators, other characteristics of the original coal/batch are additionally used. Also, various indicators of coke quality are used as recall functions. A group of first-generation models focuses on predicting cold mechanical strength indicators (*i.e*., ASTM stability, MIKUM test in Ukraine and the CIS countries, IRSID in Europe, DI 150/30 in Japan). Later second-generation models use CRI and CSR as coke quality parameters. Universal models for predicting the coke quality have not been developed, which are related to the specific features of coal from different coal basins, countries, and continents, which can differ radically in composition, structure, and properties.

Some models and the results of their application, which are relatively new to the public and do not constitute a commercial secret, are considered in more detail below. Clinker and coking characteristics for the composition of coal batches and the raw material base for coking in Ukraine at its coke plants are currently assessed based on petrographic analysis data and quantified by the complex indicators C_{batch} and K_{batch} developed by the staff of the SE "UKHIN".[4] Indicators C_{batch} and K_{batch} allow to give a general quantitative assessment of the petrographic characteristics of coal batches. The values of these indicators of batch properties should be C_{batch} 53 and K_{batch} 3.7. The higher the value of the complex index C_{batch}, the better the strength characteristics of the coke obtained from this batch. In turn, the higher the value of K_{batch}, the greater the probability of obtaining coke with high strength characteristics, ceteris paribus.[12]

Paper [11] reports the results of using these complex indicators at Zaporozhkoks and Arcelor Mittal Kryvyi Rih (Ukraine). It was shown that coke from the optimized charge is characterized by higher strength indicators than coke from the "standard" charge: the crushability increased from 84.5 to 87%, and abrasion decreased from 8.9 to 7.9%.

Table 1. CSR prediction models and the variables they consider

Company/research institute/researchers	Variable characteristics of coal			
	Petrographic characteristics	Rheological properties of coal in the plastic state	Characteristics of the inorganic part	Others
British Steel	Vitrinite reflectance		Coke ash content	
Nippon Steel	Inertinite content, %, vitrinite reflectance	Maximum fluidity	Ash basicity index	
BCRA	Inertinite content, %	Maximum fluidity	Content of basic oxides in coal	Carbon and oxygen content in coal, coke porosity
Kobe Steel	Vitrinite reflectance	Maximum fluidity	Ash basicity	
BHP	Content of inert components	Maximum fluidity	Coal ash basicity	Yield of volatile matters
Inland Steel		Temperature of transition of coal into a plastic state	Ash basicity index	Sulfur content in coal
ISCOR	Vitrinite reflectance, content of fusite components	Maximum fluidity	Content of basic oxides in coal ash	
Tata Steel	Vitrinite reflectance, ratio between cohesive and inert macerals, reflectogram of vitrinite component	Maximum fluidity, free swelling index	Ash content, SiO_2:Al_2O_3 ratio, alkali index	Composite coking potential (CCP), type of coke residue according to the Gray-King method
Arcelor Mittal Ostrava	Maceral composition, vitrinite reflectogram	Maximum fluidity, free swelling index; contraction and dilation according to the Audibert-Arnu method	Ash content	Sulfur content, yield of volatile matters
Research institutes/SE UKHIN (applied at the coke production of PJSC ArcelorMittal Kryvyi Rih, OJSC Zaporizhkoks)	Maceral composition, vitrinite reflectogram, vitrinite reflectance		Ash basicity index, ash content	Sulfur content in coal, yield of volatile matters

As mentioned above, technical analysis indicators are also used to optimize the composition of coal batches.

