

ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.2478/v10266-012-0126-6

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences



ISSN (2299-2944)
Volume 12
Issue 4/2012

166 – 170

Studies of Gas Atmosphere Near the Metal-mould Interface During Casting and Solidification of Ductile Iron

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Received 02.07.2012; accepted in revised form 03.09.2012

Abstract

In sand moulds, at a distance of 3 mm from the metal- mould interface, the sensors of temperature, and of oxygen and hydrogen content were installed. Temperature and the evolution of partial gas pressure have been analysed in moulds bonded with bentonite with or without the addition of seacoal, water glass or furan resin. Moulds were poured with ductile iron. For comparison, also tests with the grey iron have been executed. It was found that the gas atmosphere near the interface depends mainly on the content of a carbonaceous substance in the mould. In the green sand moulds with 5% of seacoal or bonded with furan resin, after the mould filling, a sudden increase in the hydrogen content and the drop of oxygen is observed. This gas evolution results from the oxidation of carbon and reduction of water vapour in the mould material, and also from the reduction of water vapour and alloy reoxidation. In carbon-free sand, the evolution in the gas composition is slower because water vapour is reduced only at the interface. Changes of oxygen and hydrogen content in the controlled zone are determined by the transport phenomena.

Keywords: Ductile iron, Metal-mould interface, Gas evolution, Surface of castings

1. Introduction

Surface quality of ductile and compacted graphite irons castings determines the overall cost of production then it is the object of numerous studies [1,2,3,4 et al.] The appearance of surface defects and surface quality depends on gas atmosphere in the mould cavity and at the metal – mould interface during casting and solidification. In earlier studies [5], the authors analysed the influence of gas pressure at the metal-mould interface on the quality of the casting surface. It was found that this pressure depends on mould material but the differences were not serious enough to explain the different quality of the casting surfaces. So, it was suggested [6] that the decisive factor could be the composition of gas present at the interface. During mould pouring and solidification of casting, the air is evacuated from the mould

cavity and is replaced by gas formed in the superheated zone of mould material and produced at the interface [7,5]. Its composition has been studied only at the outflow from mould [8,9.] It was stated that the atmosphere in mould cavity is rich in hydrogen. Authors analyzed also the composition of gas evacuated from heated green sand mould. The intense reduction of water steam by seacoal was observed. [9]. Orlenius J., Dioszegi A., Dioszegi Z. analyzed the changes of hydrogen concentration in cast iron during filling of the mould [11]. A considerable increase in this concentration was observed. The goal of the present studies was to observe the evolution in the oxygen and hydrogen content as close to the metal-mould interface as possible.

2. Experimental procedure

For studies, the test mould used in earlier experiments [1,2] was adapted.

The construction of a model facilitated observations of the influence of the solidification rate. At the upper mould surface, samples of the analysed sands were placed. Gas sensors were installed at a distance of 3 mm from the mould cavity. The gas was transported by copper tubes to the oxygen, water vapour and hydrogen analysers. Oxygen was detected by zirconium cell, hydrogen by pellistor measuring the heat conductivity of the analysed gas. Sometimes the concentration of hydrogen and oxygen was registered at the flow off. The sands used in the experiments are presented in Table 1.

Table 1.

Composition of the tested sands

Sand granulation [mm]	Binder	Binder content	Seacoal [%]	Moisture [%]
0,1/0,16/0,2	bentonite	8	5	4
0,16/0,2/0,32	bentonite	8	-	4
0,16/0,2/0,32	bentonite	8	5	3
0,16/0,2/0,32	bentonite	8	-	5
0,16/0,2/0,32	water glass	R145 3.5% flodur 5, 0,35%	-	-
0,16/0,2/0,32	furan resin	Kaltharz X850- 1%, 100T3-0,5%	-	-

The sand specimens were rammed to the density of 1.65G/ccm.

