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Effect of Atmosphere in a Foundry Mould on Casting Surface Quality

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Abstract

Changes of gas pressure in the moulding sand in the zone adjacent to mould cavity were analysed during pouring of cast iron. No significant effect of pressure on the surface quality of castings was observed. In the second series of tests, the concentration of hydrogen in the gas atmosphere was measured. It has been found that the value of this concentration depends on metal composition and is particularly high in cast iron containing magnesium. This is due to the reduction of water vapour with the element that has high affinity to oxygen. The presence of hydrogen causes the formation of gas-induced defects on the casting surface.

Keywords: Sand mould, Defects on casting surface, Hydrogen concentration, Ductile iron

1. Introduction

Surface defects in castings, mainly pinholes, orange peel and scabs, are formed due to the effect of various gases emitted from the hot moulding sand [1, 2, 3 etc.]. In the zone where the sand is over-dried, the gas formed is water vapour, and in the case of sand containing carbon-forming additives also hydrogen and hydrocarbons, both being the product of reaction taking place between water vapour and carbon [4, 5]. As the gases move towards the metal-mould phase boundary, the increasing temperature causes a significant increase in pressure. Since measurement of this pressure at the phase boundary is not possible, the authors [6] have placed pressure sensors at a distance of 3 mm from the phase boundary and found that the obtained values depended on the type of moulding sand, its permeability and mainly the initial moisture content. Gases emitted from the foundry mould can damage the metal-mould interface, thus contributing to the formation of scabs and orange peel on the casting surface. The reaction of water vapour and carbon dioxide with the cast material causes the formation of both oxygen [7] and

hydrogen. This is indicated by the observed increase of hydrogen content in the metal [8] as well as its high concentration in the atmosphere filling the mould cavity during pouring [9]. The authors conducted a preliminary study in which a drop of liquid cast iron was placed in vacuum on a cold substrate made of green bentonite-bonded sand mixture. Figure 1 shows the drop shape changing in time. It has been noted that initially the metal did not wet the substrate, but after some time the drop was spreading. This indicates a change in the interfacial tension, related most probably with enrichment of the surface layer in oxygen, which is the strongest factor lowering the surface tension of cast iron. The purpose of this paper is to explain how gas pressure and composition of the atmosphere can influence the formation of surface defects in cast iron.

2. Methodology

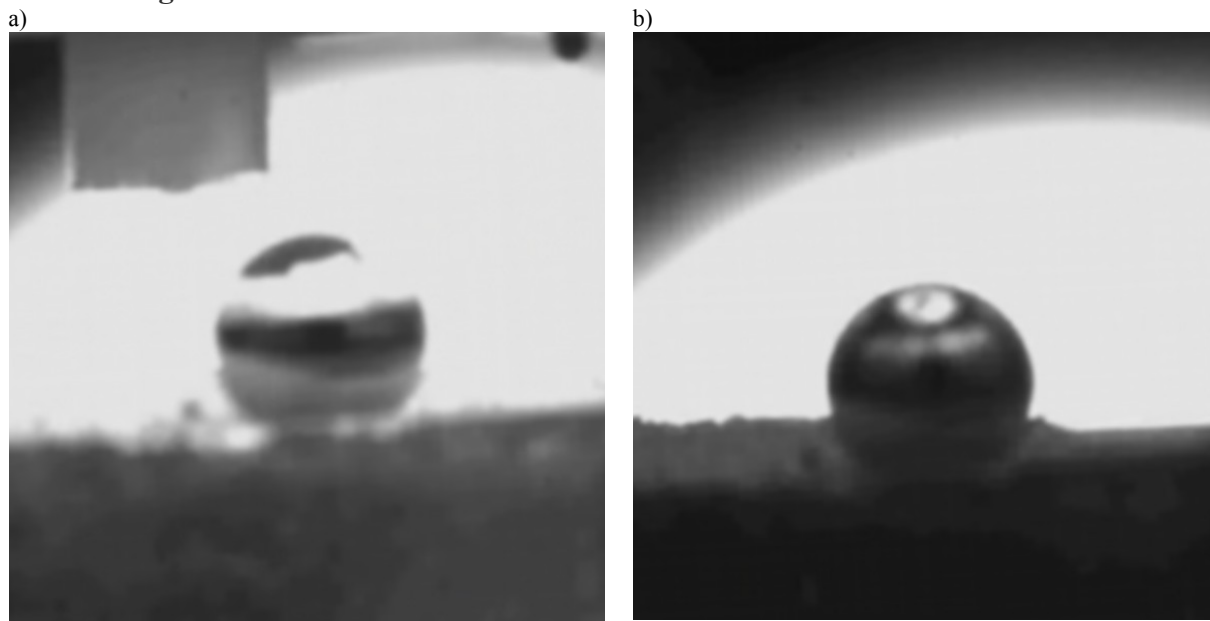## 2.1. The effect of gas pressure in moulding sand on the formation of surface defects in grey iron castings

