**P. BESTA, K. JANOVSKÁ, A. SAMOLEJOVÁ, A. BERÁNKOVÁ, I. VOZŇÁKOVÁ, M. HENDRYCH**

ISSN 0543-5846
METABK 52(2) 197-200 (2013)
UDC – UDK 669.1: 669.2: 658.5 =111

# THE CYCLE AND EFFECT OF ZINC IN THE BLAST-FURNACE PROCESS

Received – Prispjelo: 2012-03-08
Accepted – Prihvaćeno: 2012-10-01
Preliminary Note – Prethodno priopćenje

This article analyzes the effect of zinc in the blast furnac e process and it also analy sis its contents in the input and output raw materials. The results obtained in the long-term research project will be used as data here. The removal of zinc from the input raw materials is very difficult already in the sinter production stage. This is due to its uniform distribution in the raw materials, but also due to the fact that it does not transfer into gas phase during the sintering process. The content of Zinc compounds was experimentally measured in the lining. The quantity of penetrated Zinc is different in different parts of the blast furnace. As demonstrated by the research, zinc repeatedly enters the blast furnace process, which leads to its circulation.

*Key words*: iron, zinc, costs, continuous, negative carbonates

## INTRODUCTION

The blast furnace process is a set of a large number of physical and chemical, thermal and mechanical actions that do not take place separately, but in certain mutual continuity [1]. That is why the impact of the negative elements that are found in the blast furnace process must be taken into account as an important factor. An accurate determination of the harmfulness of a particular element is, however, always quite difficult. The same element can act in the individual phases of the blast furnace process quite differently. For example, alkaline carbonates are harmful to the blast furnace lining and also to coke, but they significantly reduce the viscosity of slag. The negative effect of each element must therefore be assessed in a complex way and on the basis of information and knowledge about the entire blast furnace process.

Zinc and its compounds are among the key elements affecting pig iron production technology. Zinc and lead are heavy metals [2]. These elements get into blast furnace together with the blast furnace charge in the form of oxides and sulphides. Due to the physical and chemical properties of these metals, there is a cycle created in the blast furnace between the lower parts with high temperatures, which cause reduction and evaporation, and the upper furnace stacks with low temperatures where the fumes condense. Zinc enters blast furnace primarily as a component of ore, but also through coke. Generally, we can say that zinc content in the sinter and pellets is higher than in the natural ores. This is mainly caused by the processing of waste materials, such as sludge, which often contain high amounts of this element.

An efficient use of all input raw materials naturally affects the cost aspects of metallurgical production. It is therefore necessary to consider both the metallurgical and cost factors, if not so, metallurgical companies will not be able to define and make the right decisions that ensure growth, profits and sufficient cash necessary for operation of these companies [3]. That is why detailed knowledge of economic and technological demands of the individual company processes is crucial in order to maintain the competitiveness of a metallurgical enterprise. The objective of this article is to analyze the effects of zinc in the blast furnace process. This element is cyclically returning into the blast furnace process and can have many negative consequences. The key factor is also to assess the zinc content in the output and input raw materials. The results obtained in the long-term research project will be used as data here.

## ZINC IN THE BLAST FURNACE PROCESS

There are many oxides in the blast furnace process and ZnO is a very stable one. Blast furnace charge that goes down during the process is gradually heated and a reduction of zinc compounds occurs. Zinc melting takes place at temperatures from 450 °C to 920 °C [4]. In case of presence of CaO, zinc may react according to the following reaction [4]:

$$ZnS+CaO+C \rightarrow Zn+CaS+CO \quad (1)$$

At the same time, there is a reaction with carbon and iron which have a form of the following reactions [4]:

$$ZnS+Fe \rightarrow Zn+FeS \quad (2)$$

$$ZnO+C \leftrightarrow Zn_{(g)}+CO \quad (3)$$

P. Besta, K. Janovská, A. Samolejová, A. Beránková, I. Vozňáková, M. Hendrych, Faculty of Metallurgy and Materials Engineering, VŠB – Technical University of Ostrava, Ostrava, Czech Republic

The reaction with carbon is more frequent, because the contact of ZnS with iron is closer than with solid CaO [5]. The blast furnace process also leads to reduction of zinc by means of carbon monoxide as well as by means of hydrogen. However, this process is impeded by the fact that the boiling point is lower than the temperature of the reduction. The reduced zinc immediately evaporates and returns with the gas to the upper parts of the furnace, where the temperature is lower. Zinc is oxidized by means of carbon dioxide and condenses on the surface of larger pieces of charge.