The most common quality indicators of the batch or its components, which are used to predict the coke quality, are the yield of volatiles (V^{daf}) and ash content (A^d).[8,12] On the other hand, these indicators can be close or the same for coal samples with different coking abilities.[13,14]

Mathematical models for predicting the thermochemical coke properties were analyzed in[8], taking into account the characteristics of the mineral raw materials. The results show that the influence of metal oxides and alkali metals on the CSR of coke is different. The influence of metal oxides on CSR decreases in the following sequence: $MgO > Fe_2O_3 > CaO > K_2O > Na_2O$. Similar conclusions were made by the authors of the article,[13] in which they present a version of the basicity index that takes into account the varying degrees of oxides' influence on the thermochemical properties of coke:

$$MCI = \frac{100A^d(Fe_2O_3+1.03CaO+0.43MgO+2.85Na_2O+2.34BaO+1.9K_2O)}{SiO_2+0.74Al_2O_3} \quad (1)$$

To obtain coke of improved quality, it is necessary to use raw materials with a certain alkaline-acidic ratio of oxides in the ash. Thus, numerically, the basicity index should not exceed $И_о < 2.5$ (or $I_o < 0.2$).[4]

In Ukraine, to optimize the batch composition and predict the coke thermochemical properties, the following equations are used:[14]

$$CSR = 77.14 - 11.92 \cdot И_о + 0.57 \cdot И_o \quad (2)$$

$$CRI = 13.4 + 9.35 \cdot И_о - 0.45 \cdot И_o \quad (3)$$

Given that, the nature, metamorphism degree, and transformation of the coal organic mass change their behavior during coking, an important condition for optimizing the free clinkering of coal mixtures is the temperature intervals superimposition of the components' plastic state. The complete or partial coincidence for temperature intervals of the plastic state allows better contact of the residual material of the coal grains and their joint polycondensation during clinkering, that is, to ensure the continuity of the batch plastic state in general.[7,15]

In the production of multicomponent batches, it is necessary to combine good clinkering coal, which ensures the formation of a liquid-mobile plastic mass, with fusinized components that increase the viscosity of the plastic mass and contribute to the production of large and strong coke. Increasing the number of components in coal mixtures should be due to coal with intermediate properties.[4,7]

According to the authors,[5,16] the decision about using one or another coal brand as part of the coking batch should be based on the values of vitrinite reflectance and Gieseler maximum fluidity.

As a result of studying the influence of factors and coal properties on the formation of coke properties, Jordan proposed a model[9] that takes into account the coal behavior in a plastic state and its dilatometric characteristics. The Fluidity Factor is based on the Simonis (G-factor) concept and is considered a dimensionless additive parameter for individual coal in coal mixtures. It represents the dependence between maximum fluidity and temperature, which are fixed during the determination of dilatometric characteristics.

$$Fluidity\ Factor = \frac{Tf_1+Tf_3}{2} \times \frac{MF+(Tf_3-Tf_1)}{MF \times Tf_2} \quad (4)$$

where Tf_1 – initial softening temperature, Tf_2 – maximum fluidity temperature, Tf_3 – re-solidification temperature, MF – maximum fluidity.

The authors[17] proposed a new method for evaluating the sintering ability of coal and coal mixtures based on a coefficient called Composite Coking Potential (CCP). The CCP value characterizes the suitability of the coal/coal mixture for the coke production of the desired quality, which is evaluated by the coke strength after reaction (CSR). The CCP coefficient takes into account the chemical, rheological and petrographic properties of coal raw materials, such as ash content, yield of volatile matters, swelling index, type of coke residue according to the Gray-King method (according to the Indian standard IS1353:1993), maximum fluidity, vitrinite reflectance, ratio between clinkering (vitrinite, liptinite) and inert (inertinite) macerals of coal organic mass, reflectogram of vitrinite component, SiO_2:Al_2O_3 ratio and alkalinity index. In the literature,[17] the CCP coefficient for coal is proposed to be calculated using the equation:

$$CCPofcoal = \frac{\sum_{m=1}^{10}(W_m \times R_{pm})}{100} \quad (5)$$

where W_m – Weightage (each property m is given a certain value (weight W_m), according to its effect on coal coking); R_{pm} – coking potential of the m-th property of the p-th coal sample.

The coefficient for the coal batch is calculated as follows:

$$CCPofcoalblend = \frac{\sum_{p=1}^{n}(wt_p \times CCPofcoal)}{100} \quad (6)$$

wt_p – coal fraction in the batch.