a)

b)

Fig. 1. The drop of cast iron on the sand bonded with bentonite and 4% water. a) at the moment of formation, b) after 8 s.

The study was conducted on the cast iron of nearly eutectic composition. The metal was melted in an induction furnace and heated to 1450°C, to be next transferred to a hand-operated ladle and poured into a mould shown in Figure 2.
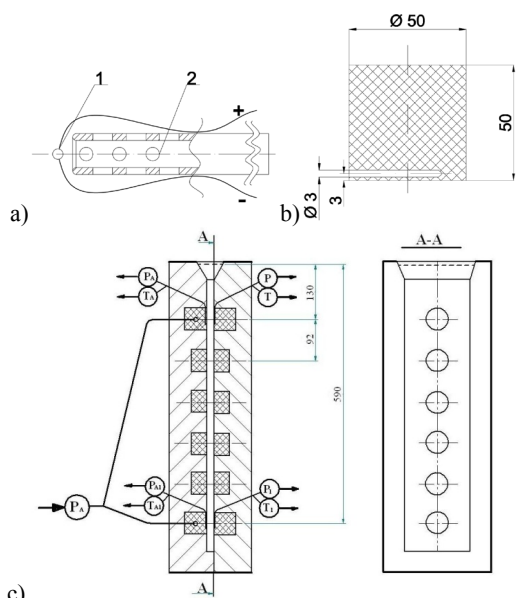

Fig. 2. Test mould for evaluation of relationship between the pressure in sand mould and the quality of casting surface. a) sensor of pressure and temperature, b) location of sensors in the sand sample, c) testing mould.

The mould was made of bentonite sand mixture containing 4 % moisture and 5% seacoal with ϕ 50x 50 mm inserts made of the bentonite sand containing 4% moisture and 5% seacoal or seacoal-free. The sand samples were compacted to a density of about 1.65 G/cm^3. Holes of 3 mm diameter were drilled in the samples, and through these holes an Ni-NiCr thermocouple (1) and pressure sensor (2) were introduced. The sensors were placed at a distance of 3 mm from the mould cavity surface. In one of the moulds, the highest and the lowest insert was fed with argon flowing in a tube, to make sensor show the pressure of 3000 Pa on pouring.

Figures 3 and 4 show changes in the pressure and temperature of the sand at a distance of 3 mm from the metal-mould interface for the bentonite sands without and with the seacoal respectively. In either case, the pressure increased rapidly during the process of pouring and then was stabilised at a level much lower than the maximum. In the sand mixture with seacoal the pressure was by about 50% higher. Figure 5 compares the pressure recorded at different levels of the casting height.

