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CONTROL OF THE METALLURGICAL PROCESSING OF ICDP CAST IRONS

KONTROLA METALURŠKE OBDELAVE LITEGA ŽELEZA ICDP

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The article is focused on the use of the measurement of oxygen activity for the management of cast-iron metallurgical processing in the operating conditions of a centrifugal-roll casting foundry. The paper presents the results of the oxygen-activity measurement recorded during the metallurgical processing of cast iron from the beginning of the melting to the inoculation of cast iron. The measurement of oxygen activity was made with specifically developed devices and the probes with a high sensitivity designed for measuring a_O in cast iron by Heraeus Electro-Nite Celox Foundry. The oxygen activities in cast iron correlate with the properties of cast iron.

Keywords: oxygen activity, ICDP iron, inoculation

Članek je osredinjen na merjenje aktivnosti kisika za vodenje metalurške obdelave litega železa v livarni pri centrifugalnem ulivanju valjev. Članek predstavlja rezultate meritev aktivnosti kisika, spremljane med metalurško obdelavo litega železa od začetka taljenja do inokulacije litega železa. Meritev aktivnosti kisika je bila izvršena s posebno razvito napravo in sondo z veliko občutljivostjo za merjenje a_O v litem železu s Celox – Foundry Heraeus ElectroNite. Aktivnosti kisika v litem železu so odvisne od lastnosti litega železa.

Ključne besede: aktivnost kisika, ICDP-železo, inokulacija

1 INTRODUCTION

The methods for the control of the metallurgical processing of cast iron in the molten state are based on the analyses of solid samples, i.e., the thermal analysis, the chill test and the spectral analysis. For a quick interpretation of the metallurgical quality of molten cast iron, the measurement of oxygen activity can be used too. The measurements are made in the furnace after melting, in the last stage before casting, after the inoculation or modification in the ladle. It is possible to rapidly analyse the level of metallurgical processing (quality) of the melt on the basis of the measured oxygen activity in real time and, if necessary, to make its adjustment.

2 OXYGEN IN CAST IRON

The oxygen content in molten cast iron influences the mechanism of solidification in the phase of eutectic transformation and it has positive, but also negative, effects on molten cast iron. The positive role of oxygen is primarily to support the formation of stable oxides for the crystallization of graphite; it also supports the heterogeneous nucleation and stabilises the solidification of cast iron. An intense formation of graphitization nuclei occurs during the transition of a melt into the solid phase, especially during the eutectic transformation. During this solidification phase, the optimum amount of oxygen has to be available.

A higher oxygen activity is also able to support the formation of exogenous and endogenous gas bubbles and pinholes in cast iron, or an increased amount of slag and inclusions in the castings. Excessive amounts of oxides can be unstable at elevated temperatures, and under certain conditions (the temperature, time, and viscosity of the melt) they dissociate or coagulate, creating an increased amount of slag. The oxygen activity in cast irons is strongly dependent on the temperature. The oxygen activity is increased by the liquidus temperature as a consequence of a release of the crystallization heat. The heat is secreted from the austenite in the concentration melt of carbon. This creates good conditions for the graphite nuclei.

A drop in the liquidus temperature starts a decrease in the oxygen activity, taking place until the beginning of the eutectic reaction. The decline in the oxygen activity is simultaneously accompanied by a formation of oxides. An increase in the oxygen activity occurs again during the eutectic transformation, as a consequence of the crystallization-heat eutectic reaction.[1,2]

The measurement of oxygen activity is normally used to control the deoxidation process of steel during the melting and casting of steel castings.

The oxygen activities in molten steel are of a higher-order, in the range of 10×10^{-6} to 100×10^{-6}, depending on the degree of deoxidation under the temperature of molten steel. Relatively high levels of oxygen activity in steel during melting correspond to the sensitivity of the probes used for the measurement (ppm).

Table 1: Informative chemical composition of the ICDP iron (*w*/%)
Tabela 1: Okvirna kemijska sestava ICDP-železa (*w*/%)

C	Mn	Si	P_{max}	S_{max}	Cr	Ni	Mo
3.0 3.5	0.5 1.5	0.7 1.5	0.1	0.03	1.5 2.0	3.8 4.8	0.2 1.0

The oxygen activity in cast iron is by about 3–4 orders of magnitude lower than that of steel, depending on whether it is measured in the cast iron with lamellar or spheroidal graphite (**Figure 1**). The relationship between the oxygen activity and the shape of graphite in the processed FeSiMg cast irons was set with the Mampay and CELOX-Foundry equipment for measuring oxygen activity, the Heraeus Electro-Nite company[3–5].

