

## HIGH-TEMPERATURE INVESTIGATION OF THE PROPERTIES OF BLAST FURNACE COKE

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The behavior of coke in the blast furnace is discussed in this article. The methods of taking charge coke samples from blast furnace have been verified. The tests of the effect of temperature on coke (subjected to laboratory tests reproducing, to a certain extent, the conditions prevailing at the tuyere level of the blast furnace) have established factors responsible for the degradation of coke. This has allowed the parameters characterizing the structure to be described as follows:  $L_c$ , the crystallite height is contained in range 1.5932 - 3.2620 nm;  $L_a$ , the crystallite width is in the range 2.82013 - 5.7737 nm; and the crystallinity factor,  $W_k$ , is contained in the range 0.147 - 0.77014.

**Key words:** *coke from blast furnace, graphitization of coke, tuyere level, strength properties in high temperatures*

**Visoko temperaturno istraživanje svojstava koksa za visoke peći.** U radu se raspravlja o ponašanju visokopećnog koksa. Za uzimanje koksa iz visoke peći koristile su se razne metode. Ispitivanje učinaka temperature na koks (izloženog laboratorijskoj ispitnoj proizvodnji, do određene mjere, uvjeti koji pretežu na razini duvnice) daju faktore odgovorne za raspad koksa. To je omogućilo nastajanje takvih parametara zahvaljujući kojima se formira struktura prema slijedećem opisu:  $L_c$ , visina kristala u rasponu od 1.5932 - 3.2620 nm;  $L_a$ , širina kristala je u rasponu od 2.82013 - 5.7737 nm; a faktor kristalčnosti  $W_k$  u opsegu od 0.147 - 0.77014.

**Ključne riječi:** *koks iz visoke peći, grafitezacija koksa, razina duvnice, svojstva čvrstoće na visokoj temperaturi*

### INTRODUCTION

Over the years 1986 - 1998, the average usable volume of blast furnaces in Western Europe increased from 1575 to 1780 m<sup>3</sup>. At the same time, the productivity of pig iron increased from 1.90 to 2.47 t/m<sup>3</sup> × 24 hrs. Although the decrease in the unit consumption of fuels was small, namely from 497 to 483 kg/t pig iron, in that period, the drop in coke consumption was much greater, i.e. from 462 to 362 kg/t pig iron, chiefly due to the increased amount of coal dust blown in [1]. The increase in the volume of blast furnaces and a drop in the amount of coke per 1 ton of pig iron manufactured are an impulse for searching for the methods of improving the quality of coke. With decreasing fraction of coke in the charge, its role increases as a skeleton decisive to the aeration of charge in blast-furnace zones, where the iron-bearing part softens and melts, and lowers, where it already flows down as primary slag.

A significant effect of coke on charge aeration in the blast furnace begins at temperatures, at which ores, fluxes and other additives soften and melt. From these moments on, only coke remains in solid state. Therefore, it becomes very important to understand the factors that may have an effect on the weakening and degradation of coke lumps at temperatures above 1200 - 1300 °C.

The testing of strength properties commonly performed by the MICUM method, and even by the NIPPON STEEL (indices SCR and CRI) method which is becoming increasingly widespread, does not provide complete information of coke at temperatures of interest for blast-furnace men.

Information of a drop in the strength of coke above 1300 °C first appeared in 1977 [2].

Since that time, different tests of coke strength have been carried out worldwide at temperatures around 2000 °C, i.e. up to a probable maximum temperature of coke lumps in the blast furnace. Various testing installations have been developed, which operate at enhanced temperatures, but none of them, except those of NIPPON STEEL, have left their own local laboratories [3].

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Several articles have been published recently in the world's literature on the properties of coke at high temperatures [4]. Also in Poland, this subject is being dealt with by teams of researchers at the Academy of Mining and Metallurgy, the Institute of Coal Processing of Zabrze, and the Technical University of Czestochowa.