The increase of metallostatic pressure causes increase of the gas pressure in moulding sand. The sand temperature is also higher, due to better contact of metal with the mould. Figure 6 shows the obtained casting surface. Despite the difference of pressure in the moulding sand, the cast surface quality differs only slightly.
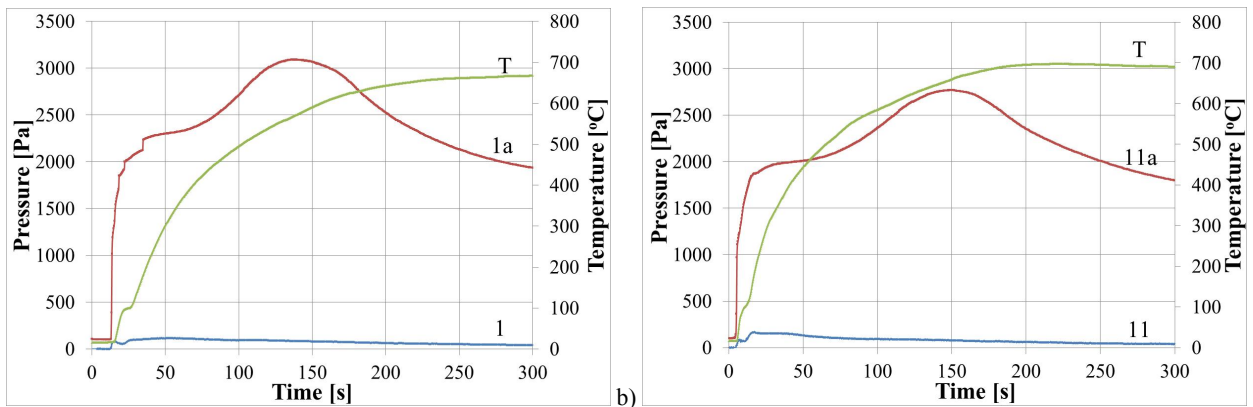
Fig. 3. Change of pressure and temperature in mold, bounded with bentonite. a) hight of the liquid metal 13 cm, b) 59 cm. 1,11 – pressure formed in the mould, 1a,11a – when the argon is introduced to the sample
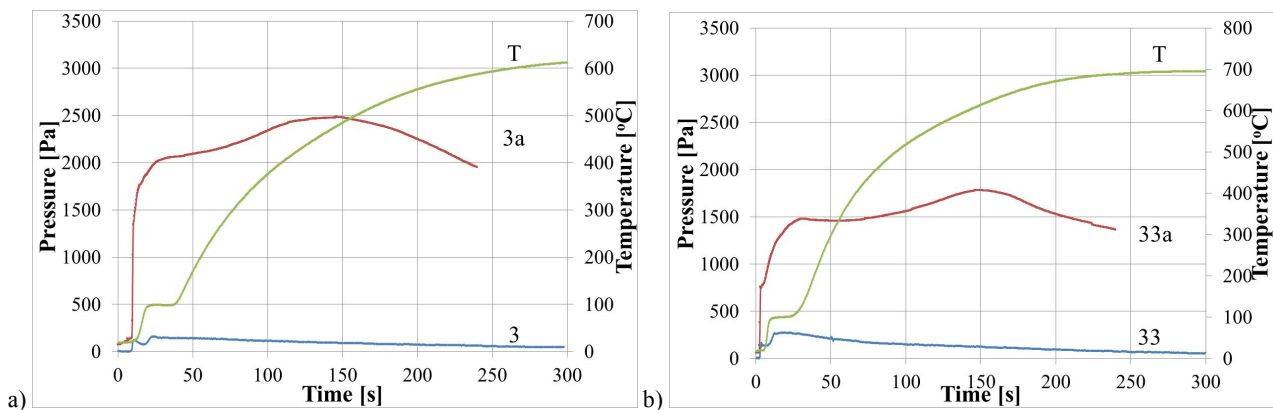