Metal was melted in a coreless induction furnace using special pig iron of the following composition: C- 4.44%, Si- 0.97%, Mn- 0.05%, P- 0.05, S- 0.013%, Cr- 0.01%. After melting and overheating to 1460 -1470°C, the melt was spheroidised with 2.5% of a master alloy containing 5.8 %Mg, 46% Si, 1.07 % RE, 1.05% Ca, 0.75% Al and was next poured into a mould. The mould filling time was 10 s. The melt of grey cast iron was prepared from the same pig iron modified with FeSi 75% and poured at 1450°C.

3. Results

Figure 1 presents the evolution of hydrogen content during mould filling and solidification of the cast iron spheroidised with an addition of magnesium. Figure 2 shows the results obtained for grey cast iron poured into the same sand mould bonded with bentonite and containing 4% of water and 5% of seacoal.

In both cases, a sudden increase in hydrogen content was observed at a distance of 3 mm from the interface for the wall thickness of 15 and 45 mm. For thinner walls, the increase was quicker, and hydrogen content reached the level of 44% and 38% for the ductile iron and grey iron, respectively. This level was stable for a few seconds, and then a slight increase was observed at a temperature of about 640°C.

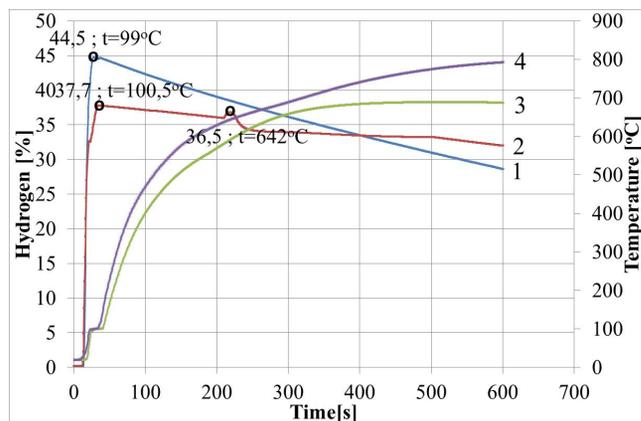


Fig. 1. Ductile iron. Evolution of hydrogen in the green sand mould with the 5% of seacoal. Content 1 - thin, 2 - thick wall, 3 - temperature in thin wall, 4 - in thick wall

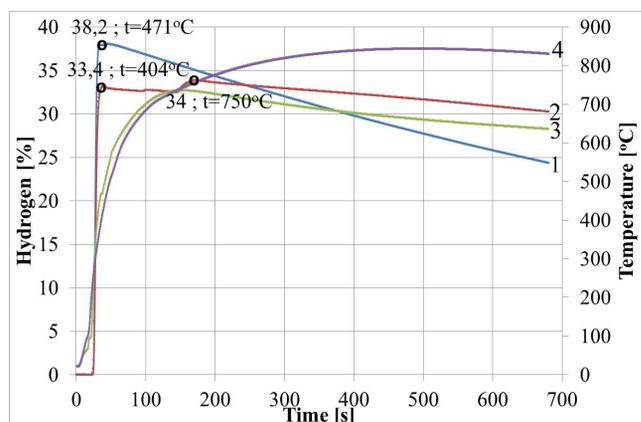


Fig. 2. Gray iron. Evolution of hydrogen in the green sand mould with the 5% of seacoal. Content 1 - thin, 2 - thick wall, 3 - temperature in thin wall, 4 - in thick wall

This maximum may be due to moisture reduction by the seacoal. At the same time, the moisture content suddenly decreased from 100 to 95% (Figure 3).