It was established that a coal mixture with a higher CCP ≥ 4.7 provides coke production with high coke strength after reaction CSR ≥ 65%. The dependence is described by the equation:

$$PredictedCSR = 51.7 + (2.8 \times CCPofcoalblend) \quad (7)$$

The mathematical model described by equation 9 is used to optimize the composition of coal batches, both in terms of properties and cost of coal raw materials, which has shown effectiveness in the Tata Steel plant (India). Its use makes it possible to obtain coke with high thermochemical properties.[11]

The safe expansion pressure of the coking batch on the walls of the coking chambers also serves as an important indicator during the assembly of coal batches for coking. Coking of batches, the bursting pressure of which is much higher than the criterion, leads to difficulties in unloading the finished coke cake and, in extreme cases - to single or mass drilling of furnaces. Drilling leads to disruption of the heating regime and the unloading schedule of the furnaces, a drop in coke production, deformation of the walls of the coking chambers and the heating space, and, as a result, acceleration of furnace wear. Therefore, when preparing batches for coking, it is necessary to solve not only the task of obtaining strong coke but also to ensure optimal conditions of operation and preservation of the furnace fund given the expansion pressure of coal raw materials. The expansion pressure of factory batches should not exceed 7 kPa.

The magnitude of the expansion pressure depends on the nature of the coal (metamorphism degree, petrographic composition, plastic mass properties) and the peculiarities of their preparation technology (bulk density, humidity, additives of fusinized components, coking speed).[4]

Research[18] on the expansion pressure study that occurs during the coking of binary coal mixtures shows that the expansion pressure in these mixtures when the ratio of the content of components belonging to different grades of coal changes in them is not subject to the rule of additivity. The change in expansion pressure occurs according to the additivity rule only in mixtures in which both components belong to the same coal brand. The authors[18] established three types of expansion pressure dependences in binary mixtures on changes in the ratio of their components:

- with participation in a binary mixture of coal G or DG with another coal rank, the expansion pressure is always less than calculated by the rule of additivity;
- with participation in a binary mixture of coal Zh with coal K or ranks PS, KS, and KO, the expansion pressure of the mixture is always higher than calculated according to the rule of additivity;
- in binary mixtures of coal K and PS (KO, KS), when adding poor clinkering ranks to the K coal up to 60-70%, the expansion pressure of the mixture is higher than according to the rule of additivity, and a further increase in the content of poor clinkering ranks, the expansion pressure of the mixture is lower than according to the rule additivity.

Research on coke production at ArcelorMittal Kryvyi Rih is conducted on the properties of coal concentrates to determine and plan the amount of bursting pressure for coal batches (since this indicator is not subject to the rule of additivity).[19] At the laboratory facility, the expansion pressure of new coal concentrates that have not been used in production before is determined, and coal concentrates that are permanently added to the raw material base of coke production at ArcelorMittal Kryvyi Rih are also periodically checked. The most dangerous from the point of view of expansion pressure during coking is coal concentrates of rank K, for which the indicator values were 25-33 kPa and 12-25 kPa, respectively. The development and accumulation of data on the determination of the bursting pressure allow timely corrections to the standard composition of the batches and reduce its value from 5.9-4.8 kPa to 3.5-3.0 kPa.

In general, the work practice of coke chemical enterprises of Ukraine shows that to obtain coke with high mechanical strength indicators M_{25} = 87-89%, M_{10} = = 6.5-7%, ash content $A^d \leq 11\%$, sulfur content $S_t^d \leq 1.00\%$, CSR - 65-70%, CRI – 25-30%, it is necessary to ensure the following quality of the coal batch: $A^d \leq 8.4\%$, $S_t^d \leq 1.10\%$, $V^{daf} \leq 27\text{-}28\%$, vitrinite reflectance $R_0 \geq 1\%$, clinkering y = 16-18 mm, basicity index $И_о < 2.5$ (or $I_o < 0.2$).[4]

On the other hand, reserves of coking coal with low sulfur and ash content in the world are quite small, so currently, the coking industry is experiencing serious difficulties and rising prices for high-quality coking coal all over the world.[14] Therefore, often, the methods of predicting/compiling the component composition of the batch do not make it possible to obtain the desired result. In this case, technologies for changing the quality of the batch itself and/or improving coking methods become relevant.