Fig. 4. Change of pressure and temperature in mold, bounded with bentonite and 5% of seacoal. a) height of the liquid metal 13 cm, b) 59 cm 3,33 – pressure formed in the mould, 3a,33a – when the argon is introduced to the sample
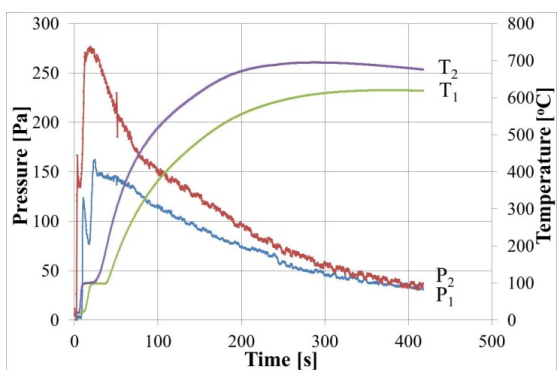

Fig. 5. Change of the pressure and temperature in the sand mold with 5% seacoal. P_1,T_1 – for 13 cm of metal height, P_2, T_2 – for 59 cm

The smoothness of the surface depends primarily on the metallostatic pressure. No significant effect of gas pressure in mould was noted, even when it raised to 3000 Pa.

The absence of apparent effect of gas pressure generated in moulding sand on the surface quality of iron castings is quite understandable as the pressure of this gas is but only a very small percent fraction of the metallostatic pressure, and the value of 300 Pa corresponds to the cast iron pressure at a depth of about 3 mm. Therefore the authors put a hypothesis that the raw casting surface quality depends not so much on the quantity as rather on the type of gas produced in the sand and on the reactions involving the presence of this gas within the region of an interface.

I Green sand , 4% of moisture

a)

a₁)

1

1a

b)

b₁)