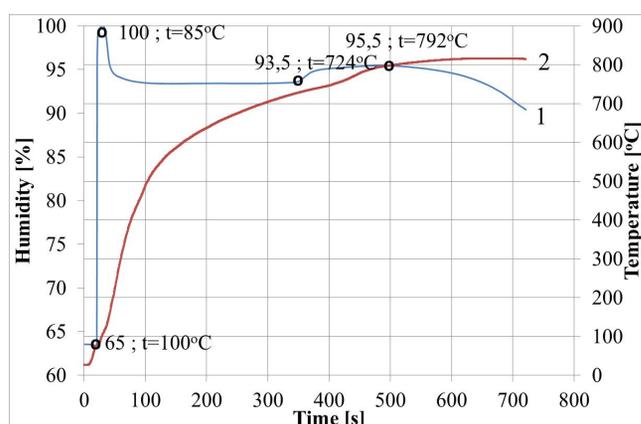


Fig. 3. Ductile iron. Humidity in the controlled zone. 1-Humidity, 2 – temperature

Later, a soft decrease of hydrogen was observed. For the 45 mm wall thickness, the evolution of hydrogen was similar, only the obtained maximum was lower, i.e. 38% for ductile iron and 33% for grey iron. In Figure 3, the results of moisture control in superheated zone are presented. It is visible that the humidity in the controlled zone remains elevated throughout the entire duration of the experiment.

Figure 4 presents the results obtained for grey iron cast in sand mould with moisture content reduced to 3%.

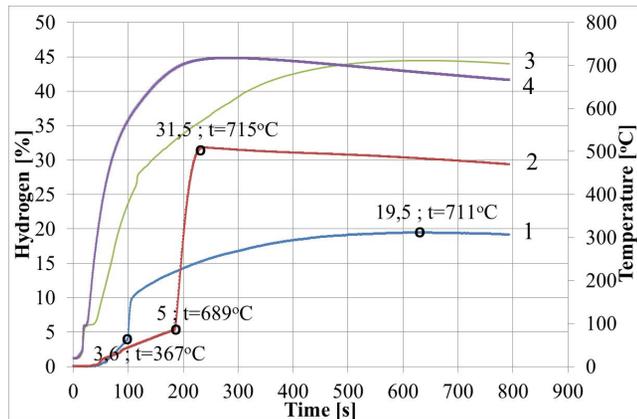


Fig. 4. Ductile iron. Evolution of hydrogen in the green sand mould with the 5% of seacoal and 3% moisture. Content 1- thin, 2- thick wall, 3- temperature in thin wall, 4 – in thick wall

Here the hydrogen content in controlled zone is much lower and reaches its maximum in a longer time. These results prove that the mould atmosphere may be controlled by its humidity.

Figure 5 presents the evolution of oxygen pressure. After 10s (end of mould filling) the pressure decreases to $1.7 \cdot 10^{-7}$ atm.

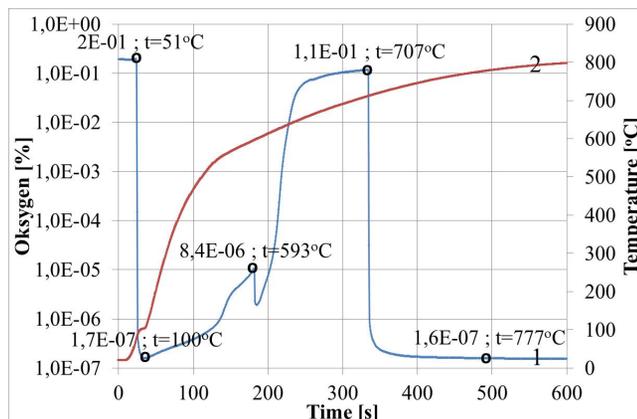


Fig. 5. Ductile iron. Evolution of oxygen in the green sand mould with the 5% of seacoal. 1- Oxygen, 2- temperature

It results from the carbon oxides formation in controlled zone and the oxidation of liquid metal. The pressure so low causes the decomposition of moisture and probably the diffusion of oxygen from outer layers of mould. Then the oxygen pressure raises to about 0.1atm at a temperature of about 700°C. Above this

temperature, the next sudden drop is observed. The obtained level is stable till 650s after the mould filling.

In the bentonite mould prepared without seacoal addition, the evolution of hydrogen is much slower. A comparison of Figures 1 and 6 proves that the main source of hydrogen is reduction of water in the mould.

