

# Reducing the Content of the >80 mm Class in Metallurgical Coke.

## 1. Literature Review

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**Abstract**—In the present research, means of reducing the content of the >80 mm class in metallurgical coke at coke batteries 1, 3, and 4 of Ural Steel are considered, in the light of the need to minimize batch cost and maximize coke quality (specifically, the strength indices  $M_{10}$  and  $M_{25}$ ). This problem was suggested by students in production education groups at the Novotroitsk branch of Moscow Institute of Steel and Alloys (MISIS). This first article in the series is a literature review, beginning in the 1960s. The influence of the following factors on the content of the >80 mm class is discussed: the rank composition of the batch; its moisture content; and coking parameters such as the coking time, the temperature in the controlled heating channels, and the coking rate. The second article will be devoted to mathematical analysis of a passive experiment based on Ural Steel data, with the goal of identifying the factors affecting the content of the >80 mm class in the coke produced at Ural Steel; the results of this analysis will be compared with literature data. The third article will present models of the content of the >80 mm class in the coke produced, with subsequent optimization and testing by laboratory coking.

**Keywords:** metallurgical coke, large (>80 mm) class, crushing, batch formulation, coke strength,  $M_{10}$ ,  $M_{25}$ , coking parameters, coke production

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### INTRODUCTION

Overall, Russian industry faces a shortage of skilled employees; coke plants are no exception. Each enterprise approaches this problem in a different way: examples include increased salary; increased benefits; organization of staff trainings (including high-level management skill building); and development of corporate values and team cohesion. One approach to staff development adopted at Ural Steel, in collaboration with Moscow Institute of Steel and Alloys (MISIS), is to create production education groups. In such groups, students in various disciplines are required to solve real production problems. This approach allows enterprises to engage students actively in production processes, while the students are able to compare their skills with those required in practice

and to gain a deeper understanding not only of theoretical disciplines but of their relationship with industrial practice. The work of the students in the production education groups involves direct mentoring by highly qualified production specialists.

Experience at Ural Steel shows that the blast furnaces perform less well when the metallurgical coke employed has a high content of the >80 mm class, as confirmed by prior research. At Krivorozhstal, when the initial coke used at 5000-mm<sup>3</sup> blast furnace contains 35% of the >60 mm class, considerable quantities of coke fines (<3 mm) are formed and are entrained from the furnace by the smokestack gas. The content of fines is 49.0% at the lower level of the furnace shaft and 26.8% in the hearth. The conclusion was that effi-

**Table 1.** Some results from [19]

Experiment	Packing density of coke in coking, g/cm <sup>3</sup>	Heating rate, deg/min	Granulometric composition (%) by size class, mm					Coke characteristics	
			>60	40–60	25–40	10–25	≤10	$d_e$ , mm	G
1	0.650	1.3	63.2	13.2	6.4	3.6	13.6	60.0	230
2		2.0	71.2	20.2	1.3	0	4.3	62.6	265
3		3.0	58.9	33.4	1.6	2.6	3.5	60.5	259
4		4.5	17.7	56.9	18.5	3.0	3.9	47.6	246

Here G (a dimensionless quantity) is the gas permeability of the coke, according to Syskov. Higher G indicates greater gas permeability.

cient operation of the 5000-mm<sup>3</sup> blast furnace requires elimination of the >60 mm class [1].

When the >60 mm class is replaced by the 40–60 mm class, blast furnace productivity is increased by 3.2–3.4% and coke consumption is lowered by 1.6–1.7%, according to [2]. Blast furnace performance when using the >60 mm is even worse than when using the >40 mm class.

In coke production at Ural Steel, the goal is to decrease the content of the >80 mm class in the metallurgical coke employed. At least two approaches are possible here: mechanical crushing of the large coke fraction; or organization of the coking batch and coking conditions so as to minimize the yield of the >80 mm class. Each option has its disadvantages.

Mechanical crushing of the >80 mm class will produce large quantities of smaller classes (including <25 mm) [3, 4]. That necessitates increase in coke plant productivity and sale of the excess <25 mm coke. For a coke plant within a steel mill, that approach may be ruled out, on account of the expense of buying and installing a crushing system; increased wear of the equipment and coke battery as a result of the increased productivity; and the negative economic impact in that steel, rather than coke, is the primary product.

The other approach, based on appropriate adjustment of the coking batch and coking conditions, necessarily depends on modeling and prediction of the coke's mechanical characteristics, such as  $M_{10}$  and  $M_{25}$  [5–14]. In other words, prediction and optimization of the yield of >80 mm coke must be supplemented by model prediction of  $M_{10}$  and  $M_{25}$ .

We select an approach based on modeling to decrease the production of the >80 mm coke class, taking into account that the literature provides well developed and tested algorithms for such modeling [15–18].

The goal of the present work is to establish coking parameters corresponding to minimum yield of the >80 mm coke class at Ural Steel coke batteries. This

problem will be addressed in three parts devoted to different topics.

1. A literature review to identify factors in batch formulation and coking with a significant influence on the formation of large coke pieces (Part 1, this work).