11

11a
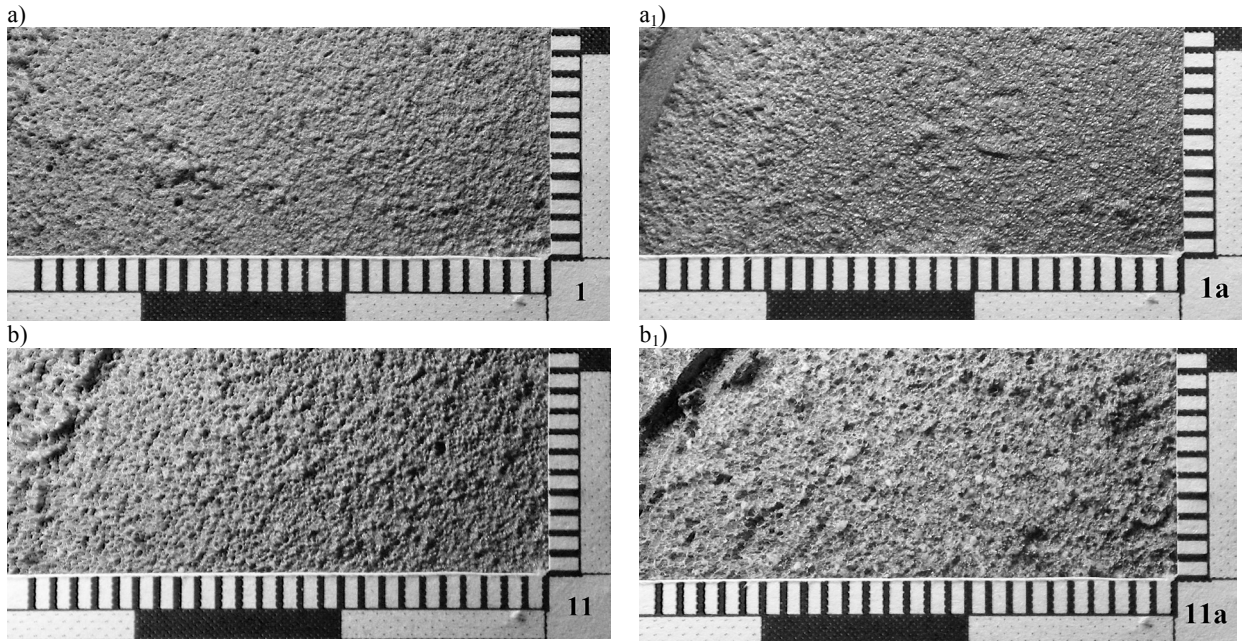
II Green sand, 4% of moisture, 5% of seacoal
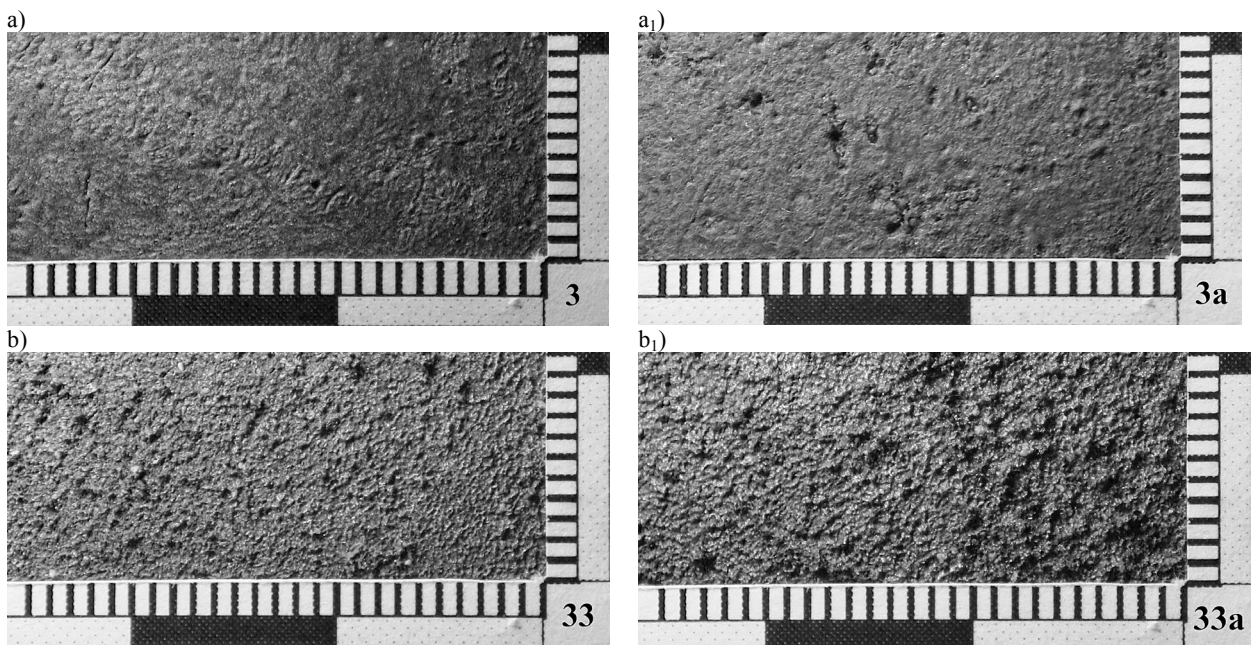
a)

a₁)

3

3a

b)

b₁)

33

33a

Fig. 6. Influence of the pressure in the mold and height of the liquid metal on surface quality. a) pressure formed in mold, a₁) – pressure of the argon introduced to test sample. height of the liquid metal 13 cm, b pressure formed in mold, b₁) – pressure of the argon introduced to test sample. height of the liquid metal 59 cm)

2.2 Testing the effect of hydrogen content in mould atmosphere

The second part of the research was carried out on samples in the shape of a stepped plate. The cross-section of a test mould is shown in Figure 7. At a distance of 3 mm from the upper plate surface, a thermocouple, a pressure sensor, and a hydrogen content sensor were placed. Tests were carried out on the cast iron with flake graphite and with spheroidal graphite.
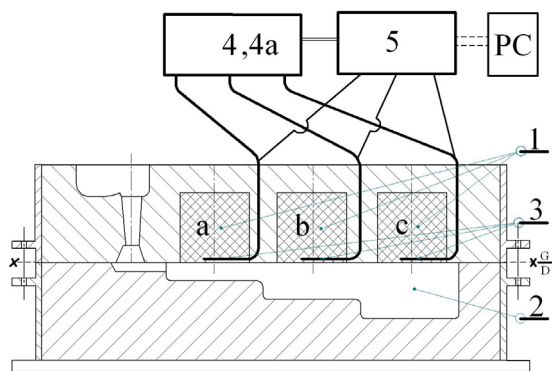

