Principles of Coal Blend Formation Required to Obtain Coke with Target Characteristics of Coke Strength after Reaction (CSR)

E V Karunova¹,², A A Kalko¹, E A Volkov¹, and O A Kalko²

¹ PAO Severstal, 30 Mira street, Cherepovets, 162608, Russia
² Cherepovets State University, 5 Lunacharsky street, Cherepovets, 162600, Russia

E-mail: evkarunova@severstal.com

Abstract. A model has been developed that allows formation of a coal blend for production of coke with the specified characteristics of CSR in industrial conditions. The model is based on experimental data on the CRI and CSR values of coal concentrates obtained during individual coking using a SKW Karbolab plant.

Nowadays the coke quality is globally assessed by a number of values characterizing its properties in regards to its functions performed in certain areas of the blast furnace. For example, requirements of European blast furnace metallurgists to coke quality are as follows: mechanical strength (M₁₀ and M₄₀), grain size (contents of coke class > 80 mm, and in skip coke – class < 40 and < 20 mm), the values CSR (coke strength after reaction) and CRI (coke reactivity index) and chemical contents [1].

The assessment method of coke «hot» strength (CSR) proposed by the Japanese company «Nippon Steel» in the 1970s (further NSC) has become a regular practice of both, domestic and foreign metallurgy, since the above mentioned values CRI and CSR complete the standard parameters of coke mechanical strength control to the utmost and adequately display changes in quality of coal blend and technological factors of coke and by-product process [2, 3].

Despite being wide spread in the global and domestic practice, the NSC method has a number of relevant drawbacks, the main of which are low reproducibility, high cost of equipment and long duration of analysis performance [4]. This means that coke manufacturers are unable to react quickly to changes in raw material and (or) technological factors. This makes usage of mathematical models of coke quality forecast in terms of CRI and CSR quite reasonable.

Development of mathematic models and theoretical basics for the forecasting methods of physical and mechanical properties of coke using coal property values has been for many years one of the key problematic issues of coke production, since the solution of this issue is of high relevance in terms of application. Most of iron and steel-making plants possess their own adopted and practice-proven forecast formulas for the «cold» coke strength values. As a rule, those are based at the coal process characteristics demonstrated during its thermal conversion: properties of plastic mass, its caking ability and data on the coal genetic nature, coking technology and coke quenching method [5-6].

A number of mathematic models [7-10] are introduced presently to enable forecasting of CRI and CSR values of coke. Such models are based on the ash basicity index and chemical and petrographic properties of coal blends taking into account methods of their preparation, coking period and quenching...
method. Such models usually rest upon bulk process data sets of a plant taken for a certain period or results of laboratory-based and box coking. The key drawback of those models is limitation of their application (the model gives a valuable forecast only for the coke quality values at certain raw material base of coals).

Coal blend formation at coke and by-product plants is mostly performed by practical knowledge based on experimental coking (laboratory-based or box coking). Lack of flexibility under the changeable conditions at the raw material market is a substantial weak point of this approach to coal blend formation. That’s why one of the relevant issues for PAO Severstal is to select ratio of the coal concentrates using mathematic models, theoretical background and forecasting methods of physical and mechanical properties of coke with regard to coal properties. Settlement of this issue shall enable minimizing the risks arising from introduction of new suppliers and shall allow to take adequate solutions in terms of ratio between net cost and quality of coal concentrates. It should be noted that such research work is carried out by OAO Altai koks together with AO Eastern Research coal chemistry institute [11].

Control and forecast of coke quality in the iron-making plant of PAO Severstal is performed using laboratory facility type SKW «Karbolab» made by the Radiotechnical Institute of Poland (Figure 1).

Figure 1. Laboratory coking facility.
Usage of this laboratory oven allows carrying out of experimental coking of coals constituting the raw material base of CherMK, both actual and artificially modeled coal blends under conditions simulating the industrial coking process. An important thing about this laboratory facility is the stability of coking parameters, which makes it possible to evaluate the impact and to match the properties of the initial raw materials and properties of the produced coke. Moreover adoption of this facility reduces the price of the high cost semi-industrial and industrial experimental coking procedure in the operating coke ovens.

Research work performed by this laboratory oven allows to:
- deepen the knowledge of process value degree of certain coal concentrates;
- improve the ranking method for the coal concentrates which constitute the coking base at PAO Severstal;
- evaluate the influence of individual factors on the CSR value under conditions of laboratory;
- develop a method assisting to find an adequate balance of the incoming coal concentrates so that to receive the target CSR value to be used in iron-making plant.

During development of a method of coal blend matching for production of coke with the target characteristics of CSR, we faced a necessity to check the assumption of additivity of the coke quality values obtained at individual coking procedures of separate coal blend components, and quality values obtained during coal blend coking. Should the data possess additivity, there arises a possibility to use the results of laboratory-based coking of individual coal concentrates for forecasting of the industrial coke quality.