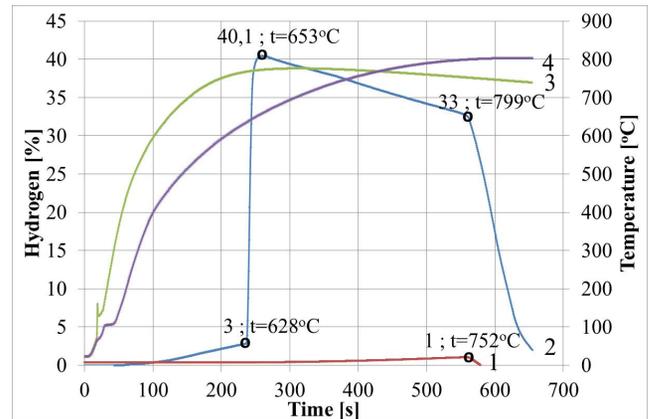


Fig. 6. Ductile iron. Evolution of hydrogen in the green sand mould. Content 1 - thin, 2 - thick wall, 3 - temperature in thin wall, 4 – in thick wall

In the seacoal-free mould, hydrogen originates only from the reduction of steam by liquid metal. An increase of the content is determined by its transport. In walls 45mm thick one can observe an increase of up to 42% but after 235s at 663°C. In thinner walls, the formation of solid metal layer and a gap between the metal and mould probably covered with oxides layer impede the transport of water steam. The experiment has been repeated for the moisture content raised to 5%. The results are presented in Figure 7.

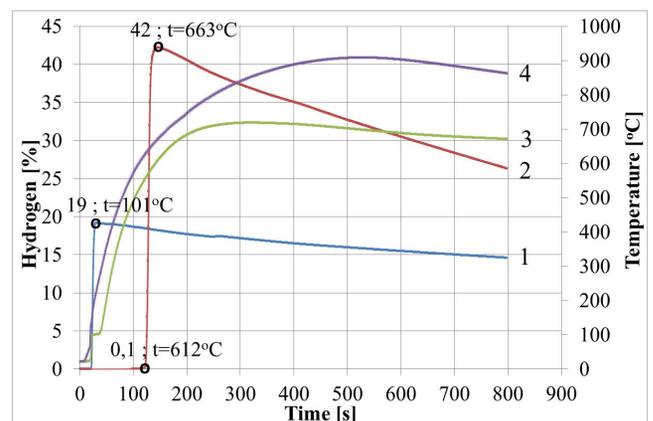


Fig. 7. Ductile iron. Evolution of hydrogen in the green sand mould Moisture content - 5%. Content 1 - thin, 2 - thick wall, 3 - temperature in thin wall, 4 - in thick wall

In 45 mm wall, the hydrogen content in the studied zone is much higher. The sudden rise begins at 612°C and reaches 42% at the temperature of 663°C. In thin-wall castings, the hydrogen content starts rising at 101°C but goes up to 19% only. It confirms

the thesis that the reaction or transport at the interface are blocked by the layer of solid metal covered with a large oxides zone. Also the drop in the oxygen pressure begins much later and the minimum is much higher than for the sand with seacoal, reaching $4 \cdot 10^{-7}$ atm. At 800°C it raises again to about 10^{-1} atm (Figure 8).

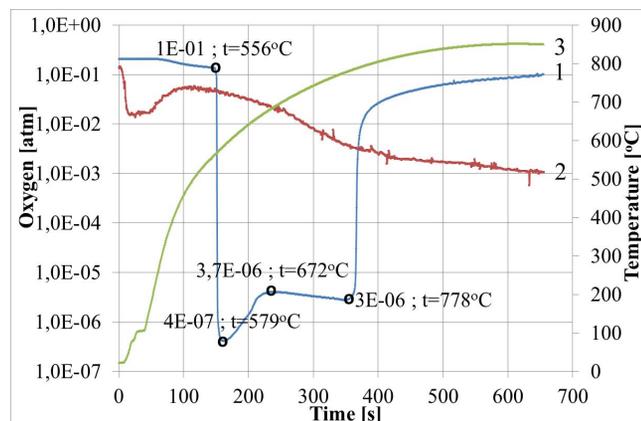


Fig. 8. Ductile iron. Evolution of oxygen in the green sand mould with the 5% of seacoal. 1 - Oxygen, 2 - temperature

The pressure of oxygen measured at the mould flow-off changes slowly. After the first drop to about 10^{-2} atm it slowly raises to a local maximum and decreases to 10^{-3} atm. It proves that the gas evacuated from mould is oxidized during mould pouring and metal solidification.