Fig.7. Test mold for the evaluation of hydrogen concentration in the mold on the surface quality of the grey and ductile iron castings. 1 –sample, 2 mold cavity, 3- sensors of pressure, temperature and hydrogen concentration,   4,4a transducers, 5 – relays. a, b, c – samples

Spheroidisation was made with an FeSiMg master alloy containing 5% Mg introduced into a hand-operated ladle, to ensure the magnesium content at a level of about 0.04%. The results are shown in Figure 8. It has been noted that for the spheroidal graphite cast iron the gas pressure was slightly lower.
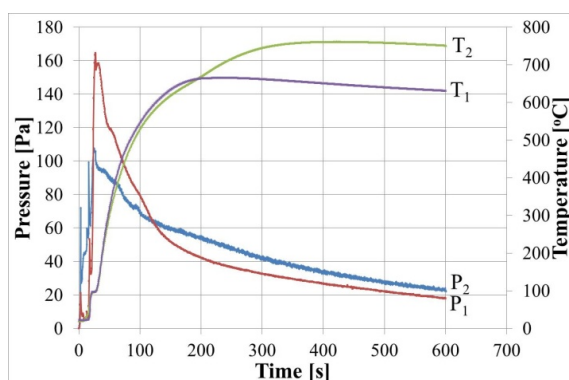

Fig. 8. Changes of pressure and temperature, for the casting of gray (P_1,T_1) and ductile (P_2,T_2) iron

The maximum pressure was observed at about 100°C, and so in the condensation zone. A similar course assumed changes in hydrogen concentration, as shown in Figure 9. The source of hydrogen in this case could be only the reduced water vapour. Since at 100°C it was not possible, most probably, hydrogen was transferred to this zone from the over-dried layer where water vapour was reduced by the coal dust added to moulding sand, and from the mould-metal interface.
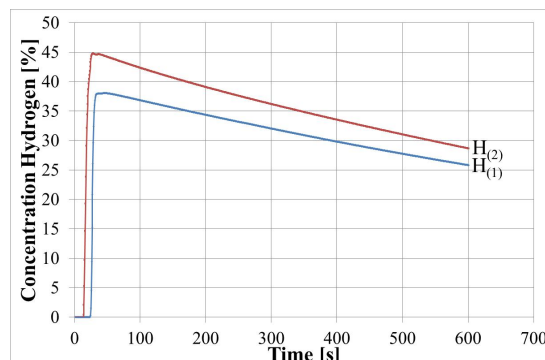

Fig. 9. Change of the hydrogen concentration in the sample of sand. H_1 – gray iron, $H_{(2)}$ – ductile iron

In the case of ductile iron, hydrogen concentration was much higher. This can be explained by a strong reducing effect of magnesium:

$$[Mg] + H_2O = MgO + H_2 \tag{1}$$

Part of the hydrogen enters the metal because its initial concentration is much lower than the equilibrium one, determined by the following relationship:

$$[H] = K\sqrt{p_{\{H\}_2}} \tag{2}$$

where K is the equilibrium constant of reaction:

$$\{H\}_2 \rightarrow 2\,[H]$$
$$\log K = \log([H]/\,p_{\{H\}_2}) = -1162/T + 2.27 + 0.5\log P_H \tag{3}$$
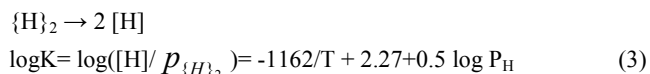
where [H] is the concentration of hydrogen in metal in $cm^3/100G$, and $P_{\{H2\}}$ is the partial pressure of hydrogen at the phase boundary, in Pa.