2. Statistical diagnostics of the correlations between the identified parameters so as to create a representative sample for model construction. The results are compared with the conclusions of the literature review in part 2.

3. Construction of mathematical models describing the relationships between the significant factors already identified, on the one hand, and the yield of the >80 mm coke class and the mechanical indices  $M_{10}$  and  $M_{25}$ , on the other. After optimization on the basis of the models, several optimal compositions of the coal batch are proposed, so as to minimize the yield of the >80 mm coke class, increase  $M_{10}$  and  $M_{25}$ , and reduce coke production costs. The proposed batches are tested in laboratory coking at Ural Steel on a Nikolaev furnace, in accordance with State Standard GOST 9521–2017 (Method of Determining the Coking Properties of Coal) (Part 3).

## LITERATURE REVIEW

The influence of the batch heating rate in a laboratory coking furnace with a one-time load of 6 kg on the granulometric composition, gas permeability (determined by the Syskov method), and mean diameter of the coke pieces was studied in [19]. Table 1 presents the basic results. It is found that increasing the heating rate decreases the yield of the >60 mm coke class.

The performance of Zaporozhe coke plant with coking periods of 14 h 43 min and 15 h 45 min was compared in [20]. The rank composition of the coking batch was as follows: 23.5% G, 35.5% Zh, 21.0% K, and 20.0% OS. Table 2 presents the results of coking.

We see in Table 2 that the content of the >80 mm class increases (by 9%) with increase in the coking

**Table 2.** Test results for coke after different coking periods [20]

Coking period	Temperature in heating channels, °C		Mechanical strength (Sundgren drum tests), kg	Strength (Micum drum tests), %		Granulometric composition (%) by size class, mm					
	machine side	coke side		$M_{10}$	$M_{40}$	>80	80–60	40–60	25–40	<25	>60
14 h 43 min	1318	1360	338	6.6	78.8	20.5	35.2	33.9	8.0	2.4	55.7
15 h 45 min	1278	1318	343	6.8	80.0	29.9	36.6	29.9	22.4	1.2	66.5

period. The mechanical characteristics  $M_{10}$  and  $M_{40}$  of the coke may be regarded as approximately the same, since the permissible discrepancy in parallel measurements is 1.0% for  $M_{10}$  and 3.0% for  $M_{40}$ , according to State Standard GOST 5953–2020 (ISO 556:1980).

The change in granulometric composition and strength ( $M_{10}$  and  $M_{40}$ ) of the coke with variation in moisture content of the batch at Kharkov coke plant was studied by specialists at the Ukrainian State Research Institute of Coal Chemistry (UKhIN) in [21]. In the experiments, a 200-kg laboratory furnace was employed. The rank composition of the coking batch was as follows: 30% G, 34% Zh, 18% K, and 18% OS. It was found that increase in the moisture content from 7.8% to 13.5% decreased the content of the >80 mm class in the coke from 18.8% to 11.4%. However, the mechanical strength  $M_{10}$  and  $M_{40}$  of the coke declined: from 8.8% and 79.0%, respectively, when the moisture content was 7.8% to 10.8% and 76.5% with 13.5% moisture content.

Crushing of the >80 mm and >60 mm classes in coke was considered in [22]. The coke obtained from an experimental serrated crusher (designed by UKhIN) was more uniform and had improved mechanical properties. However, deficiencies of the method were also noted. When the system was set to crush the >80 mm class (14.5–28.7% of the initial coke, in the experiments), this class was not eliminated. Its content was decreased to 10–15%, with increase in the yield of the <25 mm class by 6.0–7.5% of the initial mass of the >80 mm class. When the system was set to crush the >60 mm class (46.8–60.3% of the initial coke), the >80 mm class was completely eliminated. However, the yield of the <25 mm class was increased by 8–10% of the initial mass of the >60 mm class, with corresponding decrease in the utility of this technology.

Decrease in the coking period decreased the overall size of the coke and its content of the >80 mm class, according to [22]. In addition, increasing the final coking temperature to 1100°C along the axis of the coking chamber also decreased the content of large classes in the coke.

Statistical analysis of data for Kuznetsk steel works over 12 years provided useful practical information [23]. Table 3 presents the characteristics of the specific coal ranks recommended. Increasing the content of those ranks considerably reduced the proportion of the >80 mm class in the coke produced. These ranks correspond to ranks KO and KS defined in GOST 25543–2013.

The strength of coke in the 40–60 mm class was found to be higher than that of the >80 mm class by 25–30 kg (the residue in the Sundgren drum) in [23]. In the drum tests, the content of fines (<10 mm) increased by about 30 kg.

At Avdeev coke plant, the influence of quenching methods of coke quality was investigated in [24]. At all stages of the experiment, comparison of screening data for coke after dry and wet quenching revealed no significant difference in granulometric composition, but the coke strength ( $M_{10}$  and  $M_{25}$ ) differed. Depending on the productivity of the dry quenching system (one, two, or three coking chambers per hour),  $M_{40}$  was 5.4, 3.8, or 1.0% larger than in wet coking.