3. Methods of Coal and Coal Batch Quality Improvement

Research and implementation of processes for changing the batch properties to improve coke quality obtained from it are carried out in the following directions:

- improving coal quality due to a decrease in the content of sulfur and/or inorganic components;
- addition of organic and inorganic substances;
- change/selection of granulometric composition.

To improve coking coal quality, studies have been actively conducted to reduce its sulfur content.[20-24]

It is proposed to reduce the sulfur and ash content in coking coal by combining oxidation and flotation. In coal, sulfur and ash content were reduced from 2.55% and 46.16% to 1.33% and 13.41%, respectively. The most effective was the flotation and subsequent oxidation of enriched coal, the essence of which is that ordinary coal is first floated, which ensures its deashing and desulfurization, while the degree of pyrite extraction was 78.87%.

The review[24] shows the possibility of directional regulation of the transformations character of coal organic sulfur during the thermal transformation of coal. It is proposed to ensure a decrease in the sulfur content in coke due to the addition of low-metamorphosed gas coal with a high content of volatiles into the coal batch for coking. At the same time, a larger amount of sulfur passes into volatile coking products (gas, gasoline fractions, and coal tar). This is explained by the fact that during the layer coking of coal batches containing highly volatile gas coal, oxygen-, sulfur-, and hydrogen-containing radicals, which are formed more due to the presence of gas coal, can act as a hydrogen donor and a catalyst for the process of breaking chemical bonds C– S/C–C in sulfur compounds and, accordingly, increase the sulfur conversion into volatile products.

As mentioned above, in the conditions of shortage of high-quality, good-sintering coal, there is a growing interest in adding various additives to the batch composition.

The additives can be divided into several groups:

- inorganic;[4;25,26]
- poor clinkering: anthracite, coke fines;[25,26]
- organic: liquid and solid waste/waste liquids of oil refining and petrochemical (acid tars, waste oils) and coal processing industries (acid tar, heavy coal tars, polymers, heavy fractions of coal "liquefaction" processes).[26,28-32]

The paper[25] shows that adding minerals (kaolin, quartz, plagioclase, orthoclase, muscovite, bauxite, rutile, apatite, gypsum, aluminum, and magnesium oxides, lime, pyrite, siderite, hematite, magnetite, and sulfur) to the batch increases the content of isotropic and thin mosaic structures in coke significantly depending on the iron oxides content in coal ash. According to the effect on CSR and CRI, minerals are divided into those that preserve or improve these indicators and those that significantly reduce CSR. The first include apatite, plagioclase, orthoclase, muscovite, aluminum oxide, kaolin, and quartz. Pyrite, siderite, hematite, bauxite, calcite, gypsum, lime, and magnesia are classified as additives that impair these coke properties, that is, increase reactivity and reduce the coke strength after reaction. All this refers to additives in the amount of 1%.

According to the authors,[25,26] adding finely ground coke fines and anthracite increases the coke strength and the output of its large classes by reducing shrinkage. Therefore, these may be of practical interest to improve the specified characteristics or to reduce the batch cost.

A wide range of organic additives is characterized by their different aggregation state (solid and liquid substances), which determines different ways of their addition to the batch. It is expedient to add solid waste to the batch together with heavy coal tars.[30] Liquid resinous waste can be added individually in the form of a water-resin emulsion.[29] Liquid additives (used oils, kerosene, and fuel oil) affect the coal surface properties and increase the batch bulk density and the coke furnace productivity. Additives of resins, polymers, petroleum and coal pitches, and heavy fractions of "thermal liquefaction" coal increase the amount of plastic phase and expand the temperature range of coal plasticity due to chemical interaction with the coal organic mass destruction products, improve properties of plastic mass, increase ductility, and as a result, improve the structure and physical and chemical properties of coke.[29-32]

In most cases, the addition of waste additives to the batch is associated with their disposal needs without reducing the coke quality and chemical coking products.[33] Some additives are used to improve the quality of the plastic state. Mesogenic additives capable of forming liquid crystal structures (mesophase), which are the beginnings of an ordered structure and play an important role in the clinkering process and a strong coke structure formation, are of some interest. The structure and properties of coke depend on the amount and properties of the mesophase that is formed. Together with non-volatile compounds formed by thermal destruction of coal organic mass, they form flat graphite-like molecules capable of spatial orientation. The occurrence of spatial ordering in semi-coke significantly affects its physical and chemical properties and, as a result, improves the ability to order the structure at the stage of coke formation.

