METHOD OF TESTING OF REACTIVITY OF COKE WITH DIFFERENT GRAIN SIZES AND ITS VERIFICATION UNDER INDUSTRIAL CONDITIONS

NIESLER M.

Institute for Ferrous Metallurgy- Gliwice, Poland

METÓDA TESTOVANIA REAKTIVITY KOKSU RÔZNEJ ZRNITOSTI A JEJ OVERENIE V PRIEMYSELNÝCH PODMIENKACH

NIESLER M.

Ústav pre hutníctvo železa- Gliwice, Poľsko

Abstrakt

Článok obsahuje popis novej metódy testovania reaktivity koksu, ktorá umožňuje hodnotiť stupeň a intenzitu degredácie častíc koksu s rôznou počiatočnou veľkosťou. Sú prezentované výsledky testovania koksu pomocou tejto metódy, zahŕňajúce stupeň úbytku hmotnosti častíc koksu rôznej počiatočnej veľkosti, úbytok strednej veľkosti častice koksu v priebehu splyňovania a mechanický odpor po splyňovaní. Na základe výsledkov testov boli určené podmienky, pri ktorých sa má uskutočniť hodnotenie pomocou novej skúšky a boli špecifikované ukazovatele hodnotenia reaktivity koksu. Nová testovacia metóda bola overovaná v podmienkach huty Sendzimir pri hodnotení vplyvu granulometrie koksu na vysokopecný proces.

Abstract

This paper contains a description of a new method of coke reactivity testing, which makes it possible to evaluate the degree and intensity of degradation of coke grains with various initial sizes. The results of coke reactivity testing with the use of this method are presented including degrees of mass decrement of coke samples with various initial grain sizes, decrement of average-size grain of tested coke during its gasification and mechanical resistance of coke samples after gasification. Based on the test results, the conditions were determined, under which determination with the use of the new method is carried out, as well as coke reactivity evaluation indices were specified. The new testing method has been verified, under Sendzimir Steelworks conditions, as for the possibility of using it to evaluate the impact of coke granularity on the course of the blast-furnace process.

Key words: coke reactivity, reactivity testing, grain size, blast furnace, coke,

1. INTRODUCTION

Blast-furnace coke is one of the most important factors, which affect the economic efficiency of the blast-furnace process. The use of cheaper assortments of coke with smaller granularity in blast furnace is the essential factor to reduce the costs of ironmaking. Relying upon experiences of both domestic and world blast-furnace practices [1, 2, 3], it may be stated that use of the coke with smaller granularity in blast-furnace process (""nut coke II"" - i.e. 25-40 mm, ""pea coke"" - i.e. 10-25 mm, etc.) as a substitute of a part of blast-furnace coke is proved. However, use those assortments of coke cannot take place at the cost of worsening of blast furnace working conditions [4, 5], as worsened technological indices of this process could thwart economical profits resulting from the partial application of cheaper coke assortments.

Taking into consideration the issues concerning the impact of partial substitution of blast-furnace coke by its fine-grained assortments on the working conditions of blast furnace, development of a new testing method, which would be helpful in evaluation of coke reactivity in relation to its granularity, was regarded as purposeful.

The method has also been verified as regards the possibility to use it to evaluate the impact of coke granularity on the course of the blast-furnace process, based on the data received from T. Sendzimir Steelworks.

2. METHOD AND EQUIPMENT FOR DETERMINATION OF REACTIVITY OF COKE WITH VARIOUS GRAINING

2.1 SELECTION OF TESTING EQUIPMENT

For the needs of testing of coke with various graining, the equipment for determination of reductivity of ore, sinter and pellet under loading (fig. 1) and the equipment for cold barrel finishing of sinter after static reduction [6, 7] were adapted for gasification.

2.2 TESTING METHOD

The assumption of the new method of coke reactivity testing is to determine the following values: the degree of mass decrement in coke samples with various initial size of grains during their gasification in CO_2 atmosphere, decrement of average-size grains in tested coke and determination of mechanical strength of the same coke sample after gasification [8].