The rate of batch heating is the factor mainly determining the size of the coke produced, according to [2]. The independent factors considered were the coking characteristics—in particular, the rate of temperature increase in the batch and the final temperature at the center of the coke cake. The responses were assessed in terms of the coke strength ( $M_{10}$ ,  $M_{25}$ , and  $M_{40}$ ) and the content of the >80 mm class in the coke produced.

**Table 3.** Technical analysis and plastometric indices of coal samples [23]

Coal rank	Technical analysis, %		Plastometric indices, mm		$\Sigma$ LC
	$A^d$	$V^d$	$x$	$y$	
K10	8.8	21.8	36	12	44.5
K2	7.3	18.9	33	9	51.0

These ranks correspond to ranks KO and KS defined in State Standard GOST 25543–2013.

**Table 4.** Operational characteristics of coke ovens [25]

Characteristic	Furnace run, h								
	24.1	20.5	18.6	18.0	17.8	15.9	16.0	16.4	17.3
Temperature in the heating channels, °C:									
machine side	1141	1201	1246	1261	1275	1306	1314	1309	1286
coke side	1160	1235	1285	1305	1316	1352	1356	1353	1329
Granulometric composition (%) by size class, mm:									
>80	15.2	10.7	8.1	8.0	8.5	7.6	7.4	7.8	7.5
80–60	34.3	28.9	22.7	25.1	24.5	21.1	19.8	19.7	18.5
60–40	35.7	40.8	45.7	45.7	45.2	46.3	45.3	45.4	45.4
40–25	11.4	16.2	20.3	17.8	18.5	21.6	24.6	23.4	24.8
<25	3.4	3.4	3.2	3.4	3.3	3.4	3.5	3.6	3.4
Mechanical strength of coke, %:									
$M_{25}$	88.6	88.6	88.1	87.6	87.7	87.3	87.4	87.1	87.9
$M_{10}$	6.8	6.9	6.8	7.0	6.9	7.0	7.0	7.1	6.7
Technical analysis, %:									
$W^r$	4.8	4.7	4.6	4.5	4.5	4.5	4.6	4.5	4.6
$A^d$	10.7	10.4	10.4	10.3	10.3	10.3	10.4	10.5	10.5
$V^{daf}$	1.1	1.1	1.1	1.1	0.9	1.1	1.1	1.1	1.1
$S^d$	1.7	1.7	1.69	1.66	1.67	1.68	1.68	1.69	1.67

With increase in the heating wall temperature and in the coking period, the size of the coke was found to be uniform and smaller; however, the influence of the coking period was very small. With constant wall temperature, increase in the coking period was accompanied by increase in coke strength (resistance to abrasion) on account of increase in the heating rate of the batch and increase in coke readiness. It was concluded that, in order to improve coke quality, the temperature in the heating wall should be as high as is consistent with integrity of the lining on the chamber walls. The coking period should be selected so that the temperature of coke–lining contact at coke discharge from the oven is no more than 1180–1190°C, but should be at least 14 h.

Table 4 presents operational data for coke battery 1A at Mariupol coke plant [25]. On that basis, the variation in content of the >80 mm class may be predicted as a function of the coking period. With increase in temperature in the heating channels, the yield of the >80 mm class was found to fall.

The yield of the >80 mm class in the coke was considered as a function of the total content of lean components in the batch in [26]. The range observed was

20–30% for the content of the >80 mm class in the coke and 19–31% for the total content of lean components in the batch. Decrease in content of the >80 mm class in the coke was observed with increase in the total content of lean components in the batch.

The coke quality index  $I_{qu}$  was proposed to take account of the coke's granulometric composition in estimating its value in [27]

$$I_{qu} = d_{eq} + kCSR,$$

where  $d_{eq}$  is the equivalent diameter of the coke pieces, mm;  $CSR$  is the coke strength after reaction with  $CO_2$ , %; and the empirical coefficient  $k = 1.45$  and  $2.60$  for coke produced with dry and wet quenching, respectively.

Analysis of  $I_{qu}$  shows that increase in the equivalent diameter  $k_{eq}$  leads to increase in coke quality for the same quenching method, with unchanged  $CSR$ . Note that  $I_{qu}$  was derived from statistical data in the range  $d_{eq} = 42.0$ – $48.0$ ; the content of the >80 mm class was 7.1%, on average. Therefore, the results in [27] are consistent with previous findings, since  $d_{eq}$  does not exceed the value (for example, 60 mm or more) in the

granulometric composition of the coke considered in [27]. The 40–60 mm class predominates.

## CONCLUSIONS

The most significant factors affecting the content of the >80 mm class in the coke produced are the coking rate, the temperature in the heating channels, and the coking period, as well as the content of KO and KS coal in the batch. In addition, the yield of the >80 mm class is lower with greater moisture content in the batch, but that is associated with worse values of  $M_{10}$  and  $M_{25}$  for the coke.

Correspondingly, the following means of decreasing the content of the >80 mm class in the coke are effective.

1. Increasing the coking rate (increase in temperature in the heating channels with constant coking period).

2. Increasing the content of KO and KS coal in the batch.

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## CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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