These parts then gradually sink into the lower areas of the blast furnace where the temperature increases and the entire process is continuously repeated. Naturally, the amount of zinc within the scope of this cycle is not constant, because its amount increases as a result of supply of new charge. Some of the zinc also leaves the blast furnace process as part of the output of raw materials.

## EXPERIMENTAL PART

When assessing the effect of zinc and its cycle in the blast furnace process, it is necessary to accurately identify the main sources of this element. The amount of zinc entering the blast furnace process has been evaluated within the scope of this research. The evaluation included the main input raw materials of the blast furnace process. The content of zinc was exactly monitored for all input sources during the time period of ten months. The results are shown in Table 1.

The amount of zinc contained in the input raw materials was determined on the basis of the established chemical composition. Based on these data, the amount of zinc per kilogram of pig iron was determined for each raw material. At the same time, the total amount of zinc was determined in all input raw materials, as well as its relative share in each component. The highest zinc content was, as expected, detected in the sintering mixture. The three used sintering mixtures contained 61,615 % of the total content of zinc entering the blast furnace process. Coke was another important source (8,968 %) as well as pellets which together accounted for 7,925 %. Treated steel sludge was the last major source (4,689 %). In case of the sintering mixtures, it is particularly important to monitor the quality of the input ore raw materials and to monitor the content of negative elements.

The quality of ore raw materials is currently often in conflict with the efforts to reduce costs, which may mean purchasing lower-quality raw materials.

The zinc content in the output products was also monitored as part of the research. In the case of blast furnace output products, the largest proportion of zinc is transferred into blast furnace sludge. With the optimal technological process, zinc should leave the blast furnace process just in the form of sludge as well as through slag. The measured zinc content in pig iron may also be regarded as standard. The exact values of zinc content in the output products of the blast furnace process are shown in Figure 1.

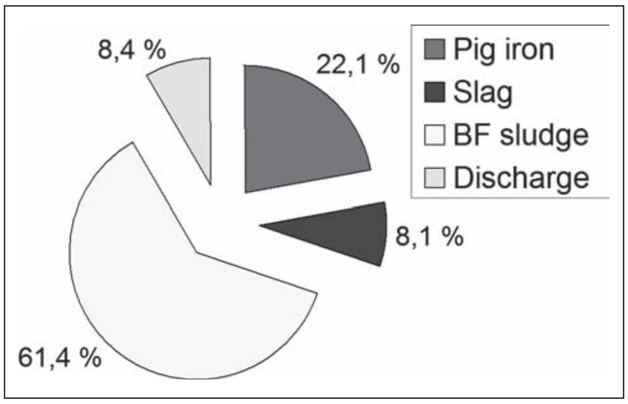


**Figure 1** Zinc in the blast furnace process products

## RESULTS AND DISCUSSIONS

Zinc cyclically enters the blast furnace process. With decreasing charge, zinc is gradually being reduced. Zinc is drifting in gaseous form into the higher parts of the furnace, where it builds up on the larger parts and returns into the process again. It can be assumed that the actual reduction and oxidation, evaporation and con-