Even if we assume that the hydrogen concentration at the phase boundary is not higher than in the examined area, then assuming the total pressure of 10^5 Pa, the equilibrium concentration of hydrogen in the metal will exceed 10 $cm^3/100g$. The dissolution is favoured by a very small radius of the hydrogen atoms and the resulting very large diffusion coefficient. In the process of progressive solidification, hydrogen solubility decreases rapidly. In the interdendritic spaces, association of dissolved gas atoms into the molecules takes place which, while escaping to the phase boundary surface, are leaving behind them minute channels forming the pinhole defects. They are visible in Figure 10 showing the appearance of ductile cast iron sample surface with a distinct defect originating from the presence of gas. Such defects are not observed in the grey iron castings.
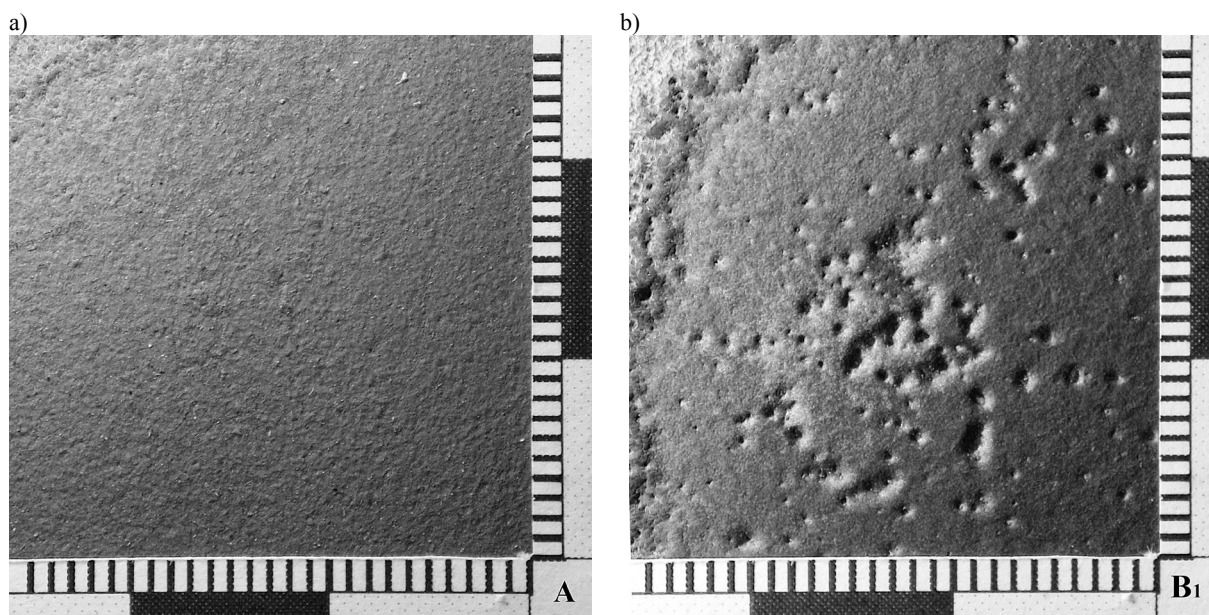
a)

b)

Fig. 10. Surface of castings. a) gray iron, b) ductile iron

3. Conclusions

As a result of the carried out studies it has been found that in the process of heating the sand mould, in a layer of the over-dried sand, an increase in pressure occurs. Pressure generated in the bentonite sand mixture is much higher when the sand contains an addition of seacoal. Compared with metallostatic pressure, the pressure at the metal – mould interface is relatively low and does not significantly affect the surface quality of castings. The main component of the forming gas is water vapour. Reaching the casting surface, it is reduced forming hydrogen, a fraction of which diffuses into metal, thus resulting in the formation of surface defects, while another fraction is transferred to the sand.

The reduction of water vapour is more intense when metal contains the constituents which are characterised by very high pressure of the oxides dissociation, e.g. magnesium in cast iron. This explains why surface defects occur less frequently in grey cast iron than in the cast iron with spheroidal graphite, especially at high concentration levels of magnesium.

Acknowledgements

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