A similar result has been obtained for the sand bonded with water glass. The raise of hydrogen content in the controlled zone is observed only near the wall of 45 mm thickness and is presented in Figure 9.

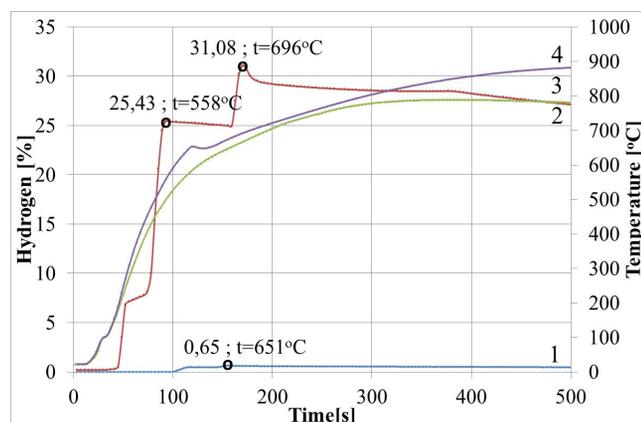


Fig. 9. Ductile iron. Evolution of hydrogen in mold bonded with water glass. Content 1 - thin, 2 - thick wall, 3 - temperature in thin wall, 4 - in thick wall

During the first 100s it raises to 25%; further sudden raise appears after 170s, at the temperature of 700°C . Probably it is an immediate consequence of the appearance of steam from water present in the water glass. Further long stabilization at the level of 25–30% results from the slow precipitation of steam from the sand bonded with water glass.

During mould filling, the oxygen pressure in the controlled zone drops quickly to about $7 \cdot 10^{-7}$ atm but immediately starts rising again and when the temperature goes up to about 700°C it reaches the value from the beginning of mould filling.

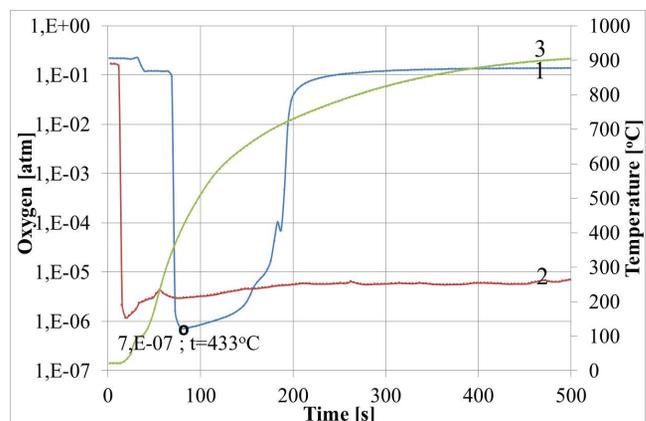


Fig. 10. Ductile iron. Evolution of oxygen in the mould bonded with water glass. 1 - Oxygen, 2 - oxygen in the flow-off, 3 - temperature

In moulds bonded with furan resin, the hydrogen evolution is similar as in green sand with seacoal addition (Figure 11).