Table 1. **Content of zinc in the input raw materials**

| | Weight | Quantity | Zn | | |
|---|---|---|---|---|---|
| | / t | / kg·kg$^{-1}$ | / % | / kg·kg$^{-1}$ | / % Total amount |
| Sinter – A | 492 645 | 0,484 | 0,007 | $3{,}38\cdot10^{-5}$ | 20,155 |
| Sinter - B | 413 314 | 0,406 | 0,006 | $2{,}43\cdot10^{-5}$ | 20,966 |
| Sinter - C | 404 004 | 0,397 | 0,006 | $2{,}38\cdot10^{-5}$ | 20,494 |
| Slag – granulation product | 9 991 | 0,009 | 0,021 | $2{,}06\cdot10^{-6}$ | 1,774 |
| Beneficiated steel slag | 92 434 | 0,091 | 0,006 | $5{,}45\cdot10^{-6}$ | 4,689 |
| Aggregate from a spoil heap | 1 350 | 0,001 | 0,003 | $3{,}98\cdot10^{-8}$ | 0,034 |
| Separated material from sinter | 12 492 | 0,012 | 0,011 | $1{,}35\cdot10^{-6}$ | 1,162 |
| Granules A (Sevgok I.) | 195 500 | 0,192 | 0,004 | $7{,}68\cdot10^{-6}$ | 6,611 |
| Granules B (Sevgok II.) | 77 698 | 0,076 | 0,002 | $1{,}52\cdot10^{-6}$ | 1,314 |
| Lump ore – záporoží | 104 814 | 0,103 | 0,004 | $4{,}12\cdot10^{-6}$ | 3,545 |
| Mn concentrate | 2 210 | 0,002 | 0,01 | $2{,}17\cdot10^{-7}$ | 0,187 |
| Limestone A (Varin) | 21 200 | 0,021 | 0,003 | $6{,}25\cdot10^{-7}$ | 0,538 |
| Limestone B (Vitosov) | 16 690 | 0,016 | 0,004 | $6{,}56\cdot10^{-7}$ | 0,564 |
| Coke | 530 400 | 0,521 | 0,002 | $1{,}04\cdot10^{-5}$ | 8,968 |
| Ground coal | 4 | $3{,}0\cdot10^{-6}$ | 0,001 | $3{,}93\cdot10^{-11}$ | $3{,}0\cdot10^{-5}$ |
| Furnace oil | 3 200 | 0,003 | 0 | 0 | 0 |
| Regenerated furnace oil | 520 | 0,0005 | 0 | 0 | 0, |
| Raw materials – Total | 2 378 466 | | | | |

densation have a negative cost effect. This is given by the character of the reduction processes of zinc oxide, which are endothermic. These processes consume large amounts of heat to run, which affects the thermal conditions, particularly in the middle part of the blast furnace. During re-oxidation and condensation of zinc in the upper part of the blast furnace, heat is released again; however its efficient use is not possible any more. Only the blast furnace gas is heated and leaves the blast furnace. Due to this fact, it can be assumed that these processes affect the total consumption of coke.

A smaller portion of zinc is caught on small grains of the charge that are carried out of the blast furnace space by the gas. Generally, the amount of condensed zinc is directly proportional to the material surface.

The conducted research has shown that the largest amount of zinc in the output products was concentrated in the blast furnace sludge. Zinc also has a tendency to accumulate in the colder parts of the blast furnace and often penetrates into the lining. The amount of zinc in different parts of the blast furnace was measured in the monitored blast furnace during its overhaul. The results are shown in Figure 2.

The amount of zinc was measured throughout the height of the blast furnace. The highest zinc contents were measured in the upper parts of the furnace (7-10 m) and then at the bottom of the furnace (19-22 m). Cracks and other forms of disruptions of the integrity of the lining surface were identified in the areas with the highest concentration of zinc. This is a consequence of zinc transformation from gaseous to solid state during which its volume increases by up to 5 %. The deposits contained mainly zinc oxide found in well-developed crystals. The structure of these crystals is very unstable and often leads to their breaking off.