The coke sample with exactly determined grain size and the weight of 400g, after having been dried in a drier at the temperature of 105-110°C for 480 min, is placed in a retort made from heat-resisting plate. During the initial stage of the sample heating, a neutral gas - nitrogen with the flow rate of 360 dm^3/h under normal conditions - is passed through the perforated bottom of the retort. After expelling of volatile matter (approx. 1% of the sample weight), which takes 45 minutes according to anticipation, heating in the atmosphere of neutral gas is continued until the temperature in the sample mass is stabilised at the level of 1050°C±10°C. Then the inflow of nitrogen is stopped and, instead, CO_2 is supplied with the flow rate of 1000 dm^3/h. The moment is considered as the beginning of determination. The sample is subject to the pressure of 0.1 Mpa exerted by a piston. The mass decrement of the sample is controlled with the use of scales, on which the retort is hung, coupled with PC. When the determination has been finished, the sample is cooled down in nitrogen atmosphere to the ambient temperature. Then the mass decrement is checked by means of laboratory scales and the sieve analysis is carried out. When the determination is performed, the sample is placed in a drum where it is subject to mechanical working. The drum performs 300 turns with the speed of 30 rev/min. Based on the next analysis, which is the grain analysis, the decrement of the coke grain size is determined following determination in consideration to the initial grain size.

The following values are specified as the determination result: the rate of coke mass decrement V_m (%/min) and rate of coke grain size decrement V_z (%/min).

3. ANALYSIS OF THE FINDINGS

Based on the determination results obtained, the analysis was carried out concerning relationship between the coke sample mass decrement and the time of its gasification as well as between the mass decrement and the coke grain size decrement before and after barrel finishing in comparison to the initial average size of the grain in tested coke.

Changes occurring in the coke samples tested during and after determination are presented in figures 2-6.

Figure 2 depicts examples of curves drawn on the basis of calculated dependences between the percentage mass decrement in coke with various average initial grain size and the time of determination at the temperature of 1050°C.

It follows from the character of the curves presented in figure 2 that the coke sample mass decrement during gasification increases, while the smallest mass decrements occur in case of blast-furnace coke. The exception here is the quick coke 0÷10 mm (the average size of grain is 2.9 mm). It may result from the fact that quick coke is less susceptible to gasification because of worse permeability and, as a result of that, more difficult gas flow and thereby smaller contact surface between quick coke and CO_2, which flows through the sample.

Fig.2 Trends of percentage decrement of coke sample mass with specific grain size depending on the time of gasification reaction

Except for the above-mentioned case, mass decrements during gasification of finer grains of coke are significantly higher. The largest coke grains are characterised by the lowest gasification dynamics, which in this case is connected with their smallest reaction surface.

Figure 3 presents dependence between the percentage mass decrements of the coke sample being determined and the average initial coke grain size.

Fig.3 Trends of percentage decrement of coke sample mass depending on average initial coke grain size following gasification for 240 minutes

It follows that the larger average initial grain size the lower coke sample mass decrement is. It means that after a specific time of gasification the coke with specific average initial grain size will be characterised by mass decrements higher than mass decrements of the coke with larger average grain sizes. It may be the result of higher reactivity of finer coke grains (except for quick coke from 0÷10 mm) and larger specific surface connected with it.

Figure 4 presents lines drawn on the basis of calculated dependences between the average coke grain sizes after gasification with barrel finishing and the average initial coke grain size.

Fig.4 Trends of grain size following gasification and barrel finishing depending on average initial grain size

Although it follows from figure 4 that the grain size following the test grows as the initial grain size is growing, the increase following gasification only is higher than following gasification with barrel finishing. It shows that during gasification grains become weaker, which is disclosed during barrel finishing.

Figure 5 presents the line, which characterises dependence between the rate of coke mass decrement and the average initial size of the coke grain.

Fig.5 Trends of percentage rate of coke mass decrement depending on average initial size of coke grain

It follows from the character of the dependence that the larger initial size of the coke grain the lower rate of the coke mass decrement is. It is connected with the reaction surface, which decreases as the coke grain size decreases.