The way of the metallurgical processing of cast iron, i.e., the management of the melt, the holding temperature and the time greatly influence the oxygen content, i.e., its activity in cast iron and the metallurgical quality of cast iron[6–8]. The default level of the oxygen activity in cast iron before an inoculation or modification consequently influences its graphitization ability, the process of crystallization, the microstructure and the resulting quality of the castings.

3 METALLURGICAL PROCESSING OF CAST IRON

The melting of the shell iron (ICDP – Indefinite Child Double Pour) of the centrifugally cast rolls was performed in 4-ton electric induction furnaces. The regulation of the chemical composition of iron (alloy) was performed in the furnaces and the subsequent inoculation was performed in the ladles. In total, 14 melts were analyzed. The microstructure of the ICDP iron is formed by the ledeburite basic metal material (BMM), in which there is extruded graphite whose surface portion is optimized in the range of 2–5 % in the evaluated area of

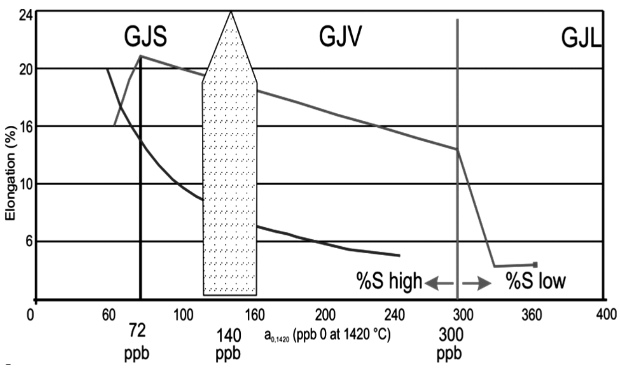

Figure 1: Oxygen activity in the cast iron with spheroidal, compacted and lamellar graphite
Slika 1: Aktivnost kisika v litem železu s kroglastim, kompaktiranim in lamelarnim grafitom

the scratch pattern. The cast iron is controlled during its melting with a spectral analysis and cooling curves analyses[7,9].

An informative chemical composition of the ICDP iron is shown in **Table 1**. The samples are sampled from the castings for metallurgical analyses, the tests of the quantity of graphite and of the hardness.

Table 2: Timeline of the melts and the measured values of oxygen activities, a_O
Tabela 2: Potek izdelave taline in izmerjene vrednosti aktivnosti kisika, a_0

Number of the melt	End of melting (h:min)	Dwell time of the charge (h:min)	a_O (10^{-9}) Furnace	a_O (10^{-9}) Ladle	Δa_O (10^{-9}) F-L
1	1:30	2:06	1159.9	699.8	460.1
2	1:40	1:40	932	721.2	210.8
3	1:40	1:30	996.1	718	278.1
4	1:40	2:00	829.3	693.5	135.8
5	1:10	3:50	877.6	766.2	111.4
6	1:40	0:45	1522.9	695.4	827.5
7	2:00	1:33	1496	708.7	787.3
8	1:20	0:55	1213.7	726.9	486.8
9	2:00	2:30	1028	700	328
10	1:20	1:20	895	518.5	376.5
11	2:25	6:20	811.4	792.63	18.77
12	1:20	0:55	1034.1	709.04	325.06
13	2:00	2:35	797.7	717.2	80.5
14	1:20	1:15	874.4	717.2	157.2

4 METHODOLOGY FOR MEASURING OXYGEN ACTIVITY

For the measurement of the oxygen activity we used Multi-Lab III by Heraeus Electro-Nite, which consists of a generator, connecting cables and a vibrating lance with a single measuring probe. The measured values are: the temperature (°C), the Emf electromotive voltage (mV), converted to a value of the oxygen activity by the melt temperature and the oxygen activity, converted to a reference temperature of 1420 °C. The reference temperatures are shown in the measurement results. The measured values are displayed on the display device in real time approximately 20–30 s after the immersion of the probe into the melt.

The aim of the measurement was to measure the oxygen activity after every metallurgical processing of the ICDP cast iron in real time in the interval of the melting of the charge, while keeping the iron at the set temperature until the inoculation in the ladle. The timeline of the melts (h) and the measured values of the oxygen activities (a_O) are shown in **Table 2**.

The graph in **Figure 2** presents the dependency of the oxygen activity (a_O) on the time (h) of melting in the furnace. The highest activity was measured in the melts with the shortest dwell time at the set temperature.