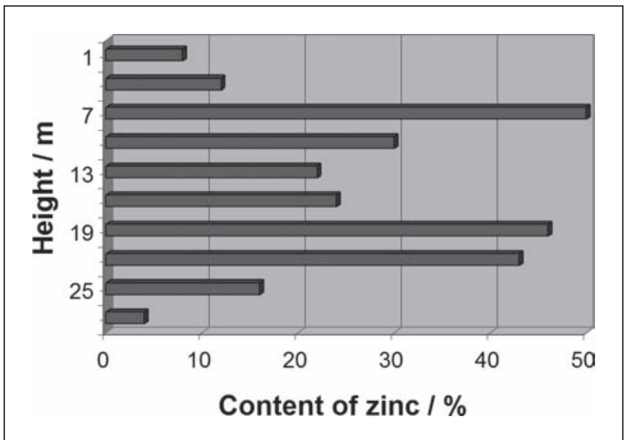


**Figure 2** Content of zinc in the blast furnace lining

In the case when they break off, the reduction of zinc will take place in the lower parts of the blast furnace again, and, after evaporation, zinc returns to the continuous cycle. The research has shown that part of oxidized zinc vapour condenses on the walls in the upper parts of the blast furnace. These deposits can later influence the gas-dynamic conditions and interfere with the effective continuation of the technological process. The release of these parts may mean a potential cooling of the blast furnace well. If there is a high concentration of zinc in the blast furnace, zinc vapours containing high concentrations may arise during tapping and these concentrations may lead to significant health risks. Determining the maximum limit of zinc in the blast furnace is always very individual. It is always necessary to consider many factors, such as the construction of the blast furnaces, wall thickness, type and intensity of cooling or the useable volume of the blast furnace.

## CONCLUSIONS

The activity of zinc in the blast furnace process can be seen in several levels. The most serious consequence of zinc cycle in the blast furnace process is its penetration into the lining pores. This leads to oxidation of these areas, resulting in the increase in volume causing damage to the integrity of the lining. The removal of zinc from the blast furnace process is primarily ensured through its allocation in the blast furnace sludge (fine and coarse), but also through the blast furnace gas. The higher the temperature of the blast furnace gas, the higher the volume if zinc it contains. Permeable charge column is often created because of this fact. This column is oriented in the axial part of the blast furnace which consists of coke. The largest amount of zinc vapours leakage occurs in the conditions of high temperatures and reduction atmosphere. The whole process is also positively influenced by high velocity of the gas flow. The deposition of zinc in the lining pores can be reduced in a very limited extent. It is important to monitor the amount of zinc entering the blast furnace process in the form of charge raw materials. As shown by the conducted research, the largest amount of zinc enters the process through sinter. It is possible to reduce the amount of zinc during the production of sintering mixture by using more fuel. Conditions suitable for removal of zinc but unsuitable for removal of sulphur are created in the sintered layer by increasing the amount of fuel in the sintering mixture. Addition of NaCl and $CaCl_2$ represents another option for reduction of zinc in the sintering process. These compounds significantly affect the evaporation of zinc. The presence of the negative elements in the input raw materials must be primarily influenced by the quality of the purchased ore materials, which will always be to some extent influenced by the economic parameters. Metallurgical enterprises must constantly look for optimal solutions, both in terms of technological and cost aspects.

## Acknowledgement

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2012/12.

## REFERENCES

[1] R. Yin, Metallurgical Process Engineering, Springer, New York, 2011, pp. 70-71.
[2] S. Bakalarczyk, P. Pomykalski, E. Weiss, Innovativeness of metallurgical production enterprises, In Metal 2011: 20th Anniversary International Conference on Metallurgy and Materials. Ostrava: TANGER, 2011, pp. 1298-1302. ISBN 978-80-87294-24-6.
[3] L. K. Reddy, Principles of engineering metallurgy, New Age International, New Delhi, 2007, pp. 182.
[4] J. Kret, Vliv alkálií na výrobu surového železa ve vysoké peci, Hutnické listy, 4 (2000), 10-14.
[5] Ch. K. Gupta, Chemical metallurgy: Principles and Practice, John Wiley & Sons, Weinheim, 2006, pp. 437-438.

**Note**: The responsible translator for English language is Petr Jaroš (English Language Tutor at the College of Tourism and Foreign Trade, Goodwill - VOŠ, Frýdek-Místek, the Czech Republic). Revised by John Vlcek (Literacy Tutor at West Suffolk College, Bury St Edmunds, England).