Figure 6 presents dependence between the rate of the coke grain decrement and the average initial coke grain size. It follows from the dependence that also the rate of the coke grain size decrement decreases as the initial coke grain size increases. It can be concluded that coke with smaller average grain sizes, as it has larger specific surface, will be gasified more quickly that the coke with larger average grain sizes.

Fig.6Trends of percentage rate of coke grain size decrement depending on average initial size of coke grain

It results from the analysis carried out that it is possible to make comparative assessment of different kinds of coke by comparison of the index of the coke grain decrement rate after a specific determination time. The dependences of changes in the coke grain size occurred within the time beginning from the initial grain size and determined on the basis of the determination results may be useful when carrying out more careful analysis of the impact of coke properties and relevant changes in grain sizes occurred during gasification on the changes in permeability conditions of the blast-furnace charge.

4. MODEL TESTING OF BLAST-FURNACE CHARGE PERMEABILITY DISTRIBUTION IN T. SENDZIMIR STEELWORKS

Within the confines of the work, model testing was carried out concerning the expected impact of the changes in grain sizes of individual assortments of coke, as a result of gasification, when lowering the charge in blast furnace, on the charge permeability.

Changes in permeability of blast-furnace charge along the height of the blast furnace shaft were analysed, assuming that we deal with dry zone (charge materials has not reached the cohesion zone yet). It was also assumed that the iron-bearing materials in the coke charge do not change their geometric shapes in the area of analysed blast furnace [9, 10]. Because of the comparative character of the analysis, the expected changes in permeability were assumed, for simplification, which take place at the determination temperature (1050°C).

Testing of changes in permeability were carried out on the basis of the gas flow resistance index K from the following equation [1]:

where

ΔP - drop of pressure, Pa

L - height of layer, m

U - rate of gas flow, m/s

The value K in this equation, which is the gas flow resistance index depending on the grain composition of the charge, was assumed according to the equation described by Hisanoi M. and Hiromitsu Y. [1]

where

$\delta D_{p.}$ - range of grain size distribution, m

$D_{p.}$ - average grain size, m

μ_F - gas viscosity, Ns/m^2

ξ - gas density, kg/m^2

As a base, the value of index K was assumed, which is characteristic for the layer formed in the throat by the charge (under conditions before commencement of oxidisation of pieces of coke) when blast-furnace coke with the fraction of 25-80 mm only was fed into the blast furnace. The value of the base index K in the throat of the blast furnace no 5 was assumed to be 100% and its changes were determined in relation just to this value under various charging conditions and levels of the blast furnace. The assortments of coke with reduced granularity mixed with iron-bearing materials or as a separated layer were introduced.

Four variants of feeding coke charges were analysed:

Base - blast-furnace coke 25-80 mm fed in a separate layer.

Blast-furnace coke 25-80 mm (91.21% of the total fuel) fed in a separate layer and the mixture of sinter and "nut coke II" (5.28% of the total fuel) and the mixture of mikhailovskie pellets with pea coal (3.51% of the whole fuel).

Blast-furnace coke with granularity narrowed down to 40-80 mm and fraction of 25-40 mm separated out of it (27.6% of blast-furnace coke) fed in a separate layer.

Blast-furnace coke with granularity narrowed down to 40-80 mm fed in a separate layer and the fraction of 25-40 mm separated out of it fed as mixed with sinter.

The gas flow resistance index K was determined depending on the granular composition of the charge with specific capacity taken up in the given area of the blast furnace. The values of the index for various variants are shown in fig.7.

basic conditions - charge, which consists of blast-furnace coke 25-80 mm only

blast-furnace coke 25-80 mm, "nut coke II" mixed with sinter, "pea coke" mixed with pellets

fraction 25-40 mm separated out of blast-furnace coke and fed as a separate layer

fraction 25-40 mm separated out of blast-furnace coke and added to sinter

Fig.7 Trends of resistance index K of blast-furnace gas flow through the charge lowered in the blast furnace, depending on the charge variant and distance of the charge from the lower edge of throat