In this research work, we have addressed to a bulk data set incorporating individual laboratory-based coking procedures of 120 samples of pure coal concentrates and 35 samples of artificially modeled coal blends made from those coal concentrates.

At Figure 2 you can see the interdependence between values of coke strength after reaction with carbon dioxide received with the coal blends and calculated value determined through the portion of

![Figure 2. Interdependence between strength characteristics of coke obtained during laboratory-based coking of coal blends and the calculated value based on the portion of involvement in the blend and individual CSR value of each blend component.](image-url)
individual concentrates involvement in the coal blend intended to be coked. The confirmed additivity of individual coking values allowed their inclusion as the key value of mathematic model of coal blend trial during development of patent RU2608524С dd 19.01.17.

Thus we can state that for the coal concentrates constituting a raw material base of the plant individual laboratory-based coking is practicable. Coke produced that way is then analysed all through; the results of the set of analyses can be used for quality evaluation of coke produced through the process flow. The key value to be identified in the produced coke samples is CSR.

Thus coal blend is formed based on the data on CSR, individual coal concentrates taking into account additivity of those values. Coal blend formation shall also address to the blast furnace process demand maintaining the certain range of strength characteristics of oven coke. Theoretical and industrial values are calculated using reduction factors via linear dependence [12].

At Figure 3 you can see a graph outlining the interdependence between coke strength value after reaction with carbon dioxide (CSR), calculated through individual coking procedures using the forecast formula and actual average value taken over the period when the coal blend consumption charts have been used at the iron-making plant of PAO Severstal.

![Figure 3. Interdependence between calculated and actual values of coke strength CSR for coke division of iron-making plant of PAO Severstal.](image)

Deviations of shift-wise actual values of CSR from the target values set in the al blend consumption charts have been analyzed in order to evaluate deviation between forecast and actual values of coke strength after reaction with carbon dioxide (CSR). It has been found that 85% of all the obtained data lies within the range of ±3%, which is in conformity with the repeatability limit used for determination of CSR. At Figure 4 you can see a diagram of deviation breakdown.

It should be noted that the developed model is used with success in the coke and by-product process stage at PAO Severstal. Its implementation enabled achievement of the CRI and CSR values of the produced coke equal to 25-35% and 48-60% accordingly which is close to the adequate values [13] and in its average meets the requirements for coke characteristics imposed at the plants of Western Europe [14].

**Conclusions**

Based on the findings of performed research work one can conclude the following:

1) values of individual coal coking are additive;
2) strength of coke acquired from a blend of coal concentrates after reaction with carbon dioxide can be calculated based on the portion of coal concentrate involvement in the coal blend to be coked and CSR values achieved during individual coking;

3) application of the proposed model may allow forecasting of the coke quality both for «cold» strength and CSR;

4) selection of the adequate contents of coal blend to be coked taking into account all the coke characteristics relevant for blast furnace procedures has become possible.

References

[1] Zolotukhin Yu A, Osadchii S P, Denisenko E V, Andreichikov N S, Kuprygin V V and Zorin M 2019 Coke and chemistry 5 12–37
[2] Muchnik D A 2010 Coke and chemistry 10 17–23
[3] Gurkin M A, Vinogradov E N, Volkov E A, Karunova E V and Kalko A A 2017 Method of coal blend formation used to obtain metallurgy coke with the target CSR value (Patent RU2608524C1)
[4] Ukhmylova G S 1995 Coke and chemistry 4 37–41
[5] Geerdes M, Chenio R, Kurunov I, Lingardi O and Rickets D 2016 Modern blast furnace procedure. Introduction (Moscow: Metallurgizdat) pp 69–70
[6] Stukov M I, Kogan L A, Kosogorov S A and Kukolev Ya B 2011 Coke and chemistry 3 50–52
[7] Stepanov Yu V, Popova N K and Koshkarov D A 2005 Coke and chemistry 5 26–34
[8] Gabov A I, Trifanov V N, Konovalova J V and Karunova E V 2012 Coal blend formation method used to obtain metallurgy coke (Patent RU2461602)
[9] Stankevich A S and etc. 2000 Coke and chemistry 5 2–10
[10] Bulanov E A, Zainutdinov V N, Kuznetsov V V and Zinovieva L A 2005 Coke and chemistry 5 23–26
[11] Savchuk N A and Kurunov I F 2000 Blast furnace plant at the turn of XXIst century (Moscow: Chermetinform) p 42
[12] Bazegskii A E, Ryabichenko A D, Khamidulin F Z, Pianov B F and Stankevich A S 2002 Coke and chemistry 9 15–22
[13] Stankevich A S, Guilliazetdinov R R, Popova N K and Koshkarov D A. 2008 Coke and chemistry 9 37–44.
[14] Lialiuk V P, Sokolova V P, Schmeltzer E O, Timofeeva D Yu and Bereza V V 2014 Coke and chemistry 6 15–22.