## EXPERIMENT

At the Technical University of Czestochowa, studies have been conducted since 1999 as part of KBN (Scientific Research Committee) Project No. 7 T08B 022 16. Research carried out within this project included changes undergone by coke when passing through the blast furnace from the moment of being loaded in the blast furnace throat down to the high-temperature zone in the tuyere area. It appears that while coke loaded to the blast furnace exhibits properties in an averaged sample repeatable enough to enable one to differentiate one coke batch from another, then the coke taken from the tuyere zone differs between particular locations of this zone. Coke taken with a horizontal probe through the tuyere set of the Katowice Steelworks' blast furnace can be an example here [5]. Table 1. shows the contents of volatile matter and the share of the coke size fraction above 20 mm in coke samples taken at different distances from the tuyere outlet.

Table 1. Contents of volatile matter and the share of coke size fraction above 20 mm in coke samples at different distances from the tuyere outlet

Tablica 1. Sadržaj hlapljive materije i udio frakcije koksa veličine preko 20 mm u uzorcima koksa na različitim udaljenostima od duvnice

Distance from the tuyere outlet [cm]	Contents of volatile matter [%]	Fraction of coke lumps above 20 mm [%]
19	0.25	35
60	0.32	32
100	0.28	42
132	0.01	21
160	0.80	49

Although the test confirmed that the coke underwent grain degradation and the reduction of volatile matter contained in it as it descended down the blast furnace, the scatter of these effects in particular samples given in Table 1. suggests that the analysis of samples taken from the tuyeres does not allow different coke batches to be compared. For this reason, it was considered advisable to use a laboratory method for the evaluation of different coke batches, which is based on parameters defined more precisely than it is the case for the blast furnace. Therefore, the method relying on the determination of thermal grindability (index  $\xi$ ) was primarily used [3].

The thermal grindability determination method, i.e. the one that models the ante-tuyere chamber of the blast furnace, is a method that has been developed at the Institute of Iron Metallurgy of Gliwice and then transferred to the

Technical University of Czestochowa and used successfully till the present day (see the schematic diagram of the installation in Figure 1.).

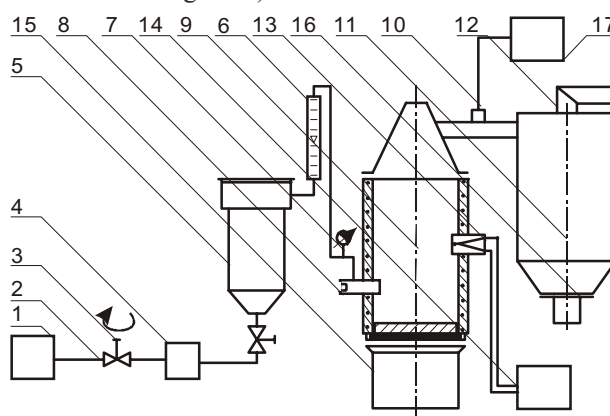


Figure 1. Schematic diagram of the installation for the testing of coke by its partial burning: 1 - compressor, 2 - compressed air line, 3 - valve, 4 - throttling disc, 5 - air oil and water separator, 6 - rotameter, 7 - pressure gauge, 8 - nozzle with a sight-glass, 9 - electric furnace, 10 - combustion-gas duct, 11 - cyclone dust separator, 12 - chimney stack, 13 - Pt-RhPt thermocouple protruding into the chamber by 10 mm, 14 - compensation temperature recorder, 15 - post-burning coke collection reservoir, 16 - coke dust reservoir, 17 - combustion-gas CO analyzer

Slika 1. Shematski dijagram uređaja za ispitivanje koksa djelomičnim sagorijevanjem: 1 - kompresor, 2 - cijev s tlačnim zrakom, 3 - ventil, 4 - prigušni disk, 5 - separator ulja i vode, 6 - mjerac broja okretaja, 7 - mjerilo za tlak, 8 - sapnica sa kontrolnim staklom, 9 - električna peć, 10 - kanal za sagorni plin, 11 - ciklonski separator za prašinu, 12 - dimnjak, 13 - termoelement Pt-RhPt koji ulazi u komoru za 10 mm, 14 - uređaj za mjerenje kompenzacijske temperature, 15 - rezervoar za skupljanje koksa nakon sagorijevanja, 16 - rezervoar za koksnu prašinu, 17 - analizator za CO iz sagorjelog plina

Thus, the sample makes up part of the fraction above 0.030 or 0.040 m (30 or 40 mm) after the MICUM test, which is broken up to below  $\varnothing$  0.013 m (13 mm) and a fraction of 0.010 to 0.013 m (10 to 13 mm) is separated. Then, it is divided into two, or possibly three parts: one for carrying out the intended test, the other for repeating the test, and the third one as a reference sample.