Based on presented data it follows that the blast-furnace gas flow resistance index K becomes higher as the dry charge is lowered within the blast-furnace shaft. As it was mentioned before, the index K in the blast-furnace throat in the base variant is assumed to be 100% and the changes in the index depending on various charge variants and levels of blast furnace were referred to it. For the base variant (1), when the charge was lowered for 15 m within the shaft, the index increased to 122% in comparison to the value of the index in the blast-furnace throat. The comparison of the variant (2) with the base variant (1) shows that when fine assortments of coke ("nut coke II" and "pea coke") were fed additionally as mixed with iron-bearing materials, the resistance index K in the highest areas of the blast furnace increased (as for the blast-furnace throat it was higher by 6.3%), while the changes became slighter as the charge was lowered. When the charge was lowered 15 m down, the resistance index K was the same as the resistance index K in the base variant. It means that application of fine assortments of coke mixed with iron-bearing materials may increase the resistance of the gas flows in the upper and lower areas of the dry zone in the blast furnace without worsening the conditions in the lower areas of the blast-furnace shaft, which is the area where permeability worsens by nature, as a result of melting of charging materials. In the variant (3), application of narrowed granularity grade of blast-furnace coke 40-80 mm and the fraction 25-40 mm separated out of the coke fed in a separate layer caused that the index K in the throat was lower than the base index by 7.8% and increased to 116.2% of the value of the index in the throat under base conditions when the charge was lowered by 15 m within the shaft. In case of the variant (4), when the fraction of 25-40 mm, separated out of the

blast-furnace coke, was added to the sinter, it was observable that the index K in the blast-furnace throat was characterised by significant (even up to 14.3%) reduction of the resistance index K in comparison to the basic conditions and when the charge was lowered by 15 m within the shaft, the index increased to 110.1% of the index value in the throat under the basic conditions. It follows from the analysis presented that the smallest gas flow resistances are achieved when narrowed granular grades of coke are applied and when they are fed to blast furnace as mixed with sinter or, in turn, in a separated layer. Application of fine-grained assortments of coke ("nut coke II" and "pea coke") fed additionally as mixed with iron-bearing materials, increases the gas flow resistance in the dry zone, which, however, may be advantageous to improvement of the degree of the blast-furnace gas chemical energy usage. Regardless of presented changes in permeability of the charge in the dry zone, as it stems from some literature data [11, 12], application of fine-grained coke assortments may affect narrowing and reduction of the cohesion zone in the blast furnace. It follows that application of fine-grained coke assortments fed in a specific manner and in proper quantity as the substitutes of a part of blast-furnace coke, not only does not worsen general permeability of the charge in the blast furnace but even may be advantageous to it. The model testing findings do not show real changes of the charge resistance coefficient down the blast furnace shaft (at various temperatures), however they help in getting acquainted with the impact of various coke assortments and the ways of feeding them into the blast-furnace charge on the changes in the charge permeability resulting from the processes of their gasification.

5. BLAST FURNACE OPERATION INDEX

The analysis determined dependences between the index of the percentage coke mass decrement rate V_m determined on the basis of the new method and the basic parameters of the blast furnace operation.

The index of percentage coke mass decrement rate is determined by the following equation:

where:

V_m - index of the coke mass decrement rate determined according to the new method, %/h

z_{av} - average initial coke grain size, mm

Figure 8 presents dependence between the index of percentage coke mass decrement rate and the unit consumption of fine assortments of the coke ("nut coke II" + "pea coke"), adjusted to a dry matter basis.

Fig.8 Trends of unit consumption of fine-grained assortments of coke ("nut coke II" and "pea coke"), adjusted to a dry matter basis, beginning from the index of percentage rate of coke mass V_m

It follows from the character of the line presented in figure 8, it may stated that increase of the unit summary consumption of fine-grained assortments of coke ("nut coke II" + "pea coke") affects the increase of the coke mass decrement rate.

Figure 9 presents dependence between unit consumption of skip coke, adjusted to a dry matter basis, and the index of percentage coke mass decrement rate.