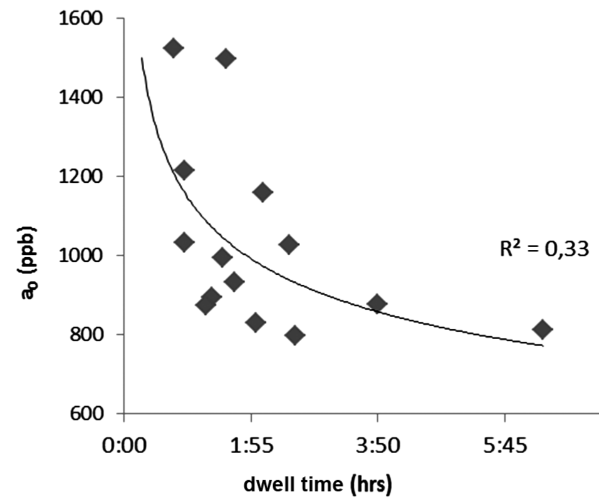

Figure 2: Oxygen activity (a_O) dependent on the dwell time (h) of the melt in the furnace

Slika 2: Odvisnost aktivnosti kisika (a_O) od časa (h) med držanjem taline v peči

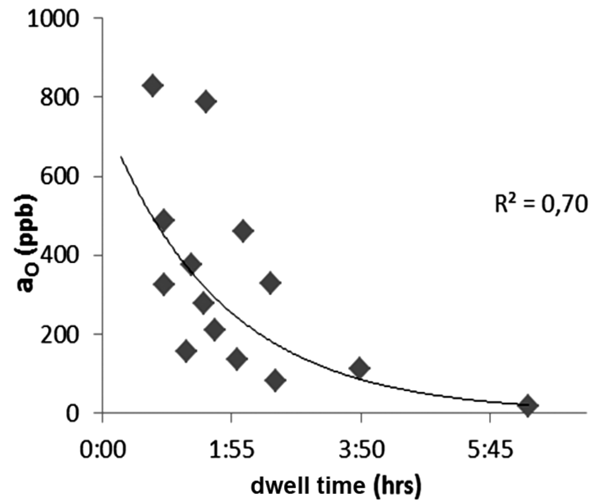

Figure 4: Difference between the initial oxygen activity a_O and the finishing a_O

Slika 4: Razlika med začetno aktivnostjo kisika a_0 in končno aktivnostjo kisika a_O

With an increasing dwell time in the furnace, the oxygen activities gradually decrease from the maximum value of 1522.9×10^{-9} at the dwell time of 45 min up to the lowest value of 811.4×10^{-9} at the dwell time of 6.3 h.

Figure 3 shows the dependence of the oxygen activity (a_O) measured in the ladle after the inoculation and the dwell time of the melt in the furnace. For the melt with the shortest dwell time, the oxygen activity was measured to be $a_O = 1522.9 \times 10^{-9}$ and after the inoculation it was $a_O = 695.4 \times 10^{-9}$. In this case, the difference in the activities a_O before and after the inoculation is the largest (54 %).

In contrast, for the melt with the longest dwell time, the lowest activity, $a_O = 811.4 \times 10^{-9}$, was measured in the furnace and after the inoculation in the ladle, it was $a_O = 792.63 \times 10^{-9}$. The decrease was only 18.8×10^{-9}. In this case the difference in the oxygen activity before and after the inoculation is only 2.5 %.

The differences between the initial oxygen activity a_O in the furnace, before pouring the melt into the ladle, and the finishing a_O, after the inoculation in the ladle (**Figure 4**) show a similarly decreasing trend as the activity a_O in the furnace depends on the dwell time of the cast iron (**Figure 2**).

5 RESULTS AND DISCUSSION

The oxygen activities were measured for the molten ICDP iron in an electric induction furnace, showing a large range of measured values (711.5×10^{-9}). The

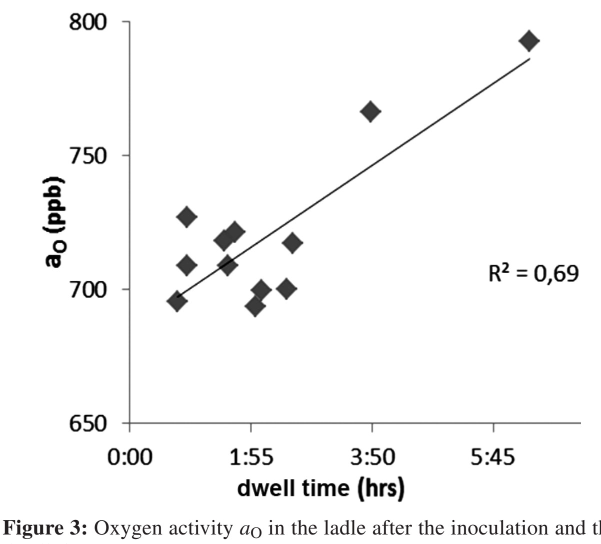

Figure 3: Oxygen activity a_O in the ladle after the inoculation and the dwell time