2 kg of coke, dried at 378 K, are loaded to the furnace of the installation. After closing the furnace with a hood with a combustion-gas duct, the coke sample is heated up to a temperature of 1273 K according to the readings of a thermocouple mounted 0.060 m (60 mm) above the nozzle on the opposite side of the furnace, at the location shown in the schematic diagram (the thermocouple protrudes by 0.010 m (10 mm)). After the temperature has been reached, the electric power supply was switched off and the furnace is left for 900 seconds to allow the partial equalization of temperature within the whole coke sample. Then, blowing of air through the nozzle was started.

The coke residue in the dust collector constitutes a strength index called "thermal grindability". A better re-

peatability of this index for the same coke was obtained by relating the amount of quick coke captured in the cyclone to the actual time of sample whirling.

Ash and its components play an important role in coke; they reduce the amount of carbon in the coke. At temperatures above 1300 °C, ash is no longer a binding factor in the coke and becomes a liquid weakening the small channels of the coke. This is confirmed, among other things, by thermal grindability tests for cokes of different ash contents. Thus, the analysis of changes in the structure of ash components in the solid phase and their effect on possible volume changes that might "burst" coke lumps was commenced, followed by the analysis of the effect of the composition and structure of this ash on its softening and melting temperatures.

Probably, the factor that influences the degradation of coke is change in the structure of carbon in the coke and the progressing graphitization of the carbon. It has been found that coke lumps, both those extracted from the blast-furnace tuyeres and those after the thermal grindability test, exhibit larger graphite contents than the charge coke does. These increases are generally the greater the higher graphite content in the charge coke is.

## RESULTS

Table 2. shows the results of the statistical processing of measurement results for three generic groups of samples. This Table indicates that the crystallinity factor and the size of crystallites increase as a result of the heat treatment of coke. This increase is already noticeable for short-time of heat treatment when determining thermal grindability. Still greater growth of coke crystallinity takes place in the blast furnace, where the increase in coke temperature from 25 °C to over 1700 °C lasts 5 - 7 hours.

Table 2. **Mean values of coke sample parameters measured diffractometrically**

Tablica 2. **Srednje vrijednosti parametara uzorka koksa izmjerene difraktometrički**

Sample	Mean values		
	$W_k$	$L_a$ [nm]	$d_{002}$ [nm]
Excess coke (from the coking plant)	0.1782 ± 0.0895	10.0517 ± 2.6326	0.36077 ± 0.002029
Coke taken from the tuyere level of the blast furnace	0.5948 ± 0.1704	21.4667 ± 4.9774	0.37520 ± 0.002029
Coke after thermal grindability tests	0.5215 ± 0.1393	14.8200 ± 2.8991	0.36077 ± 0.000905

Table 2. indicates that particular cokes in each of the states tested are different. Practice confirms coke structure fluctuations, which are chiefly due to fluctuations in the petrographic composition of charge coals, not only in different coal beds of the same colliery, but even within the same bed. The data summarized in this Table allows one to suppose that the size of crystallites in the coke extracted from the tuyeres depends on the size of crystallites in the coke charged to the blast furnace, and it surely significantly increases in the blast furnace. This increase is likely to depend on the (variable) thermal conditions of blast furnace operation, and even on the petrographic characteristic of the coking plant's charge coal. Comparison of the effects of thermal action on the coke in the blast furnace and during thermal grindability testing clearly indicates a substantial influence of the time of coke residence at high temperatures (around 1700 °C).

## CONCLUSION

It has been found from the analysis of the obtained results that the samples taken from the blast furnace (i.e. the samples subjected to heat treatment at very high temperatures - above 2000 °C, and for quite a long time of 5 to 7 hours) have undergone the highest crystallization. The lowest degree of graphitization is exhibited by coke samples taken directly from the coking plant, which have not been subjected to any thermal processes (except for the manufacturing process). The samples of the intermediary group, of the medium degree of crystallinity, are the cokes that have been subjected to thermal grindability tests at enhanced temperatures and the cokes taken from the blast furnaces before the completion of the blast-furnace process.

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