It is well known[4,34] that the crushing level of coal batch significantly affects its coke properties and determines the most important technical and economic indicators of coke chemical production - the coke quality and coke oven battery productivity. A change in the batch granulometric composition leads to fluctuations in the bulk mass density of coal loading, affects the gas permeability of the plastic mass, coke cake shrinkage, and the nature of the stress during the transition of semi-coke to coke, the amount and properties of liquid, solid and volatile products of thermal destruction and the batch clinkering.

The main principles of rational coal preparation by crushing are:[4,34,35]

reduction of the number of large and small classes in the batch for the maximum possible equalization of its material composition and ash content by size class;

optimal distribution of organic coal mass of different stages of metamorphism by batch size classes;

achieving the granulometric composition of the batch, which ensures the maximum possible increase in bulk density;

maximum crushing (the upper limit of their grain size should not exceed 3 mm with the minimum possible dust formation) of low-clinkering and/or high-ash coal since large mineralized and/or low- clinkering grains are sources of local stress that reduce coke strength.

If coal from different basins with significantly different properties (maceral composition, reflectograms of the vitrinite component, vitrinite reflectance index, *etc.*) is used in enterprises of a single country, it is recommended to change the crushing system, as it is beginning to be implemented at coke-chemical enterprises of Ukraine.[37-39] Such changes involve the transition from crushing of the entire batch (scheme BC - batch crushing, which involves crushing all components in one crusher) to differentiated (DCC - differentiated crushing of components) and/or group crushing of components (GCC - group crushing of components), which ensure components crushing and joint crushing groups of different coal rank in separate crusher units. At the same time, before grinding, it is rational to sift out small classes of both good-clinkering coal (class 6-0 mm or 8-0 mm) and low-clinkering coal (class 3-0 mm).

The authors,[36] based on the study of the coal properties used for coking at Ukrainian coking plants, divided coal concentrates into three categories based on the Grindability Index:

– solids with a Hardgrove Grindability Index of 55-65 units (all low metamorphosed coal of the gas group);

– soft coal with a Hardgrove Grindability Index of 80 units and more (most coal of medium and high degrees of metamorphism (Zh, K, KO, PS) with a vitrinite component content of 70% and more);

– intermediate coal with a Grindability Index of 66-79 units.

As a result of the established differences in the amount of degradability, due not only to the different metamorphism degrees but also to the different petrographic composition, a conclusion was made about switching expediency to progressive schemes for the preparation (GCC, DCC) of coal batches, which make it possible to avoid, on the one hand, the batch's loss of clinkering properties, and on the other hand, a large number of crack centers formation in the blast furnace coke.[36]

A powerful factor in improving coke quality in the face of a shortage of high-baking coal is the implementation of special methods for preparing coal batches for coking. Coking of stamped, dry and heat-treated, briquetted batches is a technology that allows significant reduction of good clinker coal share in the batch and usage of batches, the grade composition of which is as close as possible to the balance of coal resources in a particular basin.

An increase in the bulk density of the coal batch occurs during its tamping (the bulk density of the batch loaded into the furnace in the "usual" way is 0.72-0.73 t/m^3 per dry mass; the bulk density of the stamped cake, formed using modern equipment, is 1.017 t/m^3 per dry mass). The greater the cake density from the same batch, the greater the strength of mechanical and capillary adhesion between the coal grains, and the greater its strength. As a rule, the volume of free intergranular space in a bulk batch is 42-43%, and in a stamped one - 19-20%.[4,39]