Slika 3: Aktivnost kisika a_O v ponvi po inokulaciji in času zadržanja

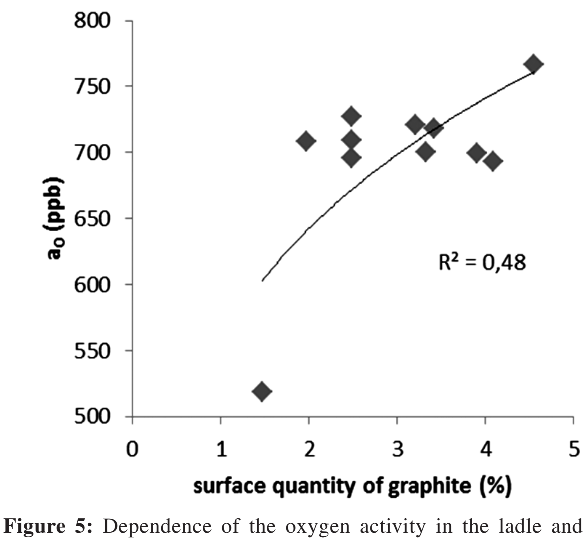

Figure 5: Dependence of the oxygen activity in the ladle and the surface quantity of graphite

Slika 5: Odvisnost med aktivnostjo kisika v ponvi in količino grafita na površini measurements were in the range of 1522.9×10^{-9} up to 811.4×10^{-9}.

The oxygen activities were measured after the inoculation in the ladle (**Figure 2**). A relatively narrow range of values (99.4×10^{-9}) from the lowest activity of $a_O = 693.5 \times 10^{-9}$ to the highest activity of $a_O = 792.6 \times 10^{-9}$ was measured.

The oxygen activities in the iron covered a relatively wide range after the melting and the dwell time. It was caused by different melting times. After the inoculation a narrow range of oxygen activities was measured in the ladle. This corresponds to the criterion set for the optimum quantity of graphite (2–5 %) in the ledeburite base of the metal mass of the ICDP iron (**Figure 5**). The quantity of graphite was established on the basis of an image analysis.

6 CONCLUSIONS

On the basis of an evaluation of these melts, it can be concluded that the value of about $a_O = 700 \times 10^{-9}$, obtained after the inoculation, provides the optimum level of metallurgical quality of this iron (type ICDP).

By measuring the oxygen activity a_O (10^{-9}) in real time, metallurgical processing and quality can be evaluated relatively quickly so as to achieve the desired parameters of the casting.

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7 REFERENCES

[1] Z. Bůžek, Základní termodynamické výpočty, Hutnické aktuality, Informetal, 1988, VÚHŽ

[2] I. C. Kulikov, Raskislenije metalov, Metalurgia, Moskva 1975

[3] F. Mampaey, D. Habets, J. Plessers, F. Seutens, On-line oxygen activity measurements to determine optimal graphite form during compacted graphite iron production, International Journal of Metalcasting, 4 (**2010**) 2, 25–40

[4] F. Mampaey, K. Beghym, Oxygen activity in cast iron measured in induction furnace at variable temperature, AFS Transactions, 114 (**2006**), 637–656

[5] HEN, Heraeus Electro-Nite, Celox-Foundry, CP 10700692, http://heraeus-electro-nite.com/en/sensorsformoltenmetals/iron/oxygencontrol_2/oxygencontrol_3.aspx

[6] J. Hampl, T. Elbel, On modelling of the effect of oxygen on graphite morphology and properties of modified cast irons, Archives of foundry engineering, 10 (**2010**) 4, 55–60

[7] T. Válek, J. Hampl, Prediction of metallurgic quality of ICDP material before tapping, 2011 International Conference on Physics Science and Technology, Physics Procedia, 22 (**2011**), 191–196

[8] J. Hampl, T. Elbel, Effect of oxygen on graphite morphology and properties of modified cast irons, Proceedings of the 10th International Foundry Conference, Opatija, 2010

[9] T. Válek, J. Hampl, Control of microstructure of cast iron Indefinite Chill Double Pour – ICDP, Archives of Foundry Engineering, 11 (**2011**) 4, 199–203