Fig.9 Trends of unit consumption of skip coke, adjusted to a dry matter basis, beginning from the index of percentage rate of coke mass V_m

It follows from the character of the curve that the skip coke consumption decreases as the percentage rate of the coke mass decrement increases to a specific value. However, when the value is exceeded, the skip coke consumption in blast furnace may increase. It means that there is a certain limit of coke mass decrement rate, which when exceeded, may result in increased unit consumption of skip coke in blast furnace. For the conditions of the blast furnace no 5, this limit is approximately 12.66 %/h. It follows that fine-grained assortments of coke may be applied as substitutes of a part of blast-furnace coke within a certain optimum range, which when exceeded, may result in increased unit consumption of the fuel in blast furnace. For the conditions of the blast furnace no 5 it ranges within 40-50 kg of fine-grained assortments of coke per one tonne of pig iron.

It follows from the character of the curve presented in figure 10, which shows the dependence between the degree of usage of gas blast-furnace chemical energy (hCO) determined by the following index

and the index of percentage rate of coke mass decrement, that in the beginning increase of percentage rate of coke mass decrement causes increase of the degree of blast-furnace gas chemical energy usage, but after the percentage rate of the coke mass decrement is exceeded, which is approximately 12.66%, the degree of the blast-furnace gas chemical energy usage decreases.

Fig.10 Trends of the index of blast-furnace gas chemical energy η_{CO}, beginning from the index of percentage rate of coke mass V_m

As it follows from the dependence presented in the figure, there is a certain optimum range of coke mass decrement rate, within which the usage of the blast-furnace gas chemical energy is the highest. It follows from figure 10 that the range between 12.60 and 12.65 %/h, which corresponds with consumption of 40 to 50 kg of fine-grained assortments of coke, as substitutes of a part of blast-furnace coke, per one tonne of pig iron, should be considered as the optimum range of the coke mass decrement rate, taking the usage of blast-furnace gas chemical energy into consideration. Thus it can be stated that reduction of unit consumption of coke, after introduction of fine-grained assortments of coke as the substitutes of a part of the blast-furnace coke, results from improvement of the degree of blast-furnace gas chemical energy usage. This would show that application of fine-grained assortments of coke in a

given amount and in a given way (mixed feeding system) does not affect worsening of the operating conditions, particularly permeability of the charge and efficiency connected with it, but it is advantageous to the improvement of the degree of blast-furnace chemical energy usage and reduction of coke consumption connected with it.

No important correlation was stated between the index of coke mass decrement percentage rate and the index of charge permeability, blast furnace production efficiency and the temperature of throat gas.

CONCLUSIONS

The following observations were made on the basis of the work:

For the purpose of assessment of changes of the coke reactivity influence on the effects occurring in blast furnace, it is important to familiarise with the coke reactivity changes along with the change of average-sized coke grain. The new method of coke reactivity testing, which was developed, makes it possible to assess the mass decrement rate and the average grain size of coke assortments with different initial grain sizes. Thus the method takes into consideration the influence of, among other things, reaction surface resulting from coke granularity on the coke reactivity.

In order to improve permeability of charge, it is advantageous to divide blast-furnace coke into two fractions (e.g. one below 40 mm and one above 40 mm) and feed them into blast furnace selectively.

Feeding fine-grained coke assortments mixed with iron-bearing materials into blast furnace may increase gas flow resistance in the "dry" zone without increasing flow resistance in the cohesion zone, which is advantageous to improvement of the degree of blast-furnace gas chemical and thermal energy usage and resultant reduction of the consumption of energy by the process (reduction of unit consumption of coke).

There is optimum contribution of fine-grained assortments of coke in blast furnace, which, when exceeded, may result in worsening of the degree of blast-furnace gas chemical energy usage and resultant increase of unit consumption of coke. For the conditions of T. Sendzimir Steelworks, the optimum range of the contribution of fine-grained coke assortment is approximately 40-50 kg/tonne of pig iron.

Optimal contribution of fine-grained coke assortments should be selected in consideration to specific technical and technological conditions of blast furnace. The newly developed method is very useful for this purpose. It enables to determinate the optimal, as for the degree of blast furnace gas chemical energy usage and resultant reduction of coke consumption, rates of mass decrement and the average grain size as well as to select optimal contribution of different coke assortments on that basis.

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