In stamped coal batch, complicated conditions are created for the evacuation of steam and gaseous products from the plastic layer. This results in an increase in gas pressure. The higher the gas pressure, the more actively steam and gaseous products of pyrolysis participate in secondary reactions with the organic coal mass. At the same time, hydrogen saturation reactions are intensified, and free bonds of fragments of macromolecules (free radicals) are formed. This leads to an increase in the number of relatively low-molecular compounds, which, at certain temperatures, can be in a plastic state and take an active part in the clinkering process. Such a change in chemistry towards reductive depolymerization has a positive effect on the plastic state of the stamped coal batch. During coking of stamped batch, temperature and, therefore, time intervals of coal plasticity (especially low-clinkering coal) expand. Positive changes in the plastic state, along with an increase in the density of the plastic layer, make it possible to use the clinkering potential of the batch to a greater extent and to obtain coke of high mechanical strength from batches of reduced clinkering.[40]

The stamping process and the strength of the coal cake depend on the characteristics of the coal raw material: degree of metamorphism; the content of mineral impurities (ash content); shapes and sizes of coal grains (small classes contribute to compaction, filling the pores between large grains and thereby increasing the bulk density); humidity (moisture acts as a binder, affects the sealing process by reducing internal friction).[40]

Since February 2017, the coal batch stamping technology has been implemented at the new coke battery No.6 (coal cake density 1.1 t/m^3), and in 2018 – at battery No.5 of coke production of ArcelorMittal Kryvyi Rih. Analyzing the data on the composition of coal batches supplied to coke batteries No. 1–4 (coking of bulk batch), it can be noted that the average share of high-volatile coal was 47.07%; the content of medium-volatile coal - 35.27%; the content of low-volatile coal - 17.66%. Using stamping technology makes it possible to obtain blast furnace coke of a higher quality than with traditional technology. In particular, coke obtained at coke batteries (CB) No.5, 6 is characterized by lower values of ash content than at CB No.1-4 (11.4% and 11.7%), total sulfur content (0.44 and 0.52) and abrasion M_{10} at the level of 6.0% and 8.1%, while at the same time higher values of mechanical strength according to the grindability index are at the level of M_{25}~88.4% and 85.7% and coke strength after reaction CSR~54, 4% and 50.8%, respectively[41].

4. Conclusions

The functionality of coke in a blast furnace is conditioned by its chemical, physicochemical, and physical properties. At the same time, its quality depends crucially on the properties of coal raw materials and the efficiency of its preparation.

For the work of coke-chemical enterprises, it is necessary to develop and implement scientifically based, economically feasible approaches for improving the coal preparation technology for coking, namely:

- prediction and optimization of batch composition, taking into account the petrographic characteristics of its components and the expansion pressure of coal concentrates;
- the need to abandon the final crushing BC scheme and switch to a more effective GCC or DCC schemes in a complex with screening of fine classes before crushing
- implementation of special methods of preparing coal charges for coking.

It is necessary to ensure the economy and efficiency of coke production while optimizing the consumption of scarce raw materials. To expand the raw material base of coking coal, it is necessary to introduce promising technologies such as coal front cleaning, batch modification using additives, rational coal preparation by crushing, coking of stamped batches, the technology of coking dry batch, the technology of coking thermally prepared batches, coking of partially briquetted batches.

These methods directly affect the bulk density of coal batch, clinkering properties, and, therefore, the quality of the obtained coke and the production capacity of coke chambers.

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ВИМОГИ ДО ДОМЕННОГО КОКСУ ТА МЕТОДИ ПІДВИЩЕННЯ ЙОГО ЯКОСТІ: ОГЛЯД

Анотація. *У статті сформульовано вимоги до характеристик металургійного коксу. Описано основні методи вдосконалення процесів підготовки вугілля до коксування, такі як прогнозування й оптимізація складу шихти з урахуванням петрографічних характеристик її компонентів і тиску розпору вугільних концентратів, модифікація властивостей шихти за допомогою добавок, раціональна підготовка вугілля шляхом подрібнення, коксування трамбованих шихт.*

Ключові слова: *кокс, петрографічний склад, якість коксівного вугілля, доменна піч, вугільна шихта, процеси коксування.*