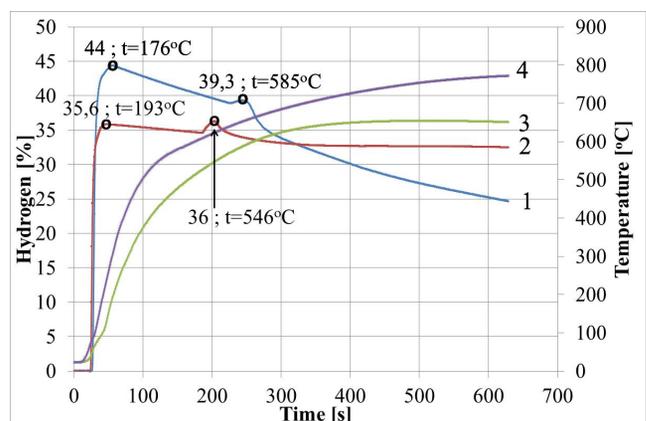


Fig. 11. Ductile iron. Evolution of hydrogen in the mould bonded with 1% of Kaltharz resin. Content 1 - thin, 2 - thick wall, 3 - temperature in thin wall, 4 - in thick wall

Having reached its first maximum just after the mould filling, it decreases until the temperature in controlled zone is 620°C , then the next raise is observed. This similarity is easy to explain. Both sands contain the carbonaceous substances, although furan sand has much less carbon in its composition. The hydrogen evolution in the controlled zone is very similar. The drop in oxygen pressure (Figure 8) is also very rapid and the minimum pressure is lower than 10^{-6} atm but instantaneously it starts raising. This raise continues up to $3 \cdot 10^{-2}$ atm when the temperature reaches 718°C . As in the case of the green sand with seacoal, the pressure of oxygen suddenly decreases but its final level is much higher, i.e. about $6 \cdot 10^{-7}$ atm (Figure 12).

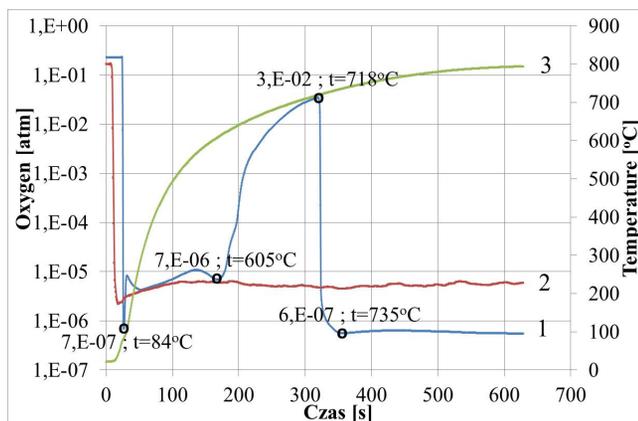


Fig. 12. Ductile iron. Evolution of oxygen in the mould bonded with 1% of Kaltharz resin. 1- Oxygen, 2- oxygen in the flow-off, 3-temperature

4. Conclusions

Gas atmosphere formed in mould cavity during pouring and casting solidification is rich in hydrogen. When mould is filled with metal, the concentration of hydrogen increases also in the sand layer contacting liquid metal.

For the metal containing magnesium, the hydrogen concentration is slightly higher. The evolution of hydrogen depends mainly on the content of carbonaceous substances in the sand. The increase in hydrogen concentration appears just during the mould filling as a result of the reduction of water vapour with carbon.

In carbon-free sand, water vapour is reduced only at the metal-mould interface. The delay in hydrogen rise in the controlled zone is determined by its transport through the superheated layer. In a thin-wall casting, the quick formation of a solid layer and the metal shrinkage cause the formation of a gap, which makes an easy way for the gas evacuation. The increase of hydrogen near the thin wall is observed only for the sand with high moisture content.

During mould filling, a sudden decrease of oxygen pressure is observed, especially for the sands with carbonaceous substances.

For the sand with seacoal content it decreases to 10^{-7} atm, when the furan resin is used for bonding it is about $7 \cdot 10^{-7}$ atm. This pressure is higher than the dissociation pressure of FeO, SiO₂ and total elimination of the reoxidation of the cast and solidified

alloy is impossible although the process can be limited to some extent.

For mould without the carbonaceous additions, the content of oxygen in controlled zone is much higher.

Acknowledgements

The study was financed by Polish Ministry of Science and Higher Education under Project No 18